CHEMISTRY

Structure &
Properties of Matter

What causes lightning and why are some places safer than others when it strikes?



OpenSciEd

HIGH SCHOOL SCIENCE

TEACHER EDITION

What causes lightning and why are some places safer than others when it strikes?

Structure and Properties of Matter : Lightning

OpenSciEd Unit C.2



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UNIT OVERVIEW

What causes lightning and why are some places safer than others when it strikes?

This unit is anchored by students noticing patterns in videos of lightning, lightning stories, and data about lightning strikes. In Lesson Set 1 (Lessons 1-5), students figure out the interactions cause lightning-like phenomena. They learn about the subatomic structure of an atom and initial ideas about charge and electrostatic forces. In Lesson Set 2 (Lessons 6-9), students figure out how the physical science ideas they developed in prior lessons apply to lightning. They develop Coulomb's law and ideas about induced polarization. In Lesson Set 3 (Lessons 10-11), students explore how so much energy, manifested as thunder and flashes of light, is transferred in lightning. Finally, in Lesson Set 4, students investigate why certain materials and places are safer than others when lightning strikes. They figure out how the molecular structure of matter leads to macroscopic properties of materials, such as the conduction of electricity through metals and the dissolving of salts in water.
Throughout the unit, students will do the following:

- Develop and use models to explain why lightning happens and why some places are safer than others when it strikes.
- Experiment with various materials to produce and analyze static interactions.
- Use simulations and other methods to model subatomic particles: electrons, protons, neutrons, as well as energy transfers that occur between particles within electric fields.
- Experimentally develop the mathematical relationship between variables in Coulomb's law: magnitude of charge, distance, and forces between charged particles.
- Obtain and communicate information about subatomic structure, static interactions within a cloud, and the effects of lightning on living things.
- Carry out investigations to determine how increasing the concentration of salt in water affects the rate of charges flowing through it and evaluate different models to determine which best explains the results.

Building Toward NGSS Performance Expectations

HS-PS1-1:
Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outer most energy level of atoms.

HS-PS1-3:
Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

HS-PS2-4:
Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

HS-PS2-6:
Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

HS-PS3-2:
Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).

HS-PS3-5:
Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

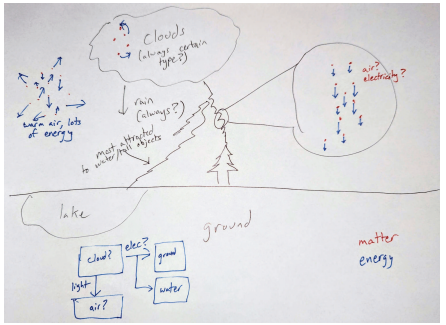
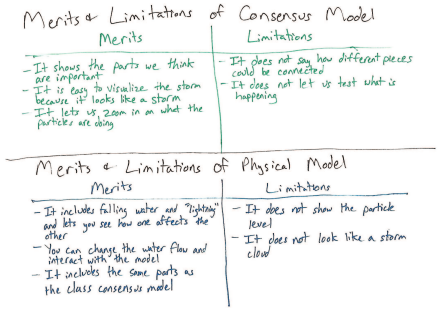
UNIT STORYLINE

Unit Question: What causes lightning and why are some places safer than others when it strikes?

How students will engage with each of the phenomena

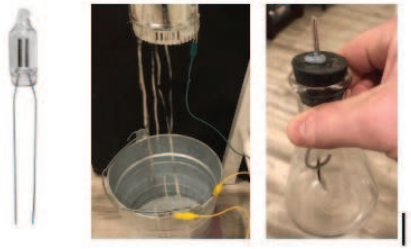
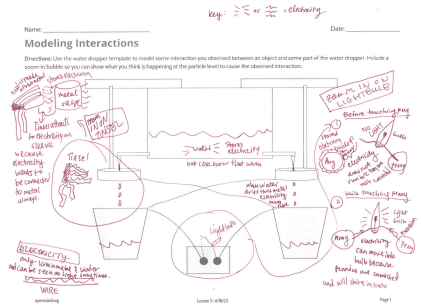
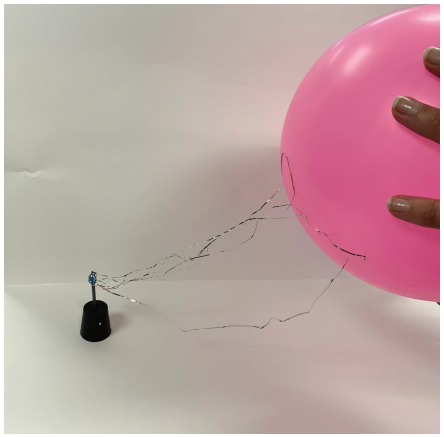
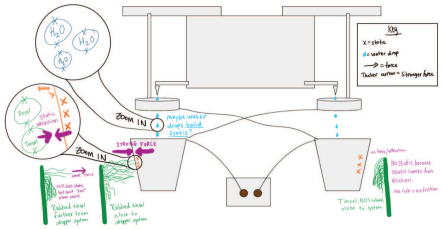
HANDS-ON/ LAB ACTIVITIES | VIDEOS OR IMAGES | DATA SETS | READINGS | COMPUTER INTERACTIVES

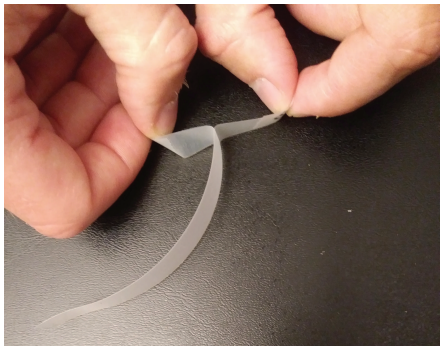
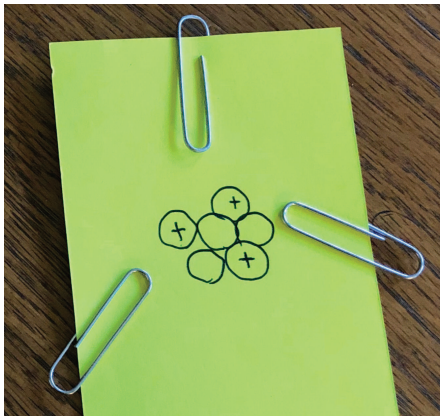
Lesson Set 1: What is lightning?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 Lesson Set 1 3 days **When and where does lightning occur and what are its impacts?** Anchoring Phenomenon	 *Slow-motion videos of lightning strikes show patterns we cannot see in real time. Lightning strikes more often and causes more harm in some places than others.*	We watch videos, engage with stories, and analyze patterns in data to try to determine how lightning forms and why some places are safer than others. We figure out: • People have looked at lightning in many different ways, but agree that it is dangerous, powerful, and accompanies rainstorms. • Lightning does not strike evenly across the earth. Lightning strikes more frequently in warmer and wetter locations and in the summer months. • Lightning can cause significant injury and death, but not always in the places with the most lightning. • We have many questions and ideas to investigate around what causes lightning and why some places seem safer than others during lightning storms.	
LESSON 2 Lesson Set 1 1 day **What parts of the (smaller-scale) system might be causing the (smaller-scale) lightning?** Investigation	 *A system with water drops falling creates lightning-like sparks without a power source.*	We analyze graphical data and examine a physical model to consider whether there is a causal relationship between falling water and lightning formation. We figure out: • Rain from clouds is correlated with lightning from clouds. • Water drops falling can create a lightning-like spark in the lab.	

⇓ **Navigation to Next Lesson:** We have so many connected questions about lightning and the damage it causes that we could start investigating anywhere and make progress on our questions. We will take stock of areas of agreement to help determine next steps.

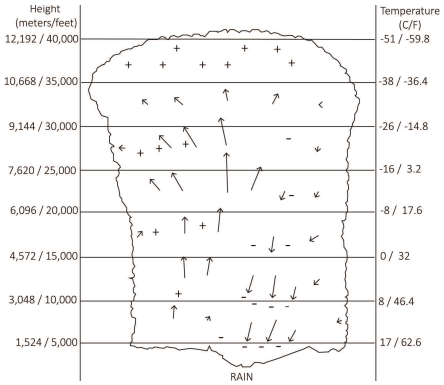
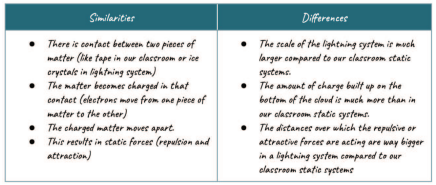
⇓ **Navigation to Next Lesson:** We figure out that water likely plays a role in the formation of lightning, or at least it does in the water dropper system. We decide to investigate this physical model further by seeing how different objects interact with it.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 3 Lesson Set 1 1 day **What is the spark in the water dropper system and what else is happening in the system before it appears?** Investigation	 *In the water dropper system, a neon light bulb glows briefly when touched to metal surfaces, a balloon sticks to these surfaces until the system produces a spark, and strings of tinsel and floss are pulled or pushed different amounts depending on where they are held in space and how long it has been since the last spark.*	We carry out two rounds of investigations by adding different test objects to the water dropper system. We record what we notice and wonder and develop a model to illustrate the patterns in forces acting on the test objects. We discuss the patterns in forces and energy transfer that we noticed. We identify related phenomena (static) that we think would produce similar interactions. We figure out: • The water dropper system acts on different objects/materials by either pushing them away (repulsive) or pulling them toward (attractive) the system. • The water dropper system allows us to make observations at a smaller scale that help explain the lightning phenomenon, which occurs at a different, larger scale. • Changes in the strength of these forces seem related both to where the objects are in space as well as to when energy is transferred out of the water dropper system (as light and sound in the form of a spark).	
⇓ **Navigation to Next Lesson:** We think static electricity would also generate some of the same kinds of interactions between objects that we detected in the water dropper system. We want to test whether static electricity produces the same types of interactions.			
LESSON 4 Lesson Set 1 2 days **What happens when we produce static electricity?** Investigation	 *We try various methods to produce static electricity with different objects or materials, then make observations of the resulting forces between objects.*	We use several objects to investigate attractions and repulsions in different materials when we rub them together. We figure out: • Attractive and repulsive forces seem to be stronger at closer distances and weaker at greater distances. • Some type of contact or friction seems needed for objects to become attractive or repulsive to other objects at a distance. • Electrostatic forces are likely responsible for the phenomena we have been observing. • Objects with charges generate electric fields. Fields generated by matter result in forces.	
⇓ **Navigation to Next Lesson:** We are not sure how friction causes matter to become charged. We also want to find out if something similar happens before or during lightning strikes.			

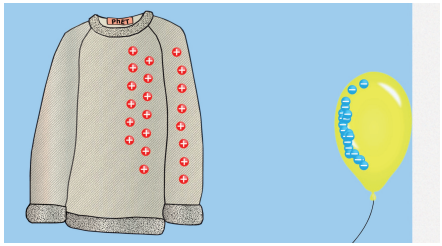
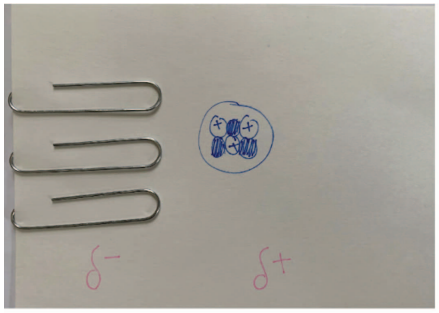
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 5 Lesson Set 1 3 days **What is happening at a particle level to produce static effects?** Investigation, Putting Pieces Together	 *People have reported hair standing on end, crackling noises, and sparks right before a lightning strike happens.*	We investigate more static interactions. We use a reading and a simulation to develop models of atomic structure to help explain the interactions we observed. We figure out: • All atoms are made of different combinations of the same three subatomic particles: positively charged protons, uncharged neutrons, and negatively charged electrons. The relative number of protons and electrons determines the atom's overall (net) charge. • Subatomic particles are organized in the atom with protons and neutrons in the nucleus and electrons surrounding the nucleus. The type of atom is based on the number of protons in it. • As objects in contact produce static, a small amount of matter in the form of electrons is removed from one object and accumulated on another. This movement changes the net charge on each object.	

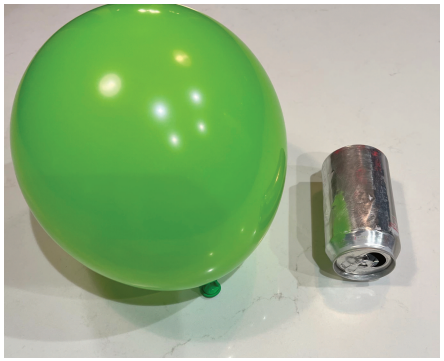
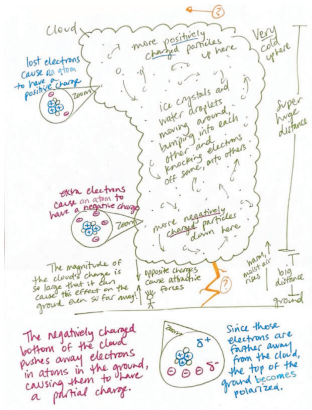
⇓ **Navigation to Next Lesson:** We developed a model to explain how moving electrons create static interactions, but now we are wondering what is causing electrons to move before a lightning strike.

Lesson Set 2: What causes a lightning strike?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 6 Lesson Set 2 1 day **What causes static in a lightning system?** Investigation	 *Collisions between ice crystals and water molecules occur within a cloud.*	We use information from a reading to compare the lightning system to our in-class static systems. We figure out: • Collisions between ice crystals and water molecules inside clouds cause the top of the cloud to be positively charged and the bottom of the cloud to be negatively charged. • Thunderclouds grow very tall due to warm, moist air rising very high in the atmosphere. • There is a massive buildup of electrons, far greater than people experience in everyday static interactions, that eventually causes those electrons to flow from the cloud to the ground. • Electricity is the movement of charges (i.e., electrons).	

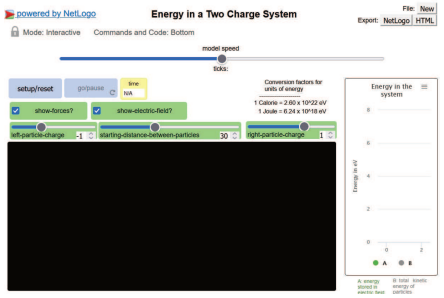
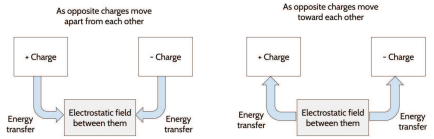
⇓ **Navigation to Next Lesson:** By comparing the static interactions in the lightning system to those in our classroom investigations, we identify that the scale of forces within both systems might explain the differences we see in the distances over which these static forces occur. We decide to dig deeper into the relationship between force, distance, and the amount of charge next.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 7 Lesson Set 2 3 days **How are electrostatic forces between objects affected by the amount of charge and the distance between them?** Investigation	 *When two charged surfaces are moved apart, they produce less force between them as measured by a digital scale, but when more charges are added to the system, they produce more force.*	We carry out an investigation to determine how electrostatic forces between objects are affected by the amount of charge and the distance between them. We compare graphs of our results and identify patterns in how different variables affect these forces. We evaluate a mathematical model for how these variables are related and use algebraic methods to predict the effects of larger-scale changes in the amount of charge and distance between charges in a system. We figure out that: • When like or unlike charges are moved farther apart, they produce significantly less force. • The strength of the electrostatic forces on any two amounts of charge, separated by a distance, can be predicted using Coulomb's law.	Coulomb's law: $F = k \cdot \left(\frac{q_1 \cdot q_2}{r^2} \right)$
⇓ Navigation to Next Lesson: While we can quantitatively predict the strength of forces between any two amounts of charge separated by any distance, we are not sure what is causing objects near the ground to experience electrostatic force interactions if the ground is neutral long before a lightning strike.			
LESSON 8 Lesson Set 2 1 day **How can something that is neutral have an attractive or repulsive interaction with another object without any contact?** Investigation	 *The attraction between neutral objects and charged objects is due to the induced polarization of atoms in neutral objects.*	We use a simulation and our paper-clip models to explain what we think is happening in atoms of neutral objects when they interact with charged objects. We figure out: • Atoms can be temporarily polarized, meaning a partial negative and partial positive charge can be induced through the movement of electrons to one "side" of the atom. • Electrons are not transferred to or from the atom when atoms are polarized. • Polarization can occur over distance; contact between objects is not required.	
⇓ Navigation to Next Lesson: We have figured out a lot about how lightning works and what makes lighting move from the cloud to the ground. We should check our DQB and see which questions we have answered.			

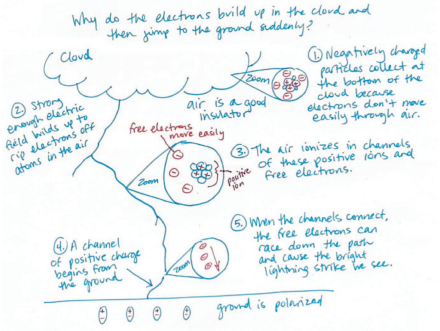
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 9 Lesson Set 2 2 days **How can we revise our models to explain what we have figured out about the lightning system?** Putting Pieces Together, Problematizing	 *All previous phenomena.*	We create Gotta-Have-It Checklists and use them to develop updated models to answer the question, "What causes lightning to strike at a particular place and time?". We take stock of the Driving Question Board and then complete an assessment task to demonstrate our understanding of static interactions and Coulomb's law. We figure out: • Causes of lightning can be explained using the matter perspective (the change in charges in the cloud). • Causes of lightning can be explained using the forces perspective (the attractive forces between the bottom of the cloud and ground). • Our remaining DQB questions are directing us to pursue the investigation of lightning from an energy perspective.	

⇓ **Navigation to Next Lesson:** While we have made a lot of progress on figuring out connections between changes in the matter and changes in the forces in the lightning system, many of our remaining DQB questions are about the energy involved in lightning strikes.

Lesson Set 3: How and why does a lightning strike transfer so much energy?

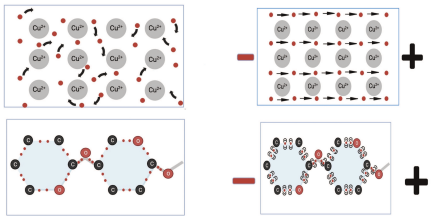
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 10 Lesson Set 3 2 days **Where does the energy come from for lightning to strike across miles of air?** Problematizing, Investigation	 *Lightning transfers a huge amount of energy, but it is unclear where this energy comes from.*	We analyze data that show that lightning transfers a LOT of energy. We use a computational model that shows energy storage between charges. We figure out: • Energy is stored in the electric field that exists between charged particles. • The electric field exists because of attractive and repulsive forces between charged particles. • Energy transfers to or from particles to or from the electric field as charged particles are moved toward or away from one another.	

⇓ **Navigation to Next Lesson:** We know that negative charges are gathered on the bottom surface of the cloud before a lightning strike, but we do not understand why they build up there rather than being pulled toward the ground constantly.

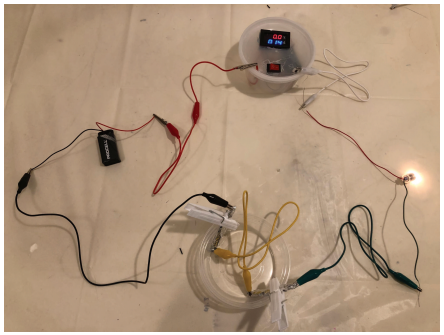
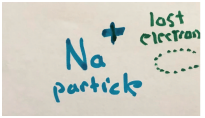
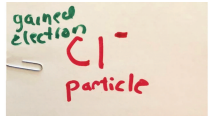
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 11 Lesson Set 3 2 days **Why do the electrons build up in the cloud and then jump to the ground suddenly?** Investigation	 *Before a lightning strike, channels of ionized air form between the cloud and the ground. When a channel connects with the ground, those free electrons can speed down it.*	We consider what we know about air to figure out that there is no easy path for electrons to move through it. We conduct research online and evaluate our sources to explain how charges move through air to cause the lightning we can see. We figure out: • Air is a good insulator because it does not let electrons move through it easily. • The electric field created by a storm cloud can rip electrons off nearby air molecules, creating ions. • Channels of ionized air branch out in segments from the cloud toward the ground. • When one of those channels connects with a channel of positive charge from the ground, electrons move easily and rapidly through the path, causing the intense lightning strike we see. • Light flashes, thunder, and nitrate formation all result from energy transfers out of strong electric fields.	

⇓ **Navigation to Next Lesson:** We figured out that air is a good insulator, but when it becomes ionized, the free electrons move through it very easily. We still have questions about why some places or materials are safer from lightning than others.

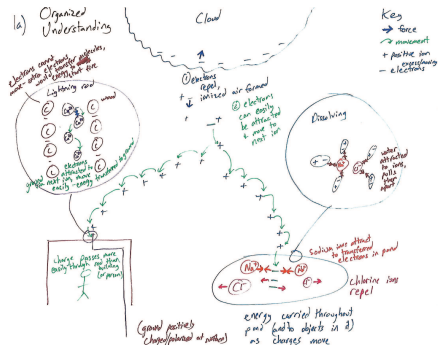
Lesson Set 4: What makes some places safer than others when lightning strikes?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 12 Lesson Set 4 2 days **Why are some structures safer than others (and safer than being outside)?** Investigation	 *Certain structures or materials are safer than others when there is lightning.*	We look at data about lightning safety, read about how lightning rods work, and examine models of metals and nonmetals. We compare two models of lightning rods and identify the merits and limitations of each. We figure out: • Metals have "free" electrons that allow them to conduct electricity relatively easily. We call these materials conductors. • Materials that are insulators do not have free electrons that can transfer energy through them. • These differences in the structures of matter help to explain differences in electrical conductivity and why some materials are safer than others during lightning.	

⇓ **Navigation to Next Lesson:** We figured out why metal is a good conductor of electricity, but we still don't know why being near water is dangerous. We are wondering, why does water conduct electricity?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 13 Lesson Set 4 3 days **Why are you supposed to get away from water when there is lightning nearby?** Investigation	 *An autopsy of 50 Canada geese revealed small lesions in their hearts which indicated electrocution as the cause of death. A light bulb glows and an ammeter reports a current when salt water bridges a gap in a circuit, but not when that water is pure (distilled).*	We determine that pure water does not conduct electricity. We argue that the salt found in different water sources conducts electricity. We plan an investigation to determine whether this is true. We evaluate different models to determine which one best explains the results of our investigations. We explain how a lightning strike on water would cause the death of a group of geese floating on it. We figure out: • Solid table salt (sodium chloride) is an ionic compound, which means it is made of positive and negative ions that form by gaining or losing an electron. • Water molecules have permanent partially positive and partially negative sides (polarity). • When water molecules make contact with solid salt they pull individual ions off, causing the salt to break apart (dissolve) and the ions to spread throughout the solution. • Ions in solution can conduct electricity. • Water in living things contains dissolved salts and other electrolytes.	 

⇓ **Navigation to Next Lesson:** We are ready to try to answer all of our questions on the Driving Question Board and we have some ideas for how to lean on the Community Agreements we have developed so that we get the most out of the final learning and assessment experiences of the unit.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 14 Lesson Set 4 3 days **Why are some places safer than others when lightning strikes?** Putting Pieces Together	 *An airplane is struck by lightning and not damaged in any way.*	We create a consensus Gotta-Have-It Checklist and use it to build models to explain lightning safety. We take stock of our DQB questions and complete an assessment task. We figure out: • The model components/relationships/mechanisms for why we should stay away from water when lightning strikes. • The model components/relationships/mechanisms for why going inside buildings with lightning rods or indoor plumbing is safer when lightning strikes. • We have answered many of our questions on the DQB! • We can use our understanding to explain related phenomena.	

⇓ **Navigation to Next Lesson:** This is the last lesson.

LESSONS 1-14
29 days total

TEACHER BACKGROUND KNOWLEDGE

Lab Safety Requirements For Science Investigations

It is important to adopt and follow appropriate safety practices when conducting hands-on science investigations and demonstrations, whether in an instructional space (traditional laboratory or classroom) or in the field. To this end, teachers must be aware of any school or district safety policies, legal safety standards, and better professional safety practices that are applicable to the activities being undertaken.

Science safety practices in instructional spaces require engineering controls and personal protective equipment (e.g., sanitized safety goggles or safety glasses with side shields as appropriate, non-latex aprons and gloves, eyewash/shower station, fume hood, appropriate ventilation, and fire extinguishers). **Science investigations should always be directly supervised by qualified adults, who should review safety procedures annually, and also before initiating any hands-on activities or demonstrations.** Prior to each investigation, students should be reminded of the specific safety procedures they must follow. Each lesson within the OpenSciEd units includes teacher guidelines for applicable safety procedures for setting up and running an investigation, as well as disassembling, disposing of, and storing materials.

Prior to the first investigation of the year, a safety acknowledgement form for students and parents/guardians should be provided and signed. You can access a model safety acknowledgement form for high school activities here: https://static.nsta.org/pdfs/SafetyAcknowledgmentForm-HighSchool.pdf

Disclaimer: The safety precautions provided for each activity are based in part on use of the specifically recommended materials and instructions, as well as legal safety standards and better professional safety practices. Be aware that selecting alternative materials or procedures for these activities may affect the activity's level of safety, and is therefore at the user's own risk.

Please follow these lab safety recommendations for any science investigation:

1. Wear sanitized safety goggles (specifically, indirectly vented chemical splash goggles) or safety glasses with side shields, as appropriate, a non-latex apron, and non-latex gloves during the set-up, hands-on investigation, and take-down segments of the activity.
2. Safety goggles are required when working with liquid biological or chemical hazards (e.g., microbes, acids, bases, etc.). Safety glasses with side shields or safety goggles may be used when working with physical hazards (sharps, springs, glass, projectiles, etc.).
3. Immediately wipe up any spilled liquid (e.g., water) and/or granules on the floor, as this is a slip-and-fall hazard.
4. Follow your *Teacher Guide* for instructions on disassembling and storing materials and disposing of waste materials.
5. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
6. Wash your hands with soap and water immediately after completing the activity.
7. Never eat any food items used in a lab activity.
8. Never taste any substance or chemical in the lab.
9. Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
10. Use caution when working with glassware, which can shatter if dropped and cut skin.
11. Use caution when using sharp [tools/materials], which can cut or puncture skin.
12. Never pour chemicals, either used or unused, back into their original container. Dispose of chemicals according to your teacher's instructions.
13. If you get a hazardous chemical on your clothing or have a clothing fire, use the emergency shower.
14. If you get a chemical in your eye, use an eyewash station immediately.
15. Point the test tubes, beakers, or other vessels away from yourself and other people when the vessels contain reactants or other substances.
16. When diluting acids or bases, the acid or base should be added to water and not water to the acid or base.
17. Projective trajectory zones must be well defined and free of any obstacles. No participant is to be in the zone during operation of the projectile..
18. Make sure the ventilation system meets the needs relative to removal of flammable vapors produced. Also make sure there are no active flames or sparks in the work zone.


Specific safety precautions are called out within the lesson using this icon and a call-out box.

Where does this unit fall within the OpenSciEd Scope and Sequence?

This unit is the second in the OpenSciEd High School Chemistry course sequence. This unit is designed to build on student ideas from *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* about energy flows at the particle level as students use patterns in electrostatics to help explain how lightning works. Along the way, they dig into the atom and develop understandings of subatomic structure, charges, and the ways in which small-scale interactions of matter and energy through forces result in material properties and macroscopic effects.

All the Performance Expectations (PEs) in this unit are shared across other Chemistry or Physics units:

- **HS-PS1-1**, **HS-PS1-3,** and **HS-PS2-6** are shared with *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*
- **HS-PS2-4** is shared with *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*
- **HS-PS3-2** is shared with *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*, *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*, and *Meteors Unit*
- **HS-PS3-5** is shared with *Fuels Unit* and *Electricity Unit*

In *Space Survival Unit*, students will leverage their initial understandings of subatomic structures and bonding to build a deeper understanding of molecular structures, periodic trends, and chemical reactions as they explore human survival in space. Students' initial ideas about fields similarly build, this time across courses as students quantify energy stored in electric fields between atoms in *Fuels Unit*, develop their thinking around the practical applications of fields in *Electricity Unit*, and quantify energy stored in gravitational fields in *Meteors Unit*. In *Meteors Unit*, they will also develop Newton's Universal Law of Gravitation, which is strikingly similar to Coulomb's Law students construct in this unit.

What is the anchoring phenomenon and why was it chosen?

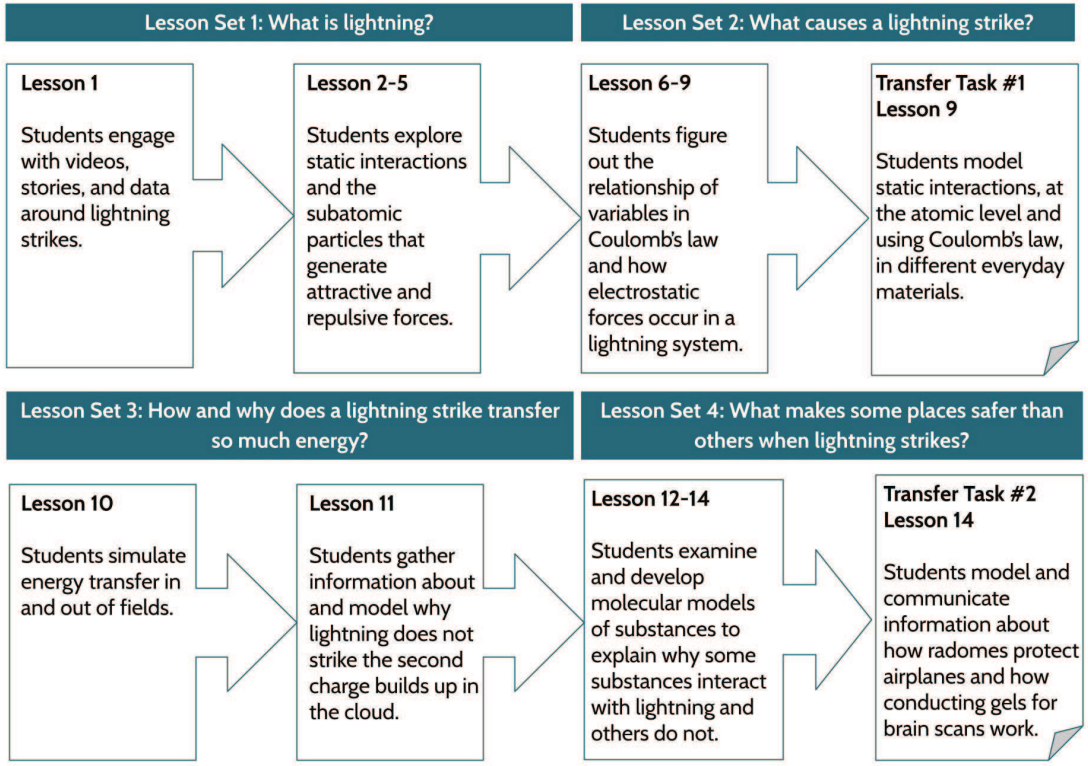
For the anchoring phenomenon, students explore slow motion-videos and data about lightning, as well as stories about lightning, and develop models for what causes it and why certain places are safer than others when it strikes. Exploring lightning allows students to 1) discover the science ideas about the structure and properties of matter and energy, 2) build from the understanding of matter and energy they developed in the prior unit, and 3) make personal connections to a relatively common natural phenomenon.

The lightning anchoring phenomenon was chosen from a group of phenomena aligned with the target performance expectations. The selection was made based on the results of a survey administered to students from across the country and in consultation with external advisory panels that include teachers, subject matter experts, and state science administrators. Lightning was chosen for the following reasons:

- Teachers and state science administrators saw high relevance to students' everyday experiences.
- Explaining the interactions involved in a lightning strike addresses the selected pieces of DCIs in this bundle at a high school level.
- Students have the opportunity to experience scaled-down versions of lightning systems in the classroom and use it to investigate static interactions.
- Reflection on lightning safety allows for molecular-level materials exploration and common lightning safety reasoning that is relevant to students' lives.

How is the unit structured?

The unit is organized into four lesson sets. Lesson Set 1 (Lessons 1-5) supports students in figuring out what lightning through engagement with related static phenomena.. Along the way they develop principles of electrostatics and subatomic structure. Lesson Set 2 (Lessons 6-9) further develops ideas about the electrostatic forces in a cloud and the relationship between the variables in Coulomb's law. A mid-unit task allows students to apply their understanding to a variety of new related phenomena. Lesson Set 3 (Lessons 10-11) shifts the focus to look at energy transfers within electrostatic fields. Lesson Set 4 (Lessons 12-14) explores why certain materials and places are safer than others when lightning strikes. Students apply these ideas in a transfer task in Lesson 14.



What elements of the NGSS three dimensions are developed in this unit?

This unit is designed to build on students' introduction to three-dimensional thinking in a chemistry context in *Polar Ice Unit* by intentionally developing vital practices and crosscutting concepts that were not as heavily emphasized in the first unit.

Because of lightning's complexity as a phenomenon and reliance on microscopic explanations, **developing and using models** **is intentionally developed** across the unit, beginning in Lesson 1 as students are supported in developing initial models using matter and energy lenses that are familiar from *Polar Ice Unit*. Students have the opportunity to move between models in Lesson 2, use a model to generate data in Lesson **3**, and design tests of and revise their own models (based on new evidence and peer feedback) in Lesson 4. This work builds an initial understanding of **attractive and repulsive forces at a distance**. In Lesson 5 they are introduced to the paper clip model to support their thinking about **atomic structure**. Through Lessons 8, 9, and 10, they continue to work with multiple types of models and revise their own models with increasing levels of independence using reflection and feedback. In Lessons 12 and 13 they evaluate the merits and limitations of particularly complex atomic-level models, and in Lesson 14 develop, receive feedback on, and revise individual models based on the unit's evidence and peer feedback.

As students move between the microscopic and lightning scales, **scale, proportion, and quantity** is also **intentionally developed** across the unit. In Lesson 1 they examine patterns across time scales. However, to explain patterns in when and where lightning strikes, they must examine lightning indirectly with smaller-scale investigations and models in Lessons 3 and 5. Orders of magnitude helps students move across the massive variation in scale in Lesson 6. Lesson 7 pushes students to quantify their thinking around **Coulomb's Law** and quantify its impact on the lightning phenomenon. In Lesson 8 they figure out that patterns are different at different scales as **induced polarization** occurs in the ground preceding lightning. In Lesson 10 they consider the significance and cause of the large energy scales associated with lightning, and in Lesson 14 they again examine patterns across different scales through modeling **materials** that have differing properties due to **force interactions**.

Obtaining, evaluating, and communicating information is also **intentionally developed** across this unit. After an early focus on modeling, students compare and integrate information from different formats in Lesson 5 to figure out **subatomic structure** and critically read adapted scientific literature in Lesson 6. These opportunities are scaffolded with reading supports. The Lesson 6 support is particularly targeted toward helping students think about how to read scientific literature. In Lesson 11, students gather and evaluate information about **interactions** that result in lightning being able to pass through air. They also communicate their findings to peers. In Lesson 12, students have a less scaffolded opportunity to evaluate multiple sources of information as different students engage with different sets in different ways. They also have an initial opportunity to evaluate multiple claims about lightning's effects in Lesson 13. In Lesson 14, they communicate to their peers about lightning safety and are assessed on this practice in the end-unit transfer task.

Patterns is also **intentionally developed** across this unit. In Lesson 1, students see patterns of when lightning appears at different time scales and across space. They are led to establish in Lesson 4 that empirical evidence is needed to be sure of patterns, and in Lesson 7 that mathematical representations are needed to identify certain patterns. Throughout Lessons 8 and 9 they examine patterns at different levels of the lightning system in order to establish causality. In Lesson 13 they once again use empirical evidence to establish patterns, and the unit concludes as they examine patterns across scales again in Lesson 14 as they develop their final models.

Using mathematics and computational thinking is **key to the sensemaking** in this unit, particularly in the context of developing **Coulomb's law** in Lesson 7 as students create a mathematical representation of forces at a distance and apply techniques of algebra and functions to represent and solve problems. Students use that same mathematical reasoning in a new context in Lesson 9.

Cause and effect is also **key to the sensemaking** in this unit. Initially, students consider the need for empirical evidence to differentiate between cause and correlation in Lesson 2 as they begin understanding the mechanisms behind lightning. They consider the different effects of changes in systems in Lesson 4. Then, in Lessons 11 and 13, they examine smaller scale mechanisms to macroscopic cause and effect relationships related to **material properties**.

This unit builds toward these performance expectations:
HS-PS1-1* Use ~~the periodic table as~~ a model ~~to predict the relative properties of elements~~ based on the patterns of electrons in ~~the outermost energy level of~~ atoms. **HS-PS1-3*** Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. **HS-PS2-4**† Use mathematical representations ~~of Newton's Law of Gravitation and~~ Coulomb's Law to describe and predict ~~the gravitational and~~ electrostatic forces between objects. **HS-PS2-6*** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. **HS-PS3-2**† Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects). **HS-PS3-5**† Develop and use a model of two objects interacting through electric ~~or magnetic~~ fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. *This performance expectation is developed across multiple units. †This performance expectation is developed across multiple courses.

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts
Developing and Using Models:: • Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria. • Design a test of a model to ascertain its reliability. • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. • Develop and/or use a model ~~(including mathematical and computational)~~ to generate data to support explanations, predict phenomena, analyze systems, and/or ~~solve problems.~~ **Obtaining, Evaluating and Communicating Information:** This unit **intentionally develops** students' engagement in these practice elements: • Critically read scientific literature adapted for classroom use to determine the central ideas ~~or conclusions~~ and/or to obtain scientific and/or technical information to summarize complex evidence, ~~concepts, processes,~~ or information presented in a text by paraphrasing them in simpler but still accurate terms. • Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question ~~or solve a problem~~.	**PS1.A: Structure and Properties of Matter** • Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (HS-PS1-1) • ~~The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.~~ (HS-PS1-1, HS-PS1-2) • The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (HS-PS1-3, secondary to HS-PS2-6) **PS2.B: Types of Interactions** • ~~Newton's law of universal gravitation and~~ Coulomb's law provide the mathematical models to describe and predict the effects of ~~gravitational and~~ electrostatic forces between distant objects. (HS-PS2-4) • Forces at a distance are explained by fields (~~gravitational,~~ electric~~, and magnetic)~~ permeating space that can transfer energy through space. ~~Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields~~. (HS-PS2-4, HS-PS2-5) • Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the ~~contact~~ forces between material objects. (HS-PS2-6, secondary to HS-PS1-1, secondary to HS-PS1-3)	**Patterns:** • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. • Mathematical representations are needed to identify some patterns. • Empirical evidence is needed to identify patterns. **Scale, Proportion, and Quantity:** • The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. • Some systems can only be studied indirectly as they are too small, too large, ~~too fast, or too slow~~ to observe directly. • Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. • Patterns observable at one scale may not be observable or exist at other scales. • Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth). The following crosscutting concepts are also **key to the sensemaking** in this unit: • Cause and Effect • Systems and System Models • Energy and Matter • Structure and Function

• Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source. • ~~Evaluate the validity and reliability of and/or~~ synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible. • Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, ~~mathematically~~). The following practices are also **key to the sensemaking** in this unit: • Using Mathematics and Computational Thinking	**PS3.A: Definitions of Energy** • Energy is a quantitative property of a system that depends on the motion and interactions of matter ~~and radiation~~ within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another ~~and between its various possible forms~~. (HS-PS3-1, HS-PS3-2) • At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2, HS-PS3-3) • These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). ~~This last concept includes radiation, a phenomenon in which energy stored in fields moves across space~~. (HS-PS3-2) **PS3.C: Relationship Between Energy and Forces** • When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5)	

*Disciplinary core ideas are reproduced verbatim from: National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press. https://doi.org/10.17226/13165 . This material may be reproduced and used by other parties with this attribution. If the original material is altered in any way, the attribution must state that the material is adapted from the original.

Connections to the Nature of Science (NOS) and Engineering, Technology, and Applications of Science (ETS)

Connections to the Nature of Science (NOS)	
Which elements of NOS are developed in the unit?	How are they developed?
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena. Theories and laws provide explanations in science. Laws are statements or descriptions of the relationships among observable phenomena.	In Lesson 7, students identify the semi-quantitative relationships in Coulomb's law from their own experimental data, with the final equation provided to them. Students use Coulomb's law to make sense of how charge moves quickly in a lightning strike and are supported in framing this equation as a law because of the way in which it describes relationships in many situations with electrostatic phenomena.
Scientific Knowledge is Based on Empirical Evidence. Science knowledge is based on empirical evidence. Science arguments are strengthened by multiple lines of evidence supporting a single explanation.	Students are explicitly introduced to empirical evidence as key to science in Lesson 4 as they test the models that they have developed. Later in the unit, they evaluate information drawn from multiple sources (Lesson 11) and evaluate claims, using data to support their evaluations (Lesson 13).
Scientific Knowledge is Open to Revision in Light of New Evidence. Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.	The *Structure of Matter* reading in Lesson 5 explicitly examines how scientists built an understanding of subatomic structure over time as they uncovered new patterns through investigation.

How does the unit build three-dimensional progressions across the course and the program?

OpenSciEd units support students in integrated development and use of the three dimensions. No one dimension can be developed in isolation from the others, as reflected in three-dimensional Lesson-Level Performance Expectations (LLPEs) which detail the specific dimensions and elements used and assessed in each lesson. However, some practices and crosscutting concepts are more productive for investigating particular anchoring phenomena, so focal practices and crosscutting concepts are articulated in each unit. All 46 SEP and 29 CCC elements are developed at some point in the high school OpenSciEd program, so all elements of a given SEP or CCC may not be present even in a unit that emphasizes developing that SEP or CCC.

This unit uses and builds upon **disciplinary core ideas (DCIs)** and other science ideas that students should have previously developed in OpenSciEd High School Chemistry and OpenSciEd Middle School.

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another. (*OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*)
- Equations that quantify energy and other variables may be developed by graphing experimental data. (*Polar Ice Unit*)
- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (*Polar Ice Unit*)
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (*Polar Ice Unit*)
- Energy transfer may occur through any of several mechanisms--conduction, convection, and radiation. These mechanisms can be explained at the particle level. (*Polar Ice Unit*)
- Objects that have absorbed energy re-emit radiation. (*Polar Ice Unit*)
- Energy transfers and matter changes happen together and together explain many chemical phenomena. (*Polar Ice Unit*)
- Air is made up of a variety of different molecules. (*Polar Ice Unit*)
- When the kinetic energy of an object changes, there is inevitably some other change in energy at the same time (*OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*).
- Convection results in movement of matter throughout storm clouds (*OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*).
- Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals) (*OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*).
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it (*Bath Bombs Unit*).
- Forces can transfer energy between objects and the particles that make up matter (*OpenSciEd Unit 8.1: Why do things sometimes get damaged when they hit each other? (Collisions Unit)*).
- Electrical and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects (*OpenSciEd Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*).
- Forces that act at a distance (electrical, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, a magnet, or a ball, respectively) (*Magnets Unit*).
- A system of objects may also contain stored (potential) energy, depending on their relative positions. (*Magnets Unit*).
- When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object. (*Magnets Unit*).

The M-E-F (matter-energy-forces) triangle, which students began building in *Polar Ice Unit* and continue throughout this unit, will be used throughout the rest of the course and in OpenSciEd High School Physics as students continue exploring the relationships between matter, energy, and forces. Students previously understood that matter is made up of particles (atoms and molecules) and that energy is a quantitative property, related to particle motion, that can be transferred through various mechanisms. In this unit, they will expand on this thinking to understand how energy can be transferred in and out of fields, generated by charged matter, through forces.

This unit begins the development of **disciplinary core ideas (DCIs)** and other science ideas that students will utilize and continue building in subsequent units in the OpenSciEd Chemistry and Physics courses:

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (*OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*)
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (*Space Survival Unit*)
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (*Space Survival Unit*)
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. (*secondary*) (*Space Survival Unit*)
- Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (*OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*)

- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. (*Meteors Unit*)
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. (*Space Survival Unit*)
- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (*OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*), (*OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*), (*Meteors Unit*)
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (*Fuels Unit*), (*Electricity Unit*), (*Meteors Unit*)
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (*Fuels Unit*), (*Electricity Unit*), (*Meteors Unit*)
- When two objects interacting through a field change relative position, the energy stored in the field is changed. (*Fuels Unit*), (*Electricity Unit*)

This unit uses and builds upon high school level **Science and Engineering Practices (SEPs)** and **Crosscutting Concepts (CCCs)** that students should have previously developed in **OpenSciEd High School Biology** and will continue to build in future units in **OpenSciEd High School Chemistry and Physics**. The progression of these practices and concepts across the program are as follows:

	Questions	Models	Investigations	Data	Math	Explanation	Argument	Obtaining
Biology	*Cancer Unit*	*Serengeti Unit, Fires Unit*	*Fires Unit, Natural Selection Unit*	*Natural Selection Unit, Cancer Unit*	*Serengeti Unit*	*Fires Unit, Cancer Unit, Natural Selection Unit*	*Speciation Unit*	*Cancer Unit, Speciation Unit*
Chemistry	*Polar Ice Unit, Oysters Unit*	*Electrostatics Unit, Space Survival Unit*	*Polar Ice Unit*	*Fuels Unit*	*Polar Ice Unit, Oysters Unit*	*Fuels Unit*	*Fuels Unit*	*Electrostatics Unit, Space Survival Unit*
Physics	*Electricity Unit, Cosmology Unit*	*Electricity Unit, Microwave Unit*	*Microwave Unit*	*Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit, Meteors Unit*	*Vehicle Collisions Unit, Meteors Unit*	*Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit*	*Vehicle Collisions Unit*	*Cosmology Unit, Microwave Unit*

	Patterns	Cause/Effect	Scale	Systems/Models	Energy/Matter	Structure/Function	Stability/Change
Biology	*Natural Selection Unit, Speciation Unit*	*Cancer Unit, Natural Selection Unit, Speciation Unit, Serengeti Unit*	*Serengeti Unit*	*Fires Unit, Cancer Unit, Serengeti Unit*	*Fires Unit, Serengeti Unit*	*Cancer Unit*	*Speciation Unit, Serengeti Unit*
Chemistry	*Electrostatics Unit, Space Survival Unit*	*Oysters Unit, Fuels Unit*	*Electrostatics Unit, Oysters Unit*	*Polar Ice Unit*	*Polar Ice Unit, Fuels Unit*	*Space Survival Unit*	*Oysters Unit*

Physics	*Cosmology Unit*, *Vehicle Collisions Unit*, *Earth's Interior Unit*	*Vehicle Collisions Unit*, *Earth's Interior Unit*	*Meteors Unit*, *Earth's Interior Unit*	*Electricity Unit*, *Vehicle Collisions Unit*, *Microwave Unit*	*Electricity Unit*, *Earth's Interior Unit*	*Earth's Interior Unit*, *Vehicle Collisions Unit*	*Electricity Unit*, *Cosmology Unit*

What are some common ideas that students might have?

Students will come into the unit with many ideas about lightning derived from previous classroom experiences, intuitive understandings of the way the world works, everyday experiences with lightning, and the conversations they have had with parents, friends, and family members.

Some relevant ideas (both accurate and inaccurate) that students may come into the unit with include the following:

1. Static interactions can cause sparks.
2. Atoms are the smallest particle of matter (students likely have not formally encountered matter at smaller scales yet). If they have conceptions of subatomic structures, they may include the following:
    a. There are protons, neutrons, and electrons. Electrons orbit the nucleus like in popular depictions.
    b. The nucleus attracts electrons, but not vice versa.
3. Metals conduct electricity better than most other materials.
4. Energy causes things to happen (when, in fact, it is a force that is causal).
5. Partial understandings about lightning such as:
    a. Lightning never strikes the same place twice.
    b. Lightning always strikes the tallest objects.
    c. It is good to stand under any protective object, including a tree, during a thunderstorm.
    d. It is unsafe to go in water when lightning is around.
    e. Lightning rods attract lightning to protect the rest of the building.
    f. Rubber tires on a vehicle are what makes a vehicle safe if struck by lightning, or thick rubber soled shoes protect you from lightning.

It is valuable to think of ideas like these not as misconceptions that need to be replaced but as productive ideas that we can use to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it improves science learning across the board. This unit intentionally addresses several of these alternate conceptions. Lessons 7-9 and 11 provide evidence that lightning tends to strike taller objects, but will not necessarily do so. Lesson 12 provides an extension opportunity for students to think about how lightning rods really protect buildings and whether rubber can affect other objects, and Lesson 13 includes guidance on supporting students' thinking around whether water attracts lightning or is so conductive that electricity will easily reach and shock objects in it..

How will I need to modify the unit if taught out of sequence?

This is the second unit of the High School Chemistry Course in the OpenSciEd Scope and Sequence. Given this placement, modifications would need to be made if teaching chemistry first, or teaching this unit earlier in the Chemistry Course. These include the following adjustments:

- Only minor modifications would be needed to teach this lesson before OpenSciEd High School Biology. Students may require additional support in the practices and crosscutting concepts that are intentionally developed in this unit if they have not previously had these experiences at the high school level.
- *Polar Ice Unit* emphasized community-building, including the development of Community Agreements in Lesson 1. If this unit is taught before that one, some supports from that unit should be brought in to help students develop a culture of working together to make progress in science sensemaking.
- *Polar Ice Unit* also contains significant support to help students develop high school-level investigative planning and techniques, introduce them to mathematics and computational thinking in a chemistry context, and scaffold their thinking around matter and energy in chemistry. If this unit is taught earlier in the year, supplemental teaching of the particle model of matter and energy transfer mechanisms will be required. Students will also require additional instruction in lab safety, conducting investigations, and using unit conversions and scientific notation.
- If taught after OpenSciEd High School Physics, students will likely already be familiar with the M-E-F triangle and fields and may require less support in sensemaking in Lessons 3-5 and 10-11 in particular.
- If taught as part of an AP Chemistry course, this unit and *Space Survival Unit*, which collectively develop student thinking around subatomic structure and compound formation, will need to be supplemented with more in-depth examination of novel Lewis diagrams, resonance, VSEPR and bond hybridization, intermolecular forces, and mass spectroscopy and photoelectron spectroscopy.

- If taught as part of AP Physics 2, this unit will require significant supplementation in order to better quantify electrical energy, model charge distribution and resulting forces and fields more systematically, and more deeply reflect on conservation of matter (specifically charge) and (electrical) energy, which are assumed but not emphasized in this unit.
- This unit does not address any Earth and space science standards, as it relies on middle school level understandings of weather. If used in an Earth science course, students will need to engage much more deeply with these standards and may also need to investigate different kinds of lightning and Earth's global electric circuit.

How do I shorten or condense the unit if needed? How can I extend the unit if needed?

We recommend allocating time so that the entire course can be taught. Depending on your priorities among physical science standards and supplemental chemistry content, you may condense and focus students on the following parts. If you condense the unit, you will lose important sensemaking for students.

- Lessons 2-3 can be shortened with students watching the provided videos instead of using the physical water dropper. This will remove an opportunity for them to plan their own investigations to test the reliability of their current models in Lesson 3.
- Lesson 4 can be shortened by removing an opportunity for peer feedback on models. Similarly, Lesson 9 can be shortened by removing an opportunity for self-assessment.
- Lesson 7 can be shortened by having each group only investigate one of the four conditions, as long as all four conditions are covered.
- Lesson 11 can be shortened by having students complete more of the research for home learning, although this is not recommended as it removes their access to peer and teacher supports while they gather information.

To extend or enhance the unit, consider following all lesson extensions.

- A number of lessons have extension opportunities and alternate activities. See Lessons 1-3, 5, 8-9, and 12-14 for built-in extensions.
- Spend more time on **material properties**, building on students' investigations in Lessons 12 and 13. Although students will have additional opportunities to engage with different materials in *Space Survival Unit*, they will benefit from investigating the properties of a wider variety of materials and beginning to question why materials made of "different stuff" interact so differently at the macroscopic and microscopic scales.
- More carefully examine **lightning** in your own community. Have students use the models they develop in this unit to explain why patterns in your community differ from other places, and how climate change may result in these patterns changing over time.
- Provide students opportunities to **communicate** with broader audiences about lightning safety or about other facets of lightning. For example, some students may be interested in phenomena like upper-atmospheric lightning and lightning on other objects in the solar system. Moving students' attention toward the solar system could be an excellent opportunity to help motivate the beginning of *Space Survival Unit*.

What mathematics concepts will students engage with in the unit?

This unit uses mathematics in three main ways:

1. Students are occasionally asked to use unit conversions and read scientific notation, keeping fresh skills built in *Polar Ice Unit*.
2. Students gather and represent data in ways that can help them identify patterns in nonlinear graphs, building off of work with linear graphs in *Polar Ice Unit*.
3. Students carry out calculations with Coulomb's law, which is a nonlinear equation.

Students engage in this mathematical thinking in Lesson 7 when they describe patterns across nonlinear graphs, evaluate the relationship between the variables in Coulomb's law, and apply techniques of algebra and functions to solve for the value of one unknown variable in the equation. Students use these mathematical relationships again in Lesson 9 as they complete a mid-unit assessment.

This unit does not assume students are fluent with the mathematical practices listed below that were not developed in *Polar Ice Unit*, but that students develop these practices as part of the sensemaking. Thus these standards are not so much prerequisites, as co-requisites. If students are simultaneously developing the skills and vocabulary in math class, you can help by making explicit connections to the mathematical standards below.

Talk with the math teacher(s) to identify the strategies students are familiar with for identifying patterns in nonlinear graphs.

Category	Code	Domain and Heading	Standard	Lesson
Algebra	CCSS.MATH.CONTENT.HS.A-REI.1	**Reasoning with Equations and Inequalities** Understand solving equations as a process of reasoning and explain the reasoning	Explain each step in solving a simple equation as following from the equality of numbers asserted at the previous step, starting from the assumption that the original equation has a solution. Construct a viable argument to justify a solution method.	7, 9

Number and Quantity	CCSS.MATH.CONTENT.HS.N-Q.1	**Quantities:** Reason quantitatively and use units to solve problems.	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; ~~choose and interpret the scale and the origin in graphs and data displays~~	7, 13
Statistics and Probability	CCSS.MATH.CONTENT.HS.S-ID.9	**Interpreting Categorical and Quantitative data:** Interpret linear models	Distinguish between correlation and causation.	2

What strategies are available to support equitable science learning in this unit?

OpenSciEd units are designed to promote equitable access to high-quality science learning experiences for all students. Each unit includes strategies which are integrated throughout the OpenSciEd routines and are intended to increase relevance and provide access to science learning for all students. OpenSciEd units support these equity goals through several specific strategies such as: 1) integrating Universal Design for Learning (UDL) Principles during the unit design process to reduce potential barriers and increase accessibility for students to engage in learning experiences; 2) developing and supporting classroom agreements that encourage a safe learning culture; 3) supporting classroom discourse to promote students in developing, sharing, and revising their ideas; and 4) specific strategies for supporting emerging multilingual students in science classrooms.

Many of these strategies are highlighted in the teacher guides in sidebar or in-line callout boxes with the headings of:

- Attending to Equity
- Supporting Emerging Multilingual Learners
- Supporting Universal Design for Learning
- Additional Guidance
- Alternate Activity
- Key Ideas
- Discussion callouts

The example callout below highlights how additional guidance is provided to attend to a variety of student needs in instruction.

ADDITIONAL GUIDANCE: Students will post their initial models in a gallery walk in the next activity section. Keeping the models anonymous will allow better discussion and sensemaking during the class consensus model building.

What are recommended adult-level learning resources for the science concepts in this unit?

The OpenSciEd instructional model focuses on the teacher being a member of the classroom community, supporting students to figure out scientific ideas motivated by their questions about phenomena. Students iteratively build their understanding of phenomena as the unit unfolds. To match the incremental build of a full scientific explanation across the unit, the science content background necessary for you to teach individual lessons incrementally builds too. Throughout the unit, we provide just-in-time science content background for you that is specific to the Disciplinary Core Ideas (DCIs) that will be figured out in a lesson. Places to look for this guidance include the "Where we are going" and "Where we are not going" sections for each lesson. Also, the expected student responses, keys, and rubrics illustrate important science ideas that should be developed in each lesson. The K-12 Science Framework is another great resource to learn more about the DCIs in this unit (**PS1.A: Structures and Properties of Matter, PS2.B: Types of Interactions, PS3.A: Definitions of Energy, and PS3.C: Relationship Between Energy and Resources**), including what students have learned previously and where they are headed in high school. In addition to the science content background information embedded in the lesson resources, below we provide recommended resources that can help build your understanding of phenomena and Performance Expectations bundle for this unit:

- To learn about the mechanisms that drive lightning:
  - Understanding lightning: https://www.weather.gov/safety/lightning-science-scienceintro
  - Notes for college course focused on lightning: http://www.atmo.arizona.edu/students/courselinks/spring15/atmo589/lecture_notes/CONTENTS.html
  - Lightning at the global scale (Earth's global electric circuit): https://scied.ucar.edu/video/atmospheric-electricity-movie
  - Upper-atmospheric lightning: https://www.albany.edu/faculty/rgk/atm101/sprite.htm
- To learn more about lightning safety:
  - National Weather Service lightning safety resources: https://www.weather.gov/safety/lightning-safety
  - CDC lightning safety tips: https://www.cdc.gov/disasters/lightning/safetytips.html
- To understand the truth (or lack thereof) behind common lightning myths:
  - National Weather Service overview of lightning myths: https://www.weather.gov/safety/lightning-myths

    - Insurance Information Institute overview of lightning myths: https://www.iii.org/article/lightning-safety-10-myths-and-the-facts
- To learn more about the water dropper:
    - Caltech demonstration and explanation: https://www.youtube.com/watch?v=r4IRbN0J_xA
    - Additional construction and explanation resource: https://rimstar.org/science_electronics_projects/how_to_make_a_kelvin_water_dropper.htm
- Fields and energy transfer in and out of fields:
    - Overview: https://www.physicsclassroom.com/class/circuits/Lesson-1/Electric-Field-and-the-Movement-of-Charge
    - Energy transfer models that incorporate fields: https://onlinelibrary.wiley.com/doi/epdf/10.1002/tea.21556

Lightning formation is complex and not fully understood. There are several related ideas that are outside the scope of NGSS but may occur to the teacher. Do not pursue these ideas with students unless they have already suggested the concepts based on evidence.

1. Much of lightning is actually between clouds, an understanding of which requires Earth science thinking beyond the scope of this unit.
2. Upper-atmospheric lightning and other phenomena (such as the unproven existence of "ball lightning") also occur or have been claimed to occur.
3. Lightning formation requires intricate dynamics within a storm cloud, which may be influenced by the presence of particulates such as smoke from fireworks.

How do I support students' emotional needs?

Depending on your setting, students may have a wide variety of experiences with lightning and storms more generally, ranging from unfamiliar to deeply, personally impacted. Particularly if there have been recent, traumatic weather events in your area, you may wish to consult with school counselors before beginning the unit.

The first lesson, which focuses most explicitly on human impacts from lightning such as injuries, property damage, and even death, includes a number of callouts with suggestions for in-the-moment support for students. Another key point at which to attend to student thinking is in Lesson 14, in which students read about how lightning causes more direct human harm in places where a higher percentage of people do not have access to safe indoor spaces. The goal of this activity is to help students communicate about lightning in a way that is sensitive to their peers' experiences, without assuming that they have always or currently have access to these spaces themselves. This is a matter of *relationship skills* and *social awareness*, as well as scientific communication for an audience. For more information, see the CASEL Framework (https://casel.org/fundamentals-of-sel/what-is-the-casel-framework/).

Once again, it is important to work with families and counseling experts when students have been significantly impacted by lightning or other storms. The Substance Abuse and Mental Health Administration has published resources to support coping after disasters and other traumatic events (https://www.samhsa.gov/find-help/disaster-distress-helpline/coping-tips). Meanwhile, some students who are concerned about storms may benefit from agency, such as that provided by FEMA's Teen Community Emergency Response Team (https://www.ready.gov/kids/teen-cert).

Guidance for Developing Your Personal Glossaries

This unit refers to two categories of academic language (i.e., vocabulary). Most often in this unit, students will have experiences with and discussions about science ideas before they know the specific vocabulary word that names that idea. After students have developed a deep understanding of a science idea through these experiences, and sometimes because they are looking for a more efficient way to express that idea, they have "earned" that word and can add the specific term to a personal glossary at the back of their notebooks. These "words we earn" should be recorded using the students' own definition whenever possible. On the other hand, "words we encounter" are "given" to students in the course of a reading, video, or other activity, often with a definition clearly stated in the text. Sometimes, words we encounter are helpful just in that lesson and need not be recorded in students' personal glossaries. However, if a word we encounter will be frequently referred to throughout the unit, it should be added.

It is best for students if you create consensus definitions in the moment, using phrases and pictorial representations that the class develops together as they discuss their experiences in the lesson. When they co-create the meaning of the word, students "own" the word--it honors their use of language and connects their specific experiences to the vocabulary of science beyond their classroom. It is especially important for emergent multilingual students to have a reference for this important vocabulary, which includes an accessible definition and visual support. Sometimes defining a word is a challenge. The *Teacher Guide* provides a suggested definition for each term to support you in helping your class develop a student-friendly definition that is also scientifically accurate.

The words we earn and words we encounter in this unit are listed in this document and in each lesson to help prepare and to avoid introducing a word before students have earned it. They are not intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection students can make with these words when they are allowed to experience them first as ideas they're trying to figure out.

Lesson	Definitions we co-construct	Definitions we encounter

L1		
L2	correlation, causation	
L3		
L4	electrostatic force, (electric) field, charge	empirical evidence
L5	proton, electron, neutron, nucleus	cathode ray tubes, subatomic particles
L6	electricity	
L7	Coulomb's law	
L8	partial charge, polarization, induced polarization	
L9		
L10	energy in a field, electric field	
L11	insulator, conductor, ion, ionization	
L12	bond, element	conductivity, resistivity, lightning rod
L13	polar, dissolve, ionic bond, ionic compound	
L14		

HOME COMMUNICATION

Dear Guardian,

Your child's high school chemistry class is starting a unit called *What causes lightning and why are some places safer than others when it strikes?*, as part of the OpenSciEd high school science curriculum. This unit develops science ideas around atomic structure, electrostatics, and the relationship between matter, forces, and energy. Throughout the unit, students will work collaboratively to build understanding of these ideas as they relate to lightning and lightning safety, and they will draw on their own experiences and everyday understandings to help them do this.

In the first lesson of the unit, students will figure out two important facts:

1. Rates of lightning strikes are not the same everywhere.
2. Rates of injuries and fatalities do not always correlate to rates of lightning strikes.

Later in the unit, students will figure out:

1. The particle level mechanism for lightning, and
2. What makes certain places safer than others during lightning storms.

You can learn more about lightning and lightning safety at https://www.cdc.gov/disasters/lightning/index.html and https://www.weather.gov/source/zhu/ZHU_Training_Page/lightning_stuff/lightning2/lightning_intro.html.

Students may experience feelings of anxiety when considering fatality data, or they may have had personal experiences with powerful storms that caused injury or property damage.

If you are concerned about your child engaging with these materials, please contact me at __(contact information here)__, if you are comfortable doing so. You can also contact the school counselor at __(contact information here)__. By knowing about these experiences in advance we can be sensitive to students' needs and provide support for students who may experience strong emotions during this unit.

Having conversations about science in our world:

- Encourage your child's curiosity through talking about their own noticings and wonderings.
- Acknowledge any emotions around lightning danger.
- Ask your child to explain what they are learning about the causes and mechanisms of lightning, and discuss how to stay safe during lightning storms.

Helping your student make sense of their learning:

- There is no need to teach your child vocabulary before the unit because words often have multiple meanings, and are often easier to remember once students have some experience with them.
- Encourage your child to expand and clarify their own thinking by asking your child for examples, saying more about their ideas, and repeating what your child said back to them.
- Ask how they might have arrived at a particular conclusion.
- Ask your child to recall what other students have said in class, and what parts of their ideas your child agreed or disagreed with.
- Rephrase what your child is saying to check your own understanding. For example, say, "If I hear you right, you are telling me that..."

Best,
(Your name or signature here)

Querido guardián,

La clase de química de la escuela secundaria de su hijo está comenzando una unidad llamada *¿Qué causa los rayos y por qué algunos lugares son más seguros que otros cuando caen?*, como parte del plan de estudios de ciencias de la escuela secundaria OpenSciEd. Esta unidad desarrolla ideas científicas sobre la estructura atómica, la electrostática y la relación entre materia, fuerzas y energía. A lo largo de la unidad, los estudiantes trabajarán en colaboración para desarrollar la comprensión de estas ideas en relación con los rayos y la seguridad contra los rayos, y aprovecharán sus propias experiencias y conocimientos cotidianos para ayudarlos a lograrlo.

En la primera lección de la unidad, los estudiantes descubrirán dos hechos importantes:

1. Los índices de caídas de rayos no son los mismos en todas partes.
2. Las tasas de lesiones y muertes no siempre se correlacionan con las tasas de caídas de rayos.

Más adelante en la unidad, los estudiantes descubrirán:

1. El mecanismo a nivel de partículas para los rayos, y
2. Lo que hace que ciertos lugares sean más seguros que otros durante las tormentas eléctricas.

Puede obtener más información sobre los rayos y la seguridad contra los rayos en https://www.cdc.gov/disasters/lightning/index.html y https://www.weather.gov/source/zhu/ZHU_Training_Page/lightning_stuff/lightning2/lightning_intro.html.

Los estudiantes pueden experimentar sentimientos de ansiedad al considerar los datos sobre fatalidades, o pueden haber tenido experiencias personales con tormentas poderosas que causaron lesiones o daños a la propiedad.

Si le preocupa que su hijo interactúe con estos materiales, comuníquese conmigo al __(información de contacto aquí)__, si se siente cómodo haciéndolo. También puede comunicarse con el consejero escolar al __(información de contacto aquí)__. Al conocer estas experiencias de antemano, podemos ser sensibles a las necesidades de los estudiantes y brindarles apoyo a los estudiantes que puedan experimentar emociones fuertes durante esta unidad.

Tener conversaciones sobre la ciencia en nuestro mundo:

- Fomente la curiosidad de su hijo hablándole sobre sus propias observaciones y preguntas.
- Reconozca cualquier emoción relacionada con el peligro de un rayo.
- Pídale a su hijo que le explique lo que está aprendiendo sobre las causas y los mecanismos de los rayos, y analice cómo mantenerse seguro durante las tormentas eléctricas.

Ayudar a su estudiante a darle sentido a su aprendizaje:

- No es necesario enseñarle vocabulario a su hijo antes de la unidad porque las palabras suelen tener múltiples significados y suelen ser más fáciles de recordar una vez que los estudiantes tienen algo de experiencia con ellas.
- Anime a su hijo a ampliar y aclarar su propio pensamiento pidiéndole ejemplos, diciéndole más sobre sus ideas y repitiendo lo que le dijo.
- Pregúnteles cómo pudieron haber llegado a una conclusión particular.
- Pídale a su hijo que recuerde lo que otros estudiantes han dicho en clase y con qué partes de sus ideas estuvo de acuerdo o en desacuerdo.
- Reformule lo que su hijo dice para comprobar su propia comprensión. Por ejemplo, diga: "Si te escucho bien, me estás diciendo que..."

Sinceramente,
(Su nombre o firma aquí)

LESSON 1: When and where does lightning occur and what are its impacts?

PREVIOUS LESSON *There is no previous lesson.*

THIS LESSON

ANCHORING PHENOMENON

3 days





Mike Lewinski, Unsplash

We watch multiple videos of lightning strikes and share what we notice and wonder. We consider stories about lightning. We look for patterns in data of national and worldwide lightning occurrences. We discuss statistics about fatalities caused by lightning. After reviewing what modeling is in science, we develop initial models for what causes lightning and how certain factors might influence it. After revisiting our Community Agreements, we have a Consensus Discussion to build our initial consensus model. We list related phenomena, then generate questions and share them to organize our Driving Question Board.

NEXT LESSON *We will identify the parts of our initial consensus model and analyze data showing the relationship between rain and lightning. We will consider the merits and limitations of the initial consensus model and the water dropper system. We will brainstorm additional objects we could use to figure out more.*

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6, HS-PS3-2, HS-PS3-5



WHAT STUDENTS WILL DO

1.A Develop a model based on evidence to illustrate and predict the relationships between components of lightning formation based on patterns observed at different scales. (SEP: 2.3; DCI: PS2.B.3, PS3.A.2; CCC: 1.1, 3.3)

1.B Ask questions that arise from different patterns observed in lightning data to clarify and seek additional information about what causes lightning and factors that impact lightning fatalities. (SEP: 1.1; DCI: PS2.B.3; CCC: 1.1)

WHAT STUDENTS WILL FIGURE OUT

- People have looked at lightning in many different ways, but agree that it is dangerous, powerful, and accompanies rainstorms.
- Lightning does not strike evenly across the earth. Lightning strikes more frequently in warmer and wetter locations and in the summer months.
- Lightning can cause significant injury and death, but not always in the places with the most lightning.
- We have many questions and ideas to investigate around what causes lightning and why some places seem safer than others during lightning storms.

Lesson 1 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	6 min		**OBSERVE REAL-TIME AND SLOW-MOTION VIDEOS OF LIGHTNING STRIKES** Show multiple videos of lightning strikes, some in real time and others in super slow motion. Tell students to record and share noticings and wonderings about lightning.	A-C	chart paper, chart paper markers, https://youtu.be/tgwEHUiGgJs?si=1GmIDrQ8ssWzDOK_, https://openscied-static.s3.amazonaws.com/videos/slomo-strike-1.gif, https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2.gif
2	14 min		**SHARE AND EXAMINE LIGHTNING STORIES** Elicit students' own experiences with lightning, then engage them with several stories related to lightning in different cultures and throughout history.	D-F	*Lightning Stories: Mythology*, *Lightning Stories: Inventors*, https://youtu.be/QhqVFakF0NO, https://www.youtube.com/watch?v=zfhbMTGaecc
3	11 min		**ANALYZE DATA IN GRAPHS AND MAPS OF LIGHTNING OCCURRENCES** Help students look for patterns in graphs of lightning flashes over time and in maps of flash density nationwide and worldwide.	G-I	*US Lightning Data* (optional), chart paper titled "Patterns We Notice About Lightning", chart paper markers
4	5 min		**ANALYZE LIGHTNING IMPACT DATA** Share information and lead a class discussion about statistics of injuries, fatalities, and other damage caused by lightning.	J-M	chart paper titled "Patterns We Notice About Lightning"
5	9 min		**RECORD PATTERNS FROM ACROSS THE DATA** Lead a Building Understandings Discussion to develop a list of patterns about lightning from across the data.	N	chart paper markers, chart paper titled "Patterns We Notice About Lightning"
					End of day 1
6	3 min		**REVIEW ELEMENTS OF SCIENTIFIC MODELS AND MODELING** Have students recall patterns in data. Lead a discussion around developing scientific models.	O-P	
7	5 min		**USE AN EXAMPLE TO REVIEW SCIENTIFIC MODELING (OPTIONAL)** Use the example of kicking a soccer ball to help students consider the importance of components, interactions, and mechanisms in modeling.	Q	
8	10 min		**DEVELOP INITIAL MODELS FOR WHAT CAUSES LIGHTNING** Have students individually develop initial models to explain what causes lightning and how certain factors might influence it on *Initial Model*.	R	*Initial Model*, chart paper titled "Patterns We Notice About Lightning"
9	7 min		**COMPLETE A SECOND PASS ON THE MODELS** Support students in considering the role that matter and energy play in when and where lightning strikes.	S-T	*Initial Model*

Part	Duration		Summary	Slide	Materials
10	6 min		**REVISIT OUR COMMUNITY AGREEMENTS** Reflect on how we are doing as a class with our Community Agreements.	U	1 green and 1 yellow sticky note or dot sticker, Internet connected device (optional), Community Agreements poster, virtual representation of the Community Agreements (optional)
11	7 min		**HAVE A GALLERY WALK THROUGH INITIAL MODELS** Post everyone's individual models around the room in a gallery walk. Have students silently circulate to compare them, recording similarities and differences in their science notebooks.	V	*Initial Model*, masking tape
12	7 min		**START DEVELOPING AN INITIAL CONSENSUS MODEL** Gather students in a Scientists Circle to work together as a class to develop an initial consensus model to explain what causes lightning.	W	*Initial Model*, chart paper, chart paper markers
					End of day 2
13	8 min		**CONTINUE DEVELOPING THE INITIAL CONSENSUS MODEL** Gather students in a Scientists Circle to continue developing the initial consensus model to explain what causes lightning.	X-Y	*Initial Model*, initial consensus model, chart paper, chart paper markers, Community Agreements poster
14	8 min		**BRAINSTORM AND SHARE RELATED PHENOMENA** Lead the class in a discussion to share examples of other instances where we have encountered something like lightning.	Z	chart paper, chart paper markers
15	20 min		**DEVELOP A CLASS DRIVING QUESTION BOARD** Students write initial questions, then gather in a Scientists Circle, and build the Driving Question Board.	AA-CC	3x3 sticky notes, colored marker, chart paper for Driving Question Board
16	7 min		**GENERATE IDEAS FOR INVESTIGATIONS** Assign categories of DQB questions to partners to brainstorm how we could find answers to them.	DD	chart paper titled "Ideas for Investigations", chart paper markers, Driving Question Board
17	2 min		**NAVIGATE** Navigate to the next lesson.	EE	chart paper for Driving Question Board, chart paper titled "Ideas for Investigations", initial consensus model
					End of day 3

Lesson 1 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Lightning Stories: Mythology* • *Lightning Stories: Inventors* • https://youtu.be/QhqVFakF0N0 • https://www.youtube.com/watch?v=zfhbMTGaecc • *Initial Model* • 1 green and 1 yellow sticky note or dot sticker • Internet connected device (optional) • 3x3 sticky notes • colored marker	• *US Lightning Data* (optional)	• chart paper • chart paper markers • https://youtu.be/tgwEHUiGgJs?si=1GmIDrQ8ssWzDOK_ • https://openscied-static.s3.amazonaws.com/videos/slomo-strike-1.gif • https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2.gif • chart paper titled "Patterns We Notice About Lightning" • Community Agreements poster • virtual representation of the Community Agreements (optional) • masking tape • initial consensus model • chart paper for Driving Question Board • chart paper titled "Ideas for Investigations" • Driving Question Board

Materials preparation (30 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

IMPORTANT NOTE: Lessons 2 and 3 will require the use of a dehumidifier if your classroom humidity is above 40%. These investigations also use a device that requires significant assembly. If your school does not have access to a dehumidifier, one may be purchased or rented at most hardware or home improvement stores. The *Lesson 2 Teacher Edition* provides more information on the use of the dehumidifier and situations in which dehumidification is not possible and *Water Dropper Construction* provides guidance on construction.

Test the videos listed below to be sure they play and that students will be able to see the details of the lightning. You might consider darkening your classroom if your projector is dim.

- a series of lightning strikes in real time at https://youtu.be/tgwEHUiGgJs?si=1GmIDrQ8ssWzDOK_
- first lightning strike in slow-motion video at https://openscied-static.s3.amazonaws.com/videos/slomo-strike-1.gif
- second lightning strike in slow-motion video at https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2.gif

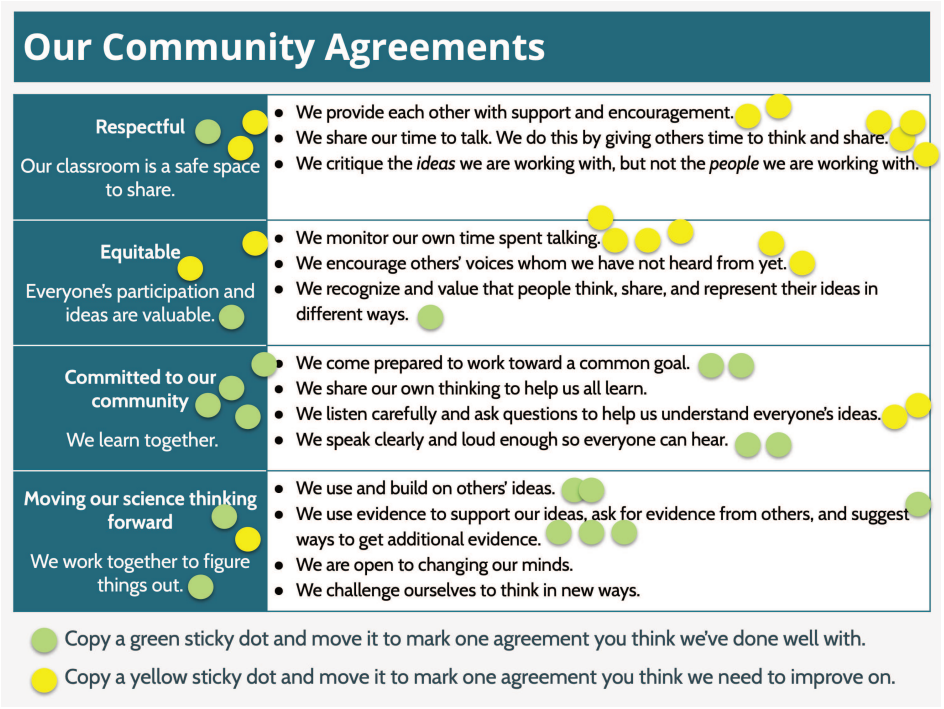
Ensure that enough copies of the following readings are available so that at least one-quarter of the class can engage with each:

- *Lightning Stories: Mythology*
- *Lightning Stories: Inventors*

Also test https://youtu.be/QhqVFakF0N0 and https://www.youtube.com/watch?v=zfhbMTGaecc, each of which will be viewed by a quarter of the class. Any of these four stories may be supplemented or replaced by others that help ground students' thinking about lightning in their experiences and those of other people.

If your Community Agreements (which you built in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*) are posted on chart paper, students can reflect on them on day 3 by marking them with green and yellow dot stickers or sticky notes. Alternatively, you might create a virtual representation of the Community Agreements so your students can mark green and yellow "stickies" or dots on them for reflection. You might use Google Jamboard (set an image of your Community Agreements as the background and have students add dots) or use a shared slide of the Community Agreements that includes a green dot and yellow dot for students to copy/paste and drag to where they want. See the example shown here of how this might look.

If you did not use *Polar Ice Unit*, you will need to develop Community Agreements in this lesson. In order to do so, see the *OpenSciEd High School Handbook* or the first lesson of *Polar Ice Unit* for more information and *Example Community Agreements* for an example of what these agreements might look like.



Lesson 1 • Where We Are Going and NOT Going

Where We Are Going

Students will be building initial models (SEP: 2.3) to explain why lightning happens (and more often in some places than others). The targeted disciplinary core ideas that we are beginning to develop are:

- **PS2.B.3: Types of Interactions.** ~~Attraction and repulsion between electric charges at the~~ atomic scale explain the structure, properties, and transformations of matter, ~~as well as the contact forces between material objects.~~
- **PS3.A.2: Definitions of Energy.** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.

Crossout explanation: PS2.B.3 is used as students consider atomic level interactions that occur during a lightning strike, but students do not yet know about electrical charges. These ideas will be developed later in the unit. Here, students simply consider what might occur during a lightning strike. Contact forces will be explored in the physics course; this unit will develop understanding of distance forces in later lessons.

This work will involve careful consideration of patterns across scales of space and time (CCC: 1.1, 3.3) and will help students uncover areas of uncertainty, which will feed into students' practice of asking questions (SEP: 1.1). This strategic sequencing of science and engineering practices with carefully selected crosscutting concepts builds toward a sense of ownership about the shared purpose of finding answers to our questions when we create a Driving Question Board. These questions will drive the work students do in the unit. The lesson ends with students gathering ideas for how they can investigate the answers to their questions, and the class is poised to begin those investigations in the next lesson.

Students' work in this lesson builds on prior work in OpenSciEd High School Biology and in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* in important ways. Students previously developed *modeling* at the high school level in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* and *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*. Although modeling was also used as a practice in *Polar Ice Unit*, the crosscutting concept of *systems and system models* was emphasized more strongly. Here, students develop modeling as a practice in physical science in a structured context through supports like soccer as a familiar context and brainstorming model components before modeling. Students' modeling also leverages understandings of energy and matter and students built in *Polar Ice Unit*.

Later in the lesson, students' use of *asking questions* builds on prior development in *Polar Ice Unit*. Students bring to the table prior experience with *patterns* from *OpenSciEd Unit B.4: How does urbanization affect nonhuman populations, and how can we minimize harmful effects? (Urbanization Unit)* and *OpenSciEd Unit B.5: What will happen to Arctic bear populations as their environment changes?(Speciation Unit)*, and *scale, proportion, and quantity* from *Serengeti Unit*. Work in this lesson can serve as pre-assessment on these crosscutting concepts, as they will be built on throughout the unit.

Exploring lightning allows students to 1) eventually discover the science ideas in HS PS2.B, 2) build from a middle school understanding of MS PS2.B, and 3) make connections to a relatively common natural phenomenon. Be aware that studying lightning could elicit emotional stress from some students, especially on day 1 of this lesson when we analyze data about the harm lightning causes. We have included these data to make exploring this phenomenon more relevant to students--by understanding how lightning works, we can determine how to stay safer from it. Since discussion about these data might elicit negative emotions from students who have experienced anxiety or loss from lightning or storms in the past, there is a moment of preparation built into the lesson before analyzing those data with teacher support provided in the Additional Guidance callouts. If a student shares a scary or emotional experience related to lightning, you (and your students) can acknowledge those feelings by saying something like, "Wow, that must have been really hard," or "I'm so sorry that happened."

In this unit, we are focused on cloud-to-ground lightning. Your students may bring up cloud-to-cloud lightning or "heat lightning" (which is not a different kind of lightning, but simply what we see from a distant storm). You will need clouds on your initial consensus model to motivate investigations in Lesson 2, but whether they are required for lightning to strike or just correlated with lightning can remain an open question at the end of this lesson.

Where We Are NOT Going

Since this lesson elevates and captures students' questions, this is generally not the time to find answers. Certainly supporting students so they can make sense of the maps and other data is encouraged, but refrain from providing information that would answer students' questions--those questions should drive students' future investigations. So, for instance, it is expected that your initial consensus model will contain several areas of uncertainty. It will be very basic and incomplete, with the point being that the class will revise, add to, and expand that model as they figure out more about how lightning works.

Students might come into this unit with several partial understandings or even inaccurate ideas of what lightning is and what causes it, such as that lightning never strikes the same place twice, lightning always strikes the tallest objects, it is good to stand under a tree during a thunderstorm, rubber tires on a vehicle are what makes it safe if struck by lightning, etc. This lesson is not the place to correct these ideas. Students will explore the static interactions that cause lightning and why certain places are safer than others through their own investigations during the unit.

In this lesson, students will not fully build the idea that attraction and repulsion explain material behavior. Instead, they get the idea on the table that particles (potentially atoms or molecules) are responsible for the macroscopic phenomenon of lightning. Students will gather more evidence of forces at work in lightning throughout Lessons 2-4, before fully tying them to transformations of matter in Lesson 6. They tie this thinking to contact forces in *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*. In addition to starting this story of matter, students identify initial evidence of energy flow in lightning, which will be expanded on in Lessons 10-11.

Students do not ask questions coming from unexpected results in this lesson, having already done so in *Polar Ice Unit*.

LEARNING PLAN for LESSON 1

1 · OBSERVE REAL-TIME AND SLOW-MOTION VIDEOS OF LIGHTNING STRIKES

6 min

MATERIALS: science notebook, chart paper, chart paper markers, https://youtu.be/tgwEHUiGgJs?si=1GmIDrQ8ssWzDOK_, https://openscied-static.s3.amazonaws.com/videos/slomo-strike-1.gif, https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2.gif

Introduce the new unit. Say, *Last unit, we figured out a lot about how human activity causes particle-level changes that affect all parts of the Earth system, including people. In this unit, we will use the same structures and strategies to figure out what is happening with a new phenomenon.*

Introduce lightning as a new phenomenon to explore.✱ Say, *The phenomenon that we will explore in this unit is one you have probably all witnessed yourselves, but I have a video here to watch so we can all have an example to be thinking about.*

ADDITIONAL GUIDANCE

If your area recently experienced a storm with lightning, use that as a way to introduce the unit. You could say something like, *After last night's storm, I was really wondering about lightning and why it happens with storms. How many of you noticed the lightning with that storm? I have a video that is not from our recent storm, but one we can watch together as an example of lightning to get us thinking carefully about it.*

Play the video linked on **slide A** and found at https://youtu.be/tgwEHUiGgJs?si=1GmIDrQ8ssWzDOK_ which shows a series of lightning strikes in real time. You may want to play the video a second time. Ask students to describe what is happening in the video--specifically, where the lightning is going from and to.

Here are some sample student responses:

- There's flashing and there are bolts/strikes.
- Some strikes/bolts are brighter than others.
- It's all across the sky and going in several directions--sometimes to the ground, sometimes maybe not.
- The bolts branch out (from larger main "lines?" to smaller ones).

Briefly elicit ideas about how we could better see what is happening. Listen for students to suggest slowing the video down.

Motivate changing the timescale of the lightning. Point out that students are starting to notice patterns in what is happening with the lightning in this video. Ask, *If we change the timescale--if we can slow the timescale down in the video--how would that help us notice patterns about the lightning?✱*

These are some sample student responses:

- We could better see where the lightning is going to/coming from and its direction.
- We could better notice how it's shaped, like those branches in the bolts.
- I wonder if we could see bolts inside/causing the flashes.
- Maybe we'll notice things we haven't been able to see yet.

Watch videos of lightning in slow motion. Display **slide B**. Direct students to set up a Notice and Wonder chart in their science notebooks. They should record their thoughts as they watch the following videos. Instruct students to focus on one video at a time, and to watch both multiple times.

- First lightning strike in slow motion: https://openscied-static.s3.amazonaws.com/videos/slomo-strike-1.gif

Display **slide C** and show the second video.

- Second lightning strike in slow motion: https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2.gif

You will likely want to play each of the videos multiple times to allow students more opportunities to record their observations. Observations students may highlight in these videos include:

✱ ATTENDING TO EQUITY

Social and Emotional Learning: Discussing lightning specifically and storms generally could elicit emotional stress from some students. Emotional stress regarding natural events can often be greater for students who feel they do not understand the situation or have no control over it. Although storms can bring impacts that students cannot control, the aim of this unit is to help students learn about how lightning works and thereby empower them to use what they know to keep themselves and their loved ones safe in the event of a lightning strike. More guidance about supporting students with this topic is provided in these Social and Emotional Learning callouts in this lesson.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

This brief discussion is intended to make explicit that different timescales allow for different observations and questions to arise from a phenomenon.

✱ STRATEGIES FOR THIS INITIAL IDEAS DISCUSSION

Use the start of a new unit to explicitly remind students about your facilitation stance in this discussion. Your role is to capture all student ideas, build excitement, and encourage as many different students to participate as possible, whether the ideas they share are "right" or "wrong." Make space for students to connect to experiences they have had outside school, too.

- Something seems to be trailing or falling down the sky before the brighter burst of lightning flashes.
- The bright burst of lightning seems to flash from bottom to top, not top to bottom.

SCIENCE NOTEBOOK



Keeping a science notebook allows students a space where they can reflect and communicate their developing understandings about science ideas and track changes in their understandings. Allow students to keep this notebook digitally, using voice-to-text or typing, if it supports their sensemaking more than handwriting does.

If your students have not yet set up their notebooks, ask them to designate a section of their binder for the current unit. They will keep all of their handouts and notes organized there. They should use dividers and/or sticky-note tabs to keep three-hole-punched handouts and notes on loose-leaf paper organized within this unit section. Optional **slide GG** is provided for you to use or modify to give students instructions on setting up their notebooks.

Facilitate an Initial Ideas Discussion.✱ Invite students to share aloud with the class what they noticed and wondered.✱

KEY IDEAS

Purpose of this discussion: To collect students' observations and questions about lightning (so we can then motivate looking at other data about lightning). The role of early Initial Ideas Discussions is to build momentum and excitement in the class. This is not the time to critique ideas or push for evidence.

Listen for these ideas:

- Something is moving or "trickling" down from the clouds to the ground before the big flashes.
- The big, bright bolts seem to be traveling from the ground back up to the cloud.
- Are the first little trickles like smaller lightning strikes? Sparks?
- The first slow-motion video shows lots of branching little trickles; the second flash (in the second and third videos) has just a couple of trickles.
- The second flash is so bright it looks like a firework or a shower of sparks.
- These videos are in black and white, so I can't tell if it's day or night--does lightning happen more often at night?
- Are those trees on the ground, or something like a mountain top? Is lightning more likely to strike higher places/taller things?
- What is lightning exactly? Light? Electricity? Some other kind of energy?

Draw on excitement about the phenomenon to motivate sharing of stories. Use student language about lightning to emphasize the ways in which it evokes memories and experiences. Say, *Whether we have seen lightning in our area a lot or not, we probably have some interesting thoughts about what lightning is or what it means.*

Encourage student-to-student talk with a focus on raising questions, clarifying, or adding on to what someone has said, rather than a focus on debating or arguing. Students might also use head nods or hand signals to show they had a similar idea to a classmate's.

Keep a class record of these initial ideas for future reference, such as when students create questions for the DQB later in this lesson, and when the class takes another look at these slow-motion videos in Lesson 11.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Reinforce that students have multiple options for *expressing* their ideas. Encourage the use of gestures, especially as students describe their ideas about the direction, motion, branching, etc. of the lightning. Invite students to point at places on the screen during discussions. Use the language(s) and terminology your students use to describe and explain their ideas, especially during this first lesson. There will be appropriate points later in the unit to name specific vocabulary.

2 · SHARE AND EXAMINE LIGHTNING STORIES

14 min

MATERIALS: *Lightning Stories: Mythology*, *Lightning Stories: Inventors*, https://youtu.be/QhqVFakF0N0, https://www.youtube.com/watch?v=zfhbMTGaecc

ALTERNATE ACTIVITY

The readings and videos in this section may be supplemented by any others that share stories about lightning, particularly if these stories are centered on the cultures and experiences of students in the classroom✱ or provide an extended foundational experience to students who have experienced lightning only infrequently. Depending on your students' context, some of these stories may be told in ways that your students are not used to--for example, with circular storytelling in https://www.youtube.com/watch?v=zfhbMTGaecc or stylized verse in portions of https://youtu.be/QhqVFakF0N0. The goal of this activity is not to provide students with information about the mechanisms of lightning but instead to inspire students to think about how people, including those in their community, have viewed and continue to to think about lightning.✱

Elicit students' lightning stories. Display **slide D**. Give students one minute to turn and talk with a partner or table group. Then ask for several volunteers to share their own stories or stories from their partner.

Suggested prompt	Sample student response
What do you know about lightning?	It is bright. It often happens during storms or with thunder, but maybe not always. It can be dangerous. You should go inside if it is nearby. It hits taller objects or water more often.
What stories, family history, or mythology have you heard about lightning?	Lightning never strikes the same place twice. Lightning is made by gods, like Thor or Zeus, when they are angry at people. Someone in my family's house got struck by lightning and it fried their appliances.
How do these stories help us make sense of lightning and its role in the world around us?	They tell us when lightning might occur. They try to explain how it happens. They show how much damage it can cause and that it must have a lot of energy or electricity.

Read and view stories about lightning. Say that people throughout the world and throughout history have told stories to try to understand what lightning is and how it happens. Point out that even though people do not always use these terms, many of the stories involve matter and energy playing special roles, just like they did throughout our first unit.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Several options are presented for students. You may allow students to choose the reading or video that is most interesting to them (providing multiple options for recruiting interest) or assign them one that you think will be engaging based on their reading level. *Lightning Stories: Mythology* is more challenging than *Lightning Stories: Inventors*, with the videos offering another way to access relevant information. All students, regardless of the medium they engage with, are framed as experts in the group discussion that follows.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

Although timescales of centuries are not the emphasis in this lesson, each reading includes a timeline. This is done to make clear to students some potentially unexpected ideas, such as Socrates proposing a mechanism for lightning over 2000 years ago, or the Oyo Empire lasting from around the time of Genghis Khan until after that of Benjamin Franklin.

Prepare to read. Display **slide E**. Divide the class into groups of four and ensure that a member of each group is assigned one of four readings or videos:

- *Lightning Stories: Mythology*
- *Lightning Stories: Inventors*
- https://youtu.be/QhqVFakF0N0
- https://www.youtube.com/watch?v=zfhbMTGaecc

Tell students that each group member will be responsible for reading and explaining one story to their group. Give students five minutes to read their individual story and record their answers to the two questions on the slide, then give groups an additional three minutes for students to share with their group.

Discuss similarities and differences. Display **slide F.** Ask groups to discuss the similarities and differences between the stories. Then ask two volunteers to share similarities and two more to share differences with the class.

Suggested prompt	Sample student response
What similarities did you notice between the stories?	They all relate to why lightning and thunder happen or what to do about it. They all have lightning and rainstorms paired together in some way. Lightning is angry or violent in all of them. The gods used lightning as a weapon.
What differences did you notice?	The exact source of the lightning varies. Several of the items focused on the causes of lightning, but the Inventors reading seemed to focus on how people could make it or use it.

Celebrate students' observations and the variety of stories they just read. Say, *Lightning plays an important role in many places and cultures, but it does not occur evenly everywhere on Earth or throughout the year. We will look at some data to help us identify patterns that could help explain why lightning occurs only sometimes.*

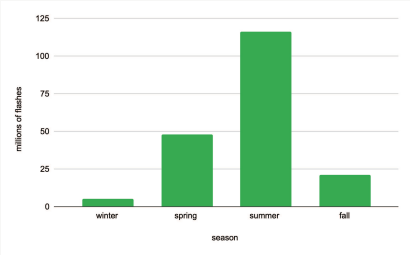
3 · ANALYZE DATA IN GRAPHS AND MAPS OF LIGHTNING OCCURRENCES

11 min

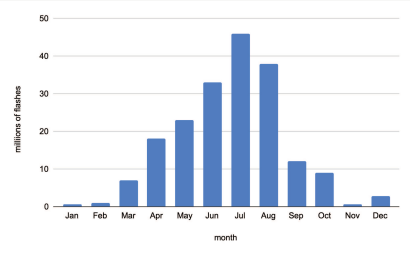
MATERIALS: science notebook, *US Lightning Data* (optional), chart paper titled "Patterns We Notice About Lightning", chart paper markers

Analyze data in graphs of lightning flashes versus time. Display **slide G** which includes the graphs also shown below. Direct students to draw a horizontal line under the text they already have in their Notice and Wonder chart to indicate that we are now gathering ideas from a different source. Prompt students to record their questions and ideas about these graphs under this line. Direct students to turn and talk with a neighbor for a moment about the following questions:

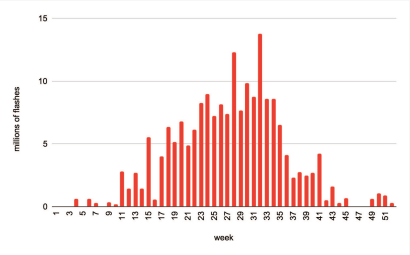
1. What do each of these graphs show?
2. What patterns do you notice across the three graphs?
3. What questions do you have about these data?



Data Source: Vaisala XWeather (2022)



Data Source: Vaisala XWeather (2022)

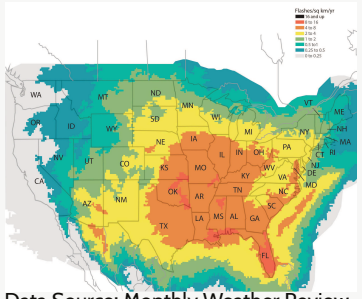


Data Source: Vaisala XWeather (2022)

If students do not pick up on the different timescales on the three graphs, ask them to focus on the *x*-axes, or ask them how the timescales are different.✱
After this brief partner talk, have students share their ideas with the whole class. Establish that lightning occurs much more frequently in the summer months than in other times of the year. Record observations on the chart paper titled "Patterns We Notice About Lightning."

Leverage wonderings like, "Where are these data from? Does lightning follow this pattern everywhere?", to motivate looking at location data next.

Analyze a map of lightning strike occurrences in the continental United States. Display **slide H.** Orient students to the flash density map, finding your home state (if shown) and discussing what the colors on the key represent (flashes per square kilometer per year).



Data Source: Monthly Weather Review

Direct students to work with a group to record what they notice and wonder in their notebooks, again under another horizontal line to indicate a new data source. Give students about three minutes. If you wish, share *US Lightning Data* so that students can more easily read the map and access specific numerical data for each state, including Hawaii, Alaska, and the District of Columbia.✱

Have a few students share their observations. Record these on "Patterns We Notice About Lightning." Listen for these ideas in particular:

- Florida, Louisiana, those bits of Alabama and Mississippi that are along the Gulf of Mexico, and parts of the Great Plains had the most lightning flashes per square kilometer per year.
- Places that are warmer, less dry, or lower tend to have more lightning, but there are some exceptions to these patterns.
- The West Coast seems to have very little lightning even though it's right on the ocean.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

Throughout the discussion, be sure to highlight to students that the general trend of the data is the same across the timescales, with week-to-week variation only visible on the rightmost chart. Point out that it is common when examining a phenomenon that some patterns only become visible when looking at particularly large or particularly small scales of time or space.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

If you make use of *US Lightning Data*, ask students, *Why is it important that the data are adjusted by area, instead of just listing how much lightning happens in each state?* Listen for the idea that some states are bigger than others. Highlight to students that the map, because it focuses on a 20-km grid, already adjusts for the size of the state by displaying each point individually, while the numerical data must be adjusted because of the variation in states' sizes.

Say, *We gathered these ideas about lightning here in the United States. Let's look next at lightning occurrences around the world and see what patterns we notice.*

ADDITIONAL GUIDANCE	If your students notice that the map is counting lightning flashes while the chart is counting lightning strikes and they ask if there is a difference, you can clarify those terms. A lightning flash includes all the lightning visible in that moment, whereas a strike means actual ground (or building, tree, etc.) contact. So, a flash can include multiple strikes. See optional **slide FF** for a labeled photo. These terms are not critical to the sensemaking of this unit, so it is not necessary to explain them unless students bring up the distinction.

Analyze a world map of lightning. Display **slide I.** Orient students to the color scale along the bottom of the map. Say, *We already have some ideas about when and where lightning happens from looking at US data, but what about the rest of the world?* You may want to explain to students that these data were collected by satellite sensors from 1995 to 2020. Use the questions below to help target students' observations.

Suggested prompt	Sample student response
Where does lightning happen most around the world?	In places where it is warm. Near the equator mostly, or near oceans. Not over oceans, the poles, or deserts.
Why might that be?	There are storms during the summer and at the equator it is kind of like summer all the time. The hot and humid parts of the United States have the most lightning, so maybe that is typical around the world.

ADDITIONAL GUIDANCE	At this point, it is important that students have observed that cold and dry areas do not seem to have as much lightning. It is not necessary that students use the language of "humidity." Additional support is built into Lesson 2 to make sure students have a common understanding of this term if it does come up.

ALTERNATE ACTIVITY

Extension opportunity: You may choose to share one or more of these links for students to explore and notice global lightning patterns, either in small groups or as home learning.

A time-lapse animation of global lightning activity month by month in 2019 is available at https://get.earthnetworks.com/resources/reports/2019-lightning-report. You may want to help students make sense of the following features of the time-lapse animation before giving them a few moments to find patterns to add to their Notice and Wonder charts:

- It is nighttime in the area above the curved line and daytime below it.
- The month is labeled at the top.
- Brighter colors (such as yellow) mean more lightning.

An interactive global lightning density map is available at https://interactive-lightning-map.vaisala.com/. Students can pan, click, and zoom on the map to see more detailed data.

Real-time data from the lightning sensors on the International Space Station are shown here: https://lightning.nsstc.nasa.gov/isslisib/isslisnrt.html. Students may be interested in comparing these patterns to ones they have observed from other global data.

Navigate to exploring data about the damage caused by lightning. You might refer to a question students have already raised about the damage lightning can cause, or say something like, *Now that we are starting to get a sense of where and when lightning happens most often, let's look at some of its impacts.*

4 · ANALYZE LIGHTNING IMPACT DATA

5 min

MATERIALS: science notebook, chart paper titled "Patterns We Notice About Lightning"

Prepare to discuss damage caused by lightning.✱ Display **slide J**. Tell students that the data we will look at next specifies how lightning causes damage to people's homes and lives, and it is okay to feel concerned by this kind of information. Use the prompts on the slide to consider why it is important to look at these difficult data.

Suggested prompt	Sample student response
How could it help us to consider lightning damage data?	If we know the harm lightning can do, we can be better informed to stay safer when lightning is around.
How can we support each other as we discuss information that could be stressful to think about?	We will treat this topic seriously and be thoughtful about it. We will be understanding and caring if someone is upset. We know it's okay to take a break if needed.

Summarize by saying something like, *Lightning can be scary because it can cause harm. One thing we as scientists can do in this class is examine data and use that information to figure out how we can be safer from lightning.*

Tell students to jot down any questions they have about these statistics on the "wonder" side of the chart in their science notebooks, under another horizontal line for this new data source.✱

Share the lightning injury information on **slide K:**

✱ ATTENDING TO EQUITY

Social and Emotional Learning: We have included damage and fatality data from lightning in this lesson to make exploring this phenomenon more relevant to students--by understanding how lightning works, we can determine how to stay safer from it. However, discussion of these data might elicit negative emotions from students who have experienced anxiety or loss from lightning or storms in the past. If you have a student who is emotionally stressed by this topic, you might offer the option of sitting out of this data sharing and discussion (the remainder of day 1) and rejoining the class for day 2 when we focus on modeling.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

- There are an estimated 400 lightning-related injuries each year in the United States.
- Of those people injured by lightning, up to 74% may have a permanent disability.
- Lightning is responsible for about 240,000 injuries per year worldwide.

Again, prompt students to record what they notice and wonder.

ADDITIONAL GUIDANCE

If your students wonder about the number of fatalities from lightning worldwide, you can share that the estimate is about 24,000 deaths and 240,000 injuries per year.
Global Hydrology Research Center. (n.d.). *Lightning primer*. National Aeronautics and Space Administration. https://ghrc.nsstc.nasa.gov/lightning/lightning_primer.html

Predict where lightning fatalities are highest. Direct students to record a prediction in their science notebooks to answer the question, *Where in the U.S. would you predict to see the most fatalities from lightning? Why?*

Invite students to share their predictions with the class and explain why they predicted that more fatalities would occur in those locations. Accept all student predictions.

Sample student reasonings:

- The areas that had the highest lightning flash density (i.e., Florida, along the Gulf Coast, in the midwestern Plains) would have the most fatalities from lightning.
- Areas that are warmer would have more fatalities from lightning, since we think lightning is correlated to warm temperatures (and maybe people are more likely to be outside, unsheltered when/where it's warm outside).

Analyze a map of lightning fatalities by state. Display **slide L.** Tell students to silently examine the map, compare its data to their predictions, and record any additional noticings or wonderings in their science notebooks under a final horizontal line for this last data source. Give students a minute or two to complete this step.

Suggested prompt	Sample student response
How does this data compare to your prediction?	Accept all responses.
Does anything surprise you about this data?	The places with the most fatalities are not always the places that get a lot of lightning.
What are you wondering?	Why is Arizona (or Colorado) in the top 10 for lightning fatalities? Does it have to do with the number of people? Is lightning sometimes more fatal or more powerful than other times? What makes lightning more damaging in some places than others?

Highlight to students that this new pattern--differences in fatalities, compared to differences in where lightning occurs--can help reveal new potential causes for lightning deaths within a population of people. It must not depend entirely on the amount of lightning received. In science, it is common that new data sets with different information or at new scales help reveal new potential causes for a phenomenon.

ALTERNATE ACTIVITY

Extension opportunity: Optional **slide M** includes maps of wildfires classified as lightning-caused. If your students have mentioned lightning's relationship with wildfires or if wildfires have a significant local connection for you, you might choose to include this data in your discussion. You will likely need to orient students to what the maps show, as they are somewhat complex.

If your students experienced *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*, they will bring in a wealth of knowledge about wildfires: what causes them, the effects they can have, and how human activities have impacted fire systems. These students will know the benefits wildfires provide to ecosystems and that they are not necessarily an example of damage done by lightning.

The goal with the maps in this extension activity is to acknowledge that wildfires can be caused by lightning (among other causes) and to elicit students' thinking and connections to the impacts of lightning. In this unit, students will not investigate how lightning causes fires, why some areas are more susceptible to wildfires, or the damage done by fires. Suggest that students look for similarities and differences between these three maps and the other maps and data students examined on previous slides. Give students a few minutes to work with their groups.

5 · RECORD PATTERNS FROM ACROSS THE DATA

9 min

MATERIALS: science notebook, chart paper markers, chart paper titled "Patterns We Notice About Lightning"

Review the "Patterns We Notice About Lightning" list as a whole class.✱ Display **slide N.** Make any additions or edits to the "Patterns We Notice About Lightning" poster by leading a Building Understandings Discussion about these patterns. Be explicit with students about your role as a facilitator in this particular discussion type.

KEY IDEAS

Purpose of this discussion: To gather and record patterns we have noticed across data sources about where or when lightning occurs.

In a Building Understandings Discussion, the role of the teacher is to prompt students for evidence to back up their ideas. When someone names a pattern, you might ask, *Can you remind us where you saw that pattern again?* You can also go back to any data sources and have students point to what they are trying to communicate.

These factors that we think influence lightning will inform part of our initial models next class, so it is important that students start to work on being able to defend their ideas with evidence.

Listen for these ideas:

- Lightning happens more often over land, but can happen over oceans/seas.
- Lightning happens more when/where temperatures are warmer (such as in the summer months or near the equator).
- Water/moisture in the air seems to be necessary--dry areas (e.g., the Sahara Desert, the American Southwest) get little to no lightning and humid areas (e.g., Florida, locations around the equator) get the most lightning.
- Looking at different data and scales of data helped us see different patterns, as well as where those patterns break down.
- Looking at data sets helped us see what might influence where lightning happens.

✱ STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

This discussion type has a different role in facilitation than an Initial Ideas Discussion. Your role is to prompt students for evidence when they bring up patterns they notice about lightning.

Tell students explicitly, *My role in this discussion is to press for evidence, regardless of whether or not the ideas are accurate. So you might hear me ask, "Where did you see that?" or "Show me with your hands what you saw the objects doing." It is my job to push us as a class to articulate the evidence we have to support our ideas.*

Summarize the patterns students point out. Say, *We will continue digging into what causes lightning next time we are together.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students suggest patterns in the matter that is present in many situations where lightning strikes (e.g., rain, water, humidity). (DCI: PS2.B.3; CCC: 1.1)
- Students suggest patterns in the energy that is present in many situations where lightning strikes (e.g., warm temperatures). (DCI: PS3.A.2; CCC: 1.1)
- Students recognize that patterns can help identify potential causes. (CCC: 1.1)
- Students identify that we saw slightly different patterns at different scales or from different data sets. (CCC: 3.3)

What to do: Although students might not use terminology about matter and energy at this point, they should identify both matter (water) and energy (warm temperatures) as potential factors from the data. Help students label their thinking about patterns and scale as such, so that they are considering these crosscutting concepts explicitly as they develop their models.

Building toward 1.A.1 Develop a model based on evidence to illustrate and predict the relationships between components of lightning formation based on patterns observed at different scales. (SEP: 2.3; DCI: PS2.B.3, PS3.A.2; CCC: 1.1, 3.3)

End of day 1

6 · REVIEW ELEMENTS OF SCIENTIFIC MODELS AND MODELING

3 min

MATERIALS: science notebook

Revisit what we figured out last class about lightning. Display **slide O.** Have a brief discussion to help students remember what they figured out last class.

Suggested prompt	Sample student response
What did we figure out about lightning last class?	Lightning happens more in the summer. Lightning happens more in hot places and places near water. There are lots of stories from around the world about lightning.
What were we wondering about, or what questions did the data raise for us?	Why does lightning happen more where it is hot and humid? What causes lightning?

Explain that we will work more with these ideas today by developing initial models for what causes lightning, but before we go there, we should review what we know about scientific models and the practice of modeling.

Review the elements of a model. Display **slide P.** Use the prompts to discuss the purpose and elements of scientific models. An alternate task follows this activity if students are not able to quickly address these prompts.✱

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Students have some experience modeling from *Polar Ice Unit*. However, it will be much more intentionally developed in this unit. Use this activity as an opportunity to gauge student thinking about modeling, and if students would benefit from more time to build understanding then continue with the optional activity on **slide Q.**

Suggested prompt	Sample student response
Why or how do scientists (like us) use models when thinking about phenomena like lightning?	Modeling helps us make sense of things we are trying to figure out. Modeling helps us show our thinking. Models help us explain and communicate to others what we know about how something works. Modeling helps us ask questions about what we don't know yet or where we are uncertain.
Why is it important to include components?	They show what is in the system. They are the important pieces that we need to explain.
Why is it important to include relationships or interactions?	They show connections between components. They show how different pieces of the model are related.
Why is it important to include mechanisms?	They explain what is happening in the phenomenon. They are ideas we can test.

7 · USE AN EXAMPLE TO REVIEW SCIENTIFIC MODELING (OPTIONAL)

5 min

MATERIALS: None

Use a concrete example to think about modeling. Display **slide Q**. Tell students, *Models should always be in service of answering a question or explaining a phenomenon.* As an example of modeling, ask student volunteers to work with you to construct a model to explain: *How do you move a soccer ball with your foot?* Invite students to call out ideas to help you draw and label this model on a whiteboard as you identify and discuss its elements together as a class. Sample student responses are shown in the table below.

Element of the model	Sample student responses	How it might be represented
Components (objects or pieces of the model)	the ball, the ground, your foot	simple line drawings of each
Relationships or interactions (how the components connect or work together)	the ball resting on the ground, your foot contacting the ball when it was at rest, the ball moving away from your foot	"before the kick," "during the kick," and "after the kick" frames with arrows showing motion

Mechanisms (why the phenomenon is occurring)	Forces acting on the ball are balanced before the kick. Your foot striking the ball provides an unbalanced force that causes a change in the soccer ball's speed (now it's moving) and direction (away from your foot). Energy is transferred from the muscles in the leg and foot to the soccer ball, resulting in a change of motion of the ball.	words describing or labeling the forces, arrows showing the directions

8 · DEVELOP INITIAL MODELS FOR WHAT CAUSES LIGHTNING

10 min

MATERIALS: *Initial Model*, chart paper titled "Patterns We Notice About Lightning"

Reintroduce the element of the Anchoring Phenomenon Routine: Attempting to make sense. Remind students that in *Polar Ice Unit*, we tried to make sense of the phenomenon by developing initial models. Say, *We do not have to worry about right or wrong answers in these models, as the goal is for us to get ideas on the table. We can return to our models throughout the unit as we figure out the things that we are currently uncertain about.*✱

Brainstorm model components with a partner. Display **slide R.** Distribute *Initial Model*.
Tell students they do not need to write their names on this yet. Set a timer for two minutes and direct students to talk with a partner to generate ideas about what components they will include in their models to answer the question, *What causes lightning to strike at a particular place and time?* They can list their ideas at the top of the handout.

ADDITIONAL GUIDANCE

Students will post their initial models in a gallery walk in the next activity section. Keeping the models anonymous will allow better discussion and sensemaking during the class consensus model building.

Individually develop initial models. Direct students to work on their own to use the components they listed to develop their initial model. Guide them to use words and/or drawings and point out the "zoom in" space. Remind students that we thought a lot about how to explain phenomena at the particle level in the last unit, so we want to continue using that scale of thinking about the different parts of a system to make sense of this phenomenon, too.

Also remind students to complete the explanation part of the handout. They should refer to the "Patterns We Notice About Lightning" poster from day 1 and choose one of those ideas to explain how that factor impacts differences in lightning.

Give students about eight minutes to work on their models. As they work, circulate and ask clarifying questions about parts of models that are blank or unclear. Encourage students to add labels, descriptions, or text where needed.

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Here, students work in multiple stages to model lightning (SEP) based on patterns that they observe or hypothesize at different scales (CCC). These patterns include DCI ideas like manifestations of energy, which will be addressed in Lesson Set 3, and attraction and repulsion between charges at the atomic scale, which students will partially develop in early lesson sets and return to at the end of the unit. These models will be explicitly revised in Lesson 9. In the meantime, students will have opportunities to develop models that explain portions of the lightning phenomenon. It is okay at this point if students' models are incomplete, as long as they generate questions and ideas for investigation that support student thinking later in the unit.

9 · COMPLETE A SECOND PASS ON THE MODELS

7 min

MATERIALS: *Initial Model*

Think about what lightning is. Display **slide S.** Give students one minute to turn and talk about whether they think lightning is energy or matter, and what evidence they have for either. Then ask for volunteers to share their ideas with the class.

ALTERNATE ACTIVITY

Building prerequisite understandings: Students should be familiar with energy and matter from *Polar Ice Unit*. If students do not readily distinguish between energy and matter, begin with matter. Elicit ideas about what matter is made of (particles) and have students represent particles. Then, ask the students to move about at increasing (safe) speeds. Ask students what changed. Use their responses to help emphasize that the motion of particles is typically how we think of energy at this point, but our understanding could change with more evidence.

Suggested prompt	Sample student response
Is lightning energy, or is lightning matter?	Lightning is energy. Lightning is matter. We think lightning is both. It is hard to know with the evidence we have.
What evidence do you have for either?	Lightning is really bright light, and light is energy. It might be kind of warm when there is lightning, and the particle motion is energy. Lightning has to be made of something, so that would be matter. Other matter is involved, like water or air.
How does answering these questions help us figure out what causes lightning?	If we know lightning is matter or energy, that might mean it is caused by changes in matter or energy. It could help us understand what matter or energy in the system might be important to cause lightning.

Revise models to include matter and energy. Display **slide T**. Say, *Now that we have thought about what lightning is, let's see if we can revise our models to show where we think matter and energy are and what they are doing.* Tell students to work with a partner to think about how to specifically model the matter changes and energy transfer involved. Suggest that students spend two minutes individually revising their models to include matter, and another two minutes revising them to include energy. Ensure that students are not just adding these components, but drawing relationships to other parts of the system.

ADDITIONAL GUIDANCE

Initial Model has students zoom in on a bolt of lightning. Use examples from *Polar Ice Unit* to clarify to students what "zooming in" means and have a brief discussion to ensure all students understand this terminology. It is not important for students to add this to their personal glossaries.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' models include components in the system that can be broken down into particles, such as air, ground, and clouds or rain. (SEP: 2.3; DCI: PS2.B.3)
- Students' models include indications of energy, such as warm temperatures. (SEP: 2.3; DCI: PS3.A.2)
- Students' models show interactions between the components. This could be something moving between components that causes. (SEP: 2.3)
- Students refer to patterns in map data, while paying attention to what might be happening at a scale too small to be seen, as evidence for particular causes for lightning strikes or fatalities. (SEP: 2.3; CCC: 1.1, 3.3)

What to do: If students struggle with the second pass at the model, remind them that the purpose of this activity is to figure out what we know and where we are uncertain. There is no "correct answer" here. You can also remind students about what was said during the brief matter and energy discussion after the first pass at the models. Encourage students to include the components we know are there–*What do we know is in the air? What is our evidence for energy in lightning?*–and to note guesses with question marks. Whether students are confident in their models or not, this is an opportunity to get an early view of their thinking and to see where there may be misconceptions around what lightning is or what causes it.

Building toward 1.A.2 Develop a model based on evidence to illustrate and predict the relationships between components of lightning formation based on patterns observed at different scales. (SEP: 2.3; DCI: PS2.B.3, PS3.A.2; CCC: 1.1, 3.3)

10 · REVISIT OUR COMMUNITY AGREEMENTS

6 min

MATERIALS: 1 green and 1 yellow sticky note or dot sticker, Internet connected device (optional), Community Agreements poster, virtual representation of the Community Agreements (optional)

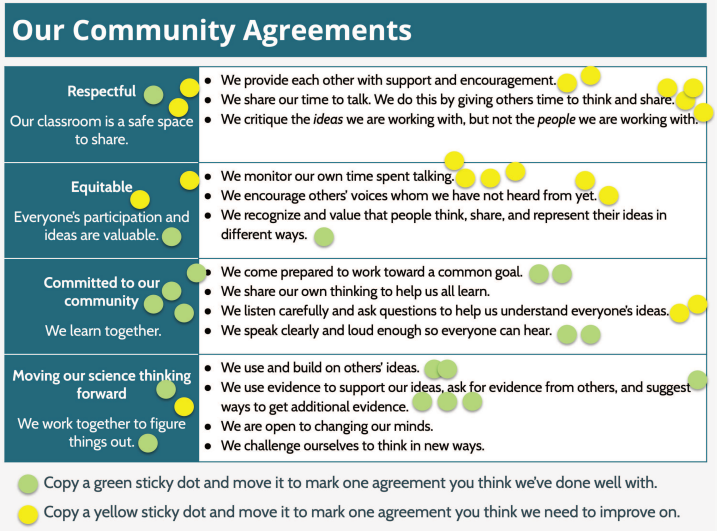
Revisit our Community Agreements. Display **slide U.** Say, *Think about what we have done the last two days of class: looking at lightning data, developing our initial models, puzzling over what we think lightning is. Which of our Community Agreements did we do well with, and which do we need to work on?*

Refer to the Community Agreements the class created during *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*. If this is a poster in the room, give students a moment to look over the poster. If you have a digital copy of the Community Agreements, add them to **slide U.** Direct students to mark one agreement they think we have done well with with a green sticky note or dot, and an agreement they think we need to develop more with a yellow sticky note or dot.

ALTERNATE ACTIVITY

If you have a digital representation of the Community Agreements that all students can access at once (see Materials Preparation section), have them mark their ideas virtually instead with green and yellow squares/stickies or circles/dots.

See the example shown here of how this might look.



Analyze the patterns in the green and yellow sticky notes.

Suggested prompt	Sample student response
What patterns do you see in the sticky notes?	Accept all responses.
Which agreements are we doing well with?	Accept all responses.
Which agreements could we develop more?	Accept all responses.
What are some ways we might continue to develop _____ (specific agreement)?	Accept all responses.

11 · HAVE A GALLERY WALK THROUGH INITIAL MODELS

7 min

MATERIALS: *Initial Model*, science notebook, masking tape

Conduct a gallery walk to compare initial models. Display **slide V.** Direct students to make a chart in their science notebooks where they will record similarities and differences they notice among the models during the gallery walk.

Then, direct students to post their models around the room. At this point, we are focusing only on the model side of the handout--we will not compare explanations about the impacts of different factors from the reverse side. Encourage students to pay particular attention to how matter and energy are represented in the models, and what role matter and energy play in lightning strikes.

Give students three to four minutes to silently circulate around the room to view classmates' models and record the similarities and differences they notice.

12 · START DEVELOPING AN INITIAL CONSENSUS MODEL

7 min

MATERIALS: *Initial Model*, science notebook, chart paper, chart paper markers

Begin to develop an initial consensus model. Gather students in a Scientists Circle. Display **slide W** and remind students of your classroom protocol for sitting or standing in a circle where everyone can be seen and heard. Direct students to bring their science notebooks and *Initial Model* with them to the circle.

Develop an initial consensus model for what causes lightning. Tell students that the goal of this discussion is to capture areas of agreement and disagreement about our individual initial models. Knowing where we agree and disagree will help us establish what we need to figure out about what causes lightning and possibly how to prevent injuries and damage from it. Be explicit with students about the shift of your role in this discussion type. See the Consensus Discussion callout for more guidance.

Facilitate a Consensus Discussion while you record the class's initial consensus model on a piece of chart paper or shared digital space titled, "What causes lightning to strike at a particular place and time?"✱ It is okay if you do not finish the discussion, as you will have more time on day 3.

KEY IDEAS

Purpose of this discussion: To develop an initial consensus model to capture the ideas we agree on, disagree with, or are uncertain about regarding what causes lightning. For example, there will likely be uncertainty about whether rain is necessary for lightning to occur. Use question marks to help show that we have some different ideas about this. In other words, we all agree that we are not in agreement on X part(s) of the model.

Be careful not to favorably respond to any one idea over others so as not to give away what might be going on in the phenomenon. The class will return to this model and evaluate their initial competing ideas as they gather more evidence throughout the unit.

Listen for these areas of agreement:

- Our model includes these components:
  - air
  - ground
  - clouds and/or rain
- Something is moving from the clouds to the ground and/or from the ground back to the clouds.
- There is evidence of energy in the warm temperature, sound of thunder, and/or flash of light.

Listen for these areas of uncertainty or disagreement:

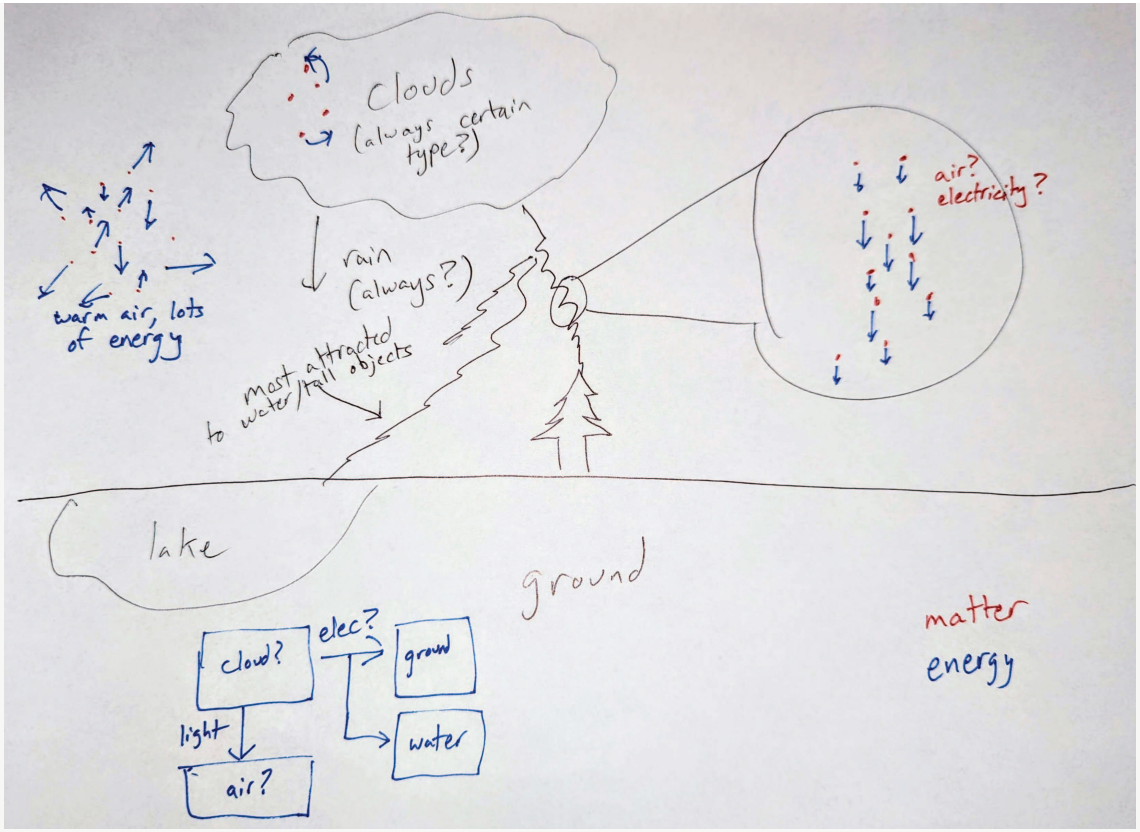
- What is moving between the clouds and ground? Light? Sparks? Electricity? Raindrops?
- Is rain always involved with lightning? (We have seen rain without lightning and we may have seen cloud-to-cloud lightning without rain... so is rain a necessary component or not?)
- Does the air need to be a certain temperature (warm/hot) or humidity for lightning to happen?
- Our particle-level zoom-in includes particles from the air (such as water), but we are not sure about the energy or forces moving around/within those particles.
- It is not clear if we should include water or tall objects as causing lightning to strike in a particular place.

See the example initial consensus model shown here, keeping in mind that the one you and your class develop may look different.

✱ STRATEGIES FOR THIS CONSENSUS DISCUSSION

Your role as a facilitator in a Consensus Discussion is to motivate students to take stock of where the class agrees as well as where there are areas of less certainty or confidence. Tell students explicitly that you will not write down everything they say. Remind them that you are checking to see where there is general agreement based on what we have seen so far and recording these ideas, as well as indicating areas where there is less certainty.

Encourage as many students as possible to contribute to this discussion because the goal of consensus is to represent the whole class, not just a few students. It may be helpful to explicitly tell this to the class at the start of the activity as well. Say that you might invite others who have not yet contributed to the conversation by asking, "[Student's name], what do you think of that?"



End of day 2

13 · CONTINUE DEVELOPING THE INITIAL CONSENSUS MODEL

8 min

MATERIALS: *Initial Model*, science notebook, initial consensus model, chart paper, chart paper markers, Community Agreements poster

Choose focal Community Agreements for today. Point out to students that we want to make sure we continue to follow our Community Agreements that we reviewed yesterday. Direct students' attention to the class-created Community Agreements poster or digital copy. Display **slide X**. Have students individually choose an agreement they will focus on today. Then, have students tell a partner why they chose that agreement and how they plan to work on it.✱

Gather in a Scientists Circle. Say, *We started to create our initial consensus model last class but we did not have time to finish, so let's do that now.* Display **slide Y** and remind students of your classroom protocol for sitting or standing in a circle where everyone can be seen and heard. Direct students to bring their science notebooks and handouts with them to the circle.

✱ ATTENDING TO EQUITY

Building classroom culture: Identifying a specific focal agreement to work on in concert with introducing the purpose of protocols, talk moves, and discourse strategies to support advancing that agreement serves two purposes. It gives students practice with new ways to interact

Continue to develop the initial consensus model for what causes lightning. Remind students that the goal of this discussion is to capture areas of agreement and disagreement about our individual initial models. Knowing where we agree and disagree will help us establish what we need to figure out about what causes lightning and possibly how to prevent injuries and damage from it. See the above Key Ideas and Consensus Discussion callouts for guidance on this discussion.

When you are done, collect students' models so that you can provide initial three-dimensional feedback to students.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' models include components in the system that can be broken down into particles, such as air, ground, and clouds or rain. (SEP: 2.3; DCI: PS2.B.3)
- Students' models include indications of energy, such as warm temperatures. (SEP: 2.3; DCI: PS3.A.2)
- Students' models show interactions between the components. This could be something moving between components that causes lightning. (SEP: 2.3)
- Students refer to patterns in map data, while paying attention to what might be happening at a scale too small to be seen, as evidence for particular causes for lightning strikes or fatalities. (SEP: 2.3; CCC: 1.1, 3.3)

What to do: As the class comes to consensus, focus on bringing out the key ideas in the discussion. Using observations from the gallery walk, encourage students who had particularly clear representations or productive ideas to share them. After the discussion, collect models so that you can provide individual feedback to students. In this feedback, ask questions to encourage students to be more explicit in their models and use of evidence, and to incorporate particular patterns across scales into their explanations. However, do not correct their thinking about scientific concepts.

Building toward 1.A.3 Develop a model based on evidence to illustrate and predict the relationships between components of lightning formation based on patterns observed at different scales. (SEP: 2.3; DCI: PS2.B.3, PS3.A.2; CCC: 1.1, 3.3)

with the members of their learning community, and it gives students experience using strategies that can help them engage in science and engineering practices more deeply over time.

14 · BRAINSTORM AND SHARE RELATED PHENOMENA

8 min

MATERIALS: science notebook, chart paper, chart paper markers

Brainstorm related phenomena. Say, *Like we did during our first unit, let's take some time to think of similar or related phenomena--other experiences we have had or things we have seen that could be related to lightning in some way. These ideas or experiences we have from our lives can help us make progress on figuring out more about lightning and lightning safety.*

Brainstorm examples of related phenomena and safety precautions. Display **slide Z.** Say, *We have already been mentioning some of our personal experiences with lightning and connected ideas, but now we want to take time to think about and record these specific ideas that we can use in this unit.*

Have students turn and talk with a partner about the prompts on the slide, also listed below:

- When and where have you experienced (or seen someone experiencing):
  - lightning?
  - something similar to lightning?
- What signals do you use to decide to protect yourself against a storm? How does where you are determine how you stay safe?

Lead an Initial Ideas Discussion to gather examples of related phenomena and safety precautions. Invite students to share their ideas with the whole class. Be sure to record these ideas on a piece of chart paper so the class can refer to them at future points in this lesson and the unit.

KEY IDEAS

Purpose of this discussion: To connect students' engagement with lightning in this lesson to their own experiences, including those that are more peripherally connected to lightning. This discussion about related phenomena is intentionally placed right before the Driving Question Board activity to lead to, along with the consensus model development, a wide variety of student questions that will be addressed throughout the unit. Push to clarify students' ideas with follow-up questions, such as, *Are those similar shocks or sparks the same thing as lightning?* or *Is anywhere inside better than anywhere outside?*

Listen for these ideas:

- We have seen lightning during thunderstorms.
- We see lightning more during the summer or when it's hot.
- We went to the beach for vacation and there was lightning and thunder every day.
- We have seen "lightning" created by something at a science museum.
- Sparks from metal hitting metal or stone seems kind of similar to lightning.
- When I rub my feet on the carpet and then touch someone, sometimes it sparks.
- I get inside or away from tall objects when clouds are dark, it starts raining, or there is lightning or thunder in the distance.
- I worry more about a storm if I am in an open area or do not have access to a safe place.

15 · DEVELOP A CLASS DRIVING QUESTION BOARD

20 min

MATERIALS: science notebook, 3x3 sticky notes, colored marker, chart paper for Driving Question Board

Reflect on the role of the Driving Question Board. Display **slide AA.** Say, *As we saw in the first unit, your questions are really important in this class. Just like we did then, we are going to compile our questions on a Driving Question Board and we will collaborate to build it so everyone's ideas are represented and organized.* Then have students briefly discuss the prompts on the slide.✱

Generate questions for the DQB.✱ Display **slide BB.**Tell students to record their questions on sticky notes for easy sharing and organizing. To help them generate questions, direct students to think back to the work we have done so far in this lesson:

- Notice and Wonder charts about lightning videos, lightning data, and damage/fatality statistics
- Individual initial models and our class initial consensus model
- Our list of related phenomena

Call attention to the instructions on the slide for writing these questions on sticky notes.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' questions for the DQB should be connected to the observations they previously made about patterns they noticed at different scales in the lightning phenomena and data. (SEP: 1.1; CCC: 1.1)
- Students should be asking "how" or "why" questions to clarify and seek additional information about the relationship between components, especially matter, that might contribute to lightning formation. (SEP: 1.1; DCI: PS2.B.3)

What to do: If students are struggling to generate questions connected to their previous observations, direct them back to their Notice and Wonder charts, related phenomena list, and initial models. If students are struggling to seek information, point them back to specific places in their initial models and ask, *What would you need to know more about to figure this out?*

Building toward 1.B Ask questions that arise from different patterns observed in lightning data to clarify and seek additional information about what causes lightning and factors that impact lightning fatalities. (SEP: 1.1; DCI: PS2.B.3; CCC: 1.1)

✱ ATTENDING TO EQUITY

As students share, reflect back on which students had their questions answered in the prior unit and consider whether *all* students see the Driving Question Board as a tool for making sense of a phenomenon. You may wish to have students individually reflect on these prompts to gather more information about how each student felt their questions and ideas were taken up in *Polar Ice Unit*.

✱ ATTENDING TO EQUITY

The first priority during the formation of the DQB is reinforcing a classroom community wherein all ideas are valued. As such, everyone should have a question on the board. Use your judgment on how to prompt students to form "how" and "why" questions. If students struggle with sharing, encourage them to go public with question) as they are, rather than focusing specifically on forming a "how" or "why" question.

Collaboratively develop the Driving Question Board. Display **slide CC** and gather students in a Scientists Circle. Say, *As we build our DQB, it is important that we hear everybody's questions, and we might find that we have questions similar to some of our classmates' questions. We want to group and organize our questions so that they can help us guide our investigations and keep track of what we want to figure out.*

Explain that you would like students to take the lead on this process. You might want to choose the first volunteer to begin and then step back. Students should use the directions on the slide to guide them. Step in when necessary to point students to some of the Community Agreements to encourage equitable participation. The student-facing directions on the slide for assembling the DQB are:

1. Choose a volunteer to go first. This student reads their question and then posts it on the DQB.
2. Raise your hand if you have a question that is related or the same.
3. The first volunteer selects the next student whose hand is raised, and that second volunteer reads their related question, says why or how it relates, and then posts it on the DQB with the first question.
4. The second volunteer selects the next student who will read another related question, say how or why it relates, post it, and call on the next student.
5. Continue until the class agrees that all the related questions have been placed. Then go back to step 1 and choose a volunteer with a different question to start a new cluster.
6. Keep posting questions until everyone has shared at least one.

Note: It is helpful to label each cluster of questions as they form with a word, phrase, or main question to summarize that cluster. Some of the questions students may have are shown on the sample DQB below.



Title the DQB with a version of the Unit Question. Propose that these questions are all related to an overarching question, such as, "What causes lightning and why are some places safer than others when it strikes?" Title the DQB with this question or a similar one as phrased by your students.

16 · GENERATE IDEAS FOR INVESTIGATIONS

7 min

MATERIALS: science notebook, chart paper titled "Ideas for Investigations", chart paper markers, Driving Question Board

Generate ideas for investigations. Display **slide DD**. Say, *We have so many questions to explore! How could we start to investigate the answers to some of these questions?*

Assign each pair of students one category of questions from the DQB to focus on first. There likely will be multiple pairs of students brainstorming investigations for each category of questions; this is fine, as it allows for diversity of thought and ideas. After they have gathered some ideas for that category of questions, pairs can choose another group of questions to consider.✱

Students should keep track of their ideas in their notebook for future reference. Give students three to four minutes to generate their ideas.

Compile a class list of Ideas for Investigations to reference throughout the unit. Invite each pair to share one or two of their ideas for investigation, and then go around to the groups again as time allows. Record these on a piece of chart paper titled "Ideas for Investigations" to keep as a class reference. The goal is to hear a variety of ideas that we may be able to investigate over the course of the whole unit.

ADDITIONAL GUIDANCE

These Ideas for Investigations should be revisited throughout the unit, just like the Driving Question Board. When a future lesson involves an investigation like one the class has suggested, take the time to point that out. If your students suggest ideas that are not planned in the unit but that you feel would be productive to pursue, use your discretion and your knowledge of the storyline to decide where these additional investigations would best fit so that the unit's lesson-level takeaways continue to build on one another.

✱ ATTENDING TO EQUITY

Universal Design for Learning: It will be helpful to students' *engagement* with this task if they can clearly see the question(s) or category of questions they are focused on for generating ideas for investigation. So, you may have students temporarily disassemble the DQB and take sticky-note questions or a category of questions to their group for reference while they generate ideas. Or, if possible, you might take photos of sections of the DQB and share those digitally for students to refer to while they brainstorm.

17 · NAVIGATE

2 min

MATERIALS: chart paper for Driving Question Board, chart paper titled "Ideas for Investigations", initial consensus model

Navigate to the next lesson. Display **slide EE**. Say, *We have a lot of questions about lightning, and we have already thought of many things we can do to start answering our questions. Let's take a moment to wrap up today's work by taking stock of what we have accomplished so far and what our next steps should be.*

Suggested prompt	Sample student response
Where did we leave off in our work today?	We thought about what lightning is. We asked a bunch of questions. We thought about what investigations we can do to answer our questions.
Last unit, what did we do after we generated questions and ideas for investigations?	We started investigating our questions. We started with a particular group of questions and analyzed data that helped answer them.

For home learning, assign students to discuss with their families what they have encountered, wondered about, and want to investigate.

Additional Lesson 1 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-LITERACY.RST.9-10.10: By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently. Students independently engage with texts and work to collaboratively synthesize their meaning, incorporating graphs as well.

LESSON 2: What parts of the (smaller-scale) system might be causing the (smaller-scale) lightning?

PREVIOUS LESSON

We watched videos of lightning strikes and discussed stories about lightning. We looked for patterns in data of lightning occurrences and fatalities caused by lightning. We developed initial models and an initial consensus model for what causes lightning and how certain factors influence it. We listed related phenomena, then generated questions and shared them to organize our Driving Question Board.

THIS LESSON

INVESTIGATION

1 day



We revisit our initial consensus model and identify its parts. We are not sure if rain is necessary in the model, so we collectively analyze data that show a relationship between rain and lightning. We consider the merits and limitations of our initial consensus model and how we can figure out more. Our teacher provides a model that produces smaller-scale "lightning." We examine this physical model and consider its merits and limitations as a model of how lightning is produced in a storm. We brainstorm additional objects we could use to figure out more about what is happening in the water dropper system.

NEXT LESSON

We will carry out two rounds of investigations by adding different test objects to the water dropper system. We will develop a model to illustrate the forces acting on the test objects. We will identify related phenomena (static) that we think would produce similar interactions.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-6, HS-PS2-4, HS-PS3-2, HS-PS3-6

WHAT STUDENTS WILL DO

2.A Use and move between multiple types of models to determine whether there is a correlational or causal relationship between falling water and lightning. (SEP: 2.4; DCI: PS2.B.2; CCC: 2.1)

WHAT STUDENTS WILL FIGURE OUT

- Rain from clouds is correlated with lightning from clouds.
- Water drops falling can create a lightning-like spark in the lab.

Lesson 2 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	7 min		**REVISIT OUR INITIAL CONSENSUS MODEL** Lead students in identifying key parts of their initial consensus model from Lesson 1.	A-C	initial consensus model
2	5 min		**MAKE PREDICTIONS AND ANALYZE DATA** Help students analyze a graph that shows the volume of rain and lightning flash rate produced by storm clouds.	D-F	*Lightning Graph*, Community Agreements
3	10 min		**DISCUSS IF FALLING WATER PRODUCES LIGHTNING** Lead students in a brief discussion of whether falling water and lightning have a causal or correlational relationship, and what students could do to figure out more.	G-L	chart paper titled "Merits and Limitations of Initial Consensus Model", initial consensus model, chart paper markers
4	12 min		**NOTICE AND WONDER ABOUT THE WATER DROPPER SYSTEM** Reveal and allow students to investigate a system with similar parts as their initial consensus model and collect students' observations and questions.	M-R	Water Dropper System Lab
5	6 min		**REVISIT MERITS AND LIMITATIONS OF THE WATER DROPPER SYSTEM** Discuss the relative merits and limitations of the water dropper system.	S	chart paper titled "Merits and Limitations of Initial Consensus Model", chart paper markers
6	5 min		**NAVIGATE** Brainstorm additional objects or materials that could be used to test interactions in the water dropper system.	T	

End of day 1

Lesson 2 • Materials List

	per student	per group	per class
Water Dropper System Lab materials	• science notebook • safety glasses with side shields or safety goggles • non-latex apron		• 2 water dropper system setups
Lesson materials	• science notebook • *Lightning Graph*		• initial consensus model • Community Agreements • chart paper titled "Merits and Limitations of Initial Consensus Model" • chart paper markers

Materials preparation (60 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Have the Community Agreements visible.

Water Dropper System Lab

- **Group size:** Set up two stations that all students can examine independently.
- **Setup:**
  - **Building the water dropper system and electroscope:** See *Water Dropper Construction* for instructions on constructing the water dropper systems that will be used in Lessons 2 and 3.
    - Watch https://youtu.be/t4npD1-PuKM?si=Zc-9iFepkc4Rd85Y to see parallel teacher directions for the water dropper system build.
    - Watch https://youtu.be/pVFJqjDK0tA?si=qbV0mpATjJTwGpyl to build the electroscope.
    - Watch https://youtu.be/3WYrtQU8yK4?si=UfMoSvHx4X4eF9CZ and use *Water Dropper Troubleshooting* for additional guidance on calibrating and troubleshooting the water dropper system. Portions of this video may also be shown to students to demonstrate the dropper functioning, if necessary.
  - Classroom environments with high humidity may prevent the formation of sparks. In this case it is recommended that you run a dehumidifier and test the relative humidity in the room until it comes down to 40% or lower if possible. Keep the dehumidifier running over the course of this lesson, and Lesson 3, to compensate for any humid air that flows in during the class.
  - https://youtu.be/3WYrtQU8yK4?si=UfMoSvHx4X4eF9CZ may be shown if the water dropper is not functioning correctly. Similar videos are included in Lesson 3. Alternatively, if construction of multiple water droppers is not possible but one is functioning properly, conduct these investigations as demos.
- **Notes for during the lab:** Avoid naming the device as a Kelvin water dropper. Simply refer to it as the water dropper system. DO allow students to touch the parts of the system as long as they do not disconnect any wires. Students will feel a very small shock.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science.* Immediately wipe up any spilled water on the floor–it is a slip and fall hazard. Use the water dropper away from electrical outlets. Additionally:
  - Wear sanitized safety glasses with side shields or safety goggles and non-latex apron during the setup, hands-on, and takedown segments of the activity.
  - Use caution when using sharp [wires, etc.], which can cut or puncture skin.
  - Wash your hands with soap and water immediately after completing this activity.
- **Disposal:** Water can be recycled between the aluminum coated buckets and plastic bin during the lab, then poured down the drain afterward.
- **Storage:** Store the system so that hot-glued components do not come undone and wires do not tangle or kink. Ensure that metal components are dry before storing to prevent corrosion.

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build new ideas related to the following disciplinary core idea:

- **PS2.B.2 Types of Interactions:** Forces at a distance ~~are explained by fields (gravitational, electric, and magnetic)~~ permeat~~ing~~ space ~~that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.~~

Crossout explanation: PS2.B.2 is developed further later in the unit. In Lesson 3, students explicitly name forces as being involved in interactions around the water dropper. In Lesson 4, students develop the idea and name that electric fields can permeate the space around the dropper. Here, students notice hints of forces in the interactions between water and the other components of the water dropper system.

In Lesson 1, students developed an initial consensus model to explain how lightning formed. In this lesson, students identify key components in this model to determine that the role of rain is a point of confusion. If students have not mentioned rain, but instead focused on humidity, moist climates, or the like, help them link these feelings of moisture in air to the rain that can often result from it.

They use data and a physical model to decide that rain not only correlates with lightning, but could be a cause (CCC: 2.1). In doing so, students move between a pencil-and-paper model (the initial consensus model) and a physical model (the water dropper system) and consider the relative merits and limitations of each (SEP: 2.4). Before moving on, students should have questions about the water dropper system and ideas about how to investigate these questions.

Students do not engage with SEP: 2.4 in its entirety: ~~*Develop and/or use*~~ *multiple types of models to provide mechanistic accounts* ~~*and/or predict phenomena,*~~ *and move flexibly between model types based on merits and limitations.* Students will have opportunities to develop multiple types of models of the same phenomenon in Lessons 5 and 8.

In this lesson, students will co-construct a definition for the following terms, which they should add to their Personal Glossaries: *correlation*, *causation*. We recommend that you do not post any terms or ask students to record any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students do not have to be certain that falling water causes lightning, but they do have to decide that it is a strong possibility that requires further investigation. Students will use the water dropper system more in Lesson 3 before investigating other systems with static electricity in Lesson 4, and moving to the subatomic level in Lesson 5. The idea of charge will be developed primarily in Lessons 4 and 5, rather than here. This will give students the pieces needed to build a model for the role of water in lightning in Lesson 6. At no point in this unit will students fully explain the water dropper system, but at the end of *Water Dropper Construction* an explanation for the teacher is provided.

This unit does not address magnetic or gravitational fields in depth, although they are mentioned in passing in Lesson 4. Students fully establish a connection between electric and magnetic fields in *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)* and develop a deeper understanding of gravitational fields in *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*.

In this lesson, students turn toward empirical evidence to gather evidence of causation, even if they are not certain of the causal relationships leaving the lesson. They will name empirical evidence as such in Lesson 4.

LEARNING PLAN for LESSON 2

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1 · REVISIT OUR INITIAL CONSENSUS MODEL

7 min

MATERIALS: science notebook, initial consensus model

Help students recall the last class's activities. Display **slide A.** Ask, *How did we end last class?*
Look for student responses such as:

- We shared and organized our questions.
- We brainstormed ideas for investigations.
- We decided to look at areas of agreement.

Elicit any new ideas for investigations or questions that students have after talking with their families. Record these in the appropriate places.

Connect the initial consensus model and Progress Tracker.✱ Say, *We ended Lesson 1 with a lot of questions and ideas, but not a strong sense of the next step we should take. When that happens, it can be useful to return to our working model to take stock of what we know and where we have questions.* Put the initial consensus model in a visible place and say, *We should break down our model a bit. To help us do that, we can use a tool like a Progress Tracker.*

Explain that the Progress Tracker section of their science notebooks is intended:

1. as a thinking tool to help you keep track of important discoveries that you or the class makes; and
2. to provide you a place to individually organize your thoughts and reflect on what you are figuring out without having to worry whether your ideas are correct.

Display **slide B.** Have students label a blank page in their notebook with "Progress Tracker" at the top and make a table as shown on the slide. Once students have set up their Progress Tracker page, continue as follows.

ADDITIONAL GUIDANCE

The sample Progress Tracker included in these materials serves as teacher guidance for what students **may** say at various points throughout the unit. Some students may say more, others may say less. It is important that what the students write in the Progress Tracker reflects their own thinking at that particular moment. In this way, the Progress Tracker can be used to formatively assess individual student progress throughout the unit. When the class develops ideas together and comes to agreement, students will record this in their Progress Tracker and indicate the sources of evidence, but make it clear that this is a classroom consensus model.

Define the task. Display **slide C.** Say, *In your Progress Tracker, record the different parts that we decided should be in our initial consensus model. If there were any components of the model that we were not sure about, jot them down off to the side.*

Give students a couple of minutes to work, then elicit ideas from the class.

✱ ATTENDING TO EQUITY

Water plays a key role in this navigation. If students bring up clouds but do not say what clouds are, ask them and be sure the whole class is on the same page. Leverage ideas such as the air feeling humid or damp when a storm is approaching. It is important that students start to think of clouds as being made of water droplets and as a reservoir of water. Students should be familiar with clouds from *OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)* or similar middle-school instruction, so you may wish to leverage this knowledge to help focus students on the substance that composes clouds.

Suggested prompt	Sample student response
What components did we include in our model?	Ground and objects on the ground Clouds (which are made of water droplets) Air Something (lightning?) moving from the cloud to the ground through the air
What components did we consider including, but were unsure about?	Falling water / rain We were unsure what the stuff coming down was, and if it was related to a spark

Sample student Progress Tracker entry:

Question	What I figured out in words/pictures
What were the different components or parts we decided to include in our model to explain when and where lightning occurs?	• *Lightning is most common when the weather is warm and humid/wet.* • *We think that the ground, clouds, air, and maybe falling water/rain are important to lightning, in addition to whatever is moving when lightning strikes.*

ADDITIONAL GUIDANCE

The term "falling water" is emphasized rather than rain to help students easily build toward the idea in later lessons that motion of water droplets is the important feature in generating the charge differentials required for lightning, rather than rain in particular triggering lightning. You do not have to correct students if they say "rain," but consider following up with, *You mean falling water?* to help students get used to the idea.

ALTERNATE ACTIVITY

If students bring up *humidity*, ask them to explain what they mean. Depending on students' experience, they may have different working definitions of humidity. At this point there is no need to focus on development of a consensus definition. Use the language that students come up with, as long as it involves water in air and the idea that rain tends to follow after periods of high humidity. If time permits, it may be productive to ask students to draw what they mean as well.

Lead students toward an initial focus on falling water. Continue on ONE of the three paths presented in the table below, based on students' responses in the previous discussion.

Student thinking	Teacher response
Students are unsure of water's role in lightning formation.	Say, *It sounds like the role of falling water is one of the things we are uncertain about. It is probably an easier uncertainty to think about. Let's start by thinking about whether falling water has anything to do with lightning.*
Students are certain water is involved in lightning formation.	Say, *I hear many of you saying that rain or falling water somehow causes lightning.* Elicit evidence from the class. Students will likely say that in their experience, rain always accompanies lightning. Cast doubt by responding, *In our experience, it seems to be the case that when we see lightning, it is raining where we are, but has anyone actually been within a few feet of a lightning strike to see if it is raining there when the lightning hits?* Listen to student responses, then say, *It seems like we need more evidence to know for sure if falling water actually accompanies lightning in all cases.*
Students have not mentioned falling water or rain in their model.	Leverage the fact that students are uncertain what lightning is. Say, *Our models had lightning, which we saw in the video as something falling or trailing through the sky. What do you think lightning is made out of?* Listen to student responses, then say, *It sounds like we have a lot of different ideas about what exactly lightning is. Let's see if we can do something in the class to give us some evidence to determine what lightning is and where it comes from.*

2 · MAKE PREDICTIONS AND ANALYZE DATA

5 min

MATERIALS: *Lightning Graph*, Community Agreements

Give students an opportunity to make a prediction. Display **slide D.** Ask students to vote on the first prompt on the slide: *Do you think there is any relationship between clouds that produce rain and clouds that produce lightning?*

You may wish to use some method such as writing an answer on a piece of paper and holding it up or using a digital polling platform, so that you can see individual responses without students influencing each others' votes. If you wish, you may ask a couple of students to share their thinking around their vote.

Say, *If clouds that produce rain and clouds that produce lightning were related, we would expect the same clouds to do both things. I have some data that might help us see if that is the case. Before we dive into this data, I want to make sure that we are thinking about one of our Community Agreements. We agreed that we want to make progress on our scientific thinking together. When we look at data from an experiment or reliable source, what should we do if we have ideas about what it means, but others are confused?* Ensure students are thinking about sharing their ideas and trying to explain them to others before continuing.✱

✱ ATTENDING TO EQUITY

Building classroom culture: This is an important opportunity to emphasize that each individual has contributions to make to their community of learners. It is through differences in thinking that the class will grow its knowledge together. Throughout this unit, students will be asked to be open to sharing knowledge products that depict their current thinking and to be open to learning from classmates who share their knowledge, too.

Introduce a graph comparing rain volume and lightning flash rate. Distribute *Lightning Graph*. Display **slide E** and give students a minute to turn and talk with a partner to discuss initial impressions of the graph and the question on the slide.

Lead students in analyzing the graph. Display **slide F.** Lead students in a brief whole-class discussion of what the graph shows. The provided prompts are intended to dig deeper if students' initial analysis is surface-level or misses important features.

Suggested prompt	Sample student response
What does this graph tell us?	This graph tells us there tends to be more lightning flashes when there is more rainfall.
What does the title mean?	This is a graph of the rate of lightning flashes and rainfall.
What do the units on the axes mean?	The x-axis tells us the rainfall every hour. Volume of rain is measured in how many mm are covering a square kilometer. The y-axis tells us how many lightning flashes the cloud produces every minute.
What do you notice about the scales?	The numbers on the x-axis are pretty big. The y-axis scale has smaller numbers that still feel pretty large. Over 400 lightning strikes a minute is a lot.
What do you notice about the shape of the graph?	The equation is not a linear equation. The shape of the graph is not linear, as it kind of curves upward as rainfall increases.

3 · DISCUSS IF FALLING WATER PRODUCES LIGHTNING

10 min

MATERIALS: science notebook, chart paper titled "Merits and Limitations of Initial Consensus Model", initial consensus model, chart paper markers

Take a poll on the conclusion. Display **slide G**. Say, *The graph shows us that clouds that produce lightning also tend to produce more rainfall. But does that mean one is causing the other?* Assign different portions of the room to each response on the slide. Then, have students move to different parts of the room based on which statement they agree with.

Give students a minute to quickly share their evidence with the person standing closest to them. Then, ask a few students from different areas of the room to share their evidence that caused them to stand where they did. Point out that as students share their evidence, the only piece of evidence that everyone is using is the graph. Have students consider if they have sufficient evidence to support their claims. Ask for a few volunteers to share their thinking, then send students back to their seats.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Whether students think there is enough evidence to say that there is a causal relationship between falling water and lightning. (DCI: PS2.B.2; CCC: 2.1)

What to do: Disagreement at this point is fine. Accept all student ideas and push back only if all students are convinced that they can definitively state that falling water causes lightning or lightning causes rain. In this case, ask students to explain how that would work and remind them that we cannot be sure that one event causes another unless we have an explanation of the mechanism supported by experimental evidence.

Building toward 2.A.1 Use and move between multiple types of models to determine whether there is a correlational or causal relationship between falling water and lightning. (SEP: 2.4; DCI: PS2.B.2; CCC: 2.1)

Introduce new terms. Display **side H**. Say, *It sounds like we have lots of different ideas about what the graph we saw actually means. We agree that lightning and rain tend to increase or decrease together, but are not sure what the cause is. In situations like this, scientists like to think about the difference between correlation and causation. Causation is when one action or event causes another. Knowing that, what do you think correlation would be?* Students should respond that correlation is when two events happen together, without one causing the other.

Ask, *How is this different from causation?* Look for students to suggest that if scientists have identified a cause for the relationship, then it should be labeled causation.

Display **slide I** and have students stop and jot in their science notebooks about which statements show correlation, causation, or both. After a few minutes, ask students to share their thoughts. A key is below.

A. Clouds that produce rain tend to produce lightning, but there is no connection. **Correlation**
B. Clouds produce lightning because they produce rain. **Correlation** and **Causation**
C. Clouds produce rain because they produce lightning. **Correlation** and **Causation**
D. Clouds produce both lightning and rain because of some third factor. **Correlation** and **Causation**
E. We need more information to determine the relationship. **Correlation; unsure about Causation**

Update Personal Glossaries. Display **slide J**. Point out that now that we have come to some agreement on what correlation and causation mean, we should record these ideas. Give students a moment to record *correlation* and *causation* in their Personal Glossaries.

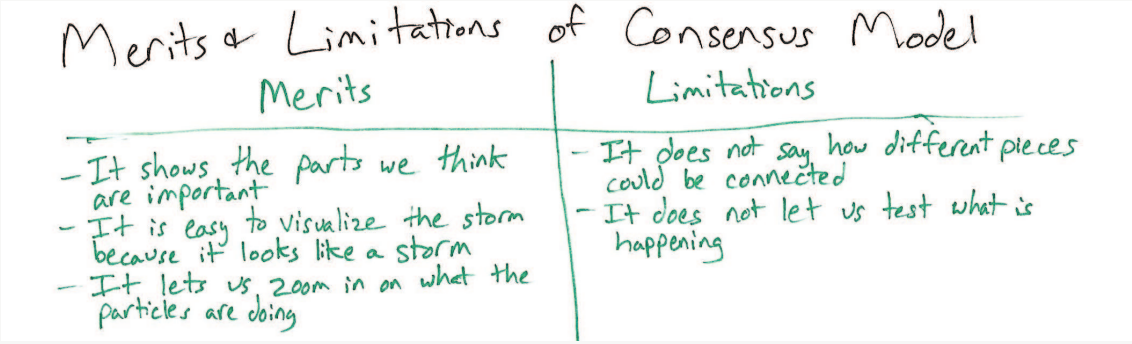
ADDITIONAL GUIDANCE

If students struggle to make sense of the differences between causation and correlation, you could provide some examples. See https://www.statology.org/correlation-does-not-imply-causation-examples/ for additional support.

Take students back to the initial consensus model. Display **slide K** and say, *We have some disagreement about the type of relationship, causation or correlation, shown in the data. Models can be used to explain phenomena, so maybe if we tie this data back to our model it will help us out.* Give students a minute to think about the two questions on the slide. Then, lead a discussion about how our initial consensus model could help us figure out if falling water really could be causing lightning. When students share their ideas about merits and limitations, record them on a piece of chart paper titled, "Merits and Limitations of Initial Consensus Model." Be sure to leave the bottom half of the chart paper empty for later in class.

Suggested prompt	Sample student response
Can our initial consensus model allow us to explain the relationship between falling water and lightning?	No, because it does not say how rain or lightning could be related. No, it shows both, but does not include any way they could be connected.

Suggested prompt	Sample student response
What merits (strengths) and limitations (weaknesses) does our model have that affect what it can explain?	Merit: It shows all the parts we think are important. Merit: It looks kind of like a storm, so it is easy to visualize what is happening. Merit: It lets us zoom in on what particles are doing. Limitation: It does not say how different pieces could be connected. Limitation: It does not let us test what is happening.



ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students identify that the initial consensus model has the following merits: shows many different parts of the system, allows the user to zoom in or out, and considers how lightning forms in the context of a realistic-looking model. (SEP: 2.4)
- Students identify that the initial consensus model has the following limitation: does not allow the user to determine whether the relationship between falling water and lightning is correlational or causal. (SEP: 2.4; CCC: 2.1)

What to do: If students struggle to identify merits of the consensus model, cover up different portions and ask students how that affects their ability to explain how lightning is produced. If students struggle with limitations, ask them questions that the model is not complete enough to answer--for example, *Why is lightning more common during the summer?* or *Why does lightning only happen during storms?*

Building toward 2.A.2 Use and move between multiple types of models to determine whether there is a correlational or causal relationship between falling water and lightning. (SEP: 2.4; DCI: PS2.B.2; CCC: 2.1)

Think about how a physical model could help us. Say, *It sounds like we need to figure out more about what is happening. It would be nice if we actually could test lightning--but that is dangerous. In cases like this, scientists will often create a physical model they can use for experiments. How might a physical model help us determine if there is a causal relationship between falling water/rain and lightning?* Listen for the idea that it lets us

see things happen in order and change parts around, so it is easier to determine if things go together or happen in a particular order, for particular reasons.

Display **slide L**. Ask, *If we were to make a smaller-scale model of a lightning storm, what components would it need to include?*

Look for students to suggest:

- a store of water, like a cloud
- falling water
- lightning
- ground or something else to strike

Say, *It sounds like we want our physical model to have all the same components or parts as our initial consensus model, but in a format we can change and manipulate. I happen to have that! It has a tank of water up top, falling water, and some materials toward the ground that spark.*

4 · NOTICE AND WONDER ABOUT THE WATER DROPPER SYSTEM

12 min

MATERIALS: Water Dropper System Lab

Introduce the water dropper system. Unveil the devices and display **slide M**. Say, *These devices contain the components listed on the slide. Take a moment to think about the types of materials used in the device. How could you categorize them?* Give students a moment to stop and jot their categories in their science notebooks, then ask for students to share their categories.✱ Look for students to suggest:

- Metal: binder clips, metal rings, aluminum coated buckets, wires with alligator clips, pennies
- Nonmetal/plastic: plastic tub and containers, aquarium air valves and tubing, plastic clothespins, bendy straws, plastic pipettes, plastic folders, hot glue
- Water

ALTERNATE ACTIVITY

Building prerequisite understandings: It is not necessary that students name these categories as metal and nonmetal. However, students should recognize that different materials have different properties, established in *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* in middle school. If students suggest unexpected categories, press them for reasoning. Use students' reasoning to emphasize that in chemistry, we establish categories based on materials' properties--that is, how they interact with the world. Substances that have similar properties are important to group together because they are probably similar in other ways that we cannot yet identify.

Display **slide N** and review the safety instructions with students.

Display **slide O**. Say, *In your notebook, make a Notice and Wonder chart like the one shown to record observations as you examine the devices.* Start the water dropper systems while students make the chart in their notebooks. Then, break them into two groups and tell students they will have four minutes to record observations and questions before sharing with the class.✱ The discuss below includes things that students might be expected to notice and wonder.

Share observations and questions. Have students return to their seats and display **slide P**.

ADDITIONAL GUIDANCE

If it does not come up as students share what they noticed, highlight that there is something happening in the space between the dropper's components. For example, something is happening in the space between the two pennies that results in a spark.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

Categorizing the materials here is a precursor to students establishing more defined ideas about conductivity in the context of structure-function relationships later in the unit. Do not name metals and nonmetals as *conductors* and *insulators* here, as this will be done in Lesson 11. Students will then be able to explain differences in behavior of these materials in Lesson 12.

✱ SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

Students may have ideas about how to investigate the water dropper's functioning (SEP3). Record these ideas, as they may be useful in the next lesson. Students will have an opportunity to test some of their own ideas as a prelude to using the water dropper as a model to generate data (SEP2).

Suggested prompt	Sample student response
What did you notice?	There is a water container over two buckets. The water passes through metal tubes. The water drips constantly. Every 30-60 seconds, there is a spark between the pennies. Each bucket is attached to a penny and the opposite metal tubing. There are wires but no battery or wall plug. The water stream appears to bend and fall before the spark, or the dripping appears to slow before the spark. You get a small shock if you touch one of the metal parts. The parts on the ground are held up by plastic containers. The sparks seem like electricity or static electricity. The foil leaves push apart before the spark, then they come back together.
What did you wonder?	Where are the sparks coming from? The water? What is the spark anyway? How can water cause the spark? Is the spark the same thing as lightning? Why are only some parts of the system metal? Is this the same thing as a static or electrical shock?

ADDITIONAL GUIDANCE

If students mention "static" or "static electricity," take a moment to discuss what they think these terms mean. The goal is not a fully fleshed-out or "dictionary" definition, but a gauge of students' current conception(s). An example might be "the phenomenon when you scuff your feet on the carpet and touch someone to shock them."

Highlight if students mention evidence of attraction or repulsion (behavior of foil leaves or water stream). If they do not, that is fine as they will see more evidence of it in Lesson 3.

Discuss matter and energy flows in the water dropper system. Display **slide Q**.

Suggested prompts	Sample student responses	Follow-up questions
What matter is moving?	Water	*What evidence do we have for that?*
How is energy transferring?	It has to be moving through the system as the water moves. It goes between the pennies.	*What evidence do we have for that?*
Do these flows show correlation or causation between falling water (rain) and sparks (lightning)?	Accept all responses.	*What additional data would you need to make the determination?*

Tie back observations to graphical data. Remind students that we are in agreement that there is a correlational relationship between falling water and lightning strikes, but that we did not have enough data to determine if it was also a causal relationship. Display **slide R** and give students a minute or two to individually consider the prompt: *How does combining our observations of the physical model with the graphical data help us determine if there is a **causal** relationship between falling water and lightning?* Ask for a few volunteers to share their ideas. At this point, students may state they are leaning toward a causal relationship as in Option B, but they cannot say it is for certain.

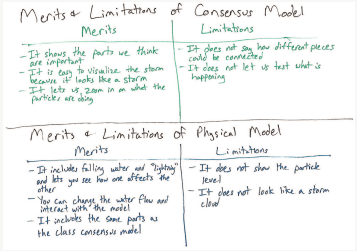
5 · REVISIT MERITS AND LIMITATIONS OF THE WATER DROPPER SYSTEM

6 min

MATERIALS: science notebook, chart paper titled "Merits and Limitations of Initial Consensus Model", chart paper markers

Address merits and limitations of the physical model. Return to the "Merits and Limitations of Initial Consensus Model" poster and add a new section for the physical model at the bottom. Display **slide S** and have students stop and jot their ideas about the prompts in their science notebooks before asking them to share with the class.

Record students' ideas on the poster.



Suggested prompt	Sample student response
What merits (strengths) does the physical model have that affect what it can explain?	It includes falling water and "lightning" and lets you see how one affects the other. You can change the water flow and interact with the model. It includes the same components as the initial consensus model.

Suggested prompt	Sample student response
What limitations (weaknesses) does the physical model have that affect what it can explain?	It does not show the particle level. It does not look like a storm cloud.
How could the physical model help us answer questions from our DQB and any new questions?	We could play with it to figure out where the spark comes from. We could learn about the spark in case it is like lightning. It can show us which parts or components of the model really matter.

ADDITIONAL GUIDANCE

If you have time, consider revising the initial consensus model using the information that came out of the discussion.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students identify that the physical model has the merit of including the same components as the initial consensus model, but with students' ability to manipulate them in real time and conduct experiments. (SEP: 2.4; DCI: PS2.B.2)
- Students identify that the physical model has the limitation of not looking like the initial consensus model or a real-world storm. (SEP: 2.4; DCI: PS2.B.2)

What to do: If students struggle to identify merits and limitations of the physical model, encourage direct comparison to the initial consensus model. Use probing questions, like: *What does the physical model let us do that the consensus model cannot?* and *What can we do with the consensus model that we cannot with the physical model?*

If this does not work, you could also spend some time mapping parts of the physical model to the initial consensus model. This could include identifying the following: a container of water, which is kind of like a cloud; some dripping water, which is like rain; the pennies, which are at the bottom like the ground; and a spark like lightning.

Building toward 2.A.3 Use and move between multiple types of models to determine whether there is a correlational or causal relationship between falling water and lightning. (SEP: 2.4; DCI: PS2.B.2; CCC: 2.1)

6 · NAVIGATE

5 min

MATERIALS: None

Take a moment to remind students of the Navigation Routine. Say, *Just like last unit, we will typically start and end lessons by taking stock of what we have done so far and what we want to figure out next. This helps us make sure that we do investigations that help us answer our questions.*

Look ahead. Say, *It sounds like the water dropper system could be useful to us in the future.* Display **slide T** and ask students to turn and talk with a partner before sharing their thoughts.

Suggested prompt	Sample student response
What other objects or materials could we put into the system to see interactions that could help us figure out: What is the spark?	If it is a spark, it is electricity. Maybe it could light up a lightbulb. We could put metal into the system to see if it carries the electricity out to shock something farther away. We could see how the spark affects other materials that react to static, like balloons.
What other objects or materials could we put into the system to see interactions that could help us figure out: What is happening in the space between the pennies that is leading to the production of the spark?	We think water might be responsible. We could try stopping the flow of water. We could change out different parts to see if the spark still works.
What other objects or materials could we put into the system to see interactions that could help us figure out: What is happening in and around the water dropper system?	We could see if different parts of the system interact differently with metals or plastics. We could see if we can make other parts of the system spark by putting materials near it.

Close out class and tell students that tomorrow they will have an opportunity to pursue some of their ideas for investigating the water dropper system. Encourage students to bring in objects they would like to test with the water dropper next class.

Additional Lesson 2 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	CCSS.MATH.CONTENT.HS.S-ID.9: Distinguish between correlation and causation. Students use a physical model to gather evidence that the relationship between water and lightning is more likely causal than correlational.

LESSON 3: What is the spark in the water dropper system and what else is happening in the system before it appears?

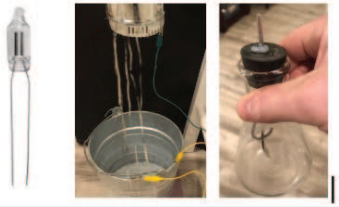
PREVIOUS LESSON

We identified the parts of our initial consensus model. We collectively analyzed data that showed a relationship between rain and lightning. We considered the merits and limitations of both our initial consensus model and a physical model of lightning. We brainstormed additional objects that we could use to figure out more about what is happening in the water dropper system.

THIS LESSON

INVESTIGATION

1 day



We carry out two rounds of investigations by adding different test objects to the water dropper system, first using objects of our choosing and then using teacher-provided objects. We record what we notice and wonder. We develop a model to illustrate the forces acting on the test objects. We discuss the patterns in forces and energy transfer that we noticed. We identify related phenomena (static) that we think would produce similar interactions.

NEXT LESSON

We will plan investigations to explore static interactions between various objects using detectors from Lesson 3 and other materials. We will observe patterns in attractions and sometimes repulsions after objects are rubbed together, and conclude that these interactions seem stronger or more noticeable at shorter distances.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6, HS-PS3-2, HS-PS3-5

WHAT STUDENTS WILL DO

3.A Use the water dropper model to generate data at a smaller scale to identify the various causes of macroscopic attractions, repulsions, or energy transfer in lightning and lightning-like systems. (SEP: 2.6; DCI: PS2.B.2; CCC: 3.2, 2.4)

WHAT STUDENTS WILL FIGURE OUT

- The water dropper system acts on different objects/materials by either pushing them away (repulsive) or pulling them toward (attractive) the system.
- The water dropper system allows us to make observations at a smaller scale that help explain the lightning phenomenon, which occurs at a different, larger scale.
- Changes in the strength of these forces seem related both to where the objects are in space as well as to when energy is transferred out of the water dropper system (as light and sound in the form of a spark).

Lesson 3 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Lead a whole-class discussion about what we wanted to investigate.	A	
2	4 min		**SET UP AN INVESTIGATION** Organize into groups and prepare data tables to record findings from the water dropper system investigations.	B-C	Water Dropper Investigation 1
3	7 min		**CONDUCT AN INVESTIGATION** Have groups carry out the first round of investigations using objects brought in by students.	D	Water Dropper Investigation 1
4	8 min		**MAKE SENSE OF INVESTIGATION FINDINGS** Share observations and develop an initial model to support observations from Round 1 of investigations.	E-F	*Model Interactions*, Water Dropper Investigation 1
5	8 min		**ADJUST INVESTIGATION USING PRIOR FINDINGS** Test various objects and their interactions with the water dropper in a second round of investigations.	G-I	Water Dropper Investigation 2
6	10 min		**SHARE NOTICINGS AND WONDERINGS (CONTINUED) AND LEAD A BUILDING UNDERSTANDINGS DISCUSSION** Lead a whole-class discussion to share and record observations about the Round 2 investigations. Lead a Building Understandings Discussion.	J-K	2 3x3 sticky notes, Matter-energy diagram on "Rules for Energy Transfer" poster, chart paper, chart paper markers
7	3 min		**NAVIGATE** Brainstorm related phenomena and questions to pursue in the next lesson.	L	"Related Phenomena" poster, chart paper markers

End of day 1

Lesson 3 • Materials List

	per student	per group	per class
Water Dropper Investigation 1 materials	• science notebook • safety glasses with side shields or safety goggles • non-latex apron	• water dropper system • objects brought in by students	
Water Dropper Investigation 2 materials	• science notebook • safety glasses with side shields or safety goggles • non-latex apron	• water dropper system • station instructions from *Investigation 2 Stations* • one or two sets of materials for Stations A-D	
Lesson materials	• science notebook • *Model Interactions* • 2 3x3 sticky notes		• Matter-energy diagram on "Rules for Energy Transfer" poster • chart paper • chart paper markers • "Related Phenomena" poster

Materials preparation (60 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Make two copies of *Investigation 2 Stations* for each water dropper station. Cut these so that each set of station directions is on its own slip of paper. These will be reused each class.

Place the four stations around the room so that groups of students will have space to work at each. Fill the water reservoirs of each water dropper system and ensure all wires are connected to the appropriate components. Calibrate the water droppers using the guidance in *Water Dropper Construction* before your first class to ensure they are producing sparks.

You will be adding to the matter-energy diagram (start of the "M-E-F triangle") from *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*. If there is not enough space to add to this diagram, start a new poster and copy over what was added in Lesson 9 of that unit.

You will add to this poster throughout the unit. See *Matter, Energy, Forces* for an example of what this representation will look like at the end of the unit.

You will close out the lesson by adding to the "Related Phenomena" poster from Lesson 1. Make sure this is available for each class.

Water Dropper Investigation 1

- **Group size:** 4 equal-sized groups
- **Setup:**
  - Place the four water dropper systems around the room so that groups of students will be able to gather around them and record observations.
  - (Re)fill the elevated water reservoir at each station. This should be done between periods by pouring the water from the buckets back into the reservoir.
  - Check the attachments of the wires and the spacing between the pennies and adjust the flow rate on the water dropper to ensure regular spark production (i.e., a spark every 20 to 40 seconds).
  - Test the water dropper systems in the conditions of your classroom the day before the investigation to ensure they produce sparks, as described in *Water Dropper Construction*.

- **Notes for during the lab:** Observe the foil leaves on the attached electroscopes while the water dropper system is running. If the leaves stop separating, this is a sign that the system will not produce sparks (and is not building up charge). At this point, recheck the attachments of the wires and the spacing between the pennies and adjust the flow rate to ensure regular spark production.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science.*
    - The water dropper system will produce very mild static shocks when touched and when lighting the neon bulb. The current produced is on the order of μA, which is far below levels that are a safety concern.
    - Wear sanitized safety glasses with side shields or safety goggles and non-latex apron during the setup, hands-on, and takedown segments of the activity.
    - Use caution when using sharps (wires, etc.), which can cut or puncture skin.
    - Use caution when working with or near sharps (tools, wires, etc.), which can cut or puncture skin.
    - Keep away from water sources to prevent shock when working with electrical circuits or electricity sources.
    - Wash your hands with soap and water immediately after completing this activity.
- **Storage:** All materials can be reused. Store materials in a cabinet in the classroom.

Water Dropper Investigation 2

- **Group size:** 4 equal-sized groups
- **Setup:**
    - Demo videos of the four stations can be found at:
        - https://youtu.be/13XohvT4ljQ
        - https://youtu.be/ntD3YM1yccs
        - https://youtu.be/bXa5YewwyII, and
        - https://youtu.be/fsZel6IWmGg.
        - These can be used to support teacher understanding or if the water dropper systems are not functioning properly.
    - Follow the instructions in *Test Object Construction* to build the test objects that students will use.
    - Prepare a materials bin for each corresponding water dropper station, as shown in *Test Object Construction*.
    - Place the test objects for each station in their own labeled materials bin (A, B, C, or D) so they can be easily distributed for the investigation.
    - Prepare an extra bin for two of the detectors if you plan to use all six water dropper systems.
    - Place the sets of directions you cut out from *Investigation 2 Stations* in their corresponding bins (A, B, C, or D).
    - (Re)fill the elevated water reservoir at each station.
    - Check the attachments of the wires and the spacing between the pennies and adjust the flow rate on the water dropper to ensure regular spark production.
    - **Testing the water dropper:** See Water Dropper Investigation 1.
- **Notes for during the lab:** See Water Dropper Investigation 1.
- **Safety:** See Water Dropper Investigation 1. In addition, note that although latex balloons work best in this investigation, they should not be used by students who are allergic. Those students should work on a different station. Alternatively, provide non-latex balloons for the class or use the video to demonstrate this station.
- **Storage:** See Water Dropper Investigation 1.

Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

In the previous lesson students used the water dropper system to determine that water likely plays a role in lightning formation. In this lesson, students continue to use the water dropper system to investigate interactions with other objects to start building a model of distance forces. This lesson is designed to coherently build new ideas related to the following disciplinary core idea:

- **PS2.B.2 Types of Interactions:** Forces at a distance ~~are explained by fields (gravitational, electric, and magnetic)~~ permeating space ~~that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.~~

Crossout explanation: PS2.B.2 is developed further later in the unit. In this lesson, students explicitly name forces as being involved in interactions around the water dropper. In Lesson 4, students develop the idea and name that electric fields can permeate the space around the dropper. In this lesson, students observe force interactions between various components of the water dropper system and the test objects that students bring near it.

The idea of attractive/repulsive forces and forces at a distance builds on students' work with distance forces in middle school in *OpenSciEd Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*. Students may not distinguish these forces as different from magnetic ones. Students may also make reference to static or static electricity, though they may not equate either with electricity produced by a battery or in the wires of devices we plug into the wall. Both of these misconceptions are okay for now, as they will be addressed in later lessons.

In this lesson students use a physical model, the water dropper system, to generate data (SEP: 2.6) to help them think about what might be happening in a larger scale lightning system (CCC: 3.2) before and during a lightning strike. Students will also notice that different test objects respond differently to the water dropper system, and objects respond differently to different parts of the water dropper system (CCC: 2.4). While students will not yet develop an explanation of the effects that they observe in this lesson, by the end of Lesson 5 students will have a mechanistic explanation for the interactions they observe during their water dropper investigations.

Students engage in SEP: 2.6 and CCC: 3.2 partially. For SEP: 2.6: *Develop and/or use a model ~~(including mathematical and computational)~~ to generate data to support explanations, predict phenomena, analyze systems, and/or ~~solve problems~~.* Students will use mathematical and computational models to solve problems in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*. For CCC: 3.2: *Some systems can only be studied indirectly as they are too small, too large, ~~too fast, or too slow~~ to observe directly.* Students already have experience examining systems indirectly, due to unmanageable time scales, from *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*.

This lesson is laying the groundwork for the idea of forces as the mechanism for energy transfer, by introducing an important correlation--distance forces decrease or disappear from the system when the movement of the spark occurs and then strengthen over time until the next spark. The force and energy relationship will be developed in Lesson 10. This is an important foundation for future work in thinking about exothermic and endothermic reactions in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*, the last unit of the course.

This lesson focuses on looking for interactions in a system which vary with time and distance. This type of scale thinking is particularly salient related to strength of forces and to distance between parts of the system. Students' work in the next four lessons will continue exploring these relationships at different scales. The work students do toward the end of this lesson motivates an eventual shift to the atomic scale later in Lesson 4 and all the way through Lesson 5. Students likely will start raising ideas about what is happening to the structure, properties, and transformations of matter in the water dropper system in this lesson, though such transformations are not likely to include atoms or subatomic particles yet, which is fine.

Where We Are NOT Going

Future lessons will help explain why forces are observed only with some parts of the system. Students may or may not introduce the idea of something "charging" in the water dropper system before a spark occurs. This lesson assumes a more colloquial reference to charging rather than a particle-model understanding about charges as small pieces of matter. For this reason, do not introduce the word if students do not bring it up, and do not push students to define it if they do. Charge will be introduced at the end of Lesson 4 and developed more fully in Lesson 5.

This unit does not address magnetic or gravitational fields in depth, although they are mentioned in passing in Lesson 4. Students fully establish a connection between electric and magnetic fields in *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)* and develop a deeper understanding of gravitational fields in *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*.

LEARNING PLAN for LESSON 3

1 · NAVIGATE

5 min

MATERIALS: None

Identify some of the rationale for testing additional objects in the water dropper system. Display **slide A**. Say to students, *Think back to the objects we said we wanted to test with our water dropper.* Give students one minute to think individually about the questions on the slide, then discuss them as a class.

Suggested prompt	Sample student response
How might these objects help us figure out more about the water dropper system?	It could help us figure out how it works. It could help us figure out how the falling water is producing sparks. It could help us figure out what the spark is. It could help us see if there was some sort of attractive force in the system pulling on stuff in the space around it (kind of like a magnet).
How might these tests help us make progress on some of the questions on our DQB?	If we figure out how the water dropper works it might help us figure out what causes lightning. It might help us figure out how lightning is connected to rain. If we figure out how this small-scale water dropper system works then we could see if those interactions/mechanisms are also at work when large-scale lightning strikes.

ADDITIONAL GUIDANCE

If students do not mention attractions (such as the water stream bending) or repulsions (such as the foil leaves pushing apart), that is fine; they will see evidence of both in the investigations in this lesson.

2 · SET UP AN INVESTIGATION

4 min

MATERIALS: Water Dropper Investigation 1

Organize students into investigation groups. Display **slide B**. Give students a minute to gather any materials they brought in to test, ✱ or let them choose from objects in the room that are not the objects they will use in the second round of investigations. Help students organize themselves into heterogeneous groups so that each group has a variety of test objects. Assign each group to a water dropper station to conduct their investigations.

If students bring in objects similar to those used in Round 2, let them test those objects in a less structured way during Round 1.

Prepare data tables. Display **slide C**. Give students a minute to prepare a Notice and Wonder chart in their notebooks like the one shown on the slide. Tell students to leave space at the bottom of their chart for one or two more test objects. If students are unsure where to start in their investigations, encourage them to place their test objects increasingly near, and eventually touch, different parts of the water dropper system (including the stream of water).

✱ ATTENDING TO EQUITY

Universal Design for Learning: Allowing and encouraging students to bring in or choose objects to test with the water dropper system supports student *engagement.* Increasing student voice can make investigations feel more relevant and engaging to students.

3 · CONDUCT AN INVESTIGATION

7 min

MATERIALS: Water Dropper Investigation 1

Conduct investigations. Display **slide D.** Say, *Our goal with this investigation is to better understand the system itself and to try and answer some of the questions on our DQB. Now is your chance to see how the objects you brought in interact with the water dropper system!* Give students seven minutes to conduct investigations with the objects of their choosing, and to record their noticings and wonderings for each object they test.✱

Circulate throughout the room to ensure students are engaging safely with the investigation and to make sure the water droppers function as they are supposed to. Keep track of the observations that students record in their notebooks to gather data for this assessment opportunity. Encourage students who are not seeing significant effects, even when touching their objects to different parts of the system, to observe others who have more clear observations.

Important note: If students' test objects are not yielding productive results, skip the sensemaking section and initial modeling and instead help students navigate toward the more structured investigations in Round 2. Have students make individual models after Round 2.

ADDITIONAL GUIDANCE

Students may want to use "detectors" such as metal, plastic, pieces of paper, or other objects that may attract to or repel from the water dropper system. These are all fine and easily managed. Objects that experience no effects are also acceptable, but encourage students who did not bring in their own materials to pick something that is more likely to see an interaction.

Students may also want to manipulate the water dropper system itself, such as by:

- replacing the pennies with other coins or other materials,
- replacing other parts of the water dropper system with different materials,
- changing water flow rates, or
- adding something to the water.

These tests could be fruitful, but could also pose logistical problems for students and teachers and lead to misunderstandings about what makes the water dropper system "work." During your first experience with this unit, you might limit students' tests to "adding things to the system" until you are comfortable with the unit's progression through ionic bonds and charges.

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Support students in explicitly using the water dropper as a model (SEP) by continually emphasizing the ways in which the water dropper system is allowing indirect study of lightning (CCC). When students notice attraction or repulsion (DCI), ask if they think something similar happens or could happen in lightning. Emphasize how the lens of scale can help us scale up observations in our model to what we observe in lightning.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students test for attractions and/or repulsions between parts of the water dropper system and their test objects. (SEP: 2.6; DCI: PS2.B.2)
- Students notice relationships between the strength of interactions they observe and the time since the water dropper last sparked. (SEP: 2.6; DCI: PS2.B.2)
- Students relate their observations of interactions and sparks in the water dropper system to the lightning phenomenon. (DCI: PS2.B.2; CCC: 3.2)

What to do: If students' observations indicate only direction of interaction (attraction or repulsion) and nothing about strength or relationship to the spark or other parts of the water dropper system, ask them how they think these might impact the interaction. Encourage students to use their test objects in different parts of the water dropper system and to pay attention to how the strength of observed interactions changes depending on the location of the test objects and the timing relative to the spark.

Building toward 3.A.1 Use the water dropper model to generate data at a smaller scale to identify the various causes of macroscopic attractions, repulsions, or energy transfer in lightning and lightning-like systems. (SEP: 2.6; DCI: PS2.B.2; CCC: 3.2, 2.4)

4 · MAKE SENSE OF INVESTIGATION FINDINGS

8 min

MATERIALS: Water Dropper Investigation 1, science notebook, *Model Interactions*

Share observations from Round 1 of investigations. Display **slide E**. Direct students to return to their seats and take one minute to look over their noticings and wonderings with the questions on the slide in mind. Then give each group an opportunity to briefly share ✱ their ideas about both prompts with the class. ✱

Suggested prompt	Sample student response
What types of interactions did you notice?	Attractions, or objects sticking together. Repulsions, or objects pushing each other away. Objects moving closer or farther from the water in the dropper.
What evidence of energy transfer to or from your test object did you observe, if any?	Something in the system made our object move without us touching it, which might be energy transfer. We didn't see much energy transfer besides the spark between the pennies, even with objects we thought would transfer energy like a battery.

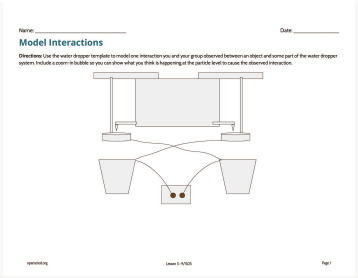
✱ SUPPORTING STUDENTS IN DEVELOPING AND USING CAUSE AND EFFECT

This is an opportunity to help students realize that different objects or materials respond differently to the water dropper system. Although students will not figure out why that is during this lesson, this is a good moment to highlight the various directions and magnitudes of effects observed and to encourage students to wonder about underlying causes. Accept all student ideas. Students will fully answer these questions by the end of Lesson 5.

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: Students may not use or know the terms *attraction* or *repulsion*, but look for gestures that indicate those interactions, such as students moving their hands closer together or farther apart, or pulling and pushing motions. Make sure the class agrees that the terms for the interactions they see are

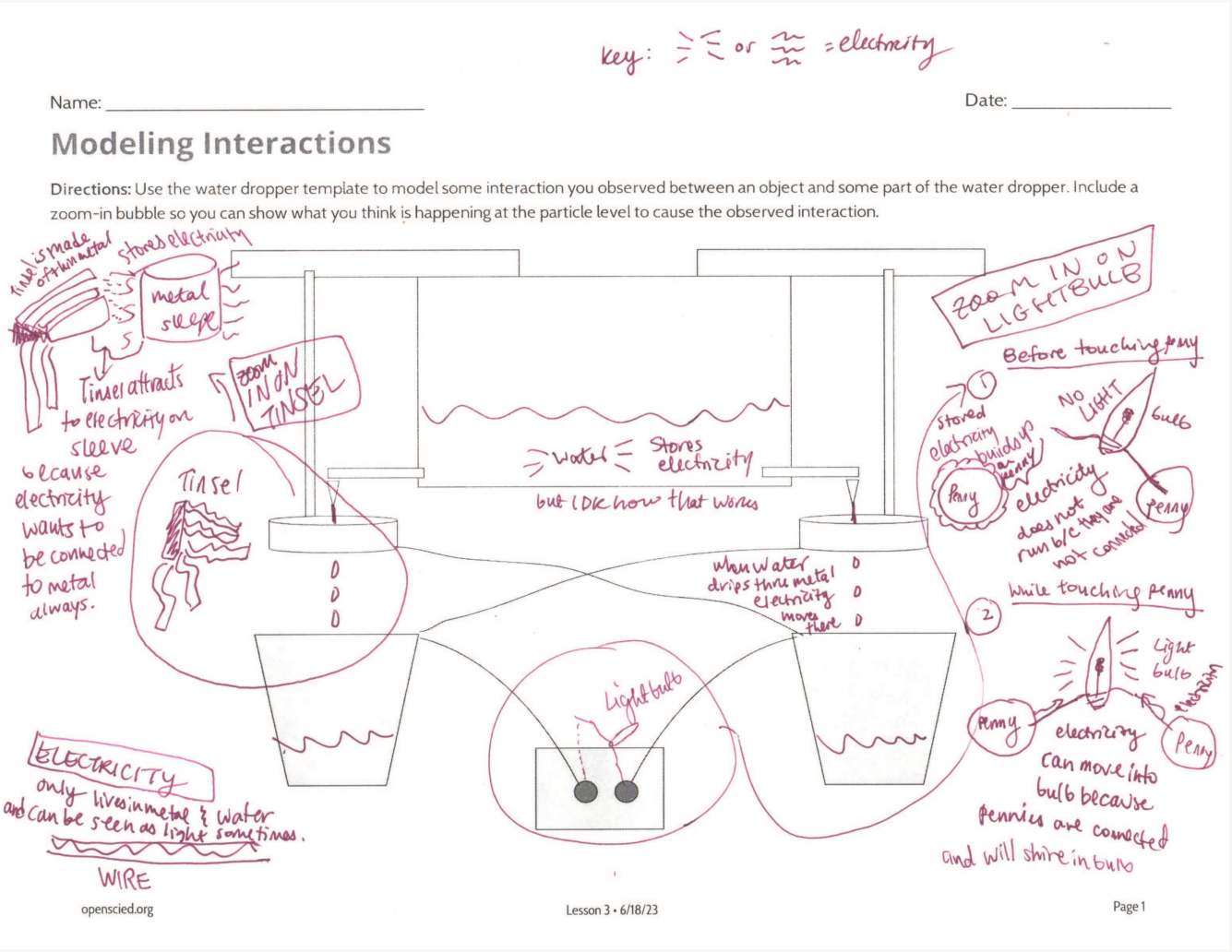
Develop initial models to account for attraction and repulsion in the system. Display **slide F.** Say, *Let's develop a model to represent our initial ideas for what caused the interactions you observed in the water dropper system.* Instruct students to choose one of the objects they tested for their model and to include a zoom-in bubble on the template provided in *Model Interactions* to represent why the object or the water dropper might have been attracted or repelled at the particle level. Encourage students to show in their model any differences in attraction or repulsion based on the object's material or the distance from the water dropper. Give students four minutes to independently develop their model. A sample is below; however, these models do not have to be perfect as students will have the opportunity to revise them in Lesson 4.


Name: _____ Date: _____

Model Interactions

Directions: Use the water dropper template to model one interaction you and your group observed between an object and some part of the water dropper system. Include a zoom-in bubble so you can show what you think is happening at the particle level to cause the observed interaction.

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attraction and repulsion, and encourage students to write the terms in their notebooks.

ALTERNATE ACTIVITY	**Building prerequisite understandings:** Students should be familiar with distance forces from middle school (formally) and everyday life (informally). If students struggle where to begin their revised models, elicit ideas about where else we see objects push or pull one another when they are not touching. Students may mention gravity and magnets. Encourage students to use one of these ideas as a basis for their models. Students will leverage this thinking more in the next lesson in the lead-up to formalizing electrostatic forces.

5 · ADJUST INVESTIGATION USING PRIOR FINDINGS

8 min

MATERIALS: Water Dropper Investigation 2, science notebook

Consider findings from Round 1 to plan for Round 2. Display **slide G.** Ask students to use their models to identify what type of object(s) would be most useful to investigate in the next round.

Suggested prompt	Sample student response
What type of object(s) would be most useful to investigate in the next round?	We should look at something really lightweight next to the dropper. We could test an object that attracts others without touching it, like magnets or a balloon. Other objects to test could be things that we have seen interact with water before.
If your group did not observe many changes or interactions in the first round, why do you think that happened?	Maybe the objects we tested are not usually very reactive, so they did not interact with the water dropper system.

Update data tables. Display **slide H**. Say, *I thought you all might want to test these types of objects and I have already prepared some of them for you!* Have students add a row to their Notice and Wonder chart, as shown on the slide. Tell them that the new row is to record what they notice and wonder during the next investigation with one of the assigned test objects.



Conduct Round 2 investigations at assigned stations. Display **slide I.** Assign each group to station A, B, C, or D and direct groups to the materials bin at each station. Let them know that the instructions for their assigned station are already in the bin along with the new test objects. Give groups five minutes to conduct the Round 2 investigations, and remind students to record their observations.

Circulate throughout the room to ensure students are engaging safely with the investigation and to make sure the water droppers function as they are supposed to. Keep track of the observations that students record in their notebooks to gather data for this assessment opportunity.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students test for attractions and/or repulsions between parts of the water dropper system and their test objects. (SEP: 2.6; DCI: PS2.B.2)
- Students notice relationships between the strength of interactions they observe and the time since the water dropper last sparked. (SEP: 2.6; DCI: PS2.B.2)
- Students relate their observations of interactions and sparks in the water dropper system to the lightning phenomenon. (DCI: PS2.B.2; CCC: 3.2)

What to do: If students' observations indicate only direction of interaction (attraction or repulsion) and nothing about strength or relationship to the spark or other parts of the water dropper system, ask them how they think these might impact the interaction. Encourage students to use their test objects in different parts of the water dropper system and to pay attention to how the strength of observed interactions changes depending on the location of the test objects and the timing relative to the spark.

Building toward 3.A.2 Use the water dropper model to generate data at a smaller scale to identify the various causes of macroscopic attractions, repulsions, or energy transfer in lightning and lightning-like systems. (SEP: 2.6; DCI: PS2.B.2; CCC: 3.2, 2.4)

ADDITIONAL GUIDANCE

Demo videos of the four stations can be found at:

- https://youtu.be/13XohvT4ljQ
- https://youtu.be/ntD3YM1yccs
- https://youtu.be/bXa5YewwyII, and
- https://youtu.be/fsZel6IWmGg.

6 · SHARE NOTICINGS AND WONDERINGS (CONTINUED) AND LEAD A BUILDING UNDERSTANDINGS DISCUSSION

10 min

MATERIALS: 2 3x3 sticky notes, science notebook, Matter-energy diagram on "Rules for Energy Transfer" poster, chart paper, chart paper markers

Share and record observations to lead into a Building Understandings Discussion.✱ Display **slide J**. Use the prompts on the slide to ask each group to share in under one minute what they noticed and wondered at their assigned station. Record these on chart paper or on a document titled "Noticings and Wonderings for Stations A-D for Class #" (where # is the class period). Encourage students to demonstrate what they saw as well, especially if they observed something particularly interesting or difficult to explain, such as the light bulb in Station A.

✱ STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

Be explicit with students about your role in this discussion, which is to prompt them for evidence when they share their ideas about the interactions they observed. Say, *My role in this discussion is to press for evidence, regardless of whether the ideas are "right" or "wrong." So you might hear me ask, "Where did you see that?" It is my job to push us as a class to articulate the evidence we have to support our ideas.*

Student responses may resemble the following:

Station	Noticings	Wonderings
A	*You can touch an end of the light bulb to any metal surface in the system and get it to briefly glow.* *How bright the bulb glows seems related to how long you wait between when you remove it and the next time you touch it to the metal in the system and/or when the spark appears.*	*Why does the bulb light up when you touch just one metal end of it to any metal component in the system?* *(Why) is the amount of electrical energy in the system changing over time?* *Is this system producing electricity? Is lightning a form of electricity? What is electricity anyway?*
B	*The piece of plastic bag sticks to metal parts of the water dropper system.* *Sometimes those things fall off the metal rings when the system sparks.*	*Is this the same thing that happens when you rub a balloon against fur, hair, or wool and stick it to a wall? Will any lightweight object stick to these components in the system?* *What is causing these materials to stick to the rings in the system?* *What is static electricity? Is there static electricity in a lightning storm?*
C	*The balloon seems attracted to metal parts of the system.* *It might have been attracted to the water too but it was hard to tell.*	*What is happening to the metal in the system that is making the balloon attracted to it?*
D	*The tinsel strings spread out farther from each other when we bring them closer to the buckets or metal rings and come back together when we bring them farther away. The same thing happens to the metal leaves in the jar.*	*Why are the forces stronger the closer you get to the water dropper system?* *Is the system acting similar to a magnet?* *How far away can you get from the system and still detect these forces?*

ADDITIONAL GUIDANCE

This lesson is laying the groundwork for the idea of forces as the mechanism for energy transfer by introducing evidence of both forces and energy transfer in the water dropper system without naming them (yet) explicitly. The lesson simply is giving students an opportunity to notice an apparent correlation in the strength of the push and pull on objects and how it drops at the moment that a spark occurs and then builds slowly again until the next spark. However, it is fine if students do not point out these patterns immediately. Use the Building Understandings Discussion to emphasize them.

Facilitate a brief Building Understandings Discussion. Display **slide K.** Ask students to take a moment to see if they can identify any patterns in their noticings about the interactions of the test objects with the water dropper system. After one minute, prompt students to consider those patterns as they respond to the three prompts on **slide K**.

KEY IDEAS

Purpose of this discussion: Highlight the evidence we have for push/pulls (forces) acting on the test objects in the system. Press students for evidence they have that is related to:

- which part of the water dropper system the test object is interacting with (being pulled toward/pushed away from), and
- differences in the direction/strength of those interactions depending on where the object is located.

Listen for these ideas:

- We saw attractions and repulsions between objects and various parts of the water dropper system.
- We saw that the object tends to move or bend either toward or away from the (nearest) edge of the (nearest) metal ring, but not other parts of the system (e.g., the plastic tub).
- We saw differences in how much the shape or motion of the test object changed (bent more/less, moved faster/slower), depending on how far we held it from one of the metal rings.
- We saw some energy transfer when the light bulb at Station A lit up and when objects at other stations were moving due to attractions or repulsions.

Suggested prompts	Sample student responses	Follow-up questions
What types of interactions did you notice?	Attractions and repulsions, like before with our own objects. It seemed as if the object was pushing or pulling on different parts of the water dropper system, like an invisible force.	*Were there any interactions that only happened near certain parts of the water dropper system?* *Were there any interactions that were dependent on timing?*
What evidence of energy transfer to or from your test object did you observe, if any?	The light bulb lit up. Besides that, we didn't see much energy transfer that wasn't movement. Movement was caused by the attraction and repulsion interactions.	*Describe the different types of energy you observed. How do they look different?*

Suggested prompts	Sample student responses	Follow-up questions
What patterns do you notice in these interactions?	There was a greater amount of attraction or repulsion if the distance from the water dropper was smaller. The objects at Stations B-D all seemed to have some kind of special force/quality which led to the attractions and repulsions. The object at Station A had electricity in it when near the water dropper since the light bulb lit up.	*Describe any patterns in the amount of attraction, repulsion, or energy transfer that you observed.* *What kinds of objects were attracted to each other? repelled by each other?* *Were there any patterns in the timing of these interactions?*

ASSESSMENT OPPORTUNITY

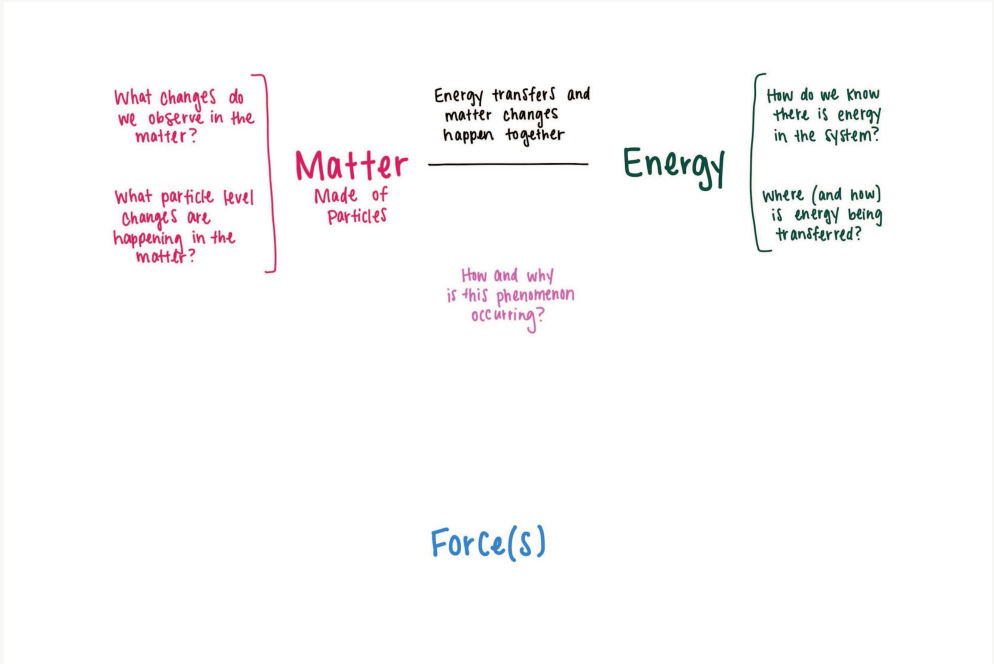
What to look/listen for in the moment:

- Students mention patterns in observed interactions, such as attractions or repulsions near the metal parts of the water dropper system. (SEP: 2.6; DCI: PS2.B.2)
- Students mention stronger interactions when objects were closer to the water dropper system. (DCI: PS2.B.2; CCC: 2.4)

What to do: If students do not mention stronger interactions at different distances or near different parts of the water dropper system, prompt them to think about why they might see different interactions in different places or times. Ask them about where they were holding their test objects or what materials the test objects were interacting with. Ask them where the light bulb was when it lit up.

Building toward 3.A.2. Use the water dropper model to generate data at a smaller scale to identify the various causes of macroscopic attractions, repulsions, or energy transfer in lightning and lightning-like systems. (SEP: 2.6; DCI: PS2.B.2; CCC: 3.2, 2.4)

Add force to the matter-energy diagram from *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*. After listening to students' discussion, summarize a key takeaway around the idea that forces are an important part of how the objects in the system interact, in addition to the particular matter the objects are made of and the energy transfers that occur. Discuss the idea that forces are related to the matter-energy diagram and add "Force(s)" to the diagram.



7 · NAVIGATE

3 min

MATERIALS: "Related Phenomena" poster, chart paper markers

Brainstorm related phenomena. Display **slide L**. Have students turn and talk with a partner about the prompt on the slide for about two minutes. Then ask students to share their related phenomena with the class. Record these ideas on the "Related Phenomena" poster from Lesson 1 so that you can refer to them at the start of the next lesson.

ADDITIONAL GUIDANCE

Students may refer to their experiences as "static electricity" or "static" without elaborating on what that looks like or means. If this happens, press students to describe their experiences in greater detail.

If they do not have terms to describe their experiences as seen in the following sample student responses, then introduce the term "static" as one way that some people refer to this kind of phenomenon. ✱

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: Students may not use or know the term "static electricity." However, many students will have experienced it and may refer to the phenomenon using other terms. Make sure the class agrees upon a term for the interactions they see as encapsulating all of the interactions they have observed, such as "when objects become charged and interact with each other," and encourage students to write those terms in their notebooks.

Suggested prompt	Sample student response
What other phenomena have you experienced that produced interactions like those we observed in the water dropper system?--for example, attractive or repulsive forces at a distance, or small sparks or shocks.	Rubbing a balloon on something. Plastic wrap or styrofoam sticking to our hands. Touching another person or door knob after rubbing feet on the ground. Magnets and metals. A spark from a wire hooked to a battery or to a wall outlet.

Brainstorm materials that we think are likely to produce static (or static electricity). Say, *While we know that some types of electricity can be dangerous to experiment with, we have also suggested some examples related to static electricity that many of you have experienced, that are much safer. Let's brainstorm how we might go about producing static electricity, and what we might want to measure in an investigation to figure out if it is connected to what is happening in the water dropper system.*

These next two questions do not appear on a slide and are meant to feel emergent from the class discussion rather than teacher led. Consider posing them to the whole class and facilitating a brief brainstorming discussion around them. Record the ideas students generate on the "Related Phenomena" poster or other chart paper.

Suggested prompt	Sample student response
What are some different ways we might go about producing static?	Accept all responses.
Do we think making static in these ways would produce all of the types of interactions we observed in the water dropper investigations?	Accept all responses.

Identify this line of thinking as our next step. Say, *Let's plan on pursuing these questions further tomorrow. I will gather some materials for you to use to plan an investigation around how we might produce static. Consider the types of static "detector" objects we can use to connect with what we saw in the water dropper system. If you want to use some of your own supplies as test objects, feel free to bring them to class.*

ALTERNATE ACTIVITY	**Extension opportunity:** The water dropper will likely be a surprising phenomenon for students. As home learning, you may wish to have them share their experience with family or community members and ask them for suggestions for different objects they would be interested in seeing detected for static effects.

ALTERNATE ACTIVITY	The end of this lesson may be an opportunity for students to self-assess given what they have figured out so far. Such self-assessment could prepare them to give better peer feedback in Lesson 4. A standard template for self-assessment may be found in the *OpenSciEd Teacher Handbook: High School Science*.

LESSON 4: What happens when we produce static electricity?

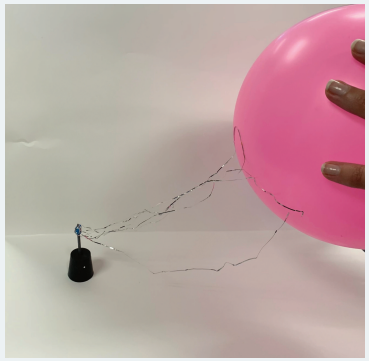
PREVIOUS LESSON

We carried out two rounds of investigations by adding different test objects to the water dropper system. We developed a model to illustrate the forces acting on the test objects. We identified related phenomena (static) that we think would produce similar interactions.

THIS LESSON

INVESTIGATION

2 days



We want to learn more about the attractions and repulsions we have observed with the water dropper system and what static electricity might have to do with them. We think about where we have experienced static electricity before and with what objects. We use several objects to investigate attractions and repulsions in different materials when we rub them together to generate static electricity. We notice patterns in the relationship between the distance between objects and the strength of the attractive or repulsive force.

NEXT LESSON

We will investigate static interactions with sticky tape to test our hypotheses about particle-level interactions. We will use a reading and simulation to examine atomic structure and develop physical models of our sticky tape observations. We will revisit our hypotheses and identify progress on DQB questions.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6, HS-PS3-2, HS-PS3-5

WHAT STUDENTS WILL DO

4.A Develop a test of a model's reliability and revise a model based on empirical evidence of patterns to explain attractions and repulsions between objects in an electric field. (SEP: 2.2, 2.3; DCI: PS2.B.2; CCC: 1.5)

WHAT STUDENTS WILL FIGURE OUT

- Attractive and repulsive forces seem to be stronger at closer distances and weaker at greater distances.
- Some type of contact or friction seems needed for objects to become attractive or repulsive to other objects at a distance.
- Electrostatic forces are likely responsible for the phenomena we have been observing.
- Objects with charges generate electric fields. Fields generated by matter result in forces.

Lesson 4 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		**NAVIGATE** Lead a discussion to decide how testing related phenomena could help us determine our models' reliability.	A	
2	8 min		**GIVE FEEDBACK ON MODELS** Support students as they exchange models with a partner and provide feedback that will help them make decisions about how to test the models' reliability.	B	Lesson 3 model, *Modeling Peer Rubric*, Community Agreements
3	5 min		**DEVELOP INVESTIGATION QUESTIONS** Have students work with a partner to develop investigation questions.	C-D	
4	12 min		**PLAN INVESTIGATIONS TO DETERMINE MODEL RELIABILITY** Have students gather in small groups to develop the investigation plans and data tables they will use in their investigations.	E-G	Lesson 3 model, *Modeling Peer Rubric*, Investigation Anchor Chart, chart paper, chart paper markers, two 5" x 7" pieces of PTFE sheet, one 5" x 7" acrylic sheet, aluminum foil, 1" polystyrene foam ball, plastic comb, fabric scraps of various types (based on availability), all detectors from stations A-D used in Lesson 3
5	10 min		**CONDUCT INVESTIGATIONS** Have students work in groups to carry out their investigations.	H	Static Investigation
6	7 min		**SHARE INVESTIGATION RESULTS** Have each group identify a spokesperson to share the results of their investigations. Lead a class discussion to identify patterns in the data.	I-J	chart paper, chart paper markers
					End of day 1
7	3 min		**NAVIGATE** Help students navigate into the lesson by emphasizing how empirical evidence has helped us identify patterns we can now better explain.	K-L	
8	5 min		**REVISE LESSON 3 MODELS TO BETTER DESCRIBE DISTANCE FORCES** Have students work individually to revise models to incorporate empirical evidence.	M	Lesson 3 model, *Model Revision*
9	7 min		**COMPARE REVISED MODELS** Have students compare similarities and differences in models with a partner.	N	*Model Revision*, *Modeling Peer Rubric*

Part	Duration		Summary	Slide	Materials
10	10 min		**HAVE A BUILDING UNDERSTANDINGS DISCUSSION** Gather students in a Scientists Circle to have a Building Understandings Discussion about the interactions between matter that occur in the water dropper and static electricity investigations.	O-P	*Model Revision*, chart paper, chart paper markers
11	15 min		**READ ABOUT AND DISCUSS DISTANCE FORCES** Support students as they use the Coherent Reading Protocol structure to help them identify electrostatic forces as they relate to static electricity phenomena.	Q-T	*Distance Forces*, *Model Revision*, M-E-F poster, class consensus model from Lesson 1
12	5 min		**UPDATE PERSONAL GLOSSARIES AND NAVIGATE** Have students update their Personal Glossaries and support navigation with an emphasis on the relationship between matter and forces.	U-V	

End of day 2

Lesson 4 • Materials List

	per student	per group	per class
Static Investigation materials	• science notebook	• two 5" x 7" pieces of PTFE sheet • one 5" x 7" acrylic sheet • aluminum foil • 1" polystyrene foam ball • plastic comb • fabric scraps of various types (based on availability) • all detectors from stations A-D used in Lesson 3	
Lesson materials	• science notebook • Lesson 3 model • *Modeling Peer Rubric* • *Model Revision* • *Distance Forces*		• Community Agreements • Investigation Anchor Chart • chart paper • chart paper markers • two 5" x 7" pieces of PTFE sheet • one 5" x 7" acrylic sheet • aluminum foil • 1" polystyrene foam ball • plastic comb • fabric scraps of various types (based on availability) • all detectors from stations A-D used in Lesson 3 • M-E-F poster • class consensus model from Lesson 1

Materials preparation (45 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Be sure to have the Investigation Anchor Chart from *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* ready to share with students. If you do not have the anchor chart available, use the teacher reference provided in Lesson 3 of that unit to help you identify the important points from the anchor chart to share with students in this lesson.

Static Investigation

- **Group size:** 4-5 students
- **Setup:** Prepare the following, which will be used in this investigation as well as in Lesson 7:
    - Two 5" x 7" pieces of PTFE sheet
    - One 5" x 7" acrylic sheet (Peel off the protection paper from both sides.)
- Students will set up their investigations based on their plans, but they will need the materials available in the room. In addition to the two pieces of PTFE sheet and the acrylic sheet you prepared above, consider providing these additional materials:
    - pieces of floss/sting
    - small piece of aluminum foil
    - 1" polystyrene foam ball
    - plastic comb
    - fabric scraps of various types such as silk, wool, rayon, felt, or acrylic (based on availability)

    - all the detectors from stations A-D used in the water dropper investigations in the previous lesson

Have these materials set out for students so they may design their investigations around them.

- **Notes for during the lab:** Classroom environments with high humidity may prevent the formation of much static. In this case, consider running a dehumidifier in the space a few hours ahead of time and test the relative humidity in the room until it comes down to 40% or lower, if possible.
    - A high level of static buildup is required for the station A detector (light bulb) from Lesson 3 to work, so you may choose to omit this item.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science.* Support students in following standard laboratory safety considerations. Do not allow students who are allergic to latex to handle the balloons directly.
- **Disposal:** All materials are reusable and do not need to be thrown away.
- **Storage:** All materials can be stored and reused next year or for other investigations.

Lesson 4 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build new ideas related to the following disciplinary core idea:

- **PS2.B.2 Types of Interactions:** Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space ~~that can transfer energy through space~~. Magnets ~~or electric currents~~ cause magnetic fields; electric charges ~~or changing magnetic fields~~ cause electric fields.

This work builds on students' prior experiences with fields and distance forces in *OpenSciEd Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*.

Crossout explanation: In this lesson, students recognize that a force they may not be familiar with is causing attraction and repulsion in their investigations. They figure out from a reading that the electrostatic force is due to electric fields, generated by charged matter. PS2.B.2 is developed further later in the unit. In Lesson 10, students establish that fields transfer energy through space. Students will figure out the electricity-magnetism connections in *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*.

Students have had a number of opportunities to model phenomena in this unit--lightning on paper in Lesson 1, lightning with a water dropper in Lessons 2 and 3, and most recently static interactions in Lesson 3. This lesson continues the work from Lesson 3 in which students began investigating forces of attraction and repulsion at a distance in the water dropper system. They will continue using many of the same materials to look for patterns in attractive and repulsive forces between a variety of materials and objects. In this lesson, students further experience modeling in two ways: first, by designing a test of their Lesson 3 model's reliability (SEP: 2.2); and second, by revising their model based on the new evidence they identified during testing (SEP: 2.3). Students will also receive feedback on their models from both peers and teachers. The work on day 1 builds on students' prior experiences with investigations in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, although in this lesson the investigation developed is firmly centered in testing and in revising students' models.

The focus of this lesson is looking for patterns in observed interactions between objects and in what students do to cause the observed interactions. Students will notice that many objects display static interactions, either attractions or repulsions, after rubbing or friction is generated with at least one of the objects. In middle school students identify patterns that help them explain systems, and realize that macroscopic patterns can relate to microscopic and even smaller-scale structures. In Lesson 1 students identified patterns with an intention of identifying causality. Here, students establish that empirical evidence is often needed to identify patterns (CCC: 1.5).

In this lesson, students will encounter or co-construct a definition for the following terms, which they should add to their Personal Glossary: *empirical evidence, electrostatic force, charge, (electric) field*. We recommend that you do not post any terms or ask students to record any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Although students are introduced to charges in this lesson, they have not built the idea that particular, charged subatomic particles exist. This idea will be built in Lesson 5, as will the mechanism of "charging" objects through electron transfer. Students will then apply these ideas to the lightning phenomenon in Lesson 6 and develop a mathematical model for the electrostatic force in Lesson 7.

Students may or may not come into this unit or lesson with a preexisting concept of charge or of opposite charges attracting. Until students have engaged with the readings in Lessons 4 and 5, probe these ideas. Push students to be more specific about what they mean by "charge." Emphasize that we need direct or trusted indirect evidence from investigations or observations (empirical evidence) to be sure how charge applies to lightning and other phenomena.

Students may wish to investigate other materials than the ones provided, such as different fabrics, light bulbs, or metals. If there is a Van de Graaff generator available, it could be a useful demonstration to help students link their observations of the water dropper system to their observations in these investigations, though it is not necessary. Students may wish to include plasma lamps like those they have seen at home or in a science classroom, but these will be explained in Lesson 11, so save those types of lamps for later.

LEARNING PLAN for LESSON 4

1 · NAVIGATE

3 min

MATERIALS: science notebook

Discuss what we figured out last class and where to go next. Display **slide A**. Say, *Let's remind ourselves about where we left off with the water dropper investigations and what we wanted to do today and why.* Have students stop and jot their responses to the prompts on the slide. Then use the prompts below to lead a brief discussion with students to help everyone recall what they figured out last class and where they wanted to go next.

Suggested prompt	Sample student response
Which related phenomena did we brainstorm at the end of Lesson 3?	We want to see if static is the same as what is happening with the water dropper system. We want to know if static causes the same attractions and repulsions. We want to try different ways to produce static electricity. Static shocks.✱ Hair sticking up.
How could testing those phenomena help us understand if our models are reliable?✱	Tests could help us figure out if static is the same as what is happening with the water dropper system. We could see if static causes the same attractions and repulsions we saw with the dropper. We would be able to see if there are different ways that static electricity could be produced.
How could testing those phenomena help us add new ideas about forces to our models?	We would be able to better understand the connection between forces and static electricity. We can see if there is repulsion with a lot of different objects.

Tell students that we want to make sure we are testing our ideas about static carefully, so that we are answering questions we have about the models we developed last class. Giving each other feedback on the Lesson 3 models can help us decide how we want to test them.

✱ ATTENDING TO EQUITY

Experiential learning, such as feeling the presence of static or experiencing a light shock, brings students close to phenomena in a relatable and memorable way.

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

In this lesson, students will test the reliability of their models. Emphasize to students that our models are only useful if they are able to consistently explain phenomena across a variety of similar situations or allow us to make consistent predictions.

2 · GIVE FEEDBACK ON MODELS

8 min

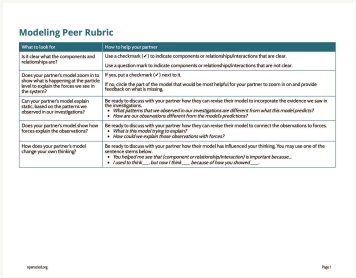
MATERIALS: Lesson 3 model, *Modeling Peer Rubric*, Community Agreements

Prepare students to give each other feedback. Display **slide B**. Explain that scientists often use feedback to sharpen their ideas. Reference the Community Agreements and tell students that in this lesson we will focus on being committed to our community. Highlight particular agreement language that emphasizes that one part of being in a community is providing honest, constructive feedback to one another. Remind students that the goal is for everyone's ideas to be pushed a little bit so that we can make more progress as a class.✱

Briefly walk students through the protocol. Explain that partners will have 5 minutes to use *Modeling Peer Rubric* to help them write feedback directly on their partner's model, and then 1 minute each to discuss and share other observations.

After students have shared, say, *Thank you for giving each other productive feedback. Now that you have had a chance to think about where your model could be strengthened, you will work with your partner to decide what you wish to investigate.*

Allow students to keep *Modeling Peer Rubric* and their models for reference as they develop tests of their models' reliability in the next activities.


Modeling Peer Rubric

What to look for	How to help your partner
Is it clear what the components and relationships are?	Use a checkmark (✓) to indicate components or relationships/interactions that are clear. Use a question mark to indicate components or relationships/interactions that are not clear.
Does your partner's model zoom in to show what is happening at the particle level to explain the forces we see in the system?	If yes, put a checkmark (✓) next to it. If no, circle the part of the model that would be most helpful for your partner to zoom in on and provide feedback on what is missing.
Can your partner's model explain patterns in the data gathered in the observations in our investigations?	Be ready to discuss with your partner how they can revise their model to incorporate the evidence we saw in our investigations. • *What patterns that we observed in our investigations are different from what this model predicts?* • *How are our observations different from the model's predictions?*
Does your partner's model show how forces explain the observations?	Be ready to discuss with your partner how they can revise their model to connect the observations to forces. • *What is the model trying to explain?* • *How could we explain those observations with forces?*
How does your partner's model change your own thinking?	Be ready to discuss with your partner how their model has influenced your thinking. You may use one of the sentence stems below. • *You helped me see that [component or relationship/interaction] is important because...* • *I used to think ___, but now I think ___ because of how you showed ___.*

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✱ ATTENDING TO EQUITY

Building classroom culture: If you want to allow your students the agency to pick a focal norm, you should feel welcome to do that here. However, if you want more direction or guidance, use the suggested norm and prompts above. Also, be sure to keep the re-norming going throughout this unit and the year; "just in time" use of norms helps students see their value in the classroom and makes the norms more relevant.

3 · DEVELOP INVESTIGATION QUESTIONS

5 min

MATERIALS: science notebook

Orient to available materials. Say, *We decided to investigate static electricity, but how are we going to do that? Let's examine the materials we have available for detecting some of the things you noticed yesterday and that may be useful for producing static electricity*. Display **slide C** and review the related materials listed.

ALTERNATE ACTIVITY

Extension opportunity: You may encourage students to make their investigations more quantitative by measuring some sort of independent variable (e.g., number or time of rubbing objects together) and dependent variable (e.g., distance at which interaction is obvious). This could be helpful in setting students up for more formal quantification of Coulomb's law in Lesson 7.

Develop investigation questions with a partner. Say, *But before we decide what data we want to collect and how we might go about producing static electricity, let's identify a question we want to answer. As you develop your investigation questions, be sure to consider if we have the materials you would need to investigate them and whether we could investigate them in the classroom.* Display **slide D.** Give students three minutes to turn and talk with a partner to discuss the prompts on the slide. Encourage students to record their responses in their science notebooks. After a few minutes, have students share their ideas as a class. Push students to articulate how the question they want to investigate is connected to the water dropper system. ✱

✱ SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

Students ask questions that can be investigated within the scope of the school laboratory, research facilities, or field with available resources and, when appropriate, frame a hypothesis based on a model or theory.

The purpose of sharing questions is to notice similarities and to evaluate the questions to ensure that they can be tested with the available materials. It is okay if there is not one central question that the class agrees on, as long as the class can agree on similarities between students' questions, that the questions will help test the reliability of students' models, and that they can be investigated in the classroom.

Suggested prompt	Sample student response
What investigation question did you develop?	What makes things stick together? What makes things repel or push away? How do we generate more or less static electricity? Can we make a light bulb light up with static?
How will investigating this question help us make progress on understanding the water dropper system and lightning?	If the same things/interactions are happening in static electricity that are happening in the water dropper system or lightning, then static electricity must be what is causing all the patterns we have seen. This will help us determine whether the same things are causing the same outcomes in all cases.

4 · PLAN INVESTIGATIONS TO DETERMINE MODEL RELIABILITY

12 min

MATERIALS: science notebook, Lesson 3 model, *Modeling Peer Rubric*, Investigation Anchor Chart, chart paper, chart paper markers, two 5" x 7" pieces of PTFE sheet, one 5" x 7" acrylic sheet, aluminum foil, 1" polystyrene foam ball, plastic comb, fabric scraps of various types (based on availability), all detectors from stations A-D used in Lesson 3

Identify possible investigation materials in small groups. Say, *Many of you had similar investigation questions. Consider the questions posed by your classmates and form groups of four or five based on common investigation questions.* Give students a few minutes to form their groups and assist students who may have trouble deciding which group to join. Encourage these students to join a group with a question that may be different from theirs but that they are curious to investigate. Have students record their group's investigation question on a new sheet of paper in their science notebooks.

Display **slide E.** Have groups use their investigation questions and the prompts on the slide to determine which objects they would use to develop an investigation. Give groups about three minutes to list the materials and detectors in their science notebooks before asking them to share with the class. Have groups share their lists and highlight any similarities.

Develop data tables for investigations. Make sure the Investigation Anchor Chart developed in *Polar Ice Unit* is visible. Say, *We have some similarities in the types of materials and detectors we could use to help make progress on our investigation questions. Because of this, it may be helpful for us to consider what types of data we would need to collect and how we could keep track of that data.* Display **slide F** and instruct students to add the data table template to their science notebooks underneath their group's investigation question.✱

Suggested prompt	Sample student response
What types of data do you need to make progress on your group's investigation question?	How different objects are interacting with each other. If static electricity is being detected by any of the detectors.

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

The goal of students' tests is to identify the reliability of their models in explaining static phenomena. Since students are trying to explore static phenomena with multiple objects to establish patterns of interactions, it is important that they manipulate different variables instead of focusing on just one independent variable. Using multiple materials, and many of the detectors from the previous lesson, will help students see those patterns and relate them back to patterns observed with the water dropper system.

Suggested prompt	Sample student response
What information do you need to add to a data table to keep track of this data?	What materials and detectors we are using. If there is any interaction between the materials and detector. What type of interaction there is, like how the material or detector moves.

Work with students to develop a data table on a piece of chart paper. One possible data table is shown, but allow for groups to customize their data tables to better reflect their investigation ideas.

Objects tested	Detector used	Interaction observed (yes/no)	Direction and/or strength of forces during interaction

Plan investigations in small groups. Display **slide G**. Read through the slide directions with students and then have them work with their groups for about five minutes to develop their final investigation plans. If there is still a poster or anchor chart displayed from *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* where students defined variables and controls, encourage students to refer to it as they think about this investigation. Encourage each group to choose a condition to vary. Then they should decide how to vary it, such as testing forces at various distances or testing multiple detectors under the same conditions. As groups plan, circulate to answer questions, give feedback, or push them to think deeper or be more specific in their plans and how they will test their models' reliability.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students articulate what materials they plan to test their model with to produce static electricity, how they plan to produce static electricity, and how they plan to detect it. (SEP 2.2; DCI: PS2.B.2)
- Students develop plans that identify patterns in interactions that would provide evidence of the reliability of their models. (SEP 2.2; CCC: 1.5)

What to do: If students have difficulty articulating any aspects of their investigation, it may help them to talk through their plan with you. As they explain what they plan to do, help them identify materials, anticipated interactions, and detectors they will use. Encourage students to return to their models and identify what is uncertain or untested, and ask them to consider the patterns that would provide evidence of reliability and the materials that could help bring them about.

Once students have completed their investigation plans, be sure to collect models before day 2. Use *Modeling Peer Rubric* to expand on the feedback students received from their peers.

Building toward 4.A.1 Develop a test of a model's reliability and revise a model based on empirical evidence of patterns to explain attractions and repulsions between objects in an electric field. (SEP: 2.2, 2.3; DCI: PS2.B.2; CCC: 1.5)

ADDITIONAL GUIDANCE

To ensure a variety of investigations among groups, it may be helpful to brainstorm all of the conditions groups might test. Some variables that groups may think of manipulating, or that may be suggested, include:

- type of material
- combination of materials used, including testing the same material with itself
- distance between objects
- amount of time rubbing objects before testing them

5 · CONDUCT INVESTIGATIONS

10 min

MATERIALS: Static Investigation

Conduct investigations in small groups. Display **slide H**. Have groups send one student to gather needed materials from the designated area in the classroom. If groups need more materials than the amount available, encourage them to develop a system to share or swap items so that groups are not left waiting with nothing to do.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students identify patterns in interactions, such as noticing multiple materials attracting or repelling, and observing that all objects attract or repel more strongly when they are closer together. (DCI: PS2.B.2; CCC: 1.5)

What to do: Students should discuss and record the interactions they observe. Encourage students to look for patterns in interactions across the different materials or detectors they use. Sample data tables can be found in *Sample Student Data*.

Building toward 4.A.2 Develop a test of a model's reliability and revise a model based on empirical evidence of patterns to explain attractions and repulsions between objects in an electric field. (SEP: 2.2, 2.3; DCI: PS2.B.2; CCC: 1.5)

6 · SHARE INVESTIGATION RESULTS

7 min

MATERIALS: science notebook, chart paper, chart paper markers

Prepare to share investigation results. Display **slide I.** Give groups two minutes to summarize their observations and choose a spokesperson.

Share investigation results. Call on groups to share one at a time, using the prompts on **slide J** as a guide. As each group's spokesperson shares a summary of their investigation and observations, record their results on a piece of chart paper. Once each group has shared, give everyone a minute to read over the recorded information and note any patterns they find. ✱ An example of several groups' results compiled be found in *Sample Student Data*.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Evidence is needed to identify patterns. In these investigations, evidence is in the form of the interactions students observe, as well as in the links between what students do to the materials--namely, rubbing them together--and the observed interactions–attraction and repulsion. The patterns of attraction and repulsion will be important to keep in mind later as students develop models of particle-level charge transfer.

Suggested prompt	Sample student response
What similarities or differences were there in our investigation designs?	We all rubbed objects together or created friction between two objects. We put objects near each other to see if there would be any interaction. Some of us used the same objects or two different objects.
What patterns do you notice in the compiled investigation results?	There was some type of interaction between most of the objects--they were either attracted or repelled by each other. Objects attracted or repelled more when they were closer together. As we moved them farther apart, the force between them was less. The objects did not have to be touching for there to be a force.

At the end of the discussion, ask students to highlight any patterns in the types of materials that tended to attract or repel. Indicate these on the chart paper with the class data.

End of day 1

7 · NAVIGATE

3 min

MATERIALS: None

Navigate into the day's lesson. Display **slide K**. Give students a minute to turn and talk with a partner about the prompts on the slide. Then discuss them as a class.

Suggested prompt	Sample student response
What new sources of information have we added in this lesson so far? ✱	We have investigated how different materials interact with each other. We have gotten feedback on our models from classmates.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Empirical evidence includes both experimental evidence and evidence from systematic observation. Patterns can be predicted from anecdotal evidence derived from everyday experiences, but empirical evidence can be used to confirm or provide evidence against predicted patterns or to identify previously unnoticed patterns.

Suggested prompt	Sample student response
What patterns do we understand better because of the tests we conducted?	We saw that the objects usually either attracted or repelled each other. We know that rubbing objects together is necessary to cause the attraction or repulsion. Heavier materials didn't work as well. Some objects had to be really close to see the attraction or repulsion.

Emphasize the role of empirical evidence. Display **slide L**. Ask, *How is what we did in these tests different from guessing at patterns based on our experience?* Listen for the suggestion that testing our ideas gives us a clearer understanding of what patterns actually exist, rather than the patterns that we think "should" exist. Highlight that the patterns we have identified through our investigations are *empirical evidence*, meaning they are evidence based on actual observations or investigation rather than predictions alone.

Suggest that since we have figured out a lot of new information through our investigations, we will return to our models and revise them to incorporate our new understandings.

8 · REVISE LESSON 3 MODELS TO BETTER DESCRIBE DISTANCE FORCES

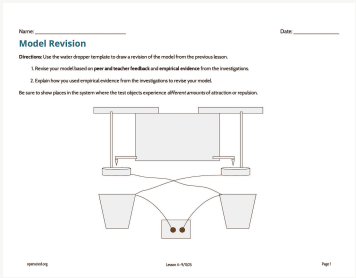
5 min

MATERIALS: science notebook, Lesson 3 model, *Model Revision*

Revise Lesson 3 models to account for attraction and repulsion in the system. Distribute *Model Revision* and display **slide M.** Ask students to do the following on their own:

1. Revise their models based on peer and teacher feedback and empirical evidence from the investigations.✱
2. Explain how they used empirical evidence from the investigations to revise their model.✱

Emphasize to students that their revised models should still show places in the system where the amount of attraction or repulsion is different based on the locations of objects. A sample model is shown.


Name: _____ Date: _____

Model Revision

Directions: Use the water dropper template to draw a revision of the model from the previous lesson.

1. Revise your model based on **peer and teacher feedback** and **empirical evidence** from the investigations.
2. Explain how you used empirical evidence from the investigations to revise your model.

Be sure to show places in the system where the test objects experience different amounts of attraction or repulsion.

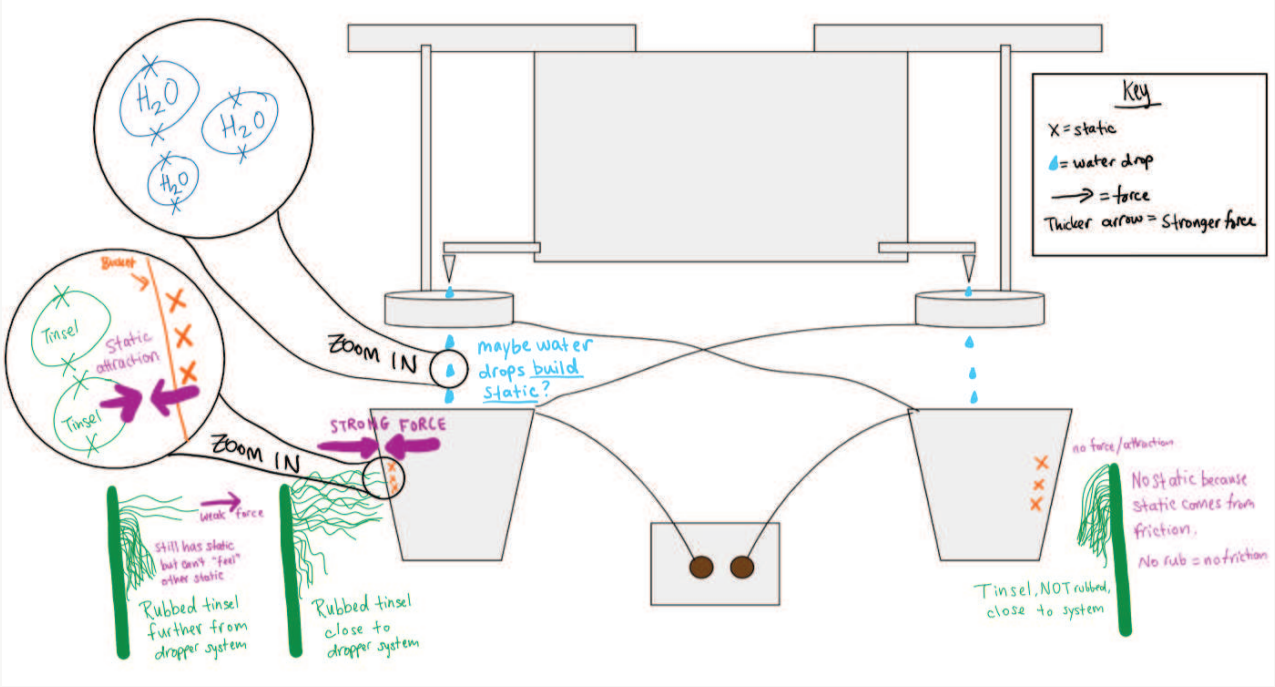
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✱ ATTENDING TO EQUITY

Universal Design for Learning: This task was structured so that all students have feedback, specific to their own models, to use in their revisions. This includes identification of where important features, like zoom-ins, need to be added. Students then have the opportunity to make revisions in their *own way* based on the feedback received. It is recommended that you add zoom-in bubbles or other scaffolding features only if they are required accommodations so that all students have choice in *expression*.

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Here students have an opportunity to explicitly revise a previous model (SEP) for the first time in the unit. They should do so using empirical evidence (CCC) that they gathered earlier in the lesson. Students are



starting to formalize forces (DCI) more than they have at any point in the chemistry course. Although not typically leveraged in chemistry courses, force thinking will remain an important tool for students' modeling throughout this unit and the rest of the course because of the importance of forces in bonding.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' revised models include the test object and the aluminum bucket as components. (SEP: 2.3)
- Students represent a force acting on the test object differently throughout space. (SEP: 2.3; DCI: PS2.B.2)
- Students explain how they used empirical evidence to revise their models. (SEP: 2.3; CCC: 1.5)

What to do: As you circulate, ask students what they are now adding to their models that was not there in Lesson 3. This will remind them to make needed changes. Encourage students to identify the particular evidence that they are using to revise their models. If students do not know where to begin, ask them to consider (1) what feedback they received and (2) where their models failed to predict or explain what they saw in the investigations. Remind students that they observed the objects interact with the detectors differently at different distances, and that this should be represented as well.

Students will not be introduced to a formal system to represent force strength until Lesson 7, but if this is a barrier to their modeling, you may suggest that they use arrows to represent forces, with the direction of the arrow showing the direction of push/pull and the length representing the strength of the force.

Building toward 4.A.3 Develop a test of a model's reliability and revise a model based on empirical evidence of patterns to explain attractions and repulsions between objects in an electric field. (SEP: 2.2, 2.3; DCI: PS2.B.2; CCC: 1.5)

9 · COMPARE REVISED MODELS

7 min

MATERIALS: science notebook, *Model Revision*, *Modeling Peer Rubric*

Compare revised models with a partner. Display **slide N**. Read through the directions on the slide. Create pairs of students, ensuring that students are working with someone they had not previously worked with. Give pairs about three minutes to share their revised models and compare them to determine similarities and differences. Circulate around the room and assist as needed. Encourage students to record the similarities and differences they have identified in their science notebooks. You may wish to have students use *Modeling Peer Rubric* to help them focus on specific places in the models where there might be similarities or differences.

10 · HAVE A BUILDING UNDERSTANDINGS DISCUSSION

10 min

MATERIALS: science notebook, *Model Revision*, chart paper, chart paper markers

Lead a Building Understandings Discussion. Use the prompts on **slides O-P** to lead this discussion with students.

KEY IDEAS

Purpose of this discussion: To establish agreement on a way to represent force interactions in the system that can account for the evidence we have.

Listen for these ideas associated with each prompt:
What similarities and differences do we notice in how the matter interacts in the different systems we modeled? (**slide O**)
Similarities
- There are forces that cause objects to attract or repel.
- Changing the distance between objects changes how strong the force is.
- Friction brings about a force, somehow.

Differences
- Sometimes the force between objects causes them to attract. Other times it causes them to repel.
- Our models represent the forces differently.
- Metals and non-metals behave differently near the water dropper.

Be sure to elicit from students the idea that forces act at a distance. Name the space where a force is acting as a *field*. Ask a few students to identify areas on their models where there are fields.

As students share their responses to the prompts on **slide P**, make a table on chart paper like the one shown below.

What forces have we heard about? (**slide P**)
- Gravity
- Magnetism
- Electrostatic force (or something similar related to charges or static; it is okay if students do not bring this up)

In what ways do these forces explain (or not explain) our observations of the material interactions? (**slide P**)
- Gravity pulls us down, which is different from what we have observed.
- Magnetism includes objects attracting and repelling.
- You need certain metals to have magnets, but we saw many different materials interacting.
- (If something like an electrostatic force is mentioned) The electrostatic force attracts or repels and affects all kinds of matter... we think.

	Gravitational	Magnetic	Electrostatic (if mentioned)
Direction of forces (attract or repel)	Attracts only	Attracts or repels	Attracts or repels?
Type(s) of matter it acts on	All	Magnets	All?

Close the discussion by highlighting uncertainty about the force that explains the static electricity phenomena we have observed. Suggest that we engage with a reading to figure out more.

ALTERNATE ACTIVITY

Building prerequisite understandings: Students should be familiar with fields from *Magnets Unit*. If they appear confused by the concept, show an image or demonstration of a magnet surrounded by iron filings. Ask students to imagine that they themselves are magnetic. Then ask questions to lead to the idea that a field is a space in which a force is active. *What would they feel if they were near a magnet? How would that feeling change if they were moved to another point around the magnet?*

11 · READ ABOUT AND DISCUSS DISTANCE FORCES

15 min

MATERIALS: *Distance Forces*, *Model Revision*, M-E-F poster, class consensus model from Lesson 1

Read about distance forces. Display **slide Q**. Distribute *Distance Forces*. Review the structure of the reading and associated prompts from the Coherent Reading Protocol.✱ Then give students six minutes to read and jot down their thoughts in *Distance Forces*, and another minute to share ideas with a partner.

Discuss the reading. Lead a discussion of the reading using the prompts on **slides R-S**.

Suggested prompts	Sample student responses	Follow-up questions
What did the reading tell us about the force behind static electricity?	It is the electrostatic force. It is pretty strong. Things that have charge are affected by it. It is related to fields.	*How does the electrostatic force cause the effects of static electricity?*

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: The reading has been broken into three chunks of text. This not only helps students to make sense of the text, it is also a strategy that can be used to support emergent multilingual learners. Also consider having students break apart compound words like *electrostatic* force. Ask students to reason about the first part of the word by asking, *What does electro sound like? What other words have you heard that sound like that?* Students will probably say "electricity." Encourage students to consider and suggest cognate words in other languages as well, such as electricidad (Spanish), électricité (French), elektrichestvo (Russian transliteration), or Elektrizität (German). Then summarize the idea of putting both words together ("electricity" and "static") to make a single compound word that indicates this force's association with both phenomena.

Suggested prompts	Sample student responses	Follow-up questions
What is charge and how does it relate to the electrostatic force?	It is a property of matter. Things can be positively or negatively charged. Objects or particles can be positively or negatively charged. Objects or particles that are charged experience the electrostatic force.	*How do charges result in an electrostatic force?* *How does that connect to what we observed by rubbing objects together in our investigation?* *Where or what are the charges in the water dropper? In lightning?* *What makes sense about charges? What is confusing?*
What are fields and how do they relate to the electrostatic force?	They are the space around a charge or magnet or something where there is a force.	*Where or what are the fields in the water dropper? In lightning?* *What makes sense about fields? What is confusing?*

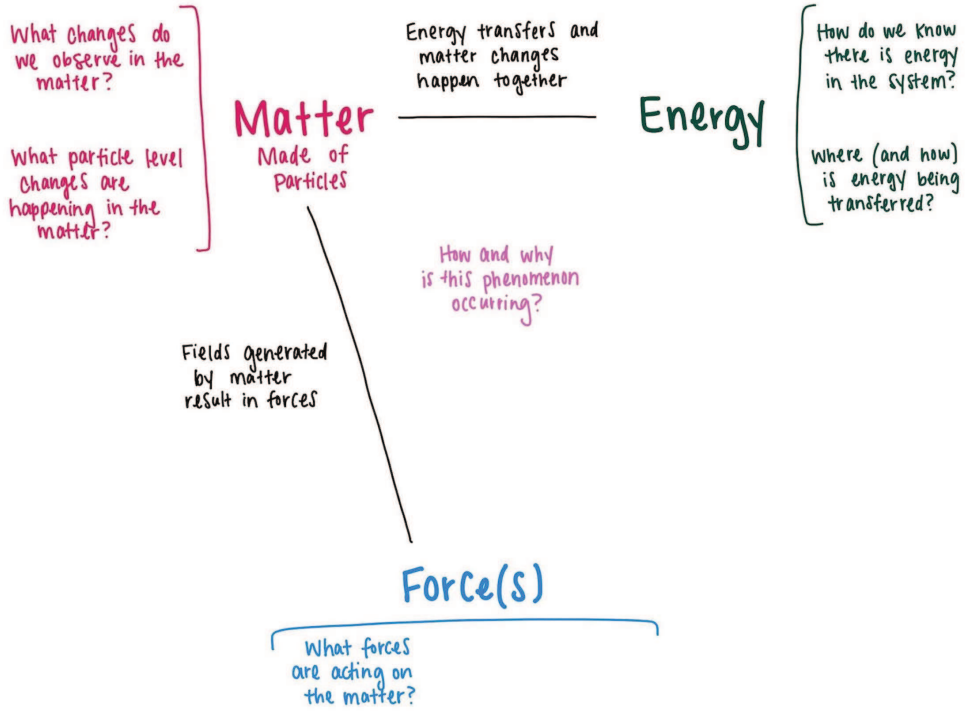
Connect to models. Ask students where we might add charges and fields in our revised models. Accept all responses at this point. Encourage students to add these ideas to their models with a question mark. Meanwhile, add them where appropriate to the class consensus model.

Update the M-E-F poster. Display **slide T** and make sure the M-E-F poster is visible. Say, *Last lesson we added Forces to this triangle, but we were not sure how forces connected to other ideas. Let's focus on this Matter-Forces connection.* Draw a line between the two as shown, and then ask, *Where do the forces come from? They are related to matter, but how specifically?*

Listen for these ideas:

- Fields come from matter that has a charge.
- Forces come from fields.

Once you have heard students' ideas, write a statement like "Fields generated by matter result in forces" on the Matter-Forces line. Write the question "What forces are acting on the matter?" below the Forces label and note that we will continue thinking about forces to help us explain matter's behavior in the future.



ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students describe the relationship among charges, fields, and the electrostatic force and propose possible revisions to their models using these ideas. (SEP: 2.3; DCI: PS2.B.2)

What to do: Students will explore charges and fields in greater depth in subsequent lessons, so it is okay if students' ideas are not fully formed. Use magnets as an analogy to help students reach the initial conclusion that matter generates fields, which cause forces. In this analogy, magnets and charges are examples of matter, lined-up iron filings and the behavior of a detector in space indicate fields, and the attraction or repulsion one experiences is evidence of forces.

Building toward 4.A.4 Develop a test of a model's reliability and revise a model based on empirical evidence of patterns to explain attractions and repulsions between objects in an electric field. (SEP: 2.2, 2.3; DCI: PS2.B.2; CCC: 1.5)

12 · UPDATE PERSONAL GLOSSARIES AND NAVIGATE

5 min

MATERIALS: science notebook

Update Personal Glossaries. Display **slide U** and give students a moment to update their glossaries. If necessary, take a moment to come to agreement on the meaning of the terms *empirical evidence*, *charge*, *electrostatic force*, and *(electric) field*.

Navigate into the next lesson. Display **slide V**. Give students a moment to individually reflect on the prompts. Then give a few students a chance to share their ideas.

Suggested prompt	Sample student response
What questions do we have about the relationship between matter and forces (particularly between charged matter and forces from electric fields)?	Why is an object or particle charged? How can friction cause an object to get a charge?
How can answering these questions help us figure out what causes lightning?	If we understand where charge comes from, we might be able to explain the shock that happens with lightning. We do not know if there is friction when there is lightning, but if we decide we definitely need friction for there to be charge that could tell us if lightning comes from charge.

Close class by thanking students for their commitment to our community throughout this lesson. Suggest that it sounds like we should dig a little more into how something becomes charged, and that we should also consider whether this has anything to do with lightning.

Additional Lesson 4 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.

Students use the Coherent Reading Protocol to connect the reading to their experiments and discuss how it extends their thinking with new information.

LESSON 5: What is happening at a particle level to produce static effects?

PREVIOUS LESSON

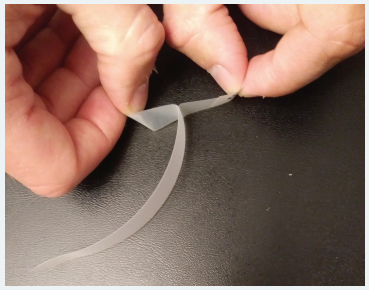
We planned investigations with several different objects to generate static. We observed attractions and repulsions involving different materials and looked for patterns in these interactions. We noticed that these interactions occurred after objects were rubbed together and that attractions or repulsions were stronger at shorter distances.

THIS LESSON

INVESTIGATION, PUTTING PIECES TOGETHER

3 days





We develop hypotheses of what is happening at the particle level to explain the interactions we observed. We investigate static interactions using sticky tape. We read about and discuss atomic structure. Individually, we use a simulation to examine atoms and subatomic particles. We use the information from the reading and simulation to develop physical models of what is happening with the sticky tape. We watch a video of a person describing a lighting strike and apply our models to explain the observations. Finally, we take an electronic exit ticket, identify progress on our DQB questions, and revisit our hypotheses.

NEXT LESSON

We will read an article to gather information about what is happening in the sky to cause static interactions before a lightning strike. Then we will use this information to compare the lightning system to our in-class static systems.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6, HS-PS3-2, HS-PS3-6



WHAT STUDENTS WILL DO

5.A Integrate information from multiple sources to explain what is happening at a scale too small to directly observe and provide evidence for the existence of protons, neutrons, and electrons. (SEP: 8.2; DCI: PS1.A.1; CCC: 3.2)

5.B Develop, use, and discuss the merits and limitations of multiple models to simulate the charged substructures of atoms, the movement of electrons, and other processes and structures too small to directly observe. (SEP: 2.1, 2.4; DCI: PS1.A.1; CCC: 3.2, 4.3)

WHAT STUDENTS WILL FIGURE OUT

- All atoms are made of different combinations of the same three subatomic particles: positively charged protons, uncharged neutrons, and negatively charged electrons. The relative number of protons and electrons determines the atom's overall (net) charge.
- Subatomic particles are organized in the atom with protons and neutrons in the nucleus and electrons surrounding the nucleus. The type of atom is based on the number of protons in it.
- As objects in contact produce static, a small amount of matter in the form of electrons is removed from one object and accumulated on another. This movement changes the net charge on each object.

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Have students stop and jot to reflect on the last class, then lead a class discussion.	A	
2	15 min		**INVESTIGATE THE STICKY TAPE PHENOMENON** Arrange students into pairs to complete the Sticky Tape Investigation.	B-F	Sticky Tape Investigation
3	23 min		**READ ABOUT ATOMIC STRUCTURE** Distribute a reading about parts of the atom and use a close reading protocol to identify central ideas. Lead a Building Understandings Discussion about subatomic particles.	G-J	*Structure of Matter*, chart paper, chart paper markers
4	2 min		**NAVIGATE** Have students stop and jot after discussing the reading to connect the information to the sticky tape investigation results.	K	
					End of day 1
5	2 min		**NAVIGATE** Have students share their responses to the stop and jot prompt.	L	
6	10 min		**EXPLORE AN ATOM SIMULATION** Have students investigate the structure of different atoms using a simulation. Lead a Consensus Discussion to synthesize information from the reading and simulation to explain atomic structure.	M-N	internet connected device, https://lab.concord.org/embeddable.html#interactives/interactions/atom-builder.json, "Atomic Structure" poster, chart paper markers
7	18 min		**DEVELOP MODELS OF THE ATOM** Lead a discussion around differences in atomic models from *Structure of Matter* and https://lab.concord.org/embeddable.html#interactives/interactions/atom-builder.json. Work with students to develop a physical model of the atom.	O-Q	3x5 notecard, 3 small paper clips
8	10 min		**EVALUATE OUR MODELS USING ROUNDTABLE DISCUSSION** Meet in a Scientists Circle and choose one group to demonstrate their paper-clip models for each of the sticky tape scenarios.	R-S	paper-clip models, chart paper, chart paper markers, Community Agreements
9	5 min		**PROBLEMATIZE WHY THE ELECTRONS ARE MOVING** Have students brainstorm initial ideas for why the electrons are moving between the atoms of different objects.	T	
					End of day 2
10	5 min		**NAVIGATE** Lead a whole-class discussion to take stock of what we have figured out about matter and static electricity.	U	

Part	Duration		Summary	Slide	Materials
11	5 min		**EXPLORE EXAMPLES OF STATIC BEFORE A STORM** Play a video of eyewitness accounts of static before a lightning storm. Lead a class discussion of what students notice and wonder.	V-W	https://youtu.be/JGFC6-vFhyQ
12	10 min		**DISCUSS WHICH VIDEO PHENOMENA CAN BE EXPLAINED WITH OUR MODELS** Have students gather in a Scientists Circle to discuss how we can use what we figured out about static to explain the phenomena we observed before lightning storms.	X-Z	paper-clip models, *Discussion Mapping Tool*, clipboard (optional)
13	5 min		**REFLECT ON OUR DISCUSSION MAPPING PROCESS** Have students stay in the Scientists Circle and lead a discussion around patterns in the discussion map. Have students consider what these data tell us.	AA-BB	*Discussion Mapping Tool*
14	7 min		**UPDATE PROGRESS TRACKERS** Have students update their Progress Trackers for the final time this lesson.	CC	
15	10 min		**COMPLETE AN ELECTRONIC EXIT TICKET AND REVISIT DQB QUESTIONS** Have students individually complete the Electronic Exit Ticket and then annotate *Our DQB Questions*.	DD-EE	link to class copy of the Electronic Exit Ticket, internet connected device, *Our DQB Questions*
16	3 min		**NAVIGATE** Facilitate a whole-class discussion about the hypotheses we made at the beginning of the lesson.	FF	

End of day 3

Lesson 5 • Materials List

	per student	per group	per class
Sticky Tape Investigation materials	• science notebook	• 3 pieces cloudy cellophane tape • permanent marker • *Sticky Tape Investigation*	
Lesson materials	• science notebook • *Structure of Matter* • 3x5 notecard • 3 small paper clips • link to class copy of the Electronic Exit Ticket • internet connected device • *Our DQB Questions*	• internet connected device • https://lab.concord.org/embeddable.html#interactives/interactions/atom-builder.json • paper-clip models	• chart paper • chart paper markers • "Atomic Structure" poster • Community Agreements • https://youtu.be/JGFC6-vFhyQ • *Discussion Mapping Tool* • clipboard (optional)

Materials preparation (40 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Review these videos:
- https://youtu.be/ja8a89iGtuk for support during the Sticky Tape Investigation
- https://youtu.be/K3qFB6xVjBE?si=qoQfFm1HY-5Ubvtc for support on building paper-clip models

Check that https://lab.concord.org/embeddable.html#interactives/interactions/atom-builder.json can be run on student devices.

Have the Community Agreements visible on day 2 during the roundtable discussion.

Make one copy of the second page of *Discussion Mapping Tool* for each class section.

After completing the discussion mapping activity, add an image of the completed discussion map from day 3 to **slide AA**. If you cannot add an image, project or pass around the completed discussion map so students can analyze the data.

Add questions from the class DQB to *Our DQB Questions* before copying for students.

Create Electronic Exit Tickets for this lesson using the directions found on *Electronic Exit Ticket*. For this lesson's Electronic Exit Ticket you will need to make a copy of https://docs.google.com/forms/d/1Wg6hQEbevn0LAO0aMg8jjIY_MVd_DizXQUn5q7gxdAw/copy

Day 1: Sticky Tape Investigation
- **Group size:** 2 students
- **Setup:** Gather materials for the investigation. Ensure that each group of students has a permanent marker to label the pieces of tape.
- **Notes for during the lab:** Students will need to collaborate with a second group. If the pieces of tape become discharged, have students repeat the procedure to charge them. Classroom environments with high humidity may prevent the formation of much static, which is needed for this investigation. If that is the case, consider running a dehumidifier in the space a few hours ahead of time and test the relative humidity in the room until it comes down to 40% or lower, if possible.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science.*
- **Disposal:** Students can dispose of the tape in the trash.
- **Storage:** Materials can be stored in a cabinet for later use.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

The targeted disciplinary core idea we are developing is:

- **PS1.A.1: Structure and Properties of Matter.** Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.

This lesson builds on the observations made about static in the previous lessons by moving students toward an atomic-level explanation of the observed phenomena. Students will engage in the focal practices of *Obtaining, Evaluating, and Communicating Information* and *Developing and Using Models* as they figure out how the charged substructure of an atom can help explain why static interactions occur (DCI: PS1.A.1).

Students' work in this lesson builds on prior work in OpenSciEd High School biology and in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* in important ways. Students previously developed the practice of *modeling* at the high school level in *Serengeti Unit* and *Fires Unit*. This is the first time in the OpenSciEd High School chemistry course that students have engaged with SEP element 2.1. In the OpenSciEd Middle School curriculum, students had experience with evaluating the limitations of models in units like *Storms Unit*, *Tsunami Unit*, *Inside Our Bodies Unit*, and *Palm Oil Unit*. Students will continue to engage with this element in future lessons of this unit as they compare the merits and limitations of using mathematical models to explain lightning phenomena.

Previously, students developed understanding around *obtaining, evaluating, and communicating information* in OpenSciEd High School biology in *Cancer Unit* and *Speciation Unit*. This is also the first time in the OpenSciEd High School chemistry course that students engage with portions of SEP element 8.2. Students continue to develop this element in later lessons and future chemistry units as they work to synthesize information from various sources to develop and revise models and explanations (in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*), as well as solve problems (in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*). They do not use it to solve problems in this lesson.

Students obtain information from multiple sources in this lesson (reading, simulation) and synthesize what they have learned about atomic structure to model what is happening at a subatomic level to explain interactions they observed during an investigation (SEP: 2.4, 8.2). The reading about the development of our current atomic model also provides an opportunity for students to engage with a historical example of the need for model revision when experimental data at the atomic scale revealed the inadequacy of the existing atomic models (SEP: 2.1; CCC: 3.2). This will help students understand the necessity of ongoing model revision based on new evidence. Using this information, students add subatomic particles to their models of the atom and model the idea of electron transfer at multiple scales to explain static repulsions and attractions (CCC: 4.3). Students will continue to move between atomic- and macro-scale models as they investigate lightning formation and conductivity in later lessons.

The crosscutting concepts in this lesson are addressed in part. In CCC: 3.2, the emphasis is on systems that are too small to study directly. Students engaged with systems that are too small and too large to observe directly in Lesson 3, and previously engaged with indirect studies of systems across timescales in *Polar Ice Unit*. Students also build on previous thinking in *Polar Ice Unit* about models simulating systems and interactions, focusing in this lesson on energy and matter flows rather than information flows.

In this lesson, students will investigate the movement of electrons between atoms and develop written and physical models of subatomic structure (SEP: 2.4). The paper-clip model of the charged substructure of the atom will be further developed in Lesson 8 to explain polarization interactions. Students are introduced to the concept of net charge in this lesson, and they will build on this idea later in the unit as they investigate ions and conductivity. Students will also co-construct a definition for the following terms, which they should add to their Personal Glossary: *proton*, *electron, neutron,* and *nucleus*. Do not ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students will learn about the movement of electrons between atoms in this lesson, but they will not investigate electron shells or make arguments about stability in this unit. A deeper understanding of electrons' location in and movement about atoms will be developed in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*. This unit will begin to introduce the idea that electrons do not orbit atoms in the same way that planets orbit the sun, although a full understanding of quantum mechanics is beyond the high school grade band. Students similarly will not use the periodic table to identify atomic mass or atomic number until the next unit, and although they may start naming elements through the simulation or attempt to define "element," they do not need to do so.

Students will not yet identify the source of electron flow in lightning in this lesson. Some students may be curious about possible connections between the types of phenomena observed in cathode ray tubes and lightning, but in this lesson, students will focus on understanding the connection between electron flow and static. They will learn more about how lightning forms in Lesson 6.

LEARNING PLAN for LESSON 5

1 · NAVIGATE

5 min

MATERIALS: science notebook

Individually stop and jot what we discovered last class. Display **slide A.** Have students stop and jot in their science notebooks about the prompts on the slide. Then call on a few students to share their ideas with the class.

Suggested prompt	Sample student response
What did we observe in our static investigations in the last lesson?	We saw attractive and repulsive interactions. We saw that tinsel was attracted to a balloon after we rubbed the balloon on a sweatshirt. Some materials did not show any change when we tried to observe static.
Make a hypothesis: What could be happening to the matter at the particle level to cause the forces and interactions we saw? ✱	Accept all responses.

Point out that we have many different hypotheses about what could be happening.

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: Scaffolds like sentence starters can model and facilitate particular oral or written language production skills, such as formulating questions, hypotheses, explanations, or arguments based on evidence. You may want to provide a skeleton statement for students to complete (e.g., If static interactions and lightning are (not) related, then we will see _____.) if they need additional support expressing their ideas. This also provides an opportunity to remind students about the difference between correlation and causation, discussed in Lesson 2. Remind students that seeing something similar to another does not mean they have the same cause. This can motivate the need to learn more information about the mechanism of electric charge to explain what we observe.

2 · INVESTIGATE THE STICKY TAPE PHENOMENON

15 min

MATERIALS: Sticky Tape Investigation

ADDITIONAL GUIDANCE	Have a Sticky Tape Investigation setup available so that you can demonstrate the investigation as students follow along using the directions on *Sticky Tape Investigation*. Alternatively, use the video on **slide B** to show the setup. A video showing the investigation can be found at https://youtu.be/fdZeMzZqeJI and on **slide D**.

Introduce the Sticky Tape Investigation. Say, *Let's use another investigation to help us gather more data to determine if our hypotheses are correct.* Arrange students into pairs. Display **slide B** and distribute a copy of *Sticky Tape Investigation* to each group. Tell students to follow along as you set up the Sticky Tape Investigation using the directions on the slide.

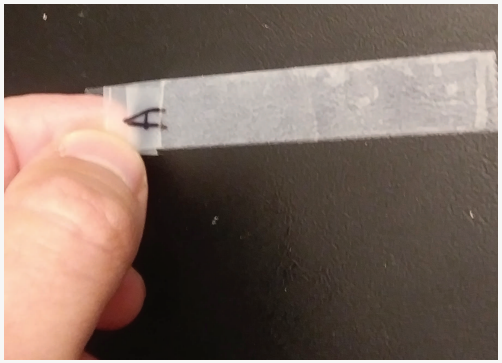
Set up data tables. Display **slide C.** Have students add a data table to their science notebooks to record the interactions they observe as the class conducts the investigation together.

Objects tested	Interaction observed
tape A & tape B	
tape A & tape A	
tape B & tape B	

ADDITIONAL GUIDANCE

If the strips lose their charge during the investigation, students can return them to the base tape and tear them apart again to recharge them. Make sure students stack them in the same order as before (B on the bottom/below and A on the top/above).

Investigate sticky tape interactions. Display **slide D**. Carry out the investigation using the directions on the slide and have each pair follow along with you. Students should test the interaction of their own tape A and tape B, then work with a neighboring pair to observe the interactions of tape A with tape A and tape B with tape B. Remind students to bring the non-sticky sides of the tape near to each other. Give students about five minutes to complete the investigation.



Discuss investigation results. After students have investigated and recorded their observations, lead a discussion to share results. Display **slide E**. Use the prompts on the slide to lead the discussion.

Suggested prompt	Sample student response
What did you observe in the interactions between tape A and tape B?	They are attracted to each other.
What did you observe in the interactions between tape A and tape A, and/or between tape B and tape B?	They repel each other. The bottoms of the tape pulled away from each other.

Compare sticky tape investigation to previous investigation results. Display **slide F**. Ask, *How are these interactions similar to or different from other interactions we have observed?* Look for students to suggest:

- We saw attractive and repulsive interactions.
- We didn't rub anything this time, but maybe the ripping apart is like rubbing?

Say, *So we see similar interactions, and we know that everything is made of atoms. In our previous investigations, we worked with substances not made of the same types of atoms. Can we agree that the sticky tape investigation used substances made of the same atoms?* Have students show nonverbal agreement.

Ask, *Since we can agree the sticky tape is made of the same types of atoms, what do you think could be happening at the particle, or atomic, level to explain the different interactions we observed?* Look for students to suggest:

- We think the tape is getting charged like the stuff got charged last class.
- We still don't know WHAT exactly gets charged, or how.
- I'm not sure; maybe something is moving around?

3 · READ ABOUT ATOMIC STRUCTURE

23 min

MATERIALS: science notebook, *Structure of Matter*, chart paper, chart paper markers

Consider the types of information we need. Display **slide G**. Say, *We are still wondering what it is about different kinds of matter that causes the interactions we are observing. I have a reading about the structure of the atoms that make up matter and how scientists learned about them. Before we read, let's think about the purpose of our reading. What kinds of information would help us explain why different types of matter were affected differently when they were exposed to static electricity?* Ask students to share some of their ideas and record them on a piece of chart paper or the whiteboard. Student ideas might include:

- the structure of atoms
- how different kinds of matter are different from each other (their makeup)

ADDITIONAL GUIDANCE

The reading strategy incorporated into *Structure of Matter* is the Coherent Reading Protocol, which students also used in the previous lesson.

Read about atomic structure. Say, *Great! Now that we have some ideas about what we want to look for as we read, let's take a moment to use a reading strategy to help us make sense of the reading.* Display **slide H** and distribute *Structure of Matter*. Pair students to complete the reading.✱ Tell students that one partner should read the first two sections and the other partner should read the last two sections. Give students about 10 minutes to complete this activity and discuss the central ideas with their partners.

ALTERNATE ACTIVITY

Extension opportunity: This reading only scratches the surface of the historical development of the atomic model. Although it is not key that students understand the details of every experiment described, the reading can be supplemented with other visuals and information about the experiments if students are interested. The bending of the beam in Thomson's experiment may be particularly helpful to visualize due to its parallels to the bending of water in the dropper. The reading can also be supplemented with information about other scientists with work in the particle space, including Homer Neal, Helen Quinn, and Luis Alvarez.

Discuss the central ideas of the reading. Display **slide I**. Call on several students to share the central idea that they identified for each chunk of text.✱

✱ ATTENDING TO EQUITY

Universal Design for Learning: Consider giving students the option of reading their two sections in a small group, reading alone, or having you read aloud as they follow along. This supports *representation* by providing various options for students as they work toward comprehending the reading. If you feel students would benefit from reading all four sections instead, have them do so with similar options for support.

✱ ATTENDING TO EQUITY

The opening of *Structure of Matter* highlights how many cultures have understood and manipulated matter throughout history. It is important for students to understand that the questions they are investigating have been asked before by people all around the world. If students question why the scientists they learn about in science classes are often white men, it is helpful to point out that while men and women of all races and nationalities have contributed to chemistry knowledge, racism and sexism have kept many of them from receiving credit for their work. This is also an opportunity to highlight current contributions from a diverse range of chemists.

Suggested prompt	Sample student response
How does this information help us make progress on explaining why different types of matter were affected differently when they were exposed to static electricity?	Accept all student responses.
What questions do you have now?	What part of the atom determines how it interacts with static? How does what is inside the atom determine how it interacts with static? What does our version of the atomic model look like? What particle is the most important?

ADDITIONAL GUIDANCE

In this discussion, you can highlight how our understanding of science is constantly being updated by pointing out that J.J. Thomson and Ernest Rutherford both received Nobel prizes even though, as we now know, their models of the atom were incorrect. You can also point out that revising our models and ideas in light of new evidence is a part of the scientific process.

Build understanding of atomic structure. Display **slide J**. Say, *There was a lot of information in the reading about atomic structure that might be important to identify. Let's take a moment to think about the types of information about atomic structure that were discussed in the reading.*✱

Suggested prompt	Sample student response
What are the smaller parts of the atom that the scientists discovered?	The electron, proton, and neutron.
What properties of these smaller parts did the reading tell us about?	Their charges. Their mass. Their location.

Say, *Great! We already have a lot of information to keep track of. Let's build a way to keep track of all of our ideas.* On a sheet of chart paper, develop a poster titled "Atomic Structure" like the one below. Leave room for an additional column to the right that you will add after the next activity in the lesson. Encourage students to copy the chart and any additional ideas in their Progress Tracker.

✱ STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

The purpose of this discussion is to build students' ideas about what is most important from what they have learned about subatomic particles so far. As students share, prompt them to support their ideas using their understanding of the different experiments discussed in the reading. It is not necessary for the class to reach a consensus at this point. Students will have the opportunity to return to their ideas and work toward consensus later in this lesson.

Atomic Structure			
Subatomic particle	**Charge**	**Relative mass**	**Location**
Electron	Negative	~1/2000	Outside the nucleus
Proton	Positive	1	Nucleus
Neutron	Neutral	1	Nucleus

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students name the three main subatomic particles (protons, neutrons, and electrons) along with their charge, relative mass, and location in the atom. (DCI: PS1.A.1)
- Students use information from the reading to explain how scientists performed experiments to understand what was happening on a subatomic scale because they could not explain macro-scale static interactions with the existing atomic models. (SEP: 8.2; CCC: 3.2)

What to do: To make sure that students have made the connection between the experiments described in *Structure of Matter* and the results, prompt them to explain their reasoning as they share the properties of each subatomic particle they learned about.

Building toward 5.A.1 Integrate information from multiple sources to explain what is happening at a scale too small to directly observe and provide evidence for the existence of protons, neutrons, and electrons. (SEP: 8.2; DCI: PS1.A.1; CCC: 3.2)

4 · NAVIGATE

2 min

MATERIALS: science notebook

Navigate. Have students answer the prompt on **slide K** in their notebooks and tell them that we will address this question at the beginning of the next class.

ALTERNATE ACTIVITY

Extension opportunity: Consider encouraging students to try the sticky tape investigation using tape they have at home. Provide different kinds of tape randomly to students who request it. Warn students that the investigation may not work with some kinds of tape, and have students reflect on why that might be the case.

End of day 1

5 · NAVIGATE

2 min

MATERIALS: science notebook

Navigate. Display **slide L**. Ask, *Now what do you think is happening to the atoms in the tape to cause the attractions and repulsions we observed?* Listen for responses such as:

- We think some part of the atom is moving.
- Electrons or protons are being pulled off of one piece of tape.
- Since the tape is sticky, maybe one piece is pulling stuff off the other piece.

Say, *It sounds like we may need more information about the atom to figure out what part is moving.*

6 · EXPLORE AN ATOM SIMULATION

10 min

MATERIALS: science notebook, internet connected device, https://lab.concord.org/embeddable.html#interactives/interactions/atom-builder.json, "Atomic Structure" poster, chart paper markers

ADDITIONAL GUIDANCE

Some students may want to start using terms such as *element* and *ion* as they discuss the simulation. That is okay. Students may notice that the element changes as protons are added or removed, but do not stress this point. In *Space Survival Unit*, students fully develop this idea. If students refer to charged atoms as ions, again, do not stress the use of this term. In Lesson 11, students will develop a definition for *ion* and will update it in *Space Survival Unit* to incorporate valence electron thinking.

Explore the atom builder. Say, *I have a simulation we can use that will let us look at a single atom. As we use the simulation, let's think of the atom we build as a single atom in the sticky tape.* Display **slide M**. Have students use a device and https://lab.concord.org/embeddable.html#interactives/interactions/atom-builder.json to investigate what happens as they add and remove subatomic particles from the sample atom. Give students about three to four minutes to explore the simulation and record observations in their science notebook.

ADDITIONAL GUIDANCE

Some students may benefit from additional directions during this activity. If students have trouble narrowing in on a pattern to identify, suggest that they pay attention to what happens to the net charge with each particle they add or take away. Help orient students to the particles as needed, tying these particles to those introduced in the reading, so it is clear that the electron movement is not indicating energy or some other feature.

Discuss simulation observations. Display **slide N**. ✱ Say, *Now we have more information to discuss about what happens when we change the number of subatomic particles in an atom. Let's develop a consensus about what we have figured out so far.* Ask students to share their observations from the reading and simulation with the class.

Suggested prompts	Sample student responses	Follow-up questions
What happened as you added or removed protons?	The type of atom changed, like it was hydrogen, and then it became helium. The charge on the atom changed.	*How did the charge change?*

✱ STRATEGIES FOR THIS CONSENSUS DISCUSSION

The purpose of a Consensus Discussion is to converge on one or more ideas that the whole class agrees upon. In this discussion, your classroom community is pressing toward a common class-level representation of the properties of subatomic particles. During this work, the class resolves disagreements where possible. Your role is to help students identify where they agree and where they still disagree. Helpful prompts include:

- What ideas are we in agreement about?
- Would anyone have represented this idea in a different way?
- Who feels like their idea is not quite represented here?
- Are there still places where we disagree? Can we clarify these areas?

Suggested prompts	Sample student responses	Follow-up questions
What happened as you added or removed electrons?	The charge on the atom changed.	*How did the charge change?*
What happened as you added or removed neutrons?	Nothing.	
What other things did you notice?	Accept all student responses.	*How does this support or refute what was stated in the reading?*
How does the information from the simulation and reading help explain what is happening to the sticky tape?	Electrons must be moving off of atoms from one piece of tape to the other, making the charge change.	

ADDITIONAL GUIDANCE

Some students may notice changes in atom size as they add electrons to the atom. You can agree that it is an interesting pattern and suggest they keep wondering why that might happen. Students will investigate periodic trends related to atomic radius in *Space Survival Unit*.

Say, *Wow! We have figured out some more properties about the subatomic particles. Let's take a moment to add them to our Progress Tracker.* Add a column to the table on the "Atomic Structure" poster and work with students to complete the new column as shown in the example. Have students add to their previous Progress Tracker entry.

Atomic Structure				
Subatomic particle	**Charge**	**Relative mass**	**Location**	**Effect when added or removed**
Electron	Negative	~1/2000	Outside the nucleus	Changes net charge
Proton	Positive	1	Nucleus	Changes net charge (and element, if mentioned)
Neutron	Neutral	1	Nucleus	- - - - - -

ADDITIONAL GUIDANCE

Understanding that losing an electron makes an atom more positive can be counterintuitive for many students. It may be helpful to draw a few hypothetical combinations of protons and electrons on the board to show students visually that when an electron is lost, there are more positive charges than negative charges left in the atom. This makes the net charge of the atom positive. Students will have more chances to practice this idea during the paper clip modeling activity in the next step.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use information from the simulation to identify that net charge is determined by the relative number of protons and electrons in an atom. (SEP: 8.2; DCI: PS1.A.1)
- Students use the simulation to examine interactions at the atomic scale to explain the relationship between subatomic particles and charge. (DCI: PS1.A.1; CCC: 3.2)
- Students refer to the reading, the simulation, and the investigations in prior lessons to provide evidence for their ideas. (SEP: 8.2)

What to do: If students are not using multiple information sources in their discussion, prompt them by asking if there are other sources of evidence that support their ideas. If students have trouble transferring the ideas from the reading, simulation, and previous investigations into a summary table, redirect them to the model of a particle used in previous units (a sphere) and ask how to update it based on what they have learned.

Building toward 5.A.2 Integrate information from multiple sources to explain what is happening at a scale too small to directly observe and provide evidence for the existence of protons, neutrons, and electrons. (SEP: 8.2; DCI: PS1.A.1; CCC: 3.2)

7 · DEVELOP MODELS OF THE ATOM

18 min

MATERIALS: science notebook, 3x5 notecard, 3 small paper clips

Celebrate progress. Take a moment to celebrate all that you have figured out about atomic structure. Say, *Wow, we have made a lot of progress! Let's try to put all of this together to develop our own model of the atom that we can use to explain the interactions we have observed.*✱

Develop initial models of atom and static interactions. Display **slide O**. Say, *Let's try to see how representing moving electrons might help us explain the differences in how matter is affected by static. In your notebook, sketch an initial model of how you think this might be happening.* Give students two minutes to develop their initial models.

Ask, *What was difficult about trying to represent moving electrons?* Look for students to say that it was hard to represent a moving object (an electron) in the matter they chose to represent. Say, *Let's try making a physical model so that we can move the electrons.*

ADDITIONAL GUIDANCE

The purpose of drawing this initial model is to motivate the benefit of using a physical model to show electrons moving. Stress that this is a quick modeling activity and students should not spend a lot of time developing their models.

Develop a physical model of the parts of an atom. Display **slide P** and distribute one notecard and three paper clips to each student. Say, *We are going to use this notecard and these paper clips to build a physical model of an atom. First, let's agree on what each of these objects will represent.*

Suggested prompts	Sample student responses	Follow-up questions
What part of the atom could be represented by the notecard?	The nucleus.	*Why do you think that?*
What part of the atom could be represented by the paper clips?	The electrons.	*Why do you think that?*

✱ ATTENDING TO EQUITY

Building classroom culture: It is important to celebrate class progress along the way to explaining our anchoring phenomenon. Figuring out ideas through inquiry and discussion may be new or challenging for some students, and taking a moment to celebrate steps along the way can help them recognize the progress they are making.

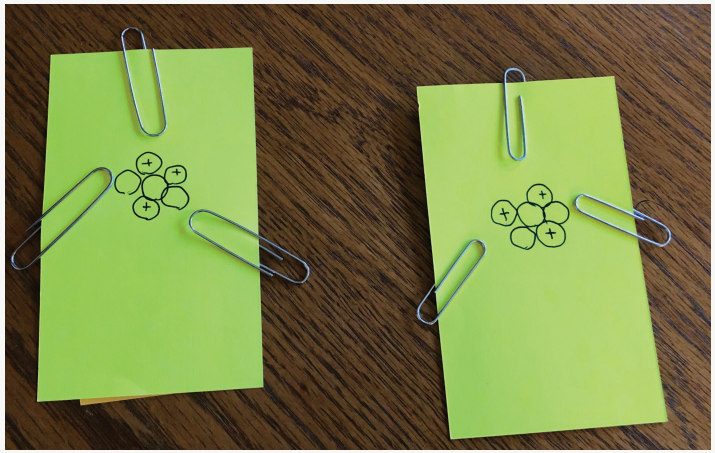
Suggested prompts	Sample student responses	Follow-up questions
How does this physical model relate to the other atomic models you have seen so far?	It has a similar structure. It's the same.	*How so? What evidence do you have for that?*

ADDITIONAL GUIDANCE

An instructional video showing this activity is available at https://youtu.be/K3qFB6xVjBE?si=qoQfFm1HY-5Ubvtc. This could be helpful to play for students who are absent or who may be struggling to make sense of what is happening to each of the notecard atoms as paper-clip electrons are moving between them.

Lithium is used in this model even though it technically only has one valence electron because students will develop this concept to explain new phenomena in *Space Survival Unit*.

After coming to agreement that the notecard represents the nucleus of the atom, have students represent it using lithium as the example atom by drawing three protons in the center of the notecard and several neutrons (three is sufficient). Emphasize that a real nucleus does not have empty space not filled by protons and neutrons, and that this is a limitation of our model.

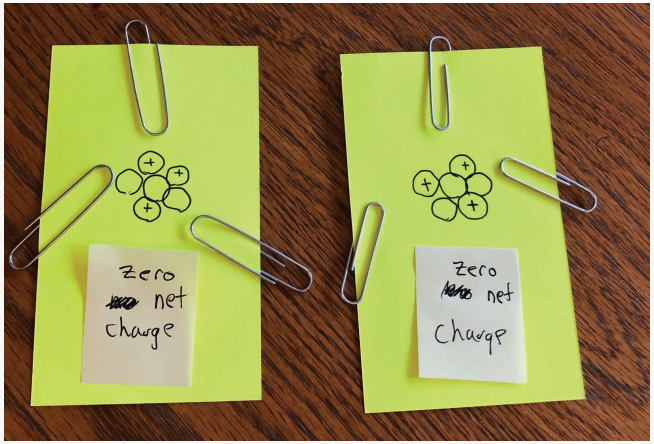


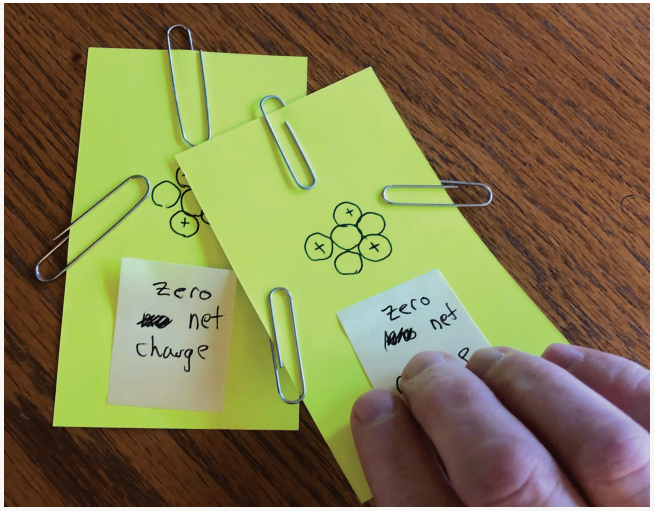
Point out that the shape of the paper clips looks like a negative symbol when viewed from the side and that we are going to use these to represent electrons. Ask students where we should attach the three paper clips to represent where they are found in the atom. Students will say around the sides. Have students attach them around the edges of the notecard.

Say, *Now that we have built a physical model of an atom, let's think about the charges on this atom.* Ask, *What is the net charge of this atom with its current configuration?* Students should say zero or neutral.

Have students work with a partner to remove an electron from one atom and transfer it to the other atom. Ask, *What has happened to the charges of the atoms now?* Students should say that one is positive (+1) and one is negative (-1).

Have students explain which atom is positive and which atom is negative. Then have students return the paper clip that was moved back to the original atom it came from to restore both models to a neutral charge of zero.





Use paper-clip models to show electron movement. Have students get into the same groups of four as in the Sticky Tape Investigation. Say, *Some of you think that the electrons in the atoms of the pieces of tape are moving from one piece to another. Let's try to show this using our paper-clip models.* Display **slide Q** and ask students to take out their paper-clip models. Have groups work together to model what is happening to the atoms on tape A and tape B as they are pulled apart and then moved near each other. Have students record their ideas in their science notebooks and save the paper-clip models in their notebooks to illustrate their thinking in the next activity.

Celebrate our progress in understanding that electrons are moving and that they can move between different atoms.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students simulate how moving electrons change the net charge on an atom. (DCI: PS1.A.1; CCC: 3.2)
- Students explain how the physical paper-clip model represents the same charged atomic substructure as the models described in *Structure of Matter* and the simulation. (SEP: 2.1, 2.4; DCI: PS1.A.1)

What to do: If students have trouble identifying net charge, have them count the number of protons drawn on the notecard and the number of paper-clip electrons attached to the edges. Use this physical model to reinforce why losing an electron makes the atom more positive and adding an electron makes the atom more negative. Have students transfer paper clips between notecards multiple times to give them more opportunities to practice identifying the net charge of the atom.

Building toward 5.B.1 Develop, use, and discuss the merits and limitations of multiple models to simulate the charged substructures of atoms, the movement of electrons, and other processes and structures too small to directly observe. (SEP: 2.1, 2.4; DCI: PS1.A.1; CCC: 3.2, 4.3)

8 · EVALUATE OUR MODELS USING ROUNDTABLE DISCUSSION

10 min

MATERIALS: science notebook, paper-clip models, chart paper, chart paper markers, Community Agreements

ADDITIONAL GUIDANCE

To allow all students to see the groups that demonstrate their models, ensure that the Scientists Circle is more of a horseshoe shape, or similar to how you organize a Scientists Circle to develop the DQB or a class consensus model.

Prepare for a roundtable discussion. Display **slide R**. Have students meet in a Scientists Circle and explain that we will be participating in a roundtable discussion about our paper-clip models. Say, *In a roundtable discussion, one group will share their models and the rest of us will be providing feedback.* Ask students which two Community Agreements it will be important to focus on for this discussion. Students will likely say *respect* and *moving our thinking forward*. If the class nominates other Community Agreements and is in agreement on why they are important, adopt those as the focus for this discussion instead.



Participate in a roundtable discussion. Display **slide S**. Say, *Let's share what we figured out about how the paper-clip models can help us explain what we saw in the Sticky Tape Investigation*. Choose one group to demonstrate their models and have them stand so that all students in the Scientists Circle can see the demonstration. ✱

Ask the group to demonstrate their paper-clip models for the four interactions they modeled on **slide Q**. Record student ideas about the final prompt, not shown on the slide, on a sheet of chart paper.✱

Suggested prompt	Sample student response
How did this group model the interactions similarly to or differently from how your group modeled them?	Accept all responses.
How did moving electrons between the notecards impact their net charges?	The atom with fewer electrons than protons had a positive charge. The atom with more electrons than protons had a negative charge.

✱ ATTENDING TO EQUITY

Choosing a group to demonstrate their models provides an opportunity to purposefully highlight a group of students who have not had other opportunities to explain their ideas to the class. Be sure to check with students before putting them on the spot and allow them to decline if they are not yet comfortable being the ones to demonstrate.

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Students use a physical model (SEP) here because it allows them to indirectly visualize (CCC) electron movement (DCI) as a change in the system at an atomic scale, with macroscopic implications (CCC). The paper-clip models will continue to be a tool for students throughout the unit, in conjunction with pencil-and-paper models and computer simulations, as they develop increasingly complex mechanisms that bridge between subatomic structures and macroscopic phenomena. Elicit limitations, such as the fact that these "atoms" are two-dimensional while real ones are three-dimensional, and reflect on how we could easily pull up the simulation or develop a three-dimensional model to provide this alternate perspective.

Suggested prompt	Sample student response
What does this help us visualize and understand about what is happening to subatomic particles in the sticky tape to cause static interactions?	When we produce static, we are actually moving very small particles of matter (electrons) around. When the strips of tape were pulled apart, electrons were removed from one strip, making it positive. Those electrons were transferred to the other strip, making it negative. When you bring the two different tape strips (A and B) back together, they show attraction because one has a net positive charge and one has a net negative charge. When you bring two of the same tape strips (A and A or B and B) together, they repel because they have the same net charge. When A and B touch, the effect disappears (or gradually decreases with each additional touch) because the electrons move back from the negative strip to the positive strip, and both strips become neutral again.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students explain that the loss or gain of electrons changes an object's net charge, leading to changes in how objects are attracted to or repelled by each other. (DCI: PS1.A.1; CCC: 4.3)
- Students use a physical model to develop a small-scale mechanism to explain investigation results (large scale). (SEP: 2.4; CCC: 3.2)

What to do: Have students use their paper-clip models and/or their diagrams of the atom to explain what is happening to the sticky tape. If students are unsure what is creating the forces that they observe, have them track the changing net charge on their models of tapes A and B through each step of the example.

Building toward 5.B.2 Develop, use, and discuss the merits and limitations of multiple models to simulate the charged substructures of atoms, the movement of electrons, and other processes and structures too small to directly observe. (SEP: 2.1, 2.4; DCI: PS1.A.1; CCC: 3.2, 4.3)

9 · PROBLEMATIZE WHY THE ELECTRONS ARE MOVING

5 min

MATERIALS: None

Problematize why the electrons are moving. Display **slide T**. Ask, *Why do you think the electrons are moving, and not other subatomic particles?* Look for students to mention:

- Electrons are easier to move because they are smaller, 1/2000th the mass, and on the outside of the atom.
- Protons are bigger and in the middle, so they might be harder to move.
- Neutrons are in the middle too and don't have any charge, so it wouldn't matter if they are moving or not.

Summarize that we are thinking it might have something to do with the charge (or lack of charge), the location of the particle, and the size of the particle. Celebrate that we have figured out a lot but still have some questions about why electrons, and not protons or neutrons, are moving between atoms of different objects.

End of day 2

10 · NAVIGATE

5 min

MATERIALS: None

Take stock of what we have figured out so far. Display **slide U**.

Suggested prompt	Sample student response
What did we figure out about matter so far?	Matter is made of protons, electrons, and neutrons.
What does that have to do with electrostatic forces?	Protons are positively charged and electrons are negatively charged. They are equal and opposite charges. When electrons move between different objects, an attractive or repulsive force occurs.

11 · EXPLORE EXAMPLES OF STATIC BEFORE A STORM

5 min

MATERIALS: science notebook, https://youtu.be/JGFC6-vFhyQ

Observe examples of static before a lightning storm. Say, *It sounds like we have some ideas about how electrons can move between objects that are touching, but what about when lightning is happening? I have a video of some people who talk about what happened to them when they were near lightning.*

Display **slide V**. Direct students to make a T-chart in their science notebook to record what they notice and wonder as they view the video. Then display **slide W**, which contains https://youtu.be/JGFC6-vFhyQ. This video shares examples of phenomena two people experienced before a lightning storm. Ask students to share with a partner what they noticed and wondered. After two minutes, lead a class discussion.✱

Suggested prompt	Sample student response
What did you notice?	People's hair was standing up! The power went out. There was a buzzing sound or feeling before the lightning. It was humid but not raining.
What did you wonder?	Why did the power go out and then come back on on its own? Why did it happen before the rain started? What was the buzzing?

✱ ATTENDING TO EQUITY

Most students likely have experienced some degree of static shock, and some may have experienced hair standing up due to static electricity. "Hair-raising" events can be very compelling. However, not all people experience static electricity the same way because of their hair type. A number of news and viral videos show this phenomenon and may be used to supplement the included video, particularly if many students have coarse or textured hair that does not tend to stand up when exposed to static. One example video may be found at https://youtu.be/jzmUiMjzpdI?si=gL8HE4UyQjwqdd-b.

Say, *It sounds like we have a lot of questions about what might be causing these effects that people see. Let's think about why there were differences in the effects of static on different objects, like hair and metal.*

12 · DISCUSS WHICH VIDEO PHENOMENA CAN BE EXPLAINED WITH OUR MODELS

10 min

MATERIALS: science notebook, paper-clip models, *Discussion Mapping Tool*, clipboard (optional)

Reintroduce the discussion mapping tool. Have students move into a Scientists Circle with their science notebooks. Keep a few paper-clip models available for students to use as needed.

Display **slide X**. Say, *We are going to use this tool from Polar Ice Unit to map our discussion.✱ This will help us think about how we can all work together when we are discussing new ideas to move our thinking forward.* After framing the questions, take a seat in the circle as a co-participant rather than as a facilitator.

Identify the phenomena seen before lightning storms. Display **slide Y**. Say, *We figured out how our model of the atom can explain what happened to the sticky tape. Let's see if we can use our model to explain the interactions we saw before lightning occurs. Look back in your science notebooks. What were some of the phenomena we saw or heard about in the video?* Look for students to suggest:

- hair standing up
- power going out
- buzzing sounds

As students are suggesting phenomena, use *Discussion Mapping Tool* to record which students offer ideas. Take a moment to show the tool to students and ask for a volunteer to continue to map the discussion before moving to the next prompt. You may want to affix *Discussion Mapping Tool* to a clipboard to make it easier to pass around.

Display **slide Z**. Say, *Now that we remember what some of the phenomena are, what do we know is similar and different about the particles that make up these different kinds of matter? Consider both the visible types of matter that people saw or talked about and the matter in the surrounding area, like the air.* Sample student responses might include:

- The particles in the appliances or wires are packed more tightly than the ones in the air around them because solids have more closely packed particles.
- The atmosphere is made of gases, including water vapor. Sometimes when it is cold, water vapor can change phase and become a liquid or even a solid.
- Particles move more quickly or slowly depending on whether the matter is a gas, liquid, or solid.
- We know that all matter is made of particles.✱

ADDITIONAL GUIDANCE

If students have experienced *OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*, they would have developed an understanding about how differences in the spacing between molecules help determine the state of matter. In *Polar Ice Unit*, this concept was used to help students identify differences in the structures of solid versus liquid water and their interactions to develop a model of (thermal) energy transfer to explain global sea level rise. It is important to have students think about these ideas to motivate the need to go to the atomic scale to explain differences in the effects of static electricity on matter.

Brainstorm possible explanations. Ask students to turn and talk with a neighbor about the second prompt on the slide and say, *Using what you know about electrostatic forces, what do you think might be happening to the particles to cause the effects that we saw?* Suggest that students use their Notice and Wonder chart to help them brainstorm possible explanations.

Before calling on a few students to share their ideas with the class, ask for a second volunteer to continue mapping the discussion. Listen for responses like:

- We heard about hair standing up. Maybe the hairs are repelling each other, just like the tape strips.

✱ ATTENDING TO EQUITY

Building classroom culture: *Discussion Mapping Tool* gives students a visual representation of the conversation patterns happening within the class. Use lines to track how the discussion moves between speakers, including yourself. After you track the first several moves, pause the discussion to show students what the map looks like. Ask for a student volunteer to map the rest of the discussion. This can be a way to involve a student who is less comfortable speaking publicly. Each time you use the discussion tool, rotate the student responsible for recording the map. While *Discussion Mapping Tool* includes codes to mark different types of contributions, you may want to track only discussion patterns the first few times you use the tool, to emphasize *equity* in the discussion. As students become more comfortable with discussion mapping, you can add contribution codes.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

Students are using models at different scales in this discussion to explain the phenomena. They are using the subatomic model of the atom, as well as the paper-clip models, to represent repelling hairs on a macroscopic scale. Use prompts such as those below to help students make connections between electron flow at different scales:

- *Are you describing what is happening in one atom or in all of the matter that makes up a hair?*
- *Is the cause of the repulsion the same every time?*

- If the hairs have the same charge, then either they all lost electrons or they all gained electrons.
- Something must be happening before lightning strikes that pulls electrons in or pushes them away.

Pause and ask for a third volunteer to continue mapping the discussion before asking the final prompt. Say, *What phenomena are we not able to explain with our paper-clip models?* Look for students to suggest that we still cannot explain the crackling noises. Students will soon have an opportunity to add any new questions to the DQB.

ADDITIONAL GUIDANCE	Students will use the paper-clip models again in later lessons. Ask students to save their models in their science notebooks or collect them for redistribution during those later lessons.

13 · REFLECT ON OUR DISCUSSION MAPPING PROCESS

5 min

MATERIALS: science notebook, *Discussion Mapping Tool*

Reflect on the discussion map. Have students remain in the Scientists Circle. Display **slide AA**. Display the discussion map by inserting an image into the slide or by projecting it another way. Have students observe the map and write any patterns they notice in their science notebook. Give students a few minutes to complete this task individually. Say, *After looking at this map, what are some things we should consider during our discussions to make sure that everybody plays a role in moving our thinking forward?* ✱ Listen for responses such as:

- We should ask questions and respond to each other instead of directing our responses to the teacher.
- We should invite people into the discussion who have not had chances to add to the discussion.
- We should monitor our airtime and give other people time to talk.

Reflect on putting pieces together. Say, *We have figured out so much about static interactions! This lesson was an example of where we put together ideas from our investigations and other sources to come up with a revised model. Let's take a moment to reflect on what it felt like to put these pieces together.* Display **slide BB**. Have students turn and talk with a neighbor about the two prompts on the slide.

✱ ATTENDING TO EQUITY

Building classroom culture: The goal of this reflection is to notice whole-class patterns and decide how all students can move discussions forward as a community. Avoid addressing the contributions or behaviors of specific students. If they are brought up, prompt students to return to the class-level patterns they observed, saying, *Let's look at the whole map. What suggestions can we make that would support our class community?* This is also an opportunity to remind students that *Discussion Mapping Tool* captures only spoken contributions, and to explicitly state that non-verbal participation and close listening are also valued contributions.

14 · UPDATE PROGRESS TRACKERS

7 min

MATERIALS: science notebook

Update Progress Trackers. Have students return to their seats. Display **slide CC**. Give students a few minutes to add anything new to their Progress Trackers. You may point out that the subatomic particles movement was an important area of focus we never documented.

Example of a completed Progress Tracker entry.

Atomic Structure					
Subatomic particle	**Charge**	**Relative mass**	**Location**	**Effect when added or removed**	**Movement between objects**
Electron	Negative	~1/2000	Outside the nucleus	Changes net charge	Moves between objects
Proton	Positive	1	Nucleus	Changes net charge (and element, if mentioned)	Does not move
Neutron	Neutral	1	Nucleus	- - - - - -	Does not move

15 · COMPLETE AN ELECTRONIC EXIT TICKET AND REVISIT DQB QUESTIONS

10 min

MATERIALS: link to class copy of the Electronic Exit Ticket, internet connected device, *Our DQB Questions*

ADDITIONAL GUIDANCE

See *Electronic Exit Ticket* for instructions on how to make the Electronic Exit Ticket.

Complete the Electronic Exit Ticket. Display **slide DD**. Have students complete the exit ticket through the class copy of https://docs.google.com/forms/d/1Wg6hQEbevn0LAO0aMg8jjIY_MVd_DizXQUn5q7gxdAw/copy.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Use *Electronic Exit Ticket Key* for guidance.

What to do: Use *Electronic Exit Ticket Key* for guidance.

Building toward 5.B.3 Develop, use, and discuss the merits and limitations of multiple models to simulate the charged substructures of atoms, the movement of electrons, and other processes and structures too small to directly observe. (SEP: 2.1, 2.4; DCI: PS1.A.1; CCC: 3.2, 4.3)

Revisit the Driving Questions. When students have completed the exit ticket, display **slide EE** and distribute *Our DQB Questions* with the list of questions developed on the Driving Question Board. Have students work individually to mark questions they think the class has answered using the key on the handout and the slide.

- We did not answer this question or any parts of it yet: **O**
- Our class answered some parts of this question, *or* I think I could answer some parts of this question: ✓
- Our class answered this question, *or* Using the ideas we developed, I could now answer this question: ✓+

Encourage students to record any new questions as well, as they will be shared at the start of Lesson 6.

ADDITIONAL GUIDANCE

Students will return to *Our DQB Questions* in the next lesson. If students do not finish the annotations in class, they can complete them for home learning to prepare for Lesson 6.

16 · NAVIGATE

3 min

MATERIALS: science notebook

Celebrate our DQB progress. Tell students it is okay if they have not finished their annotations, but elicit a few suggestions for things we have figured out about what causes lightning that we did not know at the start of the unit.

Revisit our initial hypotheses. Display **slide FF**. Say, *Let's think back to the hypotheses we made on the first day of this lesson. Take a moment to find the hypothesis you wrote in your science notebook.*

Suggested prompt	Sample student response
What have we figured out that helped us make progress in testing our hypotheses?	We observed similar phenomena like hairs repelling each other before a lightning strike. We used our model of the atom to explain how electrons moving between atoms create attractive and repulsive forces.
What does this tell us about the relationship between static and lightning?	Electrons moving between atoms might also explain what is happening before a lightning storm.
What other parts of the lightning system would it be helpful to understand?	Maybe what's happening in the cloud. How are the electrons moving in the rain and in the cloud?

Summarize student ideas. Say, *It sounds like we have a lot of questions around how electrons could be moving in the clouds to create static that leads to lightning. Let's try to figure that out in the next class!*

Additional Lesson 5 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts. Students incorporate text and information from a simulation to develop understanding around atomic structure.

LESSON 6: What causes static in a lightning system?

PREVIOUS LESSON

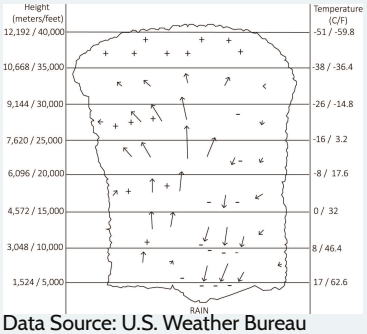
We developed hypotheses of what is happening at the particle level to explain the interactions we observed. We investigated static interactions using sticky tape. We read about and used a simulation to determine atomic structure. We developed physical models of what is happening with the sticky tape. We took an electronic exit ticket, identified progress on our DQB, and revisited our hypotheses.

THIS LESSON

INVESTIGATION

1 day





Data Source: U.S. Weather Bureau

We record the matter and force interactions within a lightning system and decide to investigate what causes static interactions to occur before lightning. Then we gather information from a reading about what is happening in the sky before a lightning strike. We use this information to compare the lightning system to our in-class static systems.

NEXT LESSON

We will carry out an investigation to determine how electrostatic forces between objects are affected by the amount of charge and the distance between them. We will compare our results and identify patterns. We will evaluate a mathematical model and use algebraic methods to predict the effects of larger-scale changes in a system.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6, HS-PS3-2, HS-PS3-5



WHAT STUDENTS WILL DO

6.A Critically read scientific literature adapted for classroom use to determine how static interactions at a different scale lead to lightning. (SEP: 8.1; DCI: PS2.B.3; CCC: 3.4)

WHAT STUDENTS WILL FIGURE OUT

- Collisions between ice crystals and water molecules inside clouds cause the top of the cloud to be positively charged and the bottom of the cloud to be negatively charged.
- Thunderclouds grow very tall due to warm, moist air rising very high in the atmosphere.
- There is a massive buildup of electrons, far greater than people experience in everyday static interactions, that eventually causes those electrons to flow from the cloud to the ground.
- Electricity is the movement of charges (i.e., electrons).

Lesson 6 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Recall where the class left off in the last lesson and identify questions from the DQB related to lightning formation.	A-B	*Our DQB Questions*, Driving Question Board
2	5 min		**THINK ABOUT STATIC ELECTRICITY** Have students work with a partner to brainstorm ideas about what might be rubbing together in a lightning system. Connect the question we are working on to questions on the DQB.	C-D	*Our DQB Questions*, M-E-F poster
3	3 min		**PREPARE TO GATHER INFORMATION FROM A READING** Have students brainstorm reading strategies that may be helpful for making sense of a difficult text.	E	*How Lightning Starts*
4	12 min		**GATHER INFORMATION FROM A READING** Students summarize scientific literature to explain how lightning starts.	F	*How Lightning Starts*
5	9 min		**MAKE SENSE OF THE READING** Give students time to discuss the most important information from the reading.	G-H	*How Lightning Starts*
6	6 min		**COMPARE SCALES** Lead a class discussion to map information in *How Lightning Starts* to the classroom static systems and update Personal Glossaries.	I-K	*How Lightning Starts*, chart paper, chart paper markers
7	5 min		**NAVIGATE** Have students consider scale in terms of distance and charge magnitude.	L	*How Lightning Starts*, Similarities and Differences T-Chart

End of day 1

Lesson 6 • Materials List

	per student	per group	per class
Lesson materials	• *Our DQB Questions* • *How Lightning Starts* • science notebook		• Driving Question Board • M-E-F poster • chart paper • chart paper markers • Similarities and Differences T-Chart

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

For more information about lightning formation, see https://www.weather.gov/jetstream/lightning.

Lesson 6 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build new ideas related to the following disciplinary core idea:

- **PS2.B.3 Types of Interactions:** Attraction and repulsion between electric charges at the atomic scale explain the ~~structure~~, properties, and transformations of matter, as well as the ~~contact~~ forces between material objects.

Crossout explanation: In this lesson, students focus on the distance forces that result from the attraction between oppositely charged particles in clouds. Students apply what they learned about atoms' structure in Lesson 5 to explain charge buildup in clouds and static interactions between clouds and the ground. In the physics course, students will explore contact forces in *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*.

This lesson builds on the middle school understanding developed in *OpenSciEd Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)* that attractive and repulsive forces can act across distances (MS PS2.B). In this lesson, students apply what they have figured out about what causes static interactions (the dislodging of electrons and the separation of those pieces of matter) to the common real-world phenomenon of lightning (HS PS2.B). Students also leverage prior understandings about convection's role in storms, developed in *OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)* and re-addressed in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*.

Students continue to develop the focal science and engineering practice of obtaining, evaluating, and communicating information, particularly by reading scientific text. The scientific literature related to lightning is mainly outside the scope of NGSS. While students will read scientific literature adapted for classroom use (HS SEP 8.1), much of the research on lightning goes far beyond electron transfer and simple energy- and force-based analysis.

In middle school, students connect macroscopic patterns to the nature of microscopic patterns (MS CCC 1.1). One intentionally developed crosscutting concept for this unit is Scale, Proportion, and Quantity, and this lesson builds on the element (HS CCC 3.4) that orders of magnitude can be used to understand how a model at one scale (the water dropper) relates to a model at another scale (lightning). Students connect the atomic patterns of static electricity that they figured out in Lesson 5 to the large-scale lightning system.
How Lightning Starts introduces the idea that in a cloud, the heavier, negatively charged pieces of matter tend to fall while the lighter, positively charged pieces of matter tend to rise. Note that it is incidental that the heavier pieces of matter tend to become negatively charged--they are not heavier due to extra electrons.

Students add the word *electricity* to their Personal Glossary in this lesson. We recommend that you do not post any terms or ask students to record any words until after your class has developed a shared understanding of their meaning. Students have been building an understanding of electricity since working with static interactions starting in Lesson 2. In Lesson 5, they built the idea that the underlying reason for attractive or repulsive static forces is the movement of electrons. Now, students expand their understanding of these static interactions to the lightning system and grasp that, at a basic level, electricity is the movement of charges or electrons. Students will continue to revise this term throughout the unit.

Where We Are NOT Going

This lesson does not address the polarization, or induced partial positive charge, of the ground. Students will explore polarization in Lesson 8. This lesson intentionally leaves that concept out of the reading so that students can focus on building toward Coulomb's law in Lesson 7.

This lesson focuses on the static interactions occurring in the cloud and does not address the ionization of air. The reading simply states that the electrons building up at the bottom of the cloud make their way to the ground; it does not address the mechanism of early lightning discharge, such as leaders or streamers. Those concepts will be addressed in Lesson 11.

This lesson addresses interactions between the cloud and the ground at a basic level but does not address interactions between lightning and other materials. The impacts of lightning strikes and lightning safety will be addressed in Lesson 12.

LEARNING PLAN for LESSON 6

1 · NAVIGATE

5 min

MATERIALS: *Our DQB Questions*, Driving Question Board

Navigate to today's work. Display **slide A.**

Suggested prompt	Sample student response
Where did we leave off last class?	We figured out what is happening with atoms when there is static. We have evidence that static interactions are involved with lightning. We marked which DQB questions we had answered.

Identify questions on the DQB that connect to today's work. Display **slide B.** Say, *Last class, I gave you a list of all of our DQB questions. You may have had some time to look through them and identify questions that we have made progress on. Now let's see if there are any questions related to what is causing electrons to move before a lightning strike. Take a moment to identify any questions about what we are trying to figure out.*

Have students independently identify questions on *Our DQB Questions* that connect to what we want to know about what is causing electrons to move before a lightning strike. After a few minutes, ask several volunteers to share some of the questions they identified. Look for students to identify questions that may have more general wording, like "What leads up to a lightning strike?" or "What happens in the sky to cause a lightning strike?"

Update the list of DQB questions. Have students share and add any new questions that arose for them as they examined the existing questions.

2 · THINK ABOUT STATIC ELECTRICITY

5 min

MATERIALS: *Our DQB Questions*, M-E-F poster

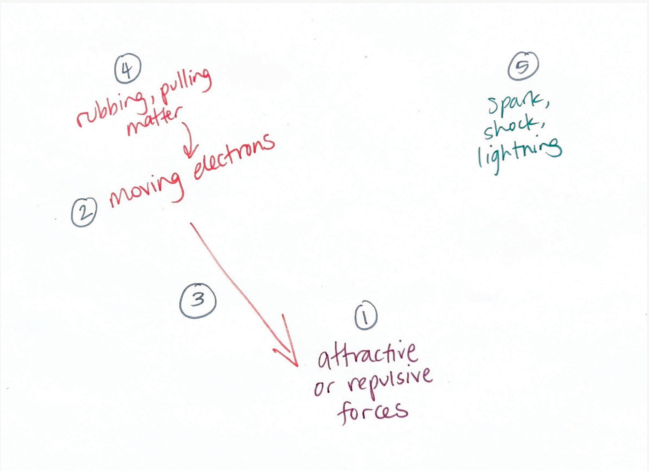
Display **slide C.** Have students turn and talk about the questions on the slide.

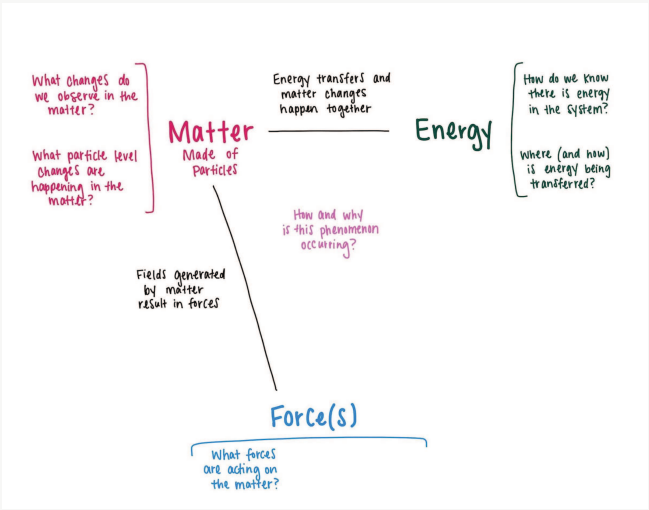
Suggested prompt	Sample student response
What do we mean by "static" or "static electricity"?	Attractive or repulsive forces.
What causes those forces?	Moving charges (electrons).

Record student responses in a shared workspace in a strategic orientation (see image).✱ This discussion parallels the matter, energy, and force triangle, so the placement of each element in the discussion model is strategic and should mirror the orientation of matter, energy, and force on the M-E-F poster. The sequence of building this model with students is shown by the numbers in the image. This public recording of student ideas should be placed near the M-E-F poster. You can also record it on a projected digital copy.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

If students do not come up with examples such as sparks or strikes, have them take a moment to think about the phenomena we have seen associated with the movement of water at different scales. For example, we have seen these phenomena at a smaller scale in our water dropper system and at a larger scale in the lightning system.





Say, *OK, so I am hearing that static interactions are attractive or repulsive forces caused by moving electrons.* (Refer to the model.)

Build out the rest of the model using the prompts below as a guide.

Suggested prompt	Sample student response
So then, what causes those electrons to move?	We had to rub things together like a balloon and our sweater.
What did we have to do to the matter to move electrons?	We had to pull things apart like two pieces of tape.
*So, all of these interactions **(point to the phrases on the model as you say them)**--rubbing matter together, which moves electrons, which causes attractive or repulsive forces—then result in what phenomenon?*	A spark. Lightning strike. Electric shock.

Summarize for the class. Say, *We have figured out that a spark or strike occurs because of attractive and/or repulsive forces from moving electrons. In our static experiments, we moved electrons around by having the matter come into contact with each other through rubbing, pulling, or colliding in some way. But what is causing the electrons to move in the lightning system?*

Brainstorm ideas with a partner. Say, *We said we have evidence that static interactions are present in a lightning system, and we know there needs to be some kind of rubbing or friction for those forces to occur, but what is doing this in the sky?* Display **slide D**. Ask students to brainstorm with a partner about the question on the slide. After a couple of minutes, select some students to share their ideas with the class. Accept all responses.

Suggested prompt	Sample student response
What might be rubbing together, pulling apart, or coming into contact to make electrons move in a lightning system?	Water droplets? Ice? Air molecules? Whatever is in the cloud – water, ice, dust.

3 · PREPARE TO GATHER INFORMATION FROM A READING

3 min

MATERIALS: *How Lightning Starts*, science notebook

Prepare to read scientific text.✱ Display **slide E** and distribute *How Lightning Starts*. Give students a moment to record the first question on the slide, "Why are we reading this article?", in their science notebook. Say, *I have a reading that might help us address the questions we just came up with. But before we read, let's talk about how to make sure we can make sense of the reading.*

Suggested prompt	Sample student response
Why are we reading this article?	To find out more about lightning. To help us figure out what lightning has to do with static.
What strategies can we use to help us make sense of scientific literature?	We can annotate. We can summarize each section. We can look up words we don't understand.

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: *How Lightning Starts* has a reading protocol built in to help students make sense of the information in the unique structure of a scientific paper. Emergent multilingual learners may particularly benefit from using this protocol, as the text has been chunked into smaller sections with places to record the important information from and reflect on the purpose of each section of the text.

4 · GATHER INFORMATION FROM A READING

12 min

MATERIALS: *How Lightning Starts*, science notebook

Gather information from the reading. Display **slide F**. Have students gather information while they read about what is happening in the sky before a lightning strike. ✱ They will use this information at the end of the lesson to compare the lightning system to our in-class static systems. Give students about 10 minutes to read and annotate *How Lightning Starts*. As students read, circulate around the room and assist as needed.

✱ SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

It is important for students to engage with scientific literature adapted for classroom use as they work to build an understanding of complex phenomena. Encourage students to look for central ideas that relate to the lesson question, unit question, or questions from the Driving Question Board.

5 · MAKE SENSE OF THE READING

9 min

MATERIALS: *How Lightning Starts*, science notebook

Discuss the central ideas from the reading. Display **slide G** and have students turn and talk with a partner. Give students about one minute for each partner to answer the question, then have pairs share their ideas with the class. The follow-up questions are intended to help students reach the sample responses if they do not bring them up after the initial prompt.

Suggested prompts	Sample student responses	Follow-up questions
What information did you get from the article to help answer our question?	Stuff rubs together in clouds. Charges build up. A LOT of charge builds up in clouds before lightning – way more than in the water dropper.	*And what happens when these things rub together?*
What static interactions are happening in the sky, according to the reading?	Matter with extra electrons builds up in the bottom of the cloud, making this area negatively charged. The top of the cloud has fewer electrons, so it is positively charged. Electrons from the bottom of the cloud move to the ground. That's lightning.	*Which areas of the cloud are negative? Positive?* *Where do electrons move then?*
Where are the electrons coming from that are causing these static interactions?	Collisions between ice crystals and water molecules inside clouds "brush off" electrons.	*What objects in the cloud are colliding?*

ALTERNATE ACTIVITY

Building prerequisite understandings: If students do not pick up on the mechanism of charge transfer in the cloud, or are unsure of this as a mechanism, have them model with their notecards and paper clips. Tell students to model collisions between ice or water particles and ask if it seems like a likely explanation for charge buildup in clouds. Return to the density demonstrations from *Polar Ice Unit* Lesson 9 and help students draw connections between this convective movement of matter and that in a cloud.

Examine new information. Display **slide H** and highlight the diagram as having come from *How Lightning Starts*. Then lead students in a short discussion around it.

Suggested prompt	Sample student response
What does the diagram show?	It shows what happens in a cloud. It shows how charge builds up in a cloud before lightning.

Suggested prompt	Sample student response
How does it support the text and help us answer our question?	It helps us see what the text is describing. It helps us visualize what happens in a cloud before lightning.

ADDITIONAL GUIDANCE

As students make sense of the reading, they might wonder why the lightning doesn't strike between the bottom and the top of the cloud. The answer is that lightning does strike there too! According to weather.gov, "The electric field within the storm is much stronger than the one between the storm base and the earth's surface, so most lightning (~75-80%) occurs within the storm cloud itself." For more information about lightning formation, see https://www.weather.gov/jetstream/lightning.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should summarize the central ideas from the reading. (SEP: 8.1)
- Students should cite evidence from the reading that helps them understand what static interactions in a cloud lead to lightning. (SEP: 8.1; DCI: PS2.B.3)
- Students compare the amount or scale of charge or distance in a lightning system to the amount or scale of charge or distance in the water dropper system. (DCI: PS2.B.3; CCC: 3.4)

What to do: Encourage students to cite specific information from *How Lightning Starts* in their responses, particularly as it relates to the amount of charge or the scale/distance involved in lightning strikes.

Building toward 6.A.1 Critically read scientific literature adapted for classroom use to determine how static interactions at a different scale lead to lightning. (SEP: 8.1; DCI: PS2.B.3; CCC: 3.4)

6 · COMPARE SCALES

6 min

MATERIALS: *How Lightning Starts*, science notebook, chart paper, chart paper markers

Use the information from the reading to compare the lightning and classroom static systems.✱ Display **slide I** and say, *This reading has helped us answer what is causing static interactions in the lightning system. We also have first-hand experiences of static interactions within our classroom.* Lead a discussion around the prompts below. Only the first two are on the slide to support readability and allow for more nuanced follow-up.

Suggested prompt	Sample student response
Examine the diagram of the thundercloud and think about our water dropper system. What is different about the distances between forces in the two systems?	The distances between forces in the thundercloud are a lot larger than those in the water dropper system. It looks small in the image, but it's really more than 5,000 feet or 1,524 meters.
How many electrons move from the cloud to the ground in a lightning bolt?	1×10^{20} electrons.

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

In this section, students explicitly consider issues of scale and order of magnitude (CCC), drawing on information in this lesson's adapted literature (SEP). Students build on thinking from Lesson 1 and explain macroscopic material behavior--in this case, the formation of lightning--with atomic-scale attraction and repulsion (DCI). Highlight that technical reading can provide information that helps us make sense of the world, including by helping us connect phenomena across vastly different scales. In

Suggested prompt	Sample student response
Think about the size of the spark and how close the pennies are in the water dropper system. How do we think the number of moving charges there compares to lightning?	There are probably way more moving charges in lightning.
What changes would we need to make to our water dropper system to make forces travel similar distances to those shown in the thundercloud diagram?	We would need to scale up our class lightning system so it is as big as the thundercloud. We would need a lot more water to build up a lot more electrons in the wires.

Compare lightning and static phenomena. Display **slide J**. Ask, *What is similar and different in terms of the static interactions within the lightning system we just learned about and the static phenomena we have explored in our classroom investigations?* Have students turn and talk about the similarities and differences. Then pull the class together to discuss and record students' ideas in a T-chart on a piece of chart paper. A sample T-chart of similarities and differences is shown:

Similarities	Differences
• There is contact between two pieces of matter (like tape in our classroom or ice crystals in a lightning system). • The matter becomes charged in that contact (electrons move from one piece of matter to the other). • The charged matter moves apart. • This results in static forces (repulsion and attraction).	• The scale of the lightning system is much larger than our classroom static systems– thousands of times larger. • The amount of charge buildup on the bottom of the cloud is much greater than in our classroom systems. • The distances over which the repulsive or attractive forces are acting are much greater in a lightning system than in our classroom systems.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use the reading to compare the charge in a water dropper to lightning. (SEP: 8.1; DCI: PS2.B.3)
- Students notice similarities in how matter becomes charged through contact in both systems and support this with evidence from the reading. (SEP: 8.1; DCI: PS2.B.3)

What to do: If students are struggling, cue them to look at numbers in the reading to help them think about the difference in scale between the lightning and water dropper systems.

Building toward 6.A.2 Critically read scientific literature adapted for classroom use to determine how static interactions at a different scale lead to lightning. (SEP: 8.1; DCI: PS2.B.3; CCC: 3.4)

Update Personal Glossaries. Say, *According to the reading and our models, what causes lightning?* Look for students to say moving charges (or electrons). Display **slide K.** Say, *What is another name we could use for the moving charges in lightning or between pennies in the water dropper system?* Look for students to suggest electricity. Have students take a moment to add *electricity* to their Personal Glossaries.
Sample glossary entry: *electricity = The movement of charges or electrons.*

this case, it helps us explain weather phenomena using ideas that are centered in chemistry's study of matter.

7 · NAVIGATE

5 min

MATERIALS: science notebook, *How Lightning Starts*, Similarities and Differences T-Chart

Navigate to the next lesson using the crosscutting concept of scale. Say, *As we think about the lightning system and our classroom static systems, what seems to be the most significant difference between the two?* Point students back to the T-chart. Look for students to suggest scale (or any related term, like size or amount). Display **slide L**.

Suggested prompt	Sample student response
Why can't our sticky tape make any visible sparks like the water dropper can?	There might not be enough charge in the tape. Maybe the tape doesn't have time to build up enough charge like the water dropper does.
Why can't the water dropper make something as impressive or dangerous as lightning?	Probably because of how much charge is built up. The amount of "jolt" a spark has. Like we could touch the spark in the water dropper system. We felt a shock but weren't hurt. A lightning bolt can be fatal.

Summarize the key relationships. Ask students to sum up what they think are the key differences in these different-sized systems. You will continue to work on these ideas next class, so they do not need to be fully explained yet. You can do this activity with a chart, notes, or a model. Together you may be able to identify that the following factors all increase together:

- the distance
- the number of electrons
- the amount of electron transfer (more collisions/rubbing)
- the size of the "zap"

Problematize that this working model is not very precise. We need precision for something as dangerous as lightning. Say, *Didn't we hear that these lightning bolts can kill or seriously harm people? Shouldn't we be able to know how to predict lightning? Could we investigate this more precisely to see how strong these forces are? Let's spend some time next class quantifying the relationship between static force, distance, and amount of charge.*

Additional Lesson 6 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.

Students previously investigated static interactions using pieces of sticky tape and the water dropper system. They relate these interactions to a reading about how lightning forms in clouds and think about contradictions between the data and reading to think more deeply about scale.

LESSON 7: How are electrostatic forces between objects affected by the amount of charge and the distance between them?

PREVIOUS LESSON

We decided to investigate what causes static interactions to occur before lightning. We read an article that could help us answer our question and gathered information about what is happening in the sky before a lightning strike. Then we used this information to compare the lightning system to our in-class static systems.

THIS LESSON

INVESTIGATION

3 days



We carry out an investigation to determine how electrostatic forces between objects are affected by the amount of charge and the distance between them. We compare graphs of our results and identify patterns in how different variables affect these forces. We evaluate a mathematical model for how these variables are related and use algebraic methods to predict the effects of larger-scale changes in the amount of charge and distance between charges in a system.

NEXT LESSON

We will observe interactions between charged and neutral objects. We will use a simulation and our paper-clip models to figure out that atoms can become temporarily polarized by proximity to charged objects, which causes the electrons to shift within atoms instead of being transferred.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-6, HS-PS2-4, HS-PS3-2, HS-PS3-6

WHAT STUDENTS WILL DO

7.A Make qualitative claims using mathematical representations of patterns in how amount of charge, distance between charges, and strength of forces are related across the class results; and compare these to patterns predicted by Coulomb's law. (SEP: 5.2, 6.1; DCI: PS2.B.1; CCC: 1.4)

7.B Apply techniques of algebra and functions to calculate the force predicted by Coulomb's law in a larger-scale system and contextualize the significance of the phenomenon. (SEP: 5.3; DCI: PS2.B.1; CCC: 3.1, 3.5)

WHAT STUDENTS WILL FIGURE OUT

- When like or unlike charges are moved farther apart, they produce significantly less force.
- The strength of the electrostatic forces on any two amounts of charge, separated by a distance, can be predicted using Coulomb's law.

Lesson 7 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Lead a whole-class discussion to identify how some of the variables related to static production may help us explain differences in scale of static electricity.	A-B	
2	11 min		**ORIENT TO INVESTIGATION MATERIALS** Orient students to the investigation materials and demonstrate the use of a digital scale as an upward- and downward-force measurement device.	C-D	Electrostatic Force Demonstration
3	11 min		**MAKE AND RECORD PREDICTIONS** Gather students into small groups and have them make and record predictions.	E-G	*Predicting Force Relationships*, Mathematical Anchor Chart from *Polar Ice Unit* (optional)
4	8 min		**ORIENT TO INVESTIGATION PROCEDURES AND SPREADSHEET** Divide students into six groups. Review investigation procedures for the first investigation students will conduct. Orient students to the structure and use of the class data spreadsheet.	H-I	*Conditions 1 & 2 Procedures* or *Conditions 3 & 4 Procedures*, https://youtu.be/DvvTSYO5sFc
5	10 min		**CARRY OUT INVESTIGATIONS** Have groups carry out the first part of the Electrostatic Force Investigation. Make sure each group records and graphs their data on their group's tab of the class spreadsheet.	J	Electrostatic Force Investigation
					End of day 1
6	10 min		**FINISH CARRYING OUT INVESTIGATIONS** Have groups carry out the second part of the investigation. Make sure each group records and graphs their data on their group's tab of the class spreadsheet.	K	Electrostatic Force Investigation
7	11 min		**ANALYZE CLASS DATA** Have students examine the groups' data from the class spreadsheet to complete *Comparing Force Relationships*.	L-M	*Comparing Force Relationships*, class copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy, Internet connected device
8	15 min		**BUILDING UNDERSTANDINGS DISCUSSION AROUND SCALE** Gather students in a Scientists Circle to interpret results based on Coulomb's law.	N-R	*Comparing Force Relationships*, Mathematical Anchor Chart from *Polar Ice Unit*, https://lab.concord.org/embeddable.html#interactives/interactions/amount-charge.json

Part	Duration		Summary	Slide	Materials
9	9 min		**EVALUATE THE MATHEMATICAL MODEL** Orient students to the units related to *k*. Have students work with a partner to make and test predictions with the equation on *Comparing Force Relationships*.	S-T	*Comparing Force Relationships*, class copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy, Internet connected device, https://docs.google.com/spreadsheets/u/2/d/1AdqrHN3LYKtPOKCisYd5IRgO6UPVcFtRlRLC85yJLuw/copy
					End of day 2
10	12 min		**FIND A COMBINATION OF CHARGES FOR EACH INVESTIGATION SYSTEM** Lead the class in calculating the amount of charge in the systems they investigated.	U	*Comparing Force Relationships*, https://docs.google.com/spreadsheets/u/2/d/1AdqrHN3LYKtPOKCisYd5IRgO6UPVcFtRlRLC85yJLuw/copy, class copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy, Internet connected device
11	7 min		**DEMONSTRATE HOW TO CALCULATE THE FORCE FOR A LARGER SCALE SYSTEM** Demonstrate how to use Coulomb's law to think about the relationships among force, distance, and charge on a larger scale.	V-W	*Solving for Force*, scientific calculator, "Solving for force using Coulomb's law" poster
12	15 min		**CALCULATE FORCE AT A LARGER SCALE** Have students work with a partner to determine forces for larger-scale distances and charges using Coulomb's law.	X-Y	*Solving for Force*, scientific calculator, "Solving for force using Coulomb's law" poster
13	6 min		**DEBRIEF FORCE CALCULATIONS** Have students turn and talk with a partner to reflect on their calculations, then discuss as a class.	Z	
14	5 min		**NAVIGATE** Have students update Progress Trackers to reflect what we figured out about Coulomb's law.	AA	
					End of day 3

Lesson 7 • Materials List

	per student	per group	per class
Electrostatic Force Demonstration materials			• 8-oz foam coffee cup • 4" x 6" piece of foam insulation board • digital scale (0.01 g) • 2 6" x 4" x 3" boxes • sticky tack • 1 5" x 7" acrylic sheet • 2 2.5" x 7" acrylic sheets • 3 5" x 7" PTFE sheets • 48 game chips • 4 clothespins • ruler
Electrostatic Force Investigation materials	• *Conditions 1 & 2 Procedures* or *Conditions 3 & 4 Procedures*	• 8-oz foam coffee cup • 4" x 6" piece of foam insulation board • digital scale (0.01 g) • 2 6" x 4" x 3" boxes • sticky tack • 1 5" x 7" acrylic sheet (for groups testing Conditions 1-2) • 2 2.5" x 7" acrylic sheets • 3 5" x 7" PTFE sheets (only 2 for groups testing Conditions 3-4) • 48 game chips • 4 clothespins • ruler	• class copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy
Lesson materials	• *Predicting Force Relationships* • science notebook • *Conditions 1 & 2 Procedures* or *Conditions 3 & 4 Procedures* • *Comparing Force Relationships* • class copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy • Internet connected device • *Solving for Force* • scientific calculator	• class copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy • Internet connected device • https://docs.google.com/spreadsheets/u/2/d/1AdqrHN3LYKtPOKCisYd5IRgO6UPVcFtRlRLC85yJLuw/copy	• Mathematical Anchor Chart from *Polar Ice Unit* (optional) • https://youtu.be/DvvTSYO5sFc • Mathematical Anchor Chart from *Polar Ice Unit* • https://lab.concord.org/embeddable.html#interactives/interactions/amount-charge.json • https://docs.google.com/spreadsheets/u/2/d/1AdqrHN3LYKtPOKCisYd5IRgO6UPVcFtRlRLC85yJLuw/copy • "Solving for force using Coulomb's law" poster

Materials preparation (90 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

- Create a copy of this spreadsheet: https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy

You will share the URL of this copy with students on **slide J**. This will be referred to as the "class copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy" or "class data spreadsheet" throughout the lesson. Review the related video that students will view on **slide I**, which shows how they will use this spreadsheet: https://youtu.be/DvvTSYO5sFc.

Watch the teacher video (https://youtu.be/jF-la-voLro) that demonstrates how the class will interact with the computational model spreadsheet (https://docs.google.com/spreadsheets/u/2/d/1AdqrHN3LYKtPOKCisYd5IRgO6UPVcFtRlRLC85yJLuw/copy).

Prepare copies of the following handouts for every student:
- *Predicting Force Relationships*
- *Comparing Force Relationships*
- *Solving for Force*

Ensure there are enough copies of the following references so that half the class has access to each:
- *Conditions 1 & 2 Procedures*
- *Conditions 3 & 4 Procedures*

These references assume a standard game chip size. If you have students raise the small acrylic sheets using a different object or method, you may have to adjust the instructions accordingly.

Create a poster on chart paper titled, "Solving for force using Coulomb's law."

Students will benefit from the Mathematical Anchor Chart that they developed in *Polar Ice Unit*. This is marked as optional for display on day 1 and required on day 2.

Test https://lab.concord.org/embeddable.html#interactives/interactions/amount-charge.json on the instructor device for use on day 2 during the Building Understandings Discussion.

Electrostatic Force Demonstration
- **Group size:** Whole class
- **Setup:** Prepare 1 lab station as outlined in *Force Station Preparation*. This will be reused by a group during the actual investigation.
- **Notes for during the lab:** Avoid weight or additional force on the digital scales, beyond what is used in the lab. Scales can be damaged if the weight placed on them exceeds the maximum of 500g.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science.* Support students in following standard laboratory safety considerations.
- **Disposal:** Materials are all reusable and do not need to be thrown away.
- **Storage:** All materials can be stored and reused for next year or for other investigations. The digital scales may not automatically shut off, so be sure to power them down at the end of the class.

Electrostatic Force Investigation
- **Group size:** 5 students
- **Setup:** Prepare 7 lab stations as outlined in *Force Station Preparation*. Classroom environments with high humidity may prevent the formation of much static. In such a case, it is recommended that you run a room dehumidifier and test the relative humidity in the space until it comes down to 40% or lower, if possible. Test the batteries on your digital scales to ensure that they are functional. Test the investigations as outlined in *Conditions 1 & 2 Procedures* and *Conditions 3 & 4 Procedures* to ensure that you are familiar with the procedures. If you cannot get the investigation to work, sample data is provided in https://docs.google.com/spreadsheets/d/1aLKJ4EebFXHguAMQEEuG0_SGLwfD1kxe5dLpqbpTCCo/edit?usp=sharing. Students may also perform similar investigations using https://phet.colorado.edu/sims/html/coulombs-law/latest/coulombs-law_en.html, although the *k* value in Coulomb's law will have to be adjusted accordingly for different units.
- **Notes for during the lab:** Avoid weight or additional force on the digital scales, beyond what is used in the lab. Scales can be damaged if the weight placed on them exceeds the maximum of 500g.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science.* Support students in following standard laboratory safety considerations.
- **Disposal:** Materials are all reusable and do not need to be thrown away.
- **Storage:** All materials can be stored and reused for next year or for other investigations. The digital scales may not automatically shut off, so be sure to power them down at the end of the class.

Lesson 7 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build new ideas related to the following disciplinary core idea:

- **PS2.B.1 Types of Interactions:** ~~Newton's law of universal gravitation and~~ Coulomb's law provide the mathematical models to describe and predict the effects of ~~gravitational and~~ electrostatic forces between distant objects.

Crossout explanation: In this lesson, students develop Coulomb's law from an investigation. In Lesson 9, students will be assessed on this portion of PS2.B.1. Students will not develop Newton's law of universal gravitation in this course, instead figuring it out in *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)* in a very similar investigation, using magnetic force as a stand-in for gravitational force.

Students enter this lesson with significant mathematical experience from *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*. This will support their thinking around SEP: 5.2 and SEP: 6.1 as they predict, graph, and describe the relationships among distance, charge, and force. Students will likely predict linear relationships based on their prior experiences, but will figure out later in the lesson that the relationship between force and distance is nonlinear. This is the first nonlinear relationship students will encounter in this course. You may wish to add it to the *Mathematical Anchor Chart* from *Polar Ice Unit* as an example. In any case, this prior tool may be useful to display to students throughout the lesson. Additionally, it may be valuable to show Coulomb's law to your students' math teachers to ensure that you use similar language to them, keeping in mind that students are not rearranging variables, just entering values, doing arithmetic, and most importantly, thinking about how the variables are connected to each other.

It should be noted that as students develop and work with Coulomb's law (SEP: 5.3), they will be similarly drawing on their experiences with calculating energy transfers in *Polar Ice Unit*. This is the only time in this unit when students will practice using Coulomb's law before a summative transfer task in Lesson 9. Therefore, significant time has been built in for students to engage with and practice this equation, which is the only one in the unit. As in *Polar Ice Unit*, students will use a class spreadsheet for data collection. A second spreadsheet is included to support students in their calculations. You should consider making these spreadsheets available to students during any assessments so they can easily check their work, lest arithmetic prevent accurate assessment of students' understanding of how the equation works. Students will also be working with scientific notation, which should be familiar from *Polar Ice Unit*.

The *k* used in Coulomb's law in this lesson is a constant that allows students to work with measurements they used in their investigation (millinewtons, centimeters, and # of elementary charges [e]). 1 e is the charge produced by a proton and -1 e is the charge produced by an electron. Other values of *k* can be used for systems that use different units of measurement for force, distance, and charge, such as Newtons, meters, or Coulombs.

In this lesson, students build on their prior thinking about patterns in the unit with an emphasis that mathematical representations are needed to identify some patterns (CCC: 1.4). While students have developed patterns from graphs before, be sure to emphasize this as a generalizable principle. Students will also consider the role of scale in the effects of Coulomb's law for the first time in this course (CCC: 3.1) and use algebraic thinking to predict the effects of changes in one variable (CCC: 3.5). Build on students' use of scale in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* and knowledge from *Polar Ice Unit* by eliciting thinking about the effects of changes in more familiar variables, like carbon dioxide and temperature, and mapping them to the variables used in this investigation.

While students have used digital scales to determine the mass of matter in their prior work in *Polar Ice Unit*, they may not have considered the distinction between mass and weight. If students experienced the middle school unit *OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*, they will have been introduced to the idea that both mass and weight are proportional when measured at the same location on Earth (i.e., double the amount of matter, which doubles the mass, would also double the weight reported on the scale). This idea will be touched on in the lesson as well.

Students have several opportunities to practice calculations with Coulomb's law in this lesson, including the optional *Coulomb's Law Practice*. The problems on this worksheet stem from the philosophy that students' practice should be contextualized within the anchoring phenomenon or other phenomena from the unit. This activity provides students more hints about how the water dropper from Lessons 2-3 works as they calculate forces between different components. Students will have all the pieces to explain the water dropper by the end of the unit, so more guidance is provided later to provide students the space to model this phenomenon in full.

In this lesson, students may add *Coulomb's law* to their Personal Glossaries if desired. We recommend that you do not post any terms or ask students to record any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students are not reasoning about limit cases associated with Coulomb's law, such as what the equation predicts will happen to the amount of force when *r* approaches 0 or when *r* approaches infinity.

Students will not use self-developed computational representations of phenomena in this lesson, as they did in *Polar Ice Unit*, or algorithmic representations, as in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*. They will use algebra to solve scientific problems, but not engineering problems. These will be addressed in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*. Furthermore, students will make qualitative and arguably semi-quantitative claims in this lesson, but not quantitative claims.

Students are not expected to have a nuanced understanding of how the experimental setup is measuring force--they must only understand that lifting the mass (whether directly or through a force at a distance) causes the reading to be negative because less mass than expected is on the scale, while applying a downward force increases the reading as the pan is being pushed downward.

LEARNING PLAN for LESSON 7

1 · NAVIGATE

5 min

MATERIALS: None

Revisit the scale of charges in the system. Display **slide A**. Say, *Last class, we wondered if the water dropper system or other staticky materials could make something as impressive as lightning. Let's think about that a little more.* Ask, *What would we have to do with the water dropper or staticky materials to make a lightning-like spark?* Listen for these ideas:

- Pick materials that were already very staticky and rub them together for a long time.
- Maybe decrease or increase the space between the pennies.
- Make a bigger dropper system with more water.
- It is impossible.

Consider possible factors. Say, *Let's get more specific.* Display **slide B.** Give students a moment to turn and talk with a partner before discussing the prompts as a class.

Suggested prompt	Sample student response
How much charge would we really need to add to the Lesson 4 test objects to make lightning?	A lot more than we had in our other investigations. A huge amount. We do not know how to measure charge though. As much as there is in lightning.
How close or far apart would the objects need to be to make lightning?	Very close because the pennies on the water dropper had to be close to make a spark. Very far away because clouds are far away from Earth's surface.

Problematize measuring force. Say, *We have identified some ways to add additional charge into the system, such as by rubbing objects together. That is one variable that could affect how big the spark is. The distance between objects in the system is another variable we could change and measure, at least to a point. But we have also identified the force as being really important in these systems, so that is something we would also want to measure to create a lightning-like spark. There must be some connection between these different variables...maybe that is something we should look into if we want to know what it takes to make lightning.*

2 · ORIENT TO INVESTIGATION MATERIALS

11 min

MATERIALS: Electrostatic Force Demonstration

Orient students to the materials for the investigation. Display **slide C**. Have students gather around the demonstration equipment. Say, *Let's see how we could measure the forces from static electricity using equipment we have in the lab.*✱

Explore how the scale measures forces. Set the digital scale to display in grams. Say, *What do you think will happen when we place the cup and foam board on the scale?* Students will say that the numbers on the scale will increase. Say, *Let's try it!*

Ask for a student volunteer to demonstrate this:

1. Turn on the digital scale with nothing on the pan.
2. Zero the scale.
3. Add the cup and foam board to the pan.
4. Report what the scale registers including the units and record this on the whiteboard.



Distinguish measures of mass and force and make predictions. Point out that scales measure mass--the amount of stuff in an object--but because Earth's gravity is constantly pulling, we can think of them as measuring force too. Say that for this reason our units will actually be grams of force, not "normal" grams.

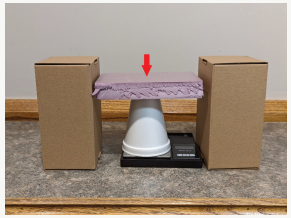
ADDITIONAL GUIDANCE

It is not critical that all students understand the distinction between mass and force right now, so do not dwell further on it at this point. In two units of the OpenSciEd high school physics course, *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)* and *OpenSciEd Unit P.3: What can we do to make driving safer for everyone? (Vehicle Collisions Unit)*, students will use these ideas as they build understanding around Newton's second law of motion.

Ask, *What would happen to the force value reported by the scale if we lightly pushed downward on the pan?* Students will say it would increase.

Ask for a student volunteer to demonstrate this:

1. Push down on the top of the foam board very, very lightly with one finger.
2. Report what the scale registers including the units and record this on the whiteboard.



Remind students that we can get an exact measure of the amount of force we are applying to the system by subtracting the grams of force of the cup and foam board. One way to do this is to first zero out the initial mass we place on the system before applying additional pushes or pulls to it.

Ask a student volunteer to do the following:

1. Zero the system.
2. Push down lightly on the foam board and report the value of this additional force on the scale.
3. Pull slightly upward on the foam board and report the value of this additional force on the scale.
4. Ask the student to describe whether that amount of force is positive or negative. They will say negative.

Introduce upward force measures. Point out that the latter of these results shows us that the scale can also detect upward force being applied. Say, *Notice how the number representing force became negative when the foam board was pulled upward, but the scale was still measuring force. All this means is that the force of attraction is pulling on the scale instead of pushing down on it.*

✱ SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

Students will carry out an investigation in this lesson, although they will not be assessed on doing so given its heavy emphasis in *Polar Ice Unit*. You may use the *Investigation Anchor Chart* to help students consider why this investigation is constructed how it is, but due to the complexity of the setup, students are not asked to do significant planning themselves.

Elicit student ideas about the investigation. Suggest that we could use electrostatic forces, instead of our hands, to cause pushes or pulls on the scale. Ask, *How could we use other classroom materials to measure electrostatic forces with the scale?* Listen for these ideas:

- We could charge up two objects, put one on the scale, and hold the other over it.
- We could take charged objects and have one on the scale so that we can see if an object near it attracts or repels it.

Elicit ideas for particular materials and charging methods. Try out a couple, then suggest that we use some common methods so that we are able to more consistently compare results.

Describe one of the conditions we will test. Display **slide D.** Say, *In Condition 1, we will charge up one sheet of acrylic, or hard plastic, by rubbing a piece of PTFE fabric against it. Then we will place that acrylic sheet on the foam board and zero the scale. Next, we will charge up a smaller acrylic sheet in the same way to ensure it has the same type of charges on it. We will then hold that second acrylic sheet at different heights above the bottom sheet using the boxes and game chips to support it. Since the bottom acrylic sheet is resting on the scale, we can measure how much force the top sheet applies to the bottom sheet. Adding more game chips to prop up the top sheet will create greater distance between the two sheets.*

Suggested prompt	Sample student response
Why is it important that we are able to change the distance between the two acrylic sheets?	We thought that lightning-like sparks might be more or less likely at different distances.
What is happening at the particle level when we rub materials together?	They charge. Electrons move from one to the other.

Narrate and demonstrate Condition 1 (like-charged acrylic sheets) by transferring charge and measuring a repulsive force. As you rub the two acrylic sheets with PTFE, ask students to verify what is going on and what the charges are on each sheet. Students will likely be unsure, so reflect back to prior investigations.

Suggested prompt	Sample student response
Let's think back to our different investigations. What types of things happened when we rubbed materials together?	They attracted or repelled.
When would they attract? When would they repel?	They would attract when the materials were different. They would sometimes repel when they had the same material or same charge.
Why do some materials attract and others repel?	Materials with like charges repel. Materials with opposite charges attract.

Have students map this thinking to the acrylic sheets.

Emphasize the range and sensitivity of the scale. Review these guidelines for using the digital scales prior to students' investigations:

- The scale can help us detect changes in relatively small amounts of downward and upward force as positive or negative values. It is sensitive enough to detect changes of 1/100th of a gram-force, but it also has a very limited range.
- The scale will be damaged if we apply too much force on it.
- Avoid directly touching the surface of the scale and only use it to detect pushes and pulls from static interactions of objects held near, but not directly touching, the pan.

3 · MAKE AND RECORD PREDICTIONS

11 min

MATERIALS: *Predicting Force Relationships*, science notebook, Mathematical Anchor Chart from *Polar Ice Unit* (optional)

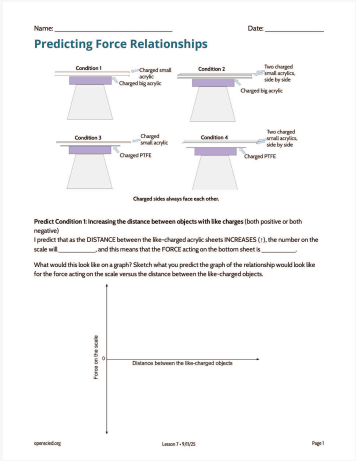
Predict the amounts of charge in various scenarios. Display **slide E.** Propose the idea that the various conditions students will test can experience forces of varying magnitudes based on different amounts of charge on each sheet. Give students three minutes to turn and talk about the scenarios presented on **slide E.**

Suggested prompt	Sample student response
How do you think the amount of charge (number of electrons) in the system during the demo would differ from the amount of charge when...	There should be a greater amount of charge on the bigger surface.
...there are 2 acrylic sheets above 1 acrylic sheet on the scale?	
...there is 1 acrylic and 1 PTFE sheet?	The PTFE sheet would have the opposite charge of the scenario with two acrylic sheets, since it would have transferred electrons to or from the acrylic sheet.
...any of the sheets are rubbed together for longer?	Rubbing sheets together for longer means more charges should have transferred onto or off of the sheets, making the charge greater.

Make and record graphical predictions.✱ Display **slide F**.

Say, *Let's make some predictions about how changing the distance between these two acrylic sheets would affect the strength of the force detected in the system.* Have students get into groups of five. Distribute *Predicting Force Relationships*. Encourage groups to use two notebooks or binders to represent the two acrylic sheets. Have students move them closer together and farther apart to help them visualize how changing the distance between objects would affect the strength of the force, as students discuss their predictions. Finally, have groups record their predicted graph for Condition 1 on *Predicting Force Relationships*.

Make additional predictions. Display **slide G.** Orient students to the next two conditions: adding more charge to one of the objects (Condition 2), and using oppositely charged objects (Condition 3). Have students individually record their related predictions on *Predicting Force Relationships* and respond to the last prompt.


Name: _____ Date: _____

Predicting Force Relationships

Condition 1 — Charged small acrylic; Charged big acrylic

Condition 2 — Two charged small acrylics, side by side; Charged big acrylic

Condition 3 — Charged small acrylic; Charged PTFE

Condition 4 — Two charged small acrylics, side by side; Charged PTFE

Charged sides always face each other.

Predict Condition 1: Increasing the distance between objects with like charges (both positive or both negative)

I predict that as the DISTANCE between the like-charged acrylic sheets INCREASES (↑), the number on the scale will _____, and this means that the FORCE acting on the bottom sheet is _____.

What would this look like on a graph? Sketch what you predict the graph of the relationship would look like for the force acting on the scale versus the distance between the like-charged objects.

Force on the scale

Distance between the like-charged objects

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✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Students' sketches of the graph of the predicted relationship will probably be a linear one. That is okay at this point. Later in the lesson, students will see that the graphs of the data they just made predictions about show a nonlinear relationship.

For different scenarios, students' sketched graphs may also slope downward since the digital scale, if tared, shows a negative number for an attraction. The general trend (absolute value of the force increasing or decreasing with the distance) is more important than whether students are properly drawing above or below the *x*-axis.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' graphs show a predicted trend (linear or nonlinear) line of decreasing *y*-values as *x*-values increase. They show a second line on the same graph with a similar trend line as the previous one, but with a shift upward in some or all of the *y*-values. (SEP: 5.2, 6.1; CCC: 1.4)
- Students label the lines in terms of the relative amount of charge they represent. (SEP: 5.2, 6.1; DCI: PS2.B.1)

What to do: Spot check student work before moving on to the investigation. Ask students who have not labeled their graphs to revisit their work.

Building toward 7.A.1 Make qualitative claims using mathematical representations of patterns in how amount of charge, distance between charges, and strength of forces are related across the class results; and compare these to patterns predicted by Coulomb's law. (SEP: 5.2, 6.1; DCI: PS2.B.1; CCC: 1.4)

4 · ORIENT TO INVESTIGATION PROCEDURES AND SPREADSHEET

8 min

MATERIALS: *Conditions 1 & 2 Procedures* or *Conditions 3 & 4 Procedures*, https://youtu.be/DvvTSYO5sFc

Assign groups and review investigation procedures. Display **slide H.** Ensure that there are four to five students per group and that half of the groups are assigned to test Conditions 1 and 2, and half are assigned to test Conditions 3 and 4. Tell students that each group is assigned a lettered tab in the class data spreadsheet and that they are to enter their data into only that tab.

Say, *You and your group are assigned to test two different conditions. Due to the timing, you will test one condition today and one condition at the start of our next class.* Tell students that the procedure for their additional condition is located on the reverse side of their handout. Distribute either *Conditions 1 & 2 Procedures* or *Conditions 3 & 4 Procedures* to each student, depending on their group's assignment. Give students three minutes to individually read the procedure for the condition they will test first (1 or 3). Elicit differences between these conditions. Students should recognize that Condition 1 has like-charged objects, while Conditions 3 has oppositely-charged objects.

Ask whether students have any questions about the investigation procedures before orienting them to the class data spreadsheet.

Orient to the class data spreadsheet. Display **slide I.** Show the video at https://youtu.be/DvvTSYO5sFc to orient students to how to enter data in the spreadsheet for their group's tab and how to produce the two related graphs.✱

✱ ATTENDING TO EQUITY

Building prerequisite understandings: Students are already familiar with Google Sheets from *Polar Ice Unit*, although this is their first time creating their own graphs. If they did not engage with this unit, you will want to more systematically walk them through graph generation, in the moment. You may also post the video so that students can use it as they create the graphs.

5 · CARRY OUT INVESTIGATIONS

10 min

MATERIALS: Electrostatic Force Investigation

Carry out the first investigation. Display **slide J.** Share the copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy (based on the section or period you are teaching) with students. Have groups carry out their first assigned investigation, either Condition 1 or Condition 3. Remind students that they will have time during the next class period to collect data for their other assigned condition. Make sure groups record data and generate their graphs before the end of the class period. Circulate around the room and assist as needed. If possible, switch out the acrylic and PTFE sheets between class periods to give them more time to discharge.

End of day 1

6 · FINISH CARRYING OUT INVESTIGATIONS

10 min

MATERIALS: Electrostatic Force Investigation

Refresh students on where they left off in the investigation. Display **slide K.** Say, *At the end of last class, you all tested one of your two conditions for this Electrostatic Force Investigation. Now is the time to finish collecting data for your second investigation. Let's take a minute to remind ourselves what we were testing in this investigation.*

Carry out the investigation. Reshare the copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy (based on the section or period you are teaching) with students. Have groups carry out their second assigned investigation, either Condition 2 or Condition 4. Make sure groups record data and generate their graphs for both of their conditions before moving on to the next step. Circulate around the room and assist as needed.

If possible, switch out the acrylic and PTFE sheets between class periods to give them more time to discharge.

7 · ANALYZE CLASS DATA

11 min

MATERIALS: *Comparing Force Relationships*, class copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy, Internet connected device

Identify and compare patterns in class investigation data. Display **slide L.** Distribute *Comparing Force Relationships* to each student. Have students access their class's copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy.

Tell students to work on their own to compare a total of four data sets: the data from their group, data from a group that tested the same condition, and data from groups that tested two of the other conditions. Give students three minutes to record similarities and differences they notice across the graphs.✱

ALTERNATE ACTIVITY

If you do not have enough Internet connected devices for each student, conduct a silent gallery walk. Have stations set up where one tab of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy is displayed. Give students about two minutes at each station. This will add five minutes to this lesson step.

Describe the relationship between different variables. Display **slide M.** Read through the question on the slide. Explain that the symbols shown with the descriptions are ones that scientists use to describe some of the variables in our investigation. Point out that the subscripts on the *q* variables are used to designate amounts of charge at two different points in space, with one set of charges at point A and the other set of charges at a different point B. Give students 30 seconds to think about the question on the slide before discussing it as a class. You may want to have students use thumbs up or down as a poll to indicate how the strength of the forces changes in each case.

Suggested prompt	Sample student response
How does the amount of charge on the top object (q_A) appear to affect the strength of the forces in the system?	More charge on the top object produces stronger forces in the system.
How does the amount of charge on the bottom object (q_B) appear to affect the strength of the forces in the system?	More charge on the bottom object also produces stronger forces in the system.

✱ SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

In this lesson step, students analyze and interpret data at a middle school level. The Identify and Interpret (I^2) strategy can be used to support students who do not readily draw meaningful comparisons between the graphs. https://media.bscs.org/icans/Icans_I2_SE.pdf

Suggested prompt	Sample student response
How does the distance between the charged objects (r) appear to affect the strength of the forces in the system?	Greater distances produce weaker forces in the system. Smaller distances produce stronger forces in the system.

Say, *It seems like we are pretty much in agreement about these relationships. What did you think about when you identified these relationships?* Listen for students to point out that they were considering the investigation data.

Say, *Well if we have evidence that supports an argument for these relationships between all three variables, then any general model would need to include all of these variables as well as the relationships we just described. Let's evaluate one possible mathematical model to see whether it predicts and describes the relationships we discovered from our investigations.*

8 · BUILDING UNDERSTANDINGS DISCUSSION AROUND SCALE

15 min

MATERIALS: *Comparing Force Relationships*, Mathematical Anchor Chart from *Polar Ice Unit*, https://lab.concord.org/embeddable.html#interactives/interactions/amount-charge.json

KEY IDEAS

Purpose of this discussion: To introduce Coulomb's law and help students consider its meaning qualitatively before using it quantitatively.

Listen for these ideas:

- Correct identification of the variables in the equation.
- Electrons moving from one surface to another when these surfaces are rubbed together, leaving one object with excess electrons (compared to protons) and the other with fewer electrons than protons. This creates an electrostatic force.
- More rubbing = more electrons moving = greater charge = greater force.
- Forces get bigger when charges are closer together because they are experiencing each others' electric fields more strongly. The equation shows how decreasing distance increases force.

Orient to an equation-based mathematical model of our system.✱ Gather students in a Scientists Circle and display **slide N**. Say, *This equation is one proposed model scientists have developed for some of the relationships we identified. It is a little more complicated than what we saw in Polar Ice Unit, but is pretty similar to some equations you have seen in math class. Let's identify the variables in this equation.* Have students locate this equation on their copy of *Comparing Force Relationships*.

Suggested prompt	Sample student response
What did we say F represented?	The strength of the forces in the system.✱
What did we say q_A represented?	The amount of charge on one surface/object.
What did we say q_B represented?	The amount of charge on a second surface/object.
What did we say r represented?	The distance separating the charged objects.

✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Use the Mathematical Anchor Chart from *Polar Ice Unit* to remind students how in equations in this course, each piece can be tied directly to a physical quantity. You may add this equation to the anchor chart, if you wish.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

Scale plays an important role in the prompts' follow-up questions. First, it helps students consider that electrons, not protons, move between atoms because they are smaller and positioned closer to the outside of the atom, where outside forces are stronger. Second, students refresh the idea from Lesson 5 that the relative numbers of electrons and protons determine an object's charge.

It may be helpful to use the paper-clip model to represent the relative numbers of protons and electrons in a piece of matter.

Have students use arrows to identify and label these same variables in the equation on *Comparing Force Relationships*. Do the same on the slide, whiteboard, or on the Mathematical Anchor Chart.

Identify what *k* represents. Say, *The only symbol we have not identified in the equation is k. Let's explain what that represents now.* Display **slide O.** Point out that *k* is a constant, which means it is always the same number for a given set of units.

Discuss the physical significance of what we have figured out. Display **slides P and Q** and lead the discussion using the prompts provided.

Suggested prompts	Sample student responses	Follow-up questions
In atoms, what particles provide positive and negative charges?	Protons provide positive charge. Electrons provide negative charge.	*Which of these particles is moving between atoms? Why?*
If both objects have both particles, how could they be positively or negatively charged instead of neutral?	Some objects have more or fewer electrons. The numbers of electrons and protons determine the charge.	*How do the numbers of electrons compared to protons determine whether the object is neutral or positively or negatively charged?*
When we rub the objects together for a while, what is happening at the particle level?	One object becomes positively charged and the other becomes negatively charged. Electrons move from one object to the other.	*What happens to the amount of charge as you rub the objects together longer? How does that affect the force?*

Introduce a simulation. Display **slide R**. Say, *Sometimes when we have a complex equation, computer simulations help us visualize what it means*. Display https://lab.concord.org/embeddable.html#interactives/interactions/amount-charge.json and discuss the prompts.

Suggested prompts	Sample student responses	Follow-up questions
Why is the force affected when we move the matter farther apart?	The objects aren't as close so they can't pull on each other as much. The electric field is weaker when they are farther apart. The equation says the force is stronger when objects are closer.	*As charged objects move together or apart in space, how is the electric field changing?* *If the two charges came together, what would their combined charge be?*
How does changing the charge change the forces that we see?	Like charges repel. Opposite charges attract. The force is stronger with more charge.	*How do these observations relate to the equation?* *What does this tell us about the forces in a cloud?*

Say, *Now that we have processed the equation a bit, we should think a little more carefully about what happens when we add numbers to it.*

ADDITIONAL GUIDANCE

Students saw this simulation's representation of an electric field in the reading in Lesson 4. It is fairly intuitive that darker-colored arrows represent a stronger electric field at that location. If students ask about the direction, you may say that it shows the direction a positive charge (often called a "test charge") would move in the electric field if it were not held in place (i.e., toward a negative charge but away from a positive charge).

9 · EVALUATE THE MATHEMATICAL MODEL

9 min

MATERIALS: *Comparing Force Relationships*, class copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYaOuQh_VehnU-f1WHfRTZq8iKX8/copy, Internet connected device, https://docs.google.com/spreadsheets/u/2/d/1AdqrHN3LYKtPOKCisYd5IRgO6UPVcFtRlRLC85yJLuw/copy

Orient students to the units related to *k*. Display **slide S.** Say, *If we measure force in millinewtons, distance in centimeters, and treat every positive charge as 1 e and every negative charge as - 1 e, then this is the value for k we would use. Let's see whether this equation can help us figure out how much charge there might be on the different objects we produced static on during our investigations.*

Explain that *k* is a little bit like the conversion factors we saw in *Polar Ice Unit*. Different values of *k* can be used for systems that use different units of measurement for force, distance, and charge, such as pounds instead of millinewtons, or feet or meters instead of centimeters.

ADDITIONAL GUIDANCE

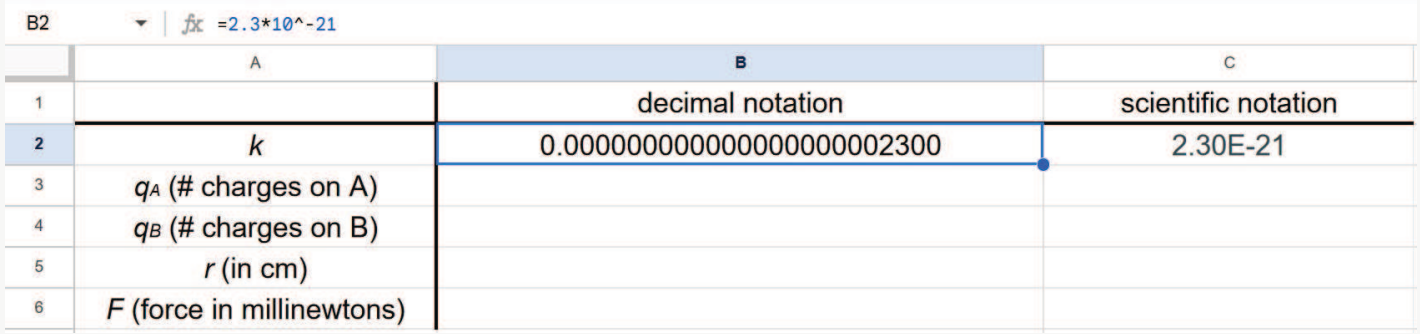
The letter "e" is a unit of measure that refers to an elementary charge; that is, the smallest unit used to measure charge. 1 e is produced by a proton and -1 e is produced by an electron.

Demonstrate how to enter the equation in the Computational Model for Electrostatic Forces spreadsheet. The steps outlined below mirror what is demonstrated in the teacher video https://youtu.be/jF-la-voLro.

Open a class copy of the spreadsheet. Refer to https://docs.google.com/spreadsheets/u/2/d/1AdqrHN3LYKtPOKCisYd5IRgO6UPVcFtRlRLC85yJLuw/copy to create a copy of the spreadsheet to use as you demonstrate these steps. Use the "example" tab when you do this. It keeps the graph that will be created in the last step hidden under a blue deletable rectangle.

Orient students to the variables shown on the spreadsheet. Ask students what the value of *k* is. When they report it, type the following into cell B2 and hit return: =2.3*10^-21

- This value should now appear in cell B2: 0.000000000000000000023
- And this value should appear in cell C2: 2.30E-21



Discuss how these values are related. Students should say the value in C2 is what we see on calculators when we use scientific notation, where the number after the E represents the value of the exponent for base 10. In this case, that value is 10^{-21}. Students should also say that this indicates how many times we divide the first number (2.30) by 10, and this results in shifting the decimal point 21 places to the left, which is what is shown in cell B2.

Now enter a value of 1 into cells B3, B4, and B5, noting what column C produces (equivalent values).

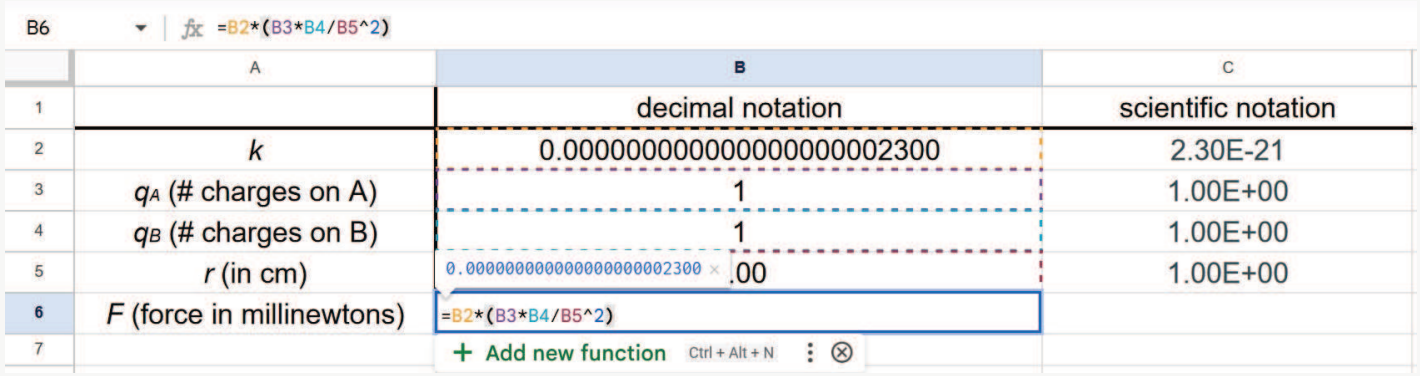
- *Note:* The number formatting on these cells ensures that *r* will display values to the hundredths place, but q_A and q_B will display only integer values.

	A	B	C
1		decimal notation	scientific notation
2	*k*	0.00000000000000000002300	2.30E-21
3	q_A (# charges on A)	1	1.00E+00
4	q_B (# charges on B)	1	1.00E+00
5	*r* (in cm)	1.00	1.00E+00
6	*F* (force in millinewtons)		

Prepare to enter the equation. Ask students now to restate how *k*, q_A, q_B, and *r* are related to force by referring to the equation shown on **slide S** and on *Comparing Force Relationships*.

Demonstrate how you can enter an equation that represents what is shown on **slide S** into cell B6, so that it will automatically generate a calculation for the amount of force based on this relationship. Enter the below equation into cell B6 by typing the related symbols: =, (, *,), and ^2, and clicking the related cells as shown in https://youtu.be/jF-la-voLro.

- Once this equation is entered into cell B6, hit return: =B2*(B3*B4/B5^2).



Ask students why the value shown in B6 is the same as the value in B2. Students should say that this is because the value for *F* is simply *k* multiplied and divided by 1.

Make predictions using the equation. Display **slide T.** Say, *We want to think about what this means at larger scales, like lightning. Let's think about what the equation predicts would happen when we change some of these variables by one order of magnitude or a factor of ten.* Give students a couple of minutes to discuss the changes on the slide with a partner and their related predictions, then discuss these as a class.

Suggested prompt	Sample student response
How would 10 times the number of charges in q_A affect the force?	It should be ten times as strong.
How would 10 times the distance of separation r between the charged objects affect the force?	It should be 1/100th as strong.
How would doing both of the above AND 10 times the number of charges in q_B affect the force?	It should have no effect. It should all cancel out.

Test these predictions as a class using the spreadsheet. Say, *Let's use the spreadsheet to test our predictions.* For each of these entries, ask students to describe how cell B6 compares to cell B2 to check their predictions. Do the following:

- Enter 10 into B3, hit return, and then compare B6 to B2. It will be 10 times the value.
- Enter 1 into B3 and 10 into B5, hit return, and then compare B6 to B2. It will be 1/100th the value.
- Enter 10 into B3, B4, and B5 , hit return, and then compare B6 to B2. It will be the same value.

	A	B	C
1		decimal notation	scientific notation
2	*k*	0.00000000000000000002300	2.30E-21
3	q_A (# charges on A)	10	1.00E+01
4	q_B (# charges on B)	1	1.00E+00
5	*r* (in cm)	1.00	1.00E+00
6	*F* (force in millinewtons)	0.00000000000000000023000	2.30E-20

	A	B	C
1		decimal notation	scientific notation
2	*k*	0.00000000000000000002300	2.30E-21
3	q_A (# charges on A)	1	1.00E+00
4	q_B (# charges on B)	1	1.00E+00
5	*r* (in cm)	10.00	1.00E+01
6	*F* (force in millinewtons)	0.00000000000000000000023	2.30E-23

Compare the predicted force value for a distance to our lab results. Suggest that we compare the mathematical model's predictions to the force values students got in their investigations, starting with the first measurement they took at the shortest separation distance. While displaying https://docs.google.com/spreadsheets/u/2/d/1AdqrHN3LYKtPOKCisYd5IRgO6UPVcFtRlRLC85yJLuw/copy, change the value for cell B5 back to 1. B6 should now be 100 times the value of B2.

Have students open the tab on https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy with their group's investigation results. Ask, *How did the force you detected at the shortest measured distance compare to the amount of force predicted by the equation*? Students should say that they got a much greater (absolute) value for force.

Emphasize the need for trying greater amounts of charge in cells B3 and B4 to see what values for these will result in the forces each group detected at the shortest measured distance. Say, *Let's also think about the differences in the conditions that different groups tested, in terms of amount of charge and types of charge in the system.*

Suggested prompt	Sample student response
What was different between groups that started with Condition 1 and groups that started with Condition 3?	Condition 1 used the same materials for both objects (acrylic sheets). Condition 3 used different materials for the objects. Condition 1 got a graph that had positive y-values on it, while Condition 3 got a graph that had negative y-values on it.

Suggested prompt	Sample student response
So, which condition (1 or 3) was producing opposite charges on each object? How do you know?	Condition 3 because it had negative y-values on the graph.

Demonstrate what happens when you enter a value with an opposite amount of charge into cell B3 or B4. Enter 10 and -10 as example values for these cells. This will change the sign for the value in cell B6 (and C6) to negative.

	A	B	C
1		decimal notation	scientific notation
2	k	0.000000000000000000002300	2.30E-21
3	q_A (# charges on A)	10	1.00E+01
4	q_B (# charges on B)	-10	-1.00E+01
5	r (in cm)	1.00	1.00E+00
6	F (force in millinewtons)	-0.000000000000000000230000	-2.30E-19

Ask, *Why would it be reasonable to assume that for our investigations, there would be the same amount of negative charge as there is positive charge in the system?* Students will say because we removed the electrons from one material and put them onto the other material.

Now direct students to the second part of the spreadsheet. Point out the series of *r* values below row 10. Explain that the graph to the right is based on the values in those rows, and it will automatically update once students enter charge values at the top of the spreadsheet. This will help students make comparisons between the graphs that the equation is predicting for these distances and the graphs that students produced from their own data.

Close class. Celebrate the progress that students have made today, not only in identifying patterns in their data, but in interpreting what they mean in the context of a mathematical model.

End of day 2

10 · FIND A COMBINATION OF CHARGES FOR EACH INVESTIGATION SYSTEM

12 min

MATERIALS: *Comparing Force Relationships*, https://docs.google.com/spreadsheets/u/2/d/1AdqrHN3LYKtPOKCisYd5IRgO6UPVcFtRlRLC85yJLuw/copy, class copy of https://docs.google.com/spreadsheets/d/1QM0e2bQLaygDj6CHYa0uQh_VehnU-f1WHfRTZq8iKX8/copy, Internet connected device

Welcome students. Emphasize that we have had many opportunities to get familiar with our equation. Say that we will continue this exploration today.

Find the amount of charge in the system and compare graphs to students' investigation data. Display **slide U**. Cue students to record their thoughts on *Comparing Force Relationships*. Share the link to the spreadsheet to create a copy for each group to use: https://docs.google.com/spreadsheets/u/2/d/1AdqrHN3LYKtPOKCisYd5IRgO6UPVcFtRlRLC85yJLuw/copy.

Divide each of the original investigation groups in half and assign a different condition (1 vs. 2, or 3 vs. 4) to each half group. Each half group should work to find a combination of charge amounts that would produce the amount of force they measured at the shortest distance for their assigned condition. This should take about two minutes, after which students should continue comparing results with the rest of their

group and recording their answers to questions 2 and 3 on *Comparing Force Relationships*. This should take about three more minutes.

Remind students:

- All Group 1s should be exploring combinations of values in cells B3 and B4 that have the same sign (both positive or both negative), to find which combination yields the amount of force actually detected at the shortest distance.
- All Group 3s should be exploring combinations of values in cells B3 and B4 that have opposite signs, to find which combination yields the amount of force actually detected at the shortest distance.

Discuss students' responses to question 3 on *Comparing Force Relationships*. Ask, *How closely did the predicted graphs of force vs. distance from the equation fit the graphs from the investigation data?*
Sample student responses include:

- *It produced a graph with the same general shape as our data (nonlinear).*
- *It predicted close to the same forces as our data.*
- *It comes close to predicting the same force values for some of the distances as for the ones we measured in our investigation.*
- *It predicts really small values of force for greater distances than those we were able to measure for.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
In Parts 1-2:

- Students describe at least two patterns in the graphs in how amount of charge, distance between charges, and strength of forces are related across the class results. (DCI: PS2.B.1; CCC: 1.4)
  Examples include:
  - Greater distances produce weaker forces and/or smaller distances produce stronger forces. All the graphs were nonlinear.
  - More charge produces stronger forces.
  - Optional: Some graphs showed negative forces and others showed positive forces, OR some graphs were flipped/mirrored across the *x*-axis compared to others.

In Part 3:

- Students describe how the shapes of the lines on the graphs compare and how well they fit the patterns predicted by Coulomb's law. (SEP: 5.2, 6.1; CCC: 1.4)

What to do: For students who struggle to see how the graphs with more charge produce more force in Parts 1-2, or who struggle to describe how close the fit of the graphs are in Part 3, encourage them to compare the *y*-values for two additional specific distances on each graph.

Building toward 7.A.2 Make qualitative claims using mathematical representations of patterns in how amount of charge, distance between charges, and strength of forces are related across the class results; and compare these to patterns predicted by Coulomb's law. (SEP: 5.2, 6.1; DCI: PS2.B.1; CCC: 1.4)

11 · DEMONSTRATE HOW TO CALCULATE THE FORCE FOR A LARGER SCALE SYSTEM

7 min

MATERIALS: *Solving for Force*, scientific calculator, "Solving for force using Coulomb's law" poster

Motivate using the equation to make predictions on a larger scale. Point out that we have investigated a small-scale system, but we want to look at a larger-scale system like lightning. Ask, *Since this equation can be used to predict the relationships among force, distance, and amounts of charge, how might we use it to make predictions for a larger-scale system?*
Listen for student responses such as:

- *If we knew the distance from the ground to the cloud and also the electrostatic forces, we could figure out how many charges are in the system.*

- *If we knew the distance from the ground to the cloud and the amount of charge in the cloud, we could figure out how much electrostatic force the charges in the cloud are producing on other charges.*

Define Coulomb's law. Display **slide V**. Tell students that scientists have found that this equation works across many different scales. Because it seems to describe how electrostatic forces work in many different situations, it is called a law. This one is named Coulomb's law.

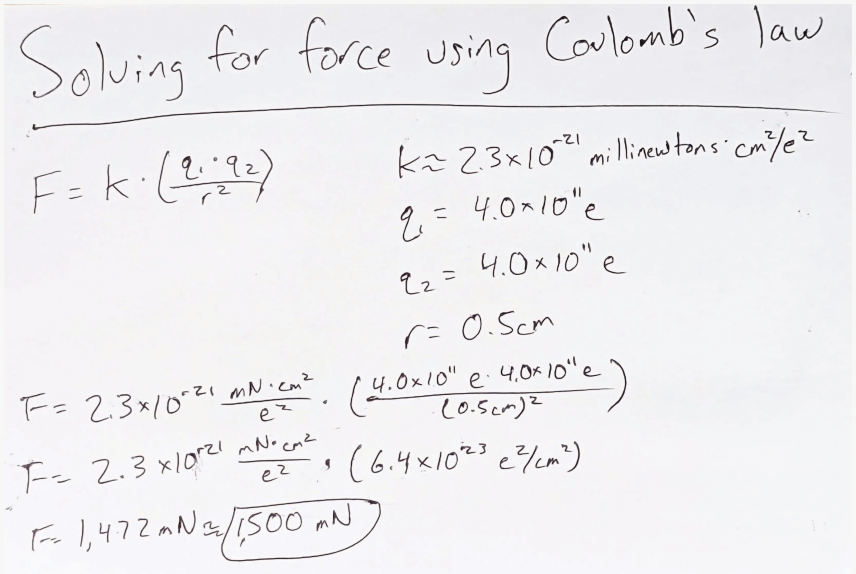
Demonstrate how to use Coulomb's law to predict forces in large-scale systems. Suggest we make predictions for a large system, on the scale of lightning. Say, *In How Lightning Starts, we read that the amount of charge near the bottom of a cloud is about 10,000 times the amount in our static investigations, which is four magnitudes greater, or 10 to the fourth power greater, than the values we measured in our investigation.*

Suggest that we think about how to work through the force calculation by hand.

Direct students' attention to the "Solving for force using Coulomb's law" poster.

Then, work through all the steps on the poster, emphasizing the importance of each step:

- Perform any necessary unit conversions to match the units in the given *k*-value (cm and e).
- Substitute the known values and their units for the corresponding values in the equation and ensure that the order of operations is maintained.
- Show any intermediate calculations you perform, such as the result of operations within parentheses, and record the corresponding units.
- Show the final result of these calculations and the corresponding units.



Revisit unit conversions. Distribute *Solving for Force*. Pair students with a partner and say that they will determine forces using these larger-scale distances and charges. Explain that each partner will use Coulomb's law to solve for the force between ground and cloud. Display **slide W** and ask students to convert each given distance into centimeters (question 1a). You may provide guidance to individual students as needed. If students readily complete this conversion, ask them to move on to question 1b.

If students struggle, work with them individually or make groups of four so that more brains are on the problem. Ensure that students are thinking carefully about the units they want to convert from and to and the conversion factor that would allow them to do so.

12 · CALCULATE FORCE AT A LARGER SCALE

15 min

MATERIALS: *Solving for Force*, scientific calculator, "Solving for force using Coulomb's law" poster

Draw what is happening in the situation. Display **slide X**. Use the prompts to elicit students' ideas about how the charge, distance, and resulting force differ between the two situations, as well as their suggestions for representing the different variables visually. Record students' ideas and sketch their suggested representations on the board. Encourage them to share responses that use proportions, not just greater/lesser comparisons.

Suggested prompts	Sample student responses	Follow-up questions
How is the charge different between the two situations?	The charge of A is twice as great for the left partner as for the right one.	*How would we show charge in a sketch?*
How is the distance different between the two situations?	The distance is 10 times greater for the left partner than for the right one.	*How would we show distance in the sketch?*
How do we expect the force to differ between the two situations?	The force is going to be greater for the right partner because they have a shorter distance. The force is going to be greater for the left partner because they have a greater charge.	*How would we show different amounts of force in the sketch?*

ADDITIONAL GUIDANCE

Students may already be familiar with arrow length as a convention for the magnitude of a force. Encourage that convention here so that it can be used throughout this and future OpenSciEd units when needed for sensemaking.

Apply Coulomb's law to a larger-scale system. Display **slide Y** and give students time to work individually, then compare their results with their partner. As students work individually, circulate around the room and assist as needed. See *Force Key* for correct answers.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students document all the steps of using an equation (Coulomb's law) to solve for the strength of the forces in a larger-scale system. (SEP: 5.3; DCI: PS2.B.1)
  This might include:
  - Writing the general equation (Coulomb's law) and the known variables, values, and units for k, q_A, q_B, and r.
  - Substituting the known values for the correct variables in the general equation.
  - Performing the related calculations using order of operations.
  - Reporting a predicted force value (F) in millinewtons.
- Students tie the difference in scales of solutions to the mathematical relationships in Coulomb's law. (SEP: 5.3; CCC: 3.5)

What to do:

Highlight to students that carefully documenting their work is a skill that spans both math and science. Collect *Solving for Force* and provide feedback as students prepare for the mid-unit, summative task in Lesson 9. If students do not document solution steps in the first part of this handout, or report that they have answers different from those expected when comparing with their partner, then give them an opportunity to practice these skills again as home learning, this time with all values doubled, or assign *Coulomb's Law Practice*.

Building toward 7.B.1 Apply techniques of algebra and functions to calculate the force predicted by Coulomb's law in a larger-scale system and contextualize the significance of the phenomenon. (SEP: 5.3; DCI: PS2.B.1; CCC: 3.1, 3.5)

13 · DEBRIEF FORCE CALCULATIONS

6 min

MATERIALS: None

Display **slide Z**. Have students turn and talk about the prompts on the slide, then discuss as a class.

Suggested prompt	Sample student response
How do our calculations from lightning compare to the forces we measured?	They are WAY bigger.
Why is that? What do you think the difference in those forces means?	The amounts of charge were much bigger than what we experienced, even though the distances were large. The forces seem dangerously large--wouldn't a big force mean that the shock is bigger?

Suggested prompt	Sample student response
How can you use what we figured out today to help explain what causes so much charge to move so quickly during a lightning strike?	The force from all that charge built up in the cloud may pull or push the charges out of the cloud to the ground. When there is lots of charge in the system, like in the bottom of a cloud, the charges can be pretty strong over large distances (like from the cloud to the ground). Pushes and pulls from all that charge built up in the bottom of the cloud must at some point cause some of the charges to start moving quickly out of the cloud.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students articulate how changes in scale of charge and distance result in changes in force. (DCI: PS2.B.1; CCC: 3.1)
- Students share their ideas about what it might mean that forces are so large. (CCC: 3.1)

What to do:

If students have trouble ideating what it means that the magnitudes of the forces and charge are so large, it may be productive to estimate for how long the acrylic sheets would need to be rubbed together to build up a similar amount of charge in the lab. Reflect on how much more powerful the lightning display is in comparison because of this difference in the amount of friction that must have been present.

If students would benefit from additional practice, consider assigning *Coulomb's Law Practice* at the end of the lesson as either in-class work or home learning.

Building toward 7.B.2 Apply techniques of algebra and functions to calculate the force predicted by Coulomb's law in a larger-scale system and contextualize the significance of the phenomenon. (SEP: 5.3; DCI: PS2.B.1; CCC: 3.1, 3.5)

14 · NAVIGATE

5 min

MATERIALS: science notebook

Navigate. Display **slide AA** and give students time to update their Progress Trackers. If desired, you may also encourage them to add *Coulomb's law* to their Personal Glossaries. A sample Progress Tracker entry is shown. Encourage students to add a note about how what they figured out relates to a phenomenon like lightning.

Question	What I figured out in words/pictures
How are electrostatic forces between objects affected by the amount of charge and the distance between them?	• *Coulomb's law lets us calculate electrostatic forces if we know other information and predict how big of a force there is to cause lightning to strike.* • *When the charge goes up, the force goes up.* • *When the distance goes up, the force goes down - very quickly.* • $F = k * q_A * q_B / r^2$

ALTERNATE ACTIVITY

If students would benefit from additional practice with calculations and reasoning around Coulomb's Law, *Coulomb's Law Practice* is provided as additional practice, with the answers available in *Coulomb's Law Key*. You may use this task in class or as home learning.

Additional Lesson 7 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSA.REI.A.1: Explain each step in solving a simple equation as following from the equality of numbers asserted at the previous step, starting from the assumption that the original equation has a solution. Construct a viable argument to justify a solution method.

Students use Coulomb's law to make predictions of relationships between variables and examine graphs of the relationship between force and distance. They then use the equation (Coulomb's law) to examine those graphical relationships.

CCSS.MATH.CONTENT.HS.N-Q.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; ~~choose and interpret the scale and the origin in graphs and data displays.~~

Students complete unit conversions as part of their calculation work.

LESSON 8: How can something that is neutral have an attractive or repulsive interaction with another object without any contact?

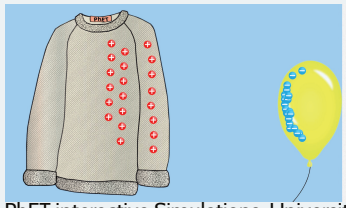
PREVIOUS LESSON

We carried out an investigation to determine how electrostatic forces between objects are affected by the amount of charge and the distance between them. We identified patterns in how different variables affect these forces. We evaluated a mathematical model and used algebraic methods to predict the effects of larger-scale changes in a system.

THIS LESSON

INVESTIGATION

1 day



PhET interactive Simulations, University of Colorado Boulder

We think back to the equation in the last class and its prediction that neutral objects should not interact with charged objects. We observe a balloon attracting multiple neutral objects. This seems odd after our prior investigation, where we measured attraction and repulsion between two charged objects. We use a simulation and our paper-clip models to explain what we think is happening in the atoms of neutral objects when they interact with charged objects. This leads us to the conclusion that atoms can be temporarily polarized, meaning a partial charge can be induced when electrons shift to one side of an atom.

NEXT LESSON

We will create Gotta-Have-It Checklists and use them to develop updated models to answer the question "What causes lightning to strike at a particular place and time?". We will take stock of the Driving Question Board, and then complete an assessment task to demonstrate our understanding of static interactions and Coulomb's law.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6, HS-PS3-2, HS-PS3-5

WHAT STUDENTS WILL DO

8.A Use multiple models to explain patterns observed at different scales in the behavior of uncharged objects when a charged object exerts a force on them. (SEP: 2.4; DCI: PS1.A.3; CCC: 1.1, 3.3)

WHAT STUDENTS WILL FIGURE OUT

- Atoms can be temporarily polarized, meaning a partial negative and partial positive charge can be induced through the movement of electrons to one "side" of the atom.
- Electrons are not transferred to or from the atom when atoms are polarized.
- Polarization can occur over a distance; contact between objects is not required.

Lesson 8 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		**NAVIGATE** Lead a brief discussion to help students remember what they learned last class.	A-B	
2	7 min		**OBSERVE STATIC PHENOMENA** Demonstrate attraction between a charged object and a neutral object.	C-D	inflated balloon with string, tinsel detector from Lessons 3 and 4, prepared paper scraps
3	10 min		**EXPLORE A SIMULATION** Have students work with a partner or small group to use a simulation to explore attraction between charged and neutral objects.	E-G	internet-connected device, https://phet.colorado.edu/sims/html/balloons-and-static-electricity/latest/balloons-and-static-electricity_all.html
4	8 min		**USE PAPER-CLIP MODELS TO MODEL POLARIZATION** Have partners use their paper-clip models to show what happens to electrons when neutral objects are brought near charged objects.	H-I	index card, 3 small paper clips
5	9 min		**NAME TERMS AND UPDATE PERSONAL GLOSSARIES** After a brief Building Understandings Discussion, have students add new terms to their Personal Glossaries.	J-M	
6	8 min		**APPLY OUR IDEAS TO LIGHTNING** Assess students' understanding by asking them to apply the ideas of partial charge and polarization to what happens to the ground during a lightning strike.	N-P	paper-clip model

End of day 1

Lesson 8 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • index card • 3 small paper clips • paper-clip model	• internet-connected device • https://phet.colorado.edu/sims/html/balloons-and-static-electricity/latest/balloons-and-static-electricity_all.html	• inflated balloon with string • tinsel detector from Lessons 3 and 4 • prepared paper scraps

Materials preparation (25 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Tear or cut a piece of plain paper (lined paper or printer paper) into small, approximately 1 cm^2 scraps for the demonstration with the balloon.

Although students do directly handle the balloon in this lesson, take student allergies into account. Record this demonstration in advance if necessary to ensure student safety. If humidity is particularly high, additional charging of the balloon or dehumidification may increase the likelihood that the balloon will stick to the wall.

Check Internet-connected devices to make sure they can run https://phet.colorado.edu/sims/html/balloons-and-static-electricity/latest/balloons-and-static-electricity_all.html.

Make sure you are familiar with the simulation https://phet.colorado.edu/sims/html/balloons-and-static-electricity/latest/balloons-and-static-electricity_all.html before using it in class. Run it once set to "Show no charges" and then again set to "Show all charges" so that you can familiarize yourself with both settings.

Lesson 8 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build new ideas related to the following disciplinary core idea:

- **PS1.A.3 Structure and Properties of Matter:** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

This lesson represents students' first engagement with PS1.A.3 in this unit. Students will continue to build this idea in Lesson 11 as they model how charge moves to create the lightning strike, and in Lesson 13 as they figure out why bodies of water are considered dangerous during a storm.

This lesson continues to build on the idea of attraction between objects at a distance that students have been building across several lessons. In middle school, students relate observed macroscopic patterns of forces at a distance to related microscopic patterns. Throughout this unit, students use the patterns of attraction and repulsion observed at the macroscopic level to infer what is happening at the subatomic level to electrons in atoms (CCC: 1.1). In this lesson, students are adding the idea of induced polarization, or the shift of electrons within atoms to create temporary partial charges in the presence of an external charge such as lightning or a balloon. Establishing these patterns requires moving beyond the visible scale to atomic and subatomic scales (CCC: 3.3).

Students are building this understanding through the use of multiple models that help them infer what is happening at the particle level (SEP: 2.4). In Lesson 2, students explicitly considered the merits and limitations of models, and they will do so again here. In Lesson 5, students used their paper-clip models to show electron transfer between atoms to explain the attraction between oppositely charged objects. In this lesson, students use a simulation to observe the movement, but not transfer, of electrons in a neutral object when a charged object is near, and they tie this more explicitly to specific atoms through the use of paper-clip models. The explanation task at the end of the lesson allows students to show that they can build mechanistic accounts using multiple models. Although this element is not directly assessed in the mid-unit transfer task in Lesson 9, students' use of multiple models in this lesson provides an opportunity for feedback on their modeling practice before the next lesson.

As students model polarization, make sure they can articulate verbally, or with their model, that this phenomenon is different from ionization. Be prepared to address misconceptions or partial understandings, such as students fully removing paper clips when representing what happens to the ground during a lightning strike. If students seem confused, prompt them to think about what happens after the lightning strike, or ask them to recall that the paper scraps were not attracted to other objects after the balloon was removed.

In this lesson, students will co-construct or encounter a definition for the following terms, which they should add to their Personal Glossary: *partial charge, polarization,* and *induced polarization*. We recommend that you do not post any terms or ask students to record any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students do not categorize materials based on electrical behavior in this lesson. In Lesson 11 they will name insulators and conductors.

While students will determine what induced polarization is and what causes it, this lesson does not address electronegativity or why electrons are not transferred in these instances. This lesson also does not address what makes some substances, such as water, permanently polar, or how that affects their properties. Water's polarity and its ability to dissolve ionic substances will be initially investigated in Lesson 13, and these ideas will be more fully addressed in the next unit.

Any other activities or demonstrations that help students observe induced polarization are appropriate here, such as holding a charged balloon near a stream of water or another balloon, but students will not distinguish between polar and nonpolar molecules or between different bond "types" until *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*.

LEARNING PLAN for LESSON 8

1 · NAVIGATE

3 min

MATERIALS: science notebook

Have students recall what they figured out last class. Display **slide A.** Ask students to answer the questions on the slide in their science notebooks. ✱ Give students a minute to write, then ask for volunteers to share their answers.

Suggested prompt	Sample student response
What did we figure out in our last class?	We figured out that there is a relationship between charge, distance, and force. We used an equation for this relationship. We figured out that the huge charge in lightning is how it can move from the cloud to the ground.
What have we decided makes something neutral at the particle level?	Equal positive and negative charge. Equal protons and electrons.

Revisit Coulomb's law. Display **slide B.** Give students a minute to think individually, then discuss the prompts on the slide.

Suggested prompt	Sample student response
What does this mathematical model predict about the interactions between neutral and charged objects?	There shouldn't be interactions between charged and neutral objects. In the equation we multiply the two objects' charges, so if one charge is zero, shouldn't the force be zero?
If the ground is neutral, what is lightning attracted to in the ground?	If the ground is neutral, lightning won't be attracted to it. There must be some charge in the ground.

✱ ATTENDING TO EQUITY

To help all students summarize or explain the complex ideas they figured out last class, sentence starters may be useful. These might include:

- When we did the Electrostatic Force Investigation, we found that the data showed that _____.
- We saw [description of the data or patterns] in our investigation.

2 · OBSERVE STATIC PHENOMENA

7 min

MATERIALS: science notebook, inflated balloon with string, tinsel detector from Lessons 3 and 4, prepared paper scraps

Review what students have observed and figured out about static phenomena. Display **slide C** and instruct students to make a Notice and Wonder chart in their science notebooks. Say, *We have seen that for objects to become charged, there must be some sort of contact with another object.* Hold up an inflated balloon with a string tied to it and ask students what they expect to happen if you hold it near the wall. Remind

students that the balloon has just been sitting on a table until now. Ask, *What charge do you expect the balloon to have? What about the wall?* Students should not expect either to have a charge. Say, *So, based on the mathematical model from last class, what do you think will happen as the objects interact?*

Demonstrate two objects of neutral charge. Hold the string so the balloon hangs near the wall; nothing will happen. Show students the tinsel they used as a detector in earlier lessons and ask what they expect to happen when you move the tinsel near the balloon. Students should expect no interaction, which is what they will see. Have students record their observations in their science notebooks.

Next, rub the balloon on hair, a sweater, or a piece of fabric and ask, *Now what do we expect to see when we move the balloon near the wall or the tinsel?* Students should now expect to see the tinsel attracted to the balloon. Move the tinsel near the balloon to "detect" the charge, then hold the balloon by the string near the wall again. This time, the balloon will stick to the wall. Have students record their noticings and wonderings in their science notebooks. Have a brief discussion about what seems to be going on here.

Suggested prompts	Sample student responses	Follow-up questions
What does it mean if the balloon is sticking to the wall?	The balloon and the wall are oppositely charged. Both objects seem charged.	*So do we think the wall is charged? How did that happen?*

Observe another interaction. Show students the scraps of paper. Bring the tinsel near the paper to show students that there is no interaction. Say, *So this detector indicates that there is not any charge on the paper. Using this information, do you think the paper will be attracted to our balloon?*



Possible responses:

- *The paper won't be attracted.*
- *Maybe the paper will become charged?*
- *I don't think it should be attracted, but the balloon stuck to the wall so now I'm not sure.*

Hold the balloon over the scraps of paper. The scraps will move and stand on end. Do not hold the balloon so close that the scraps move off the table and stick to the balloon; it is important that students see the attraction of the paper scraps without any contact between the paper and the balloon. Have students record their noticings and wonderings in their science notebooks.

Discuss what is happening to the paper. Ask a few volunteers to share their noticings and wonderings. Then display **slide D** and give students two minutes to discuss the questions on the slide with a partner. Then, ask for volunteers to share out.

Suggested prompt	Sample student response
Think back to the patterns of attraction and repulsion we have seen so far in this unit. What can we infer is happening to the subatomic particles in the paper when the balloon is near?	They could be losing or gaining electrons. Whatever charge the balloon has, the paper is getting the opposite charge. So if the balloon is negative, the paper is becoming positive.
How could this explain our observations?	Since the paper and balloon are attracted, they must have opposite charges.

Suggested prompt	Sample student response
But the balloon and paper did not actually touch... so how did the paper become charged?	I don't know, but it seems charged. Maybe electrons can still attract or repel in neutral things?

3 · EXPLORE A SIMULATION

10 min

MATERIALS: science notebook, internet-connected device, https://phet.colorado.edu/sims/html/balloons-and-static-electricity/latest/balloons-and-static-electricity_all.html

Explore the simulation. Say, *We are not sure about what is happening at the particle level that would explain why the balloon and paper scraps are even interacting. I found a simulation that may help us think about what is happening at the atomic level when we put a charged object near a neutral object.* Open the simulation https://phet.colorado.edu/sims/html/balloons-and-static-electricity/latest/balloons-and-static-electricity_all.html. Tell students that before they explore the simulation, you are going to show them a few things. Make sure the simulation is set to "show no charges," then demonstrate how students can drag the balloon and rub it on the sweater. Next, release the balloon so that students can see it attracted to the sweater, and then drag the balloon to the wall so that students can see it stick to the wall.✱

Suggested prompt	Sample student response
What can we infer is happening as I move the balloon to the sweater and then away?	The balloon is getting charged when you rub it on the sweater. The balloon is attracted to the sweater because they are oppositely charged.
What can we infer is happening next as I move the balloon to the wall?	The balloon doesn't seem as attracted to the wall. Maybe the wall has a weaker charge?

After making these initial observations and inferences, display **slide E** and tell students to go to the simulation. Have students work with a partner or small group to explore the simulation and discuss the questions on the slide as they try the different settings. Encourage students to record observations in their science notebooks.

Discuss the simulation. Display **slide F** and have a whole-class discussion. ✱ Prompt students to think about the patterns in the various interactions they have observed and to use those patterns to explain what might be happening at the subatomic level.

✱ ATTENDING TO EQUITY

Universal Design for Learning: This simulation is one of several *representations* that are provided for all students in this lesson. These alternative ways of displaying information allow students to build understanding in their own way.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Students should notice patterns in the behavior of neutral objects in the presence of a charged object. The balloon attracts the tinsel, paper scraps, and wall, even though these objects show no attraction to each other. In the simulation, students should observe the pattern of electron movement, even when electrons are not actually transferred to or from the wall.

Suggested prompt	Sample student response
Do your observations match your inferences from when you could not see the charges?	Kind of. We did see negative charges move. We saw the balloon become negatively charged when it was rubbed on the sweater.
How does the simulation help you explain why the balloon is attracted to the wall (and the paper)?	We can see the balloon push away the electrons in the wall. The balloon is attracted to the positive charges in the wall, so maybe something similar happens with the paper.
What are you still unsure about?	Do the electrons do this in other materials? Why do the electrons move but not get transferred?

Discuss different models. Display **slide G** and discuss the prompts as a class.

Suggested prompt	Sample student response
What merits (strengths) does the simulation have that the other models do not?	We can see which electrons do and don't transfer, and when. We can see that everything starts as neutral.
What are some limitations of the simulation?	It doesn't show how electrons are related to or connected with individual atoms. It really only shows charges, not actual subatomic particles.
How would zooming in with a paper-clip model help us better understand what is actually happening?	We could model individual atoms. We could think about how the electrons themselves move, not just charges more generally.

ADDITIONAL GUIDANCE

In the next activity, students will use the paper-clip model to zoom in on a more atomic-level view than the simulation provides. These prompts are intended to help students consider where the current model falls short, so as to motivate a shift to another model and thus a shift in scale.

4 · USE PAPER-CLIP MODELS TO MODEL POLARIZATION

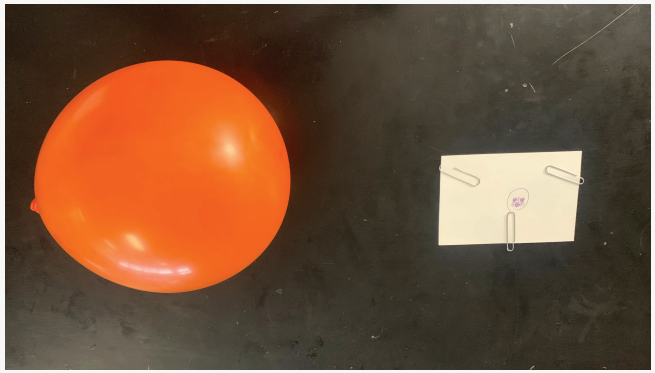
8 min

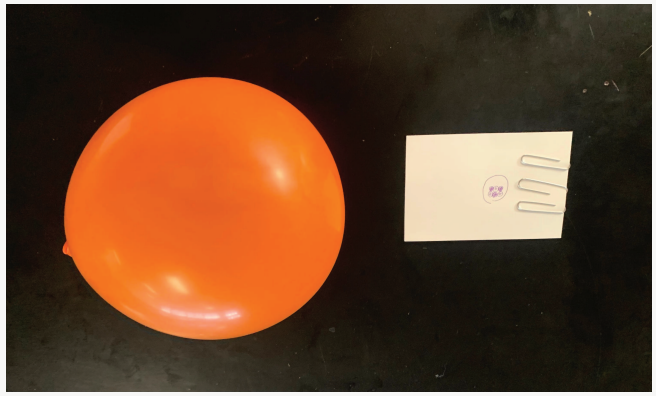
MATERIALS: science notebook, index card, 3 small paper clips

Model what is happening to the atoms in the paper scraps. Say, *Let's use our paper-clip models to help us visualize what might be happening between the balloon and the paper scraps.* Direct students to take out their paper-clip models from Lesson 5. Start by reviewing what the paper clips represent and what happens when atoms become charged.

Suggested prompt	Sample student response
When we pulled apart the top and bottom pieces of tape a few days ago, what did we decide was happening to them?	We said the tapes were becoming charged. One tape became positive and one tape became negative. The tapes became charged by losing or gaining electrons.
How did we model that using the index card and paper clips?	We moved a paper clip from one card/atom to the other card/atom. We moved a paper clip to show one atom was now positive and one was now negative.
Can someone remind us what the index card and paper clips represent?	The card represents the nucleus, consisting of protons and neutrons. The paper clips represent electrons.

Display **slide H**. Have students individually model what they think happened to the atoms in the paper scraps when the balloon was brought close to them. Prompt students to consider that the scraps did not become charged the way the balloon did, but they were still attracted to the balloon. Say, *How can we model that with the paper clips? How can we show that the paper scraps stood on end, but then fell back down as soon as we took the balloon away?* Be sure to emphasize that here, we are using the index cards to represent whole objects rather than individual atoms.✱





✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

The *Framework for K-12 Science Education* explains that, at the high school level, students should be able to work with and shift among models of several types: "*Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.*"

The simulation helps students visualize the polarization of neutral objects by charged objects, and the index cards and paper clips provide a manipulable model to help students think through the temporary nature of induced polarization.

ADDITIONAL GUIDANCE

If students are struggling with where or how to move the "electrons" on their paper-clip models, prompt them by asking whether or notthey think the paper became charged and lost or gained electrons.

Students may also move the paper clips toward the balloon instead of away from the balloon. If they do this, ask what assumptions they are making about the charge on the balloon. Even though students should see that the balloon is negatively charged in the simulation, as long as they can correctly explain why they moved the paper clips the way they did in terms of the charge on the balloon, it does not matter whether students assume the balloon's charge is positive or negative.

Review other models. Display **slide I.** Have students join with a partner to compare models. Each student should spend one to two minutes walking through their model and showing their partner what they think is happening to the electrons in the paper scraps when the balloon is brought near and then removed. After each partner has shared, students should summarize their ideas in their science notebooks.

5 · NAME TERMS AND UPDATE PERSONAL GLOSSARIES

9 min

MATERIALS: science notebook

Come to agreement about the atoms in the paper scraps. Ask students to look at the summaries they just wrote. Display **slide J** and have a brief Building Understandings Discussion about what is happening to the atoms in the paper.

KEY IDEAS

Purpose of this discussion: To realize that the atoms in the paper scraps and the wall are not becoming ionized because electrons are not being transferred. Rather, electrons are simply moving within atoms to create partially positive and partially negative "sides" of the atoms.
Listen for these ideas:

- Electrons are not transferred, but something is happening to lead to attractions between the balloon and the paper scraps/wall.
- The charge or charge-like phenomenon is temporary because the paper is attracted to the balloon but not to the tinsel.
- Electrons can move, so perhaps they are shifting within atoms and then shifting back when the charged object is removed.✱

Suggested prompts	Sample student responses	Follow-up questions
Do we think the atoms in the paper scraps or wall are becoming charged in the same way we have been talking about atoms becoming charged?	No, because the paper and tinsel didn't attract. No, because in the simulation, we saw that the negative charge in the wall didn't transfer to or from the balloon.	*Why or why not?*

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: Later in this activity, students will name this idea as *polarization*. Use the word *polar* in its geographic context (the "ends" of the Earth) to help students think about the meaning of polarization. *Polar* has cognates in many Indo-European and other languages, including a perfect cognate, *polar*, in Spanish. *Induce* also has cognates in Spanish and French, and students may connect medical examples like "noise-induced hearing loss" and "induced labor" before childbirth.

Suggested prompts	Sample student responses	Follow-up questions
Do we think there is some sort of "charge" on the paper or wall at some point, maybe even just briefly?	It seems like there is a charge just when the balloon is near. In the simulation, we saw the electrons move in the wall, but then move back. So there is some sort of charge or imbalance just for a moment.	*How might we represent that?* *Why is it the electrons that move to cause an imbalance?*

Update Personal Glossaries. Say, *Scientists have a term for the phenomenon we observed with the wall and paper scraps. We call the type of charge that occurs when electrons shift but do not actually transfer, a partial charge. Scientists show that an object has a partial charge by using the Greek lowercase letter delta.* Display **slide K**, which shows the symbols δ^+ and δ^-. Students should draw these symbols in their notebooks. They can draw an index card with the paper clips all on one side, with that side labeled δ^- and the opposite side δ^+, or they can draw another representation of an atom with the electrons shifted to one side. The important thing is that students label the partial charges on whatever model they draw. Have students add the term *partial charge* to their Personal Glossaries.

Sample glossary entry: *partial charge: when electrons shift within an atom but do not transfer to another atom.*

Define polarization. Display **slide L**. Say, W*hen electrons shift within atoms or molecules in this way, the atoms or molecules are said to be polarized.* Stress to students that this shift is within an atom or a molecule and not between two different atoms or molecules. Ask, *Have you used the term polar before? What did you use it to mean?* Accept all student responses. Highlight those in which students talk about polar opposites. Have students add the term *polarization* to their Personal Glossaries.

Sample glossary entry: *polarization: partial charge due to a shift in an atom's electrons.*

Define induced polarization. Display **slide M**. Ask, *What did you notice about the polarization of the paper scraps or wall as the balloon was moved away?* Look for students to say that the paper or wall was only polarized when the charged balloon was nearby. Say, *Scientists call this temporary state of polarization caused by non-contact interactions with charged objects, induced polarization.* Have students add the term *induced polarization* to their Personal Glossaries.
Sample glossary entry: *induced polarization: temporary polarization due to interactions with a charged object.*

6 · APPLY OUR IDEAS TO LIGHTNING

8 min

MATERIALS: science notebook, paper-clip model

Apply polarization to lightning. Say, *We have figured out some pretty big ideas about atoms, charge, and attraction. Let's see if we can apply these ideas to our lightning system.* Display **slide N**. Have students think back to the lightning videos they saw on the first day of this unit, the static investigations they have done, and *How Lightning Starts* in Lesson 6.

Suggested prompt	Sample student response
What do we know is happening to particles in clouds and in the air before a lightning strike?	Electrons get knocked off of water so the particles become charged. Electrons are transferred, and the bottom of the cloud becomes negatively charged.
If a lightning strike is a huge amount of negative charge moving downward, what do we think it is moving toward? What makes it move downward?	Maybe there is a positive charge on the ground? Maybe it is attracted to the ground?

Use paper-clip models to explain a part of the lightning system. Say, *Take a moment to think about what we have figured out about polarization. Now consider a lightning strike. Do you think something similar is happening to the atoms in the ground during a lightning strike?* Accept all student responses. Suggest using the paper-clip models to try to show or figure out what is happening in the ground right before a lightning strike. Display **slide O** and have students turn and talk with a partner about how we could use our different models and investigations to explain what is happening to cause lightning to move toward the ground.

Suggested prompt	Sample student response
How can we use our paper-clip model and the simulation to explain what causes lightning to move toward the ground?	We could show how the electrons in the lightning are affecting the ground.
What in the models or demonstration could represent charge in the lightning?	It would be like the balloon because there is negative charge in lightning and in the balloon.
What in the models or demonstration could represent the atoms in the ground?	The paper scraps that the balloon attracted. The tinsel, maybe? We could use the index card and paper clips to show electrons in the ground moving.

Write or draw explanations. Display **slide P**. Distribute *Explaining Polarization*. Have students think back to the balloon, the paper scraps, and the paper-clip models to help them reason through what is happening to the ground before a lightning strike. Give students time to write their explanations. Encourage students to give detailed, particle-level explanations; they should not say only that atoms become charged or polarized, but should describe what is happening to the electrons of those atoms when they become charged or polarized.✱

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Students conclude this lesson by drawing on multiple types of models to provide a mechanistic account (SEP) of how lightning can strike apparently neutral ground. Their explanation requires the use of patterns at a variety of scales (CCC) and an understanding of how bulk-scale interactions, like induced polarization, rely on atomic-level forces (DCI). This ideas is the final piece of the conceptual model that students began building in the anchor and will revise in the next lesson.

Collect students' explanations for feedback and celebrate their effort and what they have worked together to figure out. See *Lightning Polarization Key* for sample student responses.

ASSESSMENT OPPORTUNITY	**What to look/listen for in the moment:** See *Lightning Polarization Key* for what to look for in students' explanations. **What to do:** See *Lightning Polarization Key* for guidance on using students' explanations. Students will begin Lesson 9 by sharing what they figured out in this lesson, so reviewing these explanations will help give a clearer picture of what students will say in that navigation moment. **Building toward 8.A** Use multiple models to explain patterns observed at different scales in the behavior of uncharged objects when a charged object exerts a force on them. (SEP: 2.4; DCI: PS1.A.3; CCC: 1.1, 3.3)
ADDITIONAL GUIDANCE	Students will use the paper-clip models again in Lesson 11. Ask students to save their models in their science notebooks, or collect them to redistribute during Lesson 11.
ALTERNATE ACTIVITY	**Extension opportunity:** Provide balloons and/or paper-clip models for students to take home so that they can demonstrate this lesson's phenomenon, as well as Coulomb's law, to their families. Have students report back at the start of Lesson 9.

LESSON 9: How can we revise our models to explain what we have figured out about the lightning system?

PREVIOUS LESSON

We observed a charged object attracting neutral objects and wondered how that could happen. We used a simulation to better understand what is happening at the atomic level. We used our paper-clip models and the simulation to explain what happens in the atoms of neutral objects when they interact with charged objects. We decided that the atoms become temporarily polarized.

THIS LESSON

PUTTING PIECES TOGETHER, PROBLEMATIZING

2 days





We work with partners to create Gotta-Have-It Checklists, then use them in small groups to develop updated models to answer the question "What causes lightning to strike at a particular place and time?". We reflect on the Driving Question Board, answering questions we have made progress on and highlighting questions we still have to pursue. Then, we individually complete an assessment task to demonstrate our understanding of static interactions and Coulomb's law using modeling and mathematical- and patterns-thinking.

NEXT LESSON

We will analyze data that show that lightning transfers a LOT of energy. We will use a computational model that shows energy storage between charges to realize that the energy comes from the electric field. We will update our lightning models and apply what we figure out about energy stored in a field to storm clouds.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6, HS-PS3-2, HS-PS3-5



WHAT STUDENTS WILL DO

9.A Revise a model based on evidence to illustrate the relationships between components of the lightning system in terms of matter changes/flows within that system. (SEP: 2.3; DCI: PS1.A.1, PS2.B.1; CCC: 5.2)

9.B Use mathematical representations of Coulomb's law to describe and predict the electrostatic forces between objects. (SEP: 5.2; DCI: PS2.B.1, PS2.B.2; CCC: 1.1)

WHAT STUDENTS WILL FIGURE OUT

- Causes of lightning can be explained using the matter perspective (the change in charges in the cloud).
- Causes of lightning can be explained using the forces perspective (the attractive forces between the bottom of the cloud and ground).

Lesson 9 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		**NAVIGATE** Lead a short discussion to navigate into today's work.	A	
2	7 min		**BUILD GOTTA-HAVE-IT CHECKLISTS** Introduce the Gotta-Have-It Checklist, then pair students with a partner to draft their checklists.	B	*Gotta-Have-It Checklist*
3	5 min		**COMPARE GOTTA-HAVE-IT CHECKLISTS WITH A NEW PARTNER** Have students meet with a new partner to compare their Gotta-Have-It Checklists and revise them as needed.	C	*Gotta-Have-It Checklist*
4	8 min		**BUILD A CONSENSUS GOTTA-HAVE-IT CHECKLIST** Lead students in compiling their Gotta-Have-It Checklists into a class consensus checklist.	D	*Gotta-Have-It Checklist*, chart paper, chart paper markers
5	12 min		**REVISE INITIAL MODELS FOR WHAT CAUSES LIGHTNING** Have students individually revise their initial model to answer the question, "What causes lightning to strike at a particular place and time?"	E	*Gotta-Have-It Checklist*
6	10 min		**TAKE STOCK OF WHAT WE HAVE FIGURED OUT** Ask students to reflect on their individual growth, then identify questions that the class has figured out answers to.	F-G	*Modeling Reflection*, *Our DQB Questions* from Lesson 5
					End of day 1
7	10 min		**ANSWER QUESTIONS FROM THE DQB** Facilitate as the class works together to answer questions from the Driving Question Board.	H-J	*Our DQB Questions* from Lesson 5, 3x3 sticky notes, colored markers, chart paper titled "Questions We Have Answered", Driving Question Board, tape (optional)
8	26 min		**COMPLETE MID-UNIT TRANSFER TASK** Have students complete *Static Interactions Assessment* to demonstrate their understanding of static interactions and Coulomb's law.	K	*Static Interactions Assessment*, scientific calculator, Internet connected device (optional), https://youtu.be/vfEgzt3DgjQ?si=PN1eQqtP8no7-FQG
9	5 min		**INDIVIDUALLY REFLECT ON COMMUNITY AGREEMENTS** Have students individually reflect on the Community Agreements.	L	class copy of **Missed Video/Url ID (OP.CO.VID.L9.002) in tag** *Community Agreements Reflection*
10	4 min		**NAVIGATE TO INVESTIGATING ENERGY IN THE LIGHTNING SYSTEM** Reflect as a class on what we have already figured out about lightning related to matter and forces, and consider what we are still wondering about lightning from an energy perspective.	M-N	M-E-F poster, Driving Question Board
					End of day 2

Lesson 9 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Gotta-Have-It Checklist* • *Modeling Reflection* • *Our DQB Questions* from Lesson 5 • 3x3 sticky notes • colored markers • *Static Interactions Assessment* • scientific calculator • Internet connected device (optional) • class copy of **Missed Video/Url ID (OP.CO.VID.L9.002) in tag** *Community Agreements Reflection*		• chart paper • chart paper markers • chart paper titled "Questions We Have Answered" • Driving Question Board • tape (optional) • https://youtu.be/vfEgzt3DgjQ?si=PN1eQqtP8no7-FQG • M-E-F poster

Materials preparation (30 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Review students' explanations from the end of Lesson 8. These will support navigation into this lesson.

Be sure your Community Agreements are visible for reference during this lesson.

Students may want to reference posters from previous lessons while they build their Gotta-Have-It Checklists. The following posters may be especially helpful and should be visible to students:

- subatomic particles chart from Lesson 5
- similarities and differences between static interactions in class and the lightning system, from Lesson 6
- how to solve for force using Coulomb's law, from Lesson 7

You will also need the M-E-F poster that was last used in Lesson 6.

Two assessment options are provided for this unit. *Static Interactions Assessment* is the default, given its shorter length. *N95 Transfer Task* is available as an alternate option if you wish to have more information on student understanding and a more "real-world" application. These two tasks together could also be used in either order, with only one being graded and the other serving as additional practice before the graded assessment or as a re-assessment opportunity.

Part 2 of *Static Interactions Assessment* on day 2 uses a video found here: https://youtu.be/vfEgzt3DgjQ?si=PN1eQqtP8no7-FQG. If your students have access to 1-1 devices, post the video link in a shared space for students to access independently when they get to that part of the assessment. If not, plan to watch the video together as a class before beginning the assessment.

Make a copy of the Individual Reflection on Community Agreements survey linked here (**Missed Video/Url ID (OP.CO.VID.L9.002) in tag**) for each of your classes. Share the survey with students for them to complete at the end of day 2. Lesson 10 includes time to share selected data from the survey to inform Community Agreement revision (but you could reflect on the survey data sooner, if your schedule allows). Note that the form uses the OpenSciEd suggested Community Agreement categories (respectful, equitable, committed to our community, moving our science thinking forward) as multiple-choice response options; if your Community Agreements do not align with those categories, you will want to edit the form's language before sharing it with students.

Lesson 9 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build new ideas related to the following disciplinary core ideas:

- **PS1.A.1 Structure and Properties of Matter:** Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
- **PS2.B.1 Types of Interactions:** ~~Newton's law of universal gravitation and~~ Coulomb's law provide the mathematical models to describe and predict the effects of ~~gravitational and~~ electrostatic forces between distant objects.
- **PS2.B.2 Types of Interactions:** Forces at a distance are explained by fields (~~gravitational,~~ electric, ~~and magnetic~~) permeating space ~~that can transfer energy through space. Magnets or electric currents cause magnetic fields~~; electric charges ~~or changing magnetic fields~~ cause electric fields.

Crossout explanation: Students use reasoning around Coulomb's law (developed in Lesson 7) in their models and use it both qualitatively and quantitatively on the mid-unit transfer task on day 2. They do not develop Newton's law of universal gravitation and gravitational fields generally in this course, instead doing so in *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*. Students are assessed over DCI: PS2.B.2 in part but will not develop energy transfer in and out of fields until the next lesson and do not develop electromagnetic induction until *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*.

In this Putting Pieces Together lesson, students have the opportunity to revise the initial models they developed in Lesson 1 (SEP: 2.3). Building on students' prior work with model revision in Lesson 4, this model revision is done independently as a key opportunity to practice modeling before the mid-unit transfer task. Students will have the scaffold of a class-developed Gotta-Have-It Checklist. They engage only in parts of this element: *Develop, revise, and~~/or~~ use a model based on evidence to illustrate ~~and/or predict~~ the relationships ~~between systems or~~ between components of a system.* Students make predictions in the next lesson, and have illustrated relationships between systems in *Polar Ice Unit*.

On the mid-unit transfer task, students return to other static interactions they investigated earlier in the unit with more knowledge than they had when they initially explored these interactions. Both the in-lesson modeling and the transfer task require students to leverage understanding of subatomic structure (DCI: PS1.A.1) and Coulomb's law (DCI: PS2.B.1). On the transfer task, students additionally calculate results using Coulomb's law (SEP: 5.2), building on work done with Mathematics and Computational Thinking in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*, *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, and Lesson 7. This lesson partially addresses this element: *Use mathematical, computational, ~~and/or algorithmic~~ representations of phenomena ~~or design solutions~~ to describe and/or support claims and/or explanations,* with the remainder addressed in prior units and in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*.

In this lesson, students leverage the crosscutting concept of Energy and Matter for the first time in this unit, since it was intentionally developed in *Polar Ice Unit*. They consider matter flows throughout the lightning system (CCC: 5.2), with an emphasis on electron movement, as they develop their models. They engage partially in this element: *Changes of ~~energy and~~ matter in a system can be described in terms of ~~energy and~~ matter flows ~~into, out of, and~~ within that system.* Energy flow is emphasized in Lesson 10, and transfer in and out of the system was addressed in the prior unit.

In the transfer task, students go to the subatomic level to explain the mechanisms behind static phenomena (CCC: 1.1) as they previously did in Lessons 1 and 8.

Where We Are NOT Going

At this point in the unit, students have not yet figured out all the facets of the unit question, "What causes lightning and why are some places safer than others when it strikes?". After students revise their models, they bring up additional areas of uncertainty--where the light or thunder come from, how lightning has so much energy, or how we can keep ourselves safe. The Driving Question Board check-in at the end of day 1 and start of day 2 is an opportunity to share new questions and re-surface existing ones to motivate the remainder of the unit.

LEARNING PLAN for LESSON 9

1 · NAVIGATE

3 min

MATERIALS: None

Recall what we figured out last time. Display **slide A**. Have students turn and talk with a neighbor about the question on the slide: What did we figure out last time about what is happening in the lightning system before a lightning strike?

Invite a few students to share with the whole class. Sample student responses include:

- The bottom of a thunderstorm cloud is negatively charged, which causes the top of the ground to have a partial positive charge.
- The particles that make up the atoms in the ground under a thunderstorm cloud experience induced polarization.

Navigate to today's work. Say, *We have figured out a lot since we first created our initial models about what causes lightning, so today we will revise those models to explain what is happening in the cloud and ground system. The models you made in the previous lesson will inform your work today, as will the investigations you did in prior lessons--we are "putting the pieces together" today to explain what we have figured out. Later in this lesson, we will also check in on our DQB to take stock of the progress we have made and see what questions we still have.*

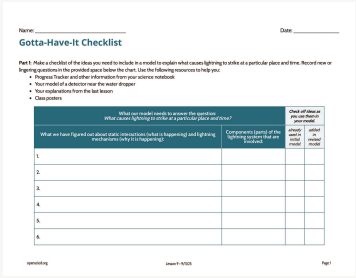
2 · BUILD GOTTA-HAVE-IT CHECKLISTS

7 min

MATERIALS: science notebook, *Gotta-Have-It Checklist*

Prepare to develop the Gotta-Have-It Checklist. Display **slide B.** Say, *In our first lesson of this unit, we talked about how important modeling is to scientists like us. Models help us make sense of what we understand (or do not) and allow us to explain and communicate with others about how something works.* Remind students that in *Polar Ice Unit*, we developed Gotta-Have-It Checklists to help us know what to put into our models; suggest that we do the same here today.

Pair students with a partner to create their checklist and distribute the *Gotta-Have-It Checklist* handout.


Name: _____ Date: _____

Gotta-Have-It Checklist

Part 1: Make a checklist of the ideas you need to include in a model to explain what causes lightning to strike at a particular place and time. Record new or lingering questions in the provided space below the chart. Use the following resources to help you:

- Progress Tracker and other information from your science notebook
- Your model of a detector near the water dropper
- Your explanations from the last lesson
- Class posters

What our model needs to answer the question: What causes lightning to strike at a particular place and time?		Check off ideas as you include them in your model.	
What we have figured out about static interactions (what is happening) and lightning mechanisms (why it is happening)	Components (parts) of the lightning system that are involved	should exist in initial model	added in revised model
1.			
2.			
3.			
4.			
5.			
6.			

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Define the task. Remind students to look back through their science notebooks, posters the class has co-created (see Materials Preparation section), readings, and possibly computer resources such as videos and simulations, to list the most important ideas for a model to answer the question, "What causes lightning to strike at a particular place and time?". Students should look for ideas they have figured out about static interactions and note the components of the lightning system that are involved. Students should leave the two rightmost columns blank for now--we will use those when revising our models later.

Point out that there is space below the chart to record any new or lingering questions that come up as students are working on their checklists.

Provide work time with partners. Give students about 7 minutes to compose their Gotta-Have-It Checklists with their partners. The answer key *Gotta-Have-It Checklist Key* is provided as a tool for you while you circulate the room and interact with students about their work.

3 · COMPARE GOTTA-HAVE-IT CHECKLISTS WITH A NEW PARTNER

5 min

MATERIALS: science notebook, *Gotta-Have-It Checklist*

Switch partners to compare Gotta-Have-It Checklists. Display **slide C.** Direct students to work with a different partner to compare their checklists using the prompts on the slide to guide their discussion. They should acknowledge ideas they agree on and also provide evidence for including ideas they did not both list already. Remind students to revise their checklists based on this discussion with their new partner.

Give students about 5 minutes to talk with these partners and revise their lists accordingly. Again, the answer key *Gotta-Have-It Checklist Key* is provided as a tool for you while you circulate the room and interact with students about their work.

4 · BUILD A CONSENSUS GOTTA-HAVE-IT CHECKLIST

8 min

MATERIALS: *Gotta-Have-It Checklist*, chart paper, chart paper markers

Build a consensus Gotta-Have-It Checklist. Display **slide D**. Use these prompts to lead a Consensus Discussion to build toward a checklist for the whole class to work from. Record students' suggestions on chart paper and encourage them to revise their own lists to include ideas that the class decides are appropriate. Students may leave additional items on their own checklists if they are supported by evidence the class has collected.

- What components did you agree that we should add to the checklist?
- What interactions and mechanisms involve those components?

KEY IDEAS

Purpose of this discussion: This Consensus Discussion is an opportunity for students to come to agreement about the most important ideas to include in their models, since they will be modeling individually and will not have an opportunity to build a class consensus model. Be explicit with students about how your and their roles will be different than in other discussion types.✱

Listen for these ideas:

- See *Gotta-Have-It Checklist Key* for important ideas that should appear on the consensus Gotta-Have-It Checklist. Additional ideas are appropriate if they are supported by evidence the class has collected.

✱ STRATEGIES FOR THIS CONSENSUS DISCUSSION

A Consensus Discussion is different from other kinds of discussions because its purpose is to converge on one or more ideas that the whole class agrees on. During this work, the class resolves disagreements where possible. Your role is to help students see where they agree and where they still disagree. Helpful prompts include:

- What ideas are we in agreement about?
- Would anyone have put this point a different way?
- Who feels like their idea is not quite represented here?
- Are there still places where we disagree? Can we clarify these?

5 · REVISE INITIAL MODELS FOR WHAT CAUSES LIGHTNING

12 min

MATERIALS: science notebook, *Gotta-Have-It Checklist*

Review key aspects of the modeling practice. Display **slide E.** Explain that now we can use our Gotta-Have-It Checklists to revise the initial models we created in Lesson 1. Give students a moment to find those initial models in their notebooks so they can refer to them during their model revisions today.

Briefly review some of the ways we can communicate our ideas in a model. While mentioning these ideas, point to how they are used in the classroom consensus model and/or sketch them on the board:

- zoom-ins to show what is happening at the particle level
- arrows
- shapes/symbols (with a key or legend)
- words and phrases

Construct revised models. Have students take out their initial models, in addition to *Gotta-Have-It Checklist*. Encourage students to reflect on their initial models by reviewing the Gotta-Have-It Checklist and considering what they will need to add or change. They should draw their models under Part 2, checking off elements from their Gotta-Have-It Checklist as they add them.✱

See the sample model in *Gotta-Have-It Checklist Key*, keeping in mind that students will represent these ideas in different ways.

As students revise their models, remind them to note areas of uncertainty in their model and record the questions they have, as we will continue pursuing answers to those questions. Some of students' lingering questions may include:

- What makes the lightning strike all at once, instead of constantly "raining down" electrons?
- Does the polarization of the ground have something to do with the differences between where lightning strikes and where it doesn't?

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Gotta-Have-It Checklist Key* for guidance and a sample model.

What to do: See *Gotta-Have-It Checklist Key* for guidance.

Building toward 9.A Revise a model based on evidence to illustrate the relationships between components of the lightning system in terms of matter changes/flows within that system. (SEP: 2.3; DCI: PS1.A.1, PS2.B.1; CCC: 5.2)

ALTERNATE ACTIVITY

Extension opportunity: Instead of collecting students' models for feedback in this lesson, have them exchange models with a partner or take their model and Gotta-Have-It Checklist home for outside feedback. You may then collect students' models and provide feedback along with the mid-unit assessment feedback.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

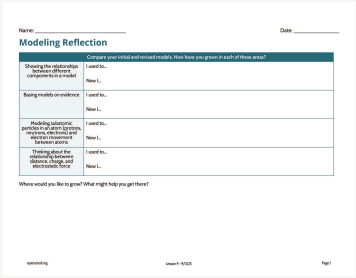
Students likely will not draw their models exactly to scale, but encourage them to show the relative height of the cloud compared to the distance between the cloud and the ground. In Lesson 6, students saw that the cloud might be about 12,000 meters tall, while the distance between the bottom of the cloud and the ground might be only 1500 meters. This provides an initial explanation for why lightning often hits the ground, despite opposite charges elsewhere in the cloud.

6 · TAKE STOCK OF WHAT WE HAVE FIGURED OUT

10 min

MATERIALS: *Modeling Reflection*, science notebook, *Our DQB Questions* from Lesson 5

Reflect on modeling. As students finish revising their models, display **slide F** and distribute *Modeling Reflection*. Explain to students the importance of acknowledging and celebrating their own growth, as well as that of the class.✱ Give them a few minutes to complete the reflection. You do not have to collect these reflections, but you may wish to encourage students to share them with you if they recognize that they are struggling with modeling or with particular science ideas. Remind students that tomorrow's work will include a mid-unit assessment.✱


Name: _____ Date: _____

Modeling Reflection

	Compare your initial and revised models. How have you grown in each of these areas?
Showing the relationships between different components in a model	I used to... Now I...
Basing models on evidence	I used to... Now I...
Modeling subatomic particles in an atom (protons, neutrons, electrons) and electron movement between atoms	I used to... Now I...
Thinking about the relationship between distance, charge, and electrostatic force	I used to... Now I...

Where would you like to grow? What might help you get there?

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Revisit the Driving Question Board. As students wrap up their reflections, display **slide G** and direct them back to *Our DQB Questions* in their notebooks from Lesson 5. Have students take a few minutes to continue analyzing the DQB questions by marking them using the key on the handout, replicated here:

- We did not answer this question or any parts of it yet: **O**
- Our class answered some parts of this question, *or* I think I could answer some parts of this question: ✓
- Our class answered this question, *or* Using the ideas we developed, I could now answer this question: ✓+

Direct students to answer one of the questions they marked with a ✓ or ✓+.

Close today's work by telling students that we will start our next class by sharing these ideas about our DQB questions.

✱ ATTENDING TO EQUITY

Building classroom culture: Students benefit personally and intellectually from feeling like they belong in and contribute to the science classroom community. The individual reflection in *Modeling Reflection* and in the return to the DQB are opportunities for students to recognize how much growth they have had both individually and as a collective.

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

This activity is also an opportunity for students to recognize their strengths and growth areas with regard to modeling (SEP), disciplinary core ideas that are emphasized throughout the unit (atomic structure, force interactions), and the crosscutting concept of Matter and Energy that underlies much of chemistry. Help students recognize that several of the prompts on their reflection require them to think about not only what they know, but how they show what they know through modeling, using a particular CCC as a lens.

End of day 1

7 · ANSWER QUESTIONS FROM THE DQB

10 min

MATERIALS: science notebook, *Our DQB Questions* from Lesson 5, 3x3 sticky notes, colored markers, chart paper titled "Questions We Have Answered", Driving Question Board, tape (optional)

Share DQB answers with a partner. Display **slide H.** Give students two to three minutes to turn and talk with a partner about the answer to at least one question they marked with a ✓ or ✓+.

Discuss why we revisit the DQB. Display **slide I.**

Say, *Last time we ended with some individual and partner reflection time about questions from our Driving Question Board, and today we will share those ideas as a whole class. It is important to take time to check in on our Driving Question Board questions so we can see the progress we have made toward answering them and use them to direct where we are going next in the unit.*

Invite students to share questions they think the class has answered, along with a brief explanation of the answer. If the class agrees that the question was fully answered, move that sticky note to a new poster near the DQB titled "Questions We Have Answered." Have a student jot the answer on a sticky note and attach it to the question.✱ If the question was partially answered, put a check mark on the question to keep track of questions we are making progress toward, but leave it on the DQB.

Summarize the task. Ask, *Overall, what have we figured out about the causes of lightning that we were wondering about earlier on?* Accept all reasonable responses.

Add any new questions to the DQB. Display **slide J**. Say, *While you worked to revise your initial models, you were prompted to record any new questions that may have come up for you. Let's take a moment to add those to our DQB.* If students had new questions during their model revisions, have them write them in marker on sticky notes and post them on the DQB now.

✱ ATTENDING TO EQUITY

This Driving Question Board check-in is intentionally placed right before the mid-unit transfer task so that students not only recognize what questions they have not answered yet, but have an opportunity to review before the transfer task. Feel free to take more time for students to share answers to questions they have figured out if it is needed.

8 · COMPLETE MID-UNIT TRANSFER TASK

26 min

MATERIALS: *Static Interactions Assessment*, scientific calculator, Internet connected device (optional), https://youtu.be/vfEgzt3DgjQ?si=PN1eQqtP8no7-FQG

Administer the mid-unit transfer task. Display **slide K.** Distribute *Static Interactions Assessment*. Give students about 25 minutes to complete this assessment task.✱

ADDITIONAL GUIDANCE

Note that Part 1 of this task asks students to choose one of two examples of the static interactions they (or other students) investigated earlier in this unit.

Part 2 of the task uses a video found here https://youtu.be/vfEgzt3DgjQ?si=PN1eQqtP8no7-FQG to introduce students to another static interaction. If your students have access to 1-1 devices, you can share the video link and have them watch independently when they get to that part of the assessment. If not, watch the video clip together as a class before beginning the assessment.

Ensure that all students have multiple means to access this assessment. It is acceptable for written portions to be generated using voice-to-text features, for example.

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: This assessment includes sections of reading of a few sentences at a time, with the alternate *N95 Transfer Task* featuring longer chunks of reading. As desired, support emergent multilinguals and other students by printing the assessment in sections. Read through a section as a class and clarify text meanings and question intents before allowing students to proceed.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Use the answer key *Static Interactions Key* to check for student understanding. If you use the alternate assessment, use *Mask Transfer Task Key*.

What to do: If students have trouble deciding which static interaction to choose in Part 1, you might assign them one of the choices or point them back to different Objects A, B, and C that you know they used in class. If students need to review the subatomic particles, have them label the electrons, protons, neutrons, and atomic nucleus on their paper-clip models. If it would be helpful to students working through Part 2 to physically carry out the charging of the balloon and observe its interaction with the can, provide materials and time for them to do that.

Building toward 9.B Use mathematical representations of Coulomb's law to describe and predict the electrostatic forces between objects. (SEP: 5.2; DCI: PS2.B.1, PS2.B.2; CCC: 1.1)

9 · INDIVIDUALLY REFLECT ON COMMUNITY AGREEMENTS

5 min

MATERIALS: class copy of Missed Video/Url ID (OP.CO.VID.L9.002) in tag *Community Agreements Reflection*

Have students complete an individual reflection about the Community Agreements. Display **slide L.** Direct students to the electronic survey you shared with them (you can make a copy of the form linked at *Community Agreements Reflection*). Explain to students that their thoughtful responses to these prompts will help us gauge how we are doing as a classroom community.✱

✱ ATTENDING TO EQUITY

Building classroom culture: It is important that you take time in an upcoming class to follow up on these reflections and revise the Community Agreements. A few minutes of reflection are written into Lesson 10, and the class will revise the agreements in Lesson 1 of the next unit. You may choose to revisit your Community Agreements whenever necessary as your class schedule allows.

10 · NAVIGATE TO INVESTIGATING ENERGY IN THE LIGHTNING SYSTEM

4 min

MATERIALS: M-E-F poster, Driving Question Board

Identify that many of our remaining DQB questions are related to energy. Display **slide M**. Say, *We have been working hard to figure out how and why lightning happens, and why some places are safer than others when it strikes. Where are many of our DQB questions steering us now?*

Ask for a few volunteers. Listen for students to point out that many of the questions are about light, heat, thunder, and lightning strikes themselves.

Ask, *What do these questions have in common? What is the underlying relationship between all of these phenomena?* Look for students to say "energy."

Point out that the M-E-F poster has been a useful tool to help us think about matter and forces in particular.

Reflect on the M-E-F poster. Display the poster and say, *This year, we have used matter, energy, and forces as different lenses to think about phenomena. We have thought about matter and forces, and matter and energy, together. But we have not really thought about energy and forces together yet.* Display **slide N**. Give students a moment to turn and talk about the prompt: *How could using the M-E-F poster help us try to connect ideas about energy and forces to help explain lightning?* Then discuss it as a class. Listen for these ideas:

- We could better understand where all the energy comes from in lightning.
- We could understand the forces that create thunder.
- We could figure out if the charge or the distance have anything to do with energy like they do with forces.

Elicit new questions about energy and forces from students and have them add these questions to the DQB. Suggest that next lesson, we dive into the connection between energy and forces. There is a lot of energy in a storm and great forces, so they must be connected somehow.

Additional Lesson 9 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSA.REI.A.1
Explain each step in solving a simple equation as following from the equality of numbers asserted at the previous step, starting from the assumption that the original equation has a solution. Construct a viable argument to justify a solution method.

Students use Coulomb's law (equation) to make predictions about the strength of attractive forces between objects by analyzing the relationship between amount of charge and distance.

LESSON 10: Where does the energy come from for lightning to strike across miles of air?

PREVIOUS LESSON

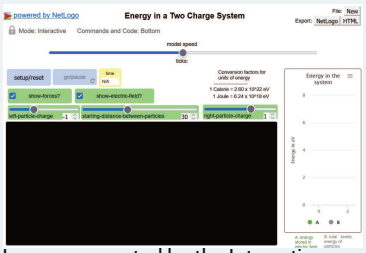
We created Gotta-Have-It Checklists, then used them to develop updated models to answer the question "What causes lightning to strike at a particular place and time?". We took stock of the Driving Question Board, and then we completed an assessment task to demonstrate our understanding of static interactions and Coulomb's law using modeling and mathematical- and patterns-thinking.

THIS LESSON

PROBLEMATIZING, INVESTIGATION

2 days





Images generated by the Interactions Project (https://concord.org/our-work/research-projects/interactions/) at the Concord Consortium.

We recognize that many of our remaining questions are related to energy, and we analyze data that show that lightning transfers a LOT of energy. We wonder where that energy is coming from, so we use a computational model that shows energy storage between charges to realize that the energy comes from the electric field, or the space between the charges. We add these ideas to our updated lightning models, and we conclude by applying what we figured out about energy stored in an electric field back to storm clouds.

NEXT LESSON

We will consider what we know about air to figure out that there is no easy path for electrons to move through it. We will conduct research for scientific information and evaluate our sources to explain how charges move through air to cause the lightning we can see.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-6, HS-PS2-4, HS-PS3-2, HS-PS3-6



WHAT STUDENTS WILL DO

10.A Use models based on evidence to illustrate the relationships between the components of a system in which energy flows between particles and an electric field. (SEP: 2.3; DCI: PS3.C.1, PS2.B.2; CCC: 5.2)

10.B Use multiple models to provide a mechanistic explanation of energy changes in a macroscopic lightning system as a result of the movement of charges at the atomic scale. (SEP: 2.4; DCI: PS3.A.1; CCC: 3.1)

WHAT STUDENTS WILL FIGURE OUT

- Energy is stored in the electric field that exists between charged particles.
- The electric field exists because of attractive and repulsive forces between charged particles.
- Energy transfers to or from particles to or from the electric field as charged particles are moved toward or away from one another.

Lesson 10 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	4 min		**REFLECT ON COMMUNITY AGREEMENTS** Encourage the class to celebrate and reflect on their experiences with the Community Agreements.	A-B	
2	5 min		**NAVIGATE** Help students re-orient to the M-E-F poster and establish their focus on the large amounts of energy transferred by lightning.	C-E	M-E-F poster
3	3 min		**REVISIT STICKY TAPE WITH AN ENERGY LENS** Have students think about sticky-tape interactions through an energy lens and consider what makes the tape move.	F	2 pieces of cellophane tape, M-E-F poster
4	3 min		**INTRODUCE A COMPUTATIONAL MODEL** Introduce the "Energy in a Two Charge System" model.	G	https://youtu.be/olh6VSMHYLA
5	15 min		**USE A COMPUTATIONAL MODEL** Have students work with a partner to use the model to complete *Energy/Charge Model*.	H	*Energy/Charge Model*, internet connected device, https://openscied-static.s3.amazonaws.com/HTML+Files/Energy+in+a+Two+Charge+System.html
6	10 min		**BUILDING UNDERSTANDINGS DISCUSSION** Lead a discussion to build a class model showing energy transfers.	I-K	*Energy/Charge Model*, "As opposite charges move..." chart paper, chart paper markers, https://openscied-static.s3.amazonaws.com/HTML+Files/Energy+in+a+Two+Charge+System.html
7	5 min		**REVISE THE M-E-F POSTER** Lead a class revision of the M-E-F poster and update Personal Glossaries.	L-M	M-E-F poster, chart paper markers
					End of day 1
8	4 min		**NAVIGATE** Have students consider how takeaways from the M-E-F poster and computational model apply to lightning.	N-O	M-E-F poster
9	15 min		**EXAMINE FEEDBACK** Have students reflect on their lightning models from Lesson 9 using teacher feedback and a self-assessment handout.	P-R	*Model Self-Assessment*, lightning model from Lesson 9
10	15 min		**REVISE MODELS** Support students in applying key takeaways and feedback to revise their lightning models.	S	*Model Self-Assessment*, lightning model from Lesson 9, M-E-F poster

Part	Duration		Summary	Slide	Materials
11	7 min		**UPDATE PROGRESS TRACKERS** Have students update their Progress Trackers to reflect what we figured out about energy, forces, and electric fields.	T	
12	4 min		**NAVIGATE** Lead a brief discussion to help navigate into Lesson 11.	U	

End of day 2

Lesson 10 • Materials List

	per student	per group	per class
Lesson materials	• *Energy/Charge Model* • science notebook • *Model Self-Assessment* • lightning model from Lesson 9	• internet connected device • https://openscied-static.s3.amazonaws.com/HTML+Files/Energy+in+a+Two+Charge+System.html	• M-E-F poster • 2 pieces of cellophane tape • https://youtu.be/olh6VSMHYLA • "As opposite charges move..." chart paper • chart paper markers • https://openscied-static.s3.amazonaws.com/HTML+Files/Energy+in+a+Two+Charge+System.html

Materials preparation (30 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Test and familiarize yourself with https://openscied-static.s3.amazonaws.com/HTML+Files/Energy+in+a+Two+Charge+System.html This walkthrough may help: https://youtu.be/olh6VSMHYLA

Prepare **slides A and B** to share anonymous whole-class data from the *Individual Reflection on Community Agreements* electronic survey in Lesson 9.

- From the results of that electronic survey, add screenshots of the graphs for "What did that student do to help you learn?" and/or "How have our Community Agreements supported you in the unit so far?" to **slide A** to celebrate what is going well for the class around their agreements.
- To **slide B**, add a screenshot of the graph for "What Community Agreement do you personally need to work on the most as we continue this unit?" to help the class reflect on how they might revise their agreements.
- You might also choose to summarize the suggestions students had for adjusting the Community Agreements on an additional slide, or you might just share those aloud (anonymously) during this first activity of the lesson.
- If you teach multiple sections and administered a different version of the survey to each one, be sure to prepare a copy of **slides A and B** with the data for each class.

Ensure that there is access to at least one internet-connected device for every two students.

Prepare a piece of vertically-oriented chart paper with two sections for models. Label the top section "As opposite charges move away from each other," and label the bottom section "As opposite charges move toward each other."

Have the class M-E-F poster ready for display.

Lesson 10 • Where We Are Going and NOT Going

Where We Are Going

This lesson is the course's first use of the concept of energy stored in fields, commonly called "potential energy." Students may be familiar with this concept from middle school, although they may have focused primarily on magnetic fields then.

Students will use multiple models (SEP: 2.4) as well as revise their own models to explain (SEP: 2.3) the transfer of energy during a lightning strike.

The targeted disciplinary core ideas that are addressed in this lesson are:

- **PS3.C.1 Relationship Between Energy and Forces:** When two objects interacting through a field change relative position, the energy stored in the field is changed.
- **PS2.B.2 Types of Interactions:** Forces at a distance are explained by fields (~~gravitational,~~ electric, ~~and magnetic~~) permeating space that can transfer energy through space. ~~Magnets or electric currents cause magnetic fields~~; electric charges ~~or changing magnetic fields~~ cause electric fields. (HS-PS2-4),(HS-PS2-5)
- **PS3.A.1 Definitions of Energy:** Energy is a quantitative property of a system that depends on the motion and interactions of matter ~~and radiation~~ within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is ~~continually~~ transferred from one object to another and between its various possible forms.

Crossout explanation: In this lesson, students focus on electric fields that result from charged particles and the forces that result from those fields. Gravitational and magnetic fields will be explored in the OpenSciEd Physics course.

From *Polar Ice Unit*, students are familiar with the ideas that energy is conserved and that it is transferred between objects or particles. Fields were identified in this unit in Lesson 4. Students also have familiarity with fields and with energy in fields from *OpenSciEd Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)* . Here, students build on this thinking by seeing how energy transfers into and out of electric fields as charges are moved and the forces between them increase or decrease.

Students use a computational model to trace the flow of energy between charged particles and the electric field between them (CCC: 5.2). This atomic-scale phenomenon (CCC: 3.1) helps students explain the massive amount of energy transferred during a lightning strike.

Where We Are NOT Going

In OpenSciEd, we intentionally avoid trying to list or name different "types" or "kinds" of energy. Instead, students focus on where the energy is stored--in the movement of particles/objects or in a field--and how it transfers.

This lesson also marks a shift in terminology from what students might be familiar with. The term *potential energy* tends to make students think that it is energy that "could" exist or is not real, and it obscures the mechanism by which energy is stored. For this reason, after students have established where the potential energy *is* (in the electric field; that is, the space between the charges), we encourage use of the term *energy in the field*.

LEARNING PLAN for LESSON 10

1 · REFLECT ON COMMUNITY AGREEMENTS

4 min

MATERIALS: None

Share data from the Lesson 9 Community Agreements Reflection.✱ Display **slide A.** See the materials preparation section for instructions on preparing slides A and B. Celebrate with the class what they are doing well to support each other and/or how the Community Agreements have supported them.

Display **slide B** and reflect on where the class identifies room for improvement in the Community Agreements. Share (either by reading aloud without names or by showing an additional slide you prepared) some suggestions students had for adjusting the agreements.

✱ ATTENDING TO EQUITY

Building classroom culture: It is important to take time to reflect on the Community Agreements. Doing so will help to reinforce those agreements that the class, or students, may be struggling to enact. Ensure that this reflection is a discussion about the class as a whole and not individual students. It should be an opportunity for all students to individually reflect on how they can adjust their interactions to support use of the Community Agreements.

2 · NAVIGATE

5 min

MATERIALS: M-E-F poster

Re-orient students to the M-E-F poster. Display **slide C** and give students a minute to turn and talk about the prompts on the slide. Then elicit ideas from a few pairs.

Suggested prompt	Sample student response
How did we explain lightning in terms of matter, forces, and energy?	Matter in clouds gets charged by rubbing and collisions. Matter and forces are connected because charged matter attracts and repels. There is a lot of energy in lightning.
Which of those categories do many of our remaining questions fall into?	Many of our remaining questions are about energy.

Say, *We know there is a lot of energy involved with lightning! Let's shift our focus to that energy.*

Focus on the energy transferred by lightning. Display **slide D.** Share the statistics on the slide with students. Then ask, *How does this scale compare to what you expected?* Listen for these student responses:

- *That sounds like a lot!*
- *It is more than I expected.*
- *It is less than I expected, but maybe that is just one bolt.*

Share some different energy units. Display **slide E.** Say, *We have measured energy mostly in calories so far. But scientists often use other units like joules and electron-volts. These units came out of different historical ways of measuring energy, but all can be used to describe the same thing.* Point out that the table shows what one of each unit is equivalent to, as well as the number of each unit in a lightning strike. Give students a moment to read the table, then ask, *What do you think of when seeing the energy transferred by lightning expressed in all three units?* Listen for these student responses:

- *That is a LOT of energy.*
- *There is a lot of variation between the different units.*
- *I wonder why we have these different units for energy.*

Ask students, *Do all these measures of energy deal with particle motion like we saw in Polar Ice Unit?* They may be unsure. Use this uncertainty to suggest that when we are sure we are talking about particle motion, we will use the phrase *kinetic energy.*

3 · REVISIT STICKY TAPE WITH AN ENERGY LENS

3 min

MATERIALS: 2 pieces of cellophane tape, M-E-F poster

Revisit sticky tape with an energy focus. Show students the sticky tape setup from Lesson 5. Stick the two pieces together, then pull them apart. Ask students, *What will happen if I move these pieces closer together?* Students should remember that they will attract. Some may say repel, and that is okay here. Slowly move the pieces of tape closer together until they attract.

Suggested prompt	Sample student response
How did the kinetic energy of the tape change?	They moved, so the kinetic energy increased.
What caused the movement?	The attraction between the pieces of tape. The charges on the tape.
Where did that energy come from?	I don't know. Maybe the attraction gave them energy.

Say, *It sounds like we are not quite sure where the energy comes from in situations where objects attract or repel. Maybe it would help us to zoom in?*

4 · INTRODUCE A COMPUTATIONAL MODEL

3 min

MATERIALS: https://youtu.be/olh6VSMHYLA

Introduce the computational model. Display **slide G.** Take a moment and ask students, *What do you notice in the image of the computational model?* Accept all responses.

Then, play https://youtu.be/olh6VSMHYLA to show students how to use the model. Alternatively, you may walk students through https://openscied-static.s3.amazonaws.com/HTML+Files/Energy+in+a+Two+Charge+System.html yourself. If you do, emphasize the following points:

- You can move the charges around.
- You can change the amount of charge.
- Energy stored in the field and kinetic energy are shown, each measured in electron-volts.
- You can visualize the forces and the electric field.
- When you press go/pause, you will see what happens to the energy when the particles move.

5 · USE A COMPUTATIONAL MODEL

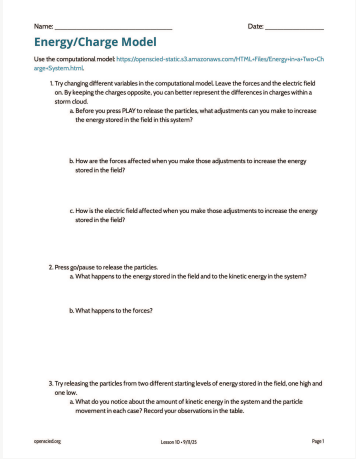
15 min

MATERIALS: *Energy/Charge Model*, internet connected device, https://openscied-static.s3.amazonaws.com/HTML+Files/Energy+in+a+Two+Charge+System.html

ALTERNATE ACTIVITY

Building prerequisite understandings: Students may yet have difficulty understanding the concepts of force or energy if they did not experience *Magnets Unit* or *Polar Ice Unit*, respectively. If this is the case, consider breaking up this activity into parts. Give students an opportunity to complete several of the prompts with a partner (for example, 1a-1c), then discuss these as a class before moving on to the next set. This will functionally break apart the Building Understandings Discussion into manageable chunks.

Investigate the computational model. Display **slide H** and distribute *Energy/Charge Model*. Tell students they will have 15 minutes to use the model ✱ to answer the prompts on the handout with a partner. *Energy/Charge Model Key* provides guidance on expected student responses.



Name: _____ Date: _____

Energy/Charge Model

Use the computational model: https://openscied-static.s3.amazonaws.com/HTML+Files/Energy+in+a+Two+Charge+System.html.

1. Try changing different variables in the computational model. Leave the forces and the electric field on. By keeping the charges opposite, you can better represent the differences in charges within a storm cloud.
   a. Before you press PLAY to release the particles, what adjustments can you make to increase the energy stored in the field in this system?

   b. How are the forces affected when you make those adjustments to increase the energy stored in the field?

   c. How is the electric field affected when you make those adjustments to increase the energy stored in the field?

2. Press go/pause to release the particles.
   a. What happens to the energy stored in the field and to the kinetic energy in the system?

   b. What happens to the forces?

3. Try releasing the particles from two different starting levels of energy stored in the field, one high and one low.
   a. What do you notice about the amount of kinetic energy in the system and the particle movement in each case? Record your observations in the table.

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✱ ATTENDING TO EQUITY

Universal Design for Learning: Students can *engage* with multiple types of models and information to help them make sense of lightning. They have their own models from Lesson 9, and can use their self-assessments, conversations with peers, the M-E-F poster, and the computational model to help them explain the energy transfer in lightning.

6 · BUILDING UNDERSTANDINGS DISCUSSION

10 min

MATERIALS: science notebook, *Energy/Charge Model*, "As opposite charges move..." chart paper, chart paper markers, https://openscied-static.s3.amazonaws.com/HTML+Files/Energy+in+a+Two+Charge+System.html

Build a class model to explain energy transfers. Display **slide I** and the prepared "As opposite charges move..." chart paper. Use the prompts on the slide to help build a class model on the chart paper, similar to the one shown below. Say, *Let's start to build a model of what was happening in the simulation as the charges moved away from and toward each other. Can we agree that there should be two opposite charges in each model?* Add two boxes (or circles) to each section of the chart paper, labeling one with a negative charge and the other with a positive charge.✱

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Students' models (SEP) draw from their thinking in Lesson Sets 1 and 2 and *Polar Ice Unit*. They use ideas about forces and electric fields, first developed in Lesson 4, and add energy thinking (DCI). This consideration of energy flows (CCC) plays a small but important role in this unit; it lays the groundwork for students to answer questions about flashes of light and thunder in the next lesson, even as students in this

KEY IDEAS

Purpose of this discussion: To establish that energy stored in the field transfers to the particles when oppositely charged particles come together, and that energy transfers from the particles to the field when those same particles move apart.✱

Listen for these ideas:

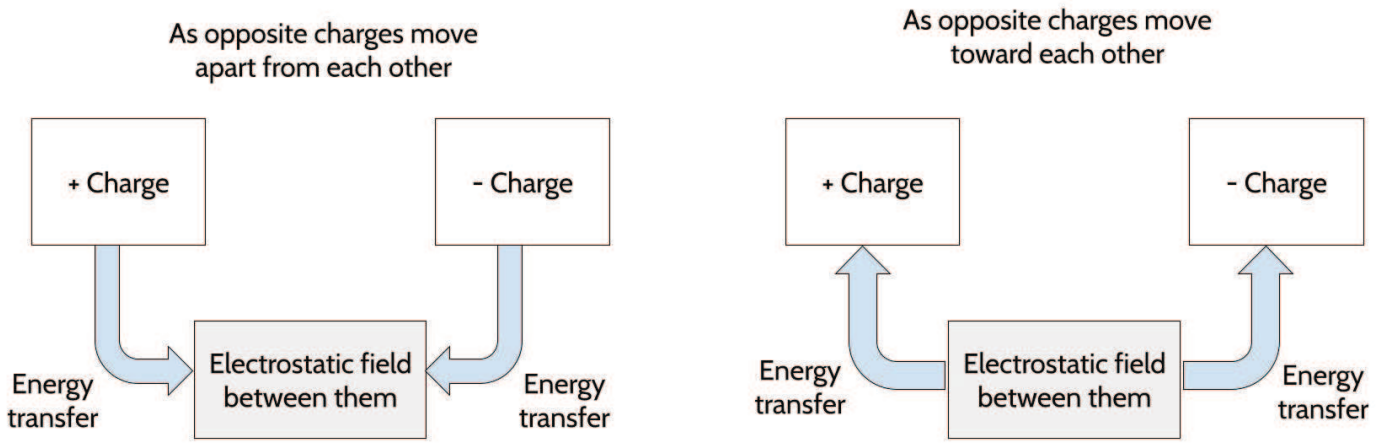
- Energy is stored in the space between the charges, where the electric field is.
- The electric field results from the forces between charges.
- Energy is transferred into the field as oppositely charged particles move apart, and transferred to the particles as they move toward each other.
- The total amount of energy in the system remains the same, whether as energy stored in the field or as kinetic energy of the particles.

Suggested prompt	Sample student response
What caused more energy to be stored in the field in the system?	Increasing the amount of charge. Moving the charges farther away from each other.
Where did the increased energy in the field come from?	From the particles? From the charges? From the charges moving away from each other. (Add the electric field between the charges in both models.)
How did the energy transfer when the charged particles were moved?	It transferred from the particles to the field when the particles moved away from each other. (Add energy transfer arrows from the charges to the electric field in the "As opposite charges move away from each other" model.) It transferred from the field to the particles when the particles moved closer together. (Add energy transfer arrows from the electric field to the charges in the "As opposite charges move toward each other" model.)

lesson are able to explain how particles' rubbing together results in huge outputs of energy.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

The energy transfer model that students develop shows that energy is conserved, even when it appears to come out of nowhere. Highlight that in situations where energy seems to have been created or destroyed because of a change in temperature or particle motion, it may have simply transferred into or out of a field.



ADDITIONAL GUIDANCE

Students may be familiar with the term *potential energy* and may want to use it in these discussions. If so, ask students to clarify what they mean by potential energy. When it becomes clear that they are referring to the energy stored in the electric field, suggest using that terminology as it more clearly indicates what is happening in the system.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Recognize that energy transfers into and out of the electric field, as a result of attractive or repulsive forces. (DCI: PS3.C.1, PS2.B.2; CCC: 5.2)
- Describe flows of energy and matter between different components of the system--particles and the electric field. (SEP: 2.3; CCC: 5.2)
- Cite evidence from the computational model regarding the flow of energy and matter. (SEP: 2.3; CCC: 5.2)

What to do: If students struggle to identify the source of energy transfers into and out of the field, present https://openscied-static.s3.amazonaws.com/HTML+Files/Energy+in+a+Two+Charge+System.html and ask students what changes occur when the particles move apart. Listen for students to say that the space between the particles increases, as does the energy stored in the field. Then ask them what changes occur when the particles move toward each other.

Building toward 10.A.1 Use models based on evidence to illustrate the relationships between the components of a system in which energy flows between particles and an electric field. (SEP: 2.3; DCI: PS3.C.1, PS2.B.2; CCC: 5.2)

Make a prediction about energy flows. Display **slide J**. Give students a minute to think about the prompts on the slide:
Will the energy stored in the field (potential energy) increase or decrease when...

1. two like charges move apart?
2. two like charges move toward each other?

Then, poll students. State each prompt, then ask students to indicate either "up" or "down" with their thumbs or pointer fingers, or in another way. You may wish to have students close their eyes for this poll.

ADDITIONAL GUIDANCE

Some students may be uncomfortable responding to the prompts with a definitive choice between two possible answers. This can be addressed in multiple ways. Having students close their eyes before showing their answers helps students feel safer from peer judgment. A discussion about the Community Agreements could serve a similar purpose. If you have time, you may wish to have students turn and talk before responding. Finally, you could suggest "I am not sure" as a third possible response, conduct an eyes-open poll, and give students time to share their rationale.

Check predictions with the computational model. Say, *Let's check our predictions with the computational model.* Display https://openscied-static.s3.amazonaws.com/HTML+Files/Energy+in+a+Two+Charge+System.html and run the computational model for both predicted situations. As you run the simulation, encourage students to record what they notice in their science notebooks or on *Energy/Charge Model*.

Display **slide K** and lead a discussion about the results. The major conclusion should be that energy is stored in the field when opposite charges are farther apart.

Suggested prompt	Sample student response
How did the results in the computational model compare to your predictions for like charges moving away from and toward each other?	The energy in the field went down when like charges moved apart. (Responses will vary depending on whether this matched students' initial predictions.) The energy in the field went up when like charges moved together. (Responses will vary depending on whether this matched students' initial predictions.)
Review your results for opposite charges and compare them to the results for like charges. What differences do you see?	Opposite charges interact in the opposite way of like charges. When different charges are pulled apart there is more energy in the field, but when like charges are pulled apart there is less energy in the field.
What general rules could we make for when there is a lot of energy stored in the field?	There is more energy in the field when opposite charges are really far apart. There is more energy in the field when the charges are bigger. The more energy is in the field, the more kinetic energy is released.
Why is this important to consider when examining how lightning interacts with materials?	There is a lot of charge built up in clouds and clouds are far from the ground. There will be a lot of energy stored in the field between clouds and the ground.

7 · REVISE THE M-E-F POSTER

5 min

MATERIALS: science notebook, M-E-F poster, chart paper markers

Revise the M-E-F poster. Display **slide L** and the M-E-F poster. Say, *We have figured out a lot of important ideas in this class!* Then ask about the prompt on the slide. Give students a minute to turn and talk if they struggle to respond. Listen for the following ideas:

- Energy is stored in the field.
- The field comes from charges, or charged matter.
- The field that stores energy is the field that causes forces.
- We know there is energy in the system when the particles are moving or move after being released.
- Energy transfers between the field and the particles.

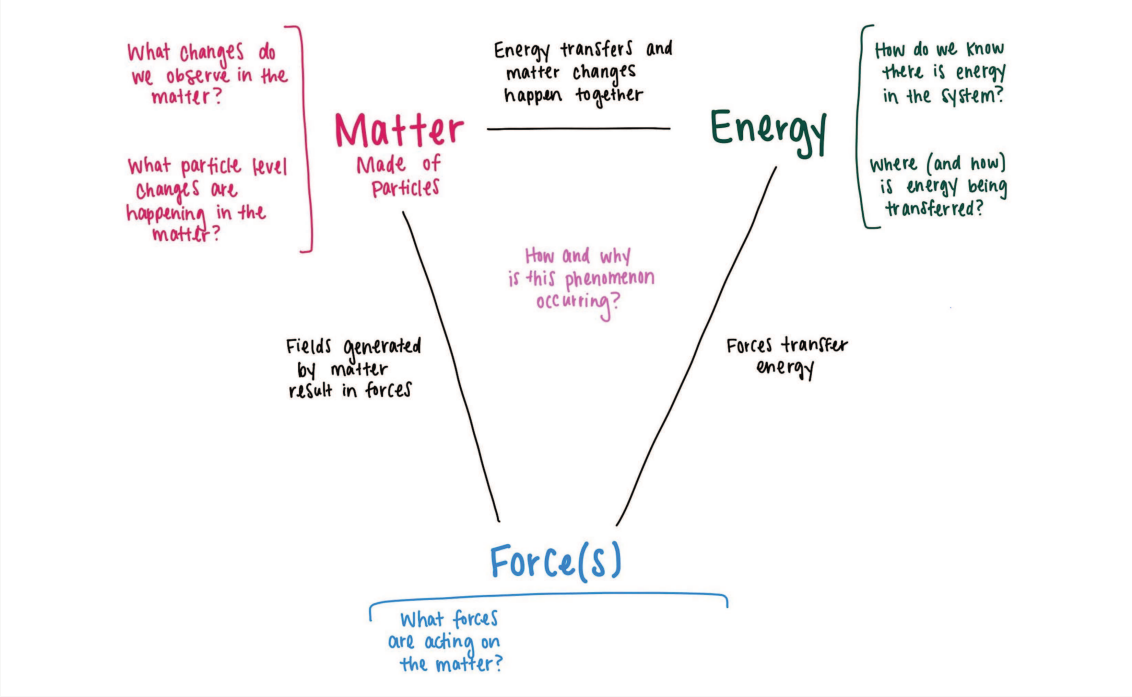
Say, *We do not yet have a forces-energy line on our M-E-F poster. Do we think we can add that now?*

Establish a Force-Energy line. Say, *In middle school, we saw that energy can transfer not only between a field and an object, but also between objects. Did forces have anything to do with that?*

Listen for these ideas:

- Energy transfers when there is a push or pull.
- Energy transfers when objects or particles collide or exert a force on one another.

Acknowledge these thoughts and add a line between Force and Energy on the M-E-F poster, labeled something like "Forces can transfer energy."



ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Generalize the idea that energy is stored in the electric field which is established by the forces between particles and suggest how these components interact, using the class M-E-F poster. (SEP: 2.3; DCI: PS3.C.1, PS2.B.2)

What to do: If students struggle to derive a general principle from the investigation, ask them to think about magnets, particularly if they are familiar with *Magnets Unit* from middle school. Say, *If we have two magnets, where is the energy stored?* Students should recognize that it is stored in the magnetic field. Then ask, *Where did this field come from?* They will note that it comes from the forces exerted by the magnets. You may also wish to return to the energy transfer model from the Building Understandings Discussion and help students map how we can tell that the different energy transfers are occurring even without a bar graph as in the computational model.

Building toward 10.A.2 Use models based on evidence to illustrate the relationships between the components of a system in which energy flows between particles and an electric field. (SEP: 2.3; DCI: PS3.C.1, PS2.B.2; CCC: 5.2)

Update Personal Glossaries. Display **slide M.** Elicit student ideas for terms we should add to our Personal Glossaries. Students should highlight *energy in a field*, but may choose other terms as well. Give students a few minutes to add these terms to their science notebooks.

Sample entry: *energy in a field = energy stored in the space between charged particles.*

End of day 1

8 · NAVIGATE

4 min

MATERIALS: M-E-F poster

Recall main takeaways from the M-E-F poster and computational model from day 1. Display **slide N**. Begin by reminding students that the computational model showed relationships between charged particles. Use the prompts on the slide to have students summarize main takeaways from the previous day.

Suggested prompt	Sample student response
What did we add to our M-E-F poster, or "matter-energy-force" model?	We added a connection between force and energy. We figured out that forces help transfer energy, which is why we connected force and energy with a line in the model.

Suggested prompt	Sample student response
How well does the computational model explain energy in lightning?	We figured out that energy can be stored in fields between charged objects. It does not directly tie into lightning, but we think that the energy in lightning is also stored in fields like we saw in the simulation. It did not show us specifically how lightning works.

Display **slide O.** Pose the first question on the slide. Once students agree that the answer is no, ask them to consider the second question on the slide.

Suggested prompt	Sample student response
Does either model fully explain the lightning phenomenon?	Nope! Neither model shows lightning or static at all.
How can we apply what we learned from these two models to the lightning phenomenon?	We have to use what we learned from these tools and include them in our own models of lightning that we made earlier in the unit.

9 · EXAMINE FEEDBACK

15 min

MATERIALS: *Model Self-Assessment*, lightning model from Lesson 9

Complete self-assessment of lightning models from Lesson 9. Distribute or instruct students to take out their models from Lesson 9. Then distribute *Model Self-Assessment*. Display **slide P**. Say, *Recently, you revised your initial lightning model to include what we figured out about electricity and what causes charge. Now look back at your revised model and feedback and use this self-assessment handout to help you reflect on what your model does well, and what you may still need to add to it.* Give students seven minutes to work on *Model Self-Assessment* independently, making sure that all students complete at least the checklist in #1.✱

ADDITIONAL GUIDANCE

If students struggle to identify missing components, ask them to show you on their model where to find each component or interaction from the checklist. If students cannot do this for everything on the checklist, tell them that this is where their model needs revision.

Have students discuss their self-assessment with a partner. Display **slide Q**. Give students three minutes to turn to their shoulder partner to discuss questions 2–4 on the handout, which go over the mechanisms ✱ of a lightning strike and provide space for students to identify the feedback that they are unsure of. As students discuss, walk around the room to listen to their reflections. As you circulate, you may wish to clarify any feedback that students identified in question 4.

Discuss the last questions on the handout as a class. Display **slide R**. Ask students to share their responses to the prompts in question 5 about how comfortable they are developing and revising models by holding up a number of fingers from 1 to 5. Use this opportunity to check for their confidence and comfort with these skills and offer space for students to ask questions and get support, especially if many students are displaying fewer than three fingers.

✱ ATTENDING TO EQUITY

Building classroom culture: Emphasize to students that working together toward a goal, like figuring out how lightning works, requires that we sometimes take time to reflect on where each person is on their individual journey.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING CAUSE AND EFFECT

Although this crosscutting concept is not highlighted in the lesson-level performance expectations (LLPEs), it is important that students consider the cause-and-effect mechanisms of lightning (see questions 2 and 3 of *Model Self-Assessment*). This is because being able to represent and explain

Suggested prompt	Sample student response
What strategies could help improve your ability to develop models?	Creating a checklist or key before we model. Using tools like a zoom-in bubble or before and after comparison to show what is going on.
What strategies could help improve your ability to revise models?	Looking at classmates' models. Asking each other questions and explaining our models to each other. For revisions we can add new things in a different color, or just start over next to or below the original model.

Use any additional time to address and clarify student questions about feedback and/or the checklist in the handout.

the lightning phenomenon relies heavily on an understanding of why one component causes another component's charges to change.

10 · REVISE MODELS

15 min

MATERIALS: *Model Self-Assessment*, lightning model from Lesson 9, M-E-F poster

Update and revise lightning models with takeaways from day 1 and self-assessment.✱ Say, *Yesterday we learned more about where the energy in lightning comes from when charged objects interact. Today we looked back at the models we made before we figured out those things. Now we can put all of our ideas together in a revised model that shows our most up-to-date understanding of how lightning works.*

Display **slide S.** Ask, *What do we need to add to the Gotta-Have-It Checklist so that it reflects the key ideas we learned about energy and forces from the computational model?* As the class agrees on ideas to add, have students add them at the end of *Model Self-Assessment*. Listen for these ideas:

- Energy stored in fields
- Connections between energy and forces
- Energy transferring from the field to the particles as opposite charges attract

Say, *Great! You have the self-assessment handout, an updated Gotta-Have-It Checklist, the M-E-F poster, and ideas from our class discussion about feedback. Use these tools to revise your lightning model from Lesson 9.* Give students 12 minutes to work on this independently. *Model Revision Key* provides an example of a possible model revision.

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Students should use both the computational model and the M-E-F poster to revise their models from Lesson 9 and explain how lightning is able to transfer so much energy from the cloud to the ground.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' models represent energy transferred into and out of the field as observed in the computational model. (SEP: 2.4; DCI: PS3A.1)
- Students' models include both atomic-scale charges and movement of those charges in the lightning system. (SEP: 2.4; CCC: 3.1)

What to do: If students' models do not include energy transferred into and out of the field, prompt them to think back to the computational model and ask them what big ideas that model helped us add to our understanding. Then ask students how they could represent those ideas (how forces transfer energy) in their model.

Building toward 10.B Use multiple models to provide a mechanistic explanation of energy changes in a macroscopic lightning system as a result of the movement of charges at the atomic scale. (SEP: 2.4; DCI: PS3.A.1; CCC: 3.1)

11 · UPDATE PROGRESS TRACKERS

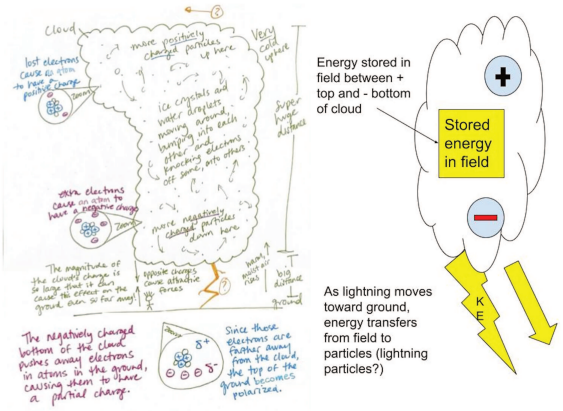
7 min

MATERIALS: science notebook

Update Progress Trackers. Display **slide T**. Give students seven minutes to update their Progress Tracker with any new information about the energy in a lightning strike. A sample entry is shown.

Question	Source of evidence
Where does the energy come from for lightning to strike across miles of air?	*Computational model* *M-E-F Poster*
What we figured out in words/pictures	

- *There is more energy stored in the field when there are more charges or when opposite charges are farther apart.*
- *When oppositely charged particles move away from each other energy is stored in the field between the particles.*
- *When oppositely charged particles move closer together energy transfers from the field to the particles.*



12 · NAVIGATE

4 min

MATERIALS: None

Help students navigate to the next lesson. Display **slide U** and lead students in a brief discussion using the prompts on the slide and additional prompts in the table.

Suggested prompt	Sample student response
How does what we figured out about energy apply to a storm cloud?	There is more energy when there are more charges or when they are farther apart.
There are both positive and negative charges in the cloud. Why does lightning strike the ground?	The forces are stronger between the bottom of the cloud and the top of the ground than between the bottom and top of the cloud.
Does that force only come into existence right before the lightning strike?	No, it was there as long as there were charges. Just like the sim with the balloon, there is a charge on the ground that could probably change or be "pushed" about.

Suggested prompt	Sample student response
Then why does lightning strike all at once instead of charges moving toward each other constantly?	Maybe the charges have to build up for a while. We are not sure.

Say, *It sounds like that is a productive path for investigation in the next lesson!* Thank students for their great ideas.

LESSON 11: Why do the electrons build up in the cloud and then jump to the ground suddenly?

PREVIOUS LESSON

We analyzed data that show that lightning transfers a LOT of energy. We used a computational model that shows energy storage between charges to realize that the energy comes from the electric field, or the space between the charges. We added these ideas to our updated lightning models, and then applied what we figured out about energy stored in an electric field back to storm clouds.

THIS LESSON

INVESTIGATION

2 days



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After rewatching slow-motion lightning videos, we consider what we know about air to figure out that there is no easy path for electrons to move through it. We conduct research for scientific information about how charges move through air, working in small groups to evaluate our sources. We use our paper-clip models to help make sense of the information we obtained to explain how charges move through air to cause the lightning we can see.

NEXT LESSON

We will brainstorm types of places we think are safe and unsafe during lightning. We will look at lightning safety data and statistics and read about how lightning rods work. We will examine models of metals and nonmetals. We will use all of this information to explain why some structures are safer than others during a lightning strike.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6, HS-PS3-2, HS-PS3-5

WHAT STUDENTS WILL DO

11.A Gather, read, and evaluate scientific information about interactions between atoms in the lightning system which cause the strike we see between the cloud and the ground. (SEP: 8.3; DCI: PS1.A.3; CCC: 2.2)

11.B Communicate information in words and diagrams about the causes of energy transfer through light and sound. (SEP: 8.5; DCI: PS3.A.2, PS3.A.4; CCC: 2.2)

WHAT STUDENTS WILL FIGURE OUT

- Air is a good insulator because it does not let electrons move through it easily.
- The electric field created by a storm cloud can rip electrons off nearby air molecules, creating ions.
- Channels of ionized air branch out in segments from the cloud toward the ground.
- When one of those channels connects with a channel of positive charge from the ground, electrons move easily and rapidly through the path, causing the intense lightning strike we see.
- Light flashes, thunder, and nitrate formation all result from energy transfers out of strong electric fields.

Lesson 11 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Recall the question the class has about charges jumping from the cloud and rewatch the slow-motion lightning videos from Lesson 1 to motivate today's work.	A-B	https://openscied-static.s3.amazonaws.com/videos/slomo-strike-1.gif, https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2.gif, https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2-slower.gif
2	12 min		**DEFINE AIR AS AN INSULATOR** Consider what we know about air and how it is a good insulator because there is no easy path for electrons to move through it.	C-H	class consensus model
3	28 min		**OBTAIN INFORMATION ABOUT CHARGES MOVING IN AIR** Organize students into small groups to conduct research for scientific information about how charges move through air. Have students work in their small groups to evaluate one another's sources.	I-K	internet connected device, *Gathering Information*, chart paper, chart paper markers
					End of day 1
4	4 min		**SHARE INFORMATION ABOUT CHARGES MOVING THROUGH THE AIR** Have students meet back with their group to complete Part D on *Gathering Information*.	L	*Gathering Information*, internet connected device
5	15 min		**MAKE SENSE OF HOW CHARGES MOVE THROUGH AIR** Have the class move to a Scientists Circle. Lead a Building Understandings Discussion to make sense of the information students obtained from their online searches.	M-Q	paper-clip model, *Gathering Information*
6	12 min		**READ ABOUT THE EFFECTS OF LIGHTNING** Support students as they read about the effects of lightning.	R-T	*Power of Lightning*, chart paper, chart paper markers, "Rules for Energy Transfer" poster (optional)
7	10 min		**COMPLETE AN ELECTRONIC EXIT TICKET** Give students time to complete an Electronic Exit Ticket that builds on the reading.	U	copy of https://docs.google.com/forms/d/1ydoISMHNbVinJF7u3VhghGWT3wxXDXoofcZJ0KXVaaI/copy, https://docs.google.com/forms/d/1iulw0L2EPYJh94FkKK-zqbr-5nO0KnLZB6tZvwFPdeO/copy *Power of Lightning*, internet connected device
8	4 min		**NAVIGATE** Use the Driving Question Board to identify the direction for next time.	V	*Our DQB Questions* (optional), Driving Question Board
					End of day 2

Lesson 11 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • internet connected device • *Gathering Information* • paper-clip model • *Power of Lightning* • copy of https://docs.google.com/forms/d/1ydoISMHNbVinJF7u3VhghGWT3wxXDXoofcZJ0KXVaaI/copy • https://docs.google.com/forms/d/1iulw0L2EPYJh94FkKK-zqbr-5n00KnLZB6tZvwFPde0/copy *Power of Lightning* • *Our DQB Questions* (optional)	• internet connected device	• https://openscied-static.s3.amazonaws.com/videos/slomo-strike-1.gif • https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2.gif • https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2-slower.gif • class consensus model • chart paper • chart paper markers • "Rules for Energy Transfer" poster (optional) • Driving Question Board

Materials preparation (25 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Be ready to project the slow-motion lightning videos from Lesson 1 found at the following links. You might consider darkening your classroom if your projector is dim.

- first lightning strike in slow motion, at https://openscied-static.s3.amazonaws.com/videos/slomo-strike-1.gif
- second lightning strike in slow motion, at https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2.gif
- part of the second lightning strike even slower, at https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2-slower.gif

Students will again use the paper-clip models from Lessons 5 and 8.

Students will develop energy transfer models as a class in this lesson. You may wish to have "Rules for Energy Transfer" from *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* ready to display to support this task.

Lesson 11 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build new ideas related to the following disciplinary core ideas:

- **PS1.A.3 Structure and Properties of Matter:** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- **PS3.A.2 Definitions of Energy:** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- **PS3.A.4 Definitions of Energy:** These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). ~~This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.~~

DCI: PS1.A.3 is present throughout the lesson as students gather information (SEP: 8.3) about lightning, use it to model the cause-and-effect relationships that occur at the particle level (CCC: 2.2), and complete an Electronic Exit Ticket that focuses on the mechanism by which ions are available to form nitrates from lightning. This work builds on students' mechanistic thinking about force interactions in lightning from Lesson 8, as well as students' integration of multiple authoritative sources in Lesson 8 of *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*. Students should have some familiarity with evaluating information from middle school, in which CCSS.ELA-LITERACY.RH.6-8.8 reads, "Distinguish among fact, opinion, and reasoned judgment in a text." In writing, 6th-grade students should similarly be able to "Support claim(s) with clear reasons and relevant evidence, using credible sources and demonstrating an understanding of the topic or text." This learning can serve as a basis for students' work with SEP: 8.3 in this lesson. In addition, example search phrases that have been checked for usefulness are provided.

Students' cause-and-effect thinking is heavily scaffolded throughout the Building Understandings Discussion, as this is the first time that students engage with CCC: 2.2 in this course.

DCI: PS3.A.2 and DCI: PS3.A.4 are introduced here for the first time in the OpenSciEd High School sequence. Students develop these ideas from a combination of reading and communicating them in both words and class-built energy transfer models (SEP: 8.5). They know from the middle school unit *OpenSciEd Unit 8.2: How can a sound make something move? (Sound Unit)* that sound waves carry energy, and in *Polar Ice Unit* they identified light (radiation) and particle motion (conduction) as energy transfer mechanisms. They also use ideas about energy transfer from fields built in this unit, most recently in Lesson 10. Students engage partially in this element: *Communicate scientific and/or technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, ~~mathematically~~).* Students will have opportunities to communicate using mathematical formats later in the chemistry course.

Because we use our paper-clip models to make sense of the ionization of air in the lightning system, our definition of *ion* at this point will simply be atoms that have a charge because they lost electrons. Students develop an understanding of the process of ionization and work to define it as:

- *Ionization:* The process in which atoms that were neutral become charged by losing an electron.

Also, note that lightning-specific terminology, such as *stepped leaders*, *positive streamers*, or *return stroke*, may be helpful to your discussion but are not critical to the sensemaking of this lesson. Use the language your students use, and it is fine if students describe what is happening in their own words and/or with less-specific vocabulary.

In this lesson, students will co-construct a definition for the following terms, which they should add to their Personal Glossary: *insulator, conductor, ion* and/or *ionization*. Do not ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

As addressed in the moment in the lesson, students who have had prior experiences with OpenSciEd courses may have encountered the similar terms *conduct*, *conduction, insulate*, and *insulation* in *OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* in the context of heat, with *conduction* reappearing in *Polar Ice Unit*.

Where We Are NOT Going

Students will have opportunities to individually gather information in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)* and will have more practice communicating information in Lesson 14 of this unit.

Students will not build an understanding of ionized molecules or negative ions. We do not introduce the terms cation or anion. Students will consider ions more deeply in Lessons 12 and 13 and in *Space Survival Unit*.

Although we are building understandings around ions in this lesson and unit, we are not working with the patterns of electrons in the outermost energy levels of atoms, or ideas such as ionic bonding. Students will identify ionic bonds in Lesson 13 and develop more complex mechanisms around them in *Space Survival Unit* and *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*.

In their reading online about ionized air, some of your students may come across the term *plasma*. Use your discretion to decide whether, or how much, you will dig into this idea. If time allows and you think it beneficial to your students, it would be appropriate to encourage them to further explore plasma(s). You may also choose simply to co-construct a basic definition based on what students heard/read in this lesson, such as naming plasma as a fourth state of matter, and/or clarifying that it is used in plasma TVs and fluorescent and neon lights but that it is not the same as blood plasma.

When students read about and discuss energy transfer models, they may recognize that they cannot develop fully satisfying models for all of the phenomena, in particular the formation of nitrates. This is okay, as it foreshadows the deeper understandings about energy transfer in reactions that students will build in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*. Students will continue to explore DCI: PS3.A.2 and DCI: PS3.A.4 not only in that unit, but in *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)* and *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)* in physics as well.

LEARNING PLAN for LESSON 11

1 · NAVIGATE

5 min

MATERIALS: https://openscied-static.s3.amazonaws.com/videos/slomo-strike-1.gif, https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2.gif, https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2-slower.gif

Navigate into today's work. Display **slide A**. Direct students to turn and talk with a neighbor about what we left off wondering about last time. Listen in on the students near you.

Summarize what you heard students talking about. Say, *Last time we were wondering why the negative charges that are collecting at the bottom of the cloud do not just travel down to the ground any time or all the time. Why do they build up there and then make this massive "jump" to the ground all at once when the lightning happens?*

Rewatch the slow-motion videos from Lesson 1. Display **slide B**. Say, *It might be helpful for us to take another look at the slow-motion videos we watched at the beginning of the unit. While we watch these again, look for clues as to why or how those charges move all at once from the cloud to the ground.*

Play the following videos from Lesson 1. You might consider darkening your classroom if your projector is dim. Then, use the prompts below to discuss what students notice.

- first lightning strike in slow motion, at https://openscied-static.s3.amazonaws.com/videos/slomo-strike-1.gif
- second lightning strike in slow motion, at https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2.gif
- part of the second lightning strike even slower, at https://openscied-static.s3.amazonaws.com/videos/slomo-strike-2-slower.gif

Suggested prompt	Sample student response
What did you notice that could help us figure out why or how the charges move between the cloud and the ground?	There are little glowing branches or streamers that trickle down from the cloud before the big strike/flash. They kind of fan out in different directions, like trails with forks in the road, not straight toward the ground. It looks like maybe the strike actually goes back up from the ground to the cloud instead of from the cloud to the ground. The brightest strike didn't happen along all of the "trails" that trickled down, just along one of them.
(If you have questions on your DQB specifically about those streamers or the direction of the strike, call attention to those now.) *We can see the glowing trails and super bright strikes moving between the cloud and the ground, but what are they moving through? What is between the cloud and the ground that the lightning passes through?*	Air.

Say, *Have we figured out how air plays into this yet? Do we think it matters? Let's dig into that some more.*

Define the system. Ask, *Based on our discussion, what all belongs in the system we are focusing on?* Listen for students to highlight air, as well as the ground and particles in the cloud.

2 · DEFINE AIR AS AN INSULATOR

12 min

MATERIALS: science notebook, class consensus model

Review what we know about the composition of air. Display **slide C**. Say, *Let's take some time to think more carefully about air. Let's consider what role it might be playing in causing the charges to build up and strike all at once instead of just trickling down all the time. So, what do we already know about air and its makeup?*

Look for students to suggest:

- Air is a mixture of gases.
- It contains nitrogen, oxygen, carbon dioxide, and water vapor.

After hearing a few initial ideas, display **slide D** to support students in reviewing the general composition of air. Say, *The air around us is a mixture of different types of gases. Most of the gas in the air is nitrogen and oxygen, and a smaller amount is carbon dioxide, water vapor, argon, and other substances.*

ADDITIONAL GUIDANCE

Slide D contains supplemental information about the composition of air. If students experienced *OpenSciEd Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit)* and *OpenSciEd Unit 7.6: How do changes in Earth's system impact our communities and what can we do about it? (Droughts and Floods Unit)*, they should know that air contains oxygen and carbon dioxide. In Lesson 3 of *Polar Ice Unit*, students examined the composition of Earth's atmosphere.

Problematize what that means for the electrons in the cloud. Display **slide E**. Say, *Let's think more about these gas molecules. Compared to other matter, like the water droplets in the cloud or the solid materials on the ground, how far apart are the particles in air?*

Look for students so suggest:

- The particles in air will be much farther apart than the particles in liquids like water or solids on the ground.
- Particles in gases have lots of space between them--they're really far apart!

Point to your lightning system class consensus model as you talk about the electrons in these different areas.

Say, *So imagine those extra electrons that are collecting on water particles at the bottom of the cloud.* Point to the end of one wire on the lightning system. Then point to the space between the two wires and display **slide F**. Have students turn and talk with a partner about the prompts, then ask for a few volunteers to share.

Suggested prompt	Sample student response
If the molecules in air are relatively far apart, how easy would it be for the electrons to move between them?	They wouldn't move well because the distance between particles is too far apart.
Do you think this is the case in all materials? Why or why not?	No, I think it would be easier in solids or liquids where the particles are closer together.

Summarize student ideas and say, *So we think that the electrons will have a harder time moving through the air. Scientists use the words "insulator" and "conductor" to describe how electrons move through different types of materials.*

Build definitions of insulator and conductor.✱ Display **slide G**. Have students turn and talk with a partner about the prompts on the slide.

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: Leverage students' prior familiarity with insulation and conduction in heat contexts from *Cup Design Unit* and *Polar Ice Unit*. In addition, consider leveraging cognates and loan words. The terms *insulator* and *conductor* have cognates or near cognates in many Romance languages and serve as the basis for loan words in many other languages. Also work with students to distinguish between *conductor* as defined here versus as the leader of a band or orchestra, and *conduct* as referring to behavior in formal contexts.

Suggested prompt	Sample student response
What do "insulator" and "conductor" mean to you?	An insulator is something that doesn't let heat through very well. A conductor is something that lets heat flow through it easily.
What could these terms mean in the context of electricity?	Insulators prevent charge or electricity flow, while conductors allow it.
What are some examples of insulators and conductors?	Insulators: Glass, paper, wood, plastic Conductors: Metal wires, or maybe all metals; water may be a conductor as well
How do those examples compare to electrons traveling through air?	It's different because they are all solids or liquids.

ALTERNATE ACTIVITY

Building prerequisite understandings: Students may not immediately recall the meaning of *conduct* and *insulate* from prior learning. If this is the case, insulated drinkware is likely familiar to students and present around the school. They may also be familiar with the appearance of building insulation, even if they are unfamiliar with its use. You can leverage these phenomena to establish the term. Use the simulations from Lesson 10 in *Polar Ice Unit* to refresh or introduce students to thermal conduction as needed.

Update Personal Glossaries. Display **slide H**. Have students take a moment to add *insulator* and *conductor* to their Personal Glossary. Sample entries:

- *insulator - a substance that electrons cannot easily move through.*
- *conductor - a substance that electrons can easily move through.*

Summarize by saying, *We have concluded that air is a good insulator and it is not easy for electrons to move through it. So it makes sense that electrons are not trickling out of the cloud through the air all the time--they end up "hanging out" in the bottom of the cloud. But then what? What happens to cause or allow them to move all at once as lightning?*

3 · OBTAIN INFORMATION ABOUT CHARGES MOVING IN AIR

28 min

MATERIALS: internet connected device, *Gathering Information*, chart paper, chart paper markers

Consider how headlines can be misleading. Display **slide I**. Say, *In a moment you will work in small groups to research how electrons can move through air to form lightning. Earlier, I was researching lightning formation. I found an article in a magazine published pretty recently titled "Detailed footage finally reveals what triggers lightning," and I was so excited thinking that scientists had figured it out! Then I read the original paper by the researchers who did this work and learned that yes, they were able to gather data that previously had been difficult or impossible to get, but that did not mean they knew exactly what was happening. You have probably encountered similar issues in English classes or online. What can we take away from that?*

Listen for ideas such as:

- Sometimes headlines can be misleading.
- The actual study was not as conclusive as the magazine headline indicated.
- That's why it's important to evaluate your sources--so you're getting the accurate information from the people who are experts about it.✱

Brainstorm possible search ideas. Explain that today, we will obtain information about how charges move through air by researching online. Display **slide J**. Ask, *What terms, phrases, or questions should we use to search for information?* Record possible ideas on the board or a piece of chart paper for students to reference. Sample search ideas include:

- How can charges move through air?
- How do electrons move in air?
- How do charges move in lightning?
- What happens to air in lightning?

Obtain and evaluate information about lightning formation. Organize students into groups of 3 or 4. Display **slide K** and distribute *Gathering Information*. Talk through the directions on the slide so that each group has a successful research experience. Explain that the goal is for each group to bring information to the class from one or two reliable sources.

Give students the remaining class time to complete Parts A, B, and C on the handout.

ADDITIONAL GUIDANCE

It is okay if students use non–peer-reviewed literature in this activity. However, it is important to support them in understanding why peer-reviewed literature is considered desirable. Peer review is run by a third party, so that the authors and reviewers do not know who each other are. The reviewers--usually multiple scientists in the same general area of research--do not focus on formatting or spelling, but instead examine whether the authors supported their arguments with evidence, explained their experimental methods well enough to be duplicated so their work can be checked, and drew reasonable conclusions from the data.

In addition, help students understand the difference between the text's usefulness (Can it help answer the questions *we* have?) and its authoritativeness (Is the author in a position to provide answers we can have some confidence in?).

✱ SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

Students may also name other heuristics, like the professionalism of the website, whether an article cites its sources, or whether it names the author. Students' familiarity with these heuristics can help generate ideas, but *Gathering Information* intentionally develops other strategies.

Although commonly used, heuristics like CRAAP (Currency, Relevance, Authority, Accuracy, Purpose) are not necessarily the most useful in identifying certain types of incorrect information, such as intentionally incorrect information. See for more:
Allchin, D. (2023). Marginalizing Misinformation the Fast-and-Frugal Way. *The Science Teacher, 90*(5).
Osborne, J., Pimentel, D., Alberts, B., Allchin, D., Barzilai, S., Bergstrom, C., Coffey, J., Donovan, B., Kivinen, K., Kozyreva. A., & Wineburg, S. (2022). *Science Education in an Age of Misinformation*. Stanford University, Stanford, CA.

ALTERNATE ACTIVITY

Students' searches will likely return videos in their results list, especially if YouTube is not blocked at your school. Use your discretion and the amount of time you have (as videos often take longer to watch than a short article would take to read) to decide whether or not you will encourage students to use videos as sources. Students would still need to evaluate the credibility and relevant expertise of the person or group who created/posted the video before using it as a source. Note that YouTube has an "about" section for channels, but the content creator may or may not have completed it.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Circulate and check in with student groups as they complete their online search and take notes on *Gathering Information*:

- In Part A.2, students name specific indicators they used to choose a search result (SEP: 8.3), such as avoiding sponsored results and carefully considering domain names.
- In Part B.4, students tell how they decided their source was authoritative, based on evidence (SEP: 8.3) such as the author's expertise in a relevant area and unbiased information.
- In Part C, students gather useful scientific information from what they read that answers their questions about the interactions in the lightning system. (SEP: 8.3; DCI: PS1.A.3)
- In Part C, students describe the causes of interactions at the particle level. (CCC: 2.2)

What to do: If students skip ahead to reading from their source without identifying it as reliable, point back to the tips in Parts A and B of the handout. Ask them to check on those, possibly by opening another tab to quickly research the author or website they are reading from. If students struggle to find information that identifies their source as authoritative, acknowledge that the source might not be reliable. It is possible that students will not have enough time to dig into their sources as much as they would like to, so consider providing extra time for gathering information as home learning and/or during the next class period.

Building toward 11.A.1 Gather, read, and evaluate scientific information about interactions between atoms in the lightning system which cause the strike we see between the cloud and the ground. (SEP: 8.3; DCI: PS1.A.3; CCC: 2.2)

End of day 1

4 · SHARE INFORMATION ABOUT CHARGES MOVING THROUGH THE AIR

4 min

MATERIALS: *Gathering Information*, internet connected device

Set up the task. Welcome students back to class and remind them about the information they gathered the previous day. Display **slide L**. Give them a few minutes to meet with their group and share what they found, with an emphasis on finding common ideas that show up in multiple sources.

5 · MAKE SENSE OF HOW CHARGES MOVE THROUGH AIR

15 min

MATERIALS: paper-clip model, *Gathering Information*, science notebook

Lead a Building Understandings Discussion about how charges move through air. Gather the class in a Scientists Circle with *Gathering Information* and the paper-clip model they used in previous lessons.

Display **slide M**. Ask, *What did we find out about how charges can move through air?* Invite groups to summarize the findings from their online searches. At this point, the focus is on sharing any synthesizing ideas about how charges move through air, rather than why certain sources are reliable. Students will have an opportunity to reflect on their experiences evaluating sources after this discussion.

Ask, *How can we use the paper-clip model to show what is happening as the electrons move through the air and finally to the ground?*

Students may suggest that we use different students' paper-clip models to represent the atoms in the cloud, in the air, and on the ground.

Use the "Key ideas" box and the prompts on **slides N-P** to facilitate this discussion. Work with the class to use the paper-clip models to show what is happening as students share. You might have students stay seated, stand and hold their models, tape them to the wall or board, or even lay them on the floor of the circle. You may find more space available if you have this discussion in the hallway.

KEY IDEAS

Purpose of this discussion: to share and synthesize information we learned about how charges move through air. In this Building Understandings Discussion, the evidence students use to support their ideas will be less about the source of the information (since they will reflect on evaluating sources later) and more about connecting what they read to what they already know--i.e., how does this new information make sense in terms of what we have already figured out about lightning?

Listen for these ideas:

- When the negative charges building up in the cloud cause a strong enough electric field, it can rip electrons off nearby particles of air, creating ions.
- Ions are charged particles (that, in this case, have lost electrons).
- Electrons can move more easily in this ionized (charged) air.
- Channels of ionized air form from the cloud in segments--those are the "branches" we saw before the strike in the slow-motion videos.
- When one of these channels gets close enough to the ground, channels of ionized air also begin to form from the positively charged ground/objects.
- When one of the channels from the cloud connects with one from the ground, the free electrons flow down it very rapidly, causing the intense lightning strike we see.

Say, *While we share the information we obtained about how charges move through air, let's use our paper-clip models to make sense of what is happening. Since each model represents only one atom, let's say we have just plucked single atoms out of the molecules in the cloud and air. First, let's show what is going on with atoms in the cloud.*

ADDITIONAL GUIDANCE

For this next portion of the activity, have the class form three groups. Most of the students (about two-thirds) should represent atoms in the air, with the remaining one-third split between representing atoms in the cloud and atoms on the ground.

Model what is happening to the atoms in the cloud. Display **slide N**. It may be helpful to have students hold two pieces of paper, one labeled "Top of the cloud" and the other "Bottom of the cloud." Have two students use their paper-clip models to represent atoms from the water molecules in the cloud. Have two other students' paper-clip model atoms "collide" with the first students' and transfer an electron, moving the now-positively charged atoms toward the top of the cloud and the now-negatively charged atoms toward the bottom of the cloud.

Suggested prompt	Sample student response
We have all these negative charges, or extra electrons, at the bottom of the cloud, but we know the air under the cloud is not a good environment for electrons to move through easily. So the electrons are all just building up at the bottom of the cloud. What did you learn happens next?	When there's enough charge built up there, some of the air molecules' electrons can get ripped off. The air "breaks down" and lets the electricity move through it. The air "ionizes"--it gets charged--because those electrons are getting pulled off.
Let's see if we can make sense of this by representing it with our paper-clip models. (Have a volunteer representing an air atom remove an electron.) What causes this atom from the air to lose that electron?	The electric field from the charged cloud. The negative charges at the bottom of the cloud are pushing off electrons from those atoms of air molecules.
I heard you mention the word "ionize." Did anyone else see or hear that word and can you explain what it means?	The gas molecules in the air lose electrons, which makes them charged--there are positive atoms that lost electrons, and then the negative electrons themselves. The charged atoms are called ions.

Gesture at the paper-clip model of the air atom that's missing an electron and ask, *So do we have an ion here?* Students should say yes or show agreement.

Model what is happening to atoms in the air. Have another two students representing air atoms bring their paper-clip models over to the electric field under the cloud and remove an electron from those atoms. Say, *Now we have some ionized air under the cloud.* Display **slide O** and discuss the next set of prompts below.

ADDITIONAL GUIDANCE

Some of your students may bring up the term *plasma*, referring to an ionized gas, and suggest that the ionized air is an example of a plasma. This is an accurate way to refer to the air along lightning's path. Use your discretion to decide whether, or how much, you will dig into this term. Elicit ideas about what students think plasma is, and if you wish, identify it as the fourth state of matter and give neon signs as a familiar example. If your students are more curious, encourage them to keep exploring the idea of plasma on their own.

Suggested prompt	Sample student response
Does all the air below the cloud ionize all at once?	No, it goes a little bit at a time, in spurts or steps.

Suggested prompt	Sample student response
(Recap what just happened to ionize the air beneath the cloud.) You said this happens a little at a time. Let's model another part of the air ionizing. (Have a few more air atom volunteers bring over their paper-clip models and remove an electron.)	Yes, those are the jagged segments, the glowing trails coming down from the cloud and branching off a bit at a time.
So, that first part of the air was ionized. Then the charged particles and free electrons near the air atoms over there caused air atoms over here to ionize also. (Gesture to the additional group of ionized paper-clip models.) Could we see that happening in the slow-motion videos?	Those are channels of air ionizing. The article I read called those "stepped leaders."

You may wish to arrange students' positive ions and free electron models into something like a line, rather than a group, to represent the channels of ionized air.

ADDITIONAL GUIDANCE

If students use lightning-specific terms such as *stepped leaders*, *positive streamers*, *return stroke*, etc., that is fine, but these words are not critical to the sensemaking of this lesson. Use the language your students use, and if someone substitutes "leader" for "streamer," or just continues to describe the channel of ionized air, there is no need to correct them.

Say, *So, when one area of air ionizes, that can cause another area nearby to ionize, and it branches out like that?* Students should say yes or show agreement. Say, *Let's show that with our models.*

Model what is happening to atoms on the ground. Have any remaining students representing air atoms bring over their paper-clip models and remove an electron, showing the next segment of ionized air, now closer to the ground. Then display **slide P** and continue with the prompts.

ADDITIONAL GUIDANCE

It is important to note that the leaders branch out in jagged segments based on how easily the air nearby can ionize. They are not "aiming" for the ground or being "pulled" to the ground, hence the indirect path of lightning to the ground.

Suggested prompt	Sample student response
We have modeled here how the air becomes ionized in segments or steps as those electrons get ripped off of atoms. What happens next?	One of the leaders/channels of ionized air makes it to the ground. I saw that positive channels also come up from the ground, too, and then they connect. Those positive streamers can come up from pointy, taller objects too (not just the ground itself).

Suggested prompt	Sample student response
Okay, so we have more going on with the positive charges on the ground at this point. Let's model that. (Have a few of the "air" students bring their paper-clip models to the "ground" students.)	The positive charges move up toward the negatively charged cloud.
When the air here near the ground ionizes, what did you say is happening with these positive ions and free electrons?	
Then what happens?	The leader from the cloud connects with that positive path to the ground/object and we get a lightning strike!
Once the cloud and ground are connected by a channel of ionized air, then what?	All the electrons along that path and cloud can speed toward the ground. That's the lightning strike!
Okay, let's show that in our model. What is going on with the electrons in the lightning strike? Can someone show us using the electron paper clips?	(Moving electron paper clips as they talk) The loose electrons here in the leader/channel closest to the ground where it connected first can move down, then the ones behind those can move down, then the ones behind those can move down--so all the electrons that had been ripped off in the ionized air channel back up to the cloud can flow to the ground.
Do we see all that with our eyes when we are watching lightning in real life?	No, it's way too fast for our eyes to see. I read that the whole strike takes only a few fractions of a second, like milliseconds. I read that sometimes the lightning can look like it's flickering when other charges from the cloud continue to travel down that same path after the original strike.

Add key terms to Personal Glossaries. Display **slide Q.** Ask, *What new term(s) should we add to our Personal Glossaries that we consider essential to making sense of changes to atoms?*

Listen for the words *ion* and/or *ionization*. Sample glossary entries:

- *ion:* atom that has a charge because it lost electrons
- *ionization:* the process in which atoms that were neutral become charged by losing an electron

Direct students' attention to the effects of lightning. Point out that this discussion focused primarily on how the matter is moving in a lightning strike. Then say, *We know from the last lesson that a lot of energy is transferred when lightning strikes. What are some pieces of evidence we have for that?* Listen for these ideas:

- Light
- Thunder/sound
- Damage to objects

Share that people have long thought about how lightning, being dangerous and powerful, can have all sorts of effects on the environment. We will look into this a little bit more.

6 · READ ABOUT THE EFFECTS OF LIGHTNING

12 min

MATERIALS: science notebook, *Power of Lightning*, chart paper, chart paper markers, "Rules for Energy Transfer" poster (optional)

Introduce the reading. Distribute *Power of Lightning* and display **slide R**. Tell students that as they read, they should record any new ideas in their notebooks that will help us think about connections between matter, energy, and forces.✱

ALTERNATE ACTIVITY

Power of Lightning may be converted to a Jigsaw by placing students in groups of four and allowing students to focus on only one section of the reading. If you do this, provide time for students to meet with others who read the same section before returning to their home groups, to ensure that each home group has a confident expert in each section.

Discuss the reading. Display **slide S** and debrief the reading using the prompts.

Suggested prompts	Sample student responses	Follow-up questions
What new information about lightning did you discover?	We learned how the flashes of light and sound of thunder are created. We read that some people think lightning might make stuff that fertilizes plants.	*How do these phenomena work?* *How certain are we about what is happening with these phenomena?*
What connections did you notice between matter and energy?	Matter moving fast emits light in lightning. Matter moves apart and comes together to make thunder. Energy from lightning might cause reactions.	*How do these compare to other ways you have seen matter and energy connected in class or in your life?* *Where is that energy coming from at the particle level?*
What connections did you notice between matter and forces?	Ions are attracted, causing new matter to form.✱	*What phenomena like this have we seen before?*
What connections did you notice between energy and forces?	Energy from electric fields causes the strong forces that create ions.	*How could we show this using the simulation from last lesson?*

Consider how we could represent these energy transfers.✱ Display **slide T** and discuss the prompts with students. Display the "Rules for Energy Transfer" poster if desired. Record energy transfer models on chart paper as suggested by students, probing to ensure that they represent what students gleaned from the reading. Possible examples are shown below.

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

This reading sets up an opportunity for students to communicate information in multiple formats--through words and suggestions for energy transfer models (SEP). The small-scale mechanistic understandings of energy transfer that students share here (CCC) will likely help answer some questions about lightning flashes and thunder claps. This thinking requires students to use multiple lenses that show that they understand energy as manifesting itself through particle motion and energy in fields (DCI), with these two means of storage explaining phenomena that students identified as energy in Lesson 1.

✱ ATTENDING TO EQUITY

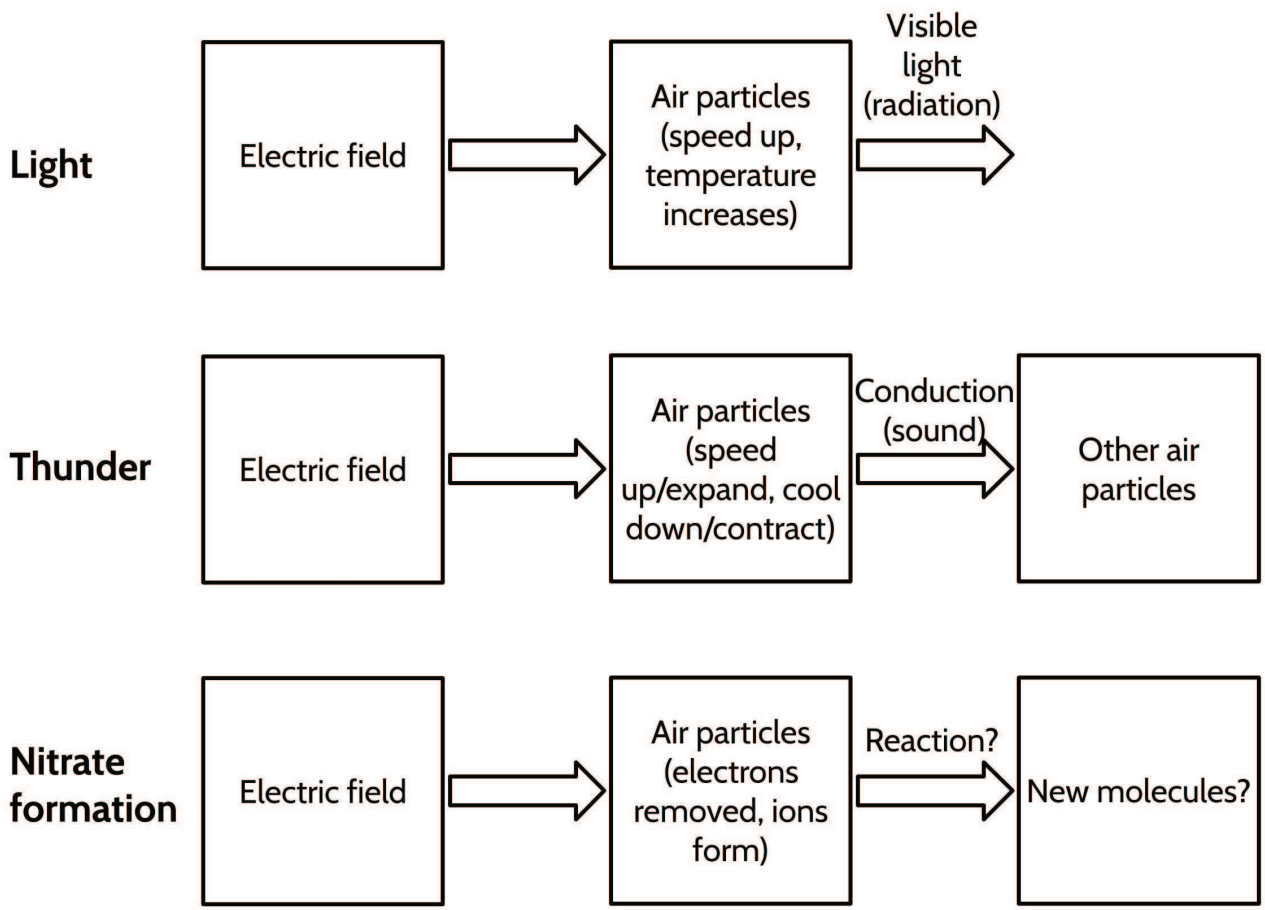
Universal Design for Learning: The language in the reading and discussion as written is intentionally focused on mechanism rather than vocabulary like *bonding*. Honor the different language *representations* that students bring to the table by acknowledging any terms that students bring up, but emphasizing that we should stick to words we all know well until we come to common definitions together. Students will develop an initial definition of *bonds* in Lesson 12 and *ionic bonds* specifically in Lesson 13.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

Students may be familiar with different "types" or "kinds" of energy from middle school. However, in this lesson students are reintroduced to several manifestations of energy (thermal energy, light, and sound) as being related to particle motion, which in

Suggested prompts	Sample student responses	Follow-up questions
How could we show energy transfer as light (radiation) with our energy transfer models?	Have energy going from the field to particles. Show the particles speeding up, then energy transfers out as light.	*Where does the energy come from?* *How does it get to the particles?* *What happens to the particles as energy is transferred to them?* *What happens to the energy next?*
How could we show energy transfer as sound (thunder) with our energy transfer models?	Have energy going from the field to particles. Say that the particles move apart, then come back together. Show the energy transferring to other particles through conduction/as sound.	
How could we show energy transfer as nitrate formation with our energy transfer models?	Have energy going from the field to particles. Show that electrons are removed, then energy is transferred to other particles as new molecules form.	

turn is due to energy stored in fields. Students spent much of *Polar Ice Unit* thinking about thermal energy, but have not named it as such in this course. Encourage students to add this term to their Personal Glossary if they are not familiar with it from middle school.


Light
Electric field
Air particles (speed up, temperature increases)
Visible light (radiation)
Thunder
Electric field
Air particles (speed up/expand, cool down/contract)
Conduction (sound)
Other air particles
Nitrate formation
Electric field
Air particles (electrons removed, ions form)
Reaction?
New molecules?

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students identify light, sound, and transfer out of fields as manifestations of energy. (DCI: PS3.A.2, PS3.A.4)
- Students communicate information about energy transfer at the microscopic level, via particle motion and fields, both verbally and diagrammatically (through suggestions about energy transfer model development). (SEP: 8.5; DCI: PS3.A.4)
- Students describe the causes of energy transfer at the particle level. (CCC: 2.2)

What to do: In addition to giving students a chance to communicate ideas through both words and energy transfer models, this opportunity also allows students to (1) reflect on the various manifestations of energy, and (2) recall energy transfer modeling from *Polar Ice Unit*. Students will have an opportunity to return to both of these ideas in *Fuels Unit*, so at this time it is okay if the work is more teacher-driven. Use the opportunity to highlight to students the multiple ways they can communicate ideas about phenomena, as they will be asked to do so again in Lesson 14. Students may struggle to completely flesh out the mechanism for nitrate formation, which is fine, as they will return to it in *Fuels Unit*.

Building toward 11.B Communicate information in words and diagrams about the causes of energy transfer through light and sound. (SEP: 8.5; DCI: PS3.A.2, PS3.A.4; CCC: 2.2)

ADDITIONAL GUIDANCE

If your students would like to dig into why we see (in the slow-motion videos) the luminosity of the lightning start at the ground and travel back up toward the cloud (even though the electrons are moving down toward the ground), you can have them do an online search for that question specifically.

Additionally, or alternatively, you might work with your paper-clip electrons to model what's going on: The electrons first start moving quickly closest to the ground where the connection happened, so we see the bright light start there. Then, as the ones "behind" them farther up the channel of ionized air start moving quickly it brightens there, and so on up toward the cloud.

You might choose to share this analogy, if it's helpful: Think of the electrons in the ionized air channel like a line of traffic backed up by a raised drawbridge. Once the bridge is lowered (and the road is connected again), the cars closest to it can start moving first, and then the ones behind them, and it takes a little time for the whole line of cars to speed up and get across the bridge.

7 · COMPLETE AN ELECTRONIC EXIT TICKET

10 min

MATERIALS: copy of https://docs.google.com/forms/d/1ydoISMHNbVinJF7u3VhghGWT3wxXDXoofcZJ0KXVaaI/copy, https://docs.google.com/forms/d/1iulwOL2EPYJh94FkKK-zqbr-5nO0KnLZB6tZvwFPdeO/copy *Power of Lightning*, internet connected device

Administer an exit ticket. Display **slide U** and ensure that students have access to the exit ticket you prepared by copying https://docs.google.com/forms/d/1ydoISMHNbVinJF7u3VhghGWT3wxXDXoofcZJ0KXVaaI/copy. Tell them that they can and should use *Power of Lightning*, as well as any other resources from the lesson, to help them complete this activity.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Electronic Exit Ticket Key* for guidance on assessing the exit ticket.

What to do: Use *Electronic Exit Ticket Key* for guidance.

Building toward 11.A.2 Gather, read, and evaluate scientific information about interactions between atoms in the lightning system which cause the strike we see between the cloud and the ground. (SEP: 8.3; DCI: PS1.A.3; CCC: 2.2)

8 · NAVIGATE

4 min

MATERIALS: *Our DQB Questions* (optional), Driving Question Board

Use the DQB to navigate to the next lesson. Display **slide V.** Call attention to the questions we still have on the DQB about staying safe from lightning. Say, *We have made great progress on figuring out how lightning works, but we still have several questions about why some places or materials are safer than others. Let's work on those next time.*

ALTERNATE ACTIVITY

If you have time, you may wish to have students take out their copies of *Our DQB Questions* from Lessons 5 and 9 and check off questions that have already been answered as you do the same on the class DQB. Give students a chance to add any new questions. Then, acknowledge that many of the remaining questions are related to safety, so this should be our next area of investigation. Some questions may revolve around whether lightning can strike the same place twice. It can, and after this lesson students have the tools to explain why. (Branching occurs randomly and charge flows to the ground after striking a particular spot, leaving that spot charged as it was before the strike, so the odds of a second strike are the same as the odds of the initial strike.)

Additional Lesson 11 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.7: Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

Students communicate information about energy transfer at different scales that they have gathered through readings and investigations into a diagrammatic (chart) representation.

CCSS.ELA-LITERACY.RST.9-10.8: Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.

Students conduct research and evaluate the validity of their sources. They compare the information in their research with that of their peers to determine whether findings support or contradict explanations of causes of lightning.

LESSON 12: Why are some structures safer than others (and safer than being outside)?

PREVIOUS LESSON *We considered what we know about air to figure out that there is no easy path for electrons to move through it. We conducted research for scientific information and evaluated our sources. We used our paper-clip models to help explain how charges move through air to cause the lightning we can see.*

THIS LESSON

INVESTIGATION

2 days





NOAA

We brainstorm places or types of places we think are safe and unsafe during lightning. We look at lightning safety data and statistics and notice patterns in the information. (Outdoors is often unsafe, while structures with metal pipes and wiring seem to be safe.) Then we read about how lightning rods work. To help explain the different effects of lightning on metal and wood, we examine models of metals and nonmetals and identify the structural differences between them. We use all of this information to explain why some structures are safer than others during a lightning strike.

NEXT LESSON *We will plan an investigation to figure out how increasing the concentration of salt in water affects the rate of charges flowing through it. We will evaluate different models. We will explain how a lightning strike on a river would cause the death of a group of geese floating on it.*

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6, HS-PS3-2, HS-PS3-5



WHAT STUDENTS WILL DO

12.A Use multiple sources of information to investigate and explain how differences in particle-level structure explain differences in electron movement through electrical conductors and insulators. (SEP: 8.2; DCI: PS2.B.3; CCC: 6.1)

12.B Use multiple sources of information to evaluate lightning rod models for how well they illustrate how the atomic structures function to transfer energy in order to protect homes and buildings. (SEP: 8.2, 2.1; DCI: PS3.A.1; CCC: 6.1)

WHAT STUDENTS WILL FIGURE OUT

- Metals have “free” electrons that allow them to conduct electricity relatively easily. We call these materials conductors.
- Materials that are insulators do not have free electrons to transfer energy through them.
- These differences in the structures of matter help to explain differences in electrical conductivity and why some materials are safer than others during lightning.

Lesson 12 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	2 min		**NAVIGATE** Help students recall that they have not yet figured out what makes some structures safer than others during lightning.	A	*Our DQB Questions* (optional), Driving Question Board
2	3 min		**BRAINSTORM IDEAS ABOUT SAFE STRUCTURES** Lead a brief brainstorming session around what makes some structures safer than others during lightning.	B	chart paper, chart paper marker
3	15 min		**OBTAIN INFORMATION ABOUT LIGHTNING STRIKES** Create groups of 3-4 students and have them visit four stations to obtain information about lightning strikes.	C	*Lightning Safety Tips*, *Lightning and Occupations*, *Lightning and Recreation*, *Lightning Strikes/Fires*, https://www.facebook.com/watch/?v=522099975619840 (optional)
4	5 min		**DISCUSS STATION FINDINGS** Lead a discussion to identify patterns seen in the data from the stations.	D-F	brainstormed list of safe and unsafe structures or materials
5	17 min		**READ ABOUT LIGHTNING RODS** Distribute a short reading about how lightning rods work.	G-H	*Lightning Rods*, *Connect, Extend, Question*
6	3 min		**NAVIGATE** Have students record their responses to two prompts.	I	
					End of day 1
7	6 min		**NAVIGATE** Consider atomic-scale differences between conductors and insulators.	J	
8	15 min		**EXAMINE MODELS OF METALS AND NONMETALS** Distribute models for students to compare the atomic structures of metals and nonmetals. Lead a brief discussion about the models.	K-M	*Metals/Nonmetals Comparison*
9	10 min		**COMPARE MODELS OF HOW LIGHTNING RODS WORK** Have students identify the merits and limitations of two models of lightning rods.	N	*Lightning Rod Models*
10	10 min		**EXPLAIN DIFFERENCES IN MATERIAL SAFETY** Lead a Building Understandings Discussion to help students explain why some structures are safer than others during lightning strikes.	O-S	*Metals/Nonmetals Comparison*, M-E-F poster
11	4 min		**NAVIGATE** Determine what to investigate next.	T	brainstormed list of safe and unsafe structures or materials
					End of day 2

Lesson 12 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Our DQB Questions* (optional) • *Lightning Rods* • *Connect, Extend, Question* • *Metals/Nonmetals Comparison* • *Lightning Rod Models*		• Driving Question Board • chart paper • chart paper marker • *Lightning Safety Tips* • *Lightning and Occupations* • *Lightning and Recreation* • *Lightning Strikes/Fires* • https://www.facebook.com/watch/?v=522099975619840 (optional) • brainstormed list of safe and unsafe structures or materials • M-E-F poster

Materials preparation (25 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Print 2 color copies of each of the following references and place them at the corresponding data stations:

- *Lightning Safety Tips*
- *Lightning and Occupations*
- *Lightning and Recreation*
- *Lightning Strikes/Fires*

Print *Metals/Nonmetals Comparison* single-sided and in color.

Have the M-E-F poster ready for display.

Lightning Strikes/Fires includes an image of a tree struck by lightning. An optional video of lightning striking a tree is also available, which students can view when they engage with this reference or together as a class: https://www.facebook.com/watch/?v=522099975619840.

Lesson 12 • Where We Are Going and NOT Going

Where We Are Going

The focus of this lesson is using differences in particle structure, specifically electrons' ability to move freely in metals, to explain the differences in conductivity observed in metals and nonmetals. Students use these ideas to develop an explanation for why buildings containing both metal and wood are safer during a lightning strike than buildings containing only wood.

This lesson is designed to coherently build new ideas related to the following disciplinary core ideas:

- **PS2.B.3: Types of Interactions.** Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, ~~and transformations of matter, as well as the contact forces between material objects~~.
- **PS3.A.1: Definitions of Energy.** Energy is a quantitative property of a system that depends on the motion and interactions of matter ~~and radiation~~ within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another ~~and between its various possible forms~~.

Crossout explanation: PS2.B.3 is used to consider structural differences between conductors and insulators. Students do not investigate contact forces in this lesson, as they only consider free and bound electrons in substances and how these impact electrical conductivity. PS3.A.1 is used as students consider transfer of energy through conduction of electricity by mobile electrons, but not through radiation.

Students should be familiar with *incorporating different sources of information to address scientific questions or solve a problem* from Lesson 5 of this unit as well as *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* (SEP: 8.2). In this lesson, students are asked to incorporate information from four lightning safety references, a lightning rod reading, and a handout comparing the atomic-level view of electrons in a metal, nonmetal, and ionized air, in order to explain why some buildings are safer than others during a lightning strike. Students engage partially in this element: *Compare, integrate, and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question ~~or solve a problem.~~* They have the opportunity to apply this practice in the context of a design problem in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*.

Students then compare merits and limitations of two different models of lightning rods (SEP: 2.1) using what they have figured out about how metals conduct electricity. As with the prior practice element, students' focus here is scientific evidence rather than design criteria.

Students use the crosscutting concept *structure and function* (CCC: 6.1). In middle school, students developed understandings around the relationship of structure and function in *One-way Mirror Unit*, *Cup Design Unit*, and *Collisions Unit*. This lesson is students' first experience using *structure and function* in OpenSciEd High School Chemistry. Students continue to use this crosscutting concept throughout *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)* as they finalize the atomic model.

In this lesson, students are developing a particle-level explanation of conductors and insulators. They will build off of their models of ionized air from Lesson 11 and extend that thinking to other nonmetals and metals to explain how lightning rods work and why it is safer inside buildings with metal than under a tree during lightning.

Students use multiple sources of information to help them develop this explanation, including data, a reading, and particle models of copper, cellulose, and ionized air. In order to explain differences in the conductivity of materials, students need to synthesize the information presented throughout the lesson.

In this lesson, students will encounter the following terms, which they should add to their Personal Glossary: *conductivity, resistivity,* and *lightning rod*. Students will also have opportunities to co-construct the terms *bond* and *element*, which they may choose to add as well. Do not ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Although students are focusing their explanations in this lesson on electron movement, they are not developing the more advanced concepts of electron configurations, orbitals, energy levels, or band gaps. Those concepts are outside the scope of NGSS and are not necessary for a high-school-level understanding of electrical conductivity (NRC, 2012). Students may have questions about why not all electrons in metals are involved in conduction, or why electrons in some other materials behave quite differently. This is good, as students will examine valence electron configuration in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)* and learn how valence electrons relate to bonding and other properties of substances.

Students also are not comparing relative conductivities of different metals; the focus is on the structural differences between metals and nonmetals.

LEARNING PLAN for LESSON 12

1 · NAVIGATE

2 min

MATERIALS: science notebook, *Our DQB Questions* (optional), Driving Question Board

Revisit the Driving Question Board. Say, *Last class we figured out a lot about how lightning moves through air and what changes are happening to the atoms and molecules in the air. But what questions do we still need to figure out?* Display **slide A** and direct students' attention to the DQB or *Our DQB Questions*. Give them a minute to look over the list of questions and chat with a partner about what they are still wondering about. Ask, *What questions from our Driving Question Board have we not answered yet?*

Listen for students to suggest:

- We still haven't answered our questions about safety.
- We are still wondering about what are safe and unsafe places to be during lightning.

2 · BRAINSTORM IDEAS ABOUT SAFE STRUCTURES

3 min

MATERIALS: science notebook, chart paper, chart paper marker

Brainstorm places to go and not go during lightning. Display **slide B**. Say, *Think about a time when you had to take shelter during a lightning storm. Use the prompts on the slide to write about that time.* ✱ Give students one minute to brainstorm on their own and add their ideas to their notebooks. After students have had a chance to brainstorm, go around the room and give several students an opportunity to share a response to the first prompt. Record these students' ideas on the chart paper. As students share, encourage other students to give a thumbs up or snaps if they have the same idea on their paper. Once there are no new ideas, repeat with the other prompts.

Suggested prompt	Sample student response
Where were you?	Accept all responses. Possible responses include: At the pool. At the ballpark. Inside.
Where did you go?	Accept all responses. Possible responses include: We went inside. We went back to the car. We went to the basement/ground floor. We went into a covered picnic area.

✱ ATTENDING TO EQUITY

Universal Design for Learning: The goal of having students reflect on a time they have had to take shelter is to support *engagement* by increasing the relevance for students as they consider what contributed to making the shelter safe or unsafe.

Suggested prompt	Sample student response
Do you think it was safe? Why or why not?	It was safe because it was inside. It wasn't safe because we were still outside.

ADDITIONAL GUIDANCE

If you live in a place where lightning is rare, or if you have students who have limited or no experience with lightning, encourage them to think about references to lightning they have seen elsewhere. They can think about popular culture such as movies, television, or books; they can also rely on stories they have heard from friends or family.

Point out areas on the chart paper where we are unsure whether a structure is safe or unsafe. Say, *While we are in agreement about most places, there are a few areas where we are not sure about safety. Let's take a look at some data and see if that will clarify things for us.*

3 · OBTAIN INFORMATION ABOUT LIGHTNING STRIKES

15 min

MATERIALS: science notebook, *Lightning Safety Tips*, *Lightning and Occupations*, *Lightning and Recreation*, *Lightning Strikes/Fires*, https://www.facebook.com/watch/?v=522099975619840 (optional)

Visit stations to obtain information about lightning strikes. Arrange students into groups of three to four. Show students where the data stations are, and tell them they will have a few minutes at each station. Display **slide C** and say, *It is really helpful when we are gathering information to have a list of questions we are trying to answer. These are the questions I would like you to try to answer as you look at each set of data. If your group thinks of any additional questions, take a moment to add them to your science notebooks.* ✱ Direct each group to one of the four stations and tell students to bring their notebooks with them. Give groups two minutes at each station to look over the data provided and take notes. Once groups have visited each station, give them a few minutes to look over their notes and try to answer the four prompts on the slide.

ADDITIONAL GUIDANCE

For larger classes, it may be helpful to have multiple stations using the same reference material. This way, you can divide the class into smaller groups for each station.

✱ ATTENDING TO EQUITY

Universal Design for Learning: The various handouts at these stations offer different types of *representation* through the incorporation of visuals, numerical or graphical data, and words.

4 · DISCUSS STATION FINDINGS

5 min

MATERIALS: science notebook, brainstormed list of safe and unsafe structures or materials

Reflect on prior experiences. Display **slide D**. Tell students to recall the structure or place that they shared about at the beginning of class. Encourage them to incorporate the new information from the data stations and reflect on their earlier decision using the prompts on the slide.

Discuss findings about lightning strikes. Bring students back to their seats and give them a moment to look over their notes from the four data stations. Display **slide E.**✱

✱ SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

The goal of this discussion is to begin to *integrate the information* from the four stations. Later in the lesson, students will *incorporate some of the information* as they

Suggested prompt	Sample student response
What did the data say about where we should go during lightning?	Inside buildings with plumbing and electrical wiring. Away from trees and water. Cars are OK sometimes.
What did the data say about where we should not go?	Outside, like golf courses, soccer fields, farms. Open structures.
What did the data say about the types of structures or materials that seem safe?	Houses or enclosed buildings. Cars, as long as they aren't convertibles.
What did the data say about the types of structures or materials that seem unsafe?	Water. Metals, if you're touching them or near them. Trees.
How does this compare to some of the places we said we sheltered in during lightning?	Cars are safe, so that was good. Open structures don't keep you safe.

Identify patterns in the data. Display **slide F** and say, *Before we look at more data, let's consider any patterns in the data so far. These could be in the classification of types of materials or safety tips.*

Suggested prompt	Sample student response
What ideas about safety tips seemed to come up at multiple stations?	Being in or near water is bad. Being outside seems more dangerous than being inside.
What patterns in the types of materials and their classification did you notice?	Water was unsafe. Wood could be safe or unsafe. Metals could be safe or unsafe. Sometimes being near metal is bad, but we also read that you should go inside a building with metal, so it isn't clear.

examine models at different scales in an effort to explain some of the patterns they identified. (SEP: 8.2)

Suggested prompt	Sample student response
So you pointed out that both metals and wood seem to be safe and unsafe, but it depends on other factors. What ideas do you have about why certain places or structures containing wood or metal are safer than others when there is lightning?	There's something about metals. We saw lightning strike a metal building and a tree and the building seemed fine but the tree caught fire, so metal seems better than wood. There must be a difference in these materials that makes one better or safer.

ADDITIONAL GUIDANCE

Students may be confused at this point, especially where metals are concerned. That is okay. If this comes up, acknowledge the confusion and agree that the data seem conflicting on metals, and suggest that more information is needed.

5 · READ ABOUT LIGHTNING RODS

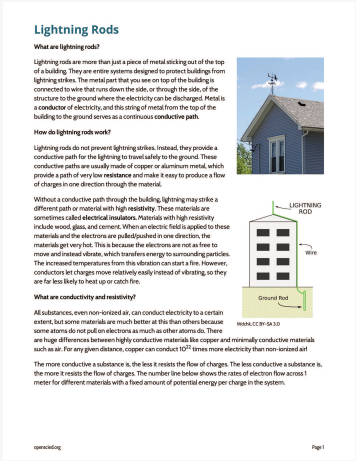
17 min

MATERIALS: *Lightning Rods*, *Connect, Extend, Question*, science notebook

Read about lightning rods. Say, *Some of you pointed out that in the image of a metal spire being struck by lightning, the building seemed to be okay. This piece of metal is called a lightning rod. Many buildings, large and small, have some version of a lightning rod on them. Let's read about how these structures can protect buildings and people.*

Display **slide G**. Say, *I have a reading about lightning rods that may help us think about why metals seem safe sometimes and unsafe other times. We will use the Connect, Extend, Question reading protocol to make sense of the reading.* Use the information on the slide to explain how students should engage with the protocol. Remind students that if they encounter a new vocabulary word, they should make a note to add it to their Personal Glossaries. Distribute *Lightning Rods* and *Connect, Extend, Question*. Give students five minutes to read the article and complete the handout.✱

Discuss information from the reading. ✱ After five minutes, discuss the prompts on **slide H** with students.✱



Lightning Rods

What are lightning rods?

Lightning rods are more than just a piece of metal sticking out of the top of a building. They are entire systems designed to protect buildings from lightning strikes. The metal part that you see on top of the building is connected to wire that runs down the side, or through the side, of the structure to the ground where the electricity can be discharged. Metal is a **conductor** of electricity, and this string of metal from the top of the building to the ground serves as a continuous **conductive path**.

How do lightning rods work?

Lightning rods do not prevent lightning strikes. Instead, they provide a conductive path for the lightning to travel safely to the ground. These conductive paths are usually made of copper or aluminum metal, which provide a path of very low **resistance** and make it easy to produce a flow of charges in one direction through the material.

Without a conductive path through the building, lightning may strike a different path or material with high **resistivity**. These materials are sometimes called **electrical insulators**. Materials with high resistivity include wood, glass, and cement. When an electric field is applied to these materials and the electrons are pulled/pushed in one direction, the materials get very hot. This is because the electrons are not as free to move and instead vibrate, which transfers energy to surrounding particles. The increased temperatures from this vibration can start a fire. However, conductors let charges move relatively easily instead of vibrating, so they are far less likely to heat up or catch fire.

What are conductivity and resistivity?

All substances, even non-ionized air, can conduct electricity to a certain extent, but some materials are much better at this than others because some atoms do not pull on electrons as much as other atoms do. There are huge differences between highly conductive materials like copper and minimally conductive materials such as air. For any given distance, copper can conduct 10^{22} times more electricity than non-ionized air!

The more conductive a substance is, the less it resists the flow of charges. The less conductive a substance is, the more it resists the flow of charges. The number line below shows the rates of electron flow across 1 meter for different materials with a fixed amount of potential energy per charge in the system.

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Suggested prompt	Sample student response
*How does this reading **connect** to the data and safety tips we examined?*	It helps us see why trees aren't safe. It explains how lightning rods work and why the building that was struck by lightning wasn't damaged. It helps explain why being in buildings with metal pipes or wires is safe when there is lightning.

✱ ATTENDING TO EQUITY

Universal Design for Learning: *Connect, Extend, Question* is provided as a reading scaffold that students can use as an alternative to the Coherent Reading Protocol featured in Lessons 4 and 5. The provision of this scaffold supports *engagement* by helping all students deepen their understanding of technical text from wherever they are.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

One goal of this discussion is to help students begin to make connections between differences in the composition of materials (structure) and how those materials interact with electricity (function). Later in the lesson, students will look at different materials at the atomic scale to try to explain why they have different interactions with electricity, specifically why some are conductive and others are not. (CCC: 6.1)

✱ ATTENDING TO EQUITY

Suggested prompt	Sample student response
*How does this help us **extend** our thinking to explain why some materials or places are safer than others when there is lightning?*	We can see that metal has higher conductivity than wood or air. Things that resist the flow of electricity can catch on fire during lightning--that could be what happened to the tree we saw.
*What **questions** do we still have?*	What makes metals better conductors? Why doesn't wood conduct like metal?

Supporting emergent multilinguals: It may help emergent multilinguals, as well as other students, to physically model conductivity and resistivity. Have one student pass through two lined-up rows of chairs (high conductivity), while another student tries to pass (safely) through a randomly arranged row of chairs (high resistivity). Encourage students to sketch these representations next to the terms in their Personal Glossaries.

ALTERNATE ACTIVITY

If you have time, you can ask students what terms from the reading they think they should add to their Personal Glossaries. Students should identify *conductivity, resistivity,* and *lightning rod*. Give them a few minutes to add these terms if they have not already done so.

Sample glossary entries:

conductivity: the extent to which a substance allows charges to flow through it

resistivity: the extent to which a substance prevents the flow of charges

lightning rod: a conductive metal rod with wiring that runs from the top of a building into the ground to protect the building from lightning

6 · NAVIGATE

3 min

MATERIALS: science notebook

Reflect on lightning rod reading. Display **slide I**. Say, *We have figured out a lot about what makes lightning rods work. Let's take a moment to reflect on how they work to keep buildings safe. I also want you to think about some of the patterns we noticed and shared about safe materials after visiting the four data stations. Take a moment to answer the prompts in your science notebook.*

End of day 1

7 · NAVIGATE

6 min

MATERIALS: None

Navigate. Give students a minute to discuss the prompt on **slide J.** Then ask for volunteers to share their ideas.

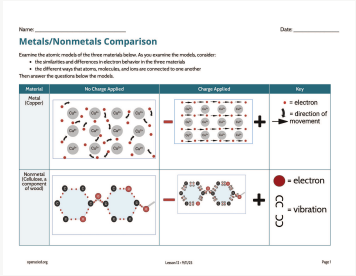
Suggested prompt	Sample student response
What materials have we been discussing so far?	Metals. Trees, so wood.
What do you think is different about them at the atomic scale that could explain why some are safer than others?	Something about their electrons. Maybe some materials have more electrons or the electrons are in a different place or do different things?

8 · EXAMINE MODELS OF METALS AND NONMETALS

15 min

MATERIALS: *Metals/Nonmetals Comparison*, science notebook

Look for particle-level similarities and differences. Say, *It sounds like we have found some answers about how metals are different from some other materials, but we still are not sure why they are better conductors. Let's zoom in to the particle level and see what similarities and differences we notice in different substances.* ✱ Distribute *Metals/Nonmetals Comparison* and display **slide K.** Direct students to work in pairs to examine the different models and complete the questions on the handout. Help orient students to what the models are showing: a metal (copper), a section of nonmetal molecule (cellulose), and ionized air. Remind students that they have already thought about ionized air with the help of their paper-clip models in Lesson 11 and that these atomic models will give them another way to represent that thinking. If it is easier for students, they can start with the ionized air model and then compare the metal and nonmetal models to it. Tell students that the goal is to identify structural differences that may help us explain why metals are good conductors and why other materials, like wood, are not.


Name: _____ Date: _____

Metals/Nonmetals Comparison

Examine the atomic models of the three materials below. As you examine the models, consider:

- the similarities and differences in electron behavior in the three materials
- the different ways that atoms, molecules, and ions are connected to one another

Then answer the questions below the models.

Material	No Charge Applied	Charge Applied	Key
Metal (Copper)			= electron = direction of movement
Nonmetal (Cellulose, a component of wood)			= electron = vibration

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Discuss similarities and differences in the models. Display **slide L.**

Suggested prompt	Sample student response
What similarities did you notice?	The electrons move at least some in all the models. There are electrons between atoms and also outside the atoms.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

The models provide a view of the structural differences that exist between metals and nonmetals. This particle-level examination allows students to make connections between the structure of different materials and their distinct observable properties, such as electrical conductivity.

Suggested prompt	Sample student response
What differences did you notice?	The electrons move more in metals and ionized air. The electrons only vibrate in wood, but they can move more freely in the other materials. Some models show electrons between atoms but others don't. In some models the atoms and electrons seem totally separate.

If students don't bring up electrons between atoms, prompt them to look at that specific aspect of the models. After a brief discussion of those differences, say, *It seems like how the electrons are connected to the atoms, or how the atoms connect to each other, is different in these different substances. When atoms are held together by electrons, we call that a bond.* Point out the bonds in cellulose and in ionized air. Then discuss metal atoms and the differences.

Suggested prompt	Sample student response
We can see the bonds in cellulose, but what about copper? Do we think there are bonds there?	There don't seem to be any. There aren't any electrons that seem to be between two copper atoms.
Think about a piece of copper wire, or anything made of copper or another metal. Do we think all of those copper atoms are just floating around?	If copper is a solid the atoms must be close together. Something is keeping the atoms close to each other. Is that a bond?

Agree that something must be holding the copper atoms together as well. Say, *There are different types of bonds, so the electrons and atoms of different substances are arranged differently and may behave differently.* Tell students they will explore this idea in more depth in later units and that for now you want to focus on electrons and conductivity. At this point, students may record *bonds* in their Personal Glossaries. Also add, *We have seen that different atoms interact or bond in different ways, and it would be nice to refer to different types of atoms using a particular term.* Introduce *elements* as this term and encourage students to add it to their Personal Glossaries as well.

ADDITIONAL GUIDANCE

Students will develop the idea of what a bond is and the different types of bonds (covalent, metallic, and ionic) in the next unit: *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*. Here we are simply helping students reason about how there are electric forces that hold ions together and about the relative strength of those forces.

Sample glossary entries:
bond: when different atoms are held together by electrons

elements: different types of atoms

Focus on the idea of conductivity. Discuss the prompts on **slide M** to help students think about the connection between electron arrangement and conductivity.

Suggested prompt	Sample student response
How do these models help explain why metals are good conductors and wood is not?	In metals and ionized air the electrons can move, so that is how electricity travels through these things. Since the electrons in wood can't move, electricity can't go through wood.
How do these models help explain why poor conductors tend to heat up quickly when strong electric forces are applied to them?	Since the electrons can't move freely and just vibrate in place, those materials get hot.
How do the reading and models work together to help you make sense of how lightning rods work?	Electrons can move through lightning rods since they are metal. Electricity moves through the lightning rod, so it doesn't make the wood in the building heat up.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students notice differences in electron arrangement and movement and suggest that these may be related to why metals are good conductors and wood is not. (DCI: PS2.B.3; CCC: 6.1)
- Students cite multiple sources of evidence in their explanation for why metals are good conductors. (SEP: 8.2; DCI: PS2.B.3)

What to do: Students may focus on the spacing or arrangement of atoms rather than the arrangement and movement of electrons. If they do, acknowledge this observation and push students to share other differences they notice, even at the subatomic scale. When students notice the electrons, prompt them to think about what that freedom of movement might have to do with electricity.

Building toward 12.A.1 Use multiple sources of information to investigate and explain how differences in particle-level structure explain differences in electron movement through electrical conductors and insulators. (SEP: 8.2; DCI: PS2.B.3; CCC: 6.1)

9 · COMPARE MODELS OF HOW LIGHTNING RODS WORK

10 min

MATERIALS: *Lightning Rod Models*, science notebook

Compare models of lightning rods. Explain that students will have two versions of a lightning rod model to evaluate. Distribute *Lightning Rod Models* and display **slide N**. Say, *We have seen how electricity could move through metals; now let's apply those ideas to lightning rods.* Have students copy the table shown on the slide into their science notebook. Tell students to use any information from this lesson to help them identify the merits and limitations of each model. Then have them develop an explanation for how the atomic-level structure of lightning rods allows them to function to protect buildings.

	Model A	Model B
Merits	• Shows + and - charges • Shows charges being released into ground • Shows - charges built up in cloud • Shows attraction between + and - charges • Shows - charges attracted to/moving toward lightning rod	• Shows charges moving through lightning rod • Shows - charges built up in cloud
Limitations	• Doesn't show charges moving through lightning rod • Doesn't show where charges came from	• Shows + charges moving through lightning rod instead of - charges • Doesn't show charges released from lightning rod into ground • Doesn't show where charges came from
Evidence	• Lightning rod reading explains that charges travel through lightning rod. • Models of metals and nonmetals show that electrons can move in metals, so electrons can move in the lightning rod. • In the lightning safety references, places that were enclosed and had metal pipes or wires were safer because they can conduct electricity.	

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students identify merits and limitations of both models and support these with evidence from different sources of information. (SEP: 8.2, 2.1)
- Students explain how the atomic-level structure of lightning rods makes them function the way they do to protect buildings. (DCI: PS3.A.1; CCC: 6.1)

What to do: Push students to cite evidence from at least two of the following: *Lightning Rods*, *Metals/Nonmetals Comparison*, *Lightning Safety Tips*, *Lightning and Occupations*, *Lightning and Recreation*, *Lightning Strikes/Fires*. Ask follow-up questions to help students connect atomic-level structures of metals such as copper or lightning rods to how metals conduct electricity.

Building toward 12.B Use multiple sources of information to evaluate lightning rod models for how well they illustrate how the atomic structures function to transfer energy in order to protect homes and buildings. (SEP: 8.2, 2.1; DCI: PS3.A.1; CCC: 6.1)

Celebrate how much we have figured out about differences in the materials. Say, *We have figured out so much information from so many different sources! Let's take a moment to put everything together to try to explain why some structures or materials are safer during lightning than others.*

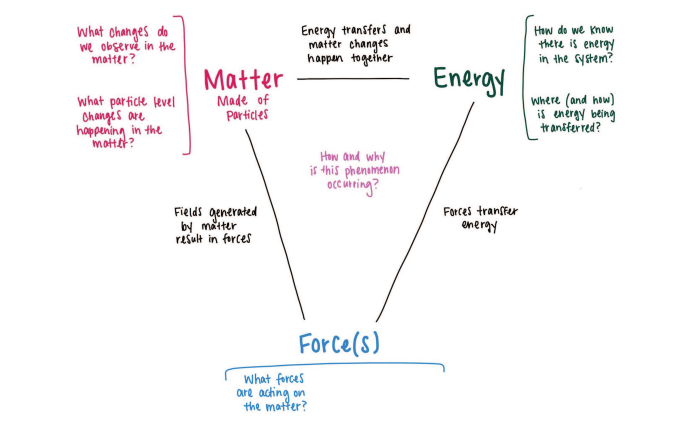
10 · EXPLAIN DIFFERENCES IN MATERIAL SAFETY

10 min

MATERIALS: *Metals/Nonmetals Comparison*, science notebook, M-E-F poster

Explain why some structures are safer than others during lightning. Display **slide O** and say, *Our Matter-Energy-Forces poster has been useful to us a few times before.. Let's see if it can help us put an explanation together.* Have the M-E-F poster from Lesson 10 visible.

Discuss differences in matter. Say, *Let's first consider matter, since the models we examined showed us the atomic structures of different types of materials.* Display **slide P**. Have students use *Metals/Nonmetals Comparison* as they refer back to the similarities and differences they noticed. Then have them extend those ideas to explain why metals and nonmetals are different in terms of conductivity. Use the prompts below to guide the discussion.



Suggested prompt	Sample student response
How is our model for ionized air from Lesson 11 similar to or different from what we see in these models?	In our model for ionized air, electrons are moving and pushing electrons off other atoms. The ionized air model seems similar to the metal; both have electrons moving from negative to positive.
Based on what you know now, what are the limitations in our models from Lesson 11? ✱	Our first models didn't show what the air molecules are like before they ionize. Our first models didn't have bonds in them.
How does the way charges move differently in metals vs. cellulose help explain why metals are better conductors?	In metals electrons can move, but in cellulose the electrons vibrate in place.

Discuss the force perspective of the M-E-F poster. Say, *Great, it sounds like we have found some key structural differences in the atoms and electrons.* Point to "What particle-level changes are happening in the matter?" on the M-E-F poster. Say, *So now we have an idea about the changes at the particle level of both metals and nonmetals. But let's consider what that might mean for the forces occurring in these materials as electricity, or lightning, interacts with them.* Display **slide Q.**✱

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Support student thinking in how *gathering new information from multiple sources* provides us with a way to *evaluate limitations of models*. Stress that the models we made in Lesson 11 were not wrong; we were working with the information we had at the time. Tell students that this is a common occurrence in science, that models evolve as scientists learn more about the phenomena they study. (SEP: 2.1)

✱ SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

Students encounter multiple pieces of information from different sources (data, a reading, and models) which can serve as evidence in their explanation of conductivity. They should use information from all of these sources in their final explanation.

Suggested prompt	Sample student response
Think about the nuclei in metal and nonmetal atoms. What is different about the forces exerted on electrons by metal and nonmetal nuclei?	Nonmetal nuclei pull more strongly on electrons. That could be why they can't move as much as electrons in metals.
What is the impact of this force on the electrons when a charge is applied?	In metals, electrons can be pushed or pulled off of atoms because the force holding them on is weaker. In nonmetals, electrons can't be pushed or pulled off of atoms.

Discuss the energy perspective of the M-E-F poster. Ask students to think about what happens when a force is applied to an object. Say, *It may help to think about this macroscopically first, such as a person pushing a book across a table. In this case, how is the force of pushing the book changing the energy of the book?* Students should suggest that the energy of the book increases because the applied force is transferring energy to the book. Say, *Great! Now let's apply that same idea to the electrons in the metals and nonmetals.* Display **slide R**. Say, *Let's think about the interactions of electricity and electrons in metals and nonmetals from the energy perspective.*

Suggested prompt	Sample student response
What is the impact, in terms of energy transfer, of weaker forces on metal electrons or the electrons in ionized air?	The moving and pushing of electrons transfers energy through the metal or the ionized air.
What is the impact of stronger forces on nonmetal electrons?	If the electrons can't move, then they can't transfer energy through the nonmetal. The electrons just vibrate in place, hitting nearby particles. These particles move faster and faster. The energy just builds up in the wood, and that's why it catches on fire.

Develop explanations for differences in building safety. Say, *We have thought about the differences in metal and nonmetal from the matter, force, and energy perspectives. Now, I want you to put all of those pieces together and write a brief explanation for why enclosed buildings with metal in them are safe during lightning, but enclosed buildings made entirely of wood are not.* Display **slide S**. Have students answer the prompt on a sheet of paper and collect these when students are done.

ALTERNATE ACTIVITY

Extension opportunity: If students have been particularly interested in lightning safety as it relates to vehicles, or if some students have the misconception that tires insulate the vehicle and that this is why they are safe during lightning, use this as an extension opportunity. Relate the metal in a car to the copper atoms in *Metals/Nonmetals Comparison* and tell students that rubber, like cellulose, is made mostly of carbon and hydrogen atoms. Then have students explain which part of the vehicle will protect them from lightning and how it can do so.

Alternatively, have students share their explanations with their families as home learning and then return to class with additional ideas about what people should do to stay safe in storms.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students incorporate information from data, a reading, and models to explain atomic-level differences between metals and nonmetals. (SEP: 8.2; DCI: PS2.B.3)
- Students explain that differences in metals and wood at the atomic level explain why some buildings are safer than others during a lightning strike. (DCI: PS2.B.3; CCC: 6.1)

What to do: If students do not show movement of electrons in the presence of charge, or do not show how metals and nonmetals differ, direct them back to *Metals/Nonmetals Comparison*. If students show the structural differences between metals and nonmetals but do not include an explanation for why that matters, encourage them to revisit what they wrote in *Connect, Extend, Question* about lightning rods, conductors, and resistors.

Building toward 12.A.2 Use multiple sources of information to investigate and explain how differences in particle-level structure explain differences in electron movement through electrical conductors and insulators. (SEP: 8.2; DCI: PS2.B.3; CCC: 6.1)

11 · NAVIGATE

4 min

MATERIALS: science notebook, brainstormed list of safe and unsafe structures or materials

Navigate. Display **slide T**. Celebrate what students have figured out about what makes metals good conductors and why nonmetals like wood are not. Say, *Let's go back to our list of safe and unsafe structures or materials. Did any of you write down anything about having to get out of or away from water?* Have students discuss the questions on **slide T** with a neighbor and tell them they will pick up right there next class.

ALTERNATE ACTIVITY

Students have not had the opportunity to receive peer feedback in several lessons. This may be a good time to do so. Instead of immediately collecting students' work at the end of the lesson, have them exchange with a peer and receive feedback from them. The *OpenSciEd Teacher Handbook: High School Science* has a general format that may be used for peer assessment.

Additional Lesson 12 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.5
Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).

As students examine data about lightning safety, read about lightning rods, and examine models of metals and nonmetals, they should identify relationships among structures and incorporate terminology such as conductor, insulator, and resistivity.

LESSON 13: Why are you supposed to get away from water when there is lightning nearby?

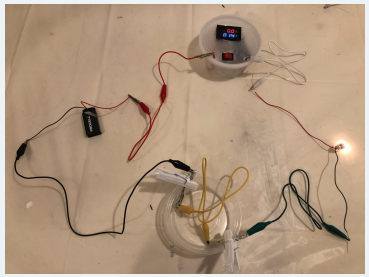
PREVIOUS LESSON

We brainstormed places or types of places we think are safe and unsafe during lightning. We looked at lightning safety data and statistics and noticed patterns in the information. We read about how lightning rods work. We examined models of metals and nonmetals and identified the structural differences between them. We used all of this information to explain why some structures are safer than others during a lightning strike.

THIS LESSON

INVESTIGATION

3 days



We test pure water and pure sodium chloride and determine that neither substance conducts electricity. We plan an investigation to figure out how increasing the concentration of salt in water affects the rate of charges flowing through it, then argue that the dissolved salt found in different water sources (ocean, lakes, swimming pools) allow the water to conduct electricity. We evaluate different models to determine which one best explains the results of our investigation. We explain how a lightning strike on a river would cause the death of a group of geese floating on it.

NEXT LESSON

We will create a consensus Gotta-Have-It Checklist and use it to build models to answer the question, "Why are some places safer than others when lightning strikes?" Then, we will take stock of which questions we have answered on our DQB and demonstrate our understanding on an assessment task.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6, HS-PS3-2, HS-PS3-5

WHAT STUDENTS WILL DO

13.A Plan and conduct an investigation to generate empirical evidence to evaluate a claim about the conductivity of water. (SEP 3.1, 7.2; DCI: PS1.A.3; CCC: 1.5)

13.B Evaluate different models to determine which best explains what causes salt to dissolve in water and what causes electricity to be conducted through it (salt water). (SEP: 2.1; DCI: PS1.A.3, PS2.B.3; CCC: 2.2)

13.C Evaluate claims and verify data presented in media using empirical evidence about properties of matter caused by interactions of charged particles. (SEP: 8.4, 7.2; DCI: PS1.A.3, PS2.B.3; CCC: 1.5)

WHAT STUDENTS WILL FIGURE OUT

- Solid table salt (sodium chloride) is an ionic compound, which means it is made of positive and negative ions that form by gaining or losing an electron.
- Water molecules have permanent partially positive and partially negative sides (polarity).
- When water molecules make contact with solid salt they pull individual ions off, causing the salt to break apart (dissolve) and the ions to spread throughout the solution.
- Ions in solution can conduct electricity.
- Water in living things contains dissolved salts and other electrolytes.

Lesson 13 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	7 min		**NAVIGATE** Navigate into today's work by reading about a strange event that occurred in water.	A-B	*Geese Lightning Strike*
2	3 min		**BRAINSTORM LIGHTNING'S INTERACTION WITH WATER** Brainstorm what happens when lightning makes contact with water.	C	
3	6 min		**DEMONSTRATE CONDUCTIVITY OF WATER** Demonstrate what an ammeter does and use it to test whether distilled water and sodium chloride conduct electricity.	D-G	Testing Distilled Water
4	4 min		**ANALYZE DATA** Share data of the percentage of salt in various water sources and have students connect this information to their ideas about water conducting electricity.	H	
5	8 min		**PLAN AN INVESTIGATION** Organize students into groups to plan the percentage of salt concentrations they wish to test.	I	*Salt Investigation Plan*, scientific calculator
6	17 min		**CARRY OUT AN INVESTIGATION** Have small groups of students carry out their investigations to test running a current through salt water of various concentrations.	J-L	Salt Water Conductivity
					End of day 1
7	4 min		**COMMUNICATE RESULTS** Have students share their investigation results from last class.	M	*Salt Investigation Plan*
8	17 min		**ATTEMPT TO EXPLAIN OUR RESULTS AND IDENTIFY KEY MODEL IDEAS** Lead a class discussion to raise key ideas about salt, water, electric current, and forces.	N-V	*Model Evaluation Checklist*, M-E-F poster, chart paper markers, 2 notecards, 2 paper clips
9	20 min		**EVALUATE CANDIDATE MODELS** Organize students into pairs to evaluate candidate models and compare their thinking.	W-BB	*Model Evaluation Checklist*, class set of *Candidate Models* organized by name, Key Model Ideas poster
10	4 min		**INTRODUCE THE HOME LEARNING** Connect to related phenomena and introduce home learning.	CC-DD	*Electrolytes*
					End of day 2

Part	Duration		Summary	Slide	Materials
11	13 min		**CONSENSUS DISCUSSION ON BEST CANDIDATE MODEL** Gather students in a Scientists Circle to come to consensus on the best candidate model.	EE	*Model Evaluation Checklist*, class set of *Candidate Models* organized by name
12	11 min		**EXPLORE POLARITY OF WATER AND IDENTIFY ADDITIONAL MODEL IDEAS** Present a video of another water phenomenon. Gather students in a Scientists Circle to continue to build consensus.	FF-JJ	*Model Evaluation Checklist*, Personal Glossary, https://youtu.be/MFhkDQrev1Y?si=L2hGVk7a6RQZ6Ws4, chart paper markers, Key Model Ideas poster, notecard, 4 paper clips, *Candidate Models*
13	5 min		**REVISIT PHENOMENON FROM DAY 1** Reread the article about the geese lightning strike phenomenon. Apply takeaways from the lesson to explain the phenomenon.	KK-LL	*Geese Lightning Strike*
14	10 min		**EVALUATE CLAIMS** Introduce various claims about lightning safety near water and instruct students to provide evidence from the unit to justify their evaluation of the claims.	MM	*Lightning Safety Claims*
15	6 min		**NAVIGATE** Navigate to the next lesson and revisit the Community Agreements.	NN-OO	Community Agreements

End of day 3

Lesson 13 • Materials List

	per student	per group	per class
Testing Distilled Water materials	• scientific calculator		• the ammeter system • 2 foil-wrapped pieces of straw (3-4") • 200 mL distilled water • distilled water gallon jug with label • 20-30 g sodium chloride
Salt Water Conductivity materials	• *Salt Investigation Plan* • *Salt Testing Procedure* • indirectly vented chemical splash goggles • non-latex apron • nitrile gloves	• the ammeter system • 2 foil-wrapped pieces of straw (3-4") • 50 g sodium chloride • 500 mL distilled water • 250-mL beaker • digital scale • stirring rod • scientific calculator	
Lesson materials	• *Geese Lightning Strike* • *Salt Investigation Plan* • scientific calculator • *Model Evaluation Checklist* • *Electrolytes* • Personal Glossary • *Lightning Safety Claims*		• M-E-F poster • chart paper markers • 2 notecards • 2 paper clips • class set of *Candidate Models* organized by name • Key Model Ideas poster • https://youtu.be/MFhkDQrev1Y?si=L2hGVk7a6RQZ6Ws4 • notecard • 4 paper clips • *Candidate Models* • Community Agreements

Materials preparation (120 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Have the M-E-F triangle poster from Lessons 9 and 10 visible for the whole class on day 2.

Review the sample calculations, which are unit conversions using units that are new to students.

Have two pieces of chart paper ready for recording key model ideas.

For days 2 and 3, you will need a class set of *Candidate Models*. There are three models (on 3 pages), so print as many sets as your largest class period divided by 3.

- It is ideal to print these in color, but grayscale will also work.
- It is recommended that you put these sheets in page protectors since they will be passed around among students in all your class periods.

- Distributing the models will go faster, especially on day 3, if you have them sorted into three stacks by name.

Day 1: Testing Distilled Water

- **Group size:** whole class
- **Setup:**
    - Reuse one of the ammeters and circuit setups listed for the next activity (Salt Water Conductivity Investigation) across all of your classes.
    - Set up the circuit as outlined in the last section of *Ammeter Construction Directions*.
    - Use 200 mL distilled water and 20-30 g sodium chloride per class.
    - Keep the distilled water gallon container with label available for students to see.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science.* Support students in following standard laboratory safety considerations. In addition:
    - Keep all materials away from electrical sockets.
    - Immediately wipe up any spilled water on the floor.
    - Short circuiting any part of the system will cause the battery to heat up quickly. Carefully check the battery throughout the investigation to ensure that it is not overheating.
- **Storage:** All materials can be stored and reused.

Day 1: Salt Water Conductivity Investigation

- **Group size:** 4-5 students
- **Setup:**
    - Build one ammeter per group (7 total). See *Ammeter Construction Directions* for printed directions on how to do this. See https://youtu.be/XUh8ZagrpnE for a video walkthrough.
    - Set up each group's circuit as outlined in the last section of *Ammeter Construction Directions*. Using the recommended color coding of alligator clips and wires will make it easier for students to interact with the testing system.
    - Create an extra pair of 3-4" foil-wrapped pieces of straw for each lab group in each class. These are the only disposable materials (other than water and salt) for each group.
    - Provide these additional materials to each group:
        - 50 g sodium chloride (table salt)
        - 500 mL distilled water
        - 250-mL beaker
        - Digital scale
        - Stirring rod



- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science.* Support students in following standard laboratory safety considerations. In addition:
    - Keep all materials away from electrical sockets.
    - Immediately wipe up any spilled water on the floor.
    - Short circuiting any part of the system will cause the battery to heat up quickly. Carefully check the battery throughout the investigation to ensure that it is not overheating.
    - Wear sanitized indirectly vented chemical safety goggles, non-latex apron and nitrile gloves during the setup, hands-on, and takedown segments of the activity.
    - Use caution when using sharps (wires, etc.), which can cut or puncture skin.
    - Use caution when working with glassware. The pieces of broken or shattered glassware are sharp and can cut hands.
    - Wash your hands with soap and water immediately after completing this activity.
- **Disposal:** Pour the salt water in the sink. Dispose of the foil-wrapped straws in the trash. Where possible, recycle foil and compost paper straws, if used.
- **Storage:** All other materials can be stored and reused.

Lesson 13 • Where We Are Going and NOT Going

Where We Are Going

The targeted disciplinary core ideas that are addressed in this lesson are:

- **PS1.A.3: Structure and Properties of Matter.** The ~~structure and~~ interactions of matter at the bulk scale are determined by electrical forces ~~within and~~ between atoms.
- **PS2.B.3: Types of Interactions.** Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter~~, as well as the contact forces between material objects~~.

Crossout explanation: DCI: PS2.B.3 is used to bring together material properties and particle-level thinking to investigate electrical conductivity and attraction or repulsion of water and ions. Contact forces are left for *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*. DCI: PS1.A.3 is used to consider how water is able to dissolve salts and the electrical forces present between those particles, but electrical forces within particles is not a part of this lesson.

Students begin by examining a puzzling phenomenon possibly related to lightning and brainstorm how lightning may interact with water. They then observe a conductivity demonstration and plan and conduct an investigation (SEP: 3.1) to test these ideas and determine their merit (SEP: 7.2). They engage partially with both of these elements:

- *Plan an investigation ~~or test a design individually and~~ collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, ~~or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled.~~*
- *Evaluate the claims, evidence, and/or reasoning behind ~~currently accepted~~ explanations ~~or solutions~~ to determine the merits of arguments.*

Students have additional opportunities to engage in investigations throughout the course, including with considerations of confounding variables in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* and with a focus on solutions in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*. Students will have opportunities to evaluate arguments around current science and proposed solutions in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*.

In their investigations students generate empirical evidence (CCC: 1.5) which allows them to evaluate their original claims about lightning and water, and they use this evidence later in the lesson to evaluate multiple other claims (SEP: 8.4) about lightning safety as it relates to water.

Students will also compare multiple explanatory models (SEP: 2.1) to determine which provides the best mechanistic explanation of both salt dissolution and conductivity through solution, based on what students observed during their investigations (CCC: 2.2). Students do not focus on design criteria in this lesson. Their engagement with CCC: 2.2 is also partial*: Cause and effect relationships can be ~~suggested and~~ predicted for complex natural ~~and human designed~~ systems by examining what is known about smaller-scale mechanisms within the system.* Here, the focus is on how natural systems, rather than designed systems, work.

Students will again use the paper-clip model, this time to represent electron transfer in an ionic compound and permanent polarity in a water molecule.

In this lesson, students will co-construct definitions for the following terms, which they should add to their Personal Glossary: *polar molecule*, *dissolve*, *ionic bond*, *ionic compound*. Do not ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

While the terms *ionic compound* and *ionic bond* will be introduced in this lesson, students will not be exploring these concepts in depth. Students will further develop the idea of what a bond is and why there are different types of bonds (covalent, metallic, and ionic) in the next unit: *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*. Here we are simply helping students reason about the electric forces that hold ions together and the relative strength of those forces.

Do not introduce details about the non-symmetrical structure of water molecules. Students do not need to know which atoms in the molecule are responsible for which part of its polarity in this unit. Students will figure that out in the next unit: *Space Survival Unit*.

Different types of salts, beyond table salt, are not introduced until the home learning assigned at the end of day 2 of this lesson. However, a differentiation opportunity exists for students who are interested in exploring whether other salts conduct electricity as readily as table salt. Road salt has been included in the kit for the field test version of this unit to support this extension opportunity for students.

LEARNING PLAN for LESSON 13

1 · NAVIGATE

7 min

MATERIALS: *Geese Lightning Strike*

Navigate. Display **slide A**. Give students 30 seconds to consider the questions on the slide on their own and then discuss them as a class. Say, *Last class, some of you mentioned having to get out of water when there was lightning. We have also noticed that lightning tends to be more common when it is humid. Let's think about lightning and water.*

Suggested prompt	Sample student response
Which of those models do you think most closely represents what happens in water?	Water is not a metal, so maybe cellulose. If water can conduct lightning, then maybe it is like metal or ionized air.
Why do you think that?	Because water can conduct electricity. If water conducts, the electrons must be able to move.

Read about a novel phenomenon. Display **slide B** and say, *I found an article that may be related to what we have been talking about; let's take a look and see if we can figure out what is going on.* Distribute *Geese Lightning Strike* and give students two or three minutes to read the brief article. Then ask, *What do you think happened to the geese?* Listen for responses such as:

- Lightning! Because the article said they were electrocuted.
- Maybe they were poisoned or something else happened.

ALTERNATE ACTIVITY

If you wish to provide students with additional support with this short reading, consider reading as a class. Support students in public reading by allowing them to read with a small group in chorus or by asking for help with word pronunciations before beginning.

2 · BRAINSTORM LIGHTNING'S INTERACTION WITH WATER

3 min

MATERIALS: None

Consider charge flow at point of contact with water. Display **slide C**. Give students 30 seconds to consider the question on the slide on their own and then discuss it as a class.

Suggested prompt	Sample student response
What do we think happens to the electrons that flow out of the cloud once they reach the surface of the water?	They travel across the water. They go into the water. They go through the water until they hit the ground.
What could we do to test these ideas?	We could try to electrify water. We could test electricity with water.

3 · DEMONSTRATE CONDUCTIVITY OF WATER

6 min

MATERIALS: Testing Distilled Water

Motivate investigating the interaction of charges with water. Say, *You suggested many ways lightning or electricity may interact with water, and you suggested that we test these ideas, so let's do that.* Display **slide D** and gather students around a similar setup as shown on the slide, where the light bulb is lit. Ask student volunteers to trace a path of one wire coming from the battery to the light bulb and the other wire going from the light bulb to the battery.

Ask students what they picture happening to the charges in the wire in the path they traced. Students should say the charges are moving. It is not important that students identify the direction of the movement right now.

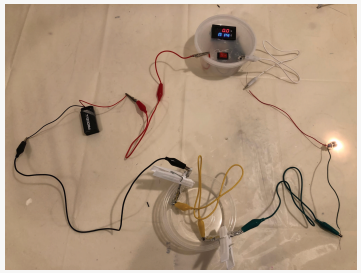
Introduce using the ammeter to measure charge flow in the system. Turn on the ammeter (before adding it to the battery-bulb system) and explain that this device can measure the charges traveling through any part of the system that we connect it to.

SAFETY PRECAUTIONS



Emphasize that the 9V batteries we are using today are the upper limit of voltage that is safe to use in the kind of investigations we are doing with electricity and water. Also emphasize that electricity from wall outlets and some other types of batteries is much higher voltage, which is more dangerous and could cause a serious shock or electrical fire hazard. Suggest that figuring out why higher voltages are so dangerous is part of what we will be working to do, but remind students that other than the battery sources we are using for this lab, it is not safe to experiment with other electricity, at school or at home.

Hook up the ammeter as shown and by following these steps:



1. Disconnect the red wire with alligator clip from the red wire on the light bulb.
2. Attach the red wire with alligator clips to the red lead on the ammeter.
3. Use a white wire with alligator clips to attach the red wire of the light bulb to the black wire on the ammeter.

Measure charge flow. Display **slide E**. Ask students to report how many milliamps (mA) are being measured in that part of the system. Students should say ~0.14.

Ask a student to use a calculator to determine how many charges per second are traveling through that part of the system. Students should calculate this by multiplying:

(0.14 mA/1) x (6.24 x 10^{15} charges/second / 1 mA) = 8.74 x 10^{14} charges per second

ADDITIONAL GUIDANCE

This activity gives students practice with the type of calculation they will have to do later for part 5 of *Salt Investigation Plan*.

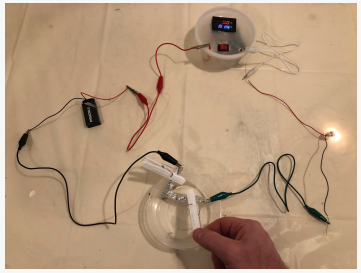
Make predictions for water. Display **slide F**. Ask students to discuss the questions with a partner for one minute.

Suggested prompt	Sample student response
What if we remove the wire connecting the foil-wrapped straws?	The light bulb won't light up anymore. The screen will say zero.
What if we add water to the beaker in the space where that wire used to be?	The light bulb will light up. There will be a number on the screen of the ammeter again.

Say, *Let's test it out! I have some water here that we can use.* Pour about 200 mL of distilled water directly from the distilled water container into the beaker.

Ask students to report what they observe. Students will say nothing. Say, *That is weird. We all said we have heard that water is supposed to conduct electricity.*

Suggest that maybe we disconnected a different wire accidentally. Suggest that we test this possibility by unclipping a clothespin and moving one foil-wrapped straw against the other to see if charge still flows when there is a continuous metal path. Test this. It will result in the light bulb lighting up and the ammeter registering a current again. Move the straw to the other side of the beaker and clip it back in its original place with the clothespin.



Ask students to consider why the water you poured into the beaker is not conducting electricity and pass the labeled container of distilled water around for students to see. Point out that it is distilled water, and then brainstorm with students why it does not work.

- This says it is distilled water. Maybe that is different from "regular" water.
- Maybe it only works with tap water or bottled water.

- If we try water from a different source, maybe it will work.

Encourage students to go back to the reading and look for clues about what might make the water the geese were in different. Students may point out that the river is connected to the ocean, or that there may be something else in the river that can conduct electricity.

Suggested prompt	Sample student response
So do we think that salt may have something to do with conductivity?	Maybe; the ocean is salty and the Great Lakes could be too. Maybe there is something in the St. Lawrence River that makes it conduct electricity.
What would we expect the conductivity to be of just salt by itself?	It will be super conductive. It will be way more conductive than water.

Test the conductivity of pure salt. Say, *Let's try the same setup, but with table salt instead of water.* Pour out the distilled water and dry the beaker and foil-wrapped straws. Display **slide G** and ask students to turn and talk with their partner to predict what will happen when we add salt; accept all ideas. Then add enough salt to the beaker so that the bottoms of both straws are in the salt. Students will see that salt by itself does not conduct electricity either!

Suggested prompt	Sample student response
Now what are we thinking?	Maybe it's not actually dangerous to be in the ocean or a pool when there is lightning. Maybe something happens when the salt and water combine.
How can we test this idea?	We should add salt to water and try again. We should test other types of water, like bottled water and tap water.

4 · ANALYZE DATA

4 min

MATERIALS: None

Compare distilled water to other water sources. Say, *It sounds like we are wondering if it is something in these other sources or types of water that might explain what is going on. Let's take a look at some of these other water sources that we are warned to stay out of during a lightning strike and see if that gives us any ideas about what might be going on.* Display **slide H**, which includes the prompt, *How might this data help us investigate the conductivity of water*? Give students a minute or two to consider how this data might help them investigate water's conductivity. Students can think or write independently, or if they prefer they can talk with a partner. Listen for these ideas on share-out:

- We should try different types of water, like tap water and bottled water.
- We should add salt to water and test the conductivity.
- We should make water that is like Lake Michigan and the ocean and see if they conduct the same.

Celebrate all student ideas.

ALTERNATE ACTIVITY

If students suggest that ocean or lake water conducts because metal is dissolved in the water, encourage them to record this idea as a question. Do not address this question yet. Instead, wait until students have completed *Electrolytes* after day 2 of this lesson. The handout will make the connection between the atoms that are common cations in salts (sodium, calcium, lithium, magnesium) and their classification as metals in pure form. Do not go further into explaining why some elements are metals. Figuring out why the electrons of some elements are more or less attracted to their atoms than the electrons of other elements is the focus of the next unit, *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*.

5 · PLAN AN INVESTIGATION

8 min

MATERIALS: *Salt Investigation Plan*, scientific calculator

Plan an investigation. Display **slide I.** Distribute a copy of *Salt Investigation Plan* to each student. Have students work in groups of five to outline their investigation plan for parts 1 and 2.✱

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' investigation plans include testing multiple different salinity percentages and electric current. (SEP 3.1; DCI: PS1A.3)
- Students' investigation plans allow for the collection of empirical evidence. (SEP 3.1; CCC: 1.5)

What to do: As students plan their investigations, ask them how they are generating evidence to address their claims that lightning killed the geese in the St. Lawrence River. If they plan to test types of water such as tap water, fountain water, or bottled water, where the salinity percentages are not known, ask students how they might compare them to known salinities of water. If the collection plans are not empirically investigable, help students reach the conclusion that they may also need to make some specific salt solutions so that they have known percentages to compare to.

Building toward 13.A.1 Plan and conduct an investigation to generate empirical evidence to evaluate a claim about the conductivity of water. (SEP 3.1, 7.2; DCI: PS1.A.3; CCC: 1.5)

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Students' investigation plans represent a culmination of work from the last two units, as they draw on investigative skills developed in *Polar Ice Unit* (SEP) and use them to gather empirical evidence of patterns (CCC, previously highlighted in Lesson 4) to help them solidify thinking around matter interactions at the bulk scale resulting from atomic forces (DCI).

6 · CARRY OUT AN INVESTIGATION

17 min

MATERIALS: Salt Water Conductivity

Review preparation, safety, and clean-up procedures. Display **slide J** and go over the safety guidelines for the investigation. Distribute a copy of *Salt Testing Procedure* to each student. Remind students to follow steps 1-7 in this reference to set up their system first and then review the safety guidelines in *Salt Testing Procedure* before carrying out the investigation they designed. Also remind students of the clean-up procedure required before they leave the lab.

Carry out investigations. Display **slide K.** Monitor students as they carry out their investigations and record their observations.

SAFETY PRECAUTIONS



If the battery **starts heating up quickly**, students have created a dangerous condition in the system called a *short circuit*. Although this is unlikely to occur, remind groups to carefully **check the temperature of the battery every minute** throughout the investigation. If at any point a group's battery heats up, have them **detach the wires from the battery** and **help debug** their setup before continuing. Look for any locations where wires or connections that can be traced back to the two ends of the battery are accidentally touching each other without being connected to any electrical device. Rearrange the system to correct this, and then have the group test it again.

ADDITIONAL GUIDANCE

Students may notice bubbles forming in the water, particularly if they have experience with *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*. These are evidence of gas formation in electrolysis. This can be left as a wondering, as students will encounter the electrolysis chemical equation in subsequent units.

Navigate. After students have cleaned up and returned to their seats, display **slide L** and have students look over parts 6 and 7 on *Salt Investigation Plan*. If they did not finish during their investigation time, allow them to finish now. If they have already answered both parts, encourage students to read over what they wrote and add anything else that they do not want to forget between now and the discussion next class.

ALTERNATE ACTIVITY

Extension opportunity: A differentiation opportunity exists for students who are interested in exploring whether other salts conduct electricity as readily as table salt. If you have access to road salt or other water-soluble salts, feel free to make these available to interested students. Encourage them to make a prediction about how the conductivities of the salts might compare, and have students write a procedure for how they will test their predictions.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students collect data during their investigation related to multiple different salinity percentages and electric current. (SEP 3.1; DCI: PS1A.3)
- Students' answers to question 6 cite evidence from the investigation to evaluate the claim about what happened to the geese. (SEP 7.2; CCC: 1.5)

What to do: As students are planning and carrying out their investigations, ask them how they are generating evidence to address their claim that lightning killed the geese in the St. Lawrence River. After their investigations, as students are completing part 6 on *Salt Investigation Plan*, make sure that they are using evidence from the investigation in their response.

Building toward 13.A.2 Plan and conduct an investigation to generate empirical evidence to evaluate a claim about the conductivity of water. (SEP 3.1, 7.2; DCI: PS1.A.3; CCC: 1.5)

End of day 1

7 · COMMUNICATE RESULTS

4 min

MATERIALS: *Salt Investigation Plan*

Navigate. Display **slide M**. Have students turn and talk with a partner about the prompts on the slide. Ensure that students are partnered with someone who was not in their lab group. After a couple of minutes, use the prompts to lead a class discussion.

Suggested prompt	Sample student response
How does adding salt to water affect the rate of charges moving through it?	Adding salt increased the rate at which charges flowed through the water. The more salt we added, the more it conducted and the higher the number on the ammeter.
What new questions do you have?	What is the salt doing? Do other things that dissolve in water also conduct electricity? Why don't water or salt conduct by themselves but they conduct together?

8 · ATTEMPT TO EXPLAIN OUR RESULTS AND IDENTIFY KEY MODEL IDEAS

17 min

MATERIALS: *Model Evaluation Checklist*, M-E-F poster, chart paper markers, 2 notecards, 2 paper clips

Transition to attempting to explain our results. Make sure that the M-E-F poster is visible to all students. Display **slide N.**✱ Say, *When we are trying to make sense of something unexpected, it often helps to start by considering what we know. Let's use our M-E-F triangle to reflect on what we know about the system from a matter perspective first.* Reference the matter corner of the M-E-F triangle.

Suggested prompts	Sample student responses	Follow-up questions
What changes did we observe in the matter?	The salt dissolves. The salt mixes with the water.	*Where does the matter that made up the salt go when it dissolves?*
What particle-level changes are happening at the same time?	The salt breaks into smaller particles. The salt particles mix with the water particles.	*If in a solid the particles that make it up are all clumped together, then what must be happening to the particles to make it so we can no longer see them after they dissolve?*

Identify questions we are trying to answer. Say, *We have started reasoning first about what happened at a particle-level--that adding the salt to water caused it to dissolve, and that salt water conducts electricity. Let's keep track of both ideas so we remember what we observed that we want to try to explain.*✱

✱ ATTENDING TO EQUITY

Universal Design for Learning: When students build a model checklist together, they feel increased *engagement* (CAST, 2019) because their ideas are represented. Be sure to support the discussion with the prompts, but try not to hold on too tight! Students can sense when you are searching for the "right answer". If the discussion lags, ask them to talk to a partner for a minute to come up with two more ideas.

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: Later in this activity, students will be introduced to the term *ionic compounds*. Highlight to students that scientists, communicating in English as well as other languages, like to combine words that are already used in various contexts to make new terms. In this

Introduce the idea of evaluating candidate models. Display **slide O** and distribute *Model Evaluation Checklist* to each student. Start a poster titled *How does water cause salt to dissolve? and Why does salt water conduct electricity?* Instruct students to add those two questions to Table 1 (and Table 3) of *Model Evaluation Checklist*.

Identify key model ideas. Display **slide P** and say, *I have models created by three different people to explain how electric current can move in salt water. We need to evaluate whether each of these models answers the two big questions we have raised about this phenomenon. To do that, let's decide as a class what these models should include to answer those two questions.* Remind students that we already agree that salt dissolves in water and that this happens by salt breaking into smaller pieces. Direct students' attention to Table 2 of *Model Evaluation Checklist* and tell them to record the model ideas there as you write them on the chart paper. Add the first key model idea to the poster:

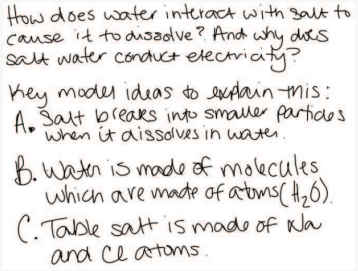
A. Table salt breaks into smaller particles when it dissolves in water.

Ask, *What do we know about the particles that make up water?* Students should identify what they know from Lesson 11, which is that water molecules are made of two types of atoms, and that the composition of the molecule is H_2O. Add this to the poster:

B. Water is made of molecules which are made of atoms (H_2O).

Share information about the composition of the salt we used in the lab. Display **slide Q**. Say, *Some of you may already know that the table salt we used in the lab is sodium chloride. Sodium has the chemical symbol "Na," and chlorine has the chemical symbol "Cl". We can use NaCl as a shorthand for table salt, just as we use H_2O for water.* Suggest we add this to the poster:

C. Table salt is made of Na and Cl atoms.



ADDITIONAL GUIDANCE

Do not tell students that salt is composed of a repeating structure of ions. Students will uncover this key idea in the model evaluation activity on day 3. Do not tell students that the salt we used in the lab is one of many types of salts that exist. They will uncover this idea in the home learning *Electrolytes* that they will be assigned at the end of this day of the lesson.

Ask, *Does that information about the types of atoms that make up table salt help us explain why or how the salt water conducts electricity?* Listen for students to say "No, not really." We need more information about those atoms or how they interact with water.

Recall what we know about moving charges. Display **slide R**. Say, *OK, let's think about what we know about how charges can move.*

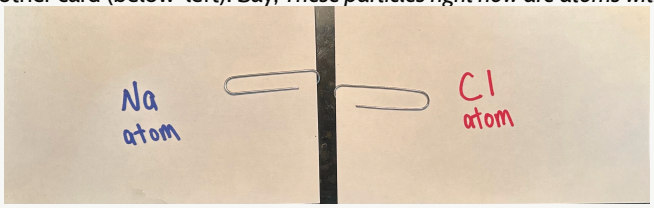
unit, we developed the idea of *ions* in Lesson 11 and *bonds* in Lesson 12. Therefore, an *ionic bond* is a bond between ions. Meanwhile, an *ionic compound* is a compound (a substance made of different types of atoms) that is made of ions (atoms that have lost or gained one or more electrons).

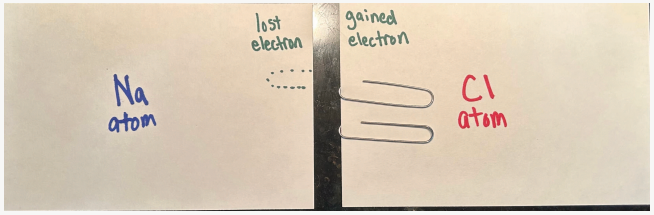
Suggested prompt	Sample student response
When electricity is conducted through a metal, what is happening with those atoms?	Electrons are moving. The "free" electrons move easily in conductors like metals.
What about when lightning moves through ionized air?	Electrons. Positive ions of gas the electrons came off of.
Do we think something similar is happening in the water—the movement of negative and/or positive charges—when salt is added to it?	Yes, that would make sense.

Consider conductivity in water. Display **slide S**. Say, *When the ammeter has a reading, such as in salty water, that tells us that there are both positive and negative charge flows present.*

Suggested prompt	Sample student response
Why is it important that there are charges moving in the water?	The charges can conduct electricity, like electrons.
Where are those charges coming from?	The salt? Something that happens between the salt and the water?

Represent this with index cards and a paper clip. Start by showing a particle of sodium (Na) on one card and a particle of chlorine (Cl) on another card (below-left). Say, *These particles right now are atoms without electrons on them.*



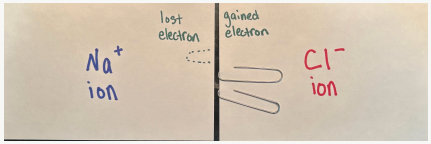


Ask, *How have we represented electrons before, using index cards?* Students will say with paper clips. Place a paper clip on each index card, then use the same motion as was used in Lesson 5 to transfer one paper clip from the sodium particle to the chlorine particle (above-right).

Suggested prompt	Sample student response
What has happened to our atoms?	Chlorine gained an electron. Chlorine took an electron from sodium.
What does that mean for their charges?	Chlorine is negative now because it has an extra electron. Sodium is positive now.

Think about where the charges come from. Display **slide T.** Remind students that solid salt did not conduct electricity, and that it only did so when it was dissolved in water.

Suggested prompt	Sample student response
Why didn't salt conduct electricity as a solid?	If the positive and negative are stuck together, it will be neutral. Opposite charges attract, so the chlorine and sodium stick together. Maybe chlorine doesn't take the electron until salt dissolves.
What do we think is happening to the salt when it dissolves?	Chlorine takes the electron from sodium. We know there are charges when salt dissolves, so the chlorine and sodium must separate.



Introduce ionic compounds. Say, *So, salt does not conduct electricity when it is solid, and we think that is because the positive and negative neutralize each other. But when salt dissolves, it splits up?* Display **slide U**. Tell students that because table salt is a substance made of these ions, it is called an *ionic compound*, and that the sodium and chlorine are held together by what is called an *ionic bond*. Remind students that in Lesson 12 they saw some examples of bonds in the models and that this is another example. Suggest that students pause here and add *ionic bond* and *ionic compound* to their Personal Glossaries.

ADDITIONAL GUIDANCE

Personal Glossary entries for ionic bond and ionic compound might look like:

Ionic compound: a compound made of positive and negative ions

Ionic bond: a bond between positive and negative ions where the ions are held together by the attraction between oppositely-charged ions

Record new key model ideas on the poster about the structure of salt and how it relates to charges in the water:

D. Salt is an ionic compound made of positive and negative ions that form by gaining or losing an electron from a neighbor.
E. These ions are held together by attractive forces.
F. These ions separate when salt dissolves in water and the charges can move in the water.

Elicit prior ideas about electric forces. Say, *Much of what we have written here is our thinking about the system from a matter perspective, though this last statement is starting to connect to energy when we say "the charges can move in the water" or that it conducts electricity. Let's use our M-E-F triangle to consider one other perspective.* Display **slide V**. Ask students to summarize a few ideas from Lessons 7 and 10 related to what they learned about the electric forces between charges as the distance between them decreases. Students should remember that the forces get stronger.

Add this key model idea to the poster:

G. Electric forces between charges are stronger when charges are closer to each other.

Have students double check that all of these ideas are in Table 2: Key Model Ideas Checklist on *Model Evaluation Checklist*.

9 · EVALUATE CANDIDATE MODELS

20 min

MATERIALS: *Model Evaluation Checklist*, class set of *Candidate Models* organized by name, Key Model Ideas poster

Give directions for evaluating candidate models. Display **slide W**. Say, *We are going to start evaluating these different models that attempt to explain how electricity is conducted through salt water. We have some key ideas to look for, so that is where we should start our evaluation.* Tell students that they will use Table 2 as a checklist to keep track of which key ideas are present in each candidate model.

Orient further to Table 3. Display **slide X**. *Say, each time you complete Table 2 for a model, move on to Table 3. Consider how many of the key ideas were present and how well they helped answer each of our two big questions. Then rate the model on a scale from 1 to 10 for each question—1 meaning it didn't answer the question at all, and 10 meaning it completely answered the question.*

Orient further to Table 4. Display **slide Y**. *This is where you decide whether or not you accept the model as valid. If not, explain why. If you decide the model is valid, add any new ideas that you see in the model to your list. We will switch partners twice so that everyone will get to examine all three candidate models, but you will only have a few minutes to talk about each model so we will need to make quick transitions.*

ALTERNATE ACTIVITY

The classroom mingle activity used here is intended to introduce some movement after a content-heavy discussion and to allow students to hear from peers they may not usually talk to. If you think your students might need more time for in-depth examination of these models, you can remove the trading models step. Instead, have each student keep the same model they began with for the entire activity and have them look for partners with different models for each round.

Distribute one model from *Candidate Models* to each student. Display **slide Z**. Direct students to stand up with their model and *Model Evaluation Checklist* in hand and find the first person they see who has a different model than they have. This first move should go very quickly.

Set a timer for seven minutes. Direct students to work together to evaluate both models and record their ideas on *Model Evaluation Checklist*. You may want to call attention to the halfway point at about three minutes.

Evaluate the last candidate model. When the timer goes off, display **slide AA** and have students trade models. Then they take their new model and find someone in the room who has the third model they have not seen yet. Set the timer for seven minutes again. Direct these new pairs to work together to evaluate both models again (confirming or questioning the ideas they recorded from their first partnership, as well as adding ideas about the new model).

Collect models and handouts. Display **slide BB**. When the timer goes off, collect *Candidate Models* to reuse for the next class. Collect *Model Evaluation Checklist* as a formative assessment.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: The answer key *Model Evaluation Key* is provided to support you in checking whether students can:

- evaluate the merits and limitations of different models by considering how well (or not) they show the cause of salt dissolving in water. (SEP: 2.1; CCC: 2.2)
- evaluate the merits and limitations of different models by considering whether they provide a mechanistic explanation for salt dissolving in water and electrical conductivity through it (salt water). (SEP: 2.1; DCI: PS1.A.3, PS2.B.3)

What to do: Some students may not have reviewed the valid model yet, so these students will not have additional key ideas listed. If you notice that students who have seen Jadon's model (the valid one) have not captured the necessary ideas, you might choose to facilitate a fishbowl-like shared discussion with two students: one with Jadon's model and one with another model. As the pair "thinks aloud" through their checklist, support their discussion as needed and pause to have the class point out key ideas to capture on their checklists.

Building toward 13.B Evaluate different models to determine which best explains what causes salt to dissolve in water and what causes electricity to be conducted through it (salt water). (SEP: 2.1; DCI: PS1.A.3, PS2.B.3; CCC: 2.2)

10 · INTRODUCE THE HOME LEARNING

4 min

MATERIALS: *Electrolytes*

Consider the role of salt in our bodies. Display **slide CC**. Say, *We have figured out that the salt in water helps explain why electric charges can travel through water. We also have salt in our bodies. While this might not be a good thing when lightning is near, it must be there for a reason.* Give students a minute to turn and talk with a partner about the prompts on the slide.

Introduce the home learning. Say, *I have a home learning assignment that could help us understand more ideas related to these questions.* Distribute a copy of *Electrolytes* to each student. Go through the directions on **slide DD.** Ask students if they have any questions about the assignment.✱

ADDITIONAL GUIDANCE

Students may question why naming conventions are different between the elements (sodium and chlorine) and compounds (sodium chloride). At this point, it is sufficient to tell them that the "-ide" ending indicates that the atoms (or in this case ions) are attracted or bonded to each other.

ALTERNATE ACTIVITY

Extension opportunity: Different types of salts, beyond table salt, are introduced in this home learning reading. It prompts students to record new questions they have at the end. If students raise questions about how well other salts conduct electricity compared to table salt, you can have them design and carry out an investigation using equipment in this lesson over the next few days, if they are interested.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Students are supported in this reading as they underline or highlight key model ideas and answer prompts. These alternate means of *representation*, in addition to the text, allow students to tie the reading to the most important takeaways from the lesson.

End of day 2

11 · CONSENSUS DISCUSSION ON BEST CANDIDATE MODEL

13 min

MATERIALS: *Model Evaluation Checklist*, class set of *Candidate Models* organized by name

Facilitate a Consensus Discussion.✱ Display **slide EE**. Distribute students' completed copies of *Model Evaluation Checklist*. Gather in a Scientists Circle and lay out four sets of the three models in the middle of the circle, with one set along each of four edges of the circle.✱ Say, *I looked through your evaluations. Which of the three models did you accept?* Look for students to say Jadon's model after some deliberation. Students may prefer superficial elements of the colorful model, or discard the model with fewer words written on it, but press students to use M-E-F thinking and to really compare each model to the checklist in Table 2 of *Model Evaluation Checklist*.

KEY IDEAS

Purpose of this discussion: To come to agreement on a single top candidate model that best meets the criteria outlined by students. See *Model Evaluation Key* for more guidance.

Listen for these ideas:

- Key model ideas: Jadon's model is most strongly aligned to these.
- Explanatory power: Jadon's model does the best job explaining our questions about the phenomena.
    - It provides a mechanism for how water interacts with the salt, causing it to dissolve. This is not true of Karla's or Miguel's model.
    - It provides a mechanism for how salt water conducts electricity, which Miguel's model does too, but Jadon's also explains how the charge flow in the water and wire interact, which is a more complete explanation.

Suggest that since we have accepted Jadon's model, we should make sure we agree on the ideas presented in that model. We should also see if the ideas in that model can help explain other related phenomena, such as the evidence presented in the home learning about electrolytes. Use the prompts below to help elicit new ideas from Jadon's model.

Suggested prompt	Sample student response
How does Jadon's model represent the particles that make up the salt differently than the other models do?	Jadon represents the salt as being made of positive and negative ions.
How does Jadon's model represent the water particles differently than the other models do?	Jadon represents the water molecules as having a positive end and a negative end.
What pattern do you notice about how those ions are arranged?	They are in a repeating pattern. It goes positive, negative, positive, negative.
If you consider all the ions in the salt, then does the salt have a net charge before it dissolves or is it neutral?	It is neutral.
According to Jadon's model, what causes one type of atom, chlorine, to be negative and the other type of neighboring atom, sodium, to be positive?	Chlorine gains an electron from a neighboring sodium atom, which loses it.

✱ STRATEGIES FOR THIS CONSENSUS DISCUSSION

Encourage restating of what others said first before adding on to it or saying whether or not there is agreement with that idea. Students might also use head nods or hand signals to show that they had a similar idea to a classmate's. For the top candidate model that is nominated, ask students to explain why they accepted that model.

✱ ATTENDING TO EQUITY

Universal Design for Learning: In a Scientists Circle, all students have a front-row seat, supporting *engagement* through recruitment of interest/proximity and sustaining effort and persistence by building community (CAST, 2019). The Scientists Circle encourages students to join the interaction space by positioning each learner directly in front of the shared discussion, so everyone can have room. Classroom spaces can be crowded, and crowding is not reflective of universal design. Make space in advance for learners with mobility devices or large body sizes, as an extra accessibility accommodation.

Suggested prompt	Sample student response
What pieces of evidence from the Electrolytes home learning support the ideas presented in Jadon's model?	The home learning discussed cations and anions, which are positive and negative ions like Jadon showed in his model. The electrolytes reading describes how the ions dissolved in water move toward different parts of the water when electricity runs through it, just like Jadon's model does.

12 · EXPLORE POLARITY OF WATER AND IDENTIFY ADDITIONAL MODEL IDEAS

11 min

MATERIALS: *Model Evaluation Checklist*, Personal Glossary, https://youtu.be/MFhkDQrev1Y?si=L2hGVk7a6RQZ6Ws4, chart paper markers, Key Model Ideas poster, notecard, 4 paper clips, *Candidate Models*

Suggest the need for additional evidence. Point out that water seems also to have positive and negative ends in Jadon's model, and that these charges do not seem to change. Say, *Since the idea that water might be permanently polarized is a new model idea that we have not tried using before, it seems like we will need some additional data to decide if we should reject or accept this key model idea.*

In order to break up time sitting in a Scientists Circle, have students stand up and gather in a semicircle around the projected video you will show next. Display **slide FF.** Ask students to be thinking about how each of the water phenomena in the video supports or refutes the idea that water molecules are permanently polar. Project https://youtu.be/MFhkDQrev1Y?si=L2hGVk7a6RQZ6Ws4.

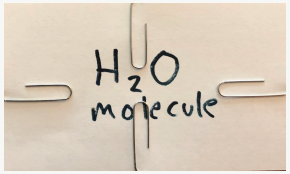
Discuss the video with a partner. Display **slide GG**. After showing the video, have students turn and talk with a neighbor about the prompts on the slide for two minutes.

Return to the Scientists Circle to continue the Consensus Discussion. Display **slide HH**.

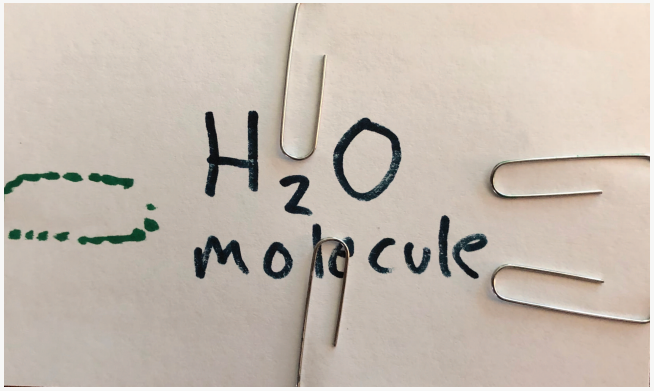
Suggested prompt	Sample student response
How does phenomenon A help support or refute the idea that water molecules are permanently polar?	Water beads up into a rounded shape. When one water droplet touched another they stuck together, like magnets. The molecules in each droplet of water must be attracted to each other.
What about phenomenon B?	Water droplets on the bottom of the watch glass grew in size as the stuff in the beaker cooled. The water molecules stuck together again. Something holds them to each other.

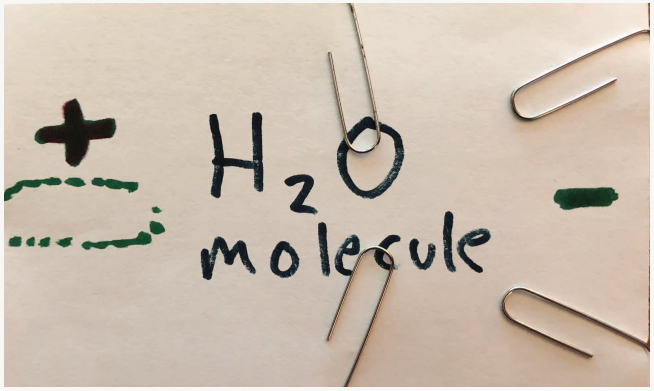
Consider polarity. Hold up a notecard with four paper clips attached, one on each side. Label the notecard as an H_2O molecule. Ask, *What do the paper clips represent in the atoms that make up the water molecule?* Students will say electrons.

Emphasize that the paper clips are equally distributed around this molecular model.



Suggested prompt	Sample student response
What do you have to do to these paper clips to better represent that water molecules are permanently polarized?	Move the electrons. Most or all of them should be on one side.
Which side of the water molecule is now more negative?	Where there are more electrons.
Which side of the water molecule is now more positive?	Where there are fewer electrons.





Display **slide II**. Label these two sides of the notecard and hold it up for students to see.

Suggested prompt	Sample student response
How would these different sides of the water molecule interact with the salt ions?	They are attracted to them. Different ions attract to different sides. The positive ion is attracted to the negative side, and the negative ion is attracted to the positive side.

Identify a difference in the strength of the force interactions. Say, *if there are attractive forces holding the oppositely charged ions together in the salt, but water can pull them off, then what does that tell us about the strength of the forces between the water molecules and the ions?* Listen for students to suggest that the forces between the water molecules and salt ions are stronger than the forces between ions.

Add a qualification to the key model idea for E in parentheses: "(relatively weak)". Then add two new key ideas to the poster:

H. Water molecules are permanently polar.
I. When these water molecules make contact with the salt they pull individual ions off of it, causing it to break apart (dissolve).

Tape the paper-clip model of water next to idea H.

Have students add these new key model ideas to Table 2 on *Model Evaluation Checklist*. Encourage students to add the words *polar molecule* and *dissolve* to their Personal Glossaries.

Sample entries:
polar molecule: *a substance that is more positive on one end and more negative on the other end*
dissolve: *when a substance breaks into smaller pieces in a liquid*

If students have questions about whether other molecules are permanently polar or other solids that dissolve in water have a structure similar to table salt, encourage students to write down these questions on a sticky note and add them to the Driving Question Board.

Continue the Consensus Discussion using the prompts below.

Suggested prompt	Sample student response
So after the salt dissolves, what charges are flowing through the water when it conducts electricity?	Electrons from one of the wires (foil) flow into the water toward the positive ions (Na^+). Positive ions of Na^+ flow toward the electrons. Negative ions of Cl^- flow toward the other wire (foil).
Why does dissolving only a small amount of salt in the water result in a lower number of milliamps (or charges per second) flowing through the system than when there was more salt dissolved in the water?	There are fewer charges per second when there is less salt dissolved because there are fewer ions in the water.

Revisit how polarity has been represented in the candidate models. Display **slide JJ.** Take out the candidate models and bring students' attention to them again. Continue the Consensus Discussion using the prompts below.

Suggested prompt	Sample student response
Where else in the past did we see or represent matter being polarized to explain some phenomena we encountered?	The balloon sticking to the wall. The ground getting polarized by the charges in the cloud above.
How have we represented matter being polarized before with our paper-clip model?	We shifted our paper clips, or electrons, to one side of the notecard.
How does Jadon's model represent the particles of water?	Jadon represents the water molecule as being polarized (having a negative and positive end).

Suggested prompt	Sample student response
Jadon's model seems to suggest that water is already polarized before it starts dissolving salt. What does that mean in terms of where one or more electrons that make up the atoms in a molecule of water are located?	They would be shifted to one side of at least one of the atoms that make up the molecule of water.
If water is already polarized before it starts dissolving salt, then maybe we should be treating it as if it is always polarized. Do you think that is a reasonable assumption?	Accept all ideas.

Wrap up the Scientists Circle by thanking each student and inviting everyone to return to their seats. Ask each student to find a shoulder partner to quickly confirm their understanding from the Scientists Circle with a thumbs up, thumbs down, or something in between.

13 · REVISIT PHENOMENON FROM DAY 1

5 min

MATERIALS: *Geese Lightning Strike*

Tie key ideas from the Scientists Circle back to the Geese Lightning Strike reading. Display **slide KK.** Hand out *Geese Lightning Strike* again if it was collected on day 1. Say, *Let's see if our key findings from the past few days can help us figure out how to explain what happened to the geese.* Give students one to two minutes to reread the brief article and to come up with an explanation with their shoulder partner about how the geese died.

Discuss how the new ideas apply to the geese phenomenon. Display **slide LL.** Call on a few students to share their explanations with the class for how the geese died. Direct students to consider the three additional prompts on the slide as the ideas about water, salinity, and conductivity are mentioned in their explanation. Give students some independent thinking time to consider the prompts before sharing, if it seems necessary. However, keep the class discussion to a couple minutes.

Suggested prompt	Sample student response
What do you think the range of salinity was of the St. Lawrence River?	A river is usually fresh water, so it could be similar to the Great Lakes' salinity, or around 0.05-0.06. It connects the Great Lakes and the Atlantic Ocean, so it might have a salinity between that of the lakes and the ocean, or between 1.0 and 3.0.
What evidence do we now have to support the idea that the lightning strike produced some type of charge flow through the birds?	There were heart lesions on all the geese. We learned that electrolytes are crucial for cells to function, which means the geese's cells had electrolytes within them to allow for charges to flow.
Could the same thing happen to other animals in the water?	Definitely! We need to be careful. All living things are made of cells, and all cells have electrolytes, so all living things could be electrocuted.

14 · EVALUATE CLAIMS

10 min

MATERIALS: *Lightning Safety Claims*

Introduce claims about lightning safety based on the geese phenomenon. Display **slide MM.** While distributing *Lightning Safety Claims* to students, say, *If lightning can kill a flock of geese sitting on a river in less than a second, it makes sense that there are many precautions we hear about from our communities and media sources to keep people safe from lightning. Now that we have learned so much about electricity and lightning, let's use our knowledge to evaluate whether or not these claims about lightning safety are fully accurate.*

Instruct students on how to evaluate claims. Read through the directions in *Lightning Safety Claims* as a class. Be sure to point out each column and what information needs to be included, and let students know whether or not you plan to collect these as an assessment.✱ Give students eight minutes to work independently on the handout.

ADDITIONAL GUIDANCE

Many students and teachers alike may be naturally skeptical of an assessment where one must infer the accuracy of multiple claims, and they may assume that many of the claims are not accurate. However, in *Lightning Safety Claims*, three of the four claims are reasonably accurate and based on widely accepted ideas regarding lightning. Refer to *Lightning Safety Claims* for details on the accuracy of each claim and what reasonable evaluations of them could be.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: The answer key *Lightning Safety Claims* is provided to support you in checking whether students can:

- evaluate the accuracy of claims by considering how well (or not) the claims about lightning safety align with key ideas about the flow of electrons through ions in water and other materials. (SEP: 8.4, 7.2; DCI: PS1.A.3, PS2.B.3)
- verify information presented in each claim using empirical evidence collected during their investigations. (SEP: 8.4, 7.2; CCC: 1.5)

What to do: Observe how students navigate the handout particularly whether or not they evaluate the claim's accuracy *before or after* finding empirical evidence to support the presented claim. Both approaches are valid, as students' thought processes are diverse when it comes to explaining complex mechanisms. Ask questions about both their final evaluation of each claim and their approach to reaching a conclusion, keeping an eye out for how students discuss empirical evidence from the lesson investigations. You may also do this after students have completed and turned in the handouts, if you choose to collect them.

If students are struggling to interpret a claim, start by helping them break it down into parts and make sense of the scenarios described by the claim. If students are still struggling to evaluate the claim after making sense of what it means, push students to refer to their conclusions from the investigation and their key takeaways from the Scientists Circle by verbalizing the patterns they noticed in the evidence they collected in *Salt Investigation Plan*.

Building toward 13.C Evaluate claims and verify data presented in media using empirical evidence about properties of matter caused by interactions of charged particles. (SEP: 8.4, 7.2; DCI: PS1.A.3, PS2.B.3; CCC: 1.5)

✱ ATTENDING TO EQUITY

The claims provided in *Lightning Safety Claims* vary in their conceptual complexity and in their relationship to the data students collected during the lesson investigations. It is encouraged that you adapt the handout to differentiate either between students or between class periods. You may do this by assigning specific claims to individual students or by allowing students to choose (as described in the handout directions) which claims they would like to evaluate.

The number of claims that a student can evaluate within the time frame provided will vary, making this assessment a good opportunity for differentiation. If you think students who have already mastered the LLPEs in this lesson can evaluate three claims within the time frame, you are welcome to set that as the expectation to add an additional challenge for those students.

15 · NAVIGATE

6 min

MATERIALS: Community Agreements

Navigate. Display **slide NN**. Have students turn and talk with a partner about the prompt on the slide. After a minute, ask for a few volunteers to share their discussion. Summarize student discussion ideas and say, *It seems like we are ready then to try to answer our driving question!*

Reflect on Community Agreements. Display **slide OO**. Read through the text in the white box on the slide:
In our next lesson, we will:

- *apply everything we have figured out to try to answer all questions on our DQB*
- *explain some related phenomena through transfer tasks; and*
- *self-assess our progress.*

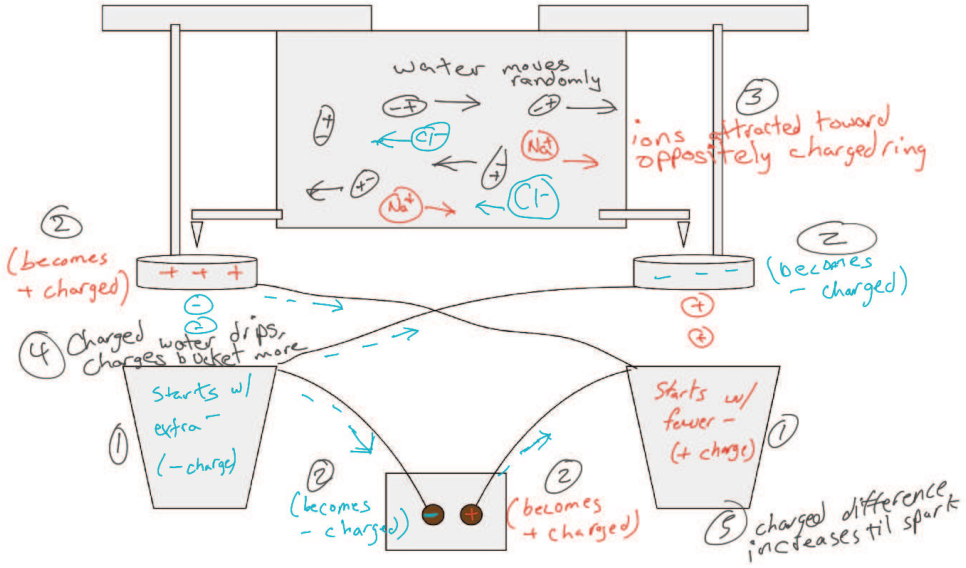
Emphasize that the next lesson is a few days long but will be focused on wrapping up our unit, just as we did at the end of *Polar Ice Unit*. Ask students to take 30 seconds to individually reflect on the question in the next box, *What community agreements will we need to lean on for all of us to get the most out of the final learning and assessment experiences of the unit?*, then discuss it as a class. Accept all ideas.

ALTERNATE ACTIVITY

If time is short, or you anticipate the class may have a lot they want to talk about, you may wish to assign the reflection on Community Agreements as a home learning assignment with a follow-up discussion of students' reflections at the start of the next lesson.

ALTERNATE ACTIVITY

Extension opportunity: Students may have added questions about the water dropper system to the DQB throughout the unit. Students now have the ability to answer these questions. You may wish to have students model the water dropper system given what they have figured out to this point, using the template included in *Model Interactions* from Lesson 3. Additionally, have students model how the water dropper might behave differently if salt water is used instead of normal tap water. Students' models will show a variety of elements that will be important in Lesson 14, including charge movement in metals, water, and air, as well as the attraction between opposite charges that results in an energy transfer between the pennies. A sample model is shown.



Additional Lesson 13 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-LITERACY.RST.9-10.8: Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. Students evaluate the extent to which several claims have been supported by evidence. They provide reasoning to support their evaluations.
SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	CCSS.MATH.CONTENT.HS.N-Q.1: Use units as a way to understand problems and to guide the solution of multi-step problems; ~~choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.~~ Students convert mA to charges per second.

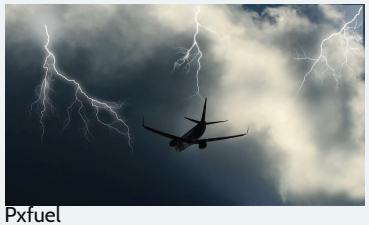
LESSON 14: Why are some places safer than others when lightning strikes?

PREVIOUS LESSON *We tested pure water and pure sodium chloride and determined that neither conducts electricity. We planned an investigation to figure out how increasing the concentration of salt in water affects the rate of charges flowing through it. We evaluated different models. We explained how a lightning strike on a river would cause the death of a group of geese floating on it.*

THIS LESSON

PUTTING PIECES TOGETHER

3 days



Pxfuel

We create a consensus Gotta-Have-It Checklist and use it to build models to answer the second half of our driving question, "Why are some places safer than others when lightning strikes?" Then, we take stock of which questions we have answered on our DQB and demonstrate our understanding on an assessment task.

NEXT LESSON *There is no next lesson.*

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-3, HS-PS2-4, HS-PS2-6, HS-PS3-2, HS-PS3-5

WHAT STUDENTS WILL DO

14.A Develop and revise a model based on evidence to illustrate and predict the relationships between components of a model that explains why certain places are safer than others when lightning strikes based on patterns observed at different scales. (SEP: 2.3; DCI: PS2.B.3; CCC: 1.1, 3.3)

14.B Communicate scientific and technical information about why the molecular-level structure is important in the safety of different materials and locations when lightning strikes. (SEP: 8.5; DCI: PS2.B.3; CCC: 6.1)

End-of-Unit Assessment: HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. (SEP: 8.5; DCI: PS2.B.3; CCC: 6.1)

WHAT STUDENTS WILL FIGURE OUT

- The model components/relationships/mechanisms for why we should stay away from water when lightning strikes.
- The model components/relationships/mechanisms for why going inside buildings with lightning rods or indoor plumbing is safer when lightning strikes.
- We have answered many of our questions on the DQB!
- We can use our understanding to explain related phenomena about airplanes and conducting gels used to mimic brain tissue.

Lesson 14 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		**NAVIGATE** Guide the class to navigate to the work in this lesson.	A	
2	22 min		**BRAINSTORM IDEAS AS A CLASS AND BUILD A CONSENSUS GOTTA-HAVE-IT CHECKLIST** Brainstorm places that are safer than others when lightning strikes. Organize students with a partner to develop a consensus Gotta-Have-It Checklist for students' final models.	B-D	*Consensus Gotta-Have-It Checklist*, Progress Tracker, other resources suggested in *Consensus Gotta-Have-It Checklist*, *Consensus Gotta-Have-It Checklist* (electronic copy)
3	15 min		**DEVELOP OUR LIGHTNING SYSTEM MODELS** Give students time to develop lightning system models to reflect why some places are safer than others when it strikes.	E	*Consensus Gotta-Have-It Checklist*
4	5 min		**NAVIGATE** Give students time to begin a short reading and reflection.	F	*Who is Safe?*
					End of day 1
5	5 min		**NAVIGATE** Give students time to return to their models, make any additions, and reflect on how they can best communicate their ideas to their peers.	G	*Consensus Gotta-Have-It Checklist*, *Who is Safe?*
6	20 min		**GIVE PEER FEEDBACK ON MODELS IN GROUPS** Students share models in small groups and give and receive peer feedback. Then, students revise models based on that feedback.	H-I	*Consensus Gotta-Have-It Checklist*
7	20 min		**REFLECT ON WHAT WE HAVE ACCOMPLISHED** Revisit the DQB with the whole class and take stock of all of the questions we have now answered.	J-L	*Our DQB Questions*, Driving Question Board
					End of day 2
8	40 min		**COMPLETE THE INDIVIDUAL ASSESSMENT** Have students individually complete an assessment task.	M	*Airplane Transfer Task* (both parts)
9	5 min		**QUICK WRITE: REFLECT ON OUR EXPERIENCES** Have students complete a quick write and then discuss what was challenging and rewarding about this unit and what the class would like to carry forward to other units.	N	
					End of day 3

Lesson 14 • Materials List

	per student	per group	per class
Lesson materials	• *Consensus Gotta-Have-It Checklist* • Progress Tracker • science notebook • other resources suggested in *Consensus Gotta-Have-It Checklist* • *Who is Safe?* • *Our DQB Questions* • *Airplane Transfer Task* (both parts)		• *Consensus Gotta-Have-It Checklist* (electronic copy) • Driving Question Board

Materials preparation (25 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Locate the Driving Question Board and make it easily accessible to students. Update *Our DQB Questions* with any new questions from the DQB.

Make space for a Scientists Circle.

Create an electronic copy of *Consensus Gotta-Have-It Checklist* for each class.

On day 2, students will engage with *Our DQB Questions*, originally given out in Lesson 5. If a large number of questions have been added to the DQB since the last update of this document, you may want to prepare updated versions to distribute to students.

Airplane Transfer Task consists of two parts. When copying the assessment, ensure that the two parts are kept separate. To help reduce the complexity of the readings in the assessment, time is built into the lesson for class discussion prior to the administration of each part.

Lesson 14 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build new ideas related to the following disciplinary core idea:

- **PS2.B.3 Types of Interactions:** Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, ~~as well as the contact forces between material objects~~.

Crossout explanation: DCI: PS2.B.3 is used to bring together material properties and particle-level thinking to investigate human safety, building on the work students did in Lessons 1, 6, and 12-13. Once again, contact forces are left for *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*.

This lesson revisits many of the same DCI, SEP, and CCC elements from Lesson 1 (SEP: 2.3; DCI: PS2.B.3; CCC: 1.1, 3.3). This gives students a great opportunity to demonstrate how much they have grown in these areas. For example, you should see an increase in the sophistication of showing causal mechanisms between components of a system. All students should have components in their models with molecular and subatomic representations, in addition to macroscopic representations.

The practice of obtaining, evaluating, and communicating information is a focal practice for this unit. Students have had several opportunities to obtain and evaluate information in previous lessons and to communicate information in Lesson 11, but in this culminating lesson they have a chance to share their scientific ideas both orally and textually with peers in class (SEP: 8.5). This requires students to highlight the ways that designed materials work at the particle level–thinking that students began to develop in Lesson 12 (CCC: 6.1).

Where We Are NOT Going

Since this is the last lesson of the unit, you can take as much time as you wish to go through the Driving Question Board with students. There will probably be unanswered questions left on the board. As an extension opportunity, you might allow students to do some independent research and share with the class what they have figured out. Use your discretion in deciding whether the class would benefit from such an activity. Questions may remain about particular elements that students have encountered throughout the unit, the nature of bonds, different types of bonding, or how reactions happen. Many of these questions will be answered in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*, so the answers should not be revealed at this time.

In this lesson, students communicate both scientific information (about water's conductivity) and technical information (about lightning rod function) through oral, graphical, and textual formats. However, they do not use math to support their thinking and they do not communicate a more complete design solution. Students will have opportunities to do the former in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)* and to do the latter elsewhere in the OpenSciEd High School sequence.

LEARNING PLAN for LESSON 14

1 · NAVIGATE

3 min

MATERIALS: None

Navigate to the purpose of today's class. Display **slide A.** Have students turn and talk with a neighbor about the questions on the slide. Then, invite a few students to share with the whole class.

Suggested prompt	Sample student response
What did we figure out last class?	We learned that pure water (just H_2O molecules) does not have dissolved ions, so actually pure water isn't a good path for lightning to follow and doesn't conduct electricity well.
How can we apply what we figured out to our big driving question: "What causes lightning and why are some places safer than others when it strikes?"	We learned why it's not a good idea to be in water when lightning strikes. Most of the water around us, like in pools, lakes, or oceans, has ions in it. We have ions in our bodies, too. Ions can conduct electricity and make a path that lightning can follow, which is why we want to stay away from water.

Say, *Wow, we have made a lot of progress recently on the second half of our driving question: "Why are some places safer than others when lightning strikes?" Let's update our models to reflect our new ideas.*

2 · BRAINSTORM IDEAS AS A CLASS AND BUILD A CONSENSUS GOTTA-HAVE-IT CHECKLIST

22 min

MATERIALS: *Consensus Gotta-Have-It Checklist*, Progress Tracker, science notebook, other resources suggested in *Consensus Gotta-Have-It Checklist*, *Consensus Gotta-Have-It Checklist* (electronic copy)

Brainstorm places and materials that are safer than others when lightning strikes. Display **slide B.** Refer to the lightning system models from Lesson 9. Say, *Our goal is to update our models to reflect the new ideas we have figured out about why some places are safer than others when lightning strikes. First, let's agree on which places or materials we figured out to stay away from when lightning is around. Think individually about these questions.*

After students have had a couple of minutes to think, ask students to share out and write the ideas on the board.✱

✱ ATTENDING TO EQUITY

Before students start their checklists, ensure that all students are comfortable with the differences between Components, Interactions/Relationships, and Mechanisms. A strong model must go beyond the components that are in the system to the ways in which they interact to cause the phenomenon that the question addresses. It may be useful to return to the soccer ball example from Lesson 1, or have students work in pairs to identify components, join with another pair or the class to identify relevant interactions, then work in pairs again to identify system mechanisms.

Suggested prompts	Sample student responses	Follow-up questions
Which places or materials that we have investigated should we stay away from when lightning strikes?	Stay away from water (Lesson 13). Avoid touching metals (Lesson 12). Do not go under a tree (Lessons 12-13).	*What patterns are there in these places or materials?*
Which places or materials that we have investigated are safer than others when lightning strikes?	Find lower elevation (Lessons 10-11). Go inside a car (Lesson 12). Go inside buildings with lightning rods or indoor plumbing (Lesson 12).	*What patterns are there in these places or materials?*

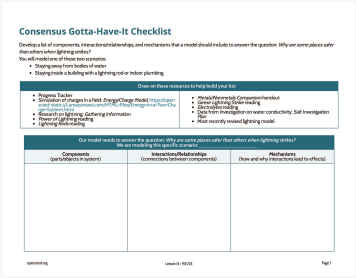
Listen for ideas about the patterns in these different situations--that it is best not to touch conductive objects, but that some structures have conductive objects to protect us while we are in contact with non-conductive objects. Form two groups, one focused on avoiding conductive objects (like bodies of water) and one on the importance of protected structures (with lightning rods or indoor plumbing).

Celebrate students' ideas and suggest that we build on our prior models in order to explain these scenarios. Note that it is often useful to begin with a Gotta-Have-It Checklist so we have a clear idea of what to put in our models.

ALTERNATE ACTIVITY

Since students will ultimately model one of two different scenarios, you can offer student choice in selecting a group for developing checklists. Allow students to choose based on their interest in the place or material they would most like to explain.

Build a Gotta-Have-It Checklist with a partner. Distribute *Consensus Gotta-Have-It Checklist* and display **slide C.** Here, allow students to start generating ideas for a Gotta-Have-It Checklist that they will use to revise their models. Encourage students to use their Progress Trackers, science notebooks, and any other resources available to them.


Consensus Gotta-Have-It Checklist

Develop a list of components, interactions/relationships, and mechanisms that a model should include to answer the question: *Why are some places safer than others when lightning strikes?*

You will model one of these two scenarios:

- Staying away from bodies of water
- Staying inside a building with a lightning rod or indoor plumbing

Draw on these resources to help build your list:

- Progress Tracker
- Simulation of charges in a Field: Energy/Charge Model (https://ngsss-scied.statistics.utah.edu/sites/default/files/2021-03/Field%20Energy%20and%20Charge%20Model%20Simulation.pdf)
- Research on lightning: Gathering information
- Power of Lightning reading
- Lightning Myth reading
- Pintails/Perennials Comparison handout
- Cause Lightning Strike reading
- Electricity Basics reading
- Data from Investigation on water conductivity: Salt Investigation
- Lightning Safety
- Most recently revised lightning model

Our model needs to answer the question: *Why are some places safer than others when lightning strikes?*
We are modeling the specific scenario: _____

Components (parts/objects in system)	Interactions/Relationships (connections between components)	Mechanisms (how and why interactions lead to effects)

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Whole-class Consensus Discussion to build a consensus Gotta-Have-It Checklist. Display **slide D.** Have student pairs share out potential model ideas and use the prompts on the slide to help guide this discussion. Record agreed-upon model ideas electronically in the class copy of *Consensus Gotta-Have-It Checklist* and encourage students to add them to their own lists as well. Students will be responsible for modeling either of two scenarios (staying away from water or staying inside buildings with lightning rods/indoor plumbing), but they should record *all* ideas at this point.✱

✱ ATTENDING TO EQUITY

Support for Universal Design for Learning: An important component of *engagement* is reducing threat. As students will soon individually develop a fairly complex model that reflects several lessons' thinking, they should be encouraged that they, along with their classmates, have already developed a comprehensive resource that they can use as they develop their models.

KEY IDEAS

Purpose of this discussion: To develop a consensus Gotta-Have-It Checklist for all the ideas needed to be able to explain why a certain material or location is safe (or unsafe) during a lightning strike. Students will work from a copy of the consensus checklist to check off the ideas that are needed for their specific material or location when they develop a model.

Your role in this discussion is to get as many students as possible to weigh in on the ideas being shared. Do not write every idea on the board right away. Let students consider whether an idea is really needed to explain one of the materials or locations. If you see that there are critical ideas missing, be sure to press the class so that the list is complete at the end of this Consensus Discussion.

Listen for these ideas:
See *Consensus Checklist Key* for potential student ideas. The ideas do not have to be organized in this way for the Consensus Discussion. The model ideas are sorted by material/location for teacher reference.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students suggest components in the system such as electrons, air, metal, water, and ions and interactions involving forces between charges. (SEP: 2.3; DCI: PS2.B.3)
- Students suggest causal mechanisms for what makes the material or location safer than others when lightning strikes. (SEP: 2.3; DCI: PS2.B.3)
- Students' suggestions reflect different scales (e.g., subatomic particles, molecules, visible materials or structures, and connections to lightning). (CCC: 3.3)
- See *Consensus Checklist Key* for more specific guidance.

What to do: Partner talk time before building the checklist should give students a good start. If students are not generating ideas as a whole class, have partners exchange draft Gotta-Have-It Checklists with another partner group to give each other feedback and generate more ideas before going public in a whole-group setting. Also, it may be helpful to pull out Progress Trackers and specific artifacts from previous lessons, such as the reading from Lesson 12, to jog students' memories.

If students need more practice developing mechanistic models focused on safety features, it may be productive to make this a more teacher-led discussion and give students the opportunity to model another phenomenon brainstormed on slide B independently.

Building toward 14.A.1 Develop and revise a model based on evidence to illustrate and predict the relationships between components of a model that explains why certain places are safer than others when lightning strikes based on patterns observed at different scales. (SEP: 2.3; DCI: PS2.B.3; CCC: 1.1, 3.3)

3 · DEVELOP OUR LIGHTNING SYSTEM MODELS

15 min

MATERIALS: science notebook, *Consensus Gotta-Have-It Checklist*

Students develop models. Display **slide E.** Students should use the class-populated version of *Consensus Gotta-Have-It Checklist* and decide whether each model idea is needed as they complete questions 1a and 1b. Then, they should check off the model ideas that they are using in their model.✱

On day 2, students will work in groups of three to give and receive peer feedback on their models. Therefore, each student should prepare to explain their model to others by completing question 2.

ALTERNATE ACTIVITY

A great way to increase student engagement is to allow even broader student choice in the location/material they are most interested in explaining. You could leverage the list of safety guidelines students brainstormed on slide B to allow students to model a different combination of related guidelines–for example, staying away from trees and metal.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Consensus Checklist Key* for guidance.

What to do: The consensus Gotta-Have-It Checklist should give students quite a bit of guidance in developing their models. Make sure all students have access to this list and are actively using it to make their models. You may wish to give students additional guidance on which model ideas to use for their specific phenomenon before they begin writing on their chart paper. Alternatively, you could have each student draft a quick version of a model in their science notebook and compare ideas in a small group using a talking stick or discussion diamond protocol as a way to generate more ideas from all students.

Building toward 14.A.2 Develop and revise a model based on evidence to illustrate and predict the relationships between components of a model that explains why certain places are safer than others when lightning strikes based on patterns observed at different scales. (SEP: 2.3; DCI: PS2.B.3; CCC: 1.1, 3.3)

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Students' individual models draw on evidence collected throughout the latter half of the unit (SEP) to show multiple ways in which attractions and repulsions at the atomic scale (DCI) explain lightning. This requires students to build on work in Lessons 1, 8, and 9 to use patterns at multiple scales in explaining phenomena. Celebrate with students the ways in which they are able to use patterns (CCC) and scale thinking (CCC) to develop much more detailed--and more fully explanatory--models than they had at the beginning of the unit.

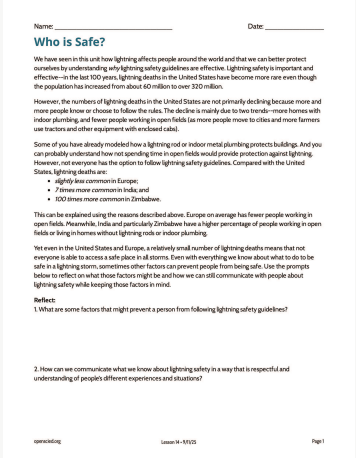
4 · NAVIGATE

5 min

MATERIALS: *Who is Safe?*

Introduce a short reading and reflection. Display **slide F**. Say, *We have some great models that we can share with classmates next time. However, when we communicate about a topic like lightning safety, it is important to remember that not everyone has the same opportunities to do what they "should" do in a storm.* Distribute *Who is Safe?* and ask students to read the handout and respond to the prompts. Say, *We have already encountered data in this unit that might evoke different feelings for different people. This reading might do the same, but it is important that we understand its ideas so we are aware of the broader world and can more respectfully and effectively communicate with one another about topics like lightning safety.*✱

Allow students to complete this work at home if they do not finish in class.



Name: _____ Date: _____

Who is Safe?

We have seen in this unit how lightning affects people around the world and that we can better protect ourselves by understanding why lightning safety guidelines are effective. Lightning safety is important and effective—in the last 100 years, lightning deaths in the United States have become more rare even though the population has increased from about 60 million to over 320 million.

However, the numbers of lightning deaths in the United States are not primarily declining because more and more people know or choose to follow the rules. The decline is mainly due to two trends—more homes with indoor plumbing, and fewer people working in open fields (as more people move to cities and more farmers use tractors and other equipment with enclosed cabs).

Some of you have already modeled how a lightning rod or indoor metal plumbing protects buildings. And you can probably understand how not spending time in open fields would provide protection against lightning. However, not everyone has the option to follow lightning safety guidelines. Compared with the United States, lightning deaths are:

- *slightly less common* in Europe;
- *7 times more common* in India; and
- *100 times more common* in Zimbabwe.

This can be explained using the reasons described above. Europe on average has fewer people working in open fields. Meanwhile, India and particularly Zimbabwe have a higher percentage of people working in open fields or living in homes without lightning rods or indoor plumbing.

Yet even in the United States and Europe, a relatively small number of lightning deaths means that not everyone is able to access a safe place in all storms. Even with everything we know about what to do to be safe in a lightning storm, sometimes other factors can prevent people from being safe. Use the prompts below to reflect on what those factors might be and how we can still communicate with people about lightning safety while keeping those factors in mind.

Reflect:

1. What are some factors that might prevent a person from following lightning safety guidelines?

2. How can we communicate what we know about lightning safety in a way that is respectful and understanding of people's different experiences and situations?

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✱ ATTENDING TO EQUITY

Social and Emotional Learning: This article focuses on lightning fatality rates across countries, which tend to be lower in places with more urbanization and access to buildings with lightning rods or indoor plumbing. This reading is intended to promote *social awareness* among students as well as *relationship skills* as students recognize an issue they may not have been aware of and take it into account as they communicate their understanding of lightning safety with their classmates. The article's discussion of death, as well as the deep global inequalities it reveals, may evoke feelings for students. Do not discount these emotions and bring in a school counselor or other expert to speak with students if necessary based on students' reactions to similar information in Lesson 1.

End of day 1

5 · NAVIGATE

5 min

MATERIALS: *Consensus Gotta-Have-It Checklist*, *Who is Safe?*

Frame the need for sharing models with classmates and getting peer feedback. Display **slide G.** Say, *Everyone has worked hard to build their specific model, but we have not had a chance to share our thinking with others and get their feedback. We want to make sure we do so in a way that is thoughtful and respectful, as discussed in the reading.* Give students five minutes to do the following:

1. Make any additions or changes to their model, if needed.
2. Re-examine their model and proposed communication to a classmate to determine whether any changes are needed before sharing out.

If students finish early, have them turn and talk with a partner about the reading.

6 · GIVE PEER FEEDBACK ON MODELS IN GROUPS

20 min

MATERIALS: science notebook, *Consensus Gotta-Have-It Checklist*

Place students in groups of three. Each trio should include students who did not work together on the Gotta-Have-It Checklist and a mix of scenarios modeled, to the extent possible.

Decide how groups will give peer feedback. There are several options for sharing and receiving peer feedback in the *OpenSciEd High School Teacher Handbook*. Choose one method for your students to use.

Explain sharing and peer feedback guidelines. Display **slide H.** Have each student bring *Consensus Gotta-Have-It Checklist* and their model to the group. Then, group members should provide the targeted model with written peer feedback. After five minutes, have the students rotate to the next model and continue the process.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use their drawn model and written text as a tool to clearly communicate the scientific ideas that explain the phenomenon. (SEP: 8.5)
- Students make connections between the molecular-level structure of the material and its function of safety during a lightning strike. (DCI: PS2.B.3; CCC: 6.1)

What to do: If students struggle or are hesitant to give their presentations to other classmates, allow them time to practice beforehand. You could also offer alternatives such as videoing themselves and playing the video for their classmates. If students' models have large gaps, you could allow groups to do a round of written feedback before students orally communicate their ideas to others.

Building toward 14.B Communicate scientific and technical information about why the molecular-level structure is important in the safety of different materials and locations when lightning strikes. (SEP: 8.5; DCI: PS2.B.3; CCC: 6.1)

Individually revise models based on feedback. Display **slide I.** Have students review their feedback and update their models based on that feedback. You may give them the option to consult with their original partners, if desired.

If time allows, ask students to share some examples of how the peer feedback helped them in their modeling. Celebrate working together as a class to improve each other's models.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students update their models to include missing components such as electrons, air, metal, water, and ions. (SEP: 2.3; DCI: PS2.B.3)
- Students' deepening articulation of the model's interactions between the components based on feedback. This could be electrons moving and pushing through the metal or the air. (SEP: 2.3; DCI: PS2.B.3)
- Students show a causal mechanism for what makes the material or location safer than others when lightning strikes. (SEP: 2.3; DCI: PS2.B.3)
- Students describe the patterns across different scales that serve as evidence for their models. (SEP: 2.3; CCC: 1.1, 3.3)

What to do: If students are not incorporating feedback into their models in a meaningful way, encourage them to go back to the feedback provider and ask follow-up questions to get more guidance on how to adjust their models. As you circulate around the room, consider asking questions such as, *Why do you think this person said that?*, *What makes this part of the model hard to understand?*, and *What could you do to make this more clear?*, that could help students make adjustments to improve.

Building toward 14.A.3 Develop and revise a model based on evidence to illustrate and predict the relationships between components of a model that explains why certain places are safer than others when lightning strikes based on patterns observed at different scales. (SEP: 2.3; DCI: PS2.B.3; CCC: 1.1, 3.3)

7 · REFLECT ON WHAT WE HAVE ACCOMPLISHED

20 min

MATERIALS: science notebook, *Our DQB Questions*, Driving Question Board

Direct students to the Driving Question Board to reflect on what we have accomplished. Say, *Wow, we have figured out so many different ideas to help answer our big question, "What causes lightning and why are some places safer than others when it strikes?" Let's take some time to revisit our questions on the DQB to see how many more of them we have answered.*

Evaluate what questions the class has answered from the DQB with a partner.✱ Display **slide J.** Provide students with *Our DQB Questions*, which you began developing in Lesson 5 to contain all of the student questions from the DQB. Add any new questions that have come up. Have students record additional questions they think the class has answered.

- We did not answer this question or any parts of it yet: **O**
- Our class answered some parts of this question, *or* I think I could answer some parts of this question: ✓
- Our class answered this question, *or* Using the ideas we have developed, I could now answer this question: ✓+

Have students select a question and write an answer with supporting evidence. Students will use this later in the Consensus Discussion.

Mark questions on the classroom DQB. Display **slide K**. Students should walk up to the DQB and mark five questions that they think the class has made progress on.

✱ ATTENDING TO EQUITY

Revisiting the Driving Question Board is important for students to feel that their questions are valued and recognized. While not all questions will have been addressed (it is more likely that 60–75% will be at least partially answered), this activity helps students recognize that they have done a lot of hard work to answer many of their own questions.

ADDITIONAL GUIDANCE

If your DQB is relatively small and hard to read by more than one or two students at a time, have students line up with their notebooks and file by the DQB. This gives students time to look over the handout while they wait.

If students have been working with a digital version of the DQB, give all students two minutes to analyze the handout in their notebooks before analyzing the class DQB for two more minutes.

Reflect on answered questions in a Scientists Circle. Show **slide L** and lead students in the following Consensus Discussion.

Suggested prompt	Sample student response
What did you notice as you looked at the Driving Question Board?	We have made progress on most of the questions! Not all of the questions are answered.
Which questions have we made the most progress on?	Accept all responses.
What have we figured out?	Students should discuss the question they chose to respond to with supporting evidence.
What questions do you have about any of the ideas that have been shared?	Accept all responses. Work through any confusion or partial understandings students may have.

KEY IDEAS

Purpose of this discussion: 1) To come to consensus about the questions we think we have answered, those we have left unanswered, or those we still wonder about. 2) To prepare for the upcoming assessment by discussing what the answers are to key questions.

Encourage as many students as possible to contribute to this discussion because consensus should represent the whole class, not just a few students. It may be helpful to explicitly tell this to the class as well. Say that during the discussion you might pause to invite others who have not yet contributed to the conversation.

Listen for these ideas:

- Students should be using their student models and other evidence collected during the unit to provide answers to questions on the DQB.
- Students should be working together to identify patterns in the types of questions they answered.
- Students should be able to provide evidence-based answers to questions related to:
    - What causes lightning?
    - How does lightning move?
    - What types of materials or places are safer than others during a thunderstorm?
- Students should be able to provide some evidence for, but might not be able to put together complete answers to, questions related to:
    - Why do we have more lightning during certain times of the day?
    - Why do we see other temporal patterns in lightning strikes?
    - How do we stop fires caused by lightning? Or, how do we address other safety issues the unit was not able to cover?

Prepare students for the end-of-unit assessment. This assessment task covers material from Lessons 10-13 and does not revisit the material assessed in Lesson 9. Say, *We have figured out so many things about what causes lightning and why some places are safer than others when it strikes. I think we are ready to demonstrate what we have learned on an assessment next class.*

End of day 2

8 · COMPLETE THE INDIVIDUAL ASSESSMENT

40 min

MATERIALS: *Airplane Transfer Task* (both parts)

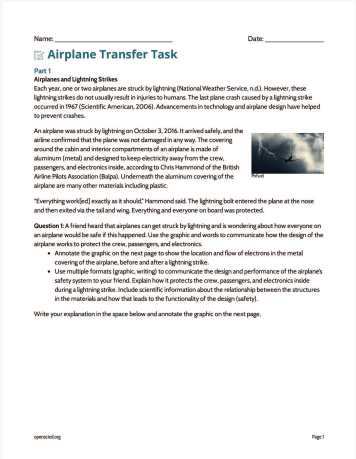
ALTERNATE ACTIVITY

If students would benefit from developing an oral rather than written explanation for Question 1 of *Airplane Transfer Task*, allow time for them to use technology to create a voice-over of their annotated graphic.

Navigate into the assessment. Display **slide M.** Say, *We have figured out a lot of great chemistry ideas in this unit. Today you will have a chance to look at two real-world problems that we can use our knowledge to figure out.* Explain that students will complete the assessment in two parts. Distribute Part 1 of *Airplane Transfer Task*. Read through the text before each question in Part 1. Give students an opportunity to ask any clarifying questions before they begin. Allow students to work on Part 1 of the assessment for about 20 minutes.

Once all students have completed Part 1, distribute Part 2 of *Airplane Transfer Task*. Explain that Part 1 was very similar to the phenomena they have studied in the unit, but Part 2 introduces a new phenomenon, conducting gels. Read through the text framing Part 2 and give students an opportunity to ask any clarifying questions before they begin. Allow students about 15 minutes to work on Part 2 of the assessment.

If students finish the assessment early, you can have them start on the reflection questions on **slide N.**



Name: _____ Date: _____

Airplane Transfer Task

Part 1

Airplanes and Lightning Strikes

Each year, one or two airplanes are struck by lightning (National Weather Service, n.d.). However, these lightning strikes do not usually result in injuries to humans. The last plane crash caused by a lightning strike occurred in 1967 (Scientific American, 2006). Advancements in technology and airplane design have helped to prevent crashes.

An airplane was struck by lightning on October 3, 2016. It arrived safely, and the airline confirmed that the plane was not damaged in any way. The covering around the cabin and interior compartments of an airplane is made of aluminum (metal) and designed to keep electricity away from the crew, passengers, and electronics inside, according to Chris Hammond of the British Airline Pilots Association (Balpa). Underneath the aluminum covering of the airplane are many other materials including plastic.

Flickr

"Everything work[ed] exactly as it should," Hammond said. The lightning bolt entered the plane at the nose and then exited via the tail and wing. Everything and everyone on board was protected.

Question 1: A friend heard that airplanes can get struck by lightning and is wondering about how everyone on an airplane would be safe if this happened. Use the graphic and words to communicate how the design of the airplane works to protect the crew, passengers, and electronics.

- Annotate the graphic on the next page to show the location and flow of electrons in the metal covering of the airplane, before and after a lightning strike.
- Use multiple formats (graphic, writing) to communicate the design and performance of the airplane's safety system to your friend. Explain how it protects the crew, passengers, and electronics inside during a lightning strike. Include scientific information about the relationship between the structures in the materials and how that leads to the functionality of the design (safety).

Write your explanation in the space below and annotate the graphic on the next page.

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ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Airplane Transfer Task Key* for guidance.

What to do: You can choose to let students complete this assessment task using their science notebook and/or Progress Tracker if they need extra support. Also, since this is a summative assessment, you can give students another opportunity to retake it to demonstrate mastery. You may also wish to spend class time on review to support students in their mastery of the key concepts.

Provide students comprehensive feedback on their assessment using *Airplane Transfer Task Key*. Consider giving qualitative feedback along with a grade, or sharing sample student responses (with students' permission) with the class to help students see a wider range of expression.

Building toward HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. (SEP: 8.5; DCI: PS2.B.3; CCC: 6.1)

9 · QUICK WRITE: REFLECT ON OUR EXPERIENCES

5 min

MATERIALS: science notebook

Reflect on experiences with the unit. Display **slide N**. Direct students to complete a quick write in their science notebook about at least two of these questions, and then discuss them as a class:

- What was most challenging in this unit?
- What was most rewarding?

✱ ATTENDING TO EQUITY

- Think about how you engaged in sensemaking discussions and experiences with classmates. How do you want to engage with those experiences in the next unit?
    - What would you do the same?
    - What would you do differently?✱

ALTERNATE ACTIVITY	**Extension opportunity:** If a large number of questions remain on the Driving Question Board that will not be answered in other units (for example, details about different types of lightning), students may research these questions as an extension to the unit.

Building classroom culture: Prompts like these are useful at the end of any unit, but particularly as students approach the middle of the school year. In addition, this can be an opportunity to encourage students to celebrate what they have figured out, while acknowledging all the territory that the class has yet to explore together.

Additional Lesson 14 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-LITERACY.SL.9-10.4 Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task. Students present their models of interactions of lightning with materials and in different places in small groups. They explain the supporting evidence so that they may receive peer feedback.

Unit C.2 Teacher Reference Materials

ASSESSMENT SYSTEM OVERVIEW

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the "Assessment Icon" in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	*Initial Model* Driving Question Board	**Pre-Assessment** The student work in Lesson 1 should be considered a pre-assessment. It is an opportunity to learn more about the ideas your students bring to this unit. Revealing these ideas early on can help you be more strategic in how to build from and leverage student ideas across the unit. The initial model developed on day 2 of Lesson 1 is a good opportunity to pre-assess student understanding of models, their compon\ents, and the interactions between air, ground, clouds, rain, and some representation of lightning to try to explain electrostatic interactions. Although students modeled in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, this unit intentionally develops modeling and therefore you should also take this opportunity to provide students with feedback on how they are using models three-dimensionally. Collect these models, encourage students to be specific in the evidence that supports them (or acknowledge where they mostly have questions), and ask whether they have incorporated patterns across scales that they encountered in the lesson. Students will have opportunities to draw models that explain lightning-like phenomena in Lessons 3 and 4, before eventually revising this initial model formally in Lesson 9. The Driving Question Board is another opportunity for pre-assessment. Reinforce students to generate open-ended questions, such as "how" and "why" questions and to post to the board. However, any questions students share, even if they are close-ended questions, can be valuable. Make note of any close-ended questions and use navigation time throughout the unit to have your students practice turning these questions into open-ended questions when they relate to the investigations underway. If students have trouble generating questions, have them ideate and try to explain patterns that they encountered throughout the lesson. This work builds on intentional development of Asking Questions and Defining Problems in *Polar Ice Unit*.
Lesson 4	*Model Interactions* *Modeling Peer Rubric*	**Peer Assessment** There will be times in your classroom when providing opportunities for students to give and receive feedback to and from others will be valuable for students' three-dimensional learning. This formal opportunity is designed for students to use *Modeling Peer Rubric* to provide feedback to each other on the model that they initially developed in *Model Interactions*. Students then revise these models based on feedback and tests that they had developed to evaluate their models. Here, students provide feedback to each other on their models' use of key components, interactions, and mechanisms, their inclusion of patterns that the class has observed, and incorporation of force thinking as developed in Lesson 3.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 5	*Discussion Mapping Tool*	**Formative + Community Building** *Discussion Mapping Tool* is a tool to be used to track students' thoughts during one of this lesson's discussions. In this discussion, students make connections between their models and real-world phenomena that they have observed. Although it is important to assess whether students are able to use their models to explain phenomena, use of the discussion mapping tool also allows for evaluation of the classroom culture at this point in time. Take steps to get more student voices on the table if there is not broad participation in the discussion.
	Lesson 5 Exit Ticket (Electronic Exit Ticket) *Electronic Exit Ticket Key*	**Summative and Community Building** Students complete an Electronic Exit Ticket in this lesson to provide quick feedback on an important LLPE. *Electronic Exit Ticket Key* provides guidance on how to provide feedback to students or take instructional steps related to their use of Developing and Using Models (SEP 2), Obtaining, Evaluating, and Communicating Information (SEP 8), atomic structure (DCI: PS1.A), Scale, Proportion, and Quantity (CCC 3), and Systems and System Models (CCC 4). These SEPs, DCI element, and the first CCC are all intentionally developed parts of the unit that students will return to in future lessons, so feedback here can be leveraged in students in their future work. Students also have an opportunity to reflect on their own contributions to the class's inquiries.
	Driving Question Board	**Formative** A relatively brief, informal Driving Question Board check-in allows students to see which questions they may have made progress on to this point in the unit (e.g., the importance of rain, what static is) and which they have not. This thinking is used to navigate into the next lesson set with an emphasis on what, exactly, is happening in a cloud to initiate lightning.
Lesson 7	*Solving for Force* *Force Key*	**Formative** This is an opportunity to assess students' use of Mathematics and Computational Thinking (SEP 5) in the context of Coulomb's law, using patterns from empirical data. Collect *Solving for Force* and use the key to provide feedback on students' documentation of their tasks and understanding of the meaning of Coulomb's law. This feedback is key as students will be assessed over this practice and disciplinary core idea in Lesson 9.
Lesson 8	*Lightning Polarization Key*	**Formative** Students develop an explanation of what is happening at the atomic and subatomic levels in a lightning strike. These should be collected for feedback, with an emphasis on students' use of multiple types of models in their thinking, use of patterns at different scales, and understanding of how atomic-scale interactions result in bulk-scale interactions between the neutral ground and charged objects.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 9	*Gotta-Have-It Checklist* *Gotta-Have-It Checklist Key*	**Formative** In Lesson 9, students develop a Gotta-Have-It Checklist to develop models to answer the question, "What causes lightning to strike at a particular place and time?" This model should explicitly incorporate aspects of other models in Lesson Sets 1-2 on top of what students did in Lesson 1. These models should leverage thinking about atomic structure and the relationship between charge, distance, and force, with an emphasis on matter flows in students' reasoning. You may collect these models to provide feedback or alternatively have students engage with a partner for peer feedback.
	Modeling Reflection	**Self-Assessment** After revising models, students reflect on how they have grown in modeling, representing atomic structure, and using thinking around Coulomb's law. This is intended primarily to support students' own thinking leading into the mid-unit task, although these reflections can be collected to inform the teachers' understanding of where students are as well.
	Driving Question Board	**Formative** Students again assess their progress on answering DQB questions. In addition to serving as a review for students, this can serve as a formative assessment for teachers to better understand which students think they have (or have not) answered and why.
	Static Interactions Assessment or *N95 Transfer Task* *Static Interactions Key* or *Mask Transfer Task Key*	**Summative** Students complete one of two mid-unit tasks focused on modeling the atomic-scale mechanisms behind either a variety of familiar phenomena (in the default task, *Static Interactions Assessment* or N95 masks (in the slightly more extensive alternate task, *N95 Transfer Task*). In either task, students will also use mathematical thinking and Coulomb's law to explain static phenomena. These tasks serve as assessments of the electrostatic portions of HS-PS2-4.
	Lesson 9 Individual Reflection	**Community Building** After completing the mid-unit task, students have the opportunity to complete an individual reflection centered around community agreements and engagement. The results of this reflection will be used to lead a discussion about classroom culture at the beginning of Lesson 10.
Lesson 10	*Energy/Charge Model* *Energy/Charge Model Key*	**Formative** In Lesson 10, students use a computational model to build understandings of how the movement of charges in an electric field results in energy transfer in and out of the field. The key provides guidance on what students should notice, in order to support subsequent standards as students build toward completing the M-E-F model (to the extent that is done in this unit).
	Model Self-Assessment	**Self-Assessment** By this point, students should have feedback on their models or mid-unit assessments from Lesson 9. They should use this feedback, along with their own self-assessment and what they have figured out in this lesson, to determine how they should revise their own models.
	Model Revision Key	**Formative** Students revise their Lesson 9 models with their new understanding of how energy transfers in and out of fields, to explain the massive energy outputs in lightning. These models should show energy transfer in and out of fields, tying particle-level interactions to the macroscopic movements of charge in the lightning system.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 11	Lesson 11 Exit Ticket (Electronic Exit Ticket) *Electronic Exit Ticket Key*	**Summative** This second Electronic Exit Ticket focuses on Obtaining, Evaluating, and Communicating Information (SEP 8) around the role of lightning in nitrate production. This connects bulk-scale properties to electrical forces at the atomic scale, with an emphasis on how small-scale mechanisms result in macroscopic effects. The feedback on the electronic exit ticket will support students going into the end-unit transfer task, which focuses on the same practice and disciplinary core idea, although with an emphasis on structure and function instead of cause and effect.
	Driving Question Board	**Formative** Students informally check back in on the Driving Question Board, identifying that they have not answered many questions about safety. This motivates the final lesson set.
Lesson 13	*Model Evaluation Checklist* *Model Evaluation Key*	**Formative** Students evaluate candidate models of how salt dissolves in water. These evaluations should be collected, with feedback focused on how students consider the relative merits and limitations and use microscopic forces to explain macroscopic effects on properties.
	Lightning Safety Claims *Lightning Safety Claims*	**Formative** Students evaluate the accuracy of claims about safety in the context of the geese phenomenon, based on various sources of information including their own empirical evidence. This assessment moment should focus on where students are in evaluating these claims. By the end of the lesson they should be fully considering their own empirical evidence, but they may not do so immediately.
Lesson 14	*Consensus Gotta-Have-It Checklist* *Consensus Checklist Key*	**Formative and Peer Assessment** Students develop a collaborative Gotta-Have-It checklist and individual models around the question, "Why is it safer to be away from water and in a building with lightning protection during a storm?" Students should use evidence from throughout the unit, in particular later lesson sets. They should consider how attraction and repulsion at the atomic scale explain patterns across different scales, in particular patterns of safe practices in lightning. Students have the opportunity to communicate their understanding to peers and use feedback on the models to make revisions.
	Driving Question Board	**Formative** This unit's final Driving Question Board check-in requires students to answer questions before they are taken off the board, providing a gauge of student understanding in many areas going into the final transfer task. Take time to address any unclear ideas as a group, emphasizing the evidence we collected to develop the answers that we have.
	Airplane Transfer Task *Airplane Transfer Task Key*	**Summative** In Lesson 14, students examine structures of different materials, such as the radome of airplanes and conductive gels used to mimic brain tissue, to explain why their properties make them good or poor conductors of electricity. They demonstrate mastery of HS-PS2-6 by completing *Airplane Transfer Task*.
Embedded in each lesson	Lesson-by-Lesson Assessment Opportunities (below)	**Formative Assessment** Use this document to see which parts of lessons or can be used as embedded formative assessments.

When	Assessment and Scoring Guidance	Purpose of Assessment
Occurs in several lessons	Progress Tracker	**Formative and Self-Assessment** The Progress Trackers are thinking tools designed to help students keep track of important discoveries that the class makes while investigating phenomena. They help students figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what the students write in the Progress Trackers reflects their own thinking at that particular moment in time. In this way, the Progress Trackers can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Trackers are meant to be a thinking tool for students, we strongly suggest that it not be collected for a summative "grade" other than for completion. Students add to their Progress Trackers in Lessons 2, 5, 7, 10, and 11.
Occurs in several lessons	Student Self-Assessment Rubrics	**Self-Assessment** Student self-assessment rubrics for giving and receiving feedback can be used throughout the unit. Opportunities include after a discussion or at the end of a class period. The rubric helps students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve for the next time, such as sentence starters for discussions. As they gain practice and proficiency with discussions, ask for their ideas about how the whole-class and small-group discussions can be more productive. Additional support can be found in the *OpenSciEd Teacher Handbook: High School Science.* In addition to the self-assessment moments described above, this tool's use is suggested as an alternate activity at the end of Lesson 3.
Occurs in several lessons	Routines and Tools to Support Peer Assessment	**Peer Assessment** There will be times in your classroom when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback. We suggest that peer feedback happen at least two times per unit. Peer feedback is most useful when there are complex and diverse ideas visible in student work and not all work is the same. Student models or explanations are good opportunities to use a peer feedback protocol. They do not need to be final pieces of student work; rather, peer feedback will be more valuable to students if they have time to revise after receiving it. This should be a formative rather than summative type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities in which they can use these experiences as evidence for the feedback they give. Additional support can be found in the *OpenSciEd Teacher Handbook: High School Science.* In addition to the peer assessment moments described above, this tool's use is suggested as an alternate activity at the end of Lesson 12.

For more information about the OpenSciEd approach to assessment and general program rubrics, visit the OpenSciEd Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every OpenSciEd lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to Science and Engineering Practice(s), alignment to Cross-Cutting Concept(s), and alignment to the Disciplinary Core Ideas.

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 1	**1.A** Develop a model based on evidence to illustrate and predict the relationships between components of lightning formation based on patterns observed at different scales. (SEP: 2.3; DCI: PS2.B.3, PS3.A.2; CCC: 1.1, 3.3) **1.B** Ask questions that arise from different patterns observed in lightning data to clarify and seek additional information about what causes lightning and factors that impact lightning fatalities. (SEP: 1.1; DCI: PS2.B.3; CCC: 1.1)	**1.A When to check for understanding:** 1. On day 1, as students summarize patterns in the data. **(slide N)** 2. On day 2, when students work on the second pass of *Initial Model*. **(slide T)** 3. On days 2-3, when students build a class consensus model. **(slides W, Y)** **What to look/listen for across opportunities 1-3:** • Students suggest patterns in the matter that is present in many situations where lightning strikes (e.g., rain, water, humidity). (DCI: PS2.B.3; CCC: 1.1) • Students suggest patterns in the energy that is present in many situations where lightning strikes (e.g., warm temperatures). (DCI: PS3.A.2; CCC: 1.1) • Students recognize that patterns can help identify potential causes. (CCC: 1.1) • Students identify that we saw slightly different patterns at different scales or from different data sets. (CCC: 3.3) • Students' models include components in the system that can be broken down into particles, such as air, ground, and clouds or rain. (SEP: 2.3; DCI: PS2.B.3) • Students' models include indications of energy, such as warm temperatures. (SEP: 2.3; DCI: PS3.A.2) • Students' models show interactions between the components. This could be something moving between components that causes lightning. (SEP: 2.3) • Students refer to patterns in map data, while paying attention to what might be happening at a scale too small to be seen, as evidence for particular causes for lightning strikes or fatalities. (SEP: 2.3; CCC: 1.1, 3.3) **1.B When to check for understanding:** • On day 3, when students generate and share questions for the DQB. **(slides BB-CC)** **What to look/listen for in the moment:** • Students' questions for the DQB should be connected to the observations they previously made about patterns they noticed at different scales in the lightning phenomena and data. (SEP: 1.1; CCC: 1.1) • Students should be asking "how" or "why" questions to clarify and seek additional information about the relationship between components, especially matter, that might contribute to lightning formation. (SEP: 1.1; DCI: PS2.B.3)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 2	**2.A** Use and move between multiple types of models to determine whether there is a correlational or causal relationship between falling water and lightning. (SEP: 2.4; DCI: PS2.B.2; CCC: 2.1)	**2.A When to check for understanding:** 1. As students vote on the relationship between falling water and lightning. (**slide G**) 2. When students discuss what information they would need to figure out whether there is a causal relationship between falling water and lightning. (**slide K**) 3. As students discuss the merits and limitations of the water dropper system. (**slide S**) **What to look/listen for across opportunities 1-3:** • Whether students think there is enough evidence to say that there is a causal relationship between falling water and lightning. (DCI: PS2.B.2; CCC: 2.1) • Students identify that the initial consensus model has the following merits: shows many different parts of the system, allows the user to zoom in or out, and considers how lightning forms in the context of a realistic-looking model. (SEP: 2.4) • Students identify that the initial consensus model has the following limitation: does not allow the user to determine whether the relationship between falling water and lightning is correlational or causal. (SEP: 2.4; CCC: 2.1) • Students identify that the physical model has the merit of including the same components as the initial consensus model, but with students' ability to manipulate them in real time and conduct experiments. (SEP: 2.4; DCI: PS2.B.2) • Students identify that the physical model has the limitation of not looking like the initial consensus model or a real-world storm. (SEP: 2.4; DCI: PS2.B.2)
Lesson 3	**3.A** Use the water dropper model to generate data at a smaller scale to identify the various causes of macroscopic attractions, repulsions, or energy transfer in lightning and lightning-like systems. (SEP: 2.6; DCI: PS2.B.2; CCC: 3.2, 2.4)	**3.A When to check for understanding:** 1. When students record observations during the water dropper investigations with their chosen objects. (**slide D**) 2. When students record observations during the water dropper investigations with their assigned objects. (**slide I**) 3. During the Building Understandings Discussion as students share their observed interactions and evidence of energy transfer. (**slide K**) **What to look/listen for across opportunities 1-3:** • Students test for attractions and/or repulsions between parts of the water dropper system and their test objects. (SEP: 2.6; DCI: PS2.B.2) • Students notice relationships between the strength of interactions they observe and the time since the water dropper last sparked. (SEP: 2.6; DCI: PS2.B.2) • Students relate their observations of interactions and sparks in the water dropper system to the lightning phenomenon. (DCI: PS2.B.2; CCC: 3.2) • Students mention patterns in observed interactions, such as attractions or repulsions near the metal parts of the water dropper system. (SEP: 2.6; DCI: PS2.B.2) • Students mention stronger interactions when objects were closer to the water dropper system. (DCI: PS2.B.2; CCC: 2.4)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 4	**4.A** Develop a test of a model's reliability and revise a model based on empirical evidence of patterns to explain attractions and repulsions between objects in an electric field. (SEP: 2.2, 2.3; DCI: PS2.B.2; CCC: 1.5)	**4.A When to check for understanding:** 1. On day 1 as students plan their static investigations. (**slide G**) 2. On day 1 as students are identifying patterns. (**slide H**) 3. On day 2 as students revise their models. (**slide M**) 4. On day 2 as students discuss the reading. (**slides R-T**) **What to look/listen for across opportunities 1-4:** • Students articulate what materials they plan to test their model with to produce static electricity, how they plan to produce static electricity, and how they plan to detect it. (SEP 2.2; DCI: PS2.B.2) • Students develop plans that identify patterns in interactions that would provide evidence of the reliability of their models. (SEP 2.2; CCC: 1.5) • Students identify patterns in interactions, such as noticing multiple materials attracting or repelling, and observing that all objects attract or repel more strongly when they are closer together. (DCI: PS2.B.2; CCC: 1.5) • Students' revised models include the test object and the aluminum bucket as components. (SEP: 2.3) • Students represent a force acting on the test object differently throughout space. (SEP: 2.3; DCI: PS2.B.2) • Students explain how they used empirical evidence to revise their models. (SEP: 2.3; CCC: 1.5) • Students describe the relationship among charges, fields, and the electrostatic force and propose possible revisions to their models using these ideas. (SEP: 2.3; DCI: PS2.B.2)
Lesson 5	**5.A** Integrate information from multiple sources to explain what is happening at a scale too small to directly observe and provide evidence for the existence of protons, neutrons, and electrons. (SEP: 8.2; DCI: PS1.A.1; CCC: 3.2) **5.B** Develop, use, and discuss the merits and limitations of multiple models to simulate the charged substructures of atoms, the movement of electrons, and other processes and structures too small to directly observe. (SEP: 2.1, 2.4; DCI: PS1.A.1; CCC: 3.2, 4.3)	**5.A When to check for understanding:** 1. During the Building Understandings Discussion about the reading on day 1. (**slide J**) 2. During the Consensus Discussion after using the simulation on day 2. (**slide N**) **What to look/listen for across opportunities 1-2:** • Students name the three main subatomic particles (protons, neutrons, and electrons) along with their charge, relative mass, and location in the atom. (DCI: PS1.A.1) • Students use information from the reading to explain how scientists performed experiments to understand what was happening on a subatomic scale because they could not explain macro-scale static interactions with the existing atomic models. (SEP: 8.2; CCC: 3.2) • Students use information from the simulation to identify that net charge is determined by the relative number of protons and electrons in an atom. (SEP: 8.2; DCI: PS1.A.1) • Students use the simulation to examine interactions at the atomic scale to explain the relationship between subatomic particles and charge. (DCI: PS1.A.1; CCC: 3.2) • Students refer to the reading, the simulation, and the investigations in prior lessons to provide evidence for their ideas. (SEP: 8.2) **5.B When to check for understanding:** 1. On day 2, as students develop, use, and apply the paper-clip model to explain investigation observations. (**slides P-Q**) 2. During the roundtable discussion on day 2. (**slide S**) 3. During the exit ticket on day 3. (**slide DD**) **What to look/listen for across opportunities 1-3:** • Students simulate how moving electrons change the net charge on an atom. (DCI: PS1.A.1; CCC: 3.2) • Students explain how the physical paper-clip model represents the same charged atomic substructure as the models described in *Structure of Matter* and the simulation. (SEP: 2.1, 2.4; DCI: PS1.A.1) • Students explain that the loss or gain of electrons changes an object's net charge, leading to changes in how objects are attracted to or repelled by each other. (DCI: PS1.A.1; CCC: 4.3) • Students use a physical model to develop a small-scale mechanism to explain investigation results (large scale). (SEP: 2.4; CCC: 3.2)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 6	**6.A** Critically read scientific literature adapted for classroom use to determine how static interactions at a different scale lead to lightning. (SEP: 8.1; DCI: PS2.B.3; CCC: 3.4)	**6.A When to check for understanding:** 1. When students are making sense of the reading. (**slides G-H**) 2. When students discuss the similarities and differences between the water dropper and lightning systems. (**slide I**). **What to look/listen for across opportunities 1-2:** • Students should summarize the central ideas from the reading. (SEP: 8.1) • Students should cite evidence from the reading that helps them understand what static interactions in a cloud lead to lightning. (SEP: 8.1; DCI: PS2.B.3) • Students compare the amount or scale of charge or distance in a lightning system to the amount or scale of charge or distance in the water dropper system. (DCI: PS2.B.3; CCC: 3.4) • Students use the reading to compare the charge in a water dropper to lightning. (SEP: 8.1; DCI: PS2.B.3) • Students notice similarities in how matter becomes charged through contact in both systems and support this with evidence from the reading. (SEP: 8.1; DCI: PS2.B.3)
Lesson 7	**7.A** Make qualitative claims using mathematical representations of patterns in how amount of charge, distance between charges, and strength of forces are related across the class results; and compare these to patterns predicted by Coulomb's law. (SEP: 5.2, 6.1; DCI: PS2.B.1; CCC: 1.4) **7.B** Apply techniques of algebra and functions to calculate the force predicted by Coulomb's law in a larger-scale system and contextualize the significance of the phenomenon. (SEP: 5.3; DCI: PS2.B.1; CCC: 3.1, 3.5)	**7.A When to check for understanding:** 1. Students' predictions on *Predicting Force Relationships*. (**slides F-G**) 2. Students' responses on *Comparing Force Relationships*. (**slide U**) **What to look/listen for across opportunities 1-2:** • Students' graphs show a predicted trend (linear or nonlinear) line of decreasing *y*-values as *x*-values increase. They show a second line on the same graph with a similar trend line as the previous one, but with a shift upward in some or all of the *y*-values. (SEP: 5.2, 6.1; CCC: 1.4) • Students label the lines in terms of the relative amount of charge they represent. (SEP: 5.2, 6.1; DCI: PS2.B.1) • Students describe at least two patterns in the graphs in how amount of charge, distance between charges, and strength of forces are related across the class results. (DCI: PS2.B.1; CCC: 1.4) • Students describe how the shapes of the lines on the graphs compare and how well they fit the patterns predicted by Coulomb's law. (SEP: 5.2, 6.1; CCC: 1.4) **7.B When to check for understanding:** 1. Students' responses in *Solving for Force*. (**slide Y**) 2. As students debrief their calculations. (**slide Z**) **What to look/listen for across opportunities 1-2:** • Students document all the steps of using an equation (Coulomb's law) to solve for the strength of the forces in a larger-scale system. (SEP: 5.3; DCI: PS2.B.1) • Students tie the difference in scales of solutions to the mathematical relationships in Coulomb's law. (SEP: 5.3; CCC: 3.5) • Students articulate how changes in scale of charge and distance result in changes in force. (DCI: PS2.B.1; CCC: 3.1) • Students share their ideas about what it might mean that forces are so large. (CCC: 3.1)
Lesson 8	**8.A** Use multiple models to explain patterns observed at different scales in the behavior of uncharged objects when a charged object exerts a force on them. (SEP: 2.4; DCI: PS1.A.3; CCC: 1.1, 3.3)	**8.A When to check for understanding:** • When students are using the ideas of polarization and partial charge to explain how and why lightning is attracted to the ground. **(slides N-P)** **What to look/listen for during the opportunity:** • See *Lightning Polarization Key* for what to look for in students' explanations.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 9	**9.A** Revise a model based on evidence to illustrate the relationships between components of the lightning system in terms of matter changes/flows within that system. (SEP: 2.3; DCI: PS1.A.1, PS2.B.1; CCC: 5.2) **9.B** Use mathematical representations of Coulomb's law to describe and predict the electrostatic forces between objects. (SEP: 5.2; DCI: PS2.B.1, PS2.B.2; CCC: 1.1)	**9.A When to check for understanding:** • When students construct their revised models. **(slide E)** **What to look/listen for in the moment:** • Students' model ideas are based on evidence from their readings about lightning and their investigations of charged objects, static interactions, and the water dropper system. (SEP: 2.3) • Students' models illustrate the relationships between components of the lightning system: the cloud, particles in the cloud, the ground/objects on the ground, and the subatomic structures of these components. (SEP: 2.3) • Students describe the relationships in the lightning system in terms of how matter moves and changes within that system. (CCC: 5.2) • Students model the charged substructure of an atom, consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (SEP: 2.3; DCI: PS1.A.1) • Students' models include the idea that electrostatic forces between objects depend on the magnitude of the charges and the distance between them. (SEP: 2.3; DCI: PS2.B.1) **9.B When to check for understanding:** As students complete the mid-unit assessment *Static Interactions Assessment* or alternatively *N95 Transfer Task*. **(slide K)** These assessments are closely aligned to portions of a performance expectation from the NGSS (HS-PS2-4). Use the answer key *Static Interactions Key* to check for student understanding. If you use the alternate assessment, use *Mask Transfer Task Key*.
Lesson 10	**10.A** Use models based on evidence to illustrate the relationships between the components of a system in which energy flows between particles and an electric field. (SEP: 2.3; DCI: PS3.C.1, PS2.B.2; CCC: 5.2) **10.B** Use multiple models to provide a mechanistic explanation of energy changes in a macroscopic lightning system as a result of the movement of charges at the atomic scale. (SEP: 2.4; DCI: PS3.A.1; CCC: 3.1)	**10.A When to check for understanding:** 1. On day 1, as students build understanding around the computational model. **(slide I)** 2. As students revise the class M-E-F poster. **(slide L)** **What to look/listen for across opportunities 1-2:** • Recognize that energy transfers into and out of the electric field, as a result of attractive or repulsive forces. (DCI: PS3.C.1, PS2.B.2; CCC: 5.2) • Describe flows of energy and matter between different components of the system--particles and the electric field. (SEP: 2.3; CCC: 5.2) • Cite evidence from the computational model regarding the flow of energy and matter. (SEP: 2.3; CCC: 5.2) • Generalize the idea that energy is stored in the electric field which is established by the forces between particles and suggest how these components interact, using the class M-E-F poster. (SEP: 2.3; DCI: PS3.C.1, PS2.B.2) **10.B When to check for understanding:** On day 2, when students are revising their models from Lesson 9. **(slide S)** **What to look/listen for in the moment:** • Students' models represent energy transferred into and out of the field as observed in the computational model. (SEP: 2.4; DCI: PS3A.1) • Students' models include both atomic-scale charges and movement of those charges in the lightning system. (SEP: 2.4; CCC: 3.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 11	**11.A** Gather, read, and evaluate scientific information about interactions between atoms in the lightning system which cause the strike we see between the cloud and the ground. (SEP: 8.3; DCI: PS1.A.3; CCC: 2.2) **11.B** Communicate information in words and diagrams about the causes of energy transfer through light and sound. (SEP: 8.5; DCI: PS3.A.2, PS3.A.4; CCC: 2.2)	**11.A When to check for understanding:** 1. When students work in small groups to complete their online search and take notes on *Gathering Information*. (**slide K**) 2. When students complete an Electronic Exit Ticket. (**slide U)** **What to look/listen for across opportunities 1-2:** • In Part A.2, students name specific indicators they used to choose a search result (SEP: 8.3), such as avoiding sponsored results and carefully considering domain names. • In Part B.4, students tell how they decided their source was authoritative, based on evidence (SEP: 8.3) such as the author's expertise in a relevant area and unbiased information. • In Part C, students gather useful scientific information from what they read that answers their questions about the interactions in the lightning system. (SEP: 8.3; DCI: PS1.A.3) • In Part C, students describe the causes of interactions at the particle level. (CCC: 2.2) • See *Electronic Exit Ticket Key* for guidance on assessing the exit ticket. **11.B When to check for understanding:** When students discuss *Power of Lightning* and suggest what related energy transfer models might look like. (**slides S-T**) **What to look/listen for during the opportunity:** • Students identify light, sound, and transfer out of fields as manifestations of energy. (DCI: PS3.A.2, PS3.A.4) • Students communicate information about energy transfer at the microscopic level, via particle motion and fields, both verbally and diagrammatically (through suggestions about energy transfer model development). (SEP: 8.5; DCI: PS3.A.4) • Students describe the causes of energy transfer at the particle level. (CCC: 2.2)
Lesson 12	**12.A** Use multiple sources of information to investigate and explain how differences in particle-level structure explain differences in electron movement through electrical conductors and insulators. (SEP: 8.2; DCI: PS2.B.3; CCC: 6.1) **12.B** Use multiple sources of information to evaluate lightning rod models for how well they illustrate how the atomic structures function to transfer energy in order to protect homes and buildings. (SEP: 8.2, 2.1; DCI: PS3.A.1; CCC: 6.1)	**12.A When to check for understanding:** 1. When students compare and discuss particle-level models of metal, wood, and ionized air. **(slides K-M)** 2. As students develop an explanation comparing the safety of buildings with and without metal during a lightning strike. (**slide S**) **What to look/listen for across opportunities 1-2:** • Students notice differences in electron arrangement and movement and suggest that these may be related to why metals are good conductors and wood is not. (DCI: PS2.B.3; CCC: 6.1) • Students cite multiple sources of evidence in their explanation for why metals are good conductors. (SEP: 8.2; DCI: PS2.B.3) • Students incorporate information from data, a reading, and models to explain atomic-level differences between metals and nonmetals. (SEP: 8.2; DCI: PS2.B.3) • Students explain that differences in metals and wood at the atomic level explain why some buildings are safer than others during a lightning strike. (DCI: PS2.B.3; CCC: 6.1) **12.B When to check for understanding:** As students identify the merits and limitations of two different models of lightning rods. (**slide N**) **What to look/listen for during the opportunity:** • Students identify merits and limitations of both models and support these with evidence from different sources of information. (SEP: 8.2, 2.1) • Students explain how the atomic-level structure of lightning rods makes them function the way they do to protect buildings. (DCI: PS3.A.1; CCC: 6.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 13	**13.A** Plan and conduct an investigation to generate empirical evidence to evaluate a claim about the conductivity of water. (SEP 3.1, 7.2; DCI: PS1.A.3; CCC: 1.5) **13.B** Evaluate different models to determine which best explains what causes salt to dissolve in water and what causes electricity to be conducted through it (salt water). (SEP: 2.1; DCI: PS1.A.3, PS2.B.3; CCC: 2.2) **13.C** Evaluate claims and verify data presented in media using empirical evidence about properties of matter caused by interactions of charged particles. (SEP: 8.4, 7.2; DCI: PS1.A.3, PS2.B.3; CCC: 1.5)	**13.A When to check for understanding:** 1. On day 1 as students plan their salt and conductivity investigation on *Salt Investigation Plan*. (**slide I**) 2. On day 1 as students conduct the investigation and record data. (**slides J-K**) **What to look/listen for across opportunities 1-2:** • Students' investigation plans include testing multiple different salinity percentages and electric current. (SEP 3.1; DCI: PS1A.3) • Students' investigation plans allow for the collection of empirical evidence. (SEP 3.1; CCC: 1.5) • Students collect data during their investigation related to multiple different salinity percentages and electric current. (SEP 3.1; DCI: PS1A.3) • Students' answers to question 6 cite evidence from the investigation to evaluate the claim about what happened to the geese. (SEP 7.2; CCC: 1.5) **13.B When to check for understanding:** As students work with a partner to complete *Model Evaluation Checklist*. (**slides Y-Z**) **What to look/listen for during the opportunity:** The answer key *Model Evaluation Key* is provided to support you in checking whether students can: • evaluate the merits and limitations of different models by considering how well (or not) they show the cause of salt dissolving in water. (SEP: 2.1; CCC: 2.2) • evaluate the merits and limitations of different models by considering whether they provide a mechanistic explanation for salt dissolving in water and electrical conductivity through it (salt water). (SEP: 2.1; DCI: PS1.A.3, PS2.B.3) **13.C When to check for understanding:** As students work independently to complete *Lightning Safety Claims*. (**slide LL**) **What to look/listen for during the opportunity:** The answer key *Lightning Safety Claims* is provided to support you in checking whether students can: • evaluate the accuracy of claims by considering how well (or not) the claims about lightning safety align with key ideas about the flow of electrons through ions in water and other materials. (SEP: 8.4, 7.2; DCI: PS1.A.3, PS2.B.3) • verify information presented in each claim using empirical evidence collected during their investigations. (SEP: 8.4, 7.2; CCC: 1.5)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 14	**14.A** Develop and revise a model based on evidence to illustrate and predict the relationships between components of a model that explains why certain places are safer than others when lightning strikes based on patterns observed at different scales. (SEP: 2.3; DCI: PS2.B.3; CCC: 1.1, 3.3) **14.B** Communicate scientific and technical information about why the molecular-level structure is important in the safety of different materials and locations when lightning strikes. (SEP: 8.5; DCI: PS2.B.3; CCC: 6.1) **End-of-Unit Assessment: HS-PS2-6.** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. (SEP: 8.5; DCI: PS2.B.3; CCC: 6.1)	**14.A When to check for understanding:** 1. As the class develops a consensus Gotta-Have-It Checklist. (**slides C-D)** 2. As students develop a model to communicate how we can keep ourselves safe from lightning. (**slide E**) 3. As students revise their models using peer feedback. (**slide I**) **What to look/listen for across opportunities 1-3:** • Students suggest components in the system such as electrons, air, metal, water, and ions and interactions involving forces between charges. (SEP: 2.3; DCI: PS2.B.3) • Students suggest causal mechanisms for what makes the material or location safer than others when lightning strikes. (SEP: 2.3; DCI: PS2.B.3) • Students' suggestions reflect different scales (e.g., subatomic particles, molecules, visible materials or structures, and connections to lightning). (CCC: 3.3) • See *Consensus Checklist Key* for more specific guidance. • Students update their models to include missing components such as electrons, air, metal, water, and ions. (SEP: 2.3; DCI: PS2.B.3) • Students' deepening articulation of the model's interactions between the components based on feedback. This could be electrons moving and pushing through the metal or the air. (SEP: 2.3; DCI: PS2.B.3) • Students show a causal mechanism for what makes the material or location safer than others when lightning strikes. (SEP: 2.3; DCI: PS2.B.3) • Students describe the patterns across different scales that serve as evidence for their models. (SEP: 2.3; CCC: 1.1, 3.3) **14.B When to check for understanding:** • While students are presenting their models in small groups. (**slide H**) **What to look/listen for during the opportunity:** • Students use their drawn model and written text as a tool to clearly communicate the scientific ideas that explain the phenomenon. (SEP: 8.5) • Students make connections between the molecular-level structure of the material and its function of safety during a lightning strike. (DCI: PS2.B.3; CCC: 6.1) **End-of-Unit Assessment:** In this lesson you will administer *Airplane Transfer Task*. This assessment task is not building toward a lesson-level performance expectation. It is designed to assess progress toward a performance expectation from the NGSS (HS-PS2-6). See *Airplane Transfer Task Key* for details.

Lesson-Specific Teacher Materials

Example Community Agreements

Respectful Our classroom is a safe space to share.	• We provide one another with support and encouragement. • We share our time to talk. We do this by giving others time to think and share. • We critique the *ideas* we are working with but not the *people* we are working with.
Equitable Everyone's participation and ideas are valuable.	• We monitor our own time spent talking. • We encourage others' voices that we have not heard yet. • We recognize and value that people think, share, and represent their ideas in different ways.
Committed to Our Community We learn together.	• We come prepared to work toward a common goal. • We share our own thinking to help us all learn. • We listen carefully and ask questions to help us understand everyone's ideas. • We speak clearly and loud enough so that everyone can hear.
Moving Our Science Thinking Forward We work together to figure things out.	• We use and build on others' ideas. • We use evidence to support our ideas, ask for evidence from others, and suggest ways to get additional evidence. • We are open to changing our minds. • We challenge ourselves to think in new ways.

Lesson 2 Teacher Reference

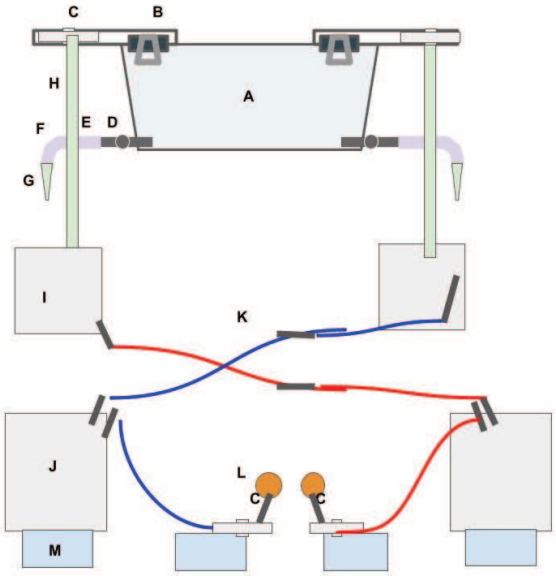
Water Dropper Construction

For Lesson 2 you will need two water dropper systems like the one pictured. For Lesson 3 you will need two more water dropper systems, so consider building all four of them now in assembly-line style to save overall construction time. You may wish to enlist students to support construction. A diagram of the system is shown and its components are listed below.

Final assembly



Assembly schematic



Materials needed

This section describes the materials needed for one water dropper system. It is recommended that you multiply these amounts by 4 so you can build the four systems needed for Lessons 2 and 3 at one time.

Safety materials needed: Safety glasses with side shields or safety goggles, non-latex apron.

Label	Item	Purpose	Quantity per Dropper Station
A	15- to 16-qt plastic tub with lid	Water reservoir and lid	1
B	1" binder clip	Holds lid	6*
C	Plastic clothespin	Holds duct coupler straps and (if desired) bulbs	6
D	Aquarium air valve (for 3/16" or 4 mm hose line)	Water line	2
E	Aquarium tubing 3/16" dia, 1" long	Water line	1
F	Bendy straw	Water line	2
G	Plastic pipette	Water line	2
H	Plastic folder strip (or ribbon)	Strap to hold duct couplers	2
I	4" HVAC aluminum coupler (metal ring)	Charge accumulator	2
J	7" aluminum (or zinc) coated bucket	Charge accumulator	2
K	21" wire with alligator clips	Wiring	7
L	Penny (shiny, not corroded or dirty)	Curved copper surface for sparking/electrical arcing	2
M	8-oz deli container	Charge accumulator platform	4
N	Classroom chair, 24"-48" high (not provided)	Holds water reservoir	1**
O	11/64" drill bit (not pictured)	Drilling holes in water reservoir	Used across all stations
P	Hand drill (or power drill if available, not pictured)	Drilling holes in water reservoir	
Q	Hot glue gun or caulk gun (not pictured)	Assembling parts of the system	
R	Scissors (not pictured)	Cutting plastic tub lid	
S	Dehumidifier (optional, useful in high-humidity areas)	Removing moisture from air so the water dropper works better	

*Two extra binder clips are suggested to clamp pipettes if the aquarium valves tend to leak.

**Avoid setting up your water dropper system on a chair, stool, or counter with metal components. While the system has been known to work when set up on a metal folding chair, the more metal there is in proximity to the system, the more easily charge will be drawn from it.

Additional materials needed for electroscope construction

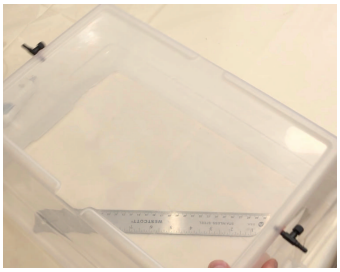
Label	Item	Purpose	Quantity needed
T	2" paper clip	Hanger	1
U	6"-by-6" aluminum foil	Leaves	1
V	Glass (or plastic) jar	Container	1
W	Strip of sticky tack	Seal	1
X	8-oz deli container lid	Top	1

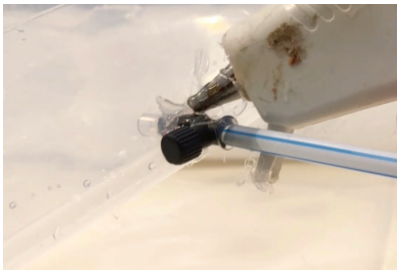
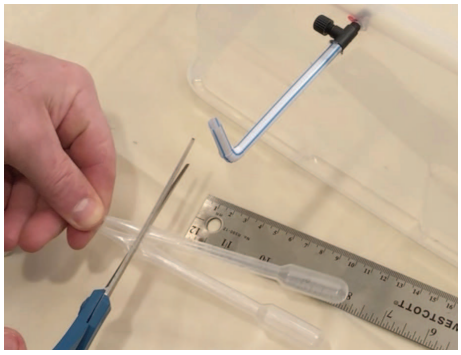
Constructing the water dropper system

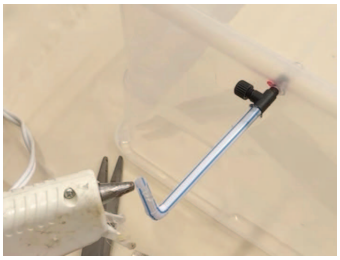
This section describes the construction of one system. It is recommended that you repeat each step below four times before moving on to the next step. This assembly-line approach will decrease the time it takes to construct the four water dropper systems needed for Lessons 2 and 3.

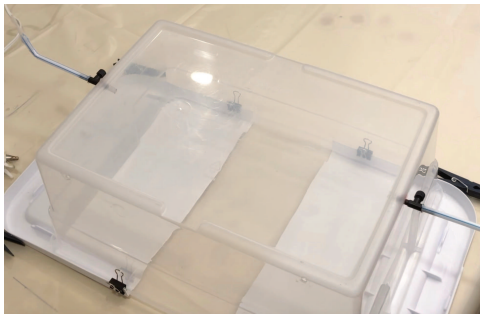
Safety notes:

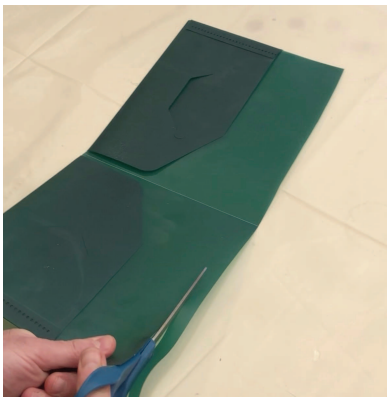
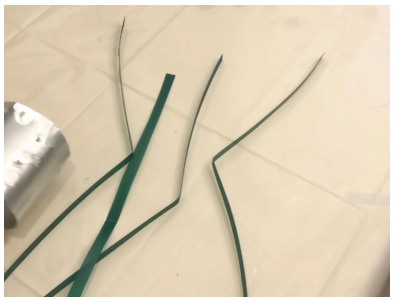
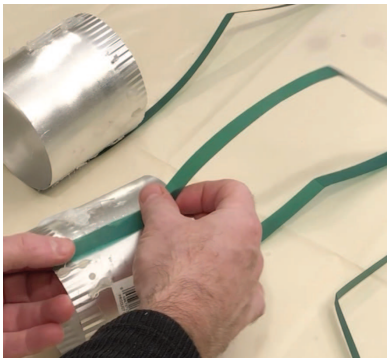
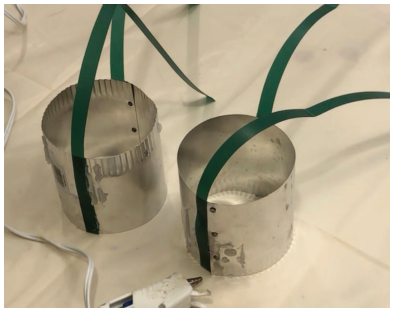
1. Wear sanitized safety glasses with side shields or safety goggles and non-latex apron during the construction set-up, hands-on and take down.
2. Use caution when using sharps (tools, wires, etc.), which can cut or puncture skin.
3. Keep away from water sources to prevent shock when working with electrical circuits or electricity sources.
4. Use caution when working with glue guns. They can be hot and will burn skin.

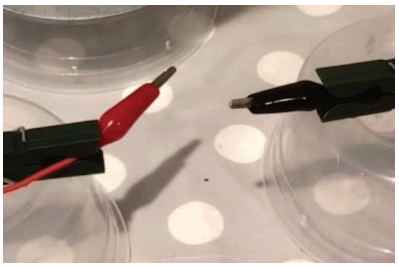
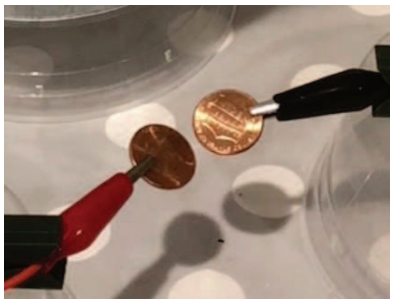
Subsystem: Water reservoir and dropper outflows		
Step	Description	Related photos
1	Mark a dot in the middle of each side of the plastic tub, 1 cm from the bottom. Use the 11/64" drill bit to drill a hole at each of these locations.	 
2	From the outside of the tub, push the end of an aquarium air valve into each of the two holes until the valve is firmly sealed.	
3	Cut the aquarium tubing to make 2 pieces, each ½" long. Slide these pieces against the nozzle of the aquarium air valve that is on the inside edge of the tub.	 

4	Apply a bead of hot glue or caulk along the edge where the aquarium tubing meets the inner surface of the tub. Do the same around the circumference where the aquarium air valve meets the outer surface of the tub.		
5	Bend 2 bendy straws. Cut 1" off the short end of both. Trim the longer end to 3" in length.		
6	Apply a ring of hot glue around the outer circumference of each outward-facing aquarium air valve. Immediately slide the long end of the bendy straw over each valve and give it a quarter turn back and forth to seal the glue. Finalize its orientation so that the plastic pipette will be downward facing relative to the bottom of the tub.		
7	Cut 1.5" off the bottom of 2 plastic pipettes. Save these pieces to use in the next step.		

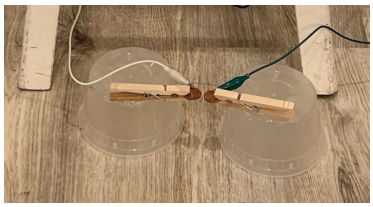
8	Apply a ring of hot glue around the outer circumference of the end of each straw. Immediately slide the cut-off pieces of pipette over the end of each straw and give them a quarter turn back and forth to seal the glue.	 

Subsystem: Water reservoir and dropper outflows		
Step	Description	Related photos
9	Cut the lid from the plastic tub in half.	
10	Hot glue 4 plastic clothespins to the corners of the two halves of the lid so that each is extended 1" past its edge.	 
11	Flip the lid halves and tub upside down. Use the binder clips to attach the edges of the tub to the lids. Slide the lid halves outward until they line up vertically with the pipette dropper outflows created in steps 1-8.	

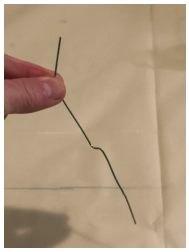
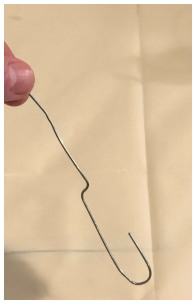
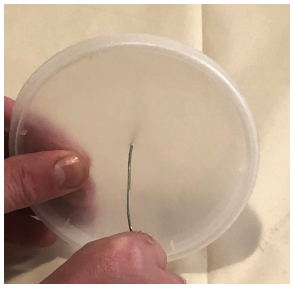
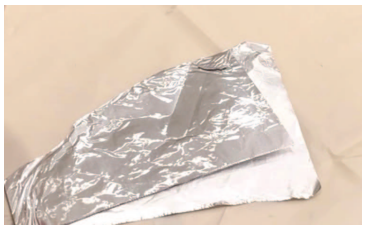
Subsystem: Hanging metal rings		
Step	Description	Related photos
12	Cut four ½"-wide strips from the long edge of the plastic folder. Unfold each strip. They should each be 19" long.	 
13	Hot glue the end of 1 plastic folder strip to the outside of one 4" HVAC aluminum coupler (metal ring). Make sure the strip is parallel to the center axis of the metal ring, adjusting its angle as needed before the glue sets. Repeat this for the second metal ring.	
14	Once the glue from the prior step has set, rotate each metal ring 180 degrees. Attach a second plastic folder strip to the outside of each ring. Again, make sure the strip is parallel to the center axis of the metal ring, adjusting its angle as needed before the glue sets.	 

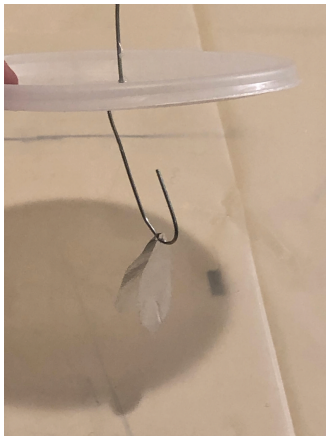
Sub-system: Charge accumulators		
Step	Description	Related photos
15	(This step may be omitted to improve future ease of storage.) Flip over the 2 aluminum coated buckets. Hot glue the bottom of one 8-oz deli container to the bottom of each bucket. When the glue is dry, turn the buckets upright.	 
16	Build the penny holders: Flip over two 8-oz deli containers. Hot glue a plastic clothespin to the bottom of each container.	 
17	Attach the edge of 1 alligator clip to the end of each clothespin. Clip a shiny copper penny with one of the alligator clips. Clip a second penny with the other alligator clip.	 

Assemble all of the parts now for the subsystems you have created, placing one water reservoir and dropper outflows subsystem on the chair at each station.

Final system: Assembly		
Step	Description	Related photos
18	Place 1 chair on a lab or work table at each station, for a total of 4 stations. The photo shows the system on a stool, rather than on a chair on a table. Clip the straps of each hanging metal ring to the clothespins on each lid half. Slide the lid halves in or out so that each pipette nozzle aligns with the center of the corresponding metal ring. Slide the straps in the clothespins as needed to adjust the height of each metal ring so that the top edge is level with the tip of the pipette.	
19	Connect one penny to each aluminum coated bucket with an alligator clip. Slide the penny holders toward each other until the edges of the pennies are 0.125”-0.25” apart but not touching. Use an alligator clip to connect the left metal ring to the rim of the right bucket. If the wires are too short, connect two together but make sure the “teeth” do not touch other objects in the system. Use an alligator clip to connect the right metal ring to the rim of the left bucket.	
20	Build a electroscope as described below. Attach the electroscope to the rim of the right bucket using an alligator clip.	

Build one electroscope to help you determine whether charge is accumulating in each water dropper system. Use a wire with alligator clips to attach the paper clip in the electroscope to one of the aluminum coated buckets in the water dropper system, fine-tuning the flow rate as you confirm that the system is slowly accumulating charge. Detach the electroscope and move it to the next water dropper system to test all four stations for Lessons 2 and 3. The electroscope should remain attached to the rest of the system before students investigate it.

Sub-system: electroscope		
Step	Description	Related photos
21	Straighten out half of the end of a paper clip. Bend the other end of the paper clip to make a smooth J-hook shape.	 
22	Use the straightened end of the paper clip to poke a hole in the center of the deli container lid. Slide the paper clip halfway through the lid and hot glue it into position.	 
23	Fold the piece of aluminum foil in half. Poke a hole in the center with the tip of a pencil or pen. The hole's diameter should be wider than the paper clip's but smaller than 1/4".	 
24	Cut out a teardrop shape (approximately 1" x 1/2") in the aluminum foil so that the narrow end of the teardrop surrounds the hole. Carefully open up and separate the foil teardrops so that they do not tear. Flatten each foil "leaf" against the table surface, keeping the holes open.	 

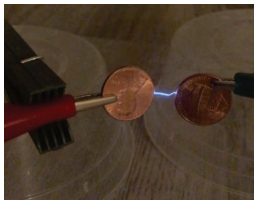
25	Roll out a strip of sticky tack so that it is long enough to go around the lip of a jar, then attach it to the jar.	
26	Slide each leaf of aluminum foil onto the hook end of the paper clip through the hole in the top of the leaf. Shake it slightly to ensure that both leaves of aluminum foil rest flatly against each other but are not stuck together. Set the lid on the jar, centering the hook and leaves in the center of the jar. Press down on the lid to seal it tightly against all parts of the sticky tack.	 

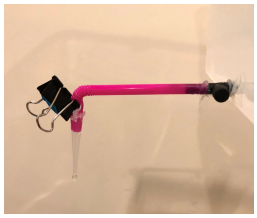
Calibrating the water dropper system to produce sparks

Test the two water dropper systems that you plan to use in Lesson 2 in the conditions of your classroom the day before to ensure sparks are produced. Environments with high humidity may prevent the formation of sparks. See *Water Dropper Troubleshooting* for more guidance on troubleshooting the water dropper system if the following procedure does not work.

1. Close the valves on the water reservoir by turning the knobs on the aquarium valves clockwise. Fill the tub with water about 3/4" to 7/8" full.
2. Add 1/2" of water to each aluminum coated bucket.
3. Start the water flow on each end of the water reservoir by turning the aquarium valve knobs 1 to 3 turns counterclockwise. Turning it farther may cause the knob to come out. If this happens, thread it back into the valve by turning the knob clockwise.
4. Adjust the pipette nozzles so that water travels through the center of each hanging metal ring and lands in the center of each bucket.
5. Adjust the flow rate so that there is a steady stream coming out of the pipette, with the stream breaking into droplets by the time it is about halfway through the metal ring. You may need to clip the straw with a binder clip just above the pipette to fine-tune the flow rate.
6. Once both streams have been flowing like this for about a minute, you should see the leaves of aluminum foil begin to separate in the electroscope. If they do not, check that all wires are still connected and continue to adjust the flow rate on each end of the water reservoir until you observe the separation of the foil leaves.

7. Dim the lights. Slide the penny holders toward each other until the pennies are about ⅛" to 1/4" apart. A spark should jump across them. Wait and watch the system until it produces another spark. Sparks should occur regularly, about every 20–45 seconds. Double check the electroscope to confirm charge buildup is occurring by observing the movements of the foil leaves, in case you need to adjust the system again. You may be able to increase the distance between the pennies to increase the size of the spark. This will also decrease how often the spark occurs. The maximum limit for the system appears to be about a 1/2" gap between the pennies. Closer spark gaps (e.g., 1/8") produce sparks more quickly than larger ones.





8. Unclip the electroscope and set it aside so that students do not see it as an integral part of the system.
9. As the water level drops in the water reservoir, the flow rate will decrease. This will, in turn, slow the rate at which water droplets form. Try to keep the tub ⅔ to ¾ filled with water. Emptying the buckets into an extra bucket to transfer water back into the reservoir can help ensure that the system valve settings are kept unaltered.
10. To shut off the water flow completely, turn the aquarium valve knobs clockwise.

How the water dropper system works

This explanation is intended for the teacher, as it uses an understanding of induction and the properties of water that students do not fully develop until later in the unit. Do not share this explanation with students. An extension opportunity has been provided in Lesson 13 for students to model how the water dropper works using understandings they build in later lesson sets.

In all likelihood, one of the buckets begins with a small charge (and compared to it, the other bucket will either be more positive or negative). If the left bucket has a small negative charge, the right metal ring will have a small negative charge, since they are connected. The right metal ring will then tend to attract positive ions from the water into its stream. The positively charged water will fall into the right bucket, making it positively charged. This in turn will make the left metal ring positively charged, causing it to attract negative ions. These negative ions will fall into the left bucket, making it even more negatively charged. As this continues, a positive feedback loop will occur, with the buckets becoming more and more charged and transferring some of their charge to the opposite metal rings, which then causes ions to move in opposite directions in the water.

Eventually, enough charge will build up that electrons will jump from the "negative" bucket to the "positive" one, through the pennies. This is seen as a small spark.

https://www.youtube.com/watch?v=r4IRbNOJ_xA includes additional explanation and a demonstration.

Lesson 2 Teacher Reference

Water Dropper Troubleshooting

The water dropper system depends on the water and aluminum coated buckets maintaining strong positive and negative charges. The buckets can discharge to the surrounding air in high humidity conditions. If your water dropper system is not producing sparks, there are several things you can try. These steps have been found in extensive testing to solve nearly all issues.

Electroscope

If you do not have the electroscope (the jar containing aluminum foil pieces) attached already, start by connecting the electroscope to the system to determine whether charge is building up.

- If the pieces of foil move apart, charge is building up.
- If no sparks occur between the pennies, move the pennies slightly closer together.

If charge still does not build up, try one or more of the following.

Check connections

Verify that all connections are correct and firmly in place. Make sure no stray wires lead to components that should not be connected.

Ensure that any alligator clip "teeth" are not touching other objects in the system. This is prone to happen where alligator clips connect to each other.

Add insulation

Ensure that the water reservoir, wires, hanging metal rings, and buckets are not near conductive surfaces. Avoid setting up your water dropper system on a chair, stool, or counter with metal components. While the system has been known to work when set up on a metal folding chair, the more metal there is in proximity to the system, the more easily charge will be drawn from it. You can add additional insulation to the bottoms of the buckets and penny holders by adding foam blocks, plastic containers, or textbooks.

Reduce humidity

This investigation works best if the humidity is below 40% or even 30%, but it has been verified in humidities up to 50%. Low humidity is important because, as students figure out in Lesson 13, water molecules are polar and help conduct charge from the droppers and buckets into the air. If a dehumidifier or air conditioning (which has a dehumidifying component) is not available, try placing fans to keep air moving around and away from the system.

Adjust water level and flow

Ensure that the water reservoir remains about 3/4 full. Adjust the flow rate so that the water exits the pipette in a steady stream but breaks into droplets by the time it exits the metal ring.

If the dropper system still does not produce sparks

Videos are provided to show the important phenomena in Lessons 2 and 3. If your area is experiencing a temporary humid spell and you are unable to make the system work even with a dehumidifier, you may use these videos to proceed with the lesson content. However, if conditions improve and you wish to have students test their own materials, you may have students do the Lessons 2 and 3 investigations at the end of Lesson 6 instead.

Test Object Construction

Build seven sets of each of the following test objects for each station. Students will need only one test object at the corresponding station in this lesson, which means only one to two sets need to be functional for any one station (A, B, C, or D) at any given time. The extra five sets you are building now will be used in Lesson 4.

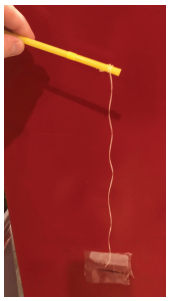
Safety notes:

- Wear sanitized safety glasses with side shields or safety goggles during the construction setup, hands-on, and takedown segments.
- Use caution when using sharps, which can cut or puncture skin.
- Use caution when working with hot glue - can burn skin!
- Wash your hands with soap and water immediately after completing this construction.

Building Test Objects for Station A

There is no construction required for Station A; students simply need a small neon light bulb (NE-2H/C2A Neon Lamp, 65-120VAC, 1.90 mA).

Building Test Objects for Station B



Take a clear sandwich bag and cut out a 2"-x-2" piece. Now tape a 12" piece of floss to the piece of the bag. Hot glue or tape the other end of the floss to the end of a straw (a bendy straw is acceptable). This is the test object. Add it to the materials bin for Station B.

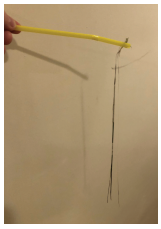
Building Test Objects for Station C

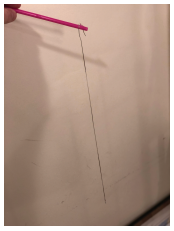
Safety note: Latex balloons work best. Make sure to consider latex allergies in your classroom and guide students with them to an alternate station, or use a non-latex alternative if necessary.

Inflate a small balloon and tie it closed. Tie a 12" piece of floss to the end of the balloon. Hot glue or tape the other end of the floss to the end of a straw (a bendy straw is acceptable). This is the test object. Add it to the materials bin for Station C.

Building Test Objects for Station D

Twist together the ends of 3 to 4 pieces of tinsel and hot glue or tape the twisted ends to the end of a straw (a bendy straw is acceptable). This is one test object. Do the same for a single piece of tinsel. This is the second test object. Add both objects to the materials bin for Station D.



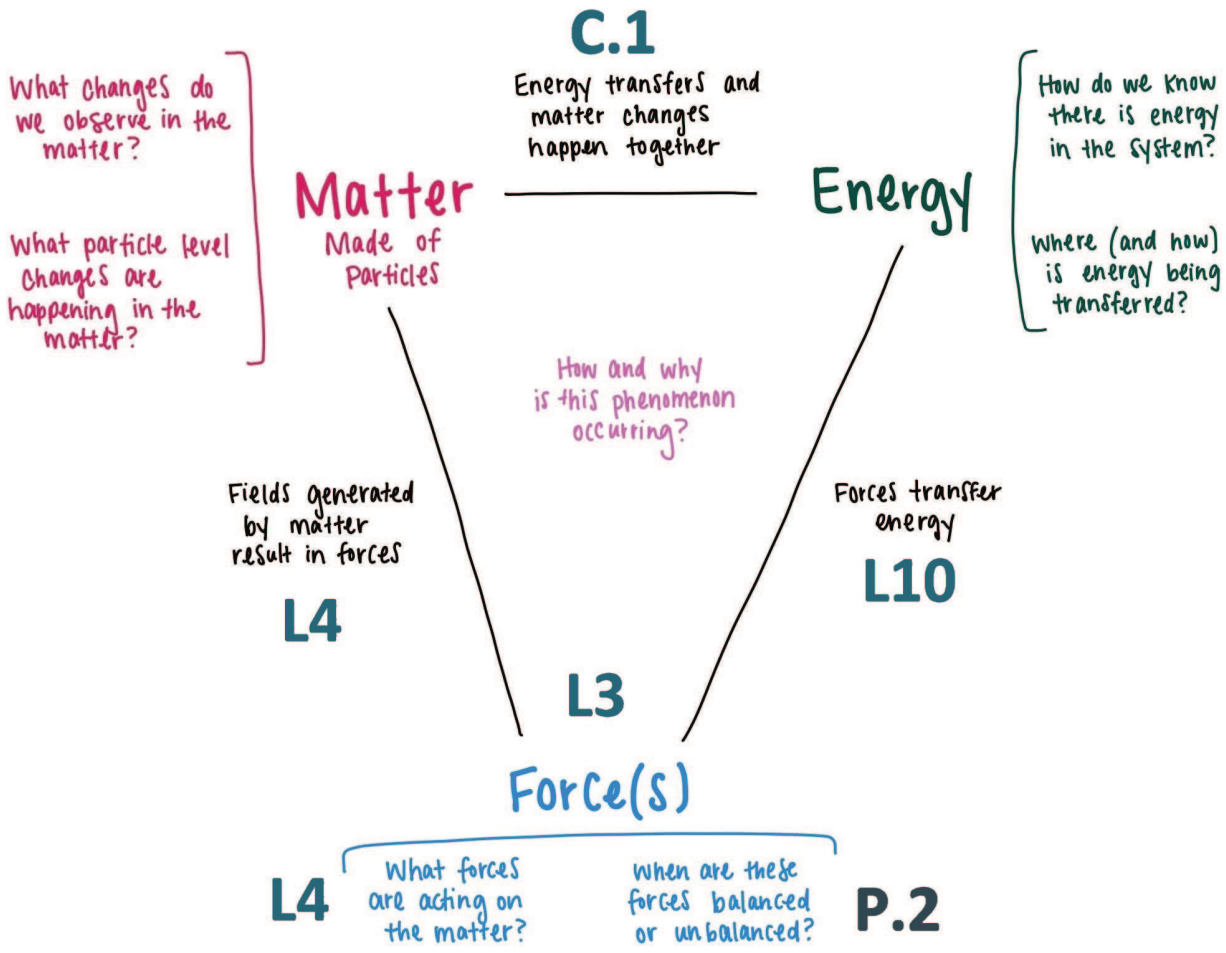


Lesson 3 Teacher Reference

Matter, Energy, Forces

In this lesson, students build on the matter-energy connection they made in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* by adding forces as another lens that can be used to make sense of phenomena. This work will continue throughout the unit, with the resulting Matter-Energy-Forces (M-E-F) triangle (or poster) being used as a tool throughout the rest of the OpenSciEd High School Chemistry and Physics courses.

Below is an annotated M-E-F triangle that explains the importance of ideas across lessons. Do not reveal connections to students before they have built them themselves.



Unit or lesson	What students figure out	Why it matters

Polar Ice Unit	We can explain much of chemistry using matter and energy. Energy transfers and matter changes happen together.	Matter has traditionally been the focus of chemistry instruction, with energy being primarily treated in physics courses. However, an understanding of energy is necessary to explain phase changes (in *Polar Ice Unit*) as well as other chemical phenomena (addressed below).
Lesson 3	Forces are needed to describe interactions between different test objects and the water dropper.	Although force language is traditionally seldom used in high school chemistry (except when considering intermolecular interactions), all bonds are by nature due to forces between one atom's protons and its neighbor's electrons. This lesson establishes the necessity of forces as a lens to be used throughout the unit alongside matter and energy.
Lesson 4	Fields generated by matter result in forces.	A field is an area of space in which we can associate a quantity--in this case, a force--with each point. In other words, an object moving through a field will experience a force at each point in the field. As students figure out, electric fields surround the water dropper, much like the magnetic field around a magnet. A charge in that electric field will feel a force. Students continue to use forces to develop models of interactions between atoms in Lessons 5-9. Students connect forces to bonding and dissolution in Lessons 12-13 and continue explaining bonding in terms of forces in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*. For more information on fields, see https://www.physicsclassroom.com/class/circuits/Lesson-1/Electric-Field-and-the-Movement-of-Charge.

Lesson 10	Forces transfer energy.	The forces-energy connection is used in this unit to explain how lightning is able to transfer so much energy. This energy is transferred from the electric field into other parts of the system (where, as we figure out in Lesson 11, it manifests as flashes of light and thunder). "Potential energy" is avoided because it tends to make students think that it is energy that could exist or is not real. It obscures the mechanism by which energy is stored in any system--as motion of objects or particles ("kinetic or thermal energy"), or in the gravitational, electric, or magnetic field between these components ("potential energy"). Students will continue using the idea of forces transferring energy, often in and out of electric fields, in subsequent units. In *Space Survival Unit*, students will note how more energy (through increased melting and boiling points) is required to overcome the forces in some materials, compared to others. In *Oysters Unit*, students will return to the idea that some bonds are harder to break than others (require more energy to break) to explain stability in reversible reactions. In *Fuels Unit*, students will explain exothermic and endothermic reactions in terms of energy transfer in and out of fields as bonds break and form. For more information about modeling energy transfer with fields, see https://onlinelibrary.wiley.com/doi/epdf/10.1002/tea.21556.
Earth's Interior Unit	We need to consider balanced and unbalanced forces in our examinations of phenomena.	Students already built an understanding of balanced and unbalanced forces in middle school in *OpenSciEd Unit 8.1: Why do things sometimes get damaged when they hit each other? (Collisions Unit)*. This idea is expanded on significantly and added to the M-E-F triangle in the OpenSciEd High School Physics course. In this unit, students will also establish that it is *unbalanced* forces that transfer energy.

Sample Student Data

Sample student procedure:

1. *Get a balloon and a piece of tinsel.*
2. *Rub balloon on sweater for 10 seconds.*
3. *Hold balloon near tinsel and observe interaction.*
4. *Repeat, but rub balloon on sweater for 20 seconds.*
5. *Hold near tinsel again.*

Sample student procedure:

1. *Get two balloons.*
2. *Rub each balloon on a sweater for 10 seconds.*
3. *Hold balloons near each other and observe interaction.*
4. *Rub balloons on sweater again for 20 seconds.*
5. *Observe interaction again.*

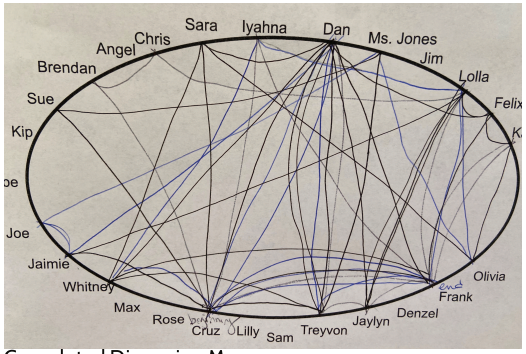
Objects tested	Detector used	Interaction observed (yes/no)	Direction and/or strength of forces during interaction
Balloon	*Tinsel*	*Yes*	*Strong attraction*
Balloon	*Tinsel*	*Yes*	*Strong attraction*
2 Balloons	*--*	*Yes*	*Balloons repelled slightly*
Balloon	*Water*	*Yes*	*Water attracted to balloon*

Lesson 5 Teacher Reference

Discussion Mapping Tool

Instructions

1. Print one copy of the second page of this tool for each class section.
2. Add students' names to the circle in the order that students are sitting. You may want to do this ahead of time and then ask students to sit according to the map.
3. Select a student recorder who will map the discussion as it happens. Decide ahead of time if you will have multiple students take turns mapping, and when you will move the map to a new student recorder.
4. If this is the first time you are using a discussion map, explain to students that each time someone speaks, the recorder will draw a line from the previous speaker to the new speaker's name. You may want to mark where the conversation begins and ends, but the goal is to map the overall conversation patterns rather than to be able to retrace the entire conversation.
5. Once the discussion begins, allow students to take the lead on moving the discussion forward. Sit in the circle as a participant rather than standing in front of the class as a facilitator. This will allow students to practice building on each other's ideas directly.
6. Be mindful of group dynamics, especially when displaying the map and discussing patterns of contributions. Avoid focusing on the contributions of single students and instead redirect the class to notice class-level patterns.



Completed Discussion Map

Discussion Mapping Codes

The key at the bottom of the discussion map contains codes that can be used to label the types of student contributions. The first few times that you create a discussion map with your students, you should focus only on recording the flow of the conversation. This allows students to get comfortable with the process. Once students have experience recording and interpreting those initial patterns, you can add discussion mapping codes to future discussion maps. Start by adding "low risk" or more accessible codes first such as claim given, evidence added, agreed, or disagreed. There is an extra column where you can add your own discussion codes as needed based on individual class needs and agreements. You may also choose to use just some of the discussion codes, based on the type of discussion that your students are having. In this case, be sure to cross out the codes that you are not using so that student recorders know not to include them.

Key Ideas

There is space to list up to three key ideas that emerge from the discussion on the tool itself so that the class can keep track of the ideas that are raised in the discussion. If you choose to use codes to annotate student contributions, you can also use the codes "1", "2", and "3" to map when those ideas are talked about.

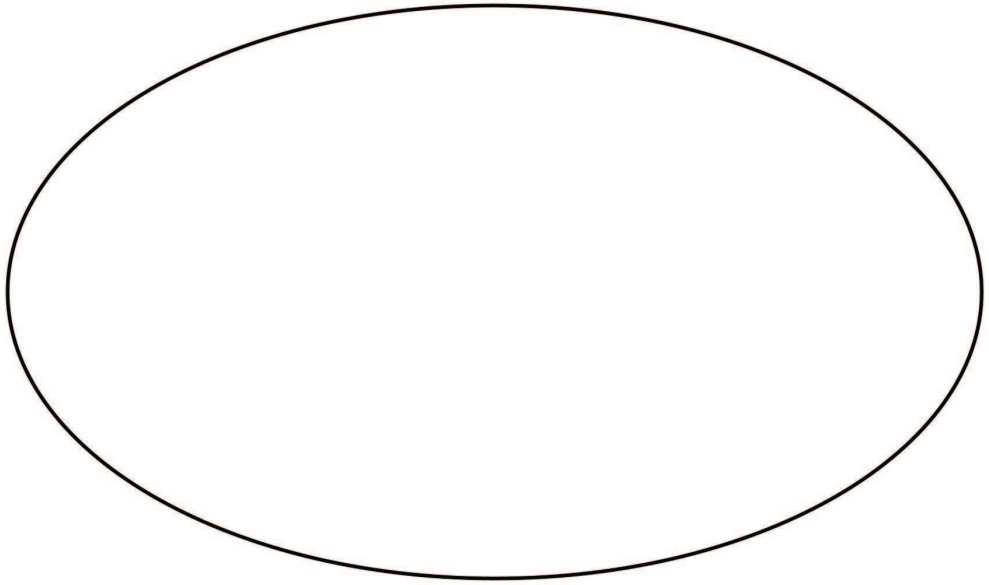
Adaptations

- For a large class, arrange students in an inner and outer circle. Have the inner circle discuss the question while the students in the outer circle map the discussion.
- Consider having sentence frames displayed on a slide or poster to support multilingual learners.

Question we are trying to answer:

Date:_____
L#: _____
Period: ___

Key Ideas



Discussion Codes (Choose up to 3)				
C- claim given	**CL**- clarified idea	**?**- asked question	**T**- tied ideas together	**I**- interrupted
E- gave evidence	**A**- affirmed/agreed	**NI**- new idea added	**RP**- related phenomena	
OT- off topic	**D**- disagreed	**R**- repeated idea	-- idea ended	

Lesson 5 Teacher Reference

Electronic Exit Ticket

What are Electronic Exit Tickets?

These are short **formative** assessments that occur 2-3 times per unit, in between other assessments. They include items to check for understanding of lesson-level PEs, to make connections between content and students' lives, and to elicit information about their experiences and to help students reflect on their own progress in focal SEPs and CCCs. They are built in Google Forms, but can be ported to any survey software.

How to create Electronic Exit Tickets

In *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, the two Electronic Exit Tickets in this unit are found:

- at the end of day 3 of **Lesson 5** (**slide DD**);
- at the end of day 2 of **Lesson 11** (**slide U**).

Select the link for the Electronic Exit Ticket that corresponds with the lesson you are teaching.
Lesson 5: https://docs.google.com/forms/d/1Wg6hQEbevn0LAO0aMg8jjIY_MVd_DizXQUn5q7gxdAw/copy
Lesson 11: https://docs.google.com/forms/d/1ydoISMHNbVinJF7u3VhghGWT3wxXDXoofcZJ0KXVaaI/copy

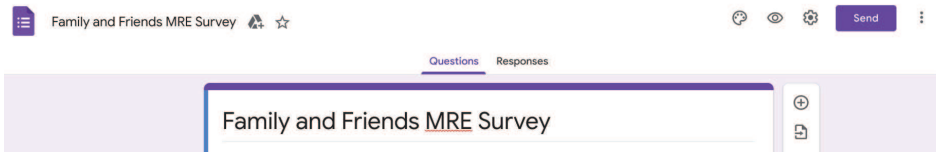
Spanish versions are available here:
Lesson 5: https://docs.google.com/forms/d/1enNHjuSne7O7koQdA9vV8t26J_PdgDyPdtHaf7l32g8/copy
Lesson 11: https://docs.google.com/forms/d/1iulw0L2EPYJh94FkKK-zqbr-5n00KnLZB6tZvwFPde0/copy

Attending to Equity
Some students may benefit from completing the Electronic Exit Tickets on a printed version. Complete the steps below to create a copy of the Electronic Exit Ticket. Once you have created a copy in your own Google Drive, click on the 3 dots in the upper right side of the form next to the SEND button. This should give you an option to print a paper copy of the Electronic Exit Ticket.

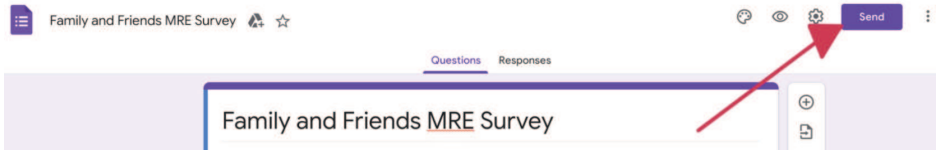
When you select the link, it will ask you to make a copy in your own Google Drive.



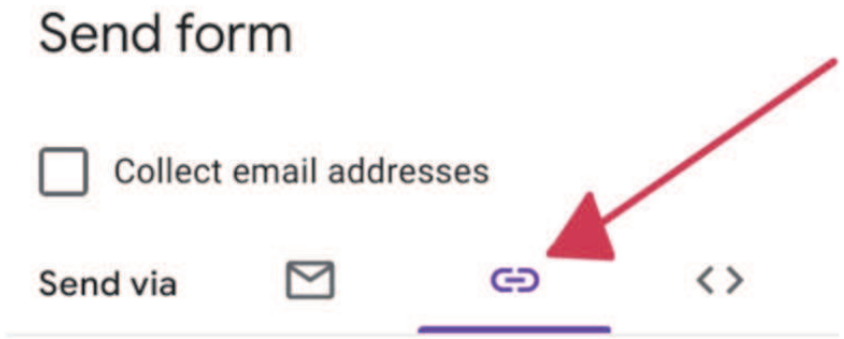
The student Electronic Exit Ticket will open in your own Google Drive.



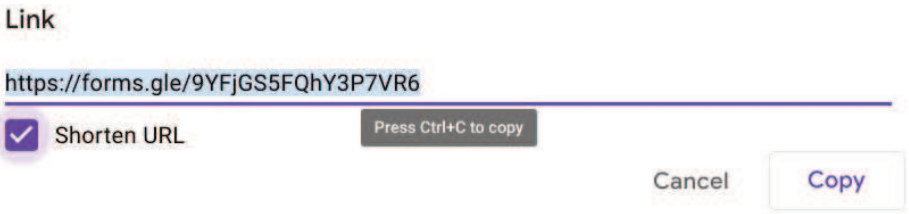
Select the “Send” button in the upper right corner to get a link to give to students.



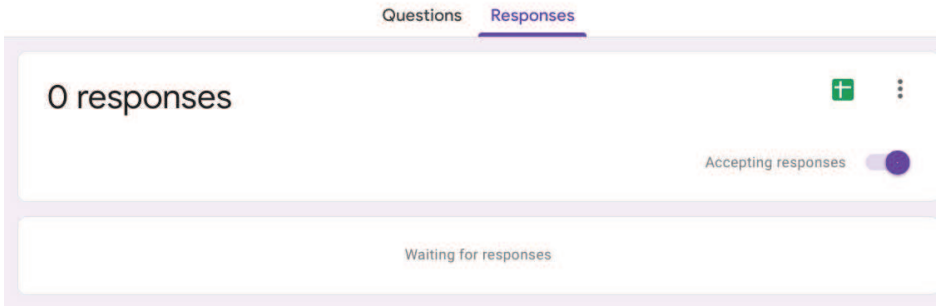
In the “Send via” panel, select the middle icon to choose to send the Electronic Exit Ticket via a link.



Copy the link it provides you or select the “Shorten URL” box and then copy the link. This second option creates a link that will be easier for students to type.



Once people submit responses they will show up in your Google Form under "Responses". Google will automatically provide you with some visualizations of these responses.



If you want to see the data in a spreadsheet format, click the sheet icon to create a Google Sheet of your data. It will automatically populate when people respond to the Electronic Exit Ticket.

For each Electronic Exit Ticket, you will need to repeat the process above. You can choose to make a copy of the Electronic Exit Ticket for each of your classes or choose to have one Electronic Exit Ticket for all of your classes.

Lesson 5: Answer Key 1

Electronic Exit Ticket Key

This Electronic Exit Ticket mainly assesses students' knowledge around LLPE 5.B.

Additionally, it assesses the SEP element from LLPE **5.A** Integrate information from multiple sources to explain what is happening at a scale too small to directly observe and provide evidence for the existence of protons, neutrons, and electrons. (SEP: 8.2; DCI: PS1.A.1; CCC: 3.2)

5.B Develop, use, and discuss the merits and limitations of multiple models to simulate the charged substructures of atoms, the movement of electrons, and other processes and structures too small to directly observe. (SEP: 2.1, 2.4; DCI: PS1.A.1; CCC: 3.2, 4.3)

Where these elements are addressed in this assessment	**2.1 Developing and Using Models** Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or the design criteria	**2.4 Developing and Using Models** Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexible between model types based on merits and limitations.	**8.2 Obtaining, Evaluating, and Communicating Information** Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem.	**PS1.A.1 Structure and Properties of Matter** Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.	**3.2 Scale, Proportion, and Quantity** Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly.	**4.3 System and System Models** Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.
Q1	x			x		
Q2				x	x	
Q3			x	x	x	x
Q4		x		x		
Q5				x	x	
Q6						

Question 1

In a reading, you come across a lithium atom represented as Li^+. A neutral atom of lithium has 3 protons. What can you infer about the number and type of subatomic particles present in Li^+?

- This lithium atom has gained an electron, so it now has 3 protons and 4 electrons.
- **This lithium atom has lost an electron, so it now has 3 protons and 2 electrons.**
- This lithium atom has gained a proton, so it now has 4 protons and 3 electrons.
- This lithium atom has lost a proton, so it now has 2 protons and 3 electrons.

Correct response: This lithium atom has lost an electron, so it now has 3 protons and 2 electrons.

Rationale for distractors:
Students should recognize that electrons are negatively charged, so a positive charge results from a loss of electrons.
Students should recognize that a charge on an atom is the result of gaining or losing electrons and that protons are not lost or gained.

What to do: Students should review the models they used in class which represented protons and neutrons in the nucleus of atoms and electrons as mobile particles surrounding the nucleus.

Question 2

In this image, the child rubbed the balloon on her hair and now there is an attraction between the hair and the balloon. The mechanism for this system is at a scale we cannot see. Which statement best describes the mechanism for why the balloon is attracted to the child's hair?



MikeRun, CC BY-SA 4.0

- Protons from the balloon moved to the hair, resulting in an attraction between oppositely charged objects.
- Atoms from the hair moved to the balloon, resulting in an attraction between oppositely charged objects.
- Electrons from the hair moved to the balloon, resulting in a repulsion between objects with the same charge.
- **Electrons from the hair moved to the balloon, resulting in an attraction between oppositely charged objects.**

Correct response: Electrons from the hair moved to the balloon, resulting in an attraction between oppositely charged objects.

Rationale for distractors:
Students should recognize that electrons transfer between objects, not protons or entire atoms.
Students should recognize that when electrons are transferred from one object to another, the result is oppositely charged objects (one positive and one negative).

What to do: Students should think back to the discussion of how modeling electron transfer helps them understand what is happening at the atomic scale when pieces of tape are ripped apart and attractions and repulsions result.

Question 3
We have many experiences of electrostatic interaction in our everyday lives. What is one example where you experienced static electricity? Describe what you think happened to the subatomic particles of the atoms in the objects that led to the interactions you saw, and use the reading, simulation, and models from class to support your explanation. Words to use: electrons, charge, positive, negative, repel, attract
What to look for in response: Students' responses should include ideas around electrons transferring from one object to another, resulting in attractions between opposite charges. They should cite *Structure of Matter*, the atom builder simulation (https://lab.concord.org/embeddable.html#interactives/interactions/atom-builder.json), and their paper-clip models in their explanations. **What to do:** Encourage students to use resources from class as evidence of their ideas. If they have difficulty incorporating specific evidence, encourage them to use their paper-clip models to show electron movement as they think through their example of static electricity.

Question 4
How did using multiple models of atomic structure help you make sense of what is happening at the particle level to cause attractions and repulsions between objects?
What to look for in response: Students mention merits of both the simulation and the paper-clip models in helping them to understand electron transfer as the mechanism for attractions and repulsions. **What to do:** If students cite only one model in their response, ask them to consider what the other model helped them to see that the first model did not.

Question 5
How did considering both the atomic and macroscopic scales help you make sense of what is happening at the particle level to cause attractions and repulsions between objects?
What to look for in response: Students mention both attractions and repulsions they observed between objects and electron transfers which result in charged atoms, and how electron transfers result in attractions and repulsions. **What to do:** If students do not link what is happening at one scale to what is happening at the other scale, push them to think about how the two ideas connect to one another.

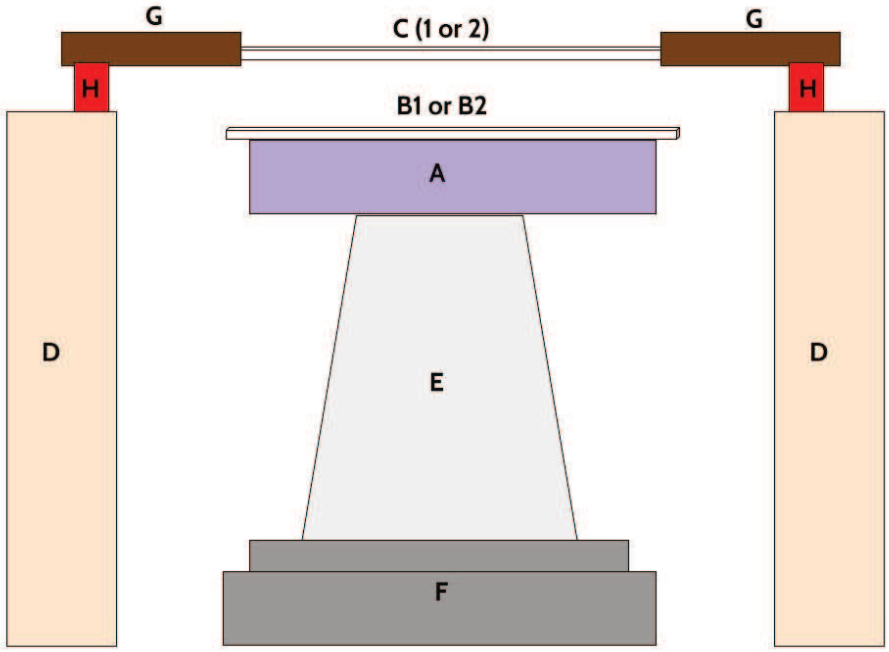
Question 6
Did you contribute an idea to class today? Did you feel your idea was heard? • **Yes, I contributed to a small group or partner, and my idea was heard.** • **Yes, I contributed to the whole group, and my idea was heard.** • Yes, I contributed, but my idea was NOT heard. • No, I did not contribute my ideas today.
Correct response: Yes, I contributed to a small group or partner OR to the whole group, and my idea was heard. **What to do:** Consider altering your classroom culture or returning to your Community Agreements if your class has a high percentage of students choosing any of the other options.

Lesson 7 Teacher Reference

Force Station Preparation

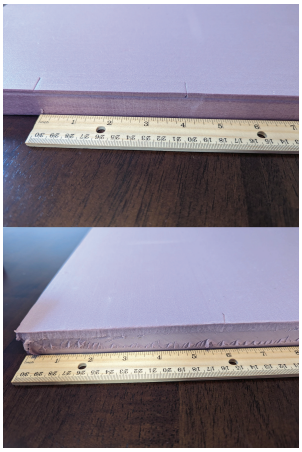
This document contains instructions to build the force stations. The teacher guide is written and the kits structured such that there is enough material for seven stations.

Label	Material	Purpose	Quantity per Force Station
A	4" x 6" piece of 1" foam insulation board	Serves as platform for charged object B1 or B2	1
B1	5" x 7" acrylic (hard plastic) sheet	Serves as lower charged object in stations with Conditions 1 and 2	1 (for stations with Conditions 1 and 2)
B2	5" x 7" PTFE (fabric-like) sheet	Serves as lower charged object in stations with Conditions 3 and 4 Charges the acrylic sheets in all stations	3 (for stations with Conditions 1 and 2) 2 (for stations with Conditions 3 and 4)
C	2.5" x 7" acrylic (hard plastic) sheet	Serves as upper charged object(s) in all stations	2
D	6" x 4" x 3" boxes	Serve as platforms for upper charged object(s)	2
E	8-oz foam coffee cup	Lifts foam board platform, allows for useful polarization effects	1
F	Digital scale (0.01 g)	Measures force exerted in each condition	1
G	Plastic clothespins (wood is also acceptable)	Hold upper charged object(s) in place on box platforms	4
H	Plastic game chips with ridges (like those used in Yahtzee and LCR)	Change distance between lower and upper charged objects	48
I (not shown)	Small piece of sticky tack	Holds cup to scale platform	1
J (not shown)	Ruler	Measures distances	1



Prepare the 4” by 6” pieces of 1” foam insulation board (A). This should be done all at once. You need to prepare at least 1 piece for each station, although this technique allows you to prepare up to 24 pieces (and share with a colleague). See video for a timelapse of this process: https://youtu.be/K1z5WAfHBcA

If you received a 24” x 24” piece, mark it every 4” along one direction and every 6” along the other.



Score deeply along these lines with a box cutter. Make sure you are working on a scratch-proof surface and take care not to cut yourself.



Repeat cuts along the same line four or five times. Flip the foam board over and cut in the same place on the opposite side of the board.

Snap the foam board along these score lines. If it does not snap easily, rescore before trying again. It is okay if the rectangles are not perfect.



Prepare acrylic sheets (B1 and C) and PTFE sheets (B2) at least one day before class. Four of the seven stations will need a 5" x 7" acrylic (hard plastic) sheet and all seven stations will need two 2.5" x 7" acrylic sheets. Because the sheets accumulate charge over time, if you have multiple sections it is best to have at least two sets that can be swapped out between classes. This will help minimize the amount of charge accumulation throughout the day. To prepare the 2.5" x 7" acrylic sheets, repeat the procedure below **seven times**. See video for a timelapse of this process: https://youtu.be/XTJa7A-Ly7I

- Note: This preparation should be done at least one day before class, as removing the protective paper from the acrylic sheets builds up charge that will need time to dissipate.

Score a straight line through the center of the 5" x 7" acrylic sheet with a box cutter, yielding two 2.5" x 7" sheets. Repeat cuts along the same line four or five times.



Flip the sheet over and cut in the same place on the opposite side of the sheet.

Pry up one half of the sheet and push down on the edge of the other half. It should snap in half along the line you cut.



Now peel off the protective paper from both sides of the half-sheets and repeat these steps seven times to prepare half-sheets for all stations (C).



Peel off the protective paper from both sides of the full acrylic sheets for stations with Conditions 1 and 2 (B1).



Cut three 5” x 7” pieces of PTFE (fabric-like) sheet for each Condition 1 and 2 station, and two pieces for each Condition 3 and 4 station (B2).



Prepare the other materials (D–H). Repeat each step below **seven times** to prepare supplies for all seven stations. See video for a timelapse of this process: https://youtu.be/4StunCc1yt0

Assemble two 6” x 4” x 3” boxes (D). If desired, use tape to help them maintain their shape, or leave them as-is so they can be easily disassembled for storage. These boxes can be replaced with similar-height stacks of books if necessary.



Stand the boxes on their smallest end on either side of the scale.



Place an 8-oz. foam coffee cup (E) on the digital scale (F) and place the piece of foam insulation board (A) on top of the coffee cup.



During the investigation, either a large acrylic sheet (B1) or PTFE sheet (B2) will be placed on top of the foam board. The small acrylic sheet(s) (C) with clothespins attached on each end (G) will be propped across the top as shown. Plastic game chips (H) will be used to increase the height of the small acrylic sheet(s).



Distribute materials. Prepare the first set of stations (A-D) for testing Conditions 1 and 2 by distributing the following:

- 1 5” x 7” acrylic sheet

- 2 2.5" x 7" acrylic sheets
- 3 5" x 7" PTFE sheets
- 48 game chips
- 4 clothespins
- Small piece of sticky tack (to keep the cup attached to the scale)
- Ruler

Distribute the same materials for testing Conditions 3 and 4 (stations E-G), but with no 5" x 7" acrylic sheet and only 2 PTFE sheets.

Label each station with a sticky note, A-G.

Lesson 7: Answer Key 1

Force Key

Note: Rules for significant figures are followed throughout this key but it is not necessary that students do so in their work, as the emphasis is on using Coulomb's law to help students contextualize the scale of lightning.

Coulomb's Law	Value of *k*
$F = k \cdot \left(\frac{q_A \cdot q_B}{r^2} \right)$	~2.3 x 10^{-21} millinewtons • cm^2 / e^2

Unit Conversions	
Distance: 1 m = 100 cm	Charge: 1 Coulomb (1 C) = 6.24 x 10^{18} e

Assigned Values for Predictions	
Partner on the left	**Partner on the right**
• Use 1.0 x 10^4 (or 10,000) m for ***r***	• Use 1.0 x 10^3 (or 1,000) m for ***r***
• Use 20.0 C for q_A	• Use 10.0 C for q_A
• Use -5.0 C for q_B	• Use -5.0 C for q_B

1. The given value of *k* uses millinewtons rather than Newtons, which are 1,000 times as great. So, to use Coulomb's law with the given *k* value, we must do some unit conversions first.

a. Convert meters to centimeters.

Partner on the left	Partner on the right
10,000 m x (100 cm / 1 m) = 1,000,000 cm	1,000 m x (100 cm / 1 m) = 100,000 cm

b. Convert Coulombs (C) to e.

Partner on the left	Partner on the right
20 C x (6.24 x 10^{18} e / 1 C) = 1.25 x 10^{20} e	10 C x (6.24 x 10^{18} e / 1 C) = 6.24 x 10^{19} e
-5 C x (6.24 x 10^{18} e / 1 C) = -3.12 x 10^{19} e	-5 C x (6.24 x 10^{18} e / 1 C) = -3.12 x 10^{19} e

2. Show how to use the Coulomb's law equation to predict the amount of force for the assigned values given in the Assigned Values for Predictions table. Document your solution steps in the space below.

Partner on the left	Partner on the right
$F = k * q_A * q_B / r^2$	$F = k * q_A * q_B / r^2$
F = (2.3 x 10^{-21}) x (1.25 x 10^{20}) x (-3.12 x 10^{19}) / (1,000,000^2) F = -8.97 x 10^6 mN ≈ -9.0 x 10^6 mN	F = (2.3 x 10^{-21}) x (6.24 x 10^{19}) x (-3.12 x 10^{19}) / (100,000^2) F = -4.48 x 10^8 mN ≈ -4.5 x 10^8 mN

3. Compare your answers with your partner. What is the magnitude of difference between your and your partner's calculated force?

The partner on the right has a calculated force about 50 times as great.

4. What might explain this difference? How did the differing variables affect force?
Even though the charge is greater on the left, the fact that the distance is greater has an outsized effect on making the force smaller. This is because the distance value is squared while the charge is not.

5. Are these forces attractive or repulsive? Explain how you know.
The forces are attractive because the sign is negative (or because there are opposite charges involved).

Lesson 7: Answer Key 2

Coulomb's Law Key

The water dropper you have observed in class is able to attract other objects and light up a neon light bulb. Use what you know about Coulomb's Law and the relationships between force, charge, and distance to complete the following calculations.



Coulomb's Law	Value of *k*
$F = k \cdot \left(\frac{q_A \cdot q_B}{r^2} \right)$	~2.3 x 10^{-21} millinewtons • cm^2 / e^2

Unit Conversions	
Coulombs: 1 C = 1000 mC 1 mC = 0.001 C	Charge: 1 Coulomb (1 C) = 6.24 x 10^{18} e

1. You rub a balloon on your sweater and transfer 1.20 x 10^{10} electrons to the balloon. The metal ring of the water dropper has lost 5.25 x 10^{8} electrons. What is the force between the metal ring and the balloon when they are 10.0 cm apart? Is this an attractive or repulsive force?

F = (2.3 x 10^{-21} mN * cm^2 / e^2) x (-1.20 x 10^{10} e) x (5.25 x 10^{8} e) / (10.0 cm)^2

= (-0.01449 mN * cm^2) / 100.0 cm^2

= -0.0001449 mN

= -0.00015 mN or -1.5 x 10^{-4} N (attractive force)

2. If the balloon is moved twice as far away, to 20.0 cm, will the force:
   a. Increase by a factor of 2
   b. Decrease by a factor of 2
   c. Increase by a factor of 4
   d. Decrease by a factor of 4

3. Now check your prediction and calculate the force using the same charges from question 1 and a distance of 20.0 cm.

F = (2.3 x 10^{-21} mN * cm^2 / e^2) x (-1.20 x 10^{10} e) x (5.25 x 10^{8} e) / (20.0 cm)^2

= (-0.01449 mN * cm^2) / 400.0 cm^2

= -0.00003623 mN

= -0.000036 mN or -3.6 x 10^{-5} N (attractive force)

4. The penny connected to the positively charged bucket builds up a charge (q_A) of 2.25 x 10^{-5} mC, and the penny connected to the negatively charged bucket builds up a charge (q_B) of -1.88 x 10^{-5} mC. If the pennies are 0.75 cm apart, what is the force of attraction between the pennies?

Calculations for Q4	
Convert mC to C (q_A): $(2.25 \times 10^{-5}$ mC) x (1C / 1000mC) = 2.25×10^{-8} C	Convert mC to C (q_B): $(-1.88 \times 10^{-5}$ mC) x (1C / 1000mC) = -1.88×10^{-8} C
Convert C to e (q_A): 2.25×10^{-8} C x $(6.24 \times 10^{18}$ e/C) = 1.404×10^{11} e	Convert C to e (q_B): -1.88×10^{-8} C x $(6.24 \times 10^{18}$ e/C) = -1.173×10^{11} e
Calculate force using Coulomb's Law: $F = (2.3 \times 10^{-21}$ mN * cm^2 / e^2) x $(1.404 \times 10^{11}$ e) x $(-1.173 \times 10^{11}$ e) / (0.75 cm)^2 $= (-37.88$ mN * cm^2) / 0.5625 cm^2 $= -67.34$ mN = -67 mN (attractive force)	

5. There is a second water dropper in the classroom. The penny connected to the positively charged bucket builds up a charge (q_A) of 1.25×10^{-5} mC, and the penny connected to the negatively charged bucket builds up a charge (q_B) of -1.00×10^{-5} mC.If the pennies are 0.25 cm apart, predict: will the force between these pennies be stronger or weaker than the force between the pennies in Question 4?

The force will be stronger because the distance is much shorter. (Accept all student predictions)

6. Check your prediction: calculate the force for the pennies in the previous question

Calculations for Q6	
Convert mC to C (q_A): $(1.25 \times 10^{-5}$ mC) x (1C / 1000mC) = 1.25×10^{-8} C	Convert mC to C (q_B): $(-1.00 \times 10^{-5}$ mC) x (1C / 1000mC) = -1.00×10^{-8} C
Convert C to e (q_A): 1.25×10^{-8} C x $(6.24 \times 10^{18}$ e/C) = 7.8×10^{10} e	Convert C to e (q_B): -1.00×10^{-8} C x $(6.24 \times 10^{18}$ e/C) = -6.24×10^{10} e
Calculate force using Coulomb's Law: $F = (2.3 \times 10^{-21}$ mN * cm^2 / e^2) x $(7.8 \times 10^{10}$ e) x $(-1.00 \times 10^{8}$ e) / (0.25 cm)^2 $= (-11.19$ mN * cm^2) / 0.0625 cm^2 $= -179.1$ mN = -180 mN (attractive force)	

Lesson 8: Answer Key

Lightning Polarization Key

Building toward 8.A Use multiple models to explain patterns observed at different scales in the behavior of uncharged objects when a charged object exerts a force on them. (SEP: 2.4; DCI: PS1.A.3; CCC: 1.1, 3.3)

3D Elements
Developing and Using Models. ~~Develop and/or~~ use multiple types of models to provide mechanistic accounts ~~and/or predict phenomena,~~ and move flexibly between model types based on merits and limitations. (SEP: 2.4)
Structure and Properties of Matter. The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (DCI: PS1.A.3)
Patterns. Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (CCC: 1.1)
Scale, Proportion, and Quantity. Patterns observable at one scale may not be observable or exist at other scales. (CCC: 3.3)

This rubric is provided as guidance for the types of responses students may have on *Explaining Polarization*. It is **not suggested** that you grade these items.

Use words and images to explain, *What is happening at the atomic and subatomic level to cause a lightning strike?*

- Make sure that you explain what is happening at the atomic and subatomic level in terms of **electrons**, **charge**, **partial charge**, and **polarization**.
- Describe how you used the **simulation** and the **paper-clip model** to arrive at this explanation.
- Make sure to think about how the lightning moves toward and strikes the **ground**.

	Foundational Understanding	Linked Understanding	Organized Understanding
3D Elements	What to look for in students' explanations: Student partially connects two of the ideas below in a mechanistic chain. • The negative charge in lightning repels electrons in other atoms, such as the atoms in the ground. • Atoms in the ground become polarized. • Lightning is attracted to the partial positive charges in the atoms in the ground. Student mentions the model they used to develop at least one of the ideas above. Student mentions patterns observed at different scales.	What to look for in students' explanations: Student partially connects the three ideas below in a mechanistic chain. • The negative charge in lightning repels electrons in other atoms, such as the atoms in the ground. • Atoms in the ground become polarized. • Lightning is attracted to the partial positive charges in the atoms in the ground. Student ties at least one of the ideas above to the model they used to develop it. Student mentions but does not connect patterns observed at different scales to appropriate models.	What to look for in students' explanations: Student clearly connects the three ideas below in a mechanistic chain. • The negative charge in lightning repels electrons in other atoms, such as the atoms in the ground, as seen in the simulation. • Atoms in the ground become polarized; this can be modeled by moving the paper-clip electrons to one side of the index card. • Lightning is attracted to the partial positive charges in the atoms in the ground. Student describes lightning's behavior as similar to the patterns observed in the simulation and modeled at the subatomic scale with index cards.

Example	The claim below is **bolded**. **Negative charge builds up and repels electrons, making the atoms in the ground become polarized because like charges repel.** This was easier to see when we looked at what particles were doing instead of just the balloon.	The claim below is **bolded**. **Negative charge builds up in the cloud and repels electrons in the ground,** just like the negative charge built up on the balloon in the simulation and repelled electrons in the wall. **This causes the atoms in the ground to become polarized. Negative charges are attracted to positive ones, so lightning can reach the ground.** The models we used help us better understand what is happening at the atomic or subatomic level.	The claim below is **bolded**. **Negative charge builds up in the cloud due to friction. This negative charge repels electrons in other atoms, like those in the ground,** much like the balloon's negative charge repelled electrons in the wall in the simulation. **The atoms in the ground become polarized,** like when electrons (paper clips) move to the opposite side of the nucleus (index card). **Negative charges are attracted to the partial positive charges in the atoms in the ground, which is how lightning reaches the ground.** The simulation helped us see how the balloon (or negative charge in a cloud) causes partial polarization in the wall (or ground), and the paper-clip model helped us see what is happening in each individual atom.
Feedback / What to Do	*Linking:* Invite students to expand on different parts of the mechanistic chain. Invite students to expand on how different models helped them figure out different model ideas.	*Organizing:* Invite students to consider places where they could more clearly tie together model ideas in a mechanistic chain. Invite students to expand on which models they used to figure out different model ideas at different scales.	*Extending:* Encourage students to identify additional situations in which polarization is at work. How can these same models be applied in those situations? What additional models, focused on which scales, might be needed to help explain them?

	Foundational Understanding	Linked Understanding	Organized Understanding
Ideas for Instruction	Trace the development of a mechanistic chain for the balloon and wall phenomenon. Have students review how different models show this chain. Ask students how the models used are different.	Give students an opportunity to compare responses and discuss the pieces that each response clearly includes. Ask students to review the strengths and limitations of the models.	Invite students to consider what happens next. Where does the "shock" of lightning come from? Is a shock inevitable in a situation of induced polarization?

Lesson 9: Answer Key 1

Gotta-Have-It Checklist Key

The ideas your students have in their checklists may not align with the numbered responses shown here. Students may have split up ideas differently and used more rows, or combined ideas and used fewer rows. They may not have written their ideas in sequential steps. This key is provided as a tool to help you look for these ideas in students' work, not to score them specifically on these exact statements. The lesson numbers where students built these ideas are provided so you can assist groups in looking for additional details if they are stuck.

Part 1: Make a checklist of the ideas you need to include in a model to explain what causes lightning to strike at a particular place and time. Record new or lingering questions in the provided space below the chart. Use the following resources to help you:

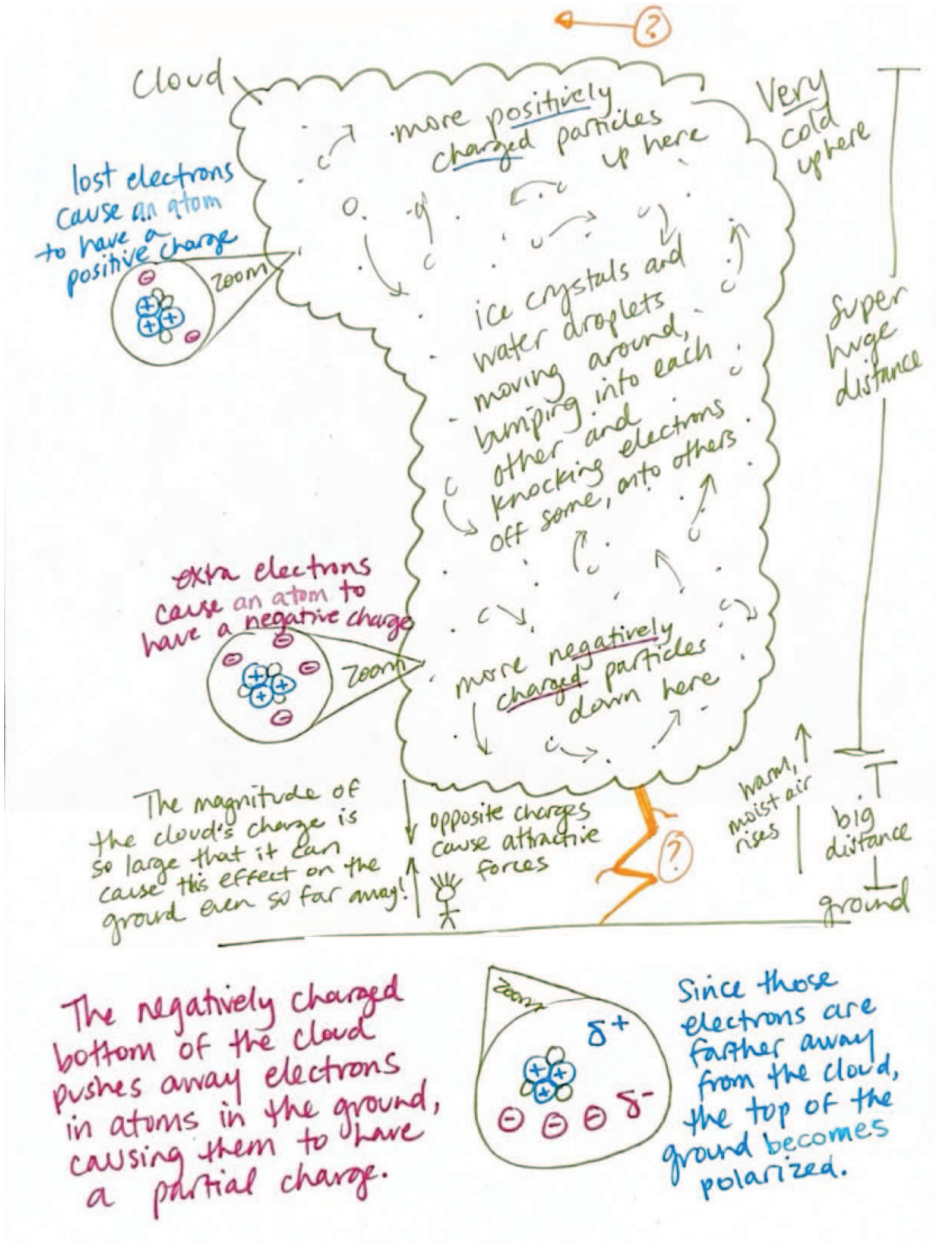
- Progress Tracker and other information from your science notebook
- Your model of a detector near the water dropper
- Your explanations from the last lesson
- Class posters

What our model needs to answer the question: *What causes lightning to strike at a particular place and time?*		***Check off ideas as you use them in your model.***	
What we have figured out about static interactions (what is happening) and lightning mechanisms (why it is happening):	**Components (parts) of the lightning system that are involved:**	*already used in initial model*	*added in revised model*
1. Warm, moist air rises from Earth's surface, and when it gets higher into the atmosphere, it condenses to form a cloud. The cloud gets tall enough and the temperatures are cold enough that ice crystals form inside the cloud. (Lesson 6)	Air, cloud (water droplets), temperature, ice crystals		
2. Water droplets and ice crystals are rubbing/colliding as they move around in the cloud. (Lesson 6)	Water droplets, ice crystals		
3. When those collisions happen, electrons are brushed off of some of the crystals or molecules and move to other crystals or molecules. (Lesson 6)	Electrons, water droplets, ice crystals		
4. The loss or addition of electrons results in different net charges on those particles/atoms. (Lesson 5) Losing electrons results in matter that is positively charged. Gaining electrons results in matter that is negatively charged.	Electrons, negatively and positively charged matter		
5. Inside the cloud, negatively charged matter builds up at the bottom of the cloud, while positively charged matter collects toward the top of the cloud. The bottom of the cloud has many, many particles with extra electrons and a strong negative charge. (Lesson 6)	Electrons, negatively and positively charged matter (cloud)		

What our model needs to answer the question: *What causes lightning to strike at a particular place and time?*		*Check off ideas as you use them in your model.*	
6. Like-charged matter results in repulsive forces, and oppositely-charged matter results in attractive forces. (Lesson 5)	Negatively and positively charged matter		
7. The more charges accumulate on either side of the system, the stronger the attractive or repulsive forces become. (Lesson 7)	Negatively and positively charged matter		
8. The accumulation of so many excess electrons/so much negative charge at the bottom of the cloud has enough force to cause the atoms in the ground to experience induced polarization and become partially positively charged (Lesson 8), even though the cloud is far away from the ground (Lesson 7).	Negatively and positively charged matter		
9. Lightning is often between the bottom of the cloud and the ground because the bottom of the cloud is actually closer to the ground than to the top of the cloud. (Lesson 6)	Cloud, ground		
10. (Additional ideas acceptable if based on evidence collected by the class.)			

What new or lingering questions came up as you considered the ideas on this checklist?
Accept all responses.

Part 2: Use your checklist to develop a model to answer the question, "What causes lightning to strike at a particular place and time?" As you use ideas from your checklist, put a check mark in the appropriate column.



What to look/listen for in the moment:

- Students' model ideas are based on evidence from their readings about lightning and their investigations of charged objects, static interactions, and the water dropper system. (SEP: 2.3)
- Students' models illustrate the relationships between components of the lightning system: the cloud, particles in the cloud, the ground/objects on the ground, and the subatomic structures of these components. (SEP: 2.3)
- Students describe the relationships in the lightning system in terms of how matter moves and changes within that system. (CCC: 5.2)
- Students model the charged substructure of an atom, consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (SEP: 2.3; DCI: PS1.A.1)
- Students' models include the idea that electrostatic forces between objects depend on the magnitude of the charges and the distance between them. (SEP: 2.3; DCI: PS2.B.1)

What to do: Circulate among groups as they are working and remind students to reference the ideas on their Gotta-Have-It Checklists as they construct their revised models. If students need help getting started, point them back to their initial models from Lesson 1 and ask what components they know more about now and what interactions they can explain. Take note of students who are struggling to participate in their group's work or articulate their ideas. Consider arranging a time to meet with these students as a guided small group to revisit the investigations and ideas they developed in previous lessons, so they are confident about what they have figured out going into the assessment on day 2. You might also have these students prepare answers to DQB questions related to the idea(s) they are struggling with and share those at the beginning of day 2. They could work with you or with peers to develop their answers.

Students will be assessed in part on SEP: 2.3, DCI: PS1.A.1, and DCI: PS2.B.1 in the mid-unit transfer task on day 2. You may collect students' models and provide brief feedback on students' use of these elements using the guidelines above, remembering that students may choose to represent models in different but equally valid ways. Alternatively, the self-assessment in the next activity provides an opportunity for students to reflect on whether they need such feedback, allowing students to submit their work for feedback voluntarily.

Lesson 9: Answer Key 2

Static Interactions Key

Performance expectation being assessed: 9.B Use mathematical representations of Coulomb's law to describe and predict the electrostatic forces between objects. (SEP: 5.2; DCI: PS2.B.1, PS2.B.2; CCC: 1.1)

This assessment is closely aligned to portions of HS-PS2-4. Use mathematical representations of ~~Newton's Law of Gravitation and~~ Coulomb's Law to describe and predict the ~~gravitational and~~ electrostatic forces between objects.

In addition to the SEP, CCC, and DCIs associated with this PE, this assessment also addresses one additional SEP element and one additional DCI element. Developing and Using Models (SEP: 2.3) is incorporated so that students have an opportunity to model charge at the level of atomic substructure (DCI: PS1.A.1), showing that they have a particle-level understanding of the mechanisms behind the other assessed DCI elements.

3D Elements addressed in this assessment	Question #						
	1a	1b	1c	2a	2b	2c	2d
2.3 Developing and Using Models. Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships ~~between systems or~~ between components of a system.	X	X	X				
5.2 Using Mathematics and Computational Thinking. Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.				X	X	X	X
PS1.A.1 Structure and Properties of Matter. Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.	X						
PS2.B.1 Types of Interactions. ~~Newton's law of universal gravitation and~~ Coulomb's law provide(s) the mathematical model(s) to describe and predict the effects of ~~gravitational and~~ electrostatic forces between distant objects.		X		X	X	X	X
PS2.B.2 Types of Interactions. Forces at a distance are explained by fields (~~gravitational,~~ electric, ~~and magnetic~~) permeating space ~~that can transfer energy through space. Magnets or electric currents cause magnetic fields~~; electric charges ~~or changing magnetic fields~~ cause electric fields.		X					
1.1 Patterns. Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	X	X	X			X	

Scoring Guidance. The response elements described below would be considered exemplary at this point in the unit. These are shown in purple text or in purple diagrams below the related question. In some cases different elements of a response are identified with a + symbol. These + elements are not meant to be all inclusive, but are suggestions for different ideas your students might include.

The following scoring guidance can help you identify different elements that students should (or could) include in their responses.

- If several of the elements marked with a + are missing from a student's response, this may indicate that the student has not mastered the science ideas or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether the student is struggling with a science practice or science idea, or both.
- If all or almost all of the elements marked with a + are present in a student's response, this may indicate that the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.

Students can respond to questions on this assessment in writing, using illustrations, gestures, and languages other than English.

Part 1

Earlier in this unit, you and your classmates investigated several static interactions. Now that you have figured out the mechanisms causing these interactions, use the questions below the table to explain what was going on in one of the phenomena you or other students experienced.

Choose a set of interactions from one row of the table for this part of the assessment. Circle that row to indicate which interaction you will focus on.

Matter interaction			Force interaction		
Object A	Rubbed on Object B	Result	Object A, now charged	Interacted with neutral Object C	Result
plastic spoon	wool	The spoon is now charged.	charged spoon	pepper flakes	There was an attractive force between the spoon and the pepper flakes.
glass rod	silk	The glass rod is now charged.	charged glass rod	tiny paper scraps	There was an attractive force between the rod and the paper scraps.

1a. How did the charges on the atoms in Object A change when you rubbed Object A on Object B? Draw a model using the subatomic structure of an atom to explain what is responsible for that change in charge.

Be sure to include:

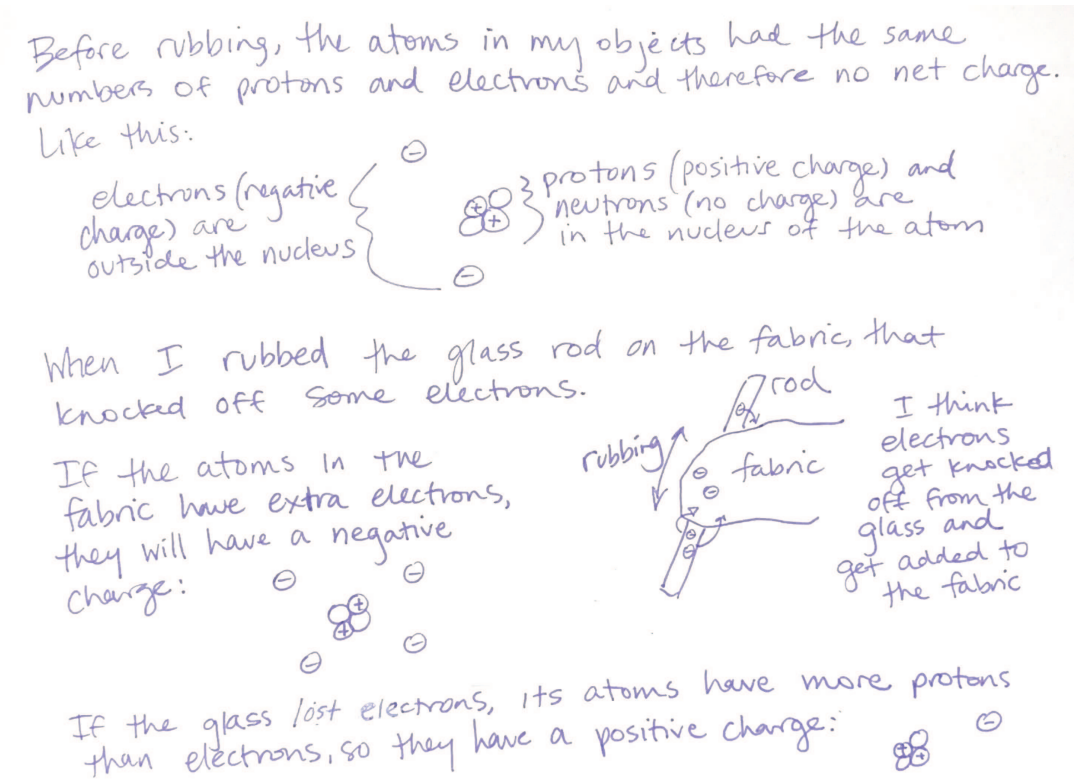
- the general location, name, and charge of all subatomic particles in any atom;
- what happened to change the charge of your Object A; and
- reasoning for what accounts for the overall charge of the atoms in your charged Object A. (SEP: 2.3; DCI: PS1.A.1; CCC: 1.1)

Key elements:

Note: Students are not expected to know whether electrons were added to or removed from Object A. You are looking for evidence of understanding that gaining electrons results in a negative charge or that losing electrons results in a positive charge.

+ components of the atom model are labeled, including the atomic nucleus
+ represents accurate location and charge of protons (+ charge) in the nucleus of the atom
+ represents accurate location and charge of neutrons (no charge) in the nucleus of the atom
+ represents accurate location and charge of electrons (- charge) around the protons and neutrons
+ mechanistic description/drawing of how net charge is neutral when the numbers of protons and electrons (or amount of positive and negative charges within an atom) are equal
+ mechanism for the change in charge is described and/or drawn with the addition or removal of electrons

Sample student response:



What to do:

Support students in representing atoms. Ask, *What are the components of an atom that we identified in Lesson 5? What are their properties? How did we represent them in the past?*

Support students to develop a mechanistic account. Ask, *How are the atoms different? If we change the number of protons, neutrons, or electrons, how does that affect the overall charge?*

After the interaction between Objects A and B led to a charged Object A, you decided to see how it would interact with a new object, Object C. Object C has a neutral charge.

1b. Why was Object C attracted to your charged Object A? Draw a model of one particle of Object C to help answer this question.

Be sure to include:

- how Object A's charge is involved;
- what is happening with the electrons in Object C;
- the cause of the attractive force; and
- the role of fields in this process. (SEP: 2.3; DCI: PS2.B.1, PS2.B.2; CCC: 1.1)

Key elements:

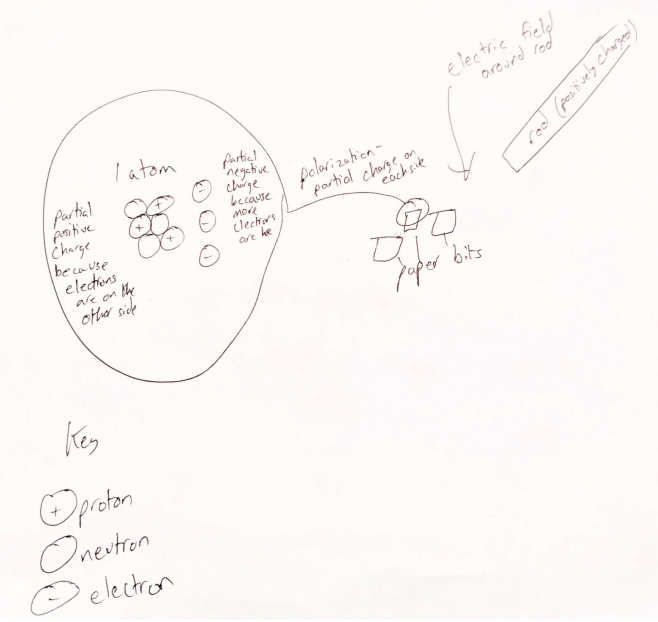
+ Charges generate fields, which result in forces between charges.
+ Opposite charges cause an attractive force; like charges cause a repulsive force.
+ When I brought Object A close to Object C, the net charge of Object A caused the electrons in Object C's atoms to move:
  - If Object A had a positive charge, it attracted the electrons in Object C's atoms.
  - If Object A had a negative charge, it repelled the electrons in Object C's atoms.
+ The atoms in Object C did not lose or gain any electrons, but the electrons moved to the same side of each atom, giving the atoms a partial charge on each side or causing induced polarization.
+ A partially (+) end and a partially (-) end are labeled on the model particle.
+ Electrons are shown hanging out more on the negative end and fewer electrons are hanging out on the positive end.

+ The (induced) polarization of the atoms in Object C gave it a net charge that was opposite Object A's charge, so they were attracted.

Sample student response:
The tiny paper scraps (Object C) and the glass rod were attracted because they had opposite charges. Let's say the glass rod had a positive charge because some of its electrons got lost to the fabric. The paper scraps are not charged, but bringing the glass rod closer to them will pull on the electrons in the atoms in the paper. The paper's atoms don't lose the electrons, but the electrons move closer to the glass rod. So the paper will have a negative charge on the near side, having been influenced by the electric field around the positively charged rod.

What to do:
Support students in explaining and showing polarization. Ask, *How do positively charged objects interact with electrons? How do negatively charged objects interact with electrons? If electrons do not leave an atom but are within a field, what do they do? How did we represent that polarization?*

Support students in tying a mechanistic account to patterns. Ask, *How did we see charged and neutral objects interact in our investigations? What did the simulation show us about what this looks like at the particle level?*



1c. What evidence of patterns identified in class supports your answers to 1a and 1b? Be sure to discuss evidence from both the macroscopic (visible) and microscopic (invisible) scales. (SEP: 2.3; CCC: 1.1)

Key elements:
+ evidence supporting prior responses
+ evidence of mechanisms across multiple scales
Examples include:

- Lesson 5 reading, paper-clip model, and sticky tape investigation to support response to 1a
- Lesson 8 simulation, paper-clip model, and observations of balloon on wall to support response to 1b

Other examples may be acceptable if they support students' reasoning.

Sample student response:
My answer to 1a is supported by the reading we did about the structure of an atom. It did not tell us exactly how the electrons move, but it gave us information about atomic structure. We used this to make a paper-clip model, which then helped us model and explain what was happening in the sticky tape investigation.

My answer to 1b is supported by the simulation. It helped us explain the balloon–wall interaction by showing us what was happening with the charges. We were able to explain this in more detail with the paper-clip model.

What to do:
Support students in identifying productive evidence. Recommend they return to their Progress Trackers and science notebooks and ask, *What investigations have we done in this unit? What models have we used? Which of them included showing the parts of an atom? Which of them helped us think about how neutral and charged objects interact?*

Support students in connecting to patterns across scales. Ask, *Which of our investigations or models focused on things we could see? Which focused on things we could not see? Which did both?*

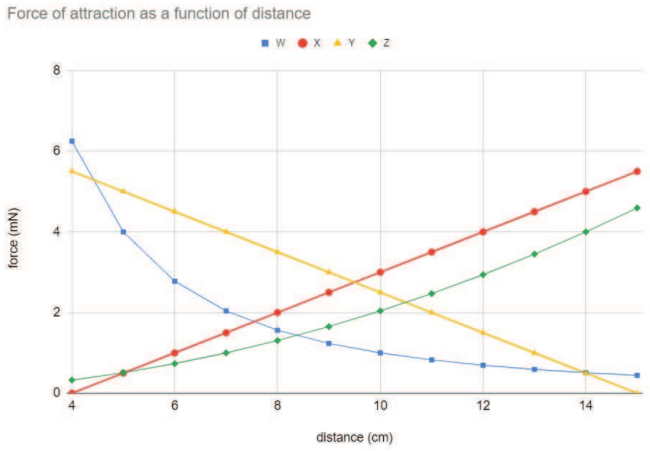
Part 2

Watch the video at https://youtu.be/vfEgzt3DgjQ?si=PN1eQqtP8no7-FQG. The child in this video noticed a relationship between the amount of time they rubbed the balloon on their hair and the effect it had on the can. Let's say the child kept track of the different lengths of time they rubbed the balloon on their hair. (This is represented in the table below; assume the balloon is discharged between each trial.) Let's also say that for each trial, the child recorded the magnitude of charge on the balloon before holding it 10 cm from the can and observing how the two objects interact.

Trial #	Balloon rubbing time	Charge	Distance between balloon and can
1	10 seconds	1.186×10^{12} *e*	10 cm
2	20 seconds	1.685×10^{12} *e*	10 cm
3	30 seconds	2.809×10^{12} *e*	10 cm

2a. Use what you know about Coulomb's law to predict which balloon trial (which length of rubbing time) will have the greatest force of attraction between the balloon and the can. (SEP: 5.2; DCI: PS2.B.1)

2b. Next, let's say the child (or their high-school-aged sibling) took the charged balloon and measured the force of attraction between it and the can at different distances. Which line in the graph (W, X, Y, or Z) most likely reflects these data? (SEP: 5.2; DCI: PS2.B.1)



2c. Use Coulomb's law to explain how it shows the pattern you selected in 2b. (SEP: 5.2; DCI: PS2.B.1; CCC: 1.1)

2d. If the child rubbed the balloon for 30 seconds, resulting in a charge of 2.809×10^{12} *e*, and the charge of the can was -2.467×10^{10} *e*, use Coulomb's law to predict the actual value of the force of attraction between that balloon and the can at a distance of 10 cm. (SEP: 5.2; DCI: PS2.B.1)

$k \approx 2.3 \times 10^{-21}$ millinewtons • cm^2 / e^2

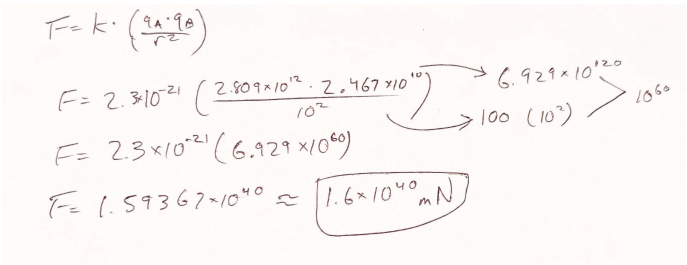
$$F = k \cdot \left(\frac{q_A \cdot q_B}{r^2} \right)$$

Coulomb's Law

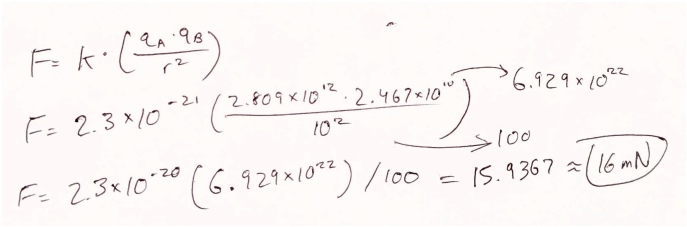
	Foundational Understanding	Linked Understanding	Organized Understanding
3D Elements	What to look for in students' mathematical thinking: 2a. There is some connection between friction and charge OR There is some connection between charge and attraction. 2b. Line W is selected. 2c. There is some connection between distance in Coulomb's law and the force. 2d. Partially correct equation setup: $F = ((2.3 \times 10^{-21})(2.809 \times 10^{12})(2.467 \times 10^{10})) / 10^{2}$	What to look for in students' mathematical thinking: 2a. The balloon that was rubbed for 30 seconds (trial 3) has the greatest charge, so it will have the greatest force of attraction between it and the can OR Coulomb's law describes that the greater the charge magnitude, the greater the attraction. 2b. Line W is selected. 2c. Distance is on the bottom in Coulomb's law, which means the force decreases as distance increases OR Distance is squared in Coulomb's law, which means it has a disproportionate (nonlinear) impact on force. 2d. Correct equation setup: $F = ((2.3 \times 10^{-21})(2.809 \times 10^{12})(2.467 \times 10^{10})) / 10^{2}$	What to look for in students' mathematical thinking: 2a. The balloon that was rubbed for 30 seconds (trial 3) has the greatest charge, so it will have the greatest force of attraction between it and the can. 2a. Coulomb's law describes that the greater the charge magnitude, the greater the attraction. 2b. Line W is selected. 2c. Distance is on the bottom in Coulomb's law, which means the force decreases as distance increases. 2c. Distance is squared in Coulomb's law, which means it has a disproportionate (nonlinear) impact on force. 2c. The graph fits the patterns described by Coulomb's law. 2d. Correct equation setup: $F = ((2.3 \times 10^{-21})(2.809 \times 10^{12})(2.467 \times 10^{10})) / 10^{2}$ 2d. Correct response: 1.5938 millinewtons (mN)
Example	2a. Rubbing an object longer allows for more charge to transfer to or from it, so trial 3 is correct. 2b. Line W 2c. The distance is on the bottom in Coulomb's law, which affects the force. 2d. See below	2a. Rubbing an object longer allows for more charge to transfer to or from it, so trial 3 is correct. 2b. Line W 2c. The distance is on the bottom in Coulomb's law. This means that when the distance gets bigger, the force gets smaller. 2d. See below	2a. Rubbing an object longer allows for more charge to transfer to or from it. Therefore trial 3 (30 seconds) will have the most charge. In Coulomb's law, the greater the charge, the greater the force, so trial 3 will also have the greatest force. 2b. Line W 2c. The distance is on the bottom in Coulomb's law. This means that when the distance gets bigger, the force gets smaller. This eliminates lines X and Y. The distance is also squared, which we saw means that the force gets MUCH smaller as the distance increases. Line W fits this pattern. 2d. See below

Feedback / What to Do	*Linking:* Support students to identify the meaning of different terms in Coulomb's law by tying them to the investigation. Ask, *How did we generate charge in the investigation? How could we have increased it? How did we vary the distance? How did that affect the force?* Encourage students to think about how graphical patterns correspond to the equation that generates them by graphing a different set of values. While doing so, support students in using Coulomb's law by sketching the system described in the problem so that it is parallel to the electrostatic force investigation, and by using resources from Lesson 7 to map each variable in the equation to its physical meaning.	*Organizing:* Invite students to examine additional details in Coulomb's law as applied to these problems. Ask, *What does rubbing the balloon have to do with force?* or *Does it matter that distance is squared and charge is not?* Encourage students to think about how graphical patterns correspond to the equation that generates them by graphing a different set of values. Support students in their calculations by giving them an opportunity to check their process with a partner. Have them carefully attend to how they enter the equation in a calculator, as this is where many errors are introduced.	*Extending:* Encourage students to consider more complex situations. Ask, *How would the problem change if the balloons were partially discharged before they were brought together?* or *How would the problem change if we lived in a universe where distance was not squared in Coulomb's law? Or where each charge was squared?*

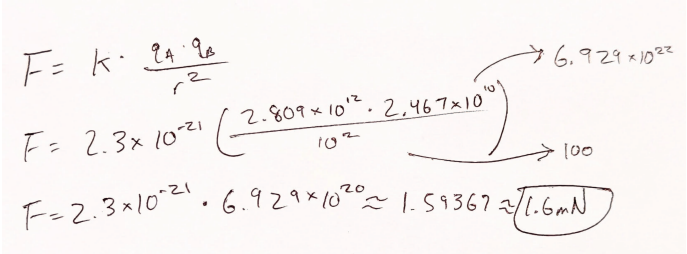
Foundational Understanding



Linked Understanding



Organized Understanding



Ideas for Instruction	Foundational Understanding	Linked Understanding	Organized Understanding
	Review the investigation and practice problems from Lesson 7, as well as the investigations and models from Lessons 5 and 8. Help students map the properties of different subatomic particles, the forces that result when different particles interact, and how atomic-scale patterns result in macroscopic-scale ones.	Review the assessment with students to help them make connections between subatomic particles, fields and forces, and the variables in Coulomb's law.	Invite students to model more complex situations, both through drawings and mathematical representations, such as building up from charged atoms to a whole charged object.

Lesson 9: Answer Key 3

Mask Transfer Task Key

Performance expectation being assessed: 9.B Use mathematical representations of Coulomb's law to describe and predict the electrostatic forces between objects. (SEP: 5.2; DCI: PS2.B.1, PS2.B.2; CCC: 1.1).

This assessment is closely aligned to portions of HS-PS2-4. Use mathematical representations of ~~Newton's Law of Gravitation and~~ Coulomb's Law to describe and predict the ~~gravitational and~~ electrostatic forces between objects.

In addition to the SEP, CCC, and DCIs associated with this PE, this assessment also addresses three additional SEP elements and one additional DCI element. Developing and Using Models (SEP: 2.3) is incorporated so that students have an opportunity to model charge at the level of atomic substructure (DCI: PS1.A.1), showing that they have a particle-level understanding of the mechanisms behind the other assessed DCI elements. Analyzing and Interpreting Data (SEP: 4.1) allows for real-world application of Coulomb's law to solve problems (SEP: 5.3).

3D Elements addressed in this assessment	Question #							
	1a	1b	2	3a	3b	4	5a	5b
2.3 Developing and Using Models. Develop, ~~revise,~~ and/or use a model based on evidence to illustrate and/or predict the relationships ~~between systems or~~ between components of a system.	X		X				X	X
5.2 Using Mathematics and Computational Thinking. Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.						X		
4.1 Analyzing and Interpreting Data. Analyze data using ~~tools, technologies, and/or~~ models (e.g., computational, mathematical) in order to make valid and reliable scientific claims ~~or determine an optimal design solution~~.				X				
5.3 Using Mathematics and Computational Thinking. Apply techniques of algebra and functions to represent and solve scientific and engineering problems.					X	X		
PS1.A.1 Structure and Properties of Matter. Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.	X	X						
PS2.B.1 Types of Interactions. ~~Newton's law of universal gravitation and~~ Coulomb's law provide(s) the mathematical model(s) to describe and predict the effects of ~~gravitational and~~ electrostatic forces between distant objects.			X	X	X	X	X	X
PS2.B.2 Types of Interactions. Forces at a distance are explained by fields (~~gravitational,~~ electric, ~~and magnetic~~) permeating space ~~that can transfer energy through space. Magnets or electric currents cause magnetic fields~~; electric charges ~~or changing magnetic fields~~ cause electric fields.		X						
1.1 Patterns. Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.			X					

Scoring Guidance. The response elements described below would be considered exemplary at this point in the unit. These are shown in purple text or in purple diagrams below the related question. In some cases different elements of a response are identified with a + symbol. These + elements are not meant to be all inclusive, but are suggestions for different ideas your students might include.

The following scoring guidance can help you identify different elements that students should (or could) include in their responses.

- If several of the elements marked with a + are missing from a student's response, this may indicate that the student has not mastered the science ideas or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether the student is struggling with a science practice or science idea, or both.
- If all or almost all of the elements marked with a + are present in a student's response, this may indicate that the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.
- If elements marked with a ++ are present in a student's response, this indicates that the student is bringing a deeper understanding of the science ideas or a deeper engagement with the practice to their response. Students should not be penalized if ideas marked with a ++ are not present in their response.

Students can respond to questions on this assessment in writing, using illustrations, gestures, and languages other than English.

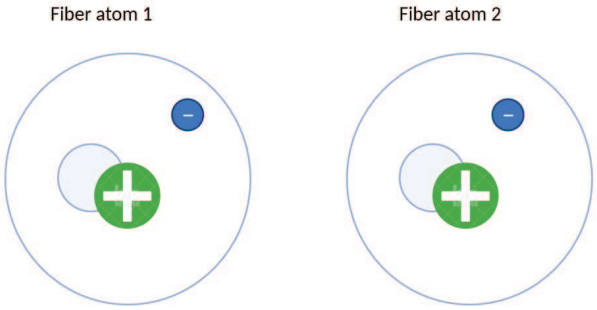
During the COVID-19 pandemic, healthcare providers and members of the public struggled to have access to high-quality masks that prevented transmission. One type of mask that was sought after was the N95 mask. These masks work with two types of filtration, mechanical and electrostatic, whereas most other masks work only with mechanical filtration. Masks are usually made with layers of material that have tiny holes. Mechanical filtration works when the holes in the layers do not line up, which blocks saliva particles containing the virus from entering our bodies. Electrostatic filtration works by creating **charge gradients** within the mask, or areas with concentrated positive and negative charges.



Kindel Media, Pexels

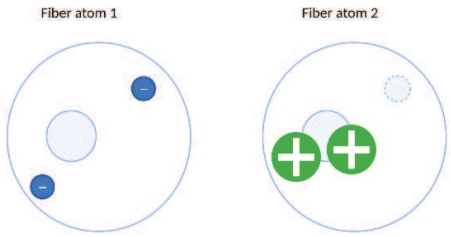
These types of masks require some chemistry to make! One process used to create charge gradients is called *melt blowing*.

The model below shows two fiber atoms in an N95 mask before melt blowing.

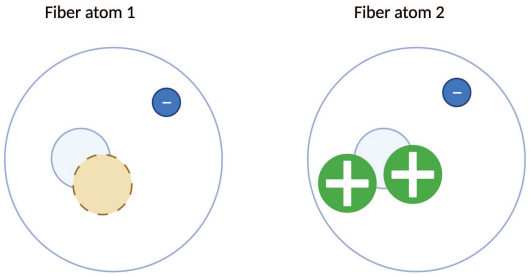


Illustrations created by OpenSciEd in BioRender

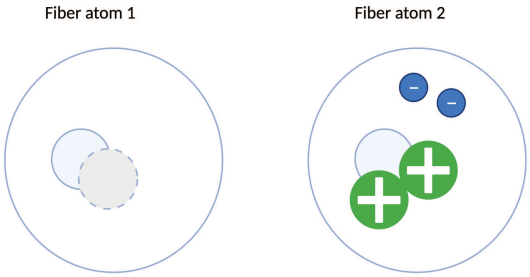
1a. Which model shows what happens to the two fiber atoms next? Circle the model you think represents the two charged atoms after they have undergone melt blowing. (SEP: 2.3; DCI: PS1.A.1)



Illustrations created by OpenSciEd in BioRender

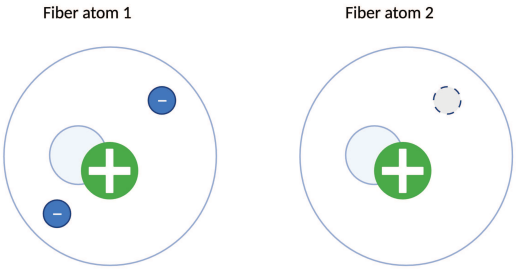


Illustrations created by OpenSciEd in BioRender



Illustrations created by OpenSciEd in BioRender

Correct response:



Illustrations created by OpenSciEd in BioRender

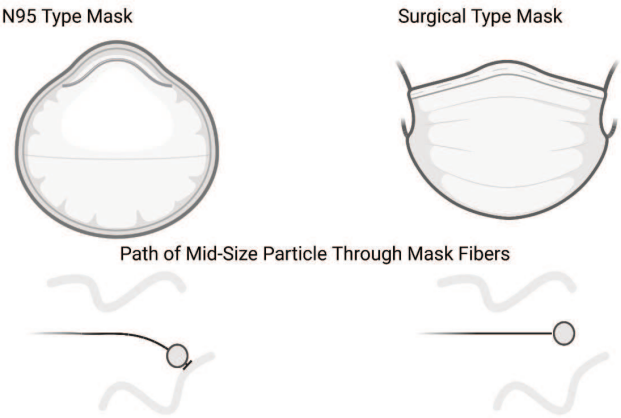
1b. Use the parts of the atom to explain why the model you chose best shows the effects of the melt blowing process on the charges of the fibers. (DCI: PS1.A.1, PS2.B.2)

Key elements:
+ protons stay within the nucleus
+ neutrons stay within the nucleus
+ electrons move from one atom to another
++ adding/removing an electron results in changes to the charge of the atom

Sample student response:
The melt blowing process must cause the fibers to interact in a way so that the electron from one fiber atom is rubbed off onto another fiber atom. The model I chose shows that the electron from fiber atom 2 is now on fiber atom 1. This makes fiber atom 1 have a negative charge and fiber atom 2 have a positive charge.

What to do: If students incorrectly state that the protons move between atoms, have them use their paper-clip models or the atom builder simulation to model the before-and-after melt blowing models as a way to identify what the correct end result of the interaction would be.

The picture on the left shows an N95 mask, where medium-sized particles flow in a curved line. The picture on the right shows a standard surgical mask, where medium-sized particles flow in a straight line.

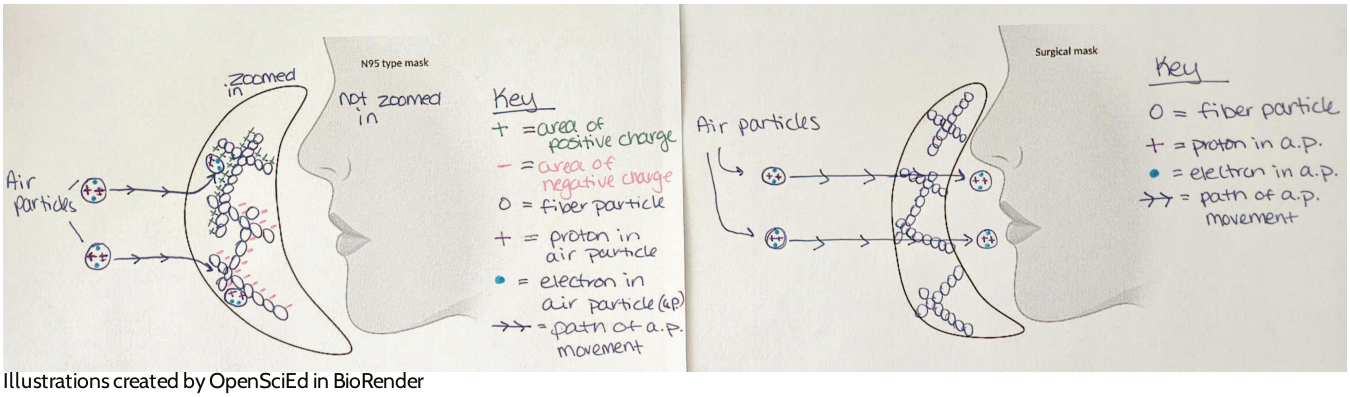


Illustrations created by OpenSciEd in BioRender

2. Using the images below, develop a model to show, at the particle scale, how an N95 mask changes the air particle path compared to a surgical mask. Be sure to include:

- mask fiber particles and their charges
- what is happening to the electrons in the air particles
- the cause of the attractive force
- the role of fields in this process (SEP: 2.3; DCI: PS2.B.1, DCI: PS2.B.2; CCC: 1.1)

Sample student model showing organized understanding.



Illustrations created by OpenSciEd in BioRender

	Foundational Understanding	Linked Understanding	Organized Understanding
3D Elements	Model shows the relationship between mask fiber particles and air particles as the air particles move through the mask. Shows charges on the fiber particles in the N95-type mask. Does not indicate charges on the fiber particles in the surgical mask. Identifies that air particles may be attracted to certain areas on the N95 mask but not the surgical mask. Uses images to provide evidence for causality of air particle movement in masks (curved versus straight paths).	Model shows the relationship between mask fiber particles and air particles as the air particles move through the mask. Shows charges on the fiber particles in the N95-type mask. Does not indicate charges on the fiber particles in the surgical mask. Identifies that air particles may be attracted to certain areas on the N95 mask but not the surgical mask. Shows air particles moving away from or toward charged areas of the N95 mask. Explains that charges generate fields, which results in the forces (attractive and repulsive) between the air and fiber particles in the N95 mask. Uses atomic scale images to provide evidence for causality of air particle movement in masks (curved versus straight paths) due to attraction and repulsion caused by opposite and like charges.	Model shows the relationship between mask fiber particles and air particles to explain the path the air particles take as they move through the mask. Shows charges on the fiber particles in the N95-type mask. Does not indicate charges on the fiber particles in the surgical mask. Shows electrons on air particles moving toward one end of the atom (induced polarization) as it was attracted to positively charged fiber particles. Shows electrons on air particles moving away from (repulsed by) negatively charged fiber particles. Shows or explains that because there are no oppositely charged areas on the surgical mask, the air particles move in a straight line. Explains that charges generate fields, which results in the forces (attractive and repulsive) between the air and fiber particles in the N95 mask. Uses atomic scale images to provide evidence for causality of air particle movement in masks (curved versus straight paths) due to attraction and repulsion caused by opposite and like charges.

Example	The differently charged parts of the N95-type mask attract and repel charged air particles. This causes the air particles to move in curved paths. The air particles move straight through the surgical mask because none of the fibers in it are charged.	The N95-type mask has differently charged areas which leads to the formation of fields that attract or repel air particles. When the air particle enters the mask, parts of it become polarized and are attracted to oppositely charged parts of the N95 mask fibers. This causes the air particle to move in a curved path. In the surgical mask, there aren't any charged areas, so the air particle moves in a straight line.	The N95-type mask has areas with negative and positive charges which creates fields that attract and repel the air particles. When the air particle enters the mask, the electrons move around to one side, causing it to become polarized. This makes the air particle move in a curved path because parts of it are attracted to the different charged areas in the mask. There aren't any charged areas in the surgical mask, so the air particles can move straight through holes between the fibers.
Feedback / What to do	*Linking:* Have students think about which subatomic parts of the air particle would and would not be attracted based on the charges in that area of the N95-type mask. Ask, *What part of the air particle's atoms would be attracted to the positively charged area of the N95 mask?* Then have students illustrate this in their models to also help develop the associated crosscutting concept. Have students consider what exactly is leading to the attraction or repulsion of air particles and N95 mask fibers. Ask, *What forms in these differently charged areas of the N95 mask that would explain the interactions between the air particles and mask fibers?*	*Organizing:* Invite students to think about the movement of electrons in an air particle, which results in polarization. Ask, *If electrons do not leave an atom but are within a field, what do they do?* Then have students illustrate this on an air particle.	*Extending:* Encourage students to consider a more complex situation. Ask, *How might using the N95 mask over and over again affect how well it attracts or repels air particles?*

Foundational Understanding	Linked Understanding	Organized Understanding

Ideas for Instruction	Review the investigation from Lesson 7 as well as the investigations and models from Lessons 5 and 8. Help students map the properties of different subatomic particles, the forces that result when different particles interact, and how atomic-scale patterns result in macroscopic-scale ones.	Review the assessment with students to help them make connections between subatomic particles, polarization, and fields and forces.	Invite students to model more complex situations, both through drawings and mathematical representations, such as building up from charged atoms to a whole charged object.

A research group evaluated the strength of the electrostatic charge of fibers in several different N95-type masks. The data they collected are shown in the table.

Type of N95 mask	Electrostatic charge (nC or nanocoulombs)
Mars-M20	1.5
K&D 8101	9
Titan Perfection	1.2
KN95	0.7

3a. Based on these data and what you know about Coulomb's law, which mask do you predict to be the most effective in a controlled test? Circle your choice. (SEP: 4.1; DCI: PS2.B.1)

Mars-M20
K&D 8101
Titan Perfection
KN95

3b. Explain your prediction in 3a. Support your prediction by using the relationships between charges and forces in Coulomb's law. (SEP: 5.3; DCI: PS2.B.1)

Key elements:
+ incorporates mathematical representation of the relationship between charge and force as represented by Coulomb's law
+ uses Coulomb's law to show that greater attractive force is due to higher charges on the particles

Additional accurate element not essential to this item:
++ greater attractive force increases the filtration ability of the mask (i.e., attracts more particles than masks with lower attractive force value)

Sample student response:
The K&D 8101 mask has the highest electrostatic charge value. Using Coulomb's law, we know that the greater the value of the charge, *q*, the higher the overall attractive force. This means that a mask with a higher attractive force has greater charges on the particles in the mask.

What to do: Point students back to *Solving for Force* and have them think about what combination of charge values could result in the data in the table. Ask them to think about how those charge values would affect how well the mask filters particles.

A new mask, called NuMask, was made that is similar to the Mars-M20 mask. The two masks were compared in a trial. The table shows the charges of the mask fibers and the mid-sized particles traveling through each mask, as well as the approximate distance between them.

Type of N95 mask	Charge of mask fiber (nC)	Charge of particle (nC)	Maximum distance between fibers and particles (nm or nanometers)	Strength of force of attraction (N)
Mars-M20	1.5	0.07	15	4.2×10^6 N
NuMask	1.2	0.07	15	3.4×10^6 N

4. Which mask would you expect to perform better in the trial, the NuMask or the Mars-M20? (SEP: 5.2) Complete the following steps using the conversion factors found on *Conversion Factors*:

- Calculate the strength of the force of attraction (N) for each mask. (SEP: 5.3; DCI: PS2.B.1)
- Use the calculated values to support your prediction. (SEP: 5.2)

Key elements:
+ uses Coulomb's law to calculate the strength of the force of attraction (N) for each mask
+ indicates that the Mars-M20 mask would perform better by comparing the attractive force (N) values for both masks

Additional accurate element not essential to this item:
++ greater attractive force increases the filtration ability of the mask (i.e.., attracts more particles than masks with lower attractive force value)

Sample student response:
The Mars-M20 mask would do better in the trial. This is because it has a higher strength of force of attraction than the NuMask. Because the strength of the attractive force is higher, more air particles would be attracted to the charged particles in the fibers of the mask and then stick to them. This means that fewer particles would go into our nose or mouth.

Mars-M20 calculations:
$1.5 \text{ nC} \times (1 \text{ C} / 0.000000001 \text{ nC}) = 1.5 \times 10^{-9} \text{ C}$
$0.07 \text{ nC} \times (1 \text{ C} / 0.000000001 \text{ nC}) = 7 \times 10^{-11} \text{ C}$
$15 \text{ nm} \times (1 \text{ m} / 0.000000001 \text{ nm}) = 1.5 \times 10^{-8} \text{ m}$

$8.987 \times 10^{9} \text{ N} \cdot \text{m}^2/\text{C}^2 \times (1.5 \times 10^{-9} \text{ C} \cdot 7 \times 10^{-11} \text{ C}) = 94.3635 \times 10^{-11} \text{ N} \cdot \text{m}^2$
$94.3635 \times 10^{-11} \text{ N} \cdot \text{m}^2 / (1.5 \times 10^{-8} \text{ m})^2 \rightarrow 94.3635 \times 10^{-11} \text{ N} / 2.25 \times 10^{-16} = 41.9 \times 10^{5} \text{ N}$, which rounds to $4.2 \times 10^{6} \text{ N}$

NuMask calculations:
$1.2 \text{ nC} \times (1 \text{ C} / 0.000000001 \text{ nC}) = 1.2 \times 10^{-9} \text{ C}$
$0.07 \text{ nC} \times (1 \text{ C} / 0.000000001 \text{ nC}) = 7 \times 10^{-11} \text{ C}$
$15 \text{ nm} \times (1 \text{ m} / 0.000000001 \text{ nm}) = 1.5 \times 10^{-8} \text{ m}$

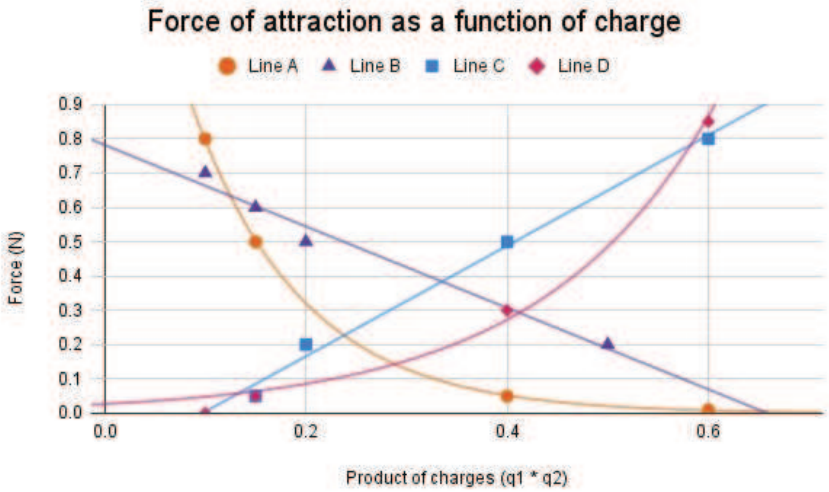
$8.987 \times 10^{9} \text{ N} \cdot \text{m}^2/\text{C}^2 \times (1.2 \times 10^{-9} \text{ C} \cdot 7 \times 10^{-11} \text{ C}) = 75.4908 \times 10^{-11} \text{ N} \cdot \text{m}^2$
$75.4908 \times 10^{-11} \text{ N} \cdot \text{m}^2 / (1.5 \times 10^{-8} \text{ m})^2 \rightarrow 75.4908 \times 10^{-11} \text{ N} / 2.25 \times 10^{-16} = 33.6 \times 10^{5} \text{ N}$, which rounds to $3.4 \times 10^{6} \text{ N}$

What to do: Ensure that students first converted nm and nC to m and C, respectively. If they struggled to do the unit conversions, remind students of how we used unit conversions in *Polar Ice Unit*. Have them look back at examples from Lesson 7. If students struggle with calculating Coulomb's law, point them back to *Solving for Force*. Ask them to think about how those charge values would affect how well the mask filters particles.

N95-type masks are not equally effective under all conditions. Because N95 masks can be expensive, people tend to use their masks multiple times. Though some masks are designed for multiple uses, most N95 mask fibers lose their charges with every use. These masks have been found to be significantly more effective in their first use compared to subsequent uses.

Many people do not understand that this decrease in effectiveness happens even when a mask looks perfectly clean. As we explored in item 4, "performance" is a question of forces and charges.

Use the following graph and what you know about chemistry to figure out what is causing this change in mask effectiveness. Note that the graph only considers forces and charges *generally*; it does not model specific objects.



5a. Which line in the graph best represents the relationship between charge and force as described in Coulomb's law, and could explain why the effectiveness of many N95 masks decreases with use? Circle your choice. (SEP: 2.3; DCI: PS2.B.1)

Line A Line B Line C Line D

5b. Explain why the line you chose best illustrates and predicts why the effectiveness of these masks decreases with repeated use. Be sure to use your understanding of the relationships in Coulomb's law to support your answer. (SEP: 2.3; DCI: PS2.B.1)

Key elements:
+ explains that Line C shows that as the product of charges decreases, the force of attraction decreases, which accounts for the phenomena described in the scenario
+ states that the relationship between charge and force as shown in Coulomb's law is directly proportional

Sample student response:
Line C best represents why the masks lose their effectiveness after each use because each time the charges decrease, the force of attraction decreases. Coulomb's law shows that there is a directly proportional relationship between the product of charges and the force, which means that as the product of charges increases, the force increases.

What to do: Support students' thinking around the scenario to the graph. Point out that the scenario considers that with each use of the mask, the charges decrease. Have students work backward on the charges portion of the graph to then think about what would happen to the force. Prompt them to do some quick calculations using Coulomb's law for additional support.

Lesson 10: Answer Key

Energy/Charge Model Key

This key is provided as guidance for the types of responses students may have on *Energy/Charge Model*. It is not suggested that you grade these items, as students will use the data to build a class consensus model explaining energy flows.

Use the computational model: https://lab.concord.org/embeddable.html#interactives/interactions/electricPE3.json.

1. Try changing different variables in the computational model. Leave the forces and the electric field on. By keeping the charges opposite, you can better represent the differences in charges within a storm cloud.
    a. Before you press PLAY to release the particles, what adjustments can you make to increase the energy stored in the field in this system?

You can increase the charges or move the particles farther away from each other.

    b. How are the forces affected when you make those adjustments to increase the energy stored in the field?

The forces go down when you move the particles apart.
The forces go up when you increase the charges.

    c. How is the electric field affected when you make those adjustments to increase the energy stored in the field?

The electric field in the middle gets weaker when you move the particles apart.
The electric field gets stronger when you increase the charges.

2. Press go/pause to release the particles.
    a. What happens to the energy stored in the field and to the kinetic energy in the system?

The energy stored in the field goes to zero, and the same number of bars of kinetic energy appear.

    b. What happens to the forces?

The forces get bigger.

3. Try releasing the particles from two different starting levels of energy stored in the field, one high and one low.
    a. What do you notice about the amount of kinetic energy in the system and the particle movement in each case? Record your observations in the table.

Starting energy stored in the field	Observations about the amount of kinetic energy	Observations about particle movement
high	The amount of kinetic energy is **high**, about the same as the starting amount of energy stored in the field.	The particles start to move slowly, then speed up.
low	The amount of kinetic energy is **low**, about the same as the starting amount of energy stored in the field.	The particles start to move a little more quickly, but do not move much before they hit.

    b. Do your observations make sense based on what we figured out in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*? Why or why not?

They do, because the energy was conserved. No energy went into or out of the system.

    c. Where did the kinetic energy come from?

It came from the energy stored in the field (potential energy).

    d. What causes the energy stored in the field to exist?

Student responses will vary, but an exemplar is shown. The whole-class discussion can help students come to consensus on an appropriate response to this prompt.

The energy in the field or space between the particles exists because the particles have charge and are pulling on each other.

4. Be prepared to discuss these questions with the class. Feel free to jot down some ideas, but you do not need to fully record your answers on this handout.

a. How did the results in the computational model compare to your predictions for like charges moving away from each other?

The energy in the field went down when like charges moved apart. (Responses will vary depending on whether this matched students' initial predictions.)

b. How did the results in the computational model compare to your predictions for like charges moving toward each other?

The energy in the field went up when like charges moved together. (Responses will vary depending on whether this matched students' initial predictions.)

c. Review your results for opposite charges and compare them to the results for like charges. What differences do you see?

Opposite charges interact in the opposite way of like charges.

When different charges are pulled apart there is more energy in the field, but when like charges are pulled apart there is less energy in the field.

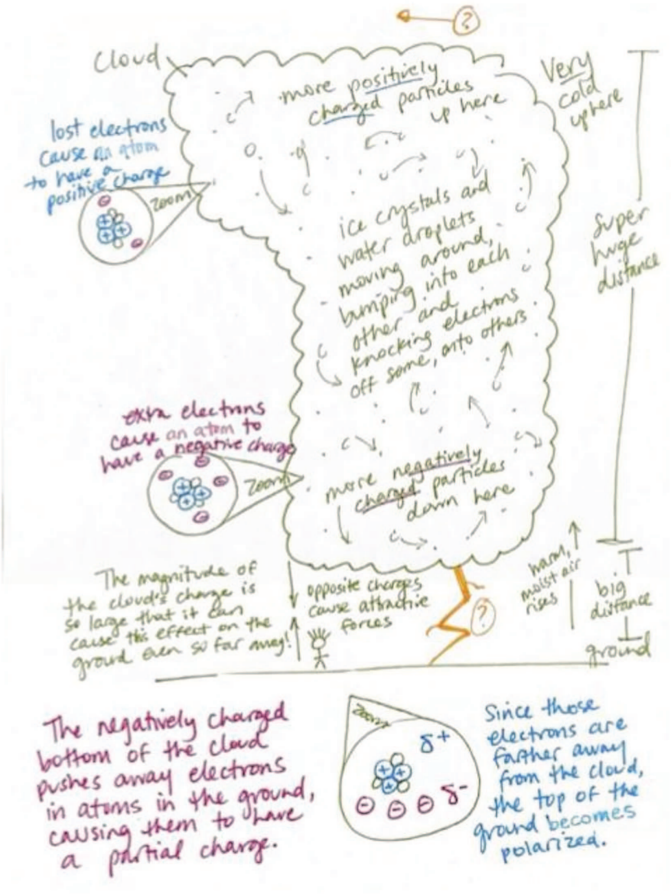
d. What general rules could we make for when there is a lot of energy stored in the field?

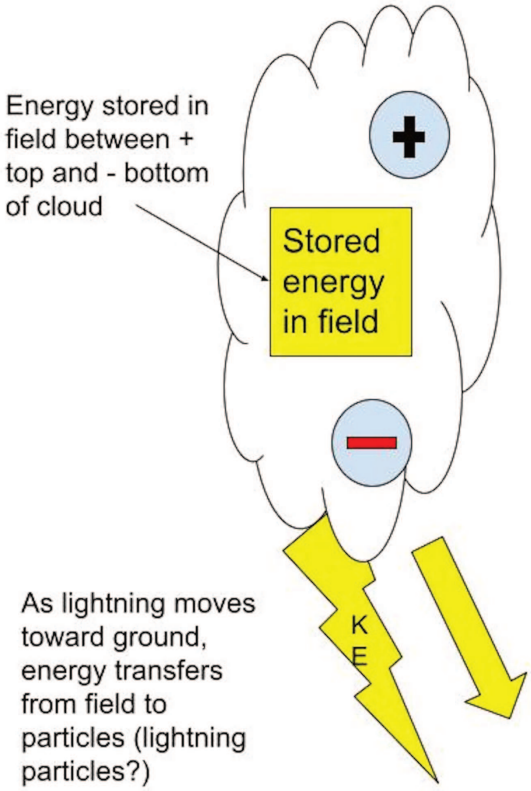
There is more energy in the field when opposite charges are really far apart.

There is more energy in the field when the charges are bigger.

The more energy is in the field, the more kinetic energy is released.

Model Revision Key





Lesson 11: Answer Key

Electronic Exit Ticket Key

This Electronic Exit Ticket mainly assesses students' knowledge around LLPE 11.A.

English L11 Exit Ticket: https://docs.google.com/forms/d/1ydoISMHNbVinJF7u3VhghGWT3wxXDXoofcZJ0KXVaaI/copy
Spanish L11 Exit Ticket: https://docs.google.com/forms/d/1iulw0L2EPYJh94FkKK-zqbr-5n0OKnLZB6tZvwFPde0/copy

11.A Gather, read, and evaluate scientific information about interactions between atoms in the lightning system which cause the strike we see between the cloud and the ground. (SEP: 8.3; DCI: PS1.A.3; CCC 2.2)

Where these elements are addressed in the assessment	**8.3 Obtaining, Evaluating, and Communicating Information** Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.	**PS1.A.3 Structure and Properties of Matter** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.	**2.2 Cause and Effect** Cause-and-effect relationships can be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller-scale mechanisms within the system.
Q1	X		X
Q2	X		X
Q3	X		
Q4	X		
Q5		X	X
Q6	X		
Q7			
Q8	X	X	
Q9			

People are still figuring out how forces and changes in energy cause matter to move in our world. Much about lightning is known. However, some areas of investigation are not completely decided.

Scientists agree that lightning produces nitrates, which are carried by rain to the ground. Some farmers say that crops look a little greener after lightning storms because of the extra nitrates. Other people say that their grass appears greener after a lightning storm.

Is lightning actually fertilizing crops? Scientists have investigated the idea that lightning produces enough nitrates to help plants grow. Here are some claims from different sources:

Source A: 2016 article on agriculture news site **Claim:** Rain, not nitrates from lightning, causes crops to get greener after lightning. **Supporting evidence:** Quote from a soil nutrition specialist with Manitoba, Canada's Department of Agriculture. No other sources shared. **Author credentials:** Not given	**Source B:** 2023 article in the peer-reviewed *Nature Geoscience* **Claim:** Nitrates from lightning were likely an important nutrient source for early plants, long ago in Earth's history. **Supporting evidence:** Analysis of ancient rock samples. Dozens of peer-reviewed sources cited. **Author credentials:** Lead author is a researcher at the Centre for Exoplanet Science, University of St. Andrews, United Kingdom, studying the conditions that could allow for life on other planets.
Source C: 2021 article in the peer-reviewed *Environmental Research Letters* **Claim:** In 2019, the percentage of nitrates in the atmosphere from lightning was about 18%. This percentage has been increasing since 2005 due to increased lightning. **Supporting evidence:** Analysis of data from the Environmental Protection Agency and satellite observations of the atmosphere. Peer-reviewed sources cited. **Author credentials:** Lead author is a researcher at the Center for Global and Regional Environmental Research, University of Iowa.	**Source D:** 2013 NOVA documentary produced by PBS **Claim:** Nitrate can be formed by chemical reactions from lightning. This nitrate falls to the Earth with raindrops, fertilizing the soil. **Supporting evidence:** Quote from a scientist with NASA's Goddard Space Flight Center, and satellite data of nitrates in the atmosphere. Other scientists are quoted elsewhere in the film, but their sources are not cited. **Author credentials:** Emmy-nominated science documentary producer

Question 1
Which source(s) would be useful in determining the *current* relationship between lightning, nitrates in the soil, and plant growth? Choose all that apply. • Source A • Source B • Source C • Source D
Correct response: Accept all responses. **Rationale for distractors:** All responses are accepted because students may have differing, valid reasoning for usefulness depending on not only the source's direct applicability to the question, but whether it is particularly useful to *the student* based on the limited information they have. **What to do:** See Question 2 and evaluate students' responses to these two questions together.

Question 2
Explain why the source(s) you chose in question 1 would be useful in determining the *current* relationship between lightning, nitrates in the soil, and plant growth?
What to look for in response: Students provide evidence from the source(s) they chose that highlights the relationship between lightning (cause), amount of nitrates in the soil (effect and cause), and current plant growth (effect). **What to do:** Ask students to expand on the evidence that led them to believe the source would be useful. Encourage them to consider how each source relates to the particular potential cause-and-effect relationship that is being addressed.

Question 3
Which claims are from authoritative sources? Choose all that apply. • Source A • **Source B** • **Source C** • Source D
Correct response: • Source B • Source C **What to do:** See students' reasoning in Question 4 for more information.

Question 4

Look back at your choices in question 3. What pieces of evidence allowed you to assess which sources are authoritative? What other information could help you be more sure of their reliability?

What to look for in response: Students mention that the sources they identified have author credentials with research experience AND/OR supporting evidence from peer-reviewed sources. Students say that comparison with other authoritative sources would help them be more sure of their reliability.

What to do: Encourage students to review *Gathering Information* with an emphasis on Part B, which focuses on authoritative sources. It may be beneficial for students to record in their notebook or explain to a peer or adult their response to each prompt in Part B so that it is clear what evidence they are basing their current evaluation on.

Question 5

Which explanation best illustrates the cause-and-effect relationship between lightning and molecules in the air to form nitrates?

- The energy from lightning heats up molecules, causing them to react to form new molecules (nitrates).
- **The energy from lightning transfers into the fields around charges in the air. This causes attraction between ions and other particles in the air to form new molecules (nitrates).**
- The energy from lightning causes particles to move apart and come back together. When they smash back together they react to form new molecules (nitrates).
- The energy from lightning causes particles to break up to form new molecules (nitrates).

Correct response: The energy from lightning transfers into the fields around charges in the air. This causes attraction between ions and other particles in the air to form new molecules (nitrates).

Rationale for distractors:
Students should recognize that the first explanation more closely describes the light emissions of lightning, and that a temperature increase is not sufficient to form the new molecules.
Students should recognize that the third explanation more closely describes the generation of thunder.
Students should recognize that the fourth explanation, although related to middle school thinking about reactions, does not fully describe the current phenomenon.

What to do: Have students discuss the cause-and-effect relationship between lightning and molecules in the air as modeled in class. Then help them transfer this understanding to nitrates, emphasizing the attraction that would likely occur between the ions that are left after lightning occurs.

Question 6

How did obtaining and evaluating information help you make sense of why the electrons build up in the cloud and then jump to the ground suddenly?

What to look for in response: Students describe examples of activities, experiences, or ways of thinking they engaged in. Sample responses:

- Researching how a lightning strike actually moves gave us information that we needed to model it.
- Looking at different sources gave us multiple perspectives, which helped us figure out more clearly what is really going on in the system.

What to do: If students do not cite particular instances of thinking or experiences from the last two days of work, provide the list above and ask students to select an experience or activity that helped them figure out what was happening at the particle level in a cloud.

Question 7
Have you experienced, heard stories about, or seen videos of situations where there was a large amount of energy transferred? What did you experience/hear/see?
What to look for in response: Accept all relevant responses. **What to do:** Note phenomena that students identify. You may anonymously share some of these as interesting related phenomena, refer to them in class when productive, or anticipate them as possible related phenomena that may be generated in the anchor lesson in future years.

Question 8
The reading talked about one impact of electrical forces on matter interactions between air and soil. To understand how electrical forces affect other materials, what types of information would you want to gather and how might you find trustworthy information?
What to look for in response: Students should discuss gathering information about what other materials exist, what they are made of, and how electrons move in and around them. They should discuss going to sources that are reliable by being peer-reviewed, having an expert author, and/or displaying no clear biases. **What to do:** Direct students to the relevant portion of the reading and reflect in small groups on how electrical forces are involved with air and soil in this particular case. Generate lists of different materials or categorize particular objects that have been used in the unit to more easily brainstorm other information that would be helpful about these particular materials.

Question 9
Describe a contribution you have made in class recently. How do you think that contribution helped your classmates?
What to look for in response: Accept all relevant responses. **What to do:** Encourage students who have incomplete responses or who speak negatively of their own contributions. Do so by highlighting their contributions individually when possible, and to their classmates when appropriate.

Lesson 13 Teacher Reference

Ammeter Construction Directions

Repeat each step of the instructions below **seven times** to make seven ammeters. It is recommended that you do this assembly-line style, in five stages, to save time. Each of the five stages is outlined on a separate page of this document. This provides a natural place to pause to make sure that all steps have been completed seven times before starting the next stage.

Materials needed for each ammeter:

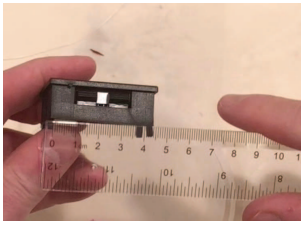
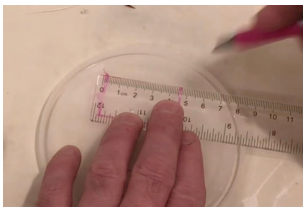
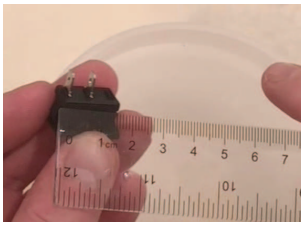
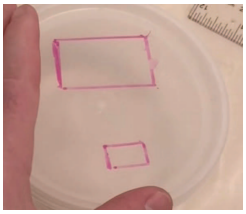
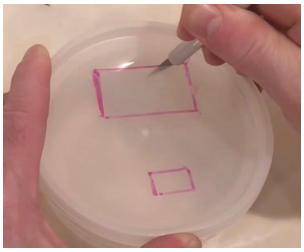
- LED Voltmeter Ammeter (Red and Blue Digital Multimeter Display Voltage Current Tester, DC 0-100V 10A)
- 9V battery
- 9V battery connector
- 2-pin boat rocker switch
- 8-oz round deli container with lid

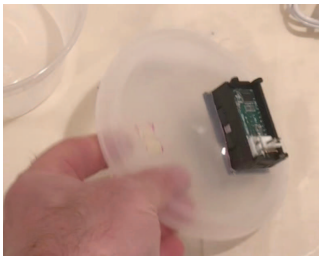
Additional materials needed for assembly:

- Ruler
- Marker
- Box cutter or utility knife
- Scissors
- Electrical tape
- Hot glue gun
- Hand drill

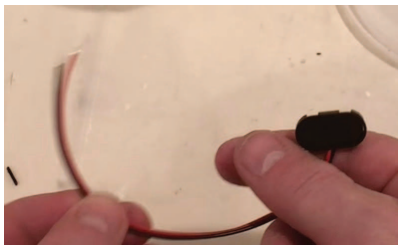
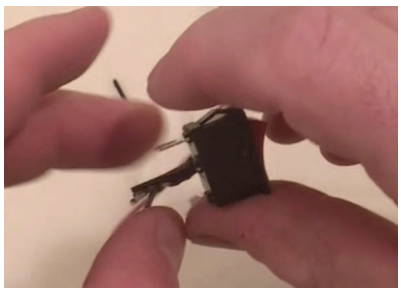
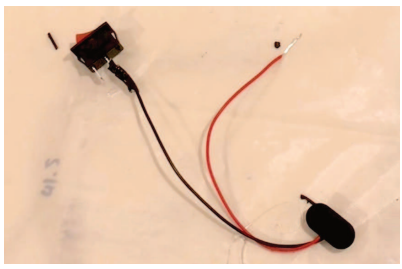
A construction video may be found at https://youtu.be/XUh8ZagrpnE.

Stage 1: Fitting holes in the lid

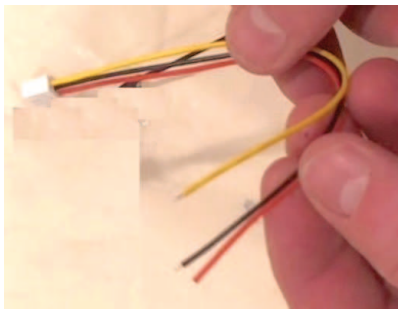
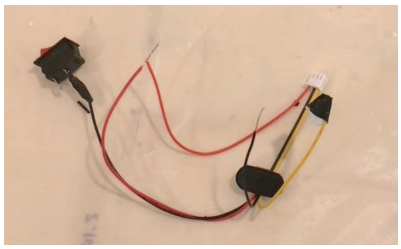
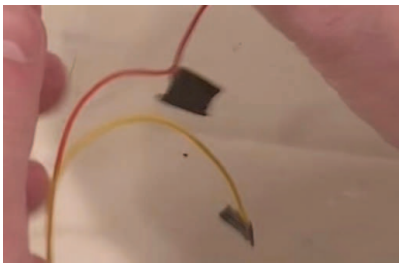
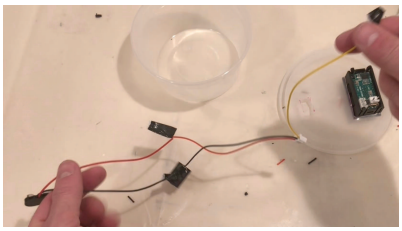
Instruction Steps	Associated Images
Measure the dimensions of the base of the LED Voltmeter Ammeter. Draw a rectangle with those same dimensions on the top half of the deli lid.	 
Measure the dimensions of the base of the rocker switch. Draw a rectangle with those same dimensions on the bottom half of the deli lid.	 
Secure the lid to the deli container. Cut out the two rectangles you drew on the lid using a box cutter or utility knife. Take off the lid and remove the pieces you cut out.	 

Secure the lid to the deli container. Push the LED Voltmeter Ammeter into the large rectangular hole in the lid. Push the rocker switch into the small rectangular hole in the lid. After confirming the fit of both objects, take off the lid and remove the rocker switch from the small hole for now.	 

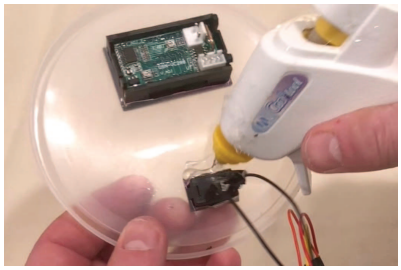
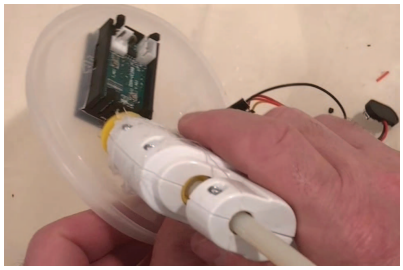
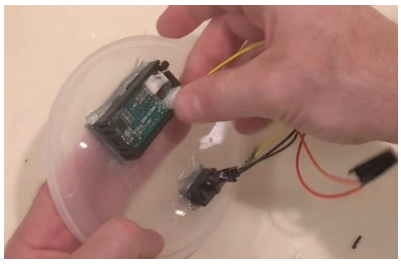
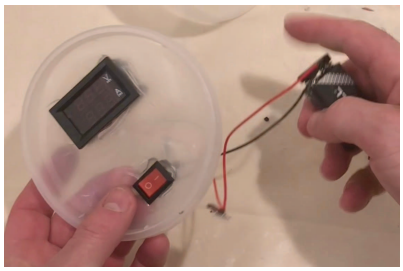
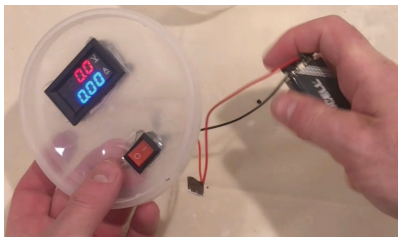
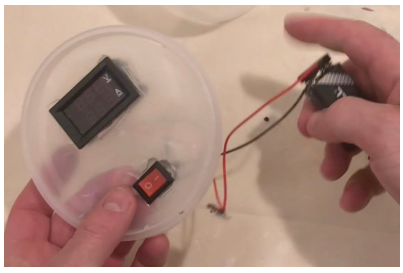
Stage 2: Attaching the battery connector to the switch

Instruction Steps	Associated Images
Strip off 1/2-1" of insulation from the end of each wire on the 9V battery connector. You can do this by using a slightly open pair of scissors. Drag the end of each wire along the edges of the scissors while applying light pressure. This should pull the insulation off the wire.	 
Thread the stripped end of the black wire of the battery connector through the hole in one of the metal prongs on the back of the rocker switch. Twist the end of the wire around the rest of the wire, like you would a twist tie.	 
Wrap a small piece of electrical tape around the twisted wire and the metal prong on the switch so that no metal is visible. The second image shows how the battery connector is attached to the rocker switch at this stage of the build.	 

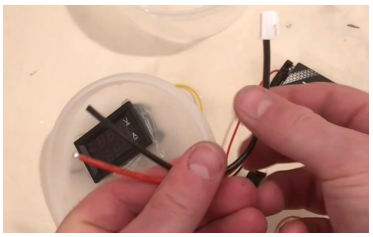
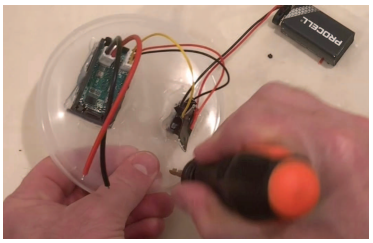
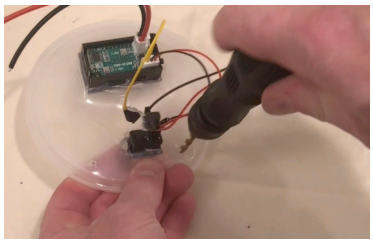
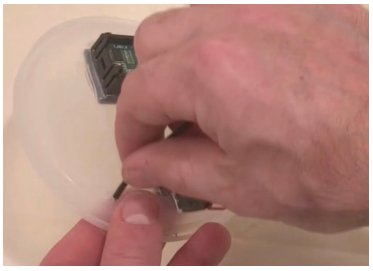
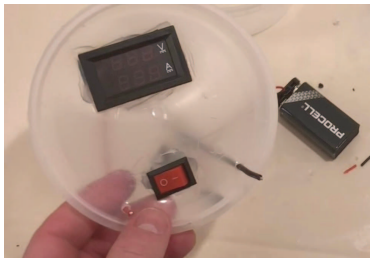
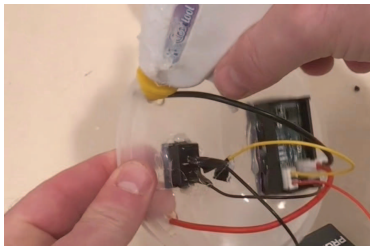
Stage 3: Attaching the first adapter to the battery connector and switch

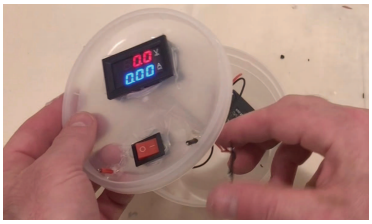
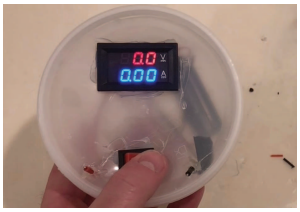
Instruction Steps	Associated Images
Locate the three-wire adapter included with the LED Voltmeter Ammeter. Strip off 1/2-1" of insulation from the end of the red wire and the black wire. Do not do this for the yellow wire.	 
Twist the stripped end of this red wire around the stripped end of the red wire from the battery connector. Wrap a small piece of electrical tape around the twisted ends of these wires. Wrap a small piece of electrical tape around the end of the yellow wire. This wire is for measuring voltage and is not used in this unit.	 
Thread the stripped end of the black wire from the adapter through the hole in the other metal prong on the back of the rocker switch. Twist the end of the wire around the rest of the wire to secure it. Wrap a small piece of electrical tape around the twisted wire and the metal prong on the switch so that no metal is visible. The second image shows the assembly at this stage of the build.	 

Stage 4: Connecting power to the ammeter panel

Instruction Steps	Associated Images
Thread the battery connector and wires through the small hole in the lid so that the rocker switch is on the outside. Ensure that the switch is pushed flush into the hole and that the wires and the battery connector are on the underside of the lid.	 
Use the hot glue gun to apply glue along the edges of the switch where it meets the underside of the lid. Do the same for the LED Voltmeter Ammeter.	 
Connect the white coupling clip for the three-wire adapter to the bottom white port on the back of the ammeter panel. Align it so that the clip snaps into the port. Attach a 9V battery to the battery connector.	 
Flip the rocker switch to test that the LED display turns on. Flip the switch back off for now.	 

Stage 5: Positioning the circuit leads

Instruction Steps	Associated Images
Locate the two-wire adapter included with the LED Voltmeter Ammeter. Snap the white coupling clip into the top white port on the back of the ammeter panel.	 
Use the hand drill to make two holes in the lid. The holes should be on either side of the rocker switch, about 1" from the switch.	 
Thread the red wire through the left hole (when viewed from the top of the lid). Thread the black wire through the right hole.	 
Use the hot glue gun to apply glue where each wire meets the lid. Do this on both the top and bottom sides of the lid.	 

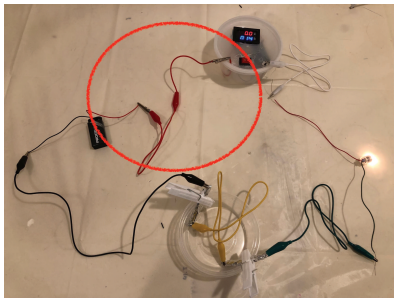
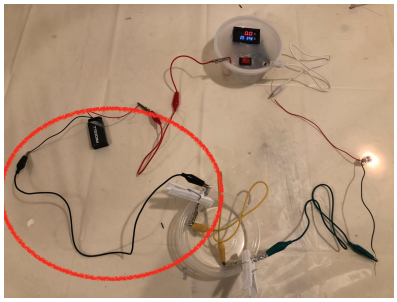
Flip the switch on to test that the ammeter panel still works. Guide all the wires and the battery into the deli container. Secure the lid to the container. You may want to test the wire connections by giving the container a slight shake. If the connections are tight, the panel will remain powered. If the LED display turns off with the shake, disassemble the ammeter and check various connections. If you find a loose connection, tighten the twisted wires, retape them, and test the power again.		

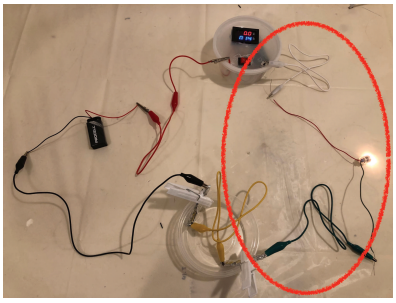
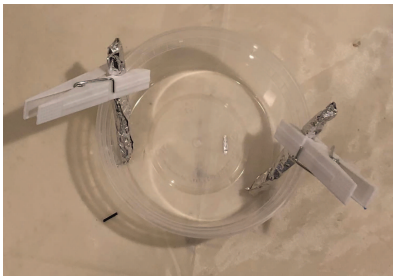
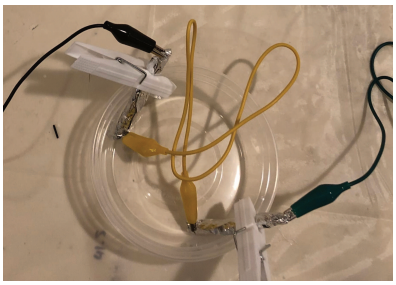
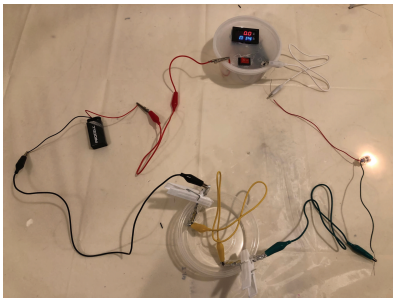
Setting up the circuit

For each investigation station, connect wires with alligator clips as described below to build the setup students will use. The colors of the wires described below match what is shown in the images.

Materials needed for the circuit:

- Five wires with alligator clips, one each of red, white, green, black, yellow
- Light bulb (E10, 12V, 0.3A)
- E10 Screw-Mount Bulbs Holder
- 9V battery
- 9V battery connector
- Two pieces of straw wrapped in aluminum foil or two straightened paper clips
- Two clothespins

Use a red wire with alligator clips to connect the red wire of the battery connector to the red lead on the ammeter.	
Use a black wire with alligator clips to connect the black wire of the battery connector to a piece of straw wrapped in aluminum foil.	

Use a wire to connect the black wire connected to the ammeter to one of the wires on the light bulb, and another wire to connect the light bulb to the other foil-wrapped straw.	
Use a clothespin to secure each foil-wrapped straw wrapped in aluminum foil to the side of the beaker so that the ends of the straws are inside the beaker.	
Connect each end of a yellow wire to one of the foil-wrapped straws to complete the circuit.	
When the circuit is complete, it should look something like the image shown here.	

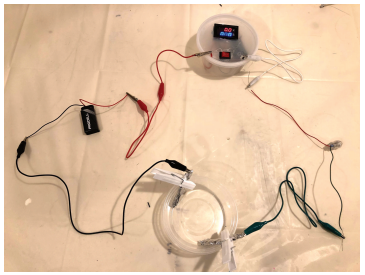
Lesson 13: Answer Key 1

Salt Investigation Key

Investigation Question: How does dissolving salt in water affect the rate of charges moving through it?

1. Examine the Water Source Information table and the Supplies Available table below.

Water Source Information	
Water Source	**% of Salt**
Distilled water	0.00
Drinking water	0.10
Lake Michigan water	0.05 - 0.06
Ocean water	3.30 - 3.80
Pool water	3.50 - 4.00
How % of Salt Is Determined	
A 1% salt solution means that 1 g of salt is dissolved in 100 g of water.	
The density of water is 1 g/mL. So, 100 g of water has a volume of 100 mL. You could also say that: 100 g water = 100 mL water	

Supplies Available	
Ammeter system (see image)	
50 g table salt	
500 mL distilled water	
250-mL beaker	
Digital scale	
Stirring rod	
Safety supplies: sanitized indirectly vented chemical safety goggles, non-latex apron, nitrile gloves	

2. **Use mathematical thinking to plan your investigation.** Use the table below to:

- Determine the different percentages (greater than 0.00%) of salt in water that you want to test. Then calculate the masses of salt needed to achieve those percentages.
- Outline a procedure for how you plan to use the limited supplies available to test these percentages of salt and collect data.

Percentages of Salt in Water to Test and Masses of Salt Needed
1% - 1.0 g NaCl in 99 g (99 mL) of water
2% - 2.0 g NaCl in 98 g (98 mL) of water
3% - 3.0 g NaCl in 97 g (97 mL) of water
5 % - 5.0 g NaCl in 95 g (95 mL) of water
7.5 % - 7.5 g NaCl in 92.4 g (92.5 mL) of water
10% - 10 g NaCl in 90 g (90 mL) of water
Investigation Procedure
1. Gather materials: a beaker, stirring rod, scale, salt, water, ammeter. 2. Pour 100 mL distilled water into the beaker. 3. Measure 1 g NaCl on scale and add to the beaker. Record the exact mass and stir to dissolve. 4. Add foil-wrapped straws to beaker and record ammeter reading. 5. Repeat steps 3-4 with a 2%, 3%, 5%, 7.5%, and 10% NaCl solution. Ensure students attend to investigation safety, including: • Wear sanitized indirectly vented chemical safety goggles, non-latex apron and nitrile gloves during the setup, hands-on, and takedown segments of the activity. • Use caution when using sharps (wires, etc.), which can cut or puncture skin. • Immediately clean up any liquid spilled on the floor, so it does not become a slip/fall hazard. • Use caution when working with or near sharps (tools, wires, etc.), which can cut or puncture skin. • Keep away from water sources to prevent shock when working with electrical circuits or electricity sources. • Use caution when working with glassware. The pieces of broken or shattered glassware are sharp and can cut hands. • Wash your hands with soap and water immediately after completing this activity.

3. **Set up your data table.** In the table below, enter the values for columns A-C based on your investigation plan.

Salt solution % (column A)	Mass of salt (g) dissolved in water (column B)	Mass of water (g) (column C)	Observations of light bulb (column D)	Current (mA) (column E)	Charges per second flowing through the system (column F)
1	1.0 g	99 g	Very dim light	0.03 mA	(0.03 mA / 1) x (6.24 x 10^{15} charges/second / 1 mA) = 1.9 x 10^{14} charges/second
2	2.0 g	98 g	Slightly brighter light	0.05 mA	(0.05 mA / 1) x (6.24 x 10^{15} charges/second / 1 mA) = 3.1 x 10^{14} charges/second
3	3.0 g	97 g	Bright light, brighter than 2%	0.06 mA	(0.06 mA / 1) x (6.24 x 10^{15} charges/second / 1 mA) = 3.7 x 10^{14} charges/second
5	5.0 g	95 g	Bright light, brighter than 2%	0.09 mA	(0.09 mA / 1) x (6.24 x 10^{15} charges/second / 1mA) = 5.6 x 10^{14} charges/second
7.5	7.5 g	92.5 g	Bright light, seems fully lit	0.11 mA	(0.11 mA / 1) x (6.24 x 10^{15} charges/second / 1mA) = 6.9 x 10^{14} charges/second
10	10.0 g	90 g	Bright light, seems fully lit	0.12 mA	(0.12 mA / 1) x (6.24 x 10^{15} charges/secon / 1 mA) = 7.5 x 10^{14} charges/second

4. **Carry out your investigation.** Record the investigation data in columns D and E of the data table.
5. **Use mathematical thinking.** Calculate the number of charges per second flowing through each salt solution. Add these values to column F. Use the following ratio to help you:
1 mA of current = 6.24 x 10^{15} charges per second

6. **Evaluate our claim.** Respond to the claim in the table below. Use specific evidence from columns E and F to support your response.

Claim: 50 geese were electrocuted by lightning while sitting on the St. Lawrence River.
The data from the Salt Investigation support the claim that the geese were electrocuted by lightning. In the Salt Investigation, the greater the percentage of salt in the water, the higher the current, or charges moving per second. The water source information shows that Lake Michigan has a salinity of 0.05-0.06 %, and ocean water has a salinity of 3.30 - 3.80 %. Since the St. Lawrence River goes from the Great Lakes to the Atlantic Ocean, it probably has a salinity between the salinity of Lake Michigan and ocean water. The data shows that even a 1% NaCl solution can conduct electricity, so the St. Lawrence River would conduct electricity if it was struck by lightning.

7. What new questions does this investigation raise for you?
Accept all responses.

Lesson 13: Answer Key 2

Model Evaluation Key

Directions:

1. Before you evaluate the candidate models, add the questions about the phenomena that the models are trying to explain in Table 1: Questions the Model Is Trying to Answer AND in Table 3: Explanatory Power.
2. Add key model ideas your class decided are necessary to explain these phenomena in Table 2: Key Model Ideas Checklist.
3. Evaluate each candidate model using Tables 2 and 3 to keep a record of:
    - which models use which of the key ideas your class is looking for [yes or no] (*Table 2*); and
    - your rating of each model's explanatory power [scale of 1-10] (*Table 3*). *Note*: Student ratings may vary from the sample provided.
4. Use Table 4: Candidate Model Evaluation to explain whether you accept each model, and provide reasoning for why or why not. *Note*: Sample answers are provided, but students may use different words.
5. Add any new model ideas from the models you have accepted in the space below Table 4.

* **Note for Table 4: Candidate Model Evaluation**: In many cases where current flows through salt solutions, new substances are made (products). While students saw no evidence of this in their investigation, revisiting this phenomenon during the next unit, *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*, may provide some students a meaningful extension opportunity that further emphasizes the nature of science related to how and why models are revised in light of new evidence.

Table 1: Questions the Model Is Trying to Answer

What questions is the model trying to answer?
Q1: How does water cause salt to dissolve?
Q2: Why does salt water conduct electricity?How are we getting charge flow in salt water?

Table 2: Key Model Ideas Checklist

Key Model Ideas For each idea, write *yes* or *no* to indicate whether that idea is present in each candidate model.	Candidate models		
	Karla	Jadon	Miguel
A. Table salt breaks into smaller particles when it dissolves in water.	yes	yes	no
B. Water is made of molecules which are made of atoms (H_2O).	yes	yes	yes
C. Table salt is made of Na and Cl atoms.	yes	yes	yes
D. Salt is an ionic compound made of positive and negative ions that form by gaining or losing an electron from a neighbor.	no	yes	yes
E. These ions are held together by attractive forces. (relatively weak; but note that this portion is added later in the lesson)	yes	yes	no
F. These ions separate when salt dissolves in water and the charges can move in the water.	yes	yes	no

G. Electric forces between charges are stronger when charges are closer to each other.	no	yes	no

Table 3: Explanatory Power

Explanatory Power: How well does the model explain the phenomena?	Candidate models		
Rate on a scale of 1 (not well) to 10 (very well).	Karla	Jadon	Miguel
Q1: How does water cause salt to dissolve?	1	9	1
Q2: Why does salt water conduct electricity??	4	10	10

Table 4: Candidate Model Evaluation

Model by:	Karla	Jadon	Miguel
Accepted or Rejected	Rejected	Accepted	Rejected
Reasoning	The model does not really answer the question about how the salt is getting dissolved? What's causing that? Also, we said there would be positive charges moving, too (and this model only shows electrons moving).	This model shows that water molecules' positive and negative sides pull salt apart into its Na^+ and Cl^- ions, which can then move, allowing electric current to flow.	The model shows charge movement but does not explain how the salt is getting dissolved. What's causing those free electrons to be there?

Sample new ideas the models show:

- These ions are held together by **relatively weak** attractive forces.
- Water molecules are permanently polar (they have positively and negatively charged sides).
- When these water molecules make contact with the salt they pull individual ions off of it, causing it to break apart (dissolve).

Name: _____ Date: _____

Lesson 13: Answer Key 3

Lightning Safety Claims

Directions:

1. Examine the claims and data about lightning, water, and lightning safety presented in articles and videos from across the web.
2. **Choose 2-3 claims to evaluate.** *Note:* The handout includes four claims to allow for modifications or student choice in this activity. Students are not required to complete all four rows shown in this key.
3. Below the claim, evaluate the claim's accuracy by checking a box to describe it as *fully accurate, partially accurate,* or *not accurate.* *Note:* Although this is a valuable assessment opportunity, it is encouraged that you accept a fairly broad range of student answers based on the evidence and reasoning provided.
4. Use evidence and ideas that we figured out during this lesson and unit to verify the accuracy of the claim and explain how the evidence and ideas support your evaluation of the claim.

Claim	Evidence	Reasoning
Evaluate each claim as: • Fully accurate • Partially accurate • Not accurate *Note:* In this key, some claims may have two boxes checked. This means that it is OK for students to check either one of the boxes, depending on their evidence and reasoning.	List evidence and ideas that you investigated in the unit that could help support your evaluation. Also include where the evidence and ideas came from.	Explain how your evidence helps support your evaluation.
Lightning is attracted to metal, tall buildings or trees, and water. This is why a person should never be in water, near metal, or under a tree when there is lightning nearby. *Adapted from Answers.com* **Your evaluation of the claim:** • Fully accurate • Partially accurate • Not accurate	• *A spark occurred in the water dropper system between pennies that were close together. (Lesson 2)* • *Electrons (negative charges) are attracted to positive charges. (Lessons 3-4)* • *Lightning is energy in the form of moving electrons in a strong electric field. (Lesson 10 simulation)*	*This claim is not fully accurate. Lightning cannot be attracted because lightning is not a "thing". If lightning is just electrons and not related to strong electric fields, then lightning would be everywhere and attracted to all positively charged protons, which are everywhere!* *Note:* If a student provides an explanation for "partially accurate" here, it may look something like the below. *We do, however, see lightning strike metal, tall buildings/trees, and water more frequently either because they are good at helping electrons move (metal, water) or because they are closer to the clouds where the lightning is generated (tall buildings and trees).*

A bolt of lightning that hits a house or building — even one that is protected against severe weather — can travel through plumbing, into metal pipes, and shock anyone who comes into contact with a faucet or appliance, such as a shower. Metal pipes are not only excellent conductors of electricity, but they also carry tap water laden with impurities that help conduct electrical current. Likewise, lightning does not have to strike a swimming pool itself to cause electrical shocks in the pool. A pool is connected to a much larger area with a network of underground pipes, electric wires, and gas lines. If lightning strikes any of those, the electricity can travel into the pool. *Adapted from The New York Times and UXL Encyclopedia* **Your evaluation of the claim:** • Fully accurate • Partially accurate • Not accurate	• *Tap water allowed the light bulb in the conductivity meter to turn on. (Lesson 13 investigation)* • *Tap water is different from distilled water because it has some ions in it. (Lesson 13 investigation)* • *Metal conducts electricity because the conductivity meter and all wires are made of metal.* • *Energy is transferred in lightning in the form of moving charges/electrons in a strong electric field. (Lesson 10 simulation)*	*This claim is likely accurate because we have seen metal touching tap water conduct electricity. We also learned that the structures of both metal and water with dissolved ions in it allow for electrons to move well, which is how lightning is defined.* *Note:* If a student provides an explanation for "partially accurate" here, it may look something like the below. *But if lightning were to strike an area and continue to travel through the entire network of pipes, wires, and water, and that area was connected to the local power grid, then theoretically all the buildings of an entire neighborhood would be struck by the one lightning bolt, and that does not happen on a huge scale like that.*

Marine scientist Mustafa Asfur stumbled on a possible solution to a long-standing mystery: why bolts of lightning are brighter over the ocean than they are over land. More than 90 percent of lightning bolts strike over the continents, but the lightning that strikes the ocean can be far more intense and dangerous for boaters. Rare "superbolts," for example, with flashes 100 or 1,000 times brighter and more powerful than a regular bolt, are far more likely to hit the ocean. Asfur discovered that, in the lab at least, lightning-like discharges are brighter over saltwater than over fresh water or soil. Discharges over Dead Sea water, which is about 680 times saltier than water from the Sea of Galilee, which is barely salty, were nearly 40 times brighter. Flashes over Sea of Galilee water were 1.5 times brighter than over wet soil. *Adapted from Hakai Magazine* **Your evaluation of the claim:** • Fully accurate • Partially accurate • Not accurate	• *At 1.5% salinity the conductivity meter light bulb was very faintly glowing and the current was 0.05 mA, but at 10.5% salinity the bulb was normal brightness with a current of 0.12 mA. (Lesson 13 investigation)* • *Salt water means there are ions dissolved in it, and dissolved ions help conduct electricity. (Lesson 13 Electrolytes reading)*	*This claim is likely accurate because we have seen saltier water allow for more electrical current to move through a light bulb. A light bulb helps us see the energy of electrons moving, just like lightning. We also understand that the presence of ions in water allows for positive and negative charges to move when electricity is run through it because they are separated by the water and can move freely toward a positive or negative end.* *Note:* If a student provides an explanation for "partially accurate" here, it may look something like the below. *I put the claim as "partially accurate," however, because more evidence or information is needed to know for sure whether the claim is accurate.*
Someone swimming in fresh water is at greater risk of death from lightning than someone in seawater. Because fresh water is a poor conductor of electricity, a human body becomes the sponge for electrical current from a nearby lightning strike. In contrast, saltwater disperses electrical current rapidly in all directions and a body would receive less current from a nearby strike. *Sourced from Triton News Network* **Your evaluation of the claim:** • Fully accurate • Partially accurate • Not accurate	• *Great Lakes water which is fresh water has 0.05% salinity, which is way less than ocean water which has at least 3.80% salinity.* • *At 1.5% salinity the conductivity meter light bulb was very faintly glowing and the current was 0.05 mA, but at 10.5% salinity the bulb was normal brightness with a current of 0.12 mA. (Lesson 13 investigation)* • *Human bodies contain lots of electrolytes, which conduct electricity. (Lesson 13 Electrolytes reading)*	*This claim is accurate because we saw in our experiment that more salt in the water made it better at conducting electricity. We also know that the salinity of fresh water from a natural body of water like the Great Lakes is much less than that of ocean water, so a lightning strike in the fresh water would have a harder time continuing to conduct the electricity and would find a person swimming in it to be an ideal conductor of electricity.* *Note:* If a student provides an explanation for "partially accurate" here, it may look something like the below. *We do not have evidence to show that the human body would act like a "sponge" for the current since we don't know the difference in salinity between the human body and the salt water. It makes sense though, based on what we do know about electrons finding a pathway to flow.*

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Lesson 14: Answer Key 1

Consensus Checklist Key

Building toward 14.A Develop and revise a model based on evidence to illustrate and predict the relationships between components of a model that explains why certain places are safer than others when lightning strikes based on patterns observed at different scales. (SEP: 2.3; DCI: PS2.B.3; CCC: 1.1, 3.3)

3D Elements Addressed in This Assessment	
SEP	Develop, ~~revise, and/or use~~ a model based on evidence to illustrate ~~and/or predict~~ the relationships ~~between systems or~~ between components of a system. (SEP: 2.3)
DCI	Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, ~~as well as the contact forces between material objects.~~ (DCI: PS2.B.3)
CCC	Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (CCC: 1.1)
	Patterns observable at one scale may not be observable or exist at other scales. (CCC: 3.3)

Develop a list of components, interactions/relationships, and mechanisms that a model should include to answer the question: *Why are some places safer than others when lightning strikes?*

You will model one of these two scenarios:

- Staying away from bodies of water
- Staying inside a building with a lightning rod or indoor plumbing

Draw on these resources to help build your list:	
• Progress Tracker • Simulation of charges in a field: *Energy/Charge Model*, https://openscied-static.s3.amazonaws.com/HTML+Files/Energy+in+a+Two+Charge+System.html • Research on lightning: *Gathering Information* • *Power of Lightning* reading • *Lightning Rods* reading	• *Metals/Nonmetals Comparison* handout • *Geese Lightning Strike* reading • *Electrolytes* reading • Data from investigation on water conductivity: *Salt Investigation Plan* • Most recently revised lightning model

Our model needs to answer the question: *Why are some places safer than others when lightning strikes?* We are modeling this specific scenario: _____		
Components (parts/objects in system)	**Interactions/Relationships** (connections between components)	**Mechanisms** (how and why interactions lead to effects)

Either scenario Electrons Energy Charge at bottom of cloud Ionized air	Repulsive forces between electrons that are near each other or attractive forces between electrons and positive ions that are near each other Electrons move freely in conductors	Electrons pushed away through material by nearby electrons or pulled by nearby positive ions Electron motion transfers energy through conductive material Electrons do not move through an insulating material, so they do not transfer energy
Staying away from bodies of water Water molecules (polar) Dissolved ions (e.g., Na^+ and Cl^-)	Attractive forces holding Na^+ and Cl^- together before dissolution Attractive forces between charged ends of water molecules and ions Dissolved ions move freely in water	Water molecules surround salt and pull off individual ions Positive and negative ions move in opposite directions when lightning strikes water. Moving charge carries energy. (Optional): Living things in water can be harmed if they are in or near the water, because they also contain ions which can move freely through fluids in their body and transfer energy.
Staying inside a building with a lightning rod or indoor plumbing Lightning rod or plumbing (made of metal) Wood building material Ground	Electrons move freely in a lightning rod or plumbing, but not in wood Ground polarized so that positive charge is near surface	Electrons move freely throughout the lightning rod or plumbing, so they can easily carry energy to materials. Because of the metal in the system, charge (and energy) does not flow through the wood, so it cannot catch fire.

After your class has developed a consensus Gotta-Have-It Checklist:

1a. Build a model to explain: *Why are some places safer than others when lightning strikes?*

Specifically, your model should focus on one of the following:

- *Why is it safer to be away from water during a storm?*
- *Why is it safer to be in a building with lightning protection during a storm?*

Use the Gotta-Have-It Checklist and check off items as you include them in your model. Make your thinking clear by using:

- zoom-ins
- arrows
- shapes/symbols (with a key or legend)
- words and phrases

See below for guidance. Note: It is not necessary for students to include information about how the charge differential is generated in the cloud, as this idea was modeled completely in Lesson 9.

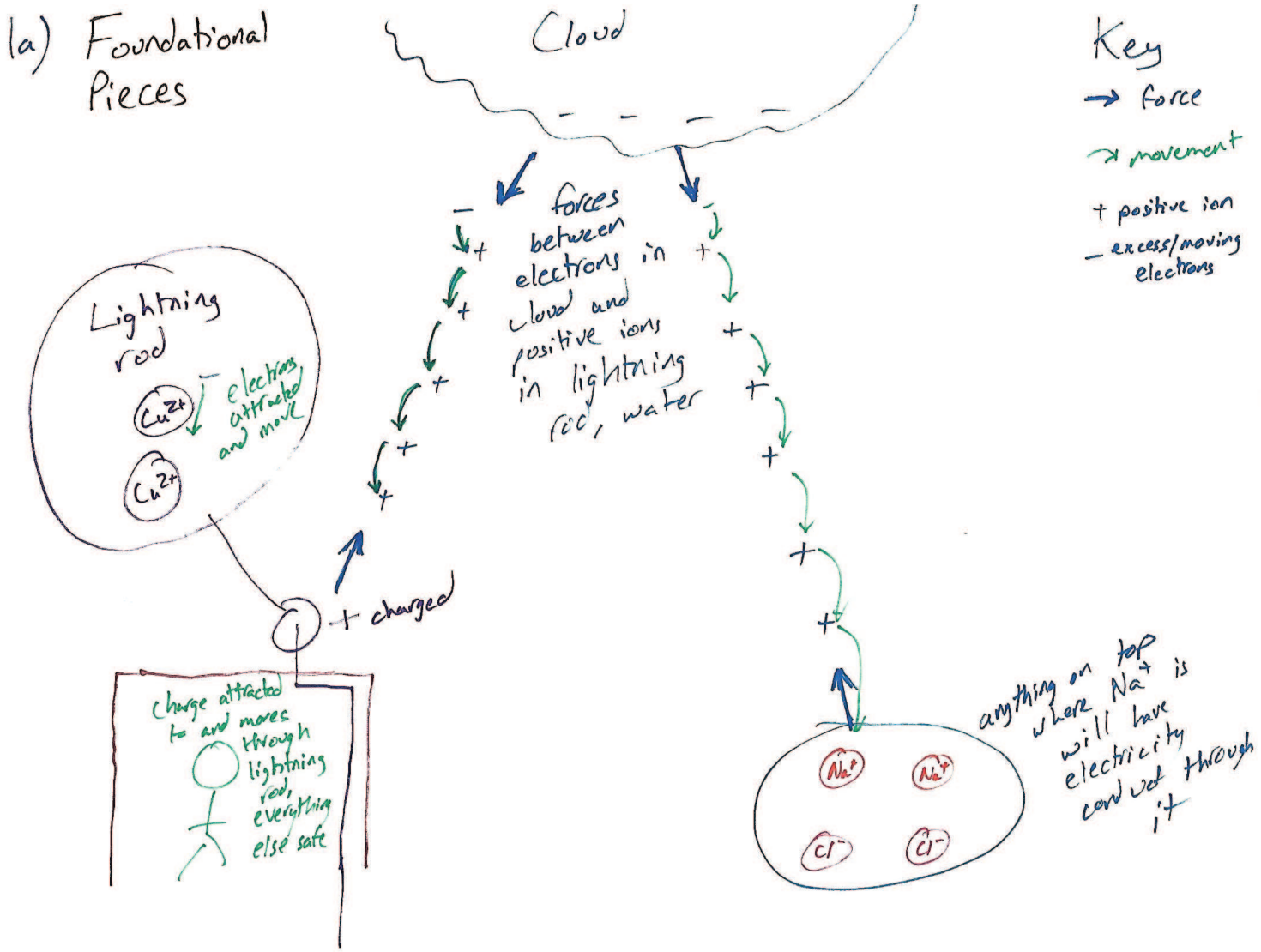
1b. In this unit, we identified a lot of evidence of patterns at different scales (global patterns from maps and data, visible evidence from investigations, particle-level evidence from simulations). Explain how this evidence supports your model at multiple scales.

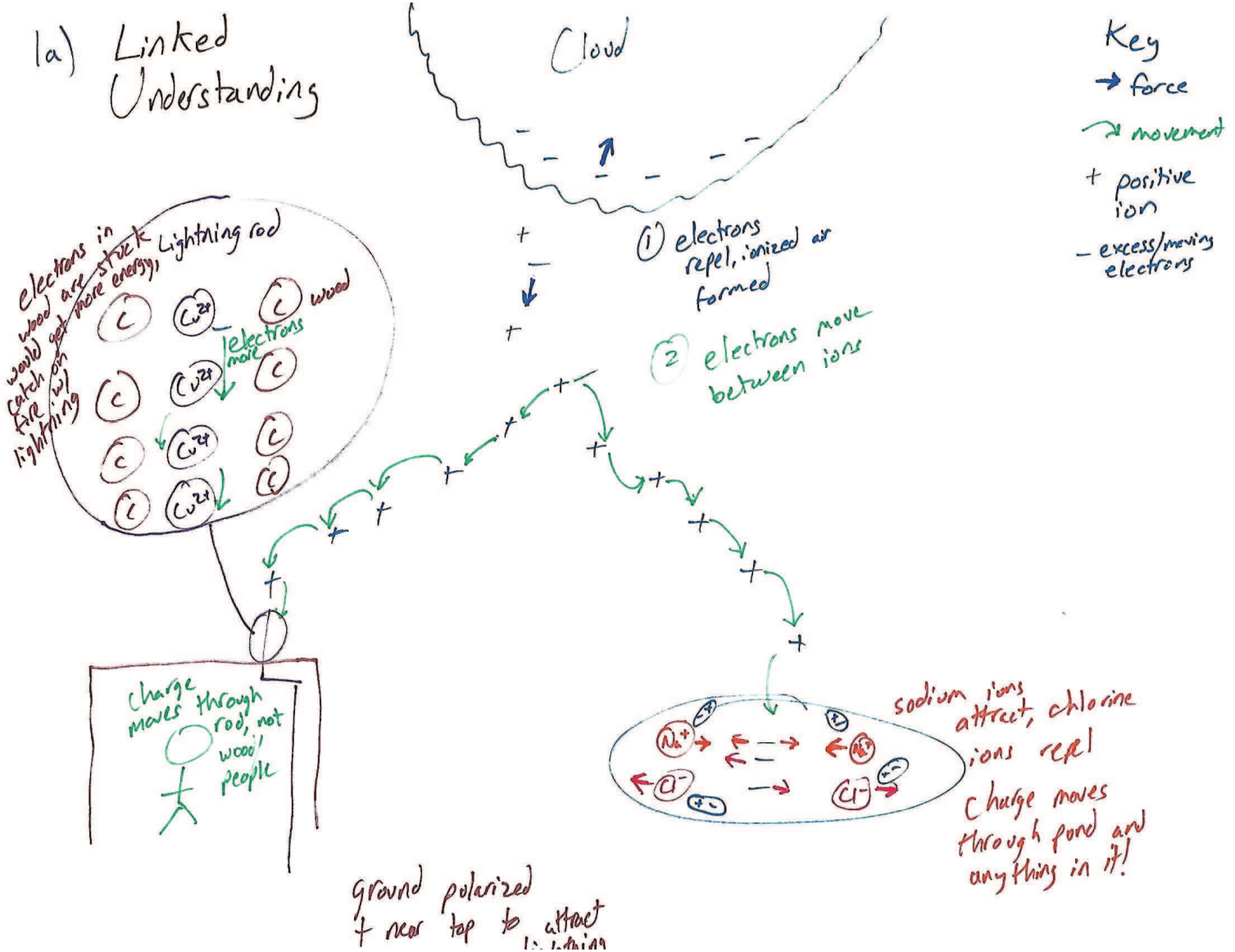
See below for guidance

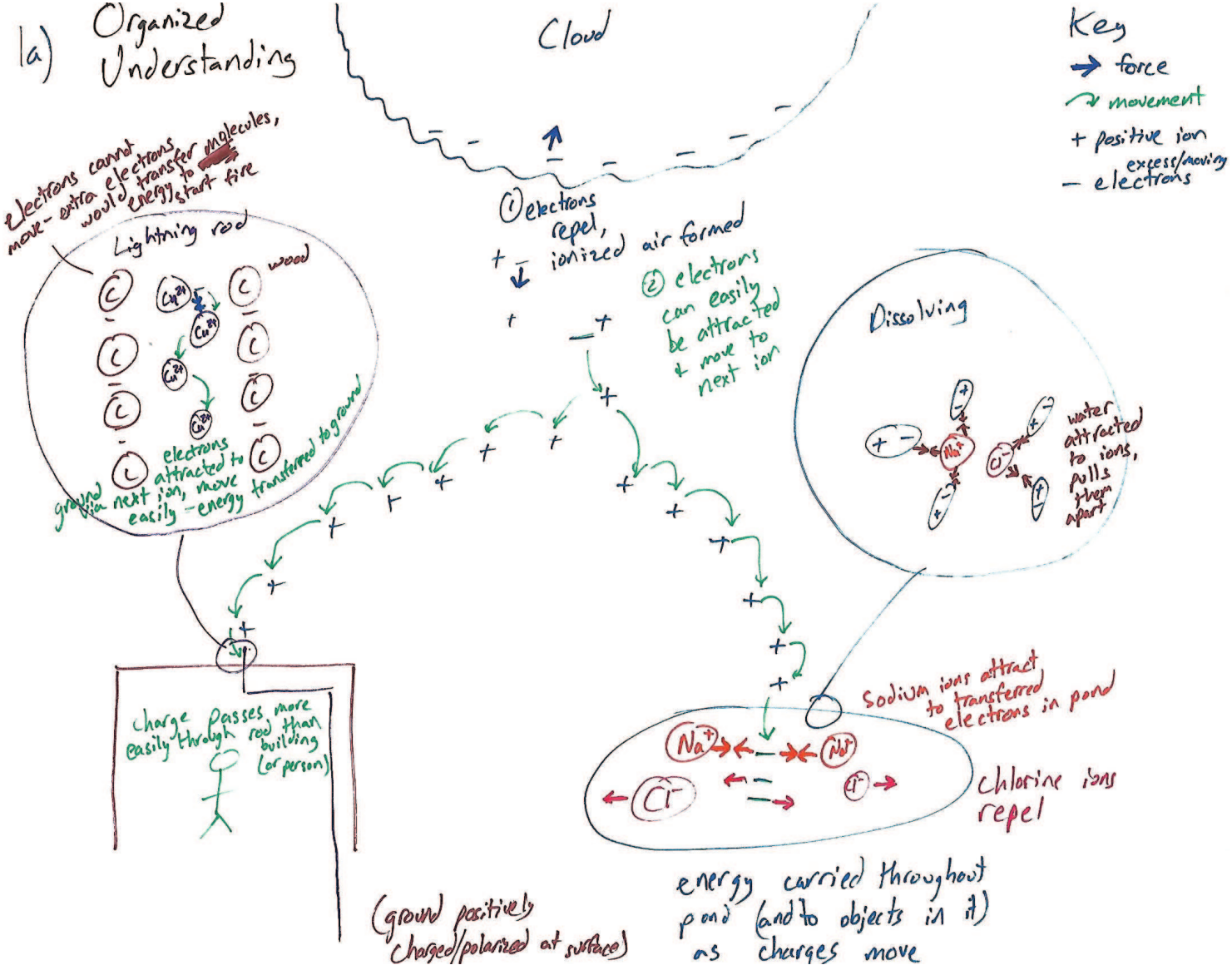
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	Foundational Understanding	Linked Understanding	Organized Understanding
3D Elements	What to look for in this model and evidence (the response to #2 may provide supplementary evidence): • The model shows *some* of the key components such as electrons, ionized air, energy, charge at the bottom of a cloud, water molecules, dissolved ions, and molecules in a metal as compared to wood. • The model somewhat accurately represents key interactions such as attractive and repulsive forces. • The impacts of forces are shown at different scales. • Mechanisms are referenced which explain how material conductivity or lack thereof, and therefore practical implications, arise from subatomic forces. • The evidence includes descriptions of patterns at one scale.	What to look for in this model and evidence (the response to #2 may provide supplementary evidence): • The model shows *most* of the key components such as electrons, ionized air, energy, charge at the bottom of a cloud, water molecules, dissolved ions, and molecules in a metal as compared to wood. • The model clearly and mostly accurately represents key interactions such as attractive and repulsive forces. • The impacts of forces are shown at different scales. • Mechanisms are partially shown which explain how material conductivity or lack thereof, and therefore practical implications, arise from subatomic forces. • The evidence includes descriptions of patterns across two different scales.	What to look for in this model and evidence (the response to #2 may provide supplementary evidence): • The model shows *all* of the key components such as electrons, ionized air, energy, charge at the bottom of a cloud, water molecules, dissolved ions, and molecules in a metal as compared to wood. • The model clearly and accurately represents key interactions such as attractive and repulsive forces. • The impacts of forces are shown at different scales. • Mechanisms are fully shown which explain how material conductivity or lack thereof, and therefore practical implications, arise from subatomic forces. • The evidence includes descriptions of patterns across three different scales.
Example	See below for (1a). 1b) Lightning rods are made of metal so they can attract and conduct lightning. Electrons move from the cloud, through ionized air, to the rod, like in our research. Water is dangerous because it does the same thing. It has ions that conduct electricity, so they can attract lightning too.	See below for (1a). 1b) I saw that charges move in different ways in different materials. Our research showed that a strong field causes electrons to be pushed off of atoms, making them ions and letting charge move. Models of different materials showed how electrons move more easily in metal (around positive ions) than in wood (stuck to nucleus). Since charge moves easily through water, it is dangerous to be in, but charge moving through metal protects the non-metallic parts of a building, keeping it safe.	See below for (1a). 1b) I figured out from the simulation that energy is transferred as charges move relative to each other. I saw that this motion happens in different ways in different materials. Our research showed that a strong field causes electrons to be pushed off of atoms, making them ions and letting charge move. Models of different materials showed how electrons move more easily in metal (around positive ions) than in wood (stuck to nucleus). We got evidence from investigations that water pulls apart salt so charge can flow through water. Since charge moves easily through water, it is dangerous to be in, but charge moving through metal protects the non-metallic parts of a building, keeping it safe.

Feedback / What to Do	*Linking:* Revisit the class Gotta-Have-It Checklist and ask students to consider which components are involved and how they interact. Support students in seeing how over the last few lessons, we found evidence (at different scales) for different components and interactions that are represented on the Gotta-Have-It Checklist. Ask students to explicitly compare their own model with a partner's and then revise accordingly to ensure that each person's model contains the best aspects of both.	*Organizing:* Review how forces at the particle level relate to the movement of charge in materials. Review the connection between forces and energy. Support students in seeing how patterns that provide evidence for different mechanisms can be seen at each of the different scales examined in the last few lessons. Ask students to revise their models after review.	*Extending:* Ask students to explain another piece of safety guidance, such as why a person is generally safe inside a vehicle. Ask students to debunk particular myths associated with lightning, such as that wearing rubber boots protects you from lightning.


1a) Foundational Pieces
Cloud
Key
→ force
↝ movement
+ positive ion
− excess/moving electrons
forces between electrons in cloud and positive ions in lightning rod, water
Lightning rod
Cu^{2+}
Cu^{2+}
electrons attracted and move
+ charged
charge attracted to and moves through lightning rod, everything else safe
Na^+
Na^+
Cl^-
Cl^-
anything on top where Na^+ is will have electricity conducted through it


1a) Linked Understanding
Cloud
Key
force
movement
+ positive ion
− excess/moving electrons
electrons in wood are struck by lightning, would get more energy, catch on fire
Lightning rod
wood
electrons move
(1) electrons repel, ionized air formed
(2) electrons move between ions
charge moves through rod, not wood/people
ground polarized + near top to attract
sodium ions attract, chlorine ions repel
charge moves through pond and anything in it!


1a) Organized Understanding
Cloud
Key
force
movement
+ positive ion
− excess/moving electrons
electrons cannot move - extra electrons would transfer energy to molecules, start fire
Lightning rod
wood
ground
electrons attracted to next ion, move easily - energy transferred to ground
① electrons repel, ionized air formed
② electrons can easily be attracted & move to next ion
Dissolving
water attracted to ions, pulls them apart
charge passes more easily through rod than building (or person)
(ground positively charged/polarized at surface)
Sodium ions attract to transferred electrons in pond
Chlorine ions repel
energy carried throughout pond (and to objects in it) as charges move

2. Use your model to communicate to a concerned friend how staying away from water and staying indoors (if possible) keeps you safer in a storm.

Sample student response:

We want to make sure that, as we are able, we stay in safer places during a storm and help others to do the same. The movement of charge through air in lightning is somewhat random. The cloud that the charge comes from is very far away from the ground, so a lightning rod or water does not attract lightning. However, both are conductive materials that can carry charge. With a lightning rod, this is a good thing. It is made of metal, and in metals the electrons do not stay easily attached to their nuclei and instead move around freely. So the electrons can move through the lightning rod to the ground without going into another material. If the energy from those electrons were instead transferred to a person or to wooden parts of the building, it could cause severe damage. Water is also conductive and it is unsafe to be near it during a storm. That is because ions and electrons can move through water easily, including through anything in or touching it--like a person or an animal. Lightning rods are safe because we are not touching them.

What to do: Look for thinking about conductive materials attracting charge. Ask students to point to evidence that supports their ideas. If they have an incomplete mental model of charge movement in these materials, return to the models in Lesson 12 and 13.

	Foundational Understanding	Linked Understanding	Organized Understanding
Ideas for Instruction	Review the models that students encountered in Lessons 10-13. Have students identify how components and interactions in these models could be applied to this related, but different, question. Have students explain their response to a peer who takes notes on it, to support thinking around communicating information.	Review the models that students encountered in Lessons 10-13. Have students identify mechanisms that are similar and different across these models and decide which mechanisms are most applicable in this situation and how they could be represented. Have students practice communicating these ideas to a peer before putting them to paper.	Invite students to predict which safety guidelines would be most useful in different situations using mechanistic models.

Lesson 14: Answer Key 2

Airplane Transfer Task Key

NGSS performance expectation being assessed: HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. (SEP: 8.5; DCI: PS2.B.3; CCC: 6.1)

One additional SEP element is used to support student sensemaking in this assessment which is not part of the NGSS performance expectation being assessed.

3D Elements Addressed in this Assessment	Question #					
	Part 1			Part 2		
	1	2	3	4	5	6
Obtaining, Evaluating, and Communicating Information. Communicate scientific and/or technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed system) in multiple formats (including orally, graphically, textually, and mathematically). (SEP: 8.5)	X	X				X
Developing and Using Models. Develop, ~~revise,~~ and/or use a model based on evidence to illustrate ~~and/or predict~~ the relationships ~~between systems or~~ between components of a system. (SEP: 2.3)			X		X	
PS2.B Types of Interactions. Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, ~~as well as the contact forces between material objects.~~	X	X	X		X	X
Structure and Function. Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (CCC: 6.1)	X		X		X	X

Scoring Guidance. The response elements described below would be considered exemplary at this point in the unit. These are shown in purple text or in purple diagrams below the related question. In some cases different elements of a response are identified with a + symbol. These + elements are not meant to be all inclusive, but are suggestions for different ideas your students might include.

The following scoring guidance can help you identify different elements that students should (or could) include in their responses.

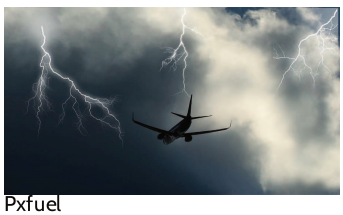
- If several of the elements marked with a + are missing from a student's response, this may indicate that the student has not mastered the science ideas or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether the student is struggling with a science practice or science idea, or both.
- If all or almost all of the elements marked with a + are present in a student's response, this may indicate that the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.
- If the elements marked with a ++ are present in a student's response, this indicates that the student is bringing a deeper understanding of the science ideas or a deeper engagement with the practice to their response. Students should not be penalized if ideas marked with a ++ are not present in their response.

Part 1

Airplanes and Lightning Strikes

Each year, one or two airplanes are struck by lightning (National Weather Service, n.d.). However, these lightning strikes do not usually result in injuries to humans. The last plane crash caused by a lightning strike occurred in 1967 (Scientific American, 2006). Advancements in technology and airplane design have helped to prevent crashes.

An airplane was struck by lightning on October 3, 2016. It arrived safely, and the airline confirmed that the plane was not damaged in any way. The covering around the cabin and interior compartments of an airplane is made of aluminum (metal) and designed to keep electricity away from the crew, passengers, and electronics inside, according to Chris Hammond of the British Airline Pilots Association (Balpa). Underneath the aluminum covering of the airplane are many other materials including plastic.



Pxfuel

"Everything work[ed] exactly as it should," Hammond said. The lightning bolt entered the plane at the nose and then exited via the tail and wing. Everything and everyone on board was protected.

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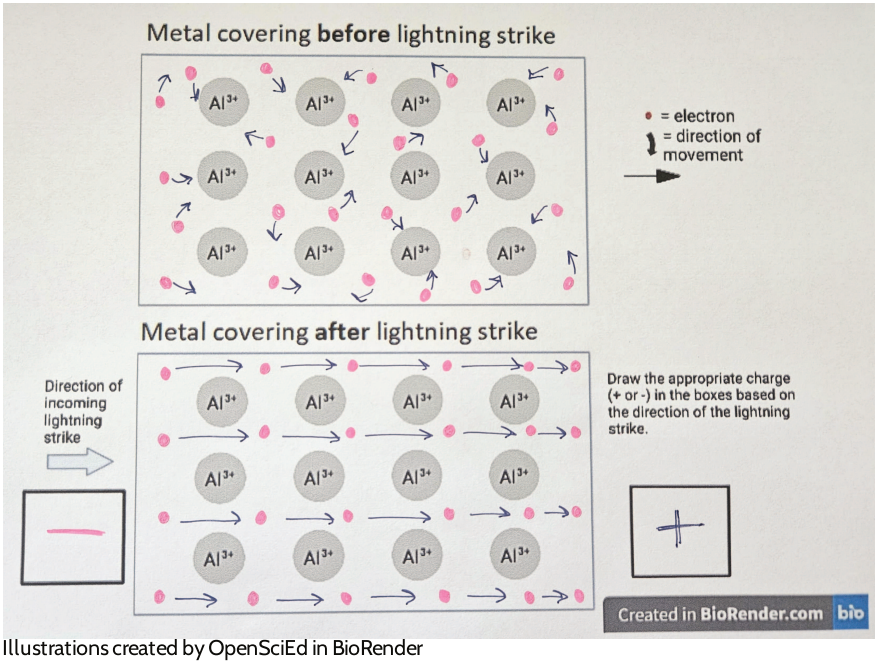
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Question 1: A friend heard that airplanes can get struck by lightning and is wondering about how everyone on an airplane would be safe if this happened. Use the graphic and words to communicate how the design of the airplane works to protect the crew, passengers, and electronics.

- Annotate the graphic on the next page to show the location and flow of electrons in the metal covering of the airplane, before and after a lightning strike.
- Use multiple formats (graphic, writing) to communicate the design and performance of the airplane's safety system to your friend. Explain how it protects the crew, passengers, and electronics inside during a lightning strike.
  Include scientific information about the relationship between the structures in the materials and how that leads to the functionality of the design (safety). (SEP: 8.5; DCI: PS2.B.3; CCC: 6.1)

Write your explanation in the space below and annotate the graphic on the next page.

Sample student annotated graphic.



Illustrations created by OpenSciEd in BioRender

	Foundational Understanding	Linked Understanding	Organized Understanding
3D Elements	Annotated graphic shows electrons distributed and moving randomly before lighting strikes. Annotated graphic shows electrons moving in the same direction after lighting strikes. Electrons are randomly distributed. Written explanation ties back to the graphic or includes scientific information from sources students used during the unit. Relates that because metals have electrons, when lightning strikes the plane, everyone inside the plane is protected. Does not connect metal structure to function.	Annotated graphic shows electrons distributed and moving randomly before lighting strikes. Annotated graphic shows electrons distributed equally and moving in the same direction after lighting strikes. Written explanation mentions the graphic and references scientific information from sources students used during the unit. Relates that because metals have electrons, when lightning strikes the plane, the electrons provide a way for the lightning to travel through the outside of the plane, protecting everyone inside.	Annotated graphic shows electrons distributed and moving randomly in the before lighting strikes. Annotated graphic shows electrons distributed equally and moving in the same direction after lighting strikes. Written explanation explicitly ties back to the graphic and references scientific information from sources students used during the unit. Relates that because metals have free electrons, when lightning strikes the plane, the electrons provide a way for the lightning to travel through the outside of the plane, protecting everyone inside.
Example	Metal has electrons floating around in it. So when it is struck by negatively charged lightning, the lightning is repelled by the electrons, which allows it to travel through the metal.	The electrons moving around in the metal on the outside of the airplane work like a lightning rod, letting the lightning move from electron to electron through the aluminum. That prevents the lightning from moving inside the plane and harming anything.	The metal on the outside of the airplane contains free electrons just moving around. When lightning strikes the airplane, the electrons move to create paths for the lightning. This lets the lightning travel safely on the outside of the plane and not to the insulated materials inside. It is a lot like a lightning rod.
Feedback / What to do	*Linking:* Have students think about the differences in the metal and nonmetal structures of airplanes and how those differences explain why lightning does not travel from the metal to the nonmetal portions (e.g., inside) of the airplane. Ask, *What is different about the structures of the metal on the outside of the airplane and the nonmetals on the inside of the airplane? How might those differences explain the path lighting takes when it strikes the airplane?*	*Organizing:* Have students explicitly link their written explanation to their annotated graphic. Ask, *How does the graphic you annotated support your explanation?*	*Extending:* Encourage students to move beyond the interaction of the lighting with the aluminum covering on the outside of the airplane. Ask, *What would happen if the airplane were not covered by aluminum?*

	Foundational Understanding	Linked Understanding	Organized Understanding

Ideas for Instruction	Review *Metals/Nonmetals Comparison* and *Lightning Strikes/Fires* from Lesson 12 with students. Help them identify which parts of the airplane are most similar to the materials described in the handout and reference. Encourage students to revisit their Progress Trackers.	Review the assessment with students to help them connect the annotated graphic to their explanation.	Invite students to use a graphical and written explanation of what would happen if the airplane were not covered by metal.

Aluminum is a great material to protect a plane from lightning, but aluminum coverings also prevent some important communication devices from working. Electrical engineers had to figure out a way to move lightning through the airplane's shell while allowing communication devices to work. Their solution is called a **radome.** A radome is made of insulating materials like plastic that cover all of the communication devices found in the nose of the airplane.

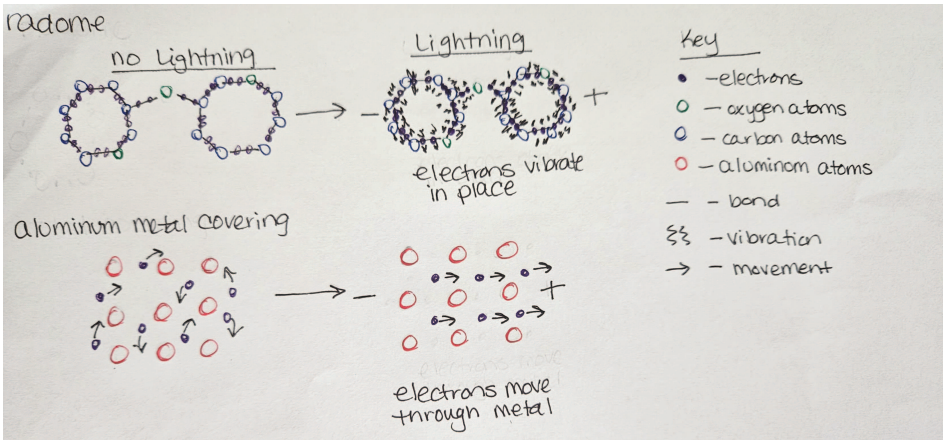
Question 2:
Radar and wireless communication can pass through the plastic of the radome, but lightning cannot.

To help explain why, use pictures or words to communicate what is different between electron movement in the radome and electron movement in the aluminum metal covering of the plane. (SEP: 8.5; DCI: PS2.B.3)


Photo of an aircraft radome. Bill Abbott, CC BY-SA 2.0

Key elements:
+ uses picture or words to communicate differences
+ electrons do not move freely through insulators/plastic
+ electrons move freely through conductors/metal

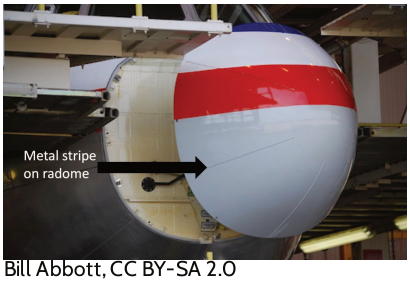
Sample student response:
The electrons in the plastic of the radome are attached to atoms and cannot move around like the electrons in the aluminum covering of the airplane.



What to do: If students incorrectly state that electrons move freely through insulators/plastic, have them look back at *Metals/Nonmetals Comparison*. Ask, *Which of the materials on the handout is most similar to plastic? Which material is most similar to aluminum?*

One vulnerability of the radome structure is that most plastics melt at high energy/temperatures caused by lightning. Radomes can melt and make a hole in the tip of the airplane. This could cause problems for the important communication devices. To protect against this, engineers added metal strips down the sides of the radome.

Question 3: Develop a model to explain how changing the design of the radome by adding metal strips protects it from lighting strikes. (SEP: 2.3; DCI: PS2.B.3; CCC: 6.1)

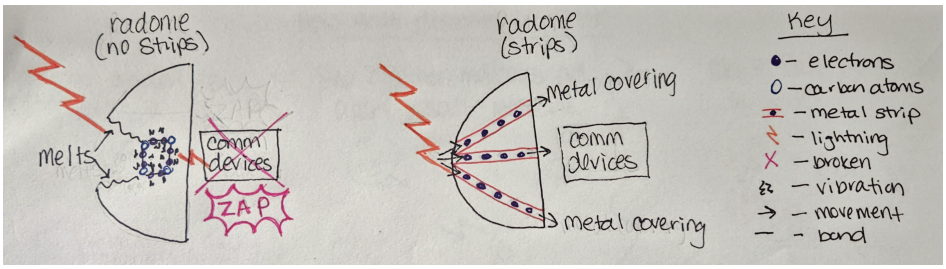


Bill Abbott, CC BY-SA 2.0

Key elements:

+ illustrates and explains the relationship between lighting strikes, radome material, and metal strips
+ metal strips contain free electrons
+ the free electrons can move in the metal, providing a path for lightning to travel
+ adding the metal to the radome allows for communication to occur and provides a path for lighting to travel if struck

Sample student response:



The plastic radome melts because the electrons in the plastic get heated. This lets the lightning reach the communication devices, which damages them. Adding metal strips helps by attracting the lightning away from the plastic parts of the radome that allow communications to pass through. Because of the free electrons in the metal strips, the lightning can travel from the radome to the aluminum covering of the airplane.

What to do: If students incorrectly state that electrons move freely through insulators/plastic, have them look back at *Metals/Nonmetals Comparison*. Ask, *Which of the materials on the handout is most similar to plastic? Which material is most similar to aluminum?* Help students think about the design changes by examining the two photographs, or encourage students to develop images showing the design changes at both the macroscopic and atomic scales.

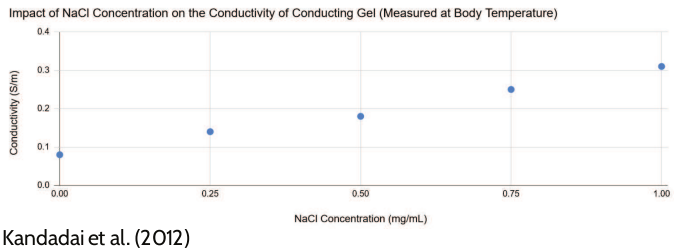
END of Part 1 - Do not continue until after the class discussion.

Part 2

Gels for "Test Brains"

Did you know that every thought you have comes from an electrical charge in your brain? Brains work by conducting electricity along pathways. If a brain is injured or damaged, these pathways can be healed. To learn how to heal brains, scientists would need access to either 1) lots of live brains, or 2) some kind of brain-like chemical substitute. In this task, you will figure out how one cutting-edge brain substitute works using what you have learned in this unit.

Conducting gels are substances that scientists use to mimic the structure of the brain and other body tissues that conduct electricity. In other words, these substances can serve as a "test brain" by allowing charge to flow through them like a real brain. This allows scientists to safely develop new medical devices without having to test them on actual brains. The conducting gel is made of gelatin, or some similar substance, and dissolved sodium chloride (NaCl) salt. The amount of NaCl dissolved into the conducting gel affects how well it conducts electricity. The graph shows the relationship between conductivity of the gel and amount of NaCl dissolved. Scientists conducted the tests on the gel when it was at body temperature to better mimic what would happen in living tissue.



Kandadai et al. (2012)

Question 4: According to the graph, what relationship is there between the amount of NaCl in the conducting gel and the level of conductivity?

Key elements:

The purpose of this item is to help students identify the relationship to support them in developing a model in Question 5 and explaining how the gel system works in Question 6.

Sample student response:
As the amount of NaCl increases, the conductivity of the gel increases. This is a direct relationship.

What to do: Support students in analyzing the graph. It is important that they identify this relationship to successfully answer Question 6.

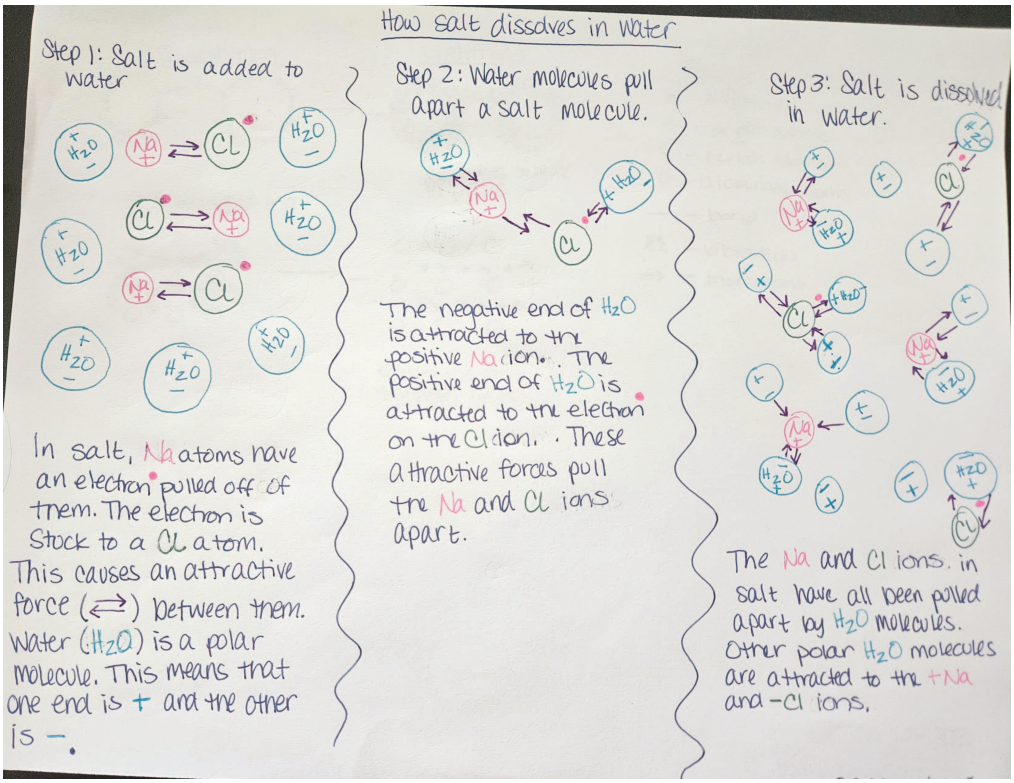
The process of making a conducting gel is very similar to making gelatin that you buy in a store. Scientists mix the base of the gel, or gelatin, with hot water. After the gelatin base has melted in the water, they add NaCl and then allow the conducting substance to solidify into a gel.

Question 5: Draw a model to explain what happens at the atomic scale to the Na and Cl atoms as salt dissolves in water. Be sure to include how the unique structure of water plays a role in dissolving the salt. (SEP: 2.3; DCI: PS2.B.3; CCC: 6.1)

Key elements:
+ shows attraction between: positive end of water and negative Cl ion, negative end of water and positive Na ion
+ shows attractive forces between oppositely charged molecules and/or ions
+ sodium (Na) has a positive charge
+ chlorine (Cl) has a negative charge
+ water is a polar molecule, so one end has a positive charge and the other a negative charge

Additional accurate element not essential to this item:
++ the attractive force between water and Na or Cl is stronger than the attractive force between Na and Cl

Sample student response:



What to do: Point students back to *Electrolytes*, which explains the role of water in dissolving electrolytes. Ask, *How can we represent NaCl to show both the atoms and their charges? How can we represent the water molecule to show that it is polar?* Remind students to show that there are attractive forces by asking, *What is holding the Na and Cl together?*

One important difference between the conducting gel and salt water is that in the gel, all the ions are stuck in place when the "test brain" is being used.

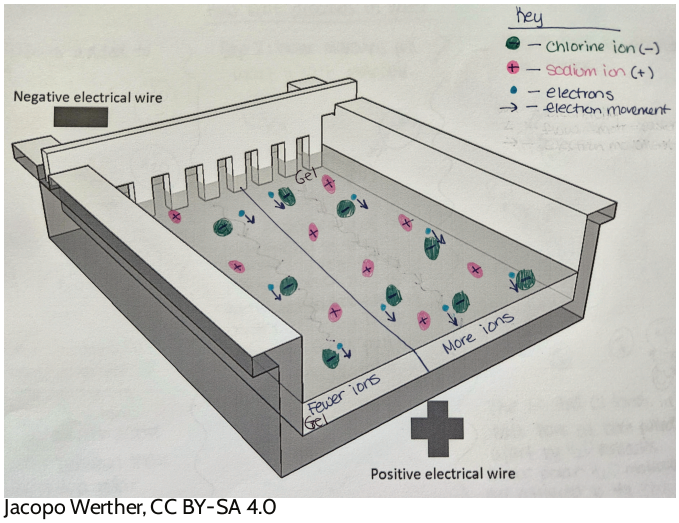
Question 6: Use your model, the information from the graph, and the diagram of the conducting gel to help communicate, visually and in writing, how the conducting gel system in the "test brain" works. Then, use scientific information about the interactions of ions with electricity to explain the graph showing changes in the conductivity of the conducting gel. (SEP: 8.5; DCI: PS2.B.3; CCC: 6.1)

Key elements:

+ visually shows and explains the impact of higher ion concentration on gel conductivity
+ increasing salt leads to more Na^+ and Cl^- ions when dissolved, which leads to more electrons
+ increasing ions allows for easier movement of electricity through the gel
+ materials with higher conductivity allow charges (such as ions) to move more easily

Sample student response:

Since the chloride ions contain electrons, the number of electrons increases. This makes it easier for electricity to flow through the gel. The graph showed that as the number of ions increased, the conductivity also increased. Conductivity is how well electricity can move through a substance. If a substance has high conductivity, electrons can move through it more easily.



Jacopo Werther, CC BY-SA 4.0

What to do: Have students look back at the graph and their answer to Question 4 to think about what will happen to the conductivity when the number of ions in the gel increases. If students struggle with thinking about what would happen if there were more ions in the gel, suggest that they create two visual representations, one showing a gel with fewer ions and one showing a gel with more ions. Additionally, review materials from prior lessons which support thinking around the interactions of lightning/electricity and the movement of electrons:

- Lesson 10: *Model Self-Assessment*
- Lesson 12: *Lightning Rods*
- Lesson 13: *Electrolytes* and *Lightning Safety Claims*

References

Kandadai, M. A., Raymond, J. L., & Shaw, G. J. (2012). Comparison of electrical conductivities of various brain phantom gels: Developing a 'Brain Gel Model'. *Materials Science & Engineering: C*, *32*(8), 2664–2667. https://doi.org/10.1016/j.msec.2012.07.024