

CHEMISTRY

Molecular Processes in
Earth Systems

**How can we find,
make, and recycle
the substances we
need to live on
and beyond Earth?**



HIGH SCHOOL SCIENCE



TEACHER EDITION

How can we find, make, and recycle the substances we need to live on and beyond Earth?

Molecular Processes in Earth Systems: Space Survival

OpenSciEd Unit C.3





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UNIT OVERVIEW

How can we find, make, and recycle the substances we need to live on and beyond Earth?

This unit is anchored by examining future plans to live and work for longer periods of time on the Moon (NASA Artemis mission). Students consider the constraints associated with this problem which leads them to develop questions about how to find, recycle, and make the substances needed for living off Earth and on it. In Lesson Set 1 (Lessons 1-5), students investigate planetary surface features (Earth's and Mars') to investigate water and its unique structure and function in erosion. They also develop understandings around physical science concepts of light and matter along with Earth and space science concepts of spectroscopy as a way to identify substances off of Earth. In Lesson Set 2 (Lessons 6-9), develop science ideas about the structure of atoms, the patterns in their bonds, the organization of the periodic table, electronegativity, bond character, and how these affect the polarity and properties of the molecule. In Lesson Set 3 (Lessons 10-12), students develop and apply the idea of conservation of matter through chemical equations in the context of a variety of substances, including those that form ionic compounds and form polyatomic ions. In Lesson Set 4 (Lessons 13-15), students consider applications of ideas students figured out to issues related to recycling and sustainability, both off Earth and on it. Students apply these ideas in a transfer task in Lesson 15.

Throughout the unit, students will do the following:

- Synthesize information from student-designed and directed investigations around water's unique properties, and liquids and gasses interaction with light and draw conclusions from the results.
- Develop and use multiple types of particle-level models as they build and work with the periodic table of the elements as a patterned arrangement that serves a purpose of predicting interactions due to elemental structure.
- Obtain and evaluate information and communicate information about the:
 - location and relative amounts of substances in the solar system;
 - ways in which scientists and engineers are substituting different substances to make the materials off of Earth we need using the materials available on site; and,
 - development of new processes and materials related to toxic soil remediation, farming/growing food, construction, medicine, transportation, storage, and cleaning water, for both off Earth and on it.

Building Toward NGSS Performance Expectations

HS-ESS1-2:

Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.

HS-ESS2-1:

Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.

HS-ESS2-5:

Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.

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-PS1-2:

Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

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-PS2-6:

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

UNIT STORYLINE

Unit Question: How can we find, make, and recycle the substances we need to live on and beyond Earth?

How students will engage with each of the phenomena



HANDS-ON/
LAB ACTIVITIES



VIDEOS
OR IMAGES



DATA SETS

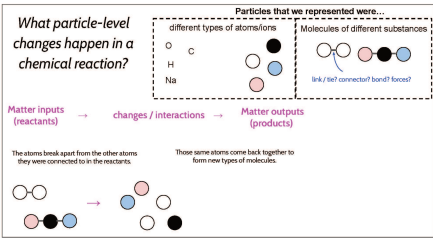


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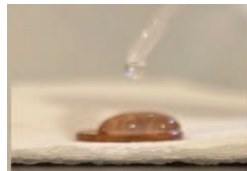
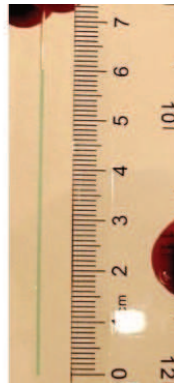


COMPUTER
INTERACTIVES

Lesson Set 1: How can we find water and other substances we need to survive on other objects in space?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 Lesson Set 1 4 days What substances would we need and how would we get them to live and work beyond Earth? Anchoring Phenomenon 	 <i>Hundreds of crews have lived and worked in space for limited amounts of time. Future space travel would require us to remain there for longer amounts of time.</i>	We examine a video of NASA's plans in the near future. We identify criteria, constraints, and solutions for living and working beyond Earth for longer periods of time. We develop models of how new substances are made through chemical reactions. We add questions to a Driving Question Board and brainstorm ideas for data and investigations that could help answer them. We figure out: • People need certain substances to live and support the kinds of work they might want to do in places beyond Earth. • The scale of the solar system and the cost and speed of space travel mean that most of the substances that we need to live and work would have to be found, recycled, or made on-site. • New substances (product(s)) can be created from one or more reactants through the rearrangement of matter in chemical reactions.	

↓ **Navigation to Next Lesson:** Though we have lots of ideas for investigations and data that we will need to answer our questions, we prioritized figuring out more about our water-related questions first.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it															
LESSON 2 Lesson Set 1 2 days How does water support life and chemical reactions? Investigation 	   Substances have different properties such as specific heat, ability to dissolve other substances, and transparency to light.	We discuss other chemical reactions that include water, what is special about water, and properties of water we previously studied. We gather information on water's properties from two out of six investigation stations. We integrate our information from across the six investigation stations. We figure out: - Water supports life and is used in chemical reactions because of its properties. - Some of those properties include surface tension, high specific heat capacity, transparency, and ability to dissolve most substances.	Water's importance for life and chemical reactions <table><tr><th>Property of Water</th><th>Importance for Life</th><th>Importance for chemical reactions</th></tr><tr><td>1. Takes a long time to get hot/cool down. High specific heat, which means it can store a lot of energy (and absorb it).</td><td>1. It regulates temperatures to help prevent extreme highs and lows.</td><td></td></tr><tr><td>2. Can see through it/transparent. In water, this is to a certain point, then it is no longer visible.</td><td>2. Allows plants and other photosynthetic organisms to live in water. This provides a food source for animals. The more light water gets through water, the greater the diversity of life.</td><td></td></tr><tr><td>3. It is good at eroding and dissolving substances.</td><td>3. It moves minerals through our bodies. It is a good solvent/transporter, making it the "hydrogen" for our bodies.</td><td>3. Because water can dissolve substances, it is also provides a way for mixtures of different dissolved substances to interact to form new substances.</td></tr><tr><td>4. Can stick to itself (cohesion) and other substances (adhesion)</td><td>4. Water is able to move up plant roots and tubes against gravity (capillary action) to reach all areas of the organism.</td><td></td></tr></table>	Property of Water	Importance for Life	Importance for chemical reactions	1. Takes a long time to get hot/cool down. High specific heat, which means it can store a lot of energy (and absorb it).	1. It regulates temperatures to help prevent extreme highs and lows.		2. Can see through it/transparent. In water, this is to a certain point, then it is no longer visible.	2. Allows plants and other photosynthetic organisms to live in water. This provides a food source for animals. The more light water gets through water, the greater the diversity of life.		3. It is good at eroding and dissolving substances.	3. It moves minerals through our bodies. It is a good solvent/transporter, making it the "hydrogen" for our bodies.	3. Because water can dissolve substances, it is also provides a way for mixtures of different dissolved substances to interact to form new substances.	4. Can stick to itself (cohesion) and other substances (adhesion)	4. Water is able to move up plant roots and tubes against gravity (capillary action) to reach all areas of the organism.	
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↓ **Navigation to Next Lesson:** We identify pictures as a source of evidence we could use to figure out whether there is water on other places beyond Earth.

LESSON 3

Lesson Set 1

1 day

How can we find evidence of the water we need on the surfaces of other objects in space?

Investigation





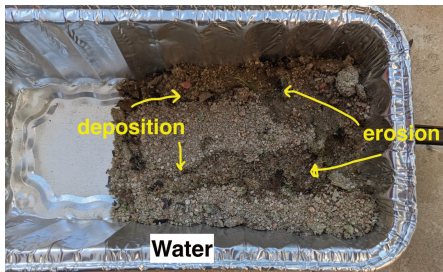
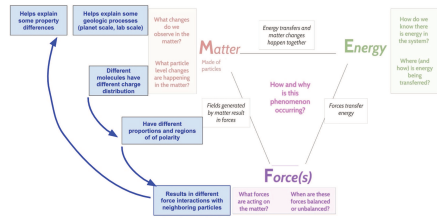
Photos of the surfaces of Earth, the Moon, and Mars have been taken from satellites or uncrewed mission vehicles above them.

We develop the “Surface Features and Causes” poster we use as evidence to support claims about which geologic processes caused the formation of surface features on Earth, the Moon, and Mars. We figure out:

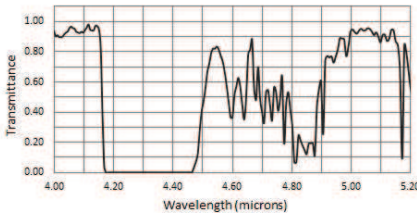
- Some surface features on Earth were produced primarily by water erosion, while others were produced primarily by tectonic processes or meteor impacts.
- Mars’s surface has some features that look similar to those produced by water erosion on Earth, while the Moon’s does not.

Surface Features and Causes	
Water interacting with the surface	Some other process interacting with the surface
River beds - erosion Sedimentary deposits - deposition by a river or glacier Cracks - drought (lack of water) Avalanches - too much water (fast melting or a lot of rain) Canyons - erosion Sea/coastal cliffs - erosion Beaches - erosion	Volcanoes - movement of magma (plate movement) Cracks - earthquakes (plate movement) Craters - asteroid or meteorite impact Avalanches, rocks falling - gravity or wind Trenches - earthquakes (plate movement) Mountains - plate movement

↓ **Navigation to Next Lesson:** We conduct investigations into what other liquids, if any, interacting with materials could have produced the surface features we see on the Moon and Mars.

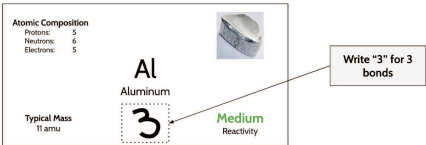
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 4 Lesson Set 1 3 days How and why do water and other liquids interact with materials to make surface features? Investigation 	 <i>Different liquids behave differently on the erosion table. Water erodes surface materials and expands when it freezes because of its polarity.</i>	We investigate how liquids interact with surface materials to help us determine that surface features on Mars were likely made by water. We examine molecular models of them to compare polarities of different liquids. We figure out: • Polar regions on molecules are due to a greater amount of negative or positive charge in that region of the molecule. • Polar regions on molecules will produce force interactions with nearby polar regions on neighboring molecules, which can be used to explain some property differences between substances. • Polar molecules could more easily erode some materials in their surroundings than nonpolar molecules.	

↴ **Navigation to Next Lesson:** We wonder where we can look for or find water other than on the planetary surface.

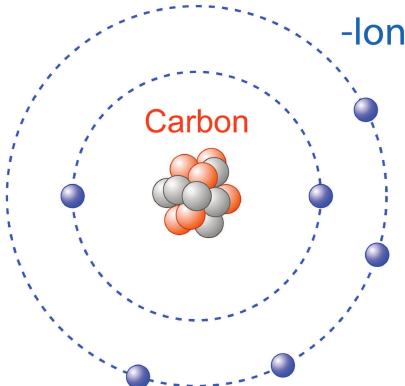
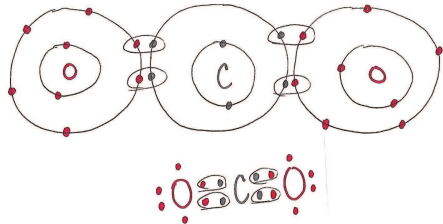
LESSON 5 Lesson Set 1 2 days How can we tell what is in the atmosphere (and just below the surface) of objects in space? Investigation 	 <i>Substances in an object's atmosphere, surface, or subsurface can be identified based on the light they absorb and transmit (spectroscopy).</i>	We use a projector-based spectrometer to investigate the absorption and transmission of light by solutions of pure substances and construct a way to graphically display this phenomenon. We use reference spectra to identify gasses in simple mixtures and in the atmospheres of objects in space. We figure out: • Different substances absorb and transmit different colors of visible light and different wavelengths of non-visible light (e.g., infrared). • Spectroscopy is the study of the light that is transmitted or emitted by different objects and is used to determine the presence of different gasses. • Scientists can perform spectra analysis on the interactions of solids with sunlight to determine the presence of substances in the soil or ice.	
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↴ **Navigation to Next Lesson:** We figure out that water can be found in some atmospheres in the solar system, but we are still wondering about other elements we need for survival.

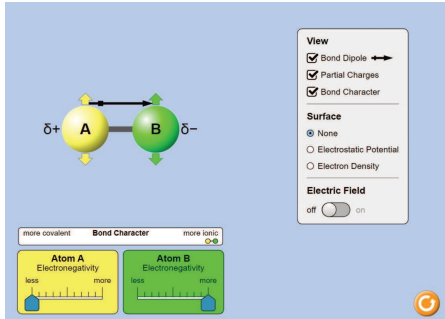
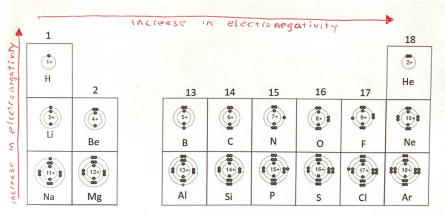
Lesson Set 2: Why do we need certain types of atoms to create the substances we need?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 6 Lesson Set 2 2 days What patterns are there between the types of atoms and the number of bonds they form in the resources we need? Investigation, Problematizing 	 <i>Different elements have different numbers of subatomic particles and can be organized into patterns based on their atomic composition, numbers of bonds/charges formed, and chemical properties.</i>	We identify patterns in the numbers of subatomic particles (especially protons) and of bonds that different elements form and use these patterns to organize the elements. We figure out: • Elements have varying numbers of protons, electrons, and neutrons which correspond to changes in typical mass and atomic number. • Each element forms a specific number of bonds/charges when it combines with other elements. • Elements are arranged on a table based on their repeating properties (numbers of bonds/charges formed, reactivity, composition, etc.). • Patterns in elements' bonds/charges repeat (periodicity), while atomic mass and number of protons increase across rows.	

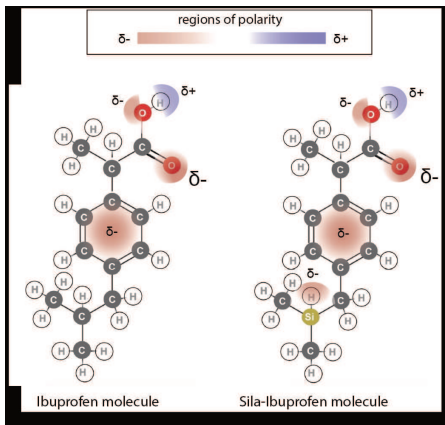
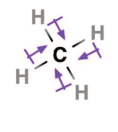
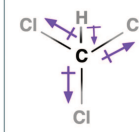
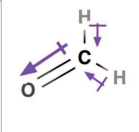
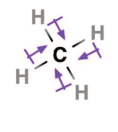
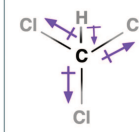
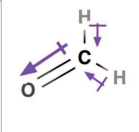
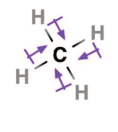
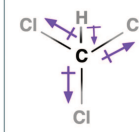
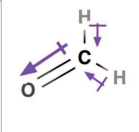
↓ **Navigation to Next Lesson:** We compare the number of electrons in carbon to the number of bonds it forms and notice that the numbers do not match. We wonder where the missing electrons went.

LESSON 7 Lesson Set 2 2 days Why is there a difference between the number of electrons an element has and the number of bonds an element forms? Investigation 	 <i>The electron shell model can account for differences in electron numbers in elements and connections formed by elements.</i>	We examine new models of atomic structure and evaluate the usefulness of different models to explain and make predictions about interactions between elements (bonds). We figure out: • Various models of atomic substructures can be used to try to account for differences in the numbers of electrons and connections formed by the element carbon. • A model of atomic structure illustrating valence electrons is best for determining the number of interactions (connections) each element will have with other elements.	
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↓ **Navigation to Next Lesson:** We wonder what is exactly happening between two elements when electrons bond to each other.

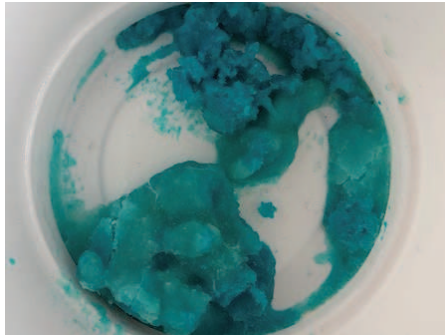
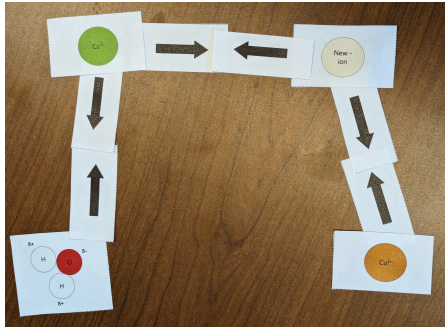
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 8 Lesson Set 2 2 days Could another substance serve as a substitute for water for some of the processes we need to use it for in space? Investigation 	 Many properties of water are different from the properties of hydrogen sulfide.	We predict whether another substance could replace water for some processes and model the structures of H₂O and H₂S molecules. We explain why the electronegativities of O and S are different and use a simulation to explore how electronegativity differences affect where electrons are in a bond, the bond characteristic, and its polarity. We figure out: - Differences in the polarity of H₂O and H₂S molecules help explain some of their property differences. - Electronegativity is a measure of how strongly a nucleus is attracted to shared electrons. Greater electronegativity equals stronger attraction. - Atoms of elements with more electron shells are larger. The size of an atom is called the atomic radius. - Electronegativity is affected by an atom's atomic radius and amount of charge.	

↓ **Navigation to Next Lesson:** We brainstormed examples of substances with undesirable properties or side effects to begin to consider substitute substances that we can use in some of the processes needed for living and working in space and on Earth.

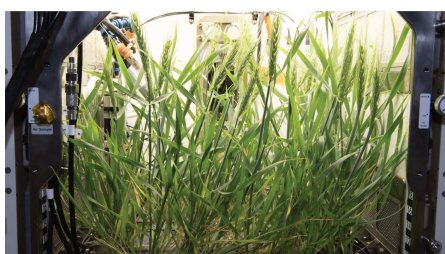
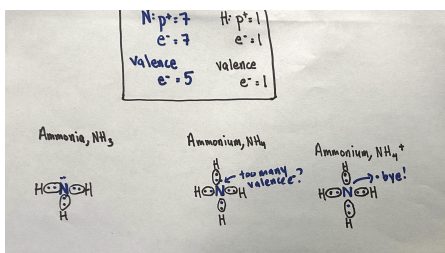
LESSON 9 Lesson Set 2 2 days How can the ideas we developed be applied to making a possible substitute for another substance? Putting Pieces Together 	 Biochemists have developed a new medicine, sila-ibuprofen, by substituting a single silicon (Si) atom for a carbon (C) atom in the ibuprofen molecule.	We describe bond characteristics in salt, wood, and metal and consider salt substitutes in our diets. We complete the Mid-Point Assessment. We figure out: - Some pairs of atoms can form double or triple bonds. - The polarity of a molecule can be determined by comparing the relative polarities of bonds within it. Which can be determined from the difference in the electronegativities of the atoms that make up the bond. - Some biochemistry and environmental chemists work on designing new substances, like medicines, that have more desirable properties or fewer side effects than those we use now.	<table border="1"> <thead> <tr> <th>Methane CH₄</th> <th>Chloroform CHCl₃</th> <th>Formaldehyde CH₂O</th> </tr> </thead> <tbody> <tr> <td></td> <td></td> <td></td> </tr> <tr> <td colspan="3"> Use different sizes and directions of dipole arrows to represent the relative shift of the electrons in each bond.  </td> </tr> </tbody> </table>	Methane CH ₄	Chloroform CHCl ₃	Formaldehyde CH ₂ O				Use different sizes and directions of dipole arrows to represent the relative shift of the electrons in each bond. 		
Methane CH ₄	Chloroform CHCl ₃	Formaldehyde CH ₂ O										
												
Use different sizes and directions of dipole arrows to represent the relative shift of the electrons in each bond. 												

↓ **Navigation to Next Lesson:** We made progress on many of our DQB questions, but we have a lot of questions about the role of water in so many of these chemical reactions.

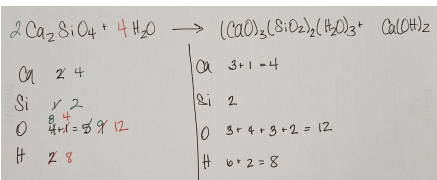
Lesson Set 3: How can we make the substances we need to survive off of Earth using the existing matter in the solar system?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 10 Lesson Set 3 1 day Why do we need water in so many reactions? Problematizing 	 <i>Dissolved copper ions can be cleaned from water with certain types of reactions.</i>	We return to the different processes we encountered in Lesson 1, with more information about the reactions that are occurring. We read about how copper can be cleaned from water by forming a precipitate and model this reaction. We figure out: • Water is involved in many reactions and must be clean for them to work properly. • Ions come together so that the substance formed is neutral. • The intermolecular forces between water (a polar molecule) and certain ions allow for the observed cleaning reaction to occur. • Some substances cannot be easily dissolved because their bonds are too strong.	

↓ **Navigation to Next Lesson:** We wonder what other substances we might need to remove from the water we find on Mars before we use it.

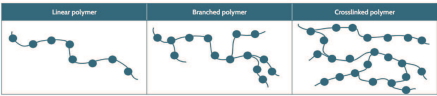
LESSON 11 Lesson Set 3 2 days How can we grow food in space? Putting Pieces Together, Investigation 	 <i>Plants can be grown in space to give us many materials for survival, but we need to enrich the soil with fertilizer.</i>	We engage in a reading about growing plants in space and model the differences between ammonia (NH_3) and ammonium (NH_4^+). We read about perchlorate ions in martian soil and model chemical reactions. We figure out: • To successfully grow plants off of Earth, nitrogen must be added to the soil. Two possible fertilizers, ammonia (NH_3) and ammonium (NH_4^+), could be added to the soil. • NH_3 and NH_4^+ have different structures and charges. Ammonium could be made successfully in space. • Polyatomic ions are substances that have many atoms but carry an overall net charge.	
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↓ **Navigation to Next Lesson:** We look to outer space to find the other materials we need to survive beyond Earth.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it																																	
LESSON 12 Lesson Set 3 2 days Which location(s) in the solar system has the elements we need and what relative amount is required to make any substance? Investigation 	<table><thead><tr><th>Process</th><th colspan="2">Reactants</th><th colspan="2">Products</th></tr></thead><tbody><tr><td>Photo-synthesis</td><td>Carbon dioxide CO₂</td><td>Water H₂O</td><td>Glucose C₆H₁₂O₆</td><td>Oxygen O₂</td></tr><tr><td>Making steel</td><td>Iron Fe</td><td>Carbon C</td><td>Manganese Mn</td><td>Steel* Fe_{0.9}C_{0.1}Mn</td></tr><tr><td>Making glass</td><td>Silica SiO₂</td><td>Sodium carbonate Na₂CO₃</td><td>Calcium carbonate CaCO₃</td><td>Glass* (Na₂O)(CaO)(SiO₂)_x</td><td>Carbon dioxide CO₂</td></tr><tr><td>Making hardened cement</td><td>Titanium silicate Ca₂SiO₄</td><td>Dicalcium silicate Ca₂SiO₄</td><td>Tricalcium aluminate Ca₃Al₂O₆</td><td colspan="2">Hardened cement* (CaO)_{1.5}(Al₂O₃)(SiO₂)_{1.5}(H₂O)_{0.5}</td></tr><tr><td>Making plastic</td><td>Terephthalic acid C₈H₆O₄</td><td>Ethylene glycol C₂H₄O₂</td><td colspan="2">Polyethylene terephthalate * [-C₆H₄(COO)-]_n</td><td>Water H₂O</td></tr></tbody></table> Three Mars rovers have sampled the chemical composition of surface material at three different locations. Experimental studies of sulfur-based concrete have been carried out on Earth.	Process	Reactants		Products		Photo-synthesis	Carbon dioxide CO ₂	Water H ₂ O	Glucose C ₆ H ₁₂ O ₆	Oxygen O ₂	Making steel	Iron Fe	Carbon C	Manganese Mn	Steel* Fe _{0.9} C _{0.1} Mn	Making glass	Silica SiO ₂	Sodium carbonate Na ₂ CO ₃	Calcium carbonate CaCO ₃	Glass* (Na ₂ O)(CaO)(SiO ₂) _x	Carbon dioxide CO ₂	Making hardened cement	Titanium silicate Ca ₂ SiO ₄	Dicalcium silicate Ca ₂ SiO ₄	Tricalcium aluminate Ca ₃ Al ₂ O ₆	Hardened cement* (CaO) _{1.5} (Al ₂ O ₃)(SiO ₂) _{1.5} (H ₂ O) _{0.5}		Making plastic	Terephthalic acid C ₈ H ₆ O ₄	Ethylene glycol C ₂ H ₄ O ₂	Polyethylene terephthalate * [-C ₆ H ₄ (COO)-] _n		Water H ₂ O	We add more molecules of some reactants and products to ensure there are equal numbers of elements on both sides of the equation. We obtain information about cement production using substances on Mars. We figure out: • Since matter cannot be created or destroyed, balanced chemical equations must have equal numbers of each element in the reactants and products. This is done by adding coefficients to reactants and products in the chemical reaction. • Mars has more of the elements needed to make the substances to live and work in space than any other location in the solar system. • It is possible to develop processes to make the substances we need that utilize in situ resources if we know what elements are present on an object in space and their amounts.	
Process	Reactants		Products																																	
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↓ **Navigation to Next Lesson:** We wonder about recycling sulfur concrete and other materials on Mars and here on Earth.

Lesson Set 4: How can we be more sustainable in what we use and produce?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 13 Lesson Set 4 2 days Why can we recycle some of the substances we need and not others? Investigation  	 <i>Different people and communities are able to recycle some substances but not others.</i>	We synthesize information from various sources to answer questions about why we recycle some of the substances we need but not others, and how this could apply to our long-term plans for living and working beyond and/or on Earth. We figure out: - We can recycle some substances by melting, freezing, and reshaping - Polymers are molecules with chains of repeating subunits (monomers). - There are a variety of naturally and synthetically produced polymers that have different characteristic properties that make them well suited to specific uses. - The structure of the polymer affects its properties.	

↓ **Navigation to Next Lesson:** We identified some candidate substances that we hope to see scientists and engineers develop more sustainable substitutes for, and wonder what new research is happening along those lines.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it						
LESSON 14 Lesson Set 4 1 day What are some more sustainable approaches we are developing to help us make the things we need off of Earth and on it? Investigation 	 <i>Innovative materials technologies could be more sustainable, both off of and on Earth.</i>	We read articles about different innovative materials technologies. We share with a partner and evaluate the arguments made in the articles. Then we share our evaluations with a pair that investigated a different set of materials technologies. We figure out: • New technologies may allow for common materials (or replacement materials) to be more sustainable. • A given material must have the right microscopic structures and resulting forces in order to produce the desired bulk-scale interactions. • Technologies that could aid living off of Earth could make life on Earth more sustainable, but in general using less of a given material is best.	<table><tr><td>Your article</td></tr><tr><td>Article Topic:</td></tr><tr><td>What is the sustainable engineering solution being described?</td></tr><tr><td>How does the engineered material work at the particle level? Use structure/function and matter/force thinking.</td></tr><tr><td>What claims does the article make about what the material could be used for?</td></tr><tr><td>How did you verify that the claims in at least one of the references match this reading? (The references that are publicly available have a * in front. If an article is behind a paywall, you can still examine its abstract and check that the journal is a reliable source.)</td></tr></table>	Your article	Article Topic:	What is the sustainable engineering solution being described?	How does the engineered material work at the particle level? Use structure/function and matter/force thinking.	What claims does the article make about what the material could be used for?	How did you verify that the claims in at least one of the references match this reading? (The references that are publicly available have a * in front. If an article is behind a paywall, you can still examine its abstract and check that the journal is a reliable source.)
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↓ **Navigation to Next Lesson:** We figure out that different materials technologies could support living off of Earth as well as sustainable living on Earth. We think that human survival beyond Earth could be possible one day, but are unsure whether it is a good idea.

LESSON 15 Lesson Set 4 3 days What is the full impact of going to space? Putting Pieces Together	Soap scum forms on surfaces due to interactions between dissolved ions.	Students read about perspectives on space travel, balance a final equation, close out the DQB, and then demonstrate their understanding on a transfer task about the formation of soap scum. We figure out: • There are competing science and ethics arguments about human survival in space. • The elements available to us in outer space limit what we can build on another planet. Matter cannot be gained or lost in a chemical reaction. • Soap scum is formed as a result of interactions between polyatomic ions and other ions that are dissolved in water.	KCO3, potassium carbonate K+ ion CO3- ion MgHCO3, magnesium bicarbonate Mg2+ ion HCO3- ion
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↓ **Navigation to Next Lesson:** This is the final lesson of the unit.

LESSONS 1-15

31 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 third in the OpenSciEd High School Chemistry course sequence. In the second unit of OpenSciEd HS Chemistry, students developed ideas around electrostatics. This unit is designed to build on student's ideas about the structure of matter, with an emphasis on the formation of covalent bonds, polarity, the periodic table, and the structure of molecules. It also contributes to core ideas for Earth and space science, especially the interactions of water with Earth's surface.

While HS-ESS2-5 and HS-PS1-2 are addressed in this unit alone in the OpenSciEd High School course sequence, many of 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 the unit taught just before this one, *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*.
- **HS-ESS1-2** is shared with *OpenSciEd Unit P.6: Why do stars shine and will they shine forever? (Stars)*
- **HS-ESS1-1** is shared with *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*

What is the anchoring phenomenon and why was it chosen?

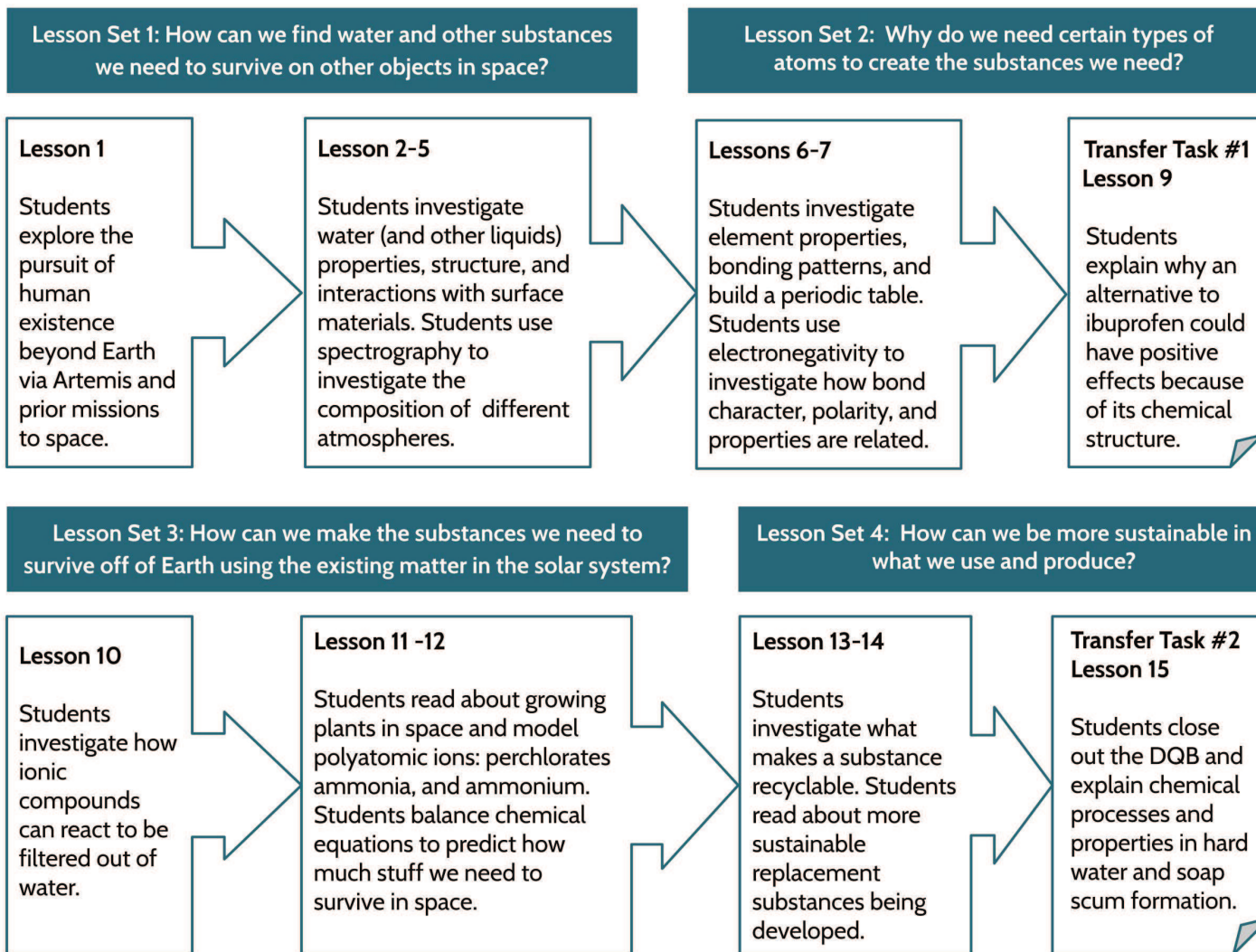
For the anchoring phenomenon, students critically view the Artemis launch video from NASA and develop models for how humans might make the needed resources to survive beyond Earth, such as water, food, and shelter. The frame of "substances for survival" allows students to zoom in on the elements and the compounds they form, especially water, and build simple reactions as specified in HS-PS1-2. Students also showed high interest in this question across racial and gender identities and their location (rural/urban) in a survey we conducted in pilot states.

The search for elements to survive off Earth anchoring phenomenon was chosen from a group of phenomena aligned with the target performance expectations 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. Search for elements and knowing how they might be engineered to survive off Earth was chosen for the following reasons:

- Teachers and administrators saw high relevance to current events related to outer space tourism and travel.
- Explaining the interactions involved in resourcing human's survival in space addresses the selected pieces of DCIs in this bundle at a high school level.
- Students can investigate the interactions of materials with "planetary" surfaces in a scaled-down way in the classroom.
- Major social considerations around space travel invite science-based answers that drive the unit, such as, "Can humans source the things we'd need to survive off of Earth?"

How is the unit structured?

The unit is organized into four lesson sets. **Lesson Set 1** (Lessons 1-5) focuses on answering the question: *How can we find water and other substances we need to survive on other objects in space?* Students investigate planetary surface features (Earth's and Mars') to investigate water and its unique structure and function in erosion. They also develop understandings around physical science concepts of light and matter along with Earth and space science concepts of spectroscopy as a way to identify substances off of Earth. **Lesson Set 2** (Lessons 6-9) focuses on answering the question: *Why do we need certain types of atoms to create the substances we need?* Students develop science ideas about the structure of atoms, the patterns in their bonds, the organization of the periodic table, electronegativity, bond character, and how these affect the polarity and properties of the molecule. **Lesson Set 3** (Lessons 10-12) focuses on answering the question: *How can we make the substances we need to survive off of Earth using the existing matter in the solar system?* Students develop and apply the idea of conservation of matter through chemical equations in the context of a variety of substances, including those that form ionic compounds and form polyatomic ions. **Lesson Set 4** (13-15) focuses on answering the question: *How can we be more sustainable in what we use and produce?* Students consider applications of ideas students figured out to issues related to sustainability, both off Earth and on it. Students investigate what makes a substance recyclable and how to alter the chemical structure of molecules to yield particular properties. Students apply these ideas in a transfer task in Lesson 15. The unit culminates by instilling hope in students that the direction of future research (and careers) in science and engineering, can lead to more sustainable approaches to the way we live and work in the future.



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

This unit is designed to support students in developing an understanding of **how matter is conserved during chemical reactions and how water interacts with materials** in a relevant context. **Developing and using models** is intentionally developed across the unit, beginning in Lesson 1 as students are supported in developing initial models about how we might use **chemical reactions** to survive in space. Students have the opportunity to extend this model in Lessons 4, 6, 7, & 8, and a transfer task is provided with a focus on modeling. Finally, students model complex polyatomic ions in Lesson 11, building more robust models of inter and **intramolecular forces and bonding** as they proceed through Lesson Sets 1 and 2.

Obtaining, evaluating, and communicating information is also intentionally developed across this unit, beginning in Lesson 2 and expanded through 4, 5 to investigate **Earth and space systems**, especially the role of **water in Earth surface processes** and **patterns in spectra**. Then, in Lesson Set 3, Lessons 10, 11, 12, 13, & 14 as students engage with **increasingly complex texts on a number of topics, leveraging a similar journal-like structure**:

- how we detect the presence of water on other planets (Lesson 5)
- using ions to clean water (Lesson 10)
- how we could create fertilizers to grow plants in space (Lesson 11)
- find the elements we need to develop materials for survival in the solar system (Lesson 12)
- recycling thermoplastics and thermoset plastics (Lesson 13)
- reading bioplastics and geopolymer printing (Lesson 14)

Across these readings, students integrate information from various sources, including their own investigations, and summarize them to describe properties of water. Students evaluate the usefulness of various sources of information in determining the structures of materials needed to survive off Earth. The readings include **journal articles adapted for classroom use, scientific text presented for the public (e.g., from NASA), scientific text structured as investigation findings**, and **videos**. Students also engage with new representations in these texts, including organic chemistry carbon chains.

Patterns are intentionally developed across this unit. Patterns support students to reason about **scale and systems** and their **relationships to causal claims**. In lesson 1, the patterns students examine simply elaborate the scope of our unit question: how will we seek to live on other planets? However, these patterns don't help students *predict* combinations or properties of substances, so students deepen their work with elemental patterns in Lesson Set 2 by *investigating a new scale*: the subatomic one (HS Patterns 1.2). Lessons 6, 7, 8, students use patterns in empirical evidence to **organize elements** in emergent categories, such as those needed for building structures for survival (e.g., metals), (HS Patterns 1.1). They build the **periodic table of the elements** from patterns of evidence, **organized by protons** and then by the **connections (bonds)** that they tend to form. **Patterns of electronegativity (subatomic scale)** form the basis of our **models for substitutes** for water in Lesson 8 and other substitutes in Lesson 9. Patterns are assessed in Lesson 15.

Structure and Function is intentionally developed in this unit. Structure and function provide an integral lens for thinking about: 1) why atoms of different elements form bonds in characteristic ways; 2) water's polar structure makes it uniquely important for survival (e.g., H₂S could not possibly substitute for it because its less-polar structure results in different functions); and 3) how detection of water on planetary surfaces is due to how **water's polar structure** functions to create **characteristic landforms** by carrying away minerals. Several unit questions depend on connecting the **molecular structure of water** with its function and behavior. Lessons 4, 7, & 8 build foundational ideas about the structure and function of atoms, especially how they function (connect) with each other and form bonds. This is revisited in Lessons 10, 11 and 12 as students use their knowledge about the structure and function of atoms to predict chemical reactions between elements.

Connections to Middle School OpenSciEd Units

This unit builds **science and engineering practices (SEPs)** that students should have previously developed in the context of physical science standards in Middle School *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* and *OpenSciEd Unit 8.4: How are we connected to the patterns we see in the sky and space? (Space Unit)*. Students' use of **Developing and Using Models** increases its sophistication from middle school as models used in a predictive manner in high school. In the Middle School *Space Unit*, students intentionally developed and used models to explain physical and Earth and space science phenomena at very different scales of time and space. Students develop, use, and revise models from the start and throughout the unit to explain patterns in the sky ranging from why Manhattanhenge occurs twice a year in the same spot, why the seasons in Australia are opposite of seasons in the Northern Hemisphere, why the Moon appears redder during a lunar eclipse but does not go completely dark, why planets go around the Sun and moons go around planets, our place in the solar system and galaxy (MS Modeling 2.2, 2.4, 2.5, 2.6). In Middle School *Bath Bombs Unit*, students investigate bath bombs, modeling the transformation of matter of bath bombs using particles that are round, but not investigating any subatomic structures. These middle-school models do not move across scales.

In Middle School OpenSciEd, students developed **Obtaining, Evaluating, and Communicating Information** as they read, evaluated, compared, and synthesized information from multiple sources including text, data, maps, graphs, and images (MS Obtaining, evaluating, and communicating information 8.1, 8.2) in the Middle School *Space Unit*, building on their experience with this practice from prior units. While students continue to use several close reading and listening protocols, some of the scaffolding from previous units is eventually removed so they can execute the practice on their own.

This unit builds upon Crosscutting Concepts that students should have previously developed in connection with **Structure and Function** within the Middle School *Bath Bombs Unit*. In Middle School *Bath Bombs Unit*, students looked for patterns of macroscopic occurrences in the bath bomb phenomena to figure out the particle-level patterns that explain the phenomena (MS Patterns 1.2, 1.3, 1.4). Students develop the idea that these particles must be made of constituent parts (atoms) because of the patterns they observe in their investigations. They use discrepant patterns to reason that the way these parts are put together is unique to different substances. Students intentionally develop patterns across the

three-year OpenSciEd Middle School sequence. In Middle School *Bath Bombs Unit*, substructure ideas about matter were limited to the ideas that some atoms could combine with others and make new substances (e.g., bath bombs + water yield new gasses). In other words, they model structures and parts, but do not indicate the causal mechanisms that link function to structure (MS Structure & Function 6.1, 6.2). Students describe and analyze the bath bomb system and attempt to account for the properties of bath bombs, but they do not have the mechanisms of the **DCI: PS1.A** necessary to completely explain the atomic structures that contribute to the function of these materials.

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-PS1-2 Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

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

HS-ESS1-2†: Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, ~~motion of distant galaxies~~, and composition of matter in the universe.

HS-ESS2-1†: Develop a model to illustrate how Earth's ~~internal~~ and surface processes operate at different spatial and temporal scales to form continental ~~and ocean-floor~~ features.

HS-ESS2-5: Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.

*This performance expectation is developed across multiple units. This unit reinforces and fully develops these NGSS PEs from a prior OpenSciEd chemistry unit.

†This performance expectation is developed across multiple courses. This unit works toward these NGSS PEs that students will fully develop in the OpenSciEd physics course.

Science and Engineering Practices

Disciplinary Core Ideas*

Crosscutting Concepts

This unit intentionally develops students' engagement in these practice elements: 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. - 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. Obtaining, Evaluating, and Communicating Information - 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. 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 (including orally, graphically, textually, and mathematically). Elements from the following practices are also key to the sensemaking in this unit: - Using Mathematics and Computational Thinking - Constructing Explanations and Designing Solutions - Engaging in Argument from Evidence	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, HS-PS2-6) PS1.B: Structure and Properties of Matter - The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2) 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. (HS-PS1-1, HS-PS1-3, HS-PS2-6) PS4.B: Electromagnetic Radiation - Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. (secondary) (HS-ESS1-2) ESS1.A: The Universe and Its Stars - The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. (HS-ESS1-2, HS-ESS1-3) The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gasses, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe. (HS-ESS1-2) Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter	This unit intentionally develops students' use of these crosscutting concept elements. 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. - Classifications or explanations used at one scale may fail or need revision when information from smaller or larger scales is introduced; thus requiring improved investigations and experiments. - Mathematical representations are needed to identify some patterns. - Empirical evidence is needed to identify patterns. 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. - The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. The following crosscutting concepts are also key to the sensemaking in this unit: - Energy and Matter
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	than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. (HS-ESS1-2, HS-ESS1-3) ESS2.A: Earth Materials and Systems - Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. A deep knowledge of how feedbacks work within and among Earth's systems is still lacking, thus limiting scientists' ability to predict some changes and their impacts. (HS-ESS2-1, HS-ESS2-2) ESS2.B: Plate Tectonics and Large-Scale System Interactions - Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust. (HS-ESS2-1) ESS2.C: The Roles of Water in Earth's Surface Processes - The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks. (HS-ESS2-5)	
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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?

Scientific Knowledge Assumes an Order and Consistency in Natural Systems Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and will continue to do so in the future. (HS-ESS1-2) Science assumes the universe is a vast single system in which basic laws are consistent.	In Lesson Set 1, students systematically apply long-term thinking about water's role on Earth with the assumption that water will behave today in the stream table as it has for thousands or even millions of years on Earth and Mars' surfaces. The operation of water's polarity functions the same on Mars as on Earth because the universe is a single system with laws that work consistently: polarity, intermolecular forces, and intramolecular forces.
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Connections to the Engineering, Technology, and Applications of Science	
Which elements of ETS are developed in the unit?	How are they developed?
Interdependence of Science, Engineering, and Technology Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers and others with wide ranges of expertise. (HS-ESS1-2)	Students think across domains as they consider the science needed to engineer for human survival. In Lesson Set 2, students are deeply engaged in figuring out the chemical reactions (science) needed for designed materials in space, and in Lesson Set 3, students must figure out ways to apply this R&D knowledge to both space survival and on-Earth life.

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

This unit uses and builds upon **disciplinary core ideas (DCIs)** and other science ideas that students should have previously developed in OpenSciEd Middle School or another middle school science program.

- MS-PS1.A: Structure and Properties of Matter (*OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*, *OpenSciEd Unit 7.3: How do things inside our bodies work together to make us feel the way we do? (Inside Our Bodies Unit)*, *OpenSciEd Unit 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)*)
 - Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. (MS-PS1-1)
 - Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it. (MS-PS1-2), (MS-PS1-3)
- MS-PS1.B: Chemical Reactions (*Bath Bombs Unit*, *Inside Our Bodies Unit*, *Maple Syrup Unit*)
 - Substances react in chemically characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. (MS-PS1-2), (MS-PS1-3), (MS-PS1-5)
 - The total number of each type of atom is conserved, and thus the mass does not change. (MS-PS1-5)
- MS-ESS2.C: The Roles of Water in Earth's Surface Processes (*OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*, *OpenSciEd Unit 6.4: What causes Earth's surface to change? (Everest Unit)*)
 - The complex patterns of the changes and the movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents, are major determinants of local weather patterns. (MS-ESS2-5)
 - Water's movements - both on the land and underground - cause weathering and erosion, which change the land's surface features and create underground formations. (MS-ESS2-2)
- MS-ESS2.D: Weather and Climate (*Storms Unit*)
 - The ocean exerts a major influence on weather and climate by absorbing energy from the Sun, releasing it over time, and globally redistributing it through ocean currents. (MS-ESS2-6)
- MS-ESS3.A: Natural Resources (*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)*)
 - Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes. (MS-ESS3-1)
- MS-ESS3.C: Human Impacts on Earth Systems (*OpenSciEd Unit 7.5: How does changing an ecosystem affect what lives there? (Palm Oil Unit)*, *Droughts and Floods Unit*)
 - Typically as human populations and per capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise. (MS-ESS3-3), (MS-ESS3-4)

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

- HS-LS1.A: Structure and Function (*OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*)
 - Systems of specialized cells within organisms help them perform essential functions for life. (HS-LS1-1)
 - Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. (HS-LS1-2)
- HS-LS1.C: Organization for Matter and Energy Flow in Organisms (*OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*)
 - The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. (HS-LS1-5)
 - The sugar molecules thus formed contain carbon, hydrogen, and oxygen; their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. (HS-LS1-6)
 - As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6), (HS-LS1-7)
- HS-ESS3.A: Natural Resources (*OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*)
 - Resource availability has guided the development of human society. (HS-ESS3-1)

This unit begins or continues 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:

- PS2.B: Types of Interactions (*OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*, *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors 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. (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)
- ESS1.A: The Universe and Its Stars (*OpenSciEd Unit P.6: Why do stars shine and will they shine forever? (Stars)*)
 - The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. (HS-ESS1-2), (HS-ESS1-3)
 - The big bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gasses, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe. (HS-ESS1-2)
 - Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode. (HS-ESS1-2), (HS-ESS1-3)
- ESS2.A: Earth Materials and Systems (*Polar Ice Unit*, *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*)
 - Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. A deep knowledge of how feedbacks work within and among Earth's systems is still lacking, thus limiting scientists' ability to predict some changes and their impacts. (HS-ESS2-1), (HS-ESS2-2)
- ESS2.B: Plate Tectonics and Large-Scale System Interactions (*Earth's Interior Unit*)
 - Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. (HS-ESS2-1), (secondary to HS-ESS1-5)
 - Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust. (HS-ESS2-1)
- ESS3.C: Human Impacts on Earth Systems (*OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*, *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*)
 - Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (HS-ESS3-4)

The M-E-F (matter-energy-forces) poster, which students began building in *Polar Ice 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 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	<i>Cancer Unit</i>	<i>Serengeti Unit, Fires Unit</i>	<i>Fires Unit, Natural Selection Unit</i>	<i>Natural Selection Unit, Cancer Unit</i>	<i>Serengeti Unit</i>	<i>Fires Unit, Cancer Unit, Natural Selection Unit</i>	<i>Speciation Unit</i>	<i>Cancer Unit, Speciation Unit</i>
Chemistry	<i>Polar Ice Unit, Oysters Unit</i>	<i>Electrostatics Unit, Space Survival Unit</i>	<i>Polar Ice Unit</i>	<i>Fuels Unit</i>	<i>Polar Ice Unit, Oysters Unit</i>	<i>Fuels Unit</i>	<i>Fuels Unit</i>	<i>Electrostatics Unit, Space Survival Unit</i>
Physics	<i>Electricity Unit, Cosmology Unit</i>	<i>Electricity Unit, Microwave Unit</i>	<i>Microwave Unit</i>	<i>Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit, Meteors Unit</i>	<i>Vehicle Collisions Unit, Meteors Unit</i>	<i>Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit</i>	<i>Vehicle Collisions Unit</i>	<i>Cosmology Unit, Microwave Unit</i>

	Patterns	Cause/Effect	Scale	Systems/Models	Energy/Matter	Structure/Function	Stability/Change
Biology	<i>Natural Selection Unit, Speciation Unit</i>	<i>Cancer Unit, Natural Selection Unit, Speciation Unit, Serengeti Unit</i>	<i>Serengeti Unit</i>	<i>Fires Unit, Cancer Unit, Serengeti Unit</i>	<i>Fires Unit, Serengeti Unit</i>	<i>Cancer Unit</i>	<i>Speciation Unit, Serengeti Unit</i>
Chemistry	<i>Electrostatics Unit, Space Survival Unit</i>	<i>Oysters Unit, Fuels Unit</i>	<i>Electrostatics Unit, Oysters Unit</i>	<i>Polar Ice Unit</i>	<i>Polar Ice Unit, Fuels Unit</i>	<i>Space Survival Unit</i>	<i>Oysters Unit</i>
Physics	<i>Cosmology Unit, Vehicle Collisions Unit, Earth's Interior Unit</i>	<i>Vehicle Collisions Unit, Earth's Interior Unit</i>	<i>Meteors Unit, Earth's Interior Unit</i>	<i>Electricity Unit, Vehicle Collisions Unit, Microwave Unit</i>	<i>Electricity Unit, Earth's Interior Unit</i>	<i>Earth's Interior Unit, Vehicle Collisions Unit</i>	<i>Electricity Unit, Cosmology Unit</i>

What are some common ideas that students might have?

Students will come into the unit with many ideas about elements for survival that are derived from previous everyday experiences, intuitive understandings of the way the world works, 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. Outer space is a place humans are likely to be going more in the coming decades.

2. Travel to space is controversial in a time of climate crisis and vast socioeconomic inequality; it may be “cool” but 7 billion people on our planet will certainly not all be going there.
3. Some students will think long-term colonization is possible despite issues such as human body deterioration in space
4. Partial understandings about water’s properties such as:
 - a. It can dissolve things
 - b. It expands when frozen, even though most things shrink when they’re cold
 - c. It is “polar” (developed in unit 2) but not why it is polar
5. Students may not understand how recycling happens and what chemical transformations have to occur for recycling to work.

Students will explore the properties of matter needed for survival off Earth and think about the ways matter can transform into other types of matter.

It is valuable to think of ideas like these not as misconceptions that need to be erased 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. Following these ideas, and building explicitly from these ideas to draw connections, is a productive pedagogical tool that will help students construct new, more accurate conceptual models of the structure and properties of matter.

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

This is the third unit of the High School Chemistry Course in the OpenSciEd Scope and Sequence. We have assumed a traditional sequencing of OpenSciEd Biology, then Chemistry, then Physics. Given this placement, the following modifications would be needed if students do not take OpenSciEd Biology first, or if the Chemistry Course is taught out of order. These include the following adjustments:

- *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)* is critical for supporting the thinking of forces in these bonds. If that unit is not taught first, you may review the nature of charges in an atom using common static electricity phenomena. This unit assumes familiarity with “opposites attract” thinking, charges, and electricity, especially that electrons “jump” or move during ionization. This unit also assumes that students have some experience with protons, neutrons, electrons, and the characteristics of ionic bonding (e.g., positive and negative charges attracting, the formation of ionic compounds/salts). They will construct and organize the periodic table in this unit.
- If taught as part of an AP Chemistry course, you may provide students with additional examination of novel Lewis diagrams, resonance, VSEPR, and bond hybridization, intermolecular forces, and mass/photoelectron spectrometry that are outside the bounds of the NGSS. This unit provides important foundational force and structure-based models so that teaching these concepts should be considerably easier for students once they have a strong understanding of intermolecular forces and the continuum of bond character.
- If used as part of an Earth and space science course, you may want to consider how Lesson Set 2 can be adjusted or shortened, as it focuses on the periodic trends and periodic table. You may extend Lesson Set 1 to include deeper exploration of the Earth’s water-based and plate-based features.
- Note that the Haber Process is **not** considered an appropriate extension during this unit because it is a focal reaction in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*.

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

The following are example options to shorten or condense parts of the unit without eliminating important sensemaking for students:

- Lessons 13 and 14 could be removed if students do not bring up recycling.
- Lesson 13: If you are short on time, you could reduce the length of the lesson by removing the videos.

To extend or enhance the unit, consider the following:

- Lesson 2: Have students engage with Station 6 data using CODAP.
- Lesson 2: If students show interest in comparing the properties of water to the properties of other materials they have studied in *Electrostatics Unit*, take time to co-create a parallel poster.
- Lesson 2: If students are interested in learning more about other potential food sources, *Thinking About Aquaculture*, is included. Since it mentions the existence of water oceans on some moons in our solar system, this handout may be placed after Lesson 4 or with Lesson 11.
- Lesson 2: Lead students through thinking about the water requirements for astronauts on past missions, such as Apollo 11, then extrapolate to how much humans would need daily to survive off of Earth. This would also have students incorporate CCSS.MATH.CONTENT.HSN.Q.A.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.
- Lesson 10: Consider demonstrating the cleaning process described in *Cleaning Metal-Contaminated Water*.
- Lesson 12: If students show interest in researching an additional location in the solar system, additional links are provided.

- Lesson 12: Provide students access to the open access chemical research paper describing the extended molecular structure of cement.
- Lesson 13: More carefully examine **recycling** in your own community. Have students examine local recycling policies and practices to determine if there are improvements to be made. You may invite someone from the city or county waste system as a guest speaker.
- Lesson 14: If students are interested in materials other than ceramics (like concrete) or polymers, such as metals, electronic materials, or composites, you may wish to have them research these materials using *Synthesis and Evaluation*.
- Lesson 15: Consider having students balance additional chemical equations beyond main group elements and combustion reactions (NGSS Assessment Boundary).

What mathematics concepts will students engage with in the unit?

This unit requires knowledge of how to multiply coefficients and interpret expressions (Lessons 11 & 12), and calculate averages and represent data in ways that can help them identify patterns in scatterplots (Lesson 5). Students engage in mathematical practices (CCSS.MP) reasoning in Lesson 5 when they describe patterns as they manipulate a dataset using graphs and maps. In order to balance equations, students will benefit from being able to skillfully find least common multiples, but for many students balancing equations may be an opportunity to practice with least common multiples in a way that is concrete and applied.

This unit does not assume students are fluent with the mathematical practices listed below, 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
Statistics and Probability	CCSS.MATH.CONTE NT.HSS.IC.B.6	Making Inferences and Justifying Conclusions. Make inferences and justify conclusions from sample surveys, experiments, and observational studies	Evaluate reports based on data.	5
Algebra	CCSS.MATH.CONTE NT.HSA-SSE.A.1.a	Seeing Structure in Expressions. Interpret the structure of expressions.	Interpret expressions that represent a quantity in terms of its context. a. Interpret parts of an expression, such as terms, factors, and coefficients.	11, 12, 15

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 callouts below highlight how additional guidance is provided to attend to a variety of student needs in instruction.

ADDITIONAL GUIDANCE: This investigation is written to allow students to choose materials to work with. In addition to water, students may think of a number of other common household chemicals (e.g., bleach, milk, juice). Encourage them to think of both safety and the liquid's chemical composition. Bleach is not safe to use in undiluted form, and juice and milk are mostly water. There is space to replace materials with student-generated ideas in *Erosion Investigation*.

*** ATTENDING TO EQUITY- Universal Design for Learning:** The goal in this moment is two-fold: (1) to support *representation* by providing students an opportunity to decode the symbols in the chemical equation and (2) to have students think about how the chemical equation can be used as a model to explain phenomena or solve problems.

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, PS1.B: Chemical Reactions, PS2.B: Types of Interactions, ESS1.A: The Universe and Its Stars, ESS2.A: Earth Materials and Systems, ESS2.C: The Roles of Water in Earth's Surface Processes**), 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:

For information about the anchor, space travel, and recycling topics:

- Bingham, J., Dawson, W., Brewer, P. R., & Paintsil, A. (2022). Media use and US Attitudes Toward Government and Private Space Exploration. *Space Policy*, 62, 101506. <http://doi.org/10.1016/j.spacepol.2022.101506>
- Kim, E.-J. (2019). *Plastic: past, present, and future*. Scribe UK.
- Romer, J. (2021). Can I Recycle This?: A Guide to Better Recycling and How to Reduce Single-Use Plastics. Penguin.
- Ted RadioHour. (2018). Lucianne Walkowicz: Should We Be Using Mars As A Backup Planet? [podcast recording]. <https://www.npr.org/2018/12/21/678642121/lucianne-walkowicz-should-we-be-using-mars-as-a-backup-planet> Accessed 29 Nov 2023.
- Weinersmith, K. & Weinersmith, Z. (2023). A City on Mars: Can we settle space, should we settle space, and have we really thought this through? Penguin.
- Whiteson, D. & Cham, J. (2023). Can we settle space? Should we? Have we really thought this through? [Podcast]. Daniel & Jorge explain the universe. Accessed through iHeart Radio.

For historical and contextual information about the periodic table and force-based models of bonding:

- Kean, S. (2011). *The Disappearing Spoon: And Other True Tales of Madness, Love, and the History of the World from the Periodic Table of the Elements*. Back Bay Books.
- Taber, K. S. (2023). Royal Society of Chemistry. (2021). Chemical bonding [white paper]. <https://edu.rsc.org/download?ac=527330>

For Gilbert Lewis' own guidance about the Lewis dot structure and the range of bond types (ionic and covalent being only parts of a wider range):

- Lewis, G. N. (1916). The atom and the molecule. *Journal of the American Chemical Society*, 38(4), 762–785. <https://doi.org/10.1021/ja02261a002>

Stay current with the news on the Artemis, Mars rover, and James Webb Telescope expeditions. These are anticipated to continue well into the 2030s and information about space colonization is likely to change rapidly.

How do I support students' emotional needs?

In this unit, students explore the challenges associated with survival in outer space. This may raise issues concerning land ownership and colonization mindsets. Students may have emotional needs related to two main issues:

- Trauma associated with history of colonization
- Strong beliefs about equity and justice issues connected with the imminence of long-term human colonization of Mars and the Moon.

Before beginning this unit, make sure to reach out to the counselor at your school for student-specific support and strategies that might be needed in regard to the students in your classroom. Consider asking the counselor to join you in the classroom for the DQB build in **Lesson 1** to gauge the extent to which students might need emotional support. Also consider planning follow-up check-ins with the counselor in regard to any students who may need additional emotional support.

Educate yourself about the connection between the mindset of Mars colonization with the history of settler-colonialism in the US. Many of the themes of space travel are the same as “manifest destiny” thinking of the 1800s, which resulted in devastating genocide and biological destruction. Similarly, modern-day governmental decision-making is actively promoting the colonization of new land on Mars with little opportunity for public input.

Plan ahead with ways to scaffold justice-oriented teaching. Consider the following websites:

- Resource: Learning for Justice: Critical Practices: <https://www.learningforjustice.org/frameworks/critical-practices>
- Facing History & Ourselves: <https://www.facinghistory.org/resource-library?search=colonialism>

Be aware that students who are struggling with difficult emotions in class may demonstrate a variety of behaviors, including but not limited to: fidgeting, withdrawal, disruption or distraction, rapid breathing, holding their breath, and change in body language or tone. If you notice a student might be struggling, share what you are observing and ask if they need some help.

What is the Learning in Places Nature-Culture Relations framework?

This unit is informed by the Learning in Places complex socio-ecological systems framework. This framework involves sensemaking across five dimensions (species, kinds & behaviors; relationships; places, lands & waters, thinking across scales, and ethical deliberation and decision-making) under an umbrella of power and historicity. These dimensions include making sense of both human and other-than-human values, needs, and behaviors across multiple temporal and spatial scales. The framework guides learners towards designing actions or making decisions for making change in adaptive and resilient ways. Students use these dimensions as they consider if humans should pursue settlements off of Earth in Lesson 15. Students are presented with four arguments and they discuss ideas around the ethics of these possible decisions.

Socio-ecological decisions are those made by individuals, communities, organizations, and institutions that are informed by and impact the natural world. These decisions are affected by relationships between humans and the natural world, which are called “nature-culture relations.” Nature-culture relations often vary by culture, context, and society and affect which socio-ecological decisions are made and enacted. Understanding the different types of philosophical connections that exist between humans and the natural world is imperative for creating and sustaining socially and environmentally just decisions.

For more about socio-ecological deliberation and decision-making, please visit <http://learninginplaces.org/>. Learning in Places Collaborative. (2022). Framework: Complex Socio-Ecological Systems. Bothell, Seattle, WA & Evanston, IL: Learning in Places.

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 co-constructed that definition and can add the specific term to a personal glossary in their science notebooks. These definitions we co-construct should be recorded using the students’ own words whenever possible. On the other hand, definitions 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, definitions 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 to the personal glossary.

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-construct the meaning of the word, students have ownership of 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 definitions we co-construct and 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 are trying to figure out.

Lesson	Definitions we co-construct	Definitions we encounter
L1		chemical changes**, payload, physical changes**, product**, reactant**, recycling*

L2		adhesion, aphotic zone, capillary action, cohesion, dysphotic zone, euphotic zone, surface tension, specific heat*,
L3		aquaculture, channel, deposition**, dune, elevation**, erosion**, oxbow lake, point bar, sediment,
L4		erosion**, frost heaving, meander, ions*, polarity*, positive feedback loop*
L5	spectroscopy, transmission spectrum, visible spectrum	infrared*, elements**
L6	atomic number, compound, molecule, periodicity	atomic mass*, bond*, charge*, electrons*, neutrons*, protons*, reactivity
L7	electron shells, valence electrons	
L8		atomic radius, attraction*, balanced forces*, dipole arrow, electronegativity, ionic bond, nonpolar covalent bond, polar covalent bond, polar molecules*, repulsion*
L9	dipole arrow, ionic bond, nonpolar covalent bond, polar covalent bond	double bond, triple bond, metallic bond, sila-ibuprofen, synthetic
L10	intermolecular force, precipitate	
L11	polyatomic ion, law of conservation of matter	decomposition
L12	balanced chemical equation, coefficient	
L13		amino acid*, cross-link, monomer, polymer, thermoplastic, thermoset
L14		
L15		hard water, soft water

* co-constructed or encountered in a previous OpenSciEd High School Biology or Chemistry Unit

** co-constructed or encountered in the middle school grade band of NGSS/OpenSciEd Middle School

HOME COMMUNICATION

Dear Guardian,

Your child's high school chemistry class is starting a unit called *How can we find, make, and recycle the substances we need to live on and beyond Earth?*, as part of the OpenSciEd high school science curriculum. This unit develops science ideas around atomic structure, trends on the periodic table, and how atomic-level interactions influence bulk-scale properties. Throughout the unit, students will draw on their own experiences and everyday understandings to help them figure out complex science ideas as they use data from our world and from their own investigations.

In the first lesson, students hear about NASA's plans to develop settlements off of Earth. Students are asked to consider what substances we would need to live and work in these places beyond Earth. In a Home Learning activity, they will ask about processes and materials you or your community uses to recycle substances. Throughout the unit, students examine substances, like water or oxygen, which are essential for life. They consider if element-level substitutions in other substances would result in a different substance with the same properties. At the end of the unit, students examine different methods we use to be more sustainable in what we use and produce. Finally, students discuss if we should even try to settle places beyond Earth.

You can learn more about NASA's plans at: <https://www.nasa.gov/specials/artemis/index.html>. For more information around perceptions of space travel, see: <https://www.npr.org/2018/12/21/678642121/lucianne-walkowicz-should-we-be-using-mars-as-a-backup-planet> or <https://omny.fm/shows/daniel-and-jorge-explain-the-universe/can-we-settle-space-should-we-have-we-really-thoug>.

The need to explore options for settlements beyond Earth is indirectly related to climate change. Your child may be one of 84% of Americans ages 16 to 25 who are at least moderately worried about climate change (as are the majority of American adults). You can learn more about *climate anxiety* and ways to support your child at <https://www.health.harvard.edu/blog/is-climate-change-keeping-you-up-at-night-you-may-have-climate-anxiety-202206132761>.

If your child or someone close to your child has been heavily impacted by climate change, 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 climate change.
- Ask your child to explain why it is important to use more sustainable manufacturing practices and discuss their ideas about their relative costs and benefits.

Emphasize that we can take action on climate change. Have honest conversations with your child about what they, personally, can do, while taking into consideration the needs of those who are most affected by climate change.

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 *¿Cómo podemos encontrar, producir y reciclar las sustancias que necesitamos para vivir en la Tierra y más allá?* como parte del plan de estudios de ciencias de la escuela secundaria OpenSciEd. Esta unidad desarrolla ideas científicas sobre la estructura atómica, las tendencias en la tabla periódica y cómo las interacciones a nivel atómico influyen en las propiedades a gran escala. A lo largo de la unidad, los estudiantes aprovecharán sus propias experiencias y conocimientos cotidianos para ayudarlos a descubrir ideas científicas complejas mientras utilizan datos de nuestro mundo y de sus propias investigaciones.

En la primera lección, los estudiantes escuchan sobre los planes de la NASA para desarrollar asentamientos fuera de la Tierra. Se pide a los estudiantes que consideren qué sustancias necesitaríamos para vivir y trabajar en estos lugares más allá de la Tierra. En una actividad de Aprendizaje en el hogar, le preguntarán sobre los procesos y materiales que usted o su comunidad utilizan para reciclar sustancias. A lo largo de la unidad, los estudiantes examinan sustancias, como el agua o el oxígeno, que son esenciales para la vida. Consideran si las sustituciones a nivel de elementos en otras sustancias darían como resultado una sustancia diferente con las mismas propiedades. Al final de la unidad, los estudiantes examinan diferentes métodos que utilizamos para ser más sostenibles en lo que usamos y producimos. Finalmente, los estudiantes discuten si deberíamos siquiera intentar establecernos en lugares más allá de la Tierra.

Puede obtener más información sobre los planes de la NASA en: <https://www.nasa.gov/specials/artemis/index.html>. Para obtener más información sobre las percepciones de los viajes espaciales, consulte: <https://www.npr.org/2018/12/21/678642121/lucianne-walkowicz-should-we-be-using-mars-as-a-backup-planet> o <https://omny.fm/shows/daniel-and-jorge-explain-the-universe/can-we-settle-space-should-we-have-we-really-thoug>.

La necesidad de explorar opciones para asentamientos más allá de la Tierra está indirectamente relacionada con el cambio climático. Su hijo puede ser uno del 84% de los estadounidenses de entre 16 y 25 años que están al menos moderadamente preocupados por el cambio climático (al igual que la mayoría de los adultos estadounidenses). Puede aprender más sobre *ansiedad climática* y formas de apoyar a su hijo en <https://www.health.harvard.edu/blog/is-climate-change-keeping-you-up-at-night-you-may-have-climate-anxiety-202206132761>.

Si su hijo o alguien cercano a él se ha visto gravemente afectado por el cambio climático, 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 dudas.
- Reconozca cualquier emoción en torno al cambio climático.
- Pídale a su hijo que le explique por qué es importante utilizar prácticas de fabricación más sostenibles y analice sus ideas sobre sus costos y beneficios relativos.

Enfatice que podemos tomar medidas sobre el cambio climático. Tenga conversaciones honestas con su hijo sobre lo que él, personalmente, puede hacer, teniendo en cuenta las necesidades de quienes se ven más afectados por el cambio climático.

Ayudar a su estudiante a hacer sentido de su aprendizaje:

- No es necesario enseñar 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 escuché bien, me estás diciendo que..."

Sinceramente,

(Su nombre o firma aquí)

LESSON 1: What substances would we need and how would we get them to live and work beyond Earth?

PREVIOUS LESSON *There is no previous lesson.*

THIS LESSON

ANCHORING PHENOMENON

4 days



NASA/ Charles Beason

We examine a video of NASA's plans in the near future. We analyze historical missions and rocket capacities. We identify criteria, constraints, and solutions for living and working beyond Earth for longer periods of time. We identify ways to find, recycle, and make substances. We compare matter inputs and outputs in different chemical processes. We develop models of how new substances are made through chemical reactions. We add questions to a Driving Question Board and brainstorm ideas for data and investigations that could help answer them.

NEXT LESSON

We will discuss other chemical reactions that include water, what is special about water, and properties of water we previously studied. We will gather information on water's properties from two out of six investigation stations. We will plan how to share this information. In a Scientists Circle, we will integrate our information from across the six investigation stations.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, HS-ESS1-2, HS-ESS2-1, HS-ESS2-5



WHAT STUDENTS WILL DO

1.A Define some of the criteria for living and working in places beyond Earth for longer periods of time and the constraints for taking all of the substances/materials we would need, and identify possible solutions for obtaining these substances/materials. (SEP: 1.8; DCI: ESS3.A.1, ESS3.C.2, PS1.B.3; CCC: 3.1)

1.B Develop and use a model to represent atom-level compositions of products and reactants and the changes and interactions that occur between the atoms in a chemical reaction that help explain why specific products form and not others. (SEP: 2.3; DCI: PS1.B.3; CCC: 3.1, 6.2)

1.C Ask questions that arise from careful observation of images (at different scales) of solar system objects and particle-level models for different chemical process/reactions and/or ask question to clarify/seek additional information and relationships about ways to find, recycle, and/or make enough of the substances we need to live and work beyond Earth and on it. (SEP: 1.1, 1.2; DCI: ESS3.A.1, ESS3.C.2, PS1.B.3; CCC: 6.2)

WHAT STUDENTS WILL FIGURE OUT

- People need certain substances to live and support the kinds of work they might want to do in places beyond Earth.
- The scale of the solar system and the cost and speed of space travel mean that most of the substances that we need to live and work would have to be found, recycled, or made on-site.
- New substances (product(s)) can be created from one or more reactants through the rearrangement of matter in chemical reactions.

Lesson 1 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		NAVIGATE Share examples of human impacts on Earth systems and some more sustainable ways of using Earth's resources.	A	
2	10 min		ANALYZE ARTEMIS VIDEO AND TRANSCRIPT Have students watch a video and annotate a transcript about NASA's Artemis program.	B-C	NASA Artemis Transcript, https://youtu.be/rMyn52-bQnQ
3	10 min		EXPLORE RELATED PHENOMENA Have the class brainstorm examples of similar things that people have tried in the past. Organize students into pairs to explore prior missions in the solar system.	D-E	Space Missions Deck with binder clip
4	8 min		DEVELOP A SCALE MODEL TO IDENTIFY ADDITIONAL CRITERIA Work with the class to develop a scale model of the Earth-Moon-ISS system and use it to visualize the relative scale of distances to other objects in the solar system.	F-I	Earth-Moon-ISS System Visualization
5	12 min		IDENTIFY CRITERIA, CONSTRAINTS, AND SOLUTIONS Organize students into pairs to discuss payload limitations, analyze rocket data, and identify criteria, constraints, and possible solutions. Have students individually complete an exit ticket.	J-L	Day 1 Exit Ticket, Crewed Transport Rockets, Space Missions Deck with binder clip
End of day 1					
6	6 min		NAVIGATE Lead a discussion to identify substances/materials that we will need to live on another planet/moon and the constraints that limit how much we can take with us.	M-N	
7	4 min		CONSIDER A RELATED SYSTEM – EARTH Lead a discussion to identify some naturally occurring substances on Earth that we cannot see evidence of from a photo taken from space.	O	
8	10 min		ANALYZE DATA AND IDENTIFY ADDITIONAL OBSERVATIONS/TESTS Organize students into groups to compare images in the deck of solar system objects from last period. Discuss ways to identify substances or tell them apart.	P-Q	Space Missions Deck with binder clip
9	4 min		RECORD QUESTIONS Have students record individual questions on blue sticky notes related to finding the substances we need to live and work in these places beyond Earth.	R	3 blue sticky notes (3" x 3"), colored marker

Part	Duration		Summary	Slide	Materials
10	7 min		IDENTIFY RECYCLING AND SUSTAINABILITY CONNECTIONS Discuss how science and engineering have helped us develop more sustainable systems for reusing/recycling substances and/or reducing waste and how this is related to our needs for living and working on and beyond Earth in the future.	S-T	https://youtu.be/rMyn52-bQnQ
11	11 min		BRAINSTORM RELATED PHENOMENA Identify substances we might need to make more of on site. Recall some chemical reactions explored in this class or previous classes. Record any of the matter inputs (reactants) and outputs (products) we recall related to these reactions.	U-V	chart paper, chart paper markers
12	3 min		INTRODUCE HOME LEARNING Introduce home-learning questions to ask family or trusted members of the community.	W	sheet of loose-leaf paper
<i>End of day 2</i>					
13	5 min		NAVIGATE Review home-learning responses about recycling substances and use these to identify physical versus chemical changes.	X	
14	3 min		IDENTIFY PARTICLE-LEVEL CHANGES AND RELATED REPRESENTATIONS IN CHEMICAL REACTIONS Lead a whole-class discussion of particle-level changes in chemical reactions.	Y	"Related phenomena: chemical reactions" poster
15	10 min		GATHER INFORMATION TO IDENTIFY PATTERNS Have students work with a partner to identify patterns in the materials and processes to make products we need for survival.	Z	<i>Materials for Survival</i> in black and white, <i>Materials for Survival</i> in color
16	10 min		DEVELOP AND AND COMPARE INITIAL MODELS Have students develop an initial particle-level explanation for a chemical reaction, then compare similarities and differences in an explanation of a different reaction.	AA-BB	<i>Initial Reaction Model</i>
17	12 min		DEVELOP A CLASS CONSENSUS MODEL Gather students in a Scientists Circle to develop an initial consensus model to help explain what is happening at a particle level in any chemical reaction and why certain product(s), but not others, are the result of a chemical reaction.	CC	<i>Initial Reaction Model</i> , chart paper, chart paper markers
18	3 min		RECORD QUESTIONS Have students record individual questions on yellow sticky notes related to recycling and making the substances we need to live and work on and beyond Earth.	DD	3 yellow sticky notes (3" x 3"), colored marker

Part	Duration		Summary	Slide	Materials
19	2 min		OPTIONAL: GATHER ADDITIONAL INFORMATION Research an additional chemical reaction for substances we care about or need for living and working beyond Earth.	EE	sheet of loose-leaf paper, <i>Materials for Survival</i> in black and white
<i>End of day 3</i>					
20	22 min		DEVELOP THE FIRST PART OF OUR DRIVING QUESTION BOARD Have students add questions to the DQB in two rounds.	FF-HH	sticky-note questions, colored marker, chart paper, chart paper markers, index cards, painter's tape, driving question panel, "Related phenomena: chemical reactions" poster
21	13 min		PLAN INVESTIGATION IDEAS AND DATA NEEDED Help students brainstorm ideas for investigations and data that we need to answer our questions.	II	chart paper, chart paper markers, painter's tape
22	6 min		NAVIGATE Lead the class to identify the substance most critical to find first so that we can live and work beyond Earth.	JJ	<i>Materials for Survival</i>
23	4 min		OPTIONAL: PREPARE AND ORGANIZE NOTEBOOKS Help students set up and organize their science notebooks for this new unit.	KK	
<i>End of day 4</i>					

Lesson 1 • Materials List

	per student	per group	per class
Earth-Moon-ISS System Visualization materials	- calculator - science notebook		8" inflatable beach ball 2.25" polystyrene foam ball - fishing line or string (6') 2 yellow sticky notes (3" x 3")
Lesson materials	<i>NASA Artemis Transcript</i> - science notebook <i>Day 1 Exit Ticket</i> 3 blue sticky notes (3" x 3") - colored marker - sheet of loose-leaf paper <i>Materials for Survival</i> in black and white <i>Initial Reaction Model</i> 3 yellow sticky notes (3" x 3") - sticky-note questions <i>Materials for Survival</i>	<i>Space Missions Deck</i> with binder clip <i>Crewed Transport Rockets</i> <i>Materials for Survival</i> in color	https://youtu.be/rMyn52-bQnQ - chart paper - chart paper markers "Related phenomena: chemical reactions" poster - index cards - painter's tape - driving question panel

Materials preparation (35 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 three-hole-punched copies of the following handouts for every student:

- NASA Artemis Transcript*
- Day 1 Exit Ticket*
- Initial Reaction Model*
- Materials for Survival* in black and white.

Ensure that each pair of students has access to either a printed or digital version of the following:

- Crewed Transport Rockets*

Ensure that each pair of students can reference a color printed or digital color version of *Materials for Survival*. This can be a non-consumable version of the handout, while the version students keep is in black and white. Since you will reuse these color versions across classes, you may want to put them in sheet protectors if available, or laminate them to increase their durability.

Ensure that each pair of students has access to either a printed or digital color version of *Space Missions Deck*. Printed color copies are recommended as they tend to enhance the interactive partner discussion and card sorting activity. If you are printing your own color copies of this resource, use thicker paper (higher weight), and make enough for your largest class period. Cut each sheet in half along the dotted lines to make a deck of information cards for each group of students. Since you will reuse these across classes, you may want to put them in half-sheet protectors (8.5" x 5.5") if available, or laminate them to increase their durability. Binder-clip each deck together.

If you are printing your own copies of these resources, use thicker paper (higher weight), and make enough for your largest class period. Since you will reuse these across classes, you may want to put them in full-sheet protectors (8.5" x 11") if available, or laminate them to increase their durability.

Make a *driving question panel* to painter's tape above the Driving Question Board (DQB) after students post their questions, that says:

- *How can we find, make, and recycle the substances we need to live on and beyond Earth?*

Remove this panel between each class period and repost it after students add their questions to the DQB.

Test <https://youtu.be/rMyn52-bQnQ>.

If you did not use *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* or *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics 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* in Lesson 1 of *Electrostatics Unit* for an example of what these agreements might look like.

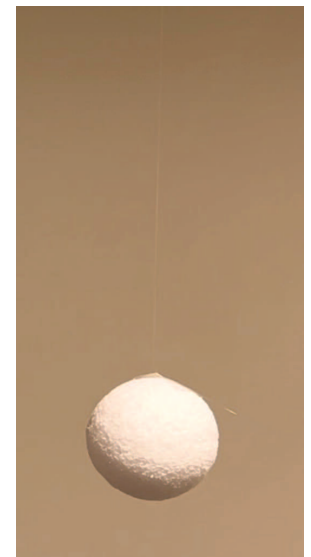
Blue and yellow sticky notes are used to distinguish two different lines of questions for the DQB. If you use a different color than these, you will need to update the slide(s) to match.

Do the following between day 1 and day 2:

- Remove the ISS from each deck of *Space Missions Deck*. Though it is needed in the deck on day 1, it will be a distractor for the task on day 2.
- Review and modify the red italicized text on **slide M** before the start of day 2, so that it accurately represents students' exit ticket responses at the end of day 1:
 - Identify the six most frequently mentioned substances/materials in student responses and make sure they are listed on the slide. These will likely include oxygen/air, food, water, and a material for shelter (e.g., bricks, concrete, cement).
 - Keep any of the other substances listed as long as each is mentioned by at least one student.
 - Replace those that students did not list in any of your classes with another frequently mentioned substance/material.

Day 1: Earth-Moon-ISS System Visualization

- **Group size:** Whole class
- **Setup:**
 - Find two locations in your room 240" (20 ft) apart. One of these is where you will hang the 2.25" polystyrene foam ball that will be visible to all students (but away from student traffic). Mark each of these locations on the floor with a sticky note.
 - Use painter's tape and 6' of fishing line (or string) to hang the foam ball above the marked spot. It should hang above the eye level of students sitting in their chairs (i.e., about 5 feet above the ground).
 - The second location you marked with painter's tape is where you will later stand with an 8" inflatable beach ball. These two locations represent a distance of 30 Earth diameters.
 - You may replace the two balls for this visualization with a 2.6" tennis ball and 9.5" basketball, but you will need to adjust their locations to represent the 30-Earth-diameter distance ($9.5" \times 30 = 285"$ or 23.75 ft). The relative scale of the diameters of the two objects *r* is about the same as that of Earth and the Moon (3.6:1).
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*.
- **Disposal:** Do not dispose of materials. Materials are all reusable.
- **Storage:** Store in cabinets for future use.



Lesson 1 • Where We Are Going and NOT Going

Where We Are Going

Students will be building initial models (SEP: 2.3) to explain a chemical process (reaction) needed for humans to live and work beyond Earth. This lesson is designed to coherently build ideas related to the following disciplinary core idea:

- **PS1.B: Chemical Reactions.** The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.

Crosscut explanation: PS1.B.3 is fully developed across several lessons later in the unit.

Students build on understanding around conservation of matter that they developed in OpenSciEd Middle School units *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* and *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)*, and OpenSciEd High School unit *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*. Examples of such prior grade work are included in *Prior Chemical Reactions*.

Additionally, this lesson leverages ideas related to two disciplinary core ideas in Performance Expectations outside of the unit bundle:

- **ESS3.A.1: Natural Resources.** Resource availability has guided the development of human society. (HS-ESS3-1)
- **ESS3.C.2: Human Impacts on Earth Systems.** Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (HS-ESS3-4)

Inclusion explanation: Students may draw on multiple funds of knowledge as they engage with ideas related to ESS3.A.1 and ESS3.C.2. These funds of knowledge include background knowledge, popular culture, and other cultural assets. Related experiences and activities may include farming, fishing, mining, manufacturing, waste handling, and recycling. Use of these two disciplinary core ideas supports students' thinking around criteria and constraints for living and working beyond Earth as well as developing questions that serve to drive the learning of the unit.

In OpenSciEd Middle School *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)*, students identified how humans are impacting Earth and discussed possible solutions to reduce that impact. Students use that thinking in this lesson as they consider how science and engineering help develop more sustainable systems for reusing/recycling substances and/or reducing waste before forming a second set of questions (yellow sticky notes) for the Driving Question Board (DCI: ESS3.C.2). Students also examined resource distribution in *Droughts and Floods Unit*. Ideas about unequal distribution among resources on Earth are leveraged in this lesson as students consider which resources might be found naturally in the solar system and which might need to be recycled or made through chemical reactions (DCI: ESS3.A.1).

In this lesson, students hear about NASA's Artemis Mission to send people to the Moon. On day 1, they develop a sense of the solar system's scale and the constraints (SEP: 1.8) related to travel in it by calculating scale factors, developing a physical scale model, and comparing it to travel times and rocket speeds (CCC: 3.1). Students brainstorm substances/materials we would need to live and work beyond Earth and develop questions around how we would find those substances/materials (SEP: 1.1, 1.2). Students examine molecular structures of the substances/materials and processes that result in their creation (CCC: 6.2). They use these structures to develop initial models of how the process occurs (SEP: 2.3).

Students engage in SEP 1.1, 1.2, 1.8, and 2.3 partially. For SEP: 1.1: Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. Students have developed portions of this element not addressed in this lesson in the prior units *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*, *Fires Unit*, *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*, *OpenSciEd Unit B.4: How does urbanization affect nonhuman populations, and how can we minimize harmful effects? (Urbanization Unit)*, *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, and *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. For SEP: 1.2: Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships. Students have developed portions of this element in a prior unit, *Polar Ice Unit*. For SEP: 1.8: Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations. This lesson will help students identify some of the criteria, technological constraints, and possible solutions for not being able to take with us all the substances we would need to live and work beyond Earth. Three possible line solutions: to 1) find, 2) recycle, or 3) make the substances we need, motivate a series of questions for the unit (SEP: 1.1, 1.2). Bear in mind that the unit is not focused on pursuing a specific engineering design solution to answer the unit Driving Question. Rather, it is setting the stage for eliciting productive questions at the intersection of Earth and Space Science (DCI: ESS), Engineering Design (DCI: ETS), and Chemistry (DCI: PS) that connect not just to living beyond Earth – but also to how, as a society, we can develop more sustainable approaches (less pollution and waste) here on Earth. For SEP: 2.3: 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 develop initial models to depict what occurs during a chemical process/reaction (DCI: PS1.B.3). Later in the unit, students have the opportunity to think about revising these models as their understanding of chemical reactions becomes more sophisticated (DCI: PS1.B.3).

Students engage in CCC: 6.2 partially. For CCC: 6.2: ~~The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.~~ This is the first time students have used this crosscutting concept element in the OpenSciEd High School Chemistry course. Students have developed portions of this element not addressed in this lesson in *Cancer Unit*.

In this lesson, students will encounter the following word, which they may add to their Personal Glossary: *recycling*. It is assumed that students will have many prior experiences that will inspire them to use their own individual meanings for this word. If, however, students ask you what the word means, you could provide this definition for those students: *It is any capture and treatment of waste materials to recover substances from them for reuse. Such treatments include things like chopping up, filtering, phase changing, or composting. Reuse could include storing and then reusing what is captured as reactants for other chemical reactions (DCI: ESS3.C.2).*

Where We Are NOT Going

Students do not need to know all the bodies in the solar system, or be familiar with their compositions, orbits, or the relative amounts of gravity they produce. In *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*, students will develop understanding of the orbits and relative gravity of bodies in the solar system.

Students do not need to reach agreement on the following in this lesson: a) whether people should try to explore the solar system or live beyond Earth, b) who should go, or c) what reasons, if any, would be worth going for. The initial transcript analysis and the costs on the data cards may help prime students to start considering these issues. Students will weigh in on them again in the last lesson of this unit.

Students should be familiar with some chemical elements from the prior unit, but they might not recall what makes one element different from another in terms of the numbers of protons, neutrons, and electrons. This is something that will be elicited in greater detail in future lessons. Some students may know the chemical formulas for some of the simple compounds that are reactants or products in various chemical reactions (e.g., H_2O or CO_2), but they will likely not know the formulas for many of the substances involved (e.g., a particular sugar or type of plastic). That is fine, as those gaps motivate the examination of additional data at the start of the next lesson and the related home learning at the end of this lesson.

Students will mention a variety of ways to identify substances on day 2, some of which may not be properties. Distinguishing what is and what is not considered a property is not a learning target of this lesson. When students share their examples of chemical reactions on day 3, some of these, such as the changes associated with dissolving salt in water or making glass out of sand, may not strictly be classified as a chemical reaction. Those are still productive examples at this point in the unit. It is sufficient in this lesson that you have introduced an initial definition that distinguishes physical changes from chemical processes on day 3. Further distinction and discussion of these differences will be revisited at various points later in the unit.

LEARNING PLAN for LESSON 1

1 • NAVIGATE

3 min

MATERIALS: None

Reflect on human impacts and sustainable ways of using Earth's resources. Display slide A. Give students half a minute to individually think about the two questions on the slide. Then discuss these as a class.

Suggested prompt	Sample student response
<i>What human impacts on Earth systems have we studied in our course or in prior science courses?</i>	In our first unit we studied climate change and polar ice melt. And we studied possible engineering solutions to slow down the transfer of energy to different parts of the Earth system. In our second unit we studied structures that people use to make lightning safer (lightning rods). In biology we studied how to manage complex ecosystems.
<i>What are some ways people have developed or are trying to develop more sustainable ways of using Earth's resources?</i>	Accept all answers.*

ADDITIONAL GUIDANCE

Students may mention the following in their responses, if they have completed these OpenSciEd units in prior grades:

- climate change, permafrost melt, and forest fires, in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*
- how to balance competing needs in complex ecosystems like the Serengeti or the forests that orangutans live in, in *OpenSciEd Unit 7.5: How does changing an ecosystem affect what lives there? (Palm Oil Unit) and Serengeti Unit*
- the impact of climate change on droughts and floods and how to reduce our carbon footprint, in *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)*

Say something like, *There are many ways of knowing that can help contribute to this second question. Science and engineering provide us just some of those ways of knowing. They often can help people expand our vision of possibilities for how we might live tomorrow, without limiting ourselves to ways we live now. This thinking about what the future might look like for all humankind, led me to wonder what are some of the more ambitious plans related to this that are in the works right now.*

* ATTENDING TO EQUITY

Universal Design for Learning

Here is a place to encourage students to share any relevant stories and/or histories from their own communities. Drawing on multiple funds of knowledge, for sustainable practices that go beyond traditional science and engineering approaches, will be a recurring theme in this unit. Here is a first opportunity to highlight the broader *relevance* of this question to all human activity across history. This may help elicit more examples from work that family or community members may be engaged in, such as farming, fishing, logging, mining, and manufacturing.

2 · ANALYZE ARTEMIS VIDEO AND TRANSCRIPT

10 min

MATERIALS: NASA Artemis Transcript, <https://youtu.be/rMyn52-bQnQ>

Orient to NASA's plans for the near future. Display **slide B**. Say, *I have a video from NASA that lays out pretty ambitious plans. Let's orient ourselves to what some of those plans are and try to figure out why NASA would be trying to do this sort of thing in the first place.* Play <https://youtu.be/rMyn52-bQnQ>.

Suggest that in order to understand what NASA is actually planning to do and why, it may make sense for us to take a moment to analyze what was said in the video more closely. Display **slide C**. Distribute a copy of *NASA Artemis Transcript* to each student. Emphasize the four focal questions on the slide and handout that students should use to make sense of the video. Remind students to underline the specific parts of the transcript that help answer these questions. Give students five minutes to do this. Then discuss these questions as class.

Suggested prompt	Sample student response
<i>Where is NASA planning to go and stay?</i>	To the Moon, Mars, and other worlds.
<i>Who is the "we", in general, that this will involve or affect?</i>	NASA Companies Other countries Everybody
<i>How is NASA going to do this?</i>	The transcript does not describe any details.
<i>Why is NASA doing this?</i>	To escape an Earth we are destroying with human activity. To satisfy our innate curiosity and desire to explore. To figure out new science and technology that can help us on Earth. Dominant countries and cultures tend to want to gain new lands or resources.

Press students for benefits to space travel, and allow students to share the negative reasons we might seek to survive in space. Encourage all responses. All of these questions and lines of thinking are valuable. It is good to have disagreement at this point in the unit, but it is important to understand everyone's perspectives.

Highlight the need for details about this plan. Say, *It sounds like missions like this in space are a big deal and for some they are even debatable. In some ways this video is hard to interpret because it fails to provide details about how we are going to accomplish such a massive undertaking.*

3 · EXPLORE RELATED PHENOMENA

10 min

MATERIALS: science notebook, *Space Missions Deck* with binder clip

Brainstorm constraints for space survival. Display **slide D**. Discuss the first question briefly as class. Then brainstorm a list of constraints that have impeded past missions from staying longer at some of these places. As students share out constraints, record them on the board.

Suggested prompt	Sample student response
<i>What has NASA done before?</i>	Didn't we go to the Moon long ago? I think we have a space station. I have heard that some companies have been sending people into space for tours.
<i>What are some constraints that may have prevented us from staying in space for longer periods of time in the past?</i>	Expenses, distance, climate/temperature, less reliable spaceships, danger

Explore prior missions in our solar system. Show slide E. Say, *Let's explore some of these places beyond Earth that people have visited, along with the places we have not visited but have explored with some sort of automated spacecraft. These two different ways of exploring places in our solar system are sometimes referred to as crewed missions and uncrewed missions.*

Distribute the card deck from *Space Missions Deck* to each pair of students as you have them review the directions on the slide. Each student takes two cards from the deck and studies them on their own. After one minute, students return the cards to the deck and partners spend six minutes studying all of the cards together as they discuss the question on the slide. Finally, take two minutes to discuss the question as a class, to help foreground that distance and time are two major constraints affecting space exploration.

Suggested prompt	Sample student response
<i>Why have people visited only some places in our solar system but not others?</i>	Long distances to these places Time it takes to travel there

Emphasize that we may want to try to get a sense of these differences in scale for all of these different places in space to see if differences in distance or time to reach some of these places could be a major factor to what we were not able to do in the past. Suggest that we try to start doing this by developing a scale model for two things that we saw are closest to Earth, the Moon and the ISS, before trying to visualize the scale of the distances to things crews have not visited yet but may be doing so in the coming decades.

ADDITIONAL GUIDANCE

The following details are provided as background information for the teacher; they are not important for students to know unless students raise related questions:

- Minimum travel time (for all past missions) in most cases refers to a mission that was a flyby rather than one where the spacecraft slowed down to go into orbit or land. The additional time it takes to slow down increases the total travel time.
- On all cards, the minimum distance from Earth provides students with a common distance measure to compare the objects. Since Earth orbits the Sun, its position relative to all other objects in the solar system changes over the course of a year. The orbits of those objects, as well as the fact that all orbits are elliptical, also cause changing distances over time. Do not discuss the shape of orbits with students, as they will cover this in *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*.
- For Earth's Moon card, the “# of crewed missions to it” includes only those missions in which the crew landed on the Moon's surface.

4 · DEVELOP A SCALE MODEL TO IDENTIFY ADDITIONAL CRITERIA

8 min

MATERIALS: Earth-Moon-ISS System Visualization

Introduce a scale model for the Moon. Keep the beach ball hidden during the first part of this discussion. Point to the polystyrene foam ball hanging in the room and say something like, *If we are trying to develop a scale model of the system and we start with this object to represent the Moon, then we need to use some mathematical thinking to help us determine the size of the object we choose to represent Earth.*

Use mathematical thinking to determine scale in the Earth-Moon-ISS system. Display **slide F**. Give students a half minute to determine which of the four answers to the question is correct. Then ask for volunteers to share their answers. Establish that the correct answer is b) Earth's diameter is about four times the Moon's. (A more accurate estimate is about 3.67 times).

Refer back to slide F. Point out to students that because an exact calculation is not needed, we can compare these diameters by using estimation and mental math. In this case, the 3 and the 12 represent thousands, so we can quickly divide or multiply using just those digits. Remind students that doing precise calculations on paper or with a calculator will sometimes be necessary, but encourage them to take any approach they like in their work with scale factors in this lesson.*

Now take out the beach ball and hold it close to the polystyrene foam ball. Ask students if the difference in scale looks relatively close to our estimate. Students should say yes.

Suggest that we now try to represent the distances between Earth, the Moon, and the ISS at the same scale. Hold the beach ball 8 inches from the foam ball and explain that the distance you are holding these apart right now is about 1 Earth diameter, but that this distance is too close to accurately represent the relative distance between the Moon and Earth in our system.



Put down the beach ball. Display **slide G**. Ask students to articulate which two numbers we need to divide, and in what order, to answer each question. Record students' responses and the calculations for both questions on the board.

* SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

This highlighting of multiple ways to engage in developing an answer (e.g., with estimation, on paper, with a calculator, with a partner) reinforces student agency. Taking a moment to practice with scale here reinforces the type of scaling up and down students have done with unit conversion in the previous OpenSciEd Chemistry units.

In the learning targets for CCSS mathematics, students developed scale models (scale drawings) in grade 7 and used the dimensions of a sphere to solve real-world and mathematical problems in grade 8.

Suggested prompt	Sample student response
About how many “Earth diameters” is it from Earth to the Moon?	383,500 divided by 12,756 is about 30.
About how many times farther is it from Earth to the Moon than to the ISS?	383,500 divided by 330 is about 1,000.

Take the beach ball and stand at the location you marked with painter’s tape. Say that you premarked this location, which is approximately 30 beach ball diameters from the foam ball. Use the tip of a pen or pencil to point to where the ISS would be located in this system, which would be between $\frac{1}{8}$ ” and $\frac{1}{4}$ ” from the surface of the beach ball (~0.5 cm). Ask students what stands out to them when we represent the relative distances this way in this part of our solar system. Accept all answers.

Expand the system. Suggest that now that we have some new ways to visualize the scale of the distances between these places and Earth, it may be helpful to do the same for some of the other objects in our solar system that we explored earlier. Display **slide H**. Divide the class so that different pairs of students work to determine the scale factor for a different object (A-D). Give students about one minute to look at the card for their assigned object and find the distance to it.

Ask students to give a thumbs-up when they are ready to check their work. Then display **slide I**. Give students a minute to check their answers and independently reflect on the prompt on the slide.

Foreground engineering thinking. Conclude the activity by saying, *This may be giving you additional ideas about some of the constraints involved for future space missions. And as with every engineering problem, understanding the constraints and criteria can help us figure out possible solutions.*

5 · IDENTIFY CRITERIA, CONSTRAINTS, AND SOLUTIONS

12 min

MATERIALS: *Day 1 Exit Ticket, Crewed Transport Rockets, Space Missions Deck* with binder clip

Introduce payload limitations. Display **slide J**. Say, *The maximum duration that a crew has stayed on the Moon is 75 hours, or just over 3 days.* Ask students to turn and talk about the question on the slide with a partner for three minutes. In this discussion students will begin to identify constraints that you will look for in their exit ticket responses at the end of the period.

ADDITIONAL GUIDANCE

The payload mass data on slide J, combined with the cost data on slide K, help students recognize that there are limits to the amount of supplies that missions are able to take with them into space.

Emphasize that the Artemis plan involves going to and eventually staying on the Moon for up to one month, and future plans involve going to and staying on Mars for even longer. Suggest that we look at data about a key piece of technology – the rockets that we use to get to these places in space -- to see what additional constraints we can identify.

Analyze and interpret data. Display **slide K**. Distribute a copy of *Crewed Transport Rockets*, which contains the same table, to each pair of students. Give students four minutes to discuss the question on the slide.



Complete an exit ticket to identify criteria, constraints, and solutions. Display **slide L**. Emphasize that going to these places in space and living and working there for longer periods of time is a relatively complex engineering problem to consider, and like every engineering problem, thinking about the criteria and constraints associated with it can help inform what science ideas we will need to dig into

to address possible solutions. Distribute *Day 1 Exit Ticket* to each student. Provide students the remaining class time to complete the exit ticket.

Collect the following before the end of the period and write a summary of student responses in **slide M** for the next day:

- *Day 1 Exit Ticket*
- *Crewed Transport Rockets*
- *Space Missions Deck*, complete sets

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Day 1 Exit Ticket Key*.

What to do: See *Day 1 Exit Ticket Key*.

Building toward: 1.A Define some of the criteria for living and working in places beyond Earth for longer periods of time and the constraints for taking all of the substances/materials we would need, and identify possible solutions for obtaining these substances/materials. (SEP: 1.8; DCI: ESS3.A.1, ESS3.C.2, PS1.B.3; CCC: 3.1)

ADDITIONAL GUIDANCE

After collecting *Space Missions Deck*, remove the ISS card from each deck.

End of day 1

6 • NAVIGATE

6 min

MATERIALS: None

ADDITIONAL GUIDANCE

Slide M should be reviewed and edited to accurately represent students' exit ticket responses from the previous day, before displaying it at the start of this period. See the preparation instructions at the start of this lesson for additional guidance.

Consider exit ticket responses. Display **slide M**. Explain that the items listed on the right side of the slide are some of the responses you saw in students' exit tickets (across all of your classes). Give students two minutes to discuss the two questions on the slide with a partner.

Remind students that since the constraints we identified indicate that we are going to be very limited in what we can take or send on a rocket, and that because we need a lot of some of these substances, we will need to consider some other solutions. Display **slide N**. Ask, *What else could we do to get these substances/materials if we can not bring them with us nor have them sent from Earth?*

Record a list of the ideas that students raise on the board (e.g., growing food, finding water, mining, manufacturing some materials (making them), recycling stuff from waste (e.g., fertilizer). You will refer to this list throughout the class period.

ADDITIONAL GUIDANCE

This is an opportunity for a brief discussion around the term *recycle*. See the "Where we are going" section at the start of this lesson for additional guidance.

Follow up by asking, *Why would it be important to be able to determine what substances are available to us on a planet, moon, or asteroid, before trying to live/work there?* Accept all responses.

7 · CONSIDER A RELATED SYSTEM – EARTH

4 min

MATERIALS: None

Introduce Earth as a related system. Say, *Let's consider what we might be able to tell about the presence of needed resources in space from a distance. And let us start with an image of a place that we know has all the resources we need to work and live – our own Earth.* Display **slide O** and discuss the question. Listen for students to identify at least the ocean and clouds as two candidates for sources/reservoirs of water.

Use the follow-up questions below to problematize whether there might be other substances that have a similar appearance from this distance. This will help generate some student questions and ideas for future investigations that are the focus of Lessons 3-5.

Suggested prompt	Sample student response
<i>What substances that we need can we see evidence of on Earth at this scale?</i>	We can see the ocean, which we know is made of water. We can see ground materials / dirt. We see clouds. This shows us there is an atmosphere made of air. And clouds are also made of water droplets.
<i>Could substances, other than water, exist on a planet or moon that look like Earth's oceans from this distance?</i>	Accept all answers.
<i>Could other planets, moons, or asteroids have clouds that look like this that are made of substances that are different from those that make up clouds on Earth?</i>	Venus and Jupiter have clouds. They might be made of other substances besides water. I have heard that the upper layers of Saturn, Neptune, and Uranus are clouds made of different substances.

8 · ANALYZE DATA AND IDENTIFY ADDITIONAL OBSERVATIONS/TESTS

10 min

MATERIALS: *Space Missions Deck* with binder clip

Compare images. Suggest that we look back at the photos from yesterday and see if there is any evidence on these solar system objects of one or more of the substances we need. Display **slide P**. Distribute *Space Missions Deck* to each group with the ISS card removed from each deck. Give groups five minutes to analyze the remaining six cards in the deck.

Display **slide Q**. Cue groups to discuss the question on the slide for an additional three minutes. Then discuss this question as a class.

Suggested prompt	Sample student response
<i>What are some additional observations/tests that an uncrewed mission could take to determine whether any of the different substances we need can be found on a planet, moon, or asteroid?</i>	Take closer photos with rovers or drones. Send an uncrewed vehicle or lander to collect rock/surface samples and look at them under a microscope. Use a gas sensor to test what is in its atmosphere. Test the properties of any of the liquids, gasses, or solids we find.

Follow up by asking how we can tell one substance from another for two gasses, or for water and another liquid.

ADDITIONAL GUIDANCE

These follow-up questions are designed to elicit any knowledge about properties or experiences that students may have had testing substances in prior grades. Students who have completed *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* may recall the following:

- Gasses have properties like density, flammability, and odor.
- Liquids have properties like density and color.
- All substances have properties like melting point and freezing point.

It is okay if students do not have ideas to share, as this discussion will motivate more questions for the Driving Question Board. Students may also share some ways to identify substances that may not be related to their properties. Distinguishing what is and what is not considered a property is not a learning target of this lesson.

Suggested prompt	Sample student response
<i>Are there ways to tell two different gasses apart?</i>	Accept all ideas.
<i>What are some ways to tell whether a liquid is water or some other substance?</i>	Accept all ideas.

9 • RECORD QUESTIONS

4 min

MATERIALS: 3 blue sticky notes (3" x 3"), colored marker, science notebook

Individually record questions. Display **slide R**. Keep students in their small groups, but emphasize that students should individually record the questions that they now have. Distribute three blue sticky notes and a colored marker to each student and give them the remaining time to record their questions. Instruct students to leave the sticky notes in their notebooks.

MATERIALS: <https://youtu.be/tMyn52-bQnQ>

Rewatch NASA video. Remind students that the question about “why” we are going to these places was a question we raised on day 1. Display **slide S**. Ask students to consider the quote on the slide and discuss what they think NASA means by this, first with a neighbor and then as a class. * Accept all answers.

If students raise ideas about developing new technologies related to ways to reuse or recycle resources in space or on Earth, then skip **slide T**. If not, discuss the question on the slide.

Suggested prompt	Sample student response
<i>How could developing ways to reuse or recycle resources in space help us figure out how to more responsibly or efficiently use the resources we have on Earth?</i>	If we could recycle more, then we wouldn't produce so much waste for landfills. We could figure out how to farm with less water, like they are trying to do in desert regions. Figuring out new ways to recycle water or air could help us figure out how to clean pollution from it on Earth. We wouldn't have to mine or drill as much as we do now. We could figure out new ways to recycle things better like clothes and plastics.

* ATTENDING TO EQUITY

Learning in Places. Students will have experienced design problems that engaged them in a conservation mindset as they learned about the 30 by 30 Initiative in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*. Some students may challenge the mindset and ethos around the inevitable use of resources from outer-space planetary bodies (e.g., mining). Multiple perspectives are important, and students who either agree or disagree with space travel will be able to build stronger arguments by understanding the science and engineering problems presented in outer space.

To respect different perspectives students may bring, keep in mind that the language of space exploration is full of problematic terms that may be evocative of historical examples of settler colonialism and the effects on Indigenous people, such as “frontier” and “colonies”. The staking of national flags in the ground also can be regarded as threatening and harmful for many communities. The unit will be richer for all students if multiple perspectives are invited and students feel safe to express their ethical considerations toward space travel.

ADDITIONAL GUIDANCE

If students ask about what counts as recycling, ask them for a couple of example substances they know that people recycle. Then say that recycling includes any process where we capture a waste material and pass it through a series of changes or treatments in order to regain and reuse some substance(s) that makes up the material.

11 · BRAINSTORM RELATED PHENOMENA

11 min

MATERIALS: chart paper, chart paper markers

Identify substances we may need to make more of. Display **slide U**. Discuss the question on the slide as a class: *What are some substances that we may have to make more of on site, rather than find or recycle, in order to work and live in these places beyond Earth?* Accept all responses.

Say, *If we have to make new substances on site, there are some ideas from chemistry that could help us figure out how to do that.* Display **slide V**. Read the text at the top of the slide to remind students what is meant by product, reactant, and chemical reaction. Have students turn and talk to discuss the questions on the slide for three minutes.

As students are doing this, title a piece of chart paper “Related phenomena: chemical reactions we know of”. Under this make two columns, one labeled Matter inputs, [old substance(s) used], *Reactants*, and the other labeled Matter outputs, [new substance(s) made], *Products*.

Ask students to share examples from their discussion with the whole group. As they do so, invite others in class to identify any matter outputs or inputs associated with the reactions. Emphasize that the matter inputs, the reactants, help us identify what substances we would have to find or recycle in order to use them to make the matter outputs, or products, which is one reason why it is helpful to list these substances if we can.

ADDITIONAL GUIDANCE

Do not worry here if an example that students share is or is not strictly defined as a chemical reaction. Other chemical changes and even some state changes may end up on the list, which is fine for now. For example, students may mention the dissolving of certain substances from the prior unit *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes?* (Electrostatics Unit), which is relevant to the upcoming work in this unit. It is also fine at this point if students refer to a substance by a general class name (i.e., saying sugar rather than glucose).

Students may also include descriptions of energy transfer that are associated with a particular reaction or process. If they do, add those in a different color (e.g., red for heat or light). If students do not know what the matter inputs or outputs are, leave question marks in that row. If students have alternate possibilities, add a question mark at the end of each one. A sample *Related phenomena: chemical reactions we know of* poster is shown.

Related phenomena: Chemical reactions we know of	
<u>Matter inputs</u> [old substance(s) used] <i>Reactants</i>	<u>Matter outputs</u> [new substance(s) made] <i>Products</i>
Carbon dioxide & water & light	Oxygen & sugar
Fuel & oxygen	CO ₂ & heat

<i>Glue? & borax?</i>	<i>Slime</i>
<i>Powder? Rocks? & water</i>	<i>Concrete</i>
<i>Sand</i>	<i>Glass</i>
<i>????</i>	<i>Plastic</i>
<i>Metal</i>	<i>Rust?</i>
<i>Dissolving salt in water</i>	<i>Salt water</i>
<i>Bath bombs + water</i>	<i>Carbon dioxide</i>
<i>Alka seltzer + water</i>	<i>???</i>
<i>Vinegar & baking soda & water</i>	<i>Gas?</i>

ADDITIONAL GUIDANCE

Later in this lesson, and in future lessons, we will refer to this as the “Related phenomena: chemical reactions” poster.

12 · INTRODUCE HOME LEARNING

3 min

MATERIALS: sheet of loose-leaf paper

Introduce the home learning. Remind students that we have drawn on funds of knowledge from our own families and communities in the past and that this has given us a bigger picture of what we need to consider and what might be possible. Suggest we do that again tonight. Display **slide W**. Have students record the two questions from the slide on a sheet of loose-leaf paper for the home-learning interview.

End of day 2

13 · NAVIGATE

5 min

MATERIALS: None

Share home learning. Display **slide X**. Discuss the two prompts on the slide and list the ideas students share on the board for the second prompt.

Suggested prompt	Sample student response
<i>What is a process that people (in our family or in our community) have used to recycle substances?</i>	We sort plastic and glass into different bins. We take metal to the scrapyard. There are some things you cannot recycle. We take our old electronics to a special site.
<i>How did the process change the material(s) they were trying to recycle?</i>	They break it up / grind it up. They sort the different types of stuff. They melt it. They bleach it.
Identify physical vs. chemical processes. Circle all the physical processes that students mentioned (melting, sorting, grinding up) and explain that these are physical processes because they do not change the types of molecules that make up the material we started with – it's the same substance before and after each of these changes. Identify any processes that students mentioned that might be considered chemical processes (such as bleaching), and explain that new types of molecules are produced in chemical processes.	

14 · IDENTIFY PARTICLE-LEVEL CHANGES AND RELATED REPRESENTATIONS IN CHEMICAL REACTIONS

3 min

MATERIALS: “Related phenomena: chemical reactions” poster

Discuss particle-level changes in chemical reactions. Reference the *Related phenomena: chemical reactions* poster and point out that we have identified some of the matter inputs (reactants) and matter outputs (products). But we will need to really understand these reactions if we plan to rely on some of them to survive beyond Earth. Display **slide Y**. Have students discuss the two prompts on the slide as a class.

Suggested prompt	Sample student response
<i>What is happening to the matter, in general, at a particle level in a chemical reaction?</i>	Molecules break apart and new molecules are made. The atoms that make up molecules rearrange to form new molecules.
<i>What are some different ways you have seen chemical reactions represented?</i>	Accept all answers.

15 · GATHER INFORMATION TO IDENTIFY PATTERNS

10 min

MATERIALS: science notebook, *Materials for Survival* in black and white, *Materials for Survival* in color

Examine patterns in the materials and processes to make products we need for survival. Inform students that you have a representation of the matter inputs and outputs for many of the processes we identified earlier that involve chemical reactions, which may be a useful reference for us to consider.

Display **slide Z** and have students meet with a partner. Distribute the color copy of *Materials for Survival* to each pair of students and a black and white copy of *Materials for Survival* to each student. Give partners five minutes to identify patterns or similarities they notice between the processes shown in the reference.

Discuss patterns in the materials and processes. After students mention that water is found in most of them, ask the follow-up questions below.

Suggested prompt	Sample student response
<i>What patterns in the processes did you notice?</i>	Water is found in most of them. C, H, and O are in a lot of processes that involve living things. The same types of atoms in the reactants are in the products. The way the atoms in each substance are organized is sometimes simple and sometimes complex.
<i>Is water always involved in these processes in the same way? Is it always a reactant or a product?</i>	No, sometimes it's a reactant and sometimes it's a product.

16 · DEVELOP AND AND COMPARE INITIAL MODELS

10 min

MATERIALS: *Initial Reaction Model*



Develop an initial model. Display **slide AA**. Distribute *Initial Reaction Model* to each student and have them complete the handout individually. Provide at least six minutes for this activity.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Initial Model Key*.

What to do: See *Initial Model Key*. This is an important pre-assessment to collect at the end of the class period. It will help inform you of students' models of chemical reactions from middle school as well as provide them with an opportunity to bring ideas from their work in *Electrostatics Unit* to the table. Examples of prior models that students will have worked with in OpenSciEd courses are included in *Prior Chemical Reactions*. Make a copy of this pre-assessment before giving it back to students and consider building additional opportunities into the last third of the unit for students to compare the models they develop at those points to the models they developed here. This can be a powerful catalyst for reflecting on their growth in understanding over time.

Building toward: 1.B Develop and use a model to represent atom-level compositions of products and reactants and the changes and interactions that occur between the atoms in a chemical reaction that help explain why specific products form and not others. (SEP: 2.3; DCI: PS1.B.3; CCC: 3.1, 6.2)

Compare explanations. Display slide BB. Have students partner with someone who explained a process involving a different chemical reaction. Instruct pairs to identify parts of their explanations that were similar and different.

17 · DEVELOP A CLASS CONSENSUS MODEL

12 min

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

Begin to develop an initial consensus model. Gather students in a Scientists Circle. Display slide CC 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 Reaction Model* with them to the circle.

Write the question, "What particle-level changes happen in a chemical reaction?" at the top of the initial consensus model.

Below that include these three headings:

Matter inputs (reactants) →
changes/interactions → Matter
outputs (products)

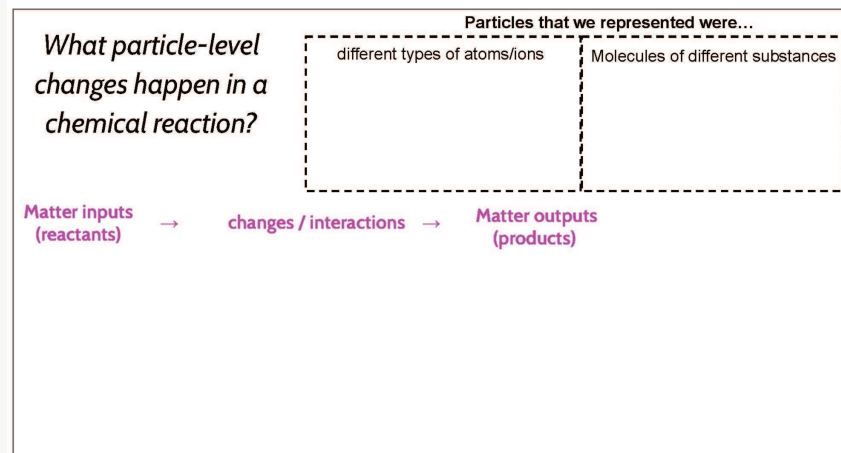
*What particle-level
changes happen in a
chemical reaction?*

Matter inputs (reactants) → changes / interactions → Matter outputs (products)

Ask students to first identify types of particles that are changing in a reaction. Establish consensus around the ideas that:

- Atoms are one of the types of particles we are representing.
- Those atoms are connected or clustered together in certain ways. We sometimes refer to these as molecules.
- If students completed the prior unit *Electrostatics Unit*, they may also say electrons.

Add and label spaces for a key to capture some different ways these types of particles were represented. An example is shown.



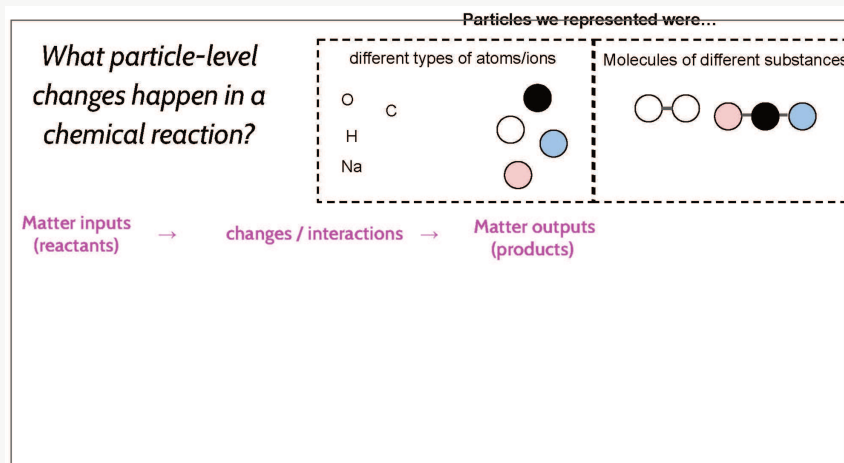
Ask students for different ways they saw atoms and molecules represented. Students will likely mention some of the representations used on *Initial Reaction Model*. These include:

- different-colored circles or different-shaped symbols for different types of atoms
- one- or two-letter abbreviations for atoms (C, O, H, Na, Cl)
- combinations of letters and numbers for molecules (CO₂, H₂O)
- representations of electrons

Ask students how we should represent the connections between atoms in molecules. Students will likely say with lines, as they saw such representations in *Materials for Survival*. Some students may point out that these lines are not in every substance shown in the reference, such as those with ions.

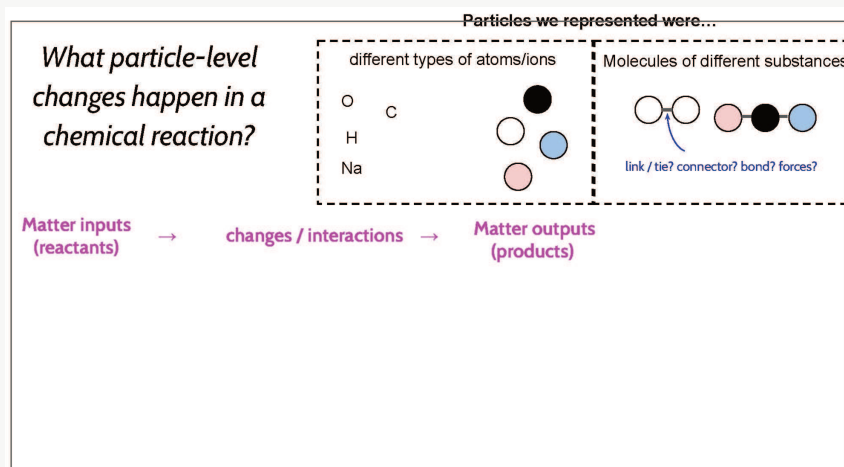
Suggest that we add these representations of a couple of molecules made of 2 or 3 atoms, to provide us with a visual reference.

Also add any representations of electrons, ions, or charges that students agree are important, if they argue for them.



Ask students what these lines might represent beyond a simple connection between atoms. Accept all ideas and list them next to an arrow pointing to one of these lines. Ideas may include:

- link/tie
- bridge
- connector
- bond
- forces
- field



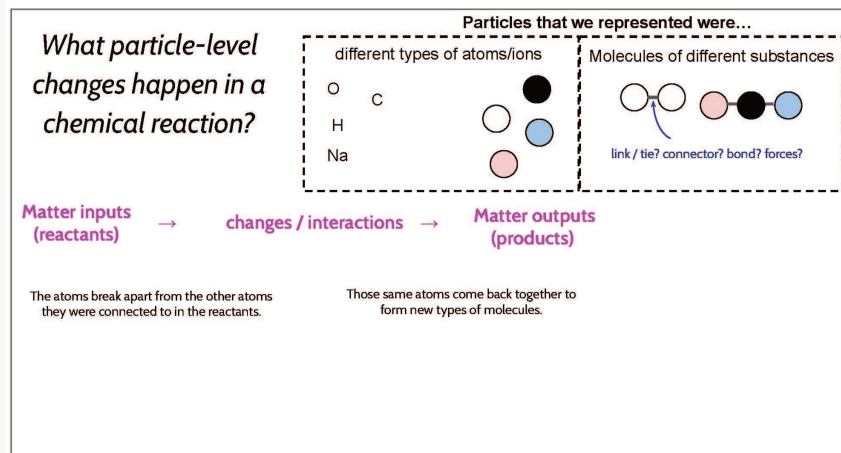
ADDITIONAL GUIDANCE

This question about what the lines between atoms represent is a key problematization move. Not exploring this question yet and encouraging multiple possibilities will help foreground that this representation is one that we take for granted and may not be able to model at this point.

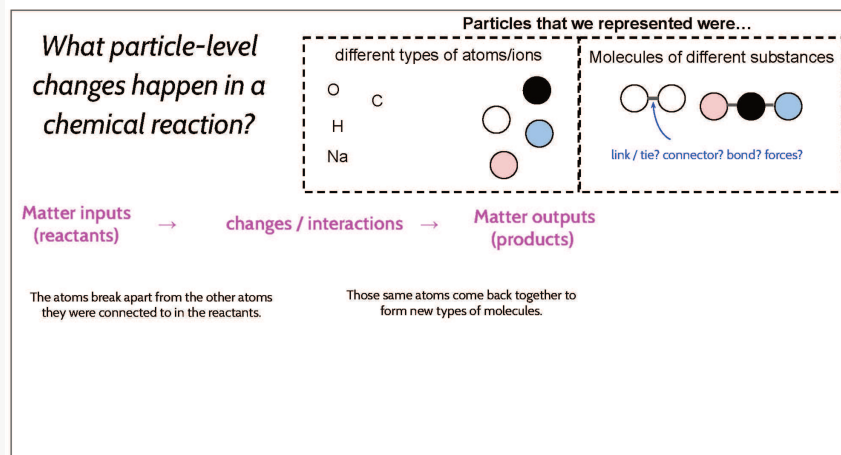
Ask students to share one thing that they agree is happening to some atoms (or ions) in every chemical reaction. Establish consensus around the idea that:

- Atoms or ions break apart from the other particles they were connected to in the reactants.
- Those same atoms come back together (connect) in new arrangements when they form the products.

Add these ideas (or similar versions in students' own words) below the arrows in the model.

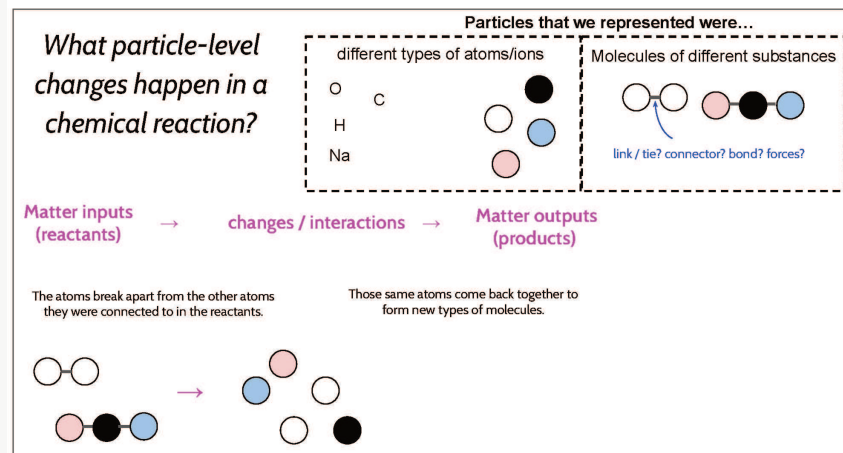


Suggest that we represent these ideas with two different types of reactant molecules, composed of three different types of unspecified atoms. If possible, use different colors to represent these atoms than the colors used in the key.



Ask students what we should model next. They will say that we should show these same atoms separated. Add that representation to the model.

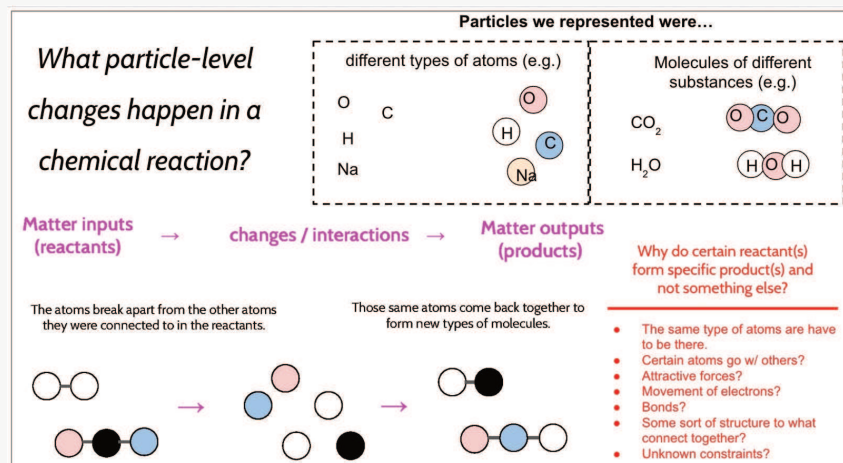
Ask students what we should model next. They will say that we should show these same atoms in new combinations.



Students may suggest other particle-level interactions that occur in a reaction. There may be less agreement around these, so capture them in a list with a question mark after each item. Examples may include:

- Force interactions
- Movement of charges
- Energy transfers
- Collisions

Ask for students' ideas and note similarities and areas of agreement. Also note areas of uncertainty and ask whether students have alternate ideas.



18 · RECORD QUESTIONS

3 min

MATERIALS: 3 yellow sticky notes (3" x 3"), colored marker, science notebook

Individually record questions. Display **slide DD**. Students should individually record the questions that they now have related to recycling or making the substances we need to survive beyond Earth. Distribute three yellow sticky notes and a colored marker to each student and give students a few minutes to record their questions. Instruct students to leave the sticky notes in their notebooks to share next period.

19 · OPTIONAL: GATHER ADDITIONAL INFORMATION

2 min

MATERIALS: sheet of loose-leaf paper, *Materials for Survival* in black and white

Introduce the home learning. Point out that we used *Materials for Survival* to uncover details about some specific chemical reactions, but that this reference did not include all the reactions for substances we might care about or need for living and working beyond Earth. Suggest that we broaden our knowledge base tonight by finding out more about another chemical reaction that is important to us. Display **slide EE**. Have students record the directions and prompts from the slide on a sheet of loose-leaf paper for their home learning.*

Collect the following before the end of the class period:

- *Initial Reaction Model*
- color copies of *Materials for Survival*

* ATTENDING TO EQUITY

Inviting students to bring in additional chemical reactions helps to incorporate related phenomena that students care about into the unit. This lesson provides an opportunity to fold in many types of chemical reactions related to making specialized substances needed to support a variety of industries including, but not limited to, food preparation/production, medicine/health care, manufacturing, mining, waste treatment, arts,

recreation/entertainment, and sports. This assignment provides a meaningful opportunity to share student research at any future point in the unit. This home learning should, however, be considered optional.

End of day 3

20 · DEVELOP THE FIRST PART OF OUR DRIVING QUESTION BOARD

22 min

MATERIALS: science notebook, sticky-note questions, colored marker, chart paper, chart paper markers, index cards, painter's tape, driving question panel, "Related phenomena: chemical reactions" poster

Review questions. Display slide FF. Ask students to review their sticky-note questions in their science notebook for one minute, and encourage them to write a new question if they have one (or save the sticky note for later in case a new question comes up for them in our Scientists Circle).



Collaboratively develop the Driving Question Board (DQB). Display slide GG. Review the protocol for building the DQB. Have students bring their science notebook, sticky-note questions, colored marker, and pencil with them to the 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. To help do that we will do two rounds of question sharing, starting with sharing at least one blue sticky note from everyone and then at least one yellow sticky note from everyone.*

* 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 at least two questions on the board by the end of this activity.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students share at least one question related to finding substances, and at least one question related to making and/or recycling substances. See *DQB Assessment Guidance Key* for guidance.

What to do: If students do not generate many questions about **finding** substances, build in additional opportunities at the end of Lessons 2-5, and at the end of day 2 of Lesson 2, to have students record new questions and keep track of them in their science notebook. At the end of Lesson 6/start of Lesson 7, ask students to mark the questions that we have made progress on. If students do not generate many questions about **making** substances, follow the same process as above across Lessons 7-10. If students do not generate many questions about **recycling** substances, follow the same process across Lessons 11-12.

Building toward: 1.C.1 Ask questions that arise from careful observation of images (at different scales) of solar system objects and particle-level models for different chemical process/reactions and/or ask question to clarify/seek additional information and relationships about ways to find, recycle, and/or make enough of the substances we need to live and work beyond Earth and on it. (SEP: 1.1, 1.2; DCI: ESS3.A.1, ESS3.C.2, PS1.B.3; CCC: 6.2)

SCIENTISTS CIRCLE



You will form a Scientists Circle in this lesson and in many future lessons. Setting up the norms and logistics for forming, equitably participating in, and breaking down that space is important to do now if this is your first time forming such a space. Having students sit in a circle so they can see and face one another can help build a sense of shared mission and a community of learners working together.

Returning to this Scientists Circle throughout the course of the unit to take stock of what the class has figured out and where they need to go next will be an important routine to help students take on greater agency in steering the direction of their learning. This circle will also help students build a sense of pride in their work. You may want to inform students that professional scientists collaborate with one another to brainstorm, discuss, and review their work, too.

Ask students to recall the prior protocols for building the DQB. Since this is the third unit in which they have done this, they may not need additional guidance. But if they do, **slide HH** can be projected to provide the following student-facing directions for assembling the DQB:

1. The first volunteer reads their [blue sticky-note] 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. [Repeat the steps for the yellow sticky notes.]

Explain that it will be helpful to label each cluster of questions as they emerge with a word, phrase, or question category to summarize that cluster. Ask a volunteer from the first set of four students who have posted their questions to listen for this and pose a suggested category to the whole class as each cluster emerges using index cards, colored marker, and painter's tape.

When 10 minutes are up, start sharing yellow sticky-note questions and ask a new volunteer to take over listening for the addition of index cards to label question clusters as they emerge, after at least four students have posted their questions.

Title the DQB. Suggest that in order to capture the broad theme of our questions, we should formalize a Driving Question for the unit. Suggest this as a possible driving question and add a related driving question panel on the top of the driving question aboard that says:

- *How can we find, make, and recycle the substances we need to live and work beyond Earth?*

ADDITIONAL GUIDANCE

In Lesson 9, we will add “and on it” to the driving question for the unit.

Recall that last period we began to consider how to make the resources we need to live and work beyond Earth, and we drew on our experiences with chemical reactions on Earth to do that. Reference the *Related phenomena: chemical reactions* poster, as well as the Driving Question on the DQB that captures the scope of our older and newer considerations. Point out that we have yet to develop some initial models as a whole class to make our thinking visible and show what is happening in these chemical reactions.

21 • PLAN INVESTIGATION IDEAS AND DATA NEEDED

13 min

MATERIALS: chart paper, chart paper markers, painter's tape

Brainstorm investigation ideas and data needed. Display **slide II** and point out that we have two broad categories of questions, blue for finding the substances we need and yellow for making and/or recycling the substances we need. Have students turn and talk with a partner for five minutes to brainstorm investigation ideas and data needed to help answer one or more clusters of questions in both categories. Ensure that half the class starts with blue clusters and half the class starts with yellow clusters. There likely will be multiple pairs of students brainstorming investigations for each cluster of questions. That is fine, as it allows for diversity of thought and ideas. After students have gathered some ideas for their first cluster of questions, pairs can choose another group of questions to consider.*

Make a public record of investigation ideas and data needed. Go around the room and have one person from each pair share an idea or example. Record students' ideas on a piece of chart paper titled, "Ideas for investigations/Data". This will be referred to as the *Ideas for investigations/Data* poster throughout the unit.

ADDITIONAL GUIDANCE

This *Ideas for Investigations/Data* poster 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: Students' sharing with partners and in the Scientists' Circle helps to foster a sense of collaboration and community which supports *engagement*.

22 • NAVIGATE

6 min

MATERIALS: *Materials for Survival*, science notebook

Identify the substance we need to find first. Display **slide JJ**. Give students three minutes to review *Materials for Survival* and record a response to the question on the slide.

Discuss the substance selected. Students will identify water as the most critical substance to find, since it is a component of so many of the processes they just looked at.

Ask students why it might make sense to prioritize investigating our questions related to water. Highlight that this will be our first line of investigations to pursue next time.

23 • OPTIONAL: PREPARE AND ORGANIZE NOTEBOOKS

4 min

MATERIALS: science notebook

Organize notebooks. Display **slide KK**. Use the directions on the slide to help students (re)organize their science notebooks for this unit.

Additional Lesson 1 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.

When obtaining and evaluating information, students identify all sources that they use, whether these resources agree or disagree with each other, and describe how the sources in combination work to answer their questions.

LESSON 2: How does water support life and chemical reactions?

PREVIOUS LESSON We examined a video of NASA's plans in the near future. We identified criteria, constraints, and solutions for living and working beyond Earth and ways to find, recycle, and make substances. We compared matter inputs and outputs and developed models of chemical reactions. We developed a Driving Question Board and brainstormed ideas for data and investigations that could help answer our questions.

THIS LESSON

INVESTIGATION

2 days



We discuss other chemical reactions that include water, what is special about water, and properties of water we previously studied. We gather information on water's properties from two out of six investigation stations. We plan how to share this information. In a Scientists Circle, we integrate our information from across the six investigation stations. We reflect on our Community Agreements with our group. We add our first Progress Tracker entry.

NEXT LESSON We will brainstorm a list of surface features on Earth and identify which types of geologic processes caused their formation. We will use patterns in surface features to develop and defend claims about which geologic processes are responsible for them.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, HS-ESS1-2, HS-ESS2-1, HS-ESS2-5



WHAT STUDENTS WILL DO

2.A Compare, integrate, and communicate information presented in different media or formats to identify patterns in water's ability to: absorb, store, and release large amounts of energy through its specific heat; transmit sunlight; and dissolve and transport materials. (SEP: 8.2, 8.5; DCI: ESS2.C.1, PS2.B.3; CCC: 1.5)

WHAT STUDENTS WILL FIGURE OUT

- Water supports life and is used in chemical reactions because of its properties.
- Some of those properties include surface tension, high specific heat capacity, transparency, and ability to dissolve most substances.

Lesson 2 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		NAVIGATE Have students discuss what substance we decided we need to find first and support the argument with evidence.	A	
2	5 min		DISCUSS PRIOR KNOWLEDGE ABOUT WATER Have the class brainstorm other chemical reactions where water was a part. Have students share prior knowledge about properties of water.	B-C	Related phenomena: chemical reactions poster from Lesson 1, <i>Materials for Survival</i> from Lesson 1
3	5 min		REVISIT COMMUNITY AGREEMENTS Frame the need to revisit and choose a focal Community Agreement.	D-E	<i>Focal Community Agreement</i> , Community Agreements
4	24 min		GATHER INFORMATION ABOUT PROPERTIES OF WATER Organize students into groups of three to four to visit two of the stations examining properties of water.	F-G	Properties of Water Investigations
5	6 min		PREPARE TO SHARE STATION FINDINGS Have students work in their group to prepare to share their station findings.	H	<i>Water's Properties Investigations</i> , chart paper, chart paper markers
6	2 min		INTRODUCE HOME LEARNING Introduce a home learning activity to consider cultural aspects of why we need water.	I	
<i>End of day 1</i>					
7	4 min		PREPARE TO SHARE STATION FINDINGS Give groups additional time to finalize how they will share station findings.	J	<i>Water's Properties Investigations</i> , chart paper, chart paper markers
8	12 min		DISCUSS STATION FINDINGS Gather students in a Scientists Circle to communicate groups' station findings.	K	<i>Water's Properties Investigations</i> , chart paper, chart paper markers
9	10 min		BUILD WATER'S IMPORTANCE FOR LIFE AND CHEMICAL REACTIONS POSTER Work with students in the Scientists Circle to build a poster relating properties of water to its importance for life and chemical reactions.	L	<i>Water's Properties Investigations</i> , chart paper, chart paper markers
10	12 min		REFLECT ON COMMUNITY AGREEMENTS Have students return to their small groups to reflect on how well they adhered to the Community Agreements they chose.	M	<i>Focal Community Agreement</i>
11	4 min		SET UP AND ADD TO PROGRESS TRACKER Have students individually set up this unit's Progress Tracker and add their first entry to it.	N	

Part	Duration		Summary	Slide	Materials
12	3 min		NAVIGATE Facilitate a turn and talk to consider how much water we need and use every day.	O-P	

End of day 2

Lesson 2 • Materials List

	per student	per group	per class
Properties of Water Investigations materials	• <i>Water's Properties Investigations</i> • science notebook • indirectly vented chemical splash goggles • nitrile gloves • non-latex apron	• See <i>Station Investigation Setup</i> for a list of materials needed at each station • copy of each station's directions found on <i>Station Investigation Directions</i>	
Lesson materials	• <i>Focal Community Agreement</i> • <i>Water's Properties Investigations</i> • science notebook	• chart paper • chart paper markers	• Related phenomena: chemical reactions poster from Lesson 1 • <i>Materials for Survival</i> from Lesson 1 • Community Agreements • chart paper • chart paper markers

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.

Have the Community Agreements visible.

Print enough copies of *Water's Properties Investigations* for one-third of your students. During the investigation, students will visit only one pair of stations: Stations 1 and 2, 3 and 4, or 5 and 6. Students will need only those pages of the handout for the two stations that their group investigates.

Station 6 has an alternate activity that has students using CODAP data rather than *Seasonal City Temperatures*; the directions are included on the last page of *Water's Properties Investigations*. If you use the CODAP alternate, be sure to print those directions and prepare for the activity by doing the following:

- Experiment with the same data that students will manipulate at this link: <https://www.openscienced.org/simulation/temp-data/>.
- As you manipulate the data set, you can follow along with this video: <https://youtu.be/bZsmczFH-bl?si=rMbBs7XOI4USIplG>.

Days 1 and 2: Properties of Water Investigations

- **Group size:** 3-4 students
- **Setup:** Gather materials for each of the stations using the guidance found on *Station Investigation Setup*. Print a copy of *Station Investigation Directions* and put the corresponding directions at each station. Consider placing these in sheet protectors for repeated use.
- **Notes for during the lab:** Make sure there are plenty of paper towels available for students
- **Safety:**
 - Indirectly vented chemical splash goggles, nitrile gloves and non-latex aprons are required for these activities.
 - Wear sanitized indirectly vented chemical splash goggles, nitrile gloves and non-latex apron during the setup, hands-on, and takedown segments of the activities.
 - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
 - An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
 - Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.

- Hand sanitizer wipes must be provided for participant use at the completion of the activities.
- Spill control containers for overflow of products produced.
- Follow procedures set up by the instructor for disposal of materials.
- Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Keep flammable liquids (e.g. acetone, alcohol) away from active flames or sparks to prevent fire.
- Use caution when working with a hot kettle! Can burn skin on direct contact.
- Use caution when working with glassware or plasticware – can break and cut/puncture skin. If they break, alert your teacher and do not handle them, due to the sharp edges on the fragments.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
- Given there is use of flammable liquids, the instructional space must have appropriate ventilation. The ventilation system in the instructional space must meet the needs relative to removing the flammable vapors produced. Use of a fume hood is also a viable alternative.
- Direct supervision will be required during all aspects of these activities.
- **Disposal:** Students can throw away paper towels, but take care to keep the paper towels away from open flames or sparks.
- **Storage:** Store acetone in a secure, fire-safe cabinet. Store vegetable oil in a secure cabinet.

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

The goal of this lesson is to broaden students' understanding of different properties of water and their importance for life and chemical reactions. This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **ESS2.C: The Roles of Water in Earth's Surface Processes.** The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, ~~expand upon freezing,~~ dissolve and transport materials, ~~and lower the viscosities and melting points of rocks.~~
- **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.

Crossout explanation: **ESS2.C.1** The property of water to lower the viscosity and melting point of rocks is incorporated in *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*. Some of the crossed out portions of **PS2.B.3** were developed in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. Contact forces are limited to atomic-scale interactions to explain cohesion and adhesion. The full idea of contact forces is developed in the OpenSciEd High School Physics course in unit *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*.

Students build on their understanding of attractive forces by considering how contact forces between material objects (cohesion and adhesion) can be explained by shifts in electric charges at the molecular scale (polarity of water). This builds upon students' prior work with the molecular structure of water developed in *Electrostatics Unit*.

Students considered water's role in chemical reactions in two OpenSciEd Middle School units, *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* and *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)*. In this lesson, students connect both the middle school understandings, along with prior work in high school chemistry, to communicate why water is needed in so many chemical reactions.

Students developed an understanding of water's impact on temperature and weather in *OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*. They use this idea, along with water's ability to absorb and store large amounts of energy from *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, to explain water's ability to regulate temperatures in this lesson. Students are not asked to think about how the specific heat of water impacts chemical reactions, as this is developed in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*.

In this lesson, students visit two of six investigation stations where they need to incorporate information from their own experimental data, data sets, readings, and maps (**SEP: 8.2**) in order to identify empirical patterns in the data (**CCC: 1.5**) to determine the properties of water and its importance for life and chemical reactions. Students work with their groups to develop plans to share the investigative information from the two stations the group visited (**SEP: 8.5**).

Students use **SEP: 8.2** and **8.5** partially. For **SEP: 8.2: 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.** Students developed the portions of the element not addressed in this lesson in the prior units *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* and *Electrostatics Unit*. For **SEP: 8.5: 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 (including orally, graphically, textually, and mathematically).** In *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)* students were asked to communicate technical information about fire management solutions. This lesson focuses on students' communication of scientific information about properties of water orally and through text, supported by empirical evidence.

In this lesson, students will encounter the following words, which they should add to their Personal Glossary: *adhesion, capillary action, cohesion, surface tension*. Students will also encounter a term that they figured out in a previous unit: *specific heat*. They may choose to revise the definition for this term as well. 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 will not build a full explanation of how water moves against gravity within a plant. We do not consider the double-pump mechanism, water potential, or general diffusion that takes place within the xylem of plants.

LEARNING PLAN for LESSON 2

1 · NAVIGATE

3 min

MATERIALS: None

Remind ourselves of what material to look for first. Display slide A.

Suggested prompt	Sample student response
<i>What substance did we argue for in the last class that we should find first?</i>	Water.
<i>What evidence did we use to support this choice?</i>	Water was found in most of the chemical reactions we looked at.

2 · DISCUSS PRIOR KNOWLEDGE ABOUT WATER

5 min

MATERIALS: Related phenomena: chemical reactions poster from Lesson 1, *Materials for Survival* from Lesson 1

Discuss prior knowledge about water's properties. Say, *Let's think about other times where we have used or seen water in a chemical reaction.* Display slide B.

Suggested prompt	Sample student response
<i>What other chemical reactions have you carried out where water was a part of the reaction (a matter input or output)?</i>	Bath bombs. MREs. Root killer and aluminum foil mixed in saltwater.
<i>What might be special about water that it is a part of all of these different chemical reactions? (Point to the Related phenomena: chemical reactions poster and hold up Materials for Survival.)</i>	Maybe because it is polar? Because it can dissolve a lot of stuff.

Consider other properties of water. Say, *We have spent some time in the first two units of the year studying different properties of water. You have already mentioned a couple. Let's think a little more about those and some of the other properties we have studied.* Display slide C.

Suggested prompt	Sample student response
<i>What properties of water have we already figured out this year that make it so important for life on Earth?</i>	It can hold onto a lot of energy (specific heat). From: Polar Ice Unit It dissolves materials. From: Electrostatics Unit It is polar. From: Electrostatics Unit

Suggested prompt	Sample student response
What is it about these properties that make water essential for life?	Accept all responses.

Highlight that we have a lot of different ideas about the properties of water that make it essential for life. Suggest that it would be a good idea to spend some time exploring more of water's properties and their connection to supporting life.

3 · REVISIT COMMUNITY AGREEMENTS

5 min

MATERIALS: *Focal Community Agreement*, *Community Agreements*

Revist Community Agreements. Say, *During our next investigation, you and your group will visit only two of six stations. This means that you will need to work with your group to effectively communicate the information you figure out to the rest of your classmates in a short period of time.*

Display slide D.

Suggested prompt	Sample student response
What are some of the challenges and needs we should consider in such work?	It will be hard to share everything. We will need to make sure that everyone understands what we investigated. We will need to communicate well with our group and the rest of the class.
Which Community Agreements would best support us in meeting those challenges and needs?	Accept all responses.

Display slide E. Distribute *Focal Community Agreement*. Give students a few minutes to complete the three pre-investigation questions on the handout where they choose a focal Community Agreement to work on today and describe how they will enact it. Students will use this later as a self-assessment opportunity. *

* ATTENDING TO EQUITY

Universal Design for Learning: Students should connect with each other in order to support *engagement*. Spending time to reflect on participation in the unit can help students of all abilities improve on how they relate to each other around science content, and classroom culture can be strengthened as a result through self-regulation.

4 · GATHER INFORMATION ABOUT PROPERTIES OF WATER

24 min

MATERIALS: *Properties of Water Investigations*

ADDITIONAL GUIDANCE	When placing students into groups for these investigations, ensure that at least two groups complete a suggested pair of stations. If you have a small class size, reduce the group size to two students to ensure that you have at least six groups.
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Review safety considerations. Organize students into groups of three to four. Display slide F. Read through the safety considerations on the slide. Ask students if they have any clarifying questions about safety before continuing with the investigation.

* ATTENDING TO EQUITY

Consider adding your local weather data to <https://www.openscienced.org/simulation/temp-data/> or *Seasonal City Temperatures* using National Weather Service public data. Simply make your own copy of <https://www.openscienced.org/simulation/temp-data/> and use the plus sign in the data table to add a new row

SAFETY PRECAUTIONS



Ensure that students wear indirectly vented chemical splash goggles while they are carrying out investigations at Stations 1, 3, 4, and 5. You may also wish to encourage students to wear them at all times regardless of the station they are working at.



Gather information about properties of water. Distribute a copy of *Water's Properties Investigations* to each student. Display **slide G**. Explain the combinations of stations students will visit with their groups. Let students know that the handout contains information for all stations, but that they will only be responsible for completing the questions pertaining to the two stations they visit. *

Water's Properties Investigations

Station 1: Stickiness to itself

One way to investigate how well the molecules of a liquid "stick" to each other is by carefully creating a large drop. Use the directions at the station to carry out such an investigation and record the related observations in the table below.

Number of drops of liquid that fit on the top of a penny	Liquid			
	Acetone	Rubbing Alcohol	Vegetable Oil	Water
Trial 1				
Trial 2				
Trial 3				
Average (mean)				

1. Empirical evidence is the evidence (data) we obtain through investigations and observations. We use this empirical evidence to identify whether there are patterns in the data. What patterns, if any, do you see in the average number of drops of each liquid?

2. Explain the differences in the average number of drops of acetone, rubbing alcohol, vegetable oil, and water on the penny using the information from *Water is Sticky* and the ideas of cohesion and surface tension. You can use models to help with your explanation.

3. Brainstorm with your group about how cohesion and surface tension might be important for life and/or chemical reactions. Record the ideas below.

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for your location. Then share a link to your copy with students after you have edited the table. Inclusion of local data can make science learning more relevant to students by placing their own locations within empirical data sets.

ALTERNATE ACTIVITY

If you are using the CODAP alternative for Station 6 and students are new to CODAP, show <https://youtu.be/bZsmczFH-bl?si=rMbBs7XOl4USIplG>.

ADDITIONAL GUIDANCE

In Station 5, students will exchange their cleaned submersion weights with you and set them up in the electric kettle the way they found them in Step 1 of the procedure, as outlined in *Station Investigation Directions*. You may want to check their station for this. This exchange of submersion weights also gives you a chance to make sure the set that students have used is cleaned and to have ready a set for them to swap into the station for the next class.

As students work through the two stations they visit, encourage them to record any new terms in their Personal Glossary. Students may choose to add the following terms (listed in alphabetical order):

- *adhesion*
- *capillary action*
- *cohesion*
- *specific heat*
- *surface tension*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should **identify patterns** in **different sources of information**, including temperature data (or CODAP data) and investigation data. (SEP: 8.2; CCC: 1.5)
- Students **use and integrate information presented in various media** to explain and identify properties of water including **water's ability to: absorb, store, and release large amounts of energy** through its specific heat; **transmit sunlight**; and **dissolve and transport materials**. (SEP: 8.2; DCI: ESS2.C.1)
- Students who visit Stations 1 and 3 **communicate information about the role of attraction of water and other liquids to materials** in order to **explain the properties of cohesion and adhesion**. (SEP: 8.5; DCI: PS2.B.3)

What to do: If students are using *Seasonal City Temperatures* and struggle to identify patterns in the temperature data, encourage them to identify any outliers in the last two columns of data and see if their location on the map can help explain it. This should lead students to recognize that Chicago, though categorized as coastal, is not along the ocean. If students are using the CODAP option and struggle to identify patterns, encourage them to manipulate the data in different ways until a pattern emerges. As students read, encourage them to take notes and collaborate with their peers using the guidance on *Focal Community Agreement*.

Building toward 2.A.1 **Compare, integrate, and communicate information presented in different media or formats to identify patterns in water's ability to: absorb, store, and release large amounts of energy** through its specific heat; **transmit sunlight**; and **dissolve and transport materials**. (SEP: 8.2, 8.5; DCI: ESS2.C.1, PS2.B.3; CCC: 1.5)

5 • PREPARE TO SHARE STATION FINDINGS

6 min

MATERIALS: *Water's Properties Investigations*, science notebook, chart paper, chart paper markers



Prepare to share station findings. Display slide H. Say, *Since we did not visit every station, we need to spend time hearing what the other groups discovered. To make sure we have time to hear from every group, you will have only two minutes to talk about each station. As you share, be sure to show how your findings explain why water is important to life and/or chemical reactions. We also want to make sure that all group members have a chance to be heard.* Read through the slide and emphasize the two constraints that groups must plan for: a two-minute time limit, and everyone's voice must be heard. Let students know that chart paper and chart paper markers are available if their group would like to make a visual representation when sharing with the rest of the class.

As groups develop their plans, circulate around the room to listen to and observe students' interactions with each other.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students collaborate with peers in their group to develop a list of talking points to effectively communicate with other peers in the class. (SEP: 8.5)

What to do: As students make their plans, encourage them to take notes and collaborate with their peers using the guidance on *Focal Community Agreement*.

Building toward 2.A.2 Compare, integrate, and communicate information presented in different media or formats to identify patterns in water's ability to: absorb, store, and release large amounts of energy through its specific heat; transmit sunlight; and dissolve and transport materials. (SEP: 8.2, 8.5; DCI: ESS2.C.1, PS2.B.3; CCC: 1.5)

6 · INTRODUCE HOME LEARNING

2 min

MATERIALS: None

Introduce the home learning. Display slide I. Say, *We have spent a lot of time thinking about why water is so special chemically, but we also need to consider water's cultural importance.* * Then read through the information on the slide.

* ATTENDING TO EQUITY

This home learning activity is a second way to increase the relevance of studying properties of water and its importance for life.

End of day 1

7 · PREPARE TO SHARE STATION FINDINGS

4 min

MATERIALS: *Water's Properties Investigations*, science notebook, chart paper, chart paper markers

ADDITIONAL GUIDANCE

In the next portion of the learning plan, students will move into a Scientists Circle. Consider having students collaborate with their groups while sitting next to them in a Scientists Circle to save some time.



Prepare to share station findings. Have students meet with their groups from the last class. Display slide J. Give groups some additional time to finalize how they will communicate station information to their classmates. Again, offer chart paper and chart paper markers to groups if they wish to communicate station information visually.

As groups develop their plans, circulate around the room to listen to and observe students' interactions with each other.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students collaborate with peers in their group to develop a list of talking points to effectively communicate with other peers in the class. (SEP: 8.5)

What to do: As students make their plans, encourage them to take notes and collaborate with their peers using the guidance on *Focal Community Agreement*.

Building toward 2.A.3 Compare, integrate, and communicate information presented in different media or formats to identify patterns in water's ability to: absorb, store, and release large amounts of energy through its specific heat; transmit sunlight; and dissolve and transport materials. (SEP: 8.2, 8.5; DCI: ESS2.C.1, PS2.B.3; CCC: 1.5)

8 • DISCUSS STATION FINDINGS

12 min

MATERIALS: *Water's Properties Investigations*, science notebook, chart paper, chart paper markers



Share station findings in a Scientists Circle. Have students take *Water's Properties Investigations* and their science notebooks with them as they move into a Scientists Circle. If groups have created a poster to share their station information, have them bring that as well.

Display slide K. As groups share, ensure that they emphasize what the property of water they investigated was, its importance for life, and/or its importance for chemical reactions.

ADDITIONAL GUIDANCE

If students share terms that others may not be familiar with, ask clarifying questions or prompt students to explain the terms. Again, those terms may be: *adhesion, capillary action, cohesion, specific heat, and surface tension*. If students use those terms, spend a moment discussing a definition for them and then encourage students to add them to their Personal Glossaries if they have not already done so. Depending on which stations students visited, they may not have read about the terms, so spending time here on defining them is essential. Another chance to discuss these terms will be during the "Water's Importance for Life and Chemical Reactions" poster development.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students communicate information orally and/or visually about properties of water which may include water's ability to: absorb, store, and release large amounts of energy through its specific heat; transmit sunlight; and dissolve and transport materials; as well as the role of attraction of water and other liquids to materials in order to explain the properties of cohesion and adhesion. (SEP: 8.5; DCI: ESS2.C.1, PS2.B.3)

What to do: As students share their station information, ensure that all members of the group have contributed either orally or by making visual representations of the data. Ask clarifying questions if the information shared is unclear or may be confusing to students.

Building toward 2.A.4 Compare, integrate, and communicate information presented in different media or formats to identify patterns in water's ability to: absorb, store, and release large amounts of energy through its specific heat; transmit sunlight; and dissolve and transport materials. (SEP: 8.2, 8.5; DCI: ESS2.C.1, PS2.B.3; CCC: 1.5)

9 · BUILD WATER'S IMPORTANCE FOR LIFE AND CHEMICAL REACTIONS POSTER

10 min

MATERIALS: *Water's Properties Investigations*, science notebook, chart paper, chart paper markers



Build the “Water’s Importance for Life and Chemical Reactions” poster. Display slide L. Start building the poster with the properties students investigated at the stations. Then move to properties students heard from their home learning. Finally, have students add properties they know from prior units of study. * A sample poster is shown.

*** SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION**

Crosscutting Concept 6 (Structure & Function) asserts that at the high school level, students can infer structure from the components of natural and designed objects (element 6.2). In this activity, students are connecting the many functional properties of water related to its structure, which will be investigated and modeled in more detail in the next lesson.

Water's importance for Life and Chemical reactions

Property of Water	Importance for Life	Importance for chemical reactions
1. Takes a long time to get hot/cool down. <u>High specific heat</u> , which means it can store a lot of energy. (and absorb)	1. It regulates temperatures to help prevent extreme highs and lows.	
2. Can see through it/transparent. In water, this is to a certain point, then it is no longer visible.	2. Allows plants and other photosynthetic organisms to live in water. This provides a food source for animals. The more light that gets through water, the greater the diversity of life.	
3. It is good at eroding and dissolving substances.	3. It moves minerals through our bodies. It is a good solvent/transporter, making it the "hydrator" for our bodies.	3. Because water can dissolve substances well, it also provides a way for mixtures of different dissolved substances to interact to form new substances.
4. Can stick to itself (<u>cohesion</u>) and other substances (<u>adhesion</u>)	4. Water is able to move up plant roots and tubes against gravity (<u>capillary action</u>) to reach all areas of the organism.	

ADDITIONAL GUIDANCE

Students have enhanced opportunities to work with patterns such that the pattern becomes water is the standout substance in all these investigations. The pattern emerges in consensus discussion, not at each individual station. This is a sample poster and may not contain everything your class adds. Use the sample as guidance for what properties the poster should include at a minimum. The numbers are shown to make it easier to keep track of information across columns; they are not intended to show ordering.

Underlined words in the sample poster are those terms that students may have added to their Personal Glossaries. If students use the terms, spend a moment discussing a definition for them and then encourage students to add them to their Personal Glossaries if they have not already done so. Depending on which stations students visited, they may not have read about the terms, so spending time here on defining them is essential.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students integrate information presented in various media to explain the importance of properties of water to life and chemical reactions. (SEP: 8.2; DCI: ESS2.C.1, PS2.B.3)

What to do: If students struggle to identify some of the properties shown on the sample poster, ask probing questions such as:

- We have considered how it shapes landforms, but in what other ways does water influence the world around us? (*temperature regulation*)
- How is it that plants are able to get water from their roots to the tops of the plant, or insects are able to skate across water? (*capillary action* and *surface tension*)
- A lot of the life on Earth lives in water. What are some properties of water that allow so much life to live in it? (*transparent to light*)

Building toward 2.A.5 Compare, integrate, and communicate information presented in different media or formats to identify patterns in water's ability to: absorb, store, and release large amounts of energy through its specific heat; transmit sunlight; and dissolve and transport materials. (SEP: 8.2, 8.5; DCI: ESS2.C.1, PS2.B.3; CCC: 1.5)

ALTERNATE ACTIVITY

Extension opportunity: If students show interest in comparing the properties of water to the properties of other materials they have studied in *Electrostatics Unit*, take time to co-create a parallel poster. For example, you could discuss properties of metals, such as conductivity, and their importance for life. Additionally, you could present students with specific heat values of metals and have students use their understanding of specific heat to explain what happens to those metals as energy is applied to them. Take care not to develop a cause-effect relationship between conductivity and specific heat values, as the basis of these two material properties is different.

An additional handout, *Thinking About Aquaculture*, is included to help students consider other potential food sources by leveraging water's ability to transmit light. Since it mentions the existence of water oceans on some moons in our solar system, this handout may be placed after Lesson 4 or with Lesson 11.

10 · REFLECT ON COMMUNITY AGREEMENTS

12 min

MATERIALS: *Focal Community Agreement*

Lead a discussion to reflect on Community Agreements. Say, *We spent a lot of time going public with our ideas. As you did this, you worked with others and synthesized information from different sources. We will be practicing this more and more throughout the unit. In order to ensure we follow our Community Agreements so that we continue to communicate effectively, take a moment to complete the post-investigation reflection section of the handout.* Display **slide M**. Go over the protocol for giving peer feedback. Encourage students to use the sentence starters on *Focal Community Agreement* as a guide to give peer feedback. Give each group member two minutes to share their focal Community Agreement and receive peer feedback. After each group member has had a chance to give and receive feedback, instruct students to complete the three prompts under item 4 on *Focal Community Agreement*. *

* ATTENDING TO EQUITY

Universal Design for Learning: The reflection section of *Focal Community Agreement* helps support students in *engagement*. Students are developing self-regulation when they can develop their own self-assessment and reflection on others' work. Peer feedback provides a lens by which students practice evaluating work and gathering new ideas as they do so.

11 · SET UP AND ADD TO PROGRESS TRACKER

4 min

MATERIALS: science notebook

Set up this unit's Progress Tracker. Display **slide N**. Say, *We have figured out a lot about how the properties of water help support life and chemical reactions. Take a moment to set up a Progress Tracker in your science notebook to record what we have figured out to answer our lesson question.* Give students three minutes to complete a Progress Tracker entry. A sample entry can be found in *Progress Tracker Key*.

12 · NAVIGATE

3 min

MATERIALS: None

Consider how much water we need each day. Display **slide O**. Say, *We know that water is super important for life. Take a moment to turn and talk with a partner about the prompts on the slide.* Give students two minutes to discuss the prompts with a partner. Then ask a few volunteers to share their ideas. Summarize ideas and point out that it sounds like we will need a lot of water!

ALTERNATE ACTIVITY

Extension opportunity: If you have additional time, or if students are interested in figuring out just how much water we have sent with astronauts in the past, you can lead them in a discussion using some of the following data:

- Apollo 11 sent 160 gallons of water for astronauts Armstrong and Aldrin to use and drink on the surface of the moon. An additional 50 gallons of water were aboard the command module for astronaut Collins. Resource: Simmons, R. (2019, April 13). Apollo 11 found water on the moon. *Orlando Sentinel*. <https://www.news-journalonline.com/story/news/state/2019/04/13/apollo-11-found-water-on-moon-from-orlando/5445279007/>
- Estimating home water use needs chart: <https://extension.psu.edu/water-system-planning-estimating-water-needs>
- How we use water: <https://www.epa.gov/watersense/how-we-use-water>

Students could use this data to then determine just how much water we would need each day to survive beyond Earth.

Brainstorm types of evidence. Display slide P. Ask, *What have you heard about or seen that we could use to find evidence of water on other places in space? How do scientists know there is water somewhere beyond Earth?* Look for students to suggest that we could look for it using pictures. Suggest that we do that in the next lesson.

Additional Lesson 2 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 translate quantitative and qualitative data from readings, their own experiments, and simulations to explain why the properties of water support life.

LESSON 3: How can we find evidence of the water we need on the surfaces of other objects in space?

PREVIOUS LESSON We discussed other chemical reactions that include water, what is special about water, and properties of water we previously studied. We gathered information on water's properties from two out of six investigation stations. We plan how to share this information. In a Scientists Circle, we integrate our information from across the six investigation stations.

THIS LESSON

INVESTIGATION

1 day



NASA, Goddard Space Flight Center, METI, ERSDAC, JAROS, and U.S./Japan ASTER Science Team

We brainstorm a list of surface features on Earth and then identify which types of geologic processes caused their formation. We identify patterns in the surface features visible in satellite images of Earth, the Moon, and Mars. We use these patterns to develop and defend claims about which geologic processes are responsible for those surface features. We wonder if the surface features that were formed due to interactions of water with materials could have been formed by other liquids.

NEXT LESSON We will investigate how liquids interact with surface materials and argue that surface features on Mars were likely made by water. We will wonder what makes water different from other liquids and will examine molecular models of them to compare their polarities. We will read about how water causes surface features, and we will model these processes. We will complete an Electronic Exit Ticket.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, ESS1-2, ESS2-1, ESS2-5



WHAT STUDENTS WILL DO

3.A Make and defend a claim about the geologic processes that were most likely responsible for the formation of different surface features on Earth and other solar objects, using evidence from satellite images at different scales. (SEP: 7.5; DCI: ESS1.C.2; CCC: 1.1)

WHAT STUDENTS WILL FIGURE OUT

- Some surface features on Earth were produced primarily by water erosion, while others were produced primarily by tectonic processes or meteor impacts.
- Mars's surface has some features that look similar to those produced by water erosion on Earth, while the Moon's does not.

Lesson 3 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	7 min		NAVIGATE Have students determine the top three candidates for water using <i>Space Missions Deck</i> from Lesson 1.	A-C	<i>Space Missions Deck</i> from Lesson 1
2	8 min		BRAINSTORM PROCESSES THAT FORM SURFACE FEATURES Have students turn and talk with a partner to brainstorm processes that form surface features. Lead a class discussion to build a “Surface Features and Causes” poster.	D-G	“Surface Features and Causes” poster, chart paper markers
3	15 min		EXAMINE SATELLITE IMAGES OF EARTH Orient students to how to interpret satellite images. Organize students into groups of 3-4 to analyze satellite images and defend their analysis.	H-M	whiteboard, dry erase marker, <i>Satellite Set A</i> or <i>Satellite Set B</i> , “Surface Features and Causes” poster, <i>Satellite Set A</i> in sheet protectors, <i>Satellite Set B</i> in sheet protectors, painter’s tape
4	12 min		ANALYZE IMAGES OF THE MOON AND MARS Have students individually analyze satellite images of the Moon and Mars. Lead a discussion around their analysis.	N-O	<i>Evaluate Satellite Images</i> , “Surface Features and Causes” poster, <i>Satellite Set A</i> in sheet protectors, <i>Satellite Set B</i> in sheet protectors
5	5 min		NAVIGATE Have students turn and talk with a partner to consider whether other liquids could have formed the surface features on the Moon and Mars.	P	

End of day 1

Lesson 3 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • whiteboard • dry erase marker • <i>Evaluate Satellite Images</i>	• <i>Space Missions Deck</i> from Lesson 1 • <i>Satellite Set A</i> or <i>Satellite Set B</i>	• “Surface Features and Causes” poster • chart paper markers • <i>Satellite Set A</i> in sheet protectors • <i>Satellite Set B</i> in sheet protectors • painter’s tape

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.

Have a set of *Space Missions Deck* from Lesson 1 available for students. Be sure to **remove** the card for the International Space Station.

Prepare a poster titled, “Surface Features.” Leave space to add “and Causes” after students have identified the surface features. The two columns should have the following titles: “Water interacting with the surface” and “Some other process interacting with the surface”.

Prepare a class set of *Satellite Set A* and *Satellite Set B* in sheet protectors. You will tape these to an area on the wall as students defend which geologic processes formed the surface features on the images.

Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

The goal of this lesson is to have students apply their prior knowledge of geologic processes when developing claims about which processes formed the surface features we see on satellite images. This lesson is designed to coherently build ideas related to the following disciplinary core idea:

- **ESS1.C: The History of Planet Earth.** Although active geologic processes, such as plate tectonics and erosion, have ~~destroyed or~~ altered most of the ~~very early~~ rock record on Earth, other objects in the solar system, such as lunar rocks, ~~asteroids,~~ and meteorites, ~~have changed little over billions of years.~~ Studying these objects can provide information about Earth's ~~formation and early history.~~

Crossout explanation: [ESS1.C.2](#) is fully developed in High School Physics *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*.

Students use this idea when they identify geologic processes (including erosion, volcanism, and meteorite impacts) that are most likely responsible for the formation of particular surface features on Earth, the Moon, and Mars. The timescale over which such processes occur, however, and what that can tell us about the history of Earth, is not a focus in this lesson or unit. It is a focus of *Meteors Unit*.

This lesson leverages students' prior knowledge of geologic processes that shape Earth's surface that they would have developed in Middle School *OpenSciEd Unit 6.4: What causes Earth's surface to change? (Everest Unit)*. These ideas were developed as students engaged with MS-ESS2-2: *Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.*

Students work with the class to develop a list of possible surface features and their causes to look for as they examine satellite images of Earth. The class orients to how to interpret images of two river systems in the United States at different scales ([CCC: 1.1](#)). Students work in small groups to develop claims about the geologic processes that caused the formation of four surface features on Earth ([SEP: 7.5](#)). They defend these claims using student-generated evidence from the class-developed poster. Students then practice individually developing and defending claims about the geologic processes that caused surface features on Mars and the Moon ([SEP: 7.5](#)).

Students engage in [SEP: 7.5](#) partially. For [SEP: 7.5](#): *Make and defend a claim based on evidence about the natural world* ~~or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.~~ Students developed this element in a prior High School Biology unit, *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*.

Students engage in the full element of [CCC: 1.1](#) in their analysis of images of the surface at a planetary scale as well as images of the surface at scales that range from meters to hundreds of kilometers across. [CCC: 1.1](#) is reused and extended to consider patterns at multiple scales, including the particle level, in Lessons 4, 7, 8, 9, and 15.

Where We Are NOT Going

Students may have some understanding of, or know names related to, landforms (e.g., oxbow). This lesson does not require that students memorize names of specific landforms caused by geologic processes.

Students may have investigated erosion and how materials can be destroyed from interacting with water, related to performance expectation MS-ESS2-1: *Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.* Students developed understanding of this performance expectation in the *OpenSciEd Middle School Everest Unit*. This lesson does not require a definition for the term *erosion*.

LEARNING PLAN for LESSON 3

1 · NAVIGATE

7 min

MATERIALS: *Space Missions Deck* from Lesson 1

Discuss where we have heard about water in the solar system. Display slide A. Say, *Last lesson, we determined that water is really special and has so many unique properties. We agreed we would need to find it out in the solar system.* Discuss the questions on the slide.

Suggested prompt	Sample student response
Where have we heard there might be water in the solar system?	Accept all responses.
How did the scientists know there was water there?	They detected it in a sample. They saw pictures of it.

ADDITIONAL GUIDANCE

Be sure to remove the International Space Station card from *Space Missions Deck* before distributing to students.

Determine which places we should examine in the solar system. Distribute a set of *Space Missions Deck* from Lesson 1 to students and display slide B. Ask, *Based on our future exploration plans and distance constraints, which three places in our solar system should be our top candidates for evaluating whether or not water is there?* Give students a few minutes to look through the cards before eliciting responses.

Look for students to suggest the Moon, Mars, and Bennu.

ADDITIONAL GUIDANCE

If students suggest Venus, push back by using the following prompts:

- What constraints would limit our ability to get to Venus?
- What other constraints would impact our ability to survive on Venus?

Guide students to reduce the list to two. Ask, *Of these three, which two should we explore for the presence of water? Why?* If students suggest Bennu, push back and stress that we want to establish a long-term settlement. Have students look at the size of Bennu as a way to remove it from further consideration.

Brainstorm types of data that would help us determine whether water is present. Display slide C. Ask, *What data would allow us to make a better determination of the presence of water?* Look for students to suggest any of the following:

- We need zoomed-in images of the surface.
- We need to look at other areas of the surface.
- We need to take samples of the soil and atmosphere.

If students do not suggest looking below the surface, say, *We also need to consider that water may not be currently visible on the surface at a particular spot. We **can** tell if it was there in the past, by looking at surface features. Or, it may still exist in the space object's system in a different reservoir or place below the surface, or at a small scale.*

2 • BRAINSTORM PROCESSES THAT FORM SURFACE FEATURES

8 min

MATERIALS: “Surface Features and Causes” poster, chart paper markers

Identify processes that lead to the development of surface features over time. Display **slide D**. Say, *Think about features here on Earth that are the result of water interacting with the surface, or of some other process. Turn and talk with a partner to brainstorm a list of possible features we would look for in an image.* Give students a few minutes to brainstorm a list with their partner. *



Develop a class list of possible features. Display **slide E**. Use the prompts on the slide to develop a list of surface features and record these on the prepared poster. A sample list is provided. *

Surface Features	
Water interacting with the surface	Some other process interacting with the surface
River beds Sedimentary deposits Cracks Avalanches Canyons Sea/ocean cliffs Beaches	Volcanoes Cracks Craters Avalanches, rocks falling Trenches Mountains

Identify the process that caused each surface feature. Display **slide F**. Say, *Let's think about the causes, or specific interactions, that led to the formation of those surface features we just identified.* Add “and Causes” to the title of the poster. Use a different-colored chart paper marker to record the causes next to each surface feature.

Lead the discussion to add causes to the “Surface Features and Causes” poster. A sample class poster is provided. Keep this poster visible for the remainder of the lesson. *

Surface Features and Causes	
Water interacting with the surface	Some other process interacting with the surface

* ATTENDING TO EQUITY

Make connections to your local area to support *relevance*. Have students consider: What are some changes you have seen in the land due to interactions with water? Depending on where you live, students may suggest changes in reservoir levels or the appearance of cracks in the ground. Students might know about oxbows, watersheds, or river patterns if they have outdoor hobbies like fishing or canoeing.

* SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Support students in thinking about the scale of these different surface features and how that may impact our ability to view them (CCC: 1.1). Use prompts such as:

- At what scale, or how big, are these different surface features?
- How might the scale of the features impact our ability to view them on satellite images?

* SUPPORTING STUDENTS IN ENGAGING IN ARGUMENT FROM EVIDENCE

It is important to build the “Surface Features and Causes” poster with the whole class. Later in this lesson, students develop and defend claims about the geologic processes that formed different surface features on Earth, the Moon, and Mars using this student-generated poster as evidence. (SEP: 7.5)

River beds - erosion
Sedimentary deposits - deposition by a river or glacier
Cracks - drought (lack of water)
Avalanches - too much water (fast melting or a lot of rain)
Canyons - erosion
Sea/ocean cliffs - erosion
Beaches - erosion

Volcanoes - movement of magma (plate movement)
Cracks - earthquakes (plate movement)
Craters - asteroid or meteorite impact
Avalanches, rocks falling - gravity or wind
Trenches - earthquakes (plate movement)
Mountains - plate movement

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students use **patterns in geologic features across different scales** to identify **possible causes**, or **geologic processes**, which **form the features**. (DCI: ESS1.C.2; CCC: 1.1)

What to do: Students may suggest processes that are not related to geologic activity, such as erosion due to wind, chemical erosion due to organisms, erosion due to temperature changes, and gravity. It is not necessary to include these processes on the poster, but keep in mind that students developed understanding of them in prior grades. If students do not suggest geologic processes, ask them to think about processes related to the movement of water, or changes in rock related to ideas students developed in middle school.

Building toward 3.A.1 Make and defend a claim about the **geologic processes** that were most likely responsible for the formation of different **surface features on Earth** and other solar objects, **using evidence** from satellite images at **different scales**. (SEP: 7.5; DCI: ESS1.C.2; CCC: 1.1)

Navigate to examining images on Earth. Say, *We have identified many different processes that could explain surface features we see on different places in the solar system.* Display **slide G**. Ask, *How might analyzing and interpreting images of these types of surface features on Earth better prepare us to do the same thing with images of the Moon and Mars?* Look for students to suggest that we know Earth better and can be more certain about the process that formed the feature.

Say, *Let's orient ourselves to examine the relationship between surface features and water processes by looking at a feature we know was made by water, the Grand Canyon!*

3 · EXAMINE SATELLITE IMAGES OF EARTH

15 min

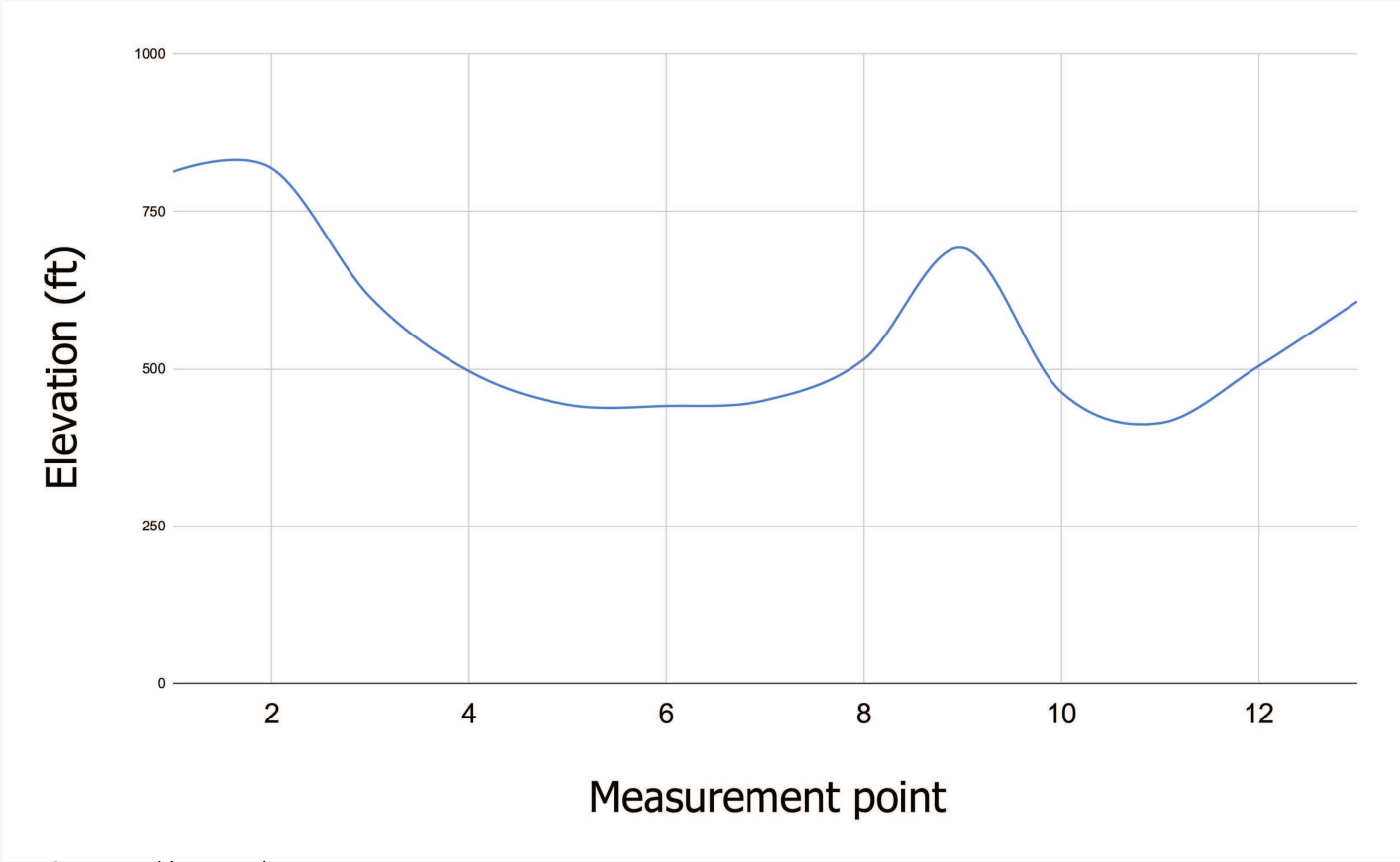
MATERIALS: science notebook, whiteboard, dry erase marker, *Satellite Set A* or *Satellite Set B*, "Surface Features and Causes" poster, *Satellite Set A* in sheet protectors, *Satellite Set B* in sheet protectors, painter's tape

Orient students to how we can interpret satellite images. Display **slide H**. Say, *Take a moment to compare the two images of the Grand Canyon and record a response to each prompt in your science notebook.* Give students two minutes to stop and jot their responses, then ask for a few volunteers to share.

Suggested prompt	Sample student response
<i>How are the features on the left related to what you see in the satellite view on the right?</i>	You can see where the river is in both of them, it's the dark portion. The higher parts look lighter in the satellite image.
<i>How would water have made these features?</i>	The river carved the land over a long period of time. Erosion.

Interpret elevation in satellite images. Distribute a whiteboard and dry erase marker to each student. Display **slide I**. Explain that the images on the slide are false-color images. This means that the images have had their colors changed or enhanced to help make surface features more visible. Tell students that they are looking at the area where the Mississippi, Illinois, and Missouri Rivers meet near the Illinois-Missouri border.

Have students draw a line on their whiteboard to show what they think the elevations are, moving from west to east. Then, ask students to show the line they drew. Point out that we have some different ideas about what the changing elevation of the land would look like. It is okay if students have different interpretations of the elevation.



Data Source: World Topographic Map

Display [slide J](#). Say, *The graph was created by using the elevation measurements at different points along the white line.* Have students compare the graph to what they drew.

Suggested prompt	Sample student response
What surface features are shown by the graph?	There are two rivers in the low spots.

Suggested prompt	Sample student response
<i>How might thinking about elevation help us figure out whether water is, or could have been, on the surface?</i>	We could look for a continuous low spot.

Develop claims about surface features. Organize students into groups of three or four. Display **slide K**. Distribute either *Satellite Set A* or *Satellite Set B* to groups, ensuring that about half of the class analyzes each set of images. Read through the directions on the slide and ask if students have any clarifying questions. Give groups four to five minutes to analyze and identify which processes the class listed on the “Surface Features and Causes” poster produced the features for the four images they examine.

ADDITIONAL GUIDANCE

All satellite images in *Satellite Set A*, *Satellite Set B*, and *Evaluate Satellite Images* have been added to a set of slides (Lesson 3 Satellite Images) which you can make available to students. This option was developed because it may be difficult to evaluate some of the images given the size of the print found on the materials.


Defend claims using evidence from satellite images. Display **slide L** and have the “Surface Features and Causes” poster visible. Go through the different processes identified on the poster and have groups hold up the satellite images that they claim show a surface feature formed by that process. If groups who analyzed the same satellite images do not agree, ask each group to use evidence from the poster to defend their claim about the geologic process that formed the surface feature.

As students share, organize and tape the prepared images in sheet protectors on the wall so that they are grouped by geologic process.

Use the table below as a key for which satellite image surface features were formed by which process. Note that some images may represent multiple processes. It is okay if groups do not point out all of the different processes in the images.

Process	Image	Reasoning
Erosion by water	Data Set A: Location 1	North Beach is smaller in size.
	Data Set A: Location 3	It looks like a river in the middle of the image.
	Data Set A: Location 4	Some of the land was washed away by the river changing course.
	Data Set B: Location 2	Some parts of the river are no longer in the same place.
	Data Set B: Location 4	It looks like a river in the middle of the image.

Deposition	Data Set A: Location 4	It looks like sediment from the river is moving into the sea.
	Data Set B: Location 2	The ground is brown where the river used to be.
Change in amount of water (drought or flood)	Data Set A: Location 3	It looks really dry.
	Data Set B: Location 4	It looks really dry.
Erosion by wind or gravity	Data Set B: Location 4	It looks like there are dunes, or wind ripples in the sand.
Plate movement	Data Set B: Location 3	It looks like a volcano.
Asteroid or meteorite impact	Data Set A: Location 2	It looks like something smashed into Earth.
	Data Set B: Location 1	It looks like something smashed into Earth.

Compare satellite images. Display slide M.

Suggested prompt	Sample student response
<i>What is similar about the images that you have identified were formed in the same way?</i>	They have the same features, like all of the river ones look like there are areas of higher elevation on either side of the flat area the river runs through. Both of the impact images look circular, like something smashed into Earth. Kind of like a drop of water in a pond.
<i>What is different about the images that you have identified were formed in the same way?</i>	The sediment was really easy to see in the Data Set A image, but it is a bit harder to tell in the Data Set B image.
<i>How will these similarities and differences help us interpret surface features on other space objects?</i>	We can see some patterns in how the features look in different places, for those features that are similar. If we think they formed in the same way, they probably would look similar.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' **claims include evidence** (e.g., **similar or different structures visible** in the images) of different regions of Earth at **different scales** from either *Satellite Set A* or *Satellite Set B*. (SEP: 7.5; CCC: 1.1)
- Students' **claims reference patterns that are similar** between surface features in **different data sources** across both *Satellite Set A* and *Satellite Set B*. (SEP: 7.5; CCC: 1.1)

What to do: If students struggle to visualize the elevation changes across the satellite images, repeat the activity from **slide J** with one or more of these images. If students do not think there is strong evidence for a particular geologic process, or think there might be multiple geologic processes that account for a surface feature, ask them to identify one that is a likely possibility and one that is a less likely possibility, and why.

Building toward 3.A.2 Make and defend a claim about the **geologic processes** that were most likely responsible for the formation of different **surface features on Earth** and other solar objects, **using evidence** from satellite images at **different scales**. (SEP: 7.5; DCI: ESS1.C.2; CCC: 1.1)

ADDITIONAL GUIDANCE

Leave the organized satellite images and “Surface Features and Causes” poster visible so that students can refer to them when they complete their analysis of surface features on the Moon and Mars in the next lesson step.

4 · ANALYZE IMAGES OF THE MOON AND MARS

12 min

MATERIALS: *Evaluate Satellite Images*, “Surface Features and Causes” poster, *Satellite Set A* in sheet protectors, *Satellite Set B* in sheet protectors

 **Individually analyze images of the Moon and Mars.** Say, *We were wondering if we could look at images of the Moon and Mars to see if there is evidence of water. Now that we have had a chance to analyze images from Earth and have started to identify patterns in surface features caused by water and other processes, let's take a moment to examine some satellite images of the Moon and Mars.*

Display **slide N** and distribute *Evaluate Satellite Images*. Give students six minutes to complete the handout.

Discuss image analysis. Display **slide O**.

Suggested prompts	Sample student responses	Follow-up questions
Which part(s) of each image was possibly formed by water?	Clavius Crater has lines, but they are cracked, not flowing Chryse Planitia has flowing lines that look like other Earth watershed images.	How do you know? What is your evidence?
Which part(s) of each image was possibly formed by something else?	Komarov Crater, Clavius Crater, Chryse Planitia, and Cerberus Fossae have impact sites.	How do you know? What is your evidence?

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use **patterns in geologic features across different scales** to identify **possible causes**, or **geologic processes**, which **form the features**. (DCI: ESS1.C.2; CCC: 1.1)
- Students' **claims reference patterns that are similar** between surface features in **different data sources** across both *Satellite Set A* and *Satellite Set B*. (SEP: 7.5; CCC: 1.1)

What to do: Encourage students to compare surface features in the images found in *Satellite Set A* and *Satellite Set B* to those they analyzed in *Evaluate Satellite Images*. Prompt students to identify areas in the images of the Moon and Mars which look similar to the surface features on Earth that they analyzed with their small groups.

Building toward 3.A.3 **Make and defend a claim about the geologic processes that were most likely responsible for the formation of different surface features on Earth** and other solar objects, **using evidence** from satellite images at **different scales**. (SEP: 7.5; DCI: ESS1.C.2; CCC: 1.1)

5 • NAVIGATE

5 min

MATERIALS: None

Consider whether other liquids could form the surface features we analyzed. Display slide P. Give students three minutes to turn and talk with a partner about the prompts on the slide. Then ask for a few volunteers to share.

Suggested prompt	Sample student response
<i>Could it be possible the surface features we thought were formed by water, were actually formed by a different liquid?</i>	Yes. No.
<i>What additional investigations do you think we need to do to support or refute our claim(s)?</i>	We could compare other liquids to water. We should see how other liquids and water interact with surface materials.

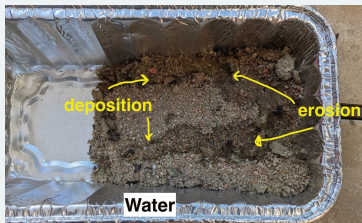
LESSON 4: How and why do water and other liquids interact with materials to make surface features?

PREVIOUS LESSON We brainstormed a list of surface features on Earth and then identified which types of geologic processes caused their formation. We used patterns in surface features to develop and defend claims about which geologic processes are responsible for them on Earth, the Moon and Mars. We wondered if the surface features could have been formed by liquids other than water.

THIS LESSON

INVESTIGATION

3 days



We investigate how liquids interact with surface materials to help us determine that surface features on Mars were likely made by water. We wonder what makes water different from other liquids and examine molecular models of them to compare their polarities. We read about how water causes surface features through both erosion and freezing. We model these processes using manipulatives. We complete an Electronic Exit Ticket.

NEXT LESSON

We will build and use a projector-based spectrometer to investigate the absorption and transmission of light by solutions of pure substances. We will examine infrared spectra of gasses, and use reference spectra to identify gasses in mixtures and the atmospheres of objects in space. We will read about other ways spectroscopy is used to identify substances in space.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, HS-ESS1-2, HS-ESS2-1, HS-ESS2-5



WHAT STUDENTS WILL DO

- 4.A** Design and conduct an investigation to determine the patterns to use as causal evidence to explain the interaction of water with Earth's surface compared to substances with similar properties. (SEP: 3.1; DCI: ESS2.A.1, ESS2.C.1; CCC: 1.1)
- 4.B** Observe patterns at multiple scales to support movement between multiple types of models that use molecular and submolecular structures that explain the properties of matter like water. (SEP: 2.4; DCI: PS1.A.3; CCC: 1.1, 6.2)
- 4.C** Compare, integrate, and evaluate information from a reading, models, and an investigation to explain how water's polarity results in its unique bulk properties. (SEP: 8.2; DCI: PS1.A.3; CCC: 6.2)

WHAT STUDENTS WILL FIGURE OUT

- Polar regions on molecules are due to a greater amount of negative or positive charge in that region of the molecule.
- Polar regions on molecules will produce force interactions with nearby polar regions on neighboring molecules, which can be used to explain some property differences between substances.
- Polar molecules could more easily erode some materials in their surroundings than nonpolar molecules.

Lesson 4 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	2 min		NAVIGATE Lead a brief discussion to help students remember where they left off in the previous lesson.	A	
2	15 min		DESIGN AN INVESTIGATION Have students design the Erosion Investigation.	B-H	Erosion Investigation
3	25 min		INVESTIGATE THE EFFECTS OF LIQUIDS ON PLANETARY SURFACES Have students work in groups to investigate substances' effects on Mars-like materials.	I-K	Erosion Investigation
<i>End of day 1</i>					
4	3 min		NAVIGATE Navigate back to the Erosion Investigation.	L	
5	7 min		COMPILE INVESTIGATION RESULTS Lead a gallery walk to share investigation results.	M	Erosion Investigation
6	6 min		RECALL PROPERTIES OF LIQUIDS Help students summarize patterns in the investigation and recall important properties of water.	N-O	<i>Erosion Investigation</i>
7	14 min		EXAMINE MOLECULAR STRUCTURES OF VARIOUS LIQUIDS Have students examine differences in polarity of substances at the molecular level.	P-S	<i>Erosion Investigation Structures</i>
8	15 min		MODEL INTERACTIONS OF WATER WITH MARS-LIKE MATERIALS Attempt to model why water is behaving so strongly compared to the other substances.	T-V	<i>Molecule Cutouts</i>
9	2 min		NAVIGATE Navigate back to class results.	W	<i>Erosion Investigation</i>
<i>End of day 2</i>					
10	3 min		NAVIGATE Navigate the class to recall what we have and have not figured out about water and its effects on Mars.	X	

Part	Duration		Summary	Slide	Materials
11	10 min		COMPLETE A READING Have students work with a partner to read about the impacts of erosion and freezing.	Y	<i>Mars Geologic Landforms</i>
12	8 min		RETURN TO MOLECULAR MODELS OF WATER Have students work with a partner to use molecule cutouts to model water's expansion during freezing.	Z	<i>Mars Geologic Landforms, Molecule Cutouts</i>
13	9 min		BUILD UNDERSTANDINGS OF WATER'S PROPERTIES AND CONNECT TO M-E-F POSTER Have students move into a Scientists Circle to make sense of our investigation and reading about water's effects on planetary surfaces and connect our M-E F poster.	AA	<i>Mars Geologic Landforms, Molecule Cutouts, "Water's Importance for Life and Chemical Reactions" poster from Lesson 2, M-E-F poster from <i>Electrostatics Unit</i>, expansion panels and arrows for the M-E-F poster</i>
14	5 min		UPDATE PROGRESS TRACKERS Have students update their Progress Trackers.	BB	
15	10 min		COMPLETE AN ELECTRONIC EXIT TICKET AND NAVIGATE Have students complete an Electronic Exit Ticket and briefly navigate to the next lesson.	CC	computer with internet access

End of day 3

Lesson 4 • Materials List

	per student	per group	per class
Erosion Investigation materials	• <i>Erosion Investigation</i> • indirectly vented chemical splash goggles • nitrile gloves • non-latex apron	• <i>Erosion Investigation Guidelines</i> • approximately 115 g sand • 2 small pans or trays • 2 paper cups • 50 mL of two of the following: water - vegetable oil - isopropyl alcohol - acetone • 2 index cards • 2 straws or pipettes	• chart paper • chart paper markers • https://youtu.be/HhZuttk_hyM?si=x3fUuhh_FnAepj6Q
Lesson materials	• <i>Erosion Investigation</i> • science notebook • <i>Erosion Investigation Structures</i> • <i>Mars Geologic Landforms</i> • computer with internet access	• <i>Molecule Cutouts</i>	• “Water’s Importance for Life and Chemical Reactions” poster from Lesson 2 • M-E-F poster from <i>Electrostatics Unit</i> • expansion panels and arrows for the M-E-F 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.

Ensure students have access to a color printed or digital version of *Erosion Investigation Structures*.

Have enough copies of *Molecule Cutouts* cut out so that each pair of students has a set of molecule cutouts to work with.

See *Electronic Exit Tickets* for instructions on how to make the Electronic Exit Ticket students will need at the end of this lesson.

Display the M-E-F poster you developed from the prior unit, *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. Use half or full sheets of colored copy paper to create the expansion panels with the following text:

- Helps explain some property differences
- Helps explain some geologic processes (planet scale, lab scale)
- Different molecules have different charge distribution
- Have different proportions and regions of polarity
- Results in different force interactions with neighboring particles

You will also want to make matching color arrows. These also can be on paper, though pipe cleaners or metal craft wire can be bent to make curved arcs to connect the expansion panels together. You will temporarily tape these panels and corresponding arrows to the side of the M-E-F poster and remove them for each class, to help connect the thinking students did in this lesson to the matter and forces thinking they did in the prior unit. You can keep these additional panels posted after the last period of your last class for this lesson. You will reference these panels again in Lesson 8 and beyond.

Day 1: Erosion Investigation

- **Group size:** 5 students
- **Setup:** Gather materials for the investigation. See *Erosion Investigation Guidance* for additional information. The total amount of materials needed for a class of 35 students is as follows:
 - ~1 800 g very dry sand (or other Mars-like material)
 - 14 small pans or trays
 - 14 pipettes for releasing liquids
 - 14 beakers (25 mL)
 - 350 mL water
 - 350 mL vegetable oil
 - 350 mL isopropyl alcohol
 - 350 mL acetone
 - 14 index cards
- **Notes for during the lab:** See *Erosion Investigation Guidance* for additional information.
- **Safety:**
 - Wear sanitized indirectly vented chemical splash goggles, nitrile gloves and non-latex apron during the setup, hands-on, and takedown segments of the activities.
 - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
 - An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
 - Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
 - Hand sanitizer wipes must be provided for participant use at the completion of the activities.
 - Clean up any spills immediately using spill control containers for overflow of products produced. Oil spills require special attention.
 - Do not ingest any of the liquids used in the lab.
 - Do not put your face over an open alcohol or acetone container. Isopropyl alcohol and acetone are harmful if ingested and can irritate skin.
 - Do not put your mouth on the straws. Never consume any liquid in the lab for any reason.
 - Follow procedures set up by the instructor for disposal of materials.
 - Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
 - Any electrical cords must be off the floor to prevent trip/fall hazards.
 - Keep flammable liquids (Isopropyl alcohol and acetone) away from active flames or sparks to prevent fire.
 - Given there is use of flammable liquids, the instructional space must have appropriate ventilation. The ventilation system in the instructional space must meet the needs relative to removing the flammable vapors produced. Use of a fume hood is also a viable alternative.
 - Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
 - Direct supervision will be required during all aspects of these activities.
- **Disposal:** Oily sand should not be returned to the outdoor environment. Sand soaked with oil must be discarded safely as oil is dangerous to wildlife. Isopropyl alcohol and acetone evaporate quickly at room temperature. Sand soaked with water, alcohol, or acetone can be returned to the outdoors safely.
- **Storage:** Store the isopropyl alcohol and acetone in a flammables cabinet. All other liquids can be safely stored in standard chemistry classroom cabinets with lids securely affixed. Cabinets should be locked to ensure safe access to chemicals.

Lesson 4 • Where We Are Going and NOT Going

Where We Are Going

The goal of this lesson is to have students use investigative data to support water's interactions with materials to form surface features they analyzed in Lesson 3. Students develop a deeper understanding of the properties of water initially explored in Lesson 2 by looking at its molecular structure. This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **ESS2.A: Earth Materials and Systems.** Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. ~~A deep knowledge of how feedbacks work within and among Earth's systems is still lacking, thus limiting scientists' ability to predict some changes and their impacts.~~
- **ESS2.C: The Roles of Water in Earth's Surface Processes.** The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, ~~and lower the viscosities and melting points of rocks.~~
- **PS1.A: Structure and Properties of Matter.** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

Crosscut explanations: **ESS2.A.1** is fully developed in High School Physics *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*. Students bring some understanding of feedback loops from *Polar Ice Unit*. In the Middle School *OpenSciEd Unit 6.4: What causes Earth's surface to change? (Everest Unit)*, students developed ideas around the interactions between Earth's systems.

Students have prior experience with **ESS2.C.1** from Lesson 2, in which they considered water's ability to absorb, store, and release large amounts of energy, transmit sunlight, and dissolve materials. The property of water to lower the viscosity and melting point of rocks is incorporated in *Earth's Interior Unit*.

Students also bring in familiarity with other unique properties of water from previous chemistry units. In *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, students addressed water's ability to absorb, store, and release energy. In *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, students modeled that water is polar because one end of its molecule is positive and one end is negative, and identified that this is due to shifts in electrons within the molecule; however, they do not have an explanation for what is causing this yet.

In this lesson, students develop investigation plans, with controlled variables, in the service of revising models (**SEP: 3.1**). Students work with multiple types of models (**SEP: 2.4**), as in *Electrostatics Unit*. While engaging in these practices, students must examine patterns across different scales (**CCC: 1.1**). Students then integrate information from a reading along with their investigation data and models to address which liquid is responsible for the surface features we observe (**SEP: 8.2**). They previously engaged in this practice element in *Electrostatics Unit* as they put pieces together around the nature of static and lightning safety. Here, students must infer properties of various liquids from their molecular structures and interactions with Earth materials using information from a reading (**CCC: 6.2**).

Students engage in **SEP: 3.1** and **8.2** partially. For **SEP: 3.1: 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.** Students developed this element in a prior unit, *Polar Ice Unit*. For **SEP: 8.2: 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.** This is the second time students have engaged with **SEP: 8.2** in this unit. Students developed this element in prior units, *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*, *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*, and *Electrostatics Unit*.

Students engage in **CCC: 6.2** partially. For **CCC: 6.2: The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of their various materials.** Students were previously introduced to portions of this element in Lesson 1. Because they are using this element with increasing sophistication, students are supported in this lesson through the use of manipulatives and multiple modalities. Students previously engaged with **CCC: 6.2** in *OpenSciEd High School Biology Cancer Unit*.

Where We Are NOT Going

Students might come into this unit with an understanding of landforms. Consistent with HS-ESS2-5, students are not memorizing names of land formations or surface processes. Students may have investigated erosion and how Earth materials can be broken down over time from interacting with water, related to the performance expectation MS-ESS2-1. This lesson does not require a definition for the term *erosion*.

Students do not consider how hydrophobic soil, or soil water repellency (SWR), conditions occur and its effects on rates of soil erosion. Much research has been conducted on how SWR increases erosion, but for the goals of this unit, it is not essential for students to understand.

The reading about riverbeds, *Mars Geologic Landforms*, outlines how specific formations on Mars could have been created by water. The terms *meanders* and *frost heaving* are in the reading, but these words are outside the boundaries of the performance expectation.

LEARNING PLAN for LESSON 4

1 · NAVIGATE

2 min

MATERIALS: None

Navigate. Give students one minute to discuss the prompts on **slide A** and then discuss as a class.

Suggested prompt	Sample student response
<i>What are some uncertainties we have about whether water was responsible for those surface features on Mars, and not some other liquid?</i>	There are lots of liquids other than water. We have only really investigated water but not other liquids.
<i>How could we investigate possible liquid-landform interactions?</i>	Try running water across sand or dirt and see what happens. Compare water to other liquids on the same materials to see if other liquids do the same thing.

2 · DESIGN AN INVESTIGATION

15 min

MATERIALS: Erosion Investigation

Discuss materials for the investigation. Tell students that you have some liquids on hand that they might want to use to investigate landform formation. Show them the water, vegetable oil, acetone, and isopropyl alcohol, as well as the sand and trays. Display **slide B** and have students discuss the questions on the slide with a partner. After two minutes, ask for students to share what they discussed.

Suggested prompt	Sample student response
<i>How could we use these materials to investigate whether the landforms on Mars were made by water or some other liquid?</i>	Compare water to the other liquids. See how different liquids affect the sand.
<i>What other materials or liquids would be important to try if they were available?</i>	Accept all suggestions.
<i>How do the properties of these liquids compare to those of water?</i>	They are all liquid at room temperature. Oil can be clear or yellowish and it is thicker (has a different viscosity), but it is still liquid at room temperature.

* ATTENDING TO EQUITY

Universal Design for Learning: This is an important opportunity to emphasize that each individual has contributions to make to their group's investigation design. The collaborative development of the investigation design helps support *engagement* by optimizing relevance, value, and authenticity.

* SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Patterns: The element of focus in this lesson is the HS CCC for 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)

ADDITIONAL GUIDANCE

This investigation is written to allow students to choose materials to work with. In addition to water, students may think of a number of other common household chemicals (e.g., bleach, milk, juice). Encourage students to consider both safety and the liquid's chemical composition. Bleach is not safe to use in undiluted form, and juice and milk are mostly water. There is space to replace materials with student-generated ideas in *Erosion Investigation*.

Throughout this lesson, provide feedback to students that helps them link causality appropriately to the patterns of water in extra-terrestrial systems.

Build consensus about materials. Say, *It is important that we come to a consensus about how we will use these materials in the investigation. This will allow us to compare data across groups.* Display **slide C** and have students share what materials they want to use in this investigation. Once the class has come to consensus about a material to use, record it on a piece of chart paper.

Suggested prompt

Sample student response

What types of landforms are we trying to recreate?

Rivers or riverbeds.

Some type of erosion, like deltas.

What could we use to mimic the movement of water in a river or stream?

Maybe a dropper or straw for dripping the liquid.

How would we want to set up the structure or shape of the land before the liquid interacts with it?

Maybe we need a slope or a hill so the liquid can run down?

We should all set it up the same way.

Discuss the purpose of the investigation. Display **slide D** and distribute *Erosion Investigation*. Say, *The images on the slide show evidence of erosion. We decided that we wanted to see if the landforms on Mars could have been formed by water. So, let's think about why we are doing this investigation.* Point students to question 1 on the investigation handout. Then encourage students to write their ideas before sharing ideas with the whole class.

Suggested prompt

Sample student response

What is the purpose of this investigation?

We want to see if water or other liquids make the same erosion patterns.

We want to see if other liquids will erode soil.



Design an investigation in small groups. Distribute a copy of *Erosion Investigation Guidelines*. Discuss with the class how each group's procedures should be similar to each other and go over the safety instructions. Add any additional agreements that all group's procedures should include to the sheet of chart paper.

Display **slide E**. Have students work in their groups to complete the first row of the table in question 2 of *Erosion Investigation*. As groups work, circulate around the room and assist as needed.

Once the majority of groups have completed the first row of the table, display **slide F**. Use the slide to help students complete the next two rows of the table in question 2 of the handout.

Once all groups have completed the first three rows of the table, display **slide G**. Ask, *What do we need to consider as a class when designing the group investigations so that we can compare the data between groups?* Accept all student ideas, but highlight those that point out that we should use similar amounts of materials in our designs. Prompt students to work with their small groups to complete the remaining rows of the table in question 2.

Have students collaboratively develop a procedure in their groups. * Display **slide H** and direct students to question 3 on *Erosion Investigation*, which has space for them to write their procedure. As groups work, assist around the room as needed and approve each group's procedure. Make sure that each group specifies which liquid other than water they would like to test. Each liquid should be tested by at least two groups; if you have fewer than six groups, make sure that each liquid is tested by at least one group. A sample procedure can be found on *Erosion Investigation Guidance*.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' **investigation plans** include **sufficiently controlled variables** to enable them to compare **water's impact on surface materials** to **other liquids' impacts**. (SEP: 3.1; DCI: ESS2.A.1, ESS2.C.1)
- Students' **investigations** will help students observe **patterns at the observable scale** to provide **evidence for causality** of landforms by various liquids. (SEP: 3.1; CCC: 1.1)
- Students' **plan and conduct investigations** which will help them **revise their models** of **how water creates surface features on Earth**. (SEP: 3.1; DCI: ESS2.A.1, ESS2.C.1)

What to do: As groups work to develop their investigation procedures, ask clarifying questions to ensure that the procedures are complete and can be replicated by others. Push students to consider if their procedures will help them answer their questions about the Mars landscape, and how to ensure they are controlling variables.

Building toward 4.A.1 **Design and conduct an investigation** to determine the **patterns to use as causal evidence** to **explain** the **interaction of water with Earth's surface** compared to **substances with similar properties**. (SEP: 3.1; DCI: ESS2.A.1, ESS2.C.1; CCC: 1.1)

3 · INVESTIGATE THE EFFECTS OF LIQUIDS ON PLANETARY SURFACES

25 min

MATERIALS: Erosion Investigation

View how to add liquids in the Erosion Investigation. Display **slide I** and have groups reference *Erosion Investigation Guidelines*. Point out the guidelines and show https://youtu.be/HhZuttk_hyM?si=x3fUuhh_FnAepj6Q to help students understand the need to control their investigation for the force of "blasting."

Conduct the Erosion Investigation. Display **slide J**. Instruct students to work in their groups to set up and conduct the Erosion Investigation with the available materials.

SAFETY PRECAUTIONS

An optional slide after **slide J** is included which shares the related safety considerations for the Erosion Investigation.



* SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

Students conduct the investigations they collaboratively designed. Students' investigation plans should help them to answer the investigation question and to revise their models of what makes water unique. Ensure that students adhere to the procedure in their investigation design so as to produce data they can use to help explain water's unique properties. Students may or may not use the language of "control" or

Distribute two index cards to each group and ask them to write the liquids used in large letters on the fronts of the cards and students' names or initials on the reverse. ✱ Point out where the data table is located on *Erosion Investigation* to record groups' experimental data.

Clean up and prepare for a gallery walk next class. Display **slide K**. Make sure that students leave their labeled setup in the designated area in the room. Remind students to check in with their groups and make sure all group members have their investigation data recorded in *Erosion Investigation*.

ALTERNATE ACTIVITY

If space is limited, or if you want to ensure that students can observe each other's results as they appear after applying the liquids, have students take pictures of their setups and upload them to a designated document, slide deck, or place in your learning management system.

“confound,” but the use of these words is less important than actually building a design that leverages them. ([SEP: 3.1](#))

End of day 1

4 · NAVIGATE

3 min

MATERIALS: None

Navigate back to the Erosion Investigation. Welcome students back to class and have a brief discussion to help them remember where they left off last class. Display **slide L**. After recapping the investigation, ask students to think about the differences they might want to look for across groups. Listen for:

- more or less erosion caused by the different liquids
- holes
- dry “riverbeds”

5 · COMPILE INVESTIGATION RESULTS

7 min

MATERIALS: Erosion Investigation

Conduct a gallery walk to examine other groups' results. Display **slide M**. Say, *As you move from group to group, do not disturb or touch the materials at the tables as this could ruin the investigation results.* Point out the Class Results column in the data table on *Erosion Investigation*. Encourage students to record their observations for each type of liquid they see, and also to write “most,” “least,” or “somewhat” for how much each substance seemed to alter the landscape, so that a pattern can emerge. When students finish recording their observations, have groups rotate to the other tables so they can see all class results.

As students do the gallery walk, ask what patterns they are noticing. Look for responses such as:

- Water caused the most erosion.
- Oil caused the least erosion.
- Alcohol and acetone seem to be between water and oil in how much erosion they cause.

Visit the table groups and check that students have recorded all the investigation results. When they have, ask groups to return to their seats and find patterns in the results. Remind students that they will share what they have learned next. Sample results can be found on *Erosion Investigation Guidance*.

MATERIALS: *Erosion Investigation*

Have a Building Understandings Discussion about the Erosion Investigation. Display **slide N**. Ask students to think for a moment about how the liquids interacted with the Mars-like material you tested in the Erosion Investigation.

Suggested prompt	Sample student response
<i>How did we control our investigations to yield results we could compare fairly?</i>	We kept the four substances separate. We all dropped the liquids in the same way. We tested and compared a lot of groups' results.
<i>What patterns did you notice in how the liquids interacted with the Mars-like material?</i>	The water was able to cause the most erosion, but alcohol also caused some. Oil just soaked into the Mars-like material.
<i>What do we already know about water from this unit and previous units?</i>	It is polar. (From C.2 Lightning unit) It has charges. (From C.2 Lightning unit) It is good at dissolving things. (From Lesson 2 investigations) It has surface tension/cohesion/sticks to itself. (From Lesson 2 investigations)

Compare investigation results to geologic formations on Mars. Display **slide O**. Have students compare the images of geologic formations on Mars to the results of their investigations. Instruct students to answer question 5 on *Erosion Investigation*. As they write, circulate to check in with struggling students and to see what students are writing in response to the prompt. Look for students to say that the landforms could have been made by water or alcohol. Ask students to consider how an investigation at this small scale can help them make sense of what is happening at the planetary scale of Earth and Mars. Listen for students to suggest:

- Impacts will look the same in our trays as they do on planets.
- Seeing how liquids affect small amounts of sand helps us figure out which liquid is doing this to planets.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students reason that alcohol also causes erosion sometimes, but that the overall **pattern** is that **water has a greater impact**. (DCI: ESS2.A.1, ESS2.C.1; CCC: 1.1)
- Students **describe the results of their investigations** that show how **water exhibits stronger force interactions than other liquids in the stream table erosion investigation**. (SEP: 3.1; DCI: ESS2.A.1, ESS2.C.1)
- Students articulate how **patterns of water's interactions with surface materials** at the **classroom investigation scale** can help **explain landforms on Earth and Mars**. (DCI: ESS2.A.1, ESS2.C.1; CCC: 1.1)

What to do: Guide students through the suggested prompts. Check their work as you circulate. If students need additional help, ask them to review *Erosion Investigation*. Use questions like these to help students reason about the strength of water's interaction with the materials:

- *Why do you think that?*
- *What's your evidence?*
- *How did you arrive at that conclusion?*
- *Can anyone repeat the evidence stated and push it a little further?*

Building toward 4.A.2 Design and conduct an investigation to determine the **patterns to use as causal evidence to explain the interaction of water with Earth's surface compared to substances with similar properties**. (SEP: 3.1; DCI: ESS2.A.1, ESS2.C.1; CCC: 1.1)

7 • EXAMINE MOLECULAR STRUCTURES OF VARIOUS LIQUIDS

14 min

MATERIALS: science notebook, *Erosion Investigation Structures*

Consider force interactions. Say, *We saw that these different liquids interacted with the surface materials in different ways, but most or all of them did interact*. Display slide P and ask, *What evidence do we already have that there are different force interactions occurring between these different liquids and surface materials?* Listen for students to refer to the different results for the different liquids, and to say that some liquids moved the surface materials around more than other liquids.

Consider a smaller scale. Tell students that it may be helpful to consider a smaller scale first. Before students try to explain something as big as a canyon or riverbed being created by moving liquid, it may help to start small, such as thinking about how drops of liquid stay together on a penny. Discuss the prompts on slide Q as a class.

Suggested prompt	Sample student response
<i>What smaller-scale properties about water that we have observed in previous investigations do we think are most relevant?</i>	Accept all answers (cohesion, dissolving, or any property of water previously observed).
<i>What molecular-level differences do we predict we will see in these liquids that can explain these properties and the results from the Erosion Investigation?</i>	Differences in polarity. Differences in the types of atoms. Differences in the presence of charges.

* SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

Students use molecular structures to help them reason about properties of liquids. The presence of partial charges, indicated by δ^+ or δ^- , and the corresponding fields they produce (red or blue coloring), help students visualize why water and other polar substances exhibit some property differences caused by attractions between neighboring molecules. (CCC: 6.2)

Give students an opportunity to compare structures. Display **slide R**. Distribute *Erosion Investigation Structures* and explain that this reference shows the molecular structures of the materials we investigated. Help students orient themselves to the models. Remind students that they saw the symbols δ^+ and δ^- in *Electrostatics Unit*, or briefly describe them as representing a greater amount of negative charge than positive (δ^-) and a greater amount of positive charge than negative (δ^+).

Identify field representations from these charges. Highlight red and blue regions in different parts of the molecules as representations of the fields produced by these charges in the space around those parts of the molecules. Ask students which color represents the field produced by a greater amount of negative charge in that part. Students will say red. Point out that blue is the color used in these representations to show the field produced by a greater amount of positive charge in that part of the molecule.

Point out that all of the molecules have at least some amount of space where there is no red or blue, and this indicates that there is a neutral charge in that region, or an equal amount of positive and negative charge, which is represented as producing no discernable differences in the fields around that part of the molecule. Tell students they will have seven minutes to compare the structures on the reference with a partner using the prompts on the slide. *

Discuss students' comparisons. Display **slide S** and lead students in a Building Understandings Discussion using the prompts on the slide.

KEY IDEAS

Purpose of this discussion: This Building Understandings Discussion supports students in using evidence from the investigation to identify that a molecule's polarity is related to how it interacts with other substances.

Listen for these ideas:

- Students notice that water has one positive side and one (or two) negative side(s), and that only a very small part (between these regions) is non-polar (or has no charge).
- Oil does not really have polar regions or charged regions, and alcohol and acetone have them but they are less concentrated than water's polar regions (or they have a higher proportion of areas that are non-polar).
- Polarity is due to uneven charge distribution in a molecule. Students will not have a mechanism for this yet.
- Water dissolves salt because these polar regions exert force interactions that can pull apart ions in other substances. Maybe there is something similar in sand that water interacts with?

Suggested prompt	Sample student response	Follow-up questions
<i>What patterns did you notice in the distribution of charge in the molecular structures?</i>	They are all made up of carbon, hydrogen, and oxygen. Water is much smaller and has fewer atoms than the other substances; oil is larger and has more atoms. They all have areas that are much more negative or positive. Water, alcohol, and acetone all have a more negative oxygen in the middle.	<i>So what do we think it is about a molecule's structure that would make the charge distribution uneven enough to make it polar?</i>

Suggested prompt	Sample student response	Follow-up questions
Which substances have a higher proportion of areas that are polar?	Water is more polar because it has only positive and negative sides, with darker colors and bigger charges. Alcohol and acetone have more polar areas than oil has.	How did you decide which areas were polar?
Which substance has the highest proportion of areas with no polarity?	Oil.	
Why would differences in polarity lead to different force interactions between particles?	They do because water is much smaller than the others, and that could explain how it erodes much more. They do because we know water is polar and good at dissolving, so maybe it is better at attracting soil particles and that causes erosion.	How could we show what we think is happening at the molecular level?

8 • MODEL INTERACTIONS OF WATER WITH MARS-LIKE MATERIALS

15 min

MATERIALS: *Molecule Cutouts*

Model a property of water. Tell students, *Now that you have thought about a smaller-scale property or interaction you have observed with water and these other liquids, and have analyzed differences in polarity due to their molecular structures, let's try to explain some of these properties using these differences.* Distribute the molecule cutouts from *Molecule Cutouts* and display **slide T**. Remind students that they just brainstormed these properties and force interaction differences. Give students three or four minutes to work with the molecule cutouts, and circulate while students are doing so. If students are unsure how to model a particular property with the cutouts, push them to think about how the stronger charges on water could lead to water exhibiting this property while other liquids do not. You can also encourage students to think of a different property to model.

Debrief the modeling activity. After a few minutes, display **slide U** and debrief with the students.

* ATTENDING TO EQUITY

Supporting Emerging Multilingual Learners
The -ian (or sometimes simply -an) suffix denotes the turning of a noun place name into an adjective of its corresponding identity. You can highlight that martian = of Mars in order to help students make these linguistic connections (e.g., American, Guatemalan, Nigerian, Cambodian, Philadelphian, Oklahoman).

Suggested prompt	Sample student response
Which property differences can you explain in terms of force interaction differences between neighboring molecules?	Cohesion, like the drops on the penny. Water sticks to itself because the positive and negative charges on different molecules attract. There is very little of a water molecule that has no polarity to it, so the polar parts would be attracted to other polar parts on neighboring molecules. Dissolving, how water is better at dissolving. Water dissolves salt because it can attract the ions in salt and pull them apart.
Which of these might be relevant to help us explain the Erosion Investigation results?	Water sticking to itself and other things. Water dissolving other substances.
 Develop models to explain investigation results. Say, <i>Last class, we designed our investigation because we were not sure about the surface features on Mars. Now that we have investigation results, and have modeled some properties of water, let's see if we can connect these two together. Let's try to model how these different substances interact with martian soil to help explain how these features formed.</i> * Display slide V. Tell students to use the molecule cutouts from <i>Molecule Cutouts</i> to help them think about which liquid would have the greatest impact on the landscape based on differences in polarity and differences in the resulting force interactions with neighboring particles. Encourage students to move the cutouts around on their desks or tables and talk through what is happening with their partners as they do so. Have students do this to help them explain both why some liquids might cause more erosion and why other liquids cause less erosion.	
ASSESSMENT OPPORTUNITY	What to look/listen for in the moment: - Students use investigation data to develop models, which includes how water erodes surface materials because water molecules are polar (an idea that originated in <i>Electrostatics Unit</i>). (SEP: 2.4; DCI: PS1.A.3) - Students relate patterns in investigation data to patterns in molecular models. (SEP: 2.4; CCC: 1.1) What to do: As students work, circulate and ask a few students to explain what they are doing. Specifically, ask students to use the arrows and molecular structures to show force interactions between molecules. Ask students which molecules might exhibit stronger forces or a greater number of force interactions on neighboring particles, and why. In the next activity, you will lead a discussion highlighting these differences in order to motivate the next lesson on molecular charge distribution and bond polarity. Building toward 4.B.1 Observe patterns at multiple scales to support movement between multiple types of models that use molecular and submolecular structures that explain the properties of matter like water. (SEP: 2.4; DCI: PS1.A.3; CCC: 1.1, 6.2)

9 · NAVIGATE

2 min

MATERIALS: *Erosion Investigation*

Navigate. Display **slide W** and have students answer question 6 on *Erosion Investigation*.

End of day 2

10 · NAVIGATE

3 min

MATERIALS: None

Navigate. Display **slide X** and discuss the prompts as a class.

Suggested prompt	Sample student response	
<i>What have we figured out about how water does what it does?</i>	Water is polar. The charges on water help it attract other particles.	
<i>Do we think water could do the same things on Mars that it does on Earth?</i>	Maybe, if the soil is similar? We don't know what Martian soil is made of. We don't know if water does this for all materials.	

Celebrate that students are willing to share uncertainty. Tell them that surfacing what they do not know is as valuable as surfacing what they do know. Tell students, *I have a resource here that might help answer some of your questions.*

11 · COMPLETE A READING

10 min

MATERIALS: *Mars Geologic Landforms*

Complete a reading. Display **slide Y** and distribute *Mars Geologic Landforms*. Have students read with a partner and work together to answer the questions in the reading.

ADDITIONAL GUIDANCE	This reading and the modeling activity will be debriefed during the Building Understandings Discussion that follows the modeling activity. You do not need to spend time debriefing the reading here unless there are student questions or misconceptions that will hinder them in the modeling activity.
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12 · RETURN TO MOLECULAR MODELS OF WATER

8 min

MATERIALS: *Mars Geologic Landforms, Molecule Cutouts*

Return to molecular models of water. Display **slide Z** and distribute the molecule cutouts from *Molecule Cutouts* again. Tell students, *This time, I want you to focus on freezing water. See if you can figure out why water expands and causes these bumps when it freezes.* Tell students to start by thinking about what happens to particle motion and arrangement when liquid freezes. Help them recall from *Polar Ice Unit* that water molecules' speed will slow down as water turns to ice. Then remind students to use the molecule cutouts and to pay attention to the charges shown on water. Ask students to consider how those charges might affect the arrangement of water molecules as they slow down.

Encourage students to use the reading to help them, and to explain their thinking to their partner as they use the molecule cutouts to model expansion and frost heaving.

ALTERNATE ACTIVITY

If students struggle, help them get started by thinking about charges and what would make water molecules attract to one another.

If students quickly figure out how to model frost heaving and have extra time, encourage them to also try to model how water creates meanders and oxbow lakes.

13 · BUILD UNDERSTANDINGS OF WATER'S PROPERTIES AND CONNECT TO M-E-F POSTER

9 min

MATERIALS: science notebook, *Mars Geologic Landforms*, *Molecule Cutouts*, “Water’s Importance for Life and Chemical Reactions” poster from Lesson 2, M-E-F poster from *Electrostatics Unit*, expansion panels and arrows for the M-E-F poster



Build consensus around why water behaves differently than other liquids. Have students move into a Scientists Circle and display **slide AA**. Lead a discussion around *Mars Geologic Landforms* and the freezing models. Ask a few partners to share their models and ideas about why water expands when it freezes and causes frost heaving. Listen for language around “pulls” and “attracts” as students share their ideas and models. Ideas may include “what” or “why” types of reasoning. Push students toward explaining why water is so different from other substances. *

Suggested prompt	Sample student response
<i>Why did the water interact with and move the Mars-like material, while other liquids did not?</i>	We think it might have something to do with water’s polarity.
<i>What about the polarity and structure of water molecules makes it expand when it freezes?</i>	The opposite charges line up. Regions of different polarity in each water molecule are attracted to each other. The molecules are arranged by charges so they end up farther apart than in a liquid.
<i>What determines whether a molecule is polar or not?</i>	Maybe the shape. If it has a positive or negative end. The polar molecules we saw all had oxygen.

* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

Use a framing of “what versus why” to guide this conversation. Students simply may be describing what happened in the investigation, like, “Water eroded more.” That is not sufficient. Press students for the “why” parts of their models. Encourage students to share the molecular-scale parts of these models. Remind students that in *Electrostatics Unit* they learned about forces between charges and about water’s polarity.

* SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Help foreground the different scales we considered and connected in this lesson and the last by reminding students that we initially wanted to explain a surface feature on Mars. This surface feature was evidence of some sort of change in matter on a very large scale – since canyons or stream beds can be on the order of kilometers long. Add that once we carried out our investigation in the lab, which was at a much smaller scale, we decided that we needed to go down to an even smaller scale, the particle level, to explain the differences in our results.

Make an explicit reference to element **CCC: 1.1** at this point, and emphasize that this sort of thinking is what we use to try to connect explanations across different scales:

- *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.*

ASSESSMENT OPPORTUNITY

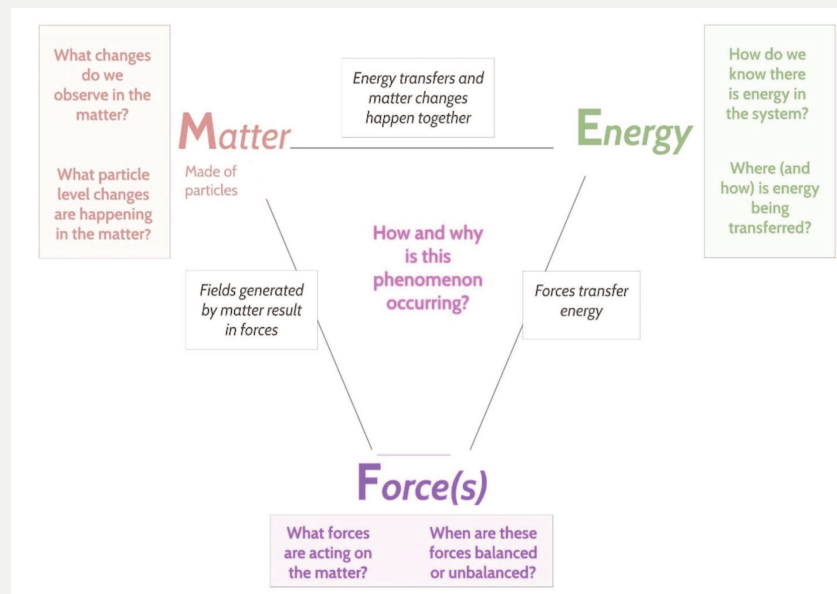
What to look/listen for in the moment:

- Students use the reading and molecule cutouts to develop models that include: as water freezes, the molecules line up, resulting in its expansion; this leads to cracks in the ground (experimental level). (SEP: 8.2; CCC: 6.2)
- Students reason that:
 - the “pull” of water on surface materials is due to its polarity, and
 - water expands when it freezes because the molecules arrange themselves in a regular pattern, due to its polarity. (DCI: PS1.A.3)

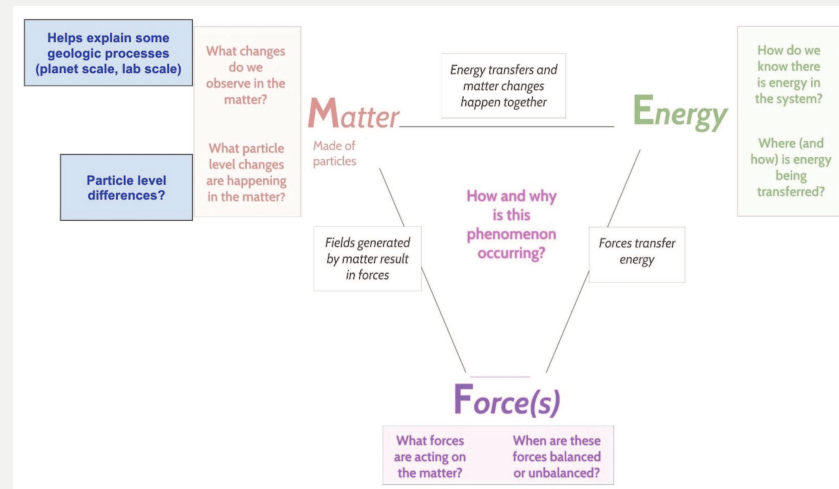
What to do: Push students to explain how both the investigation and the reading informed their models, and if they cannot do so, encourage them to find specific text from the reading that can inform and support their models.

Building toward 4.C.1 Compare, integrate, and evaluate information from a reading, models, and an investigation to explain how water's polarity results in its unique bulk properties. (SEP: 8.2; DCI: PS1.A.3; CCC: 6.2)

Have the M-E-F poster from the prior unit, *Electrostatics Unit*, visible at the start of this discussion. As you reference and add panels and arrows to it, recap how we used thinking related to the Matter and Forces sections of the poster throughout this lesson.

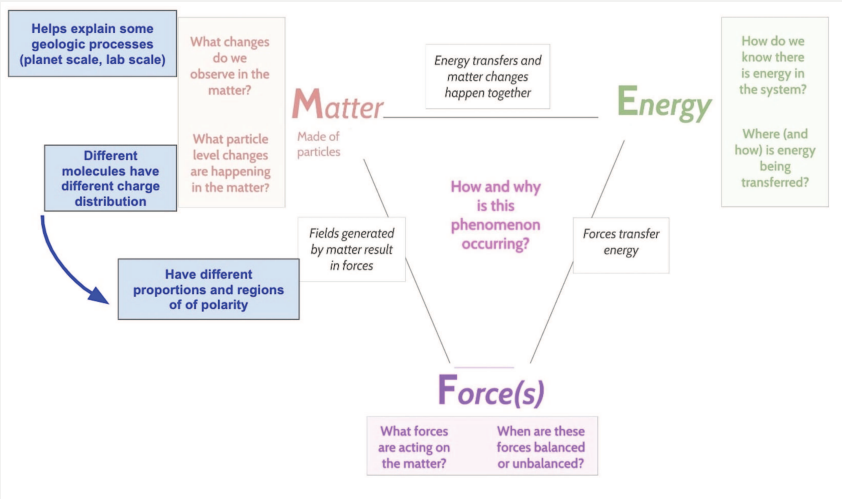


Attach the first two corresponding expansion panels shown. Emphasize that the question mark after “Particle-level differences?” indicates that we wondered if going down to the particle level could help better explain the changes in matter at a scale we can see. *

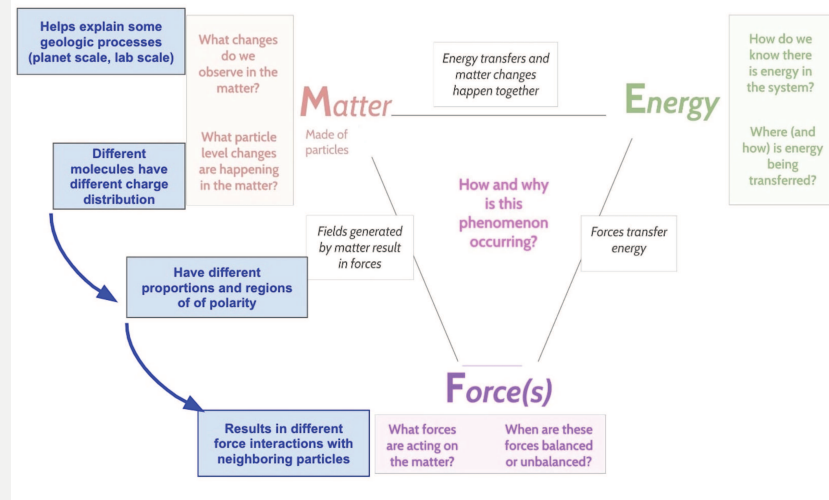


Replace (or overlay) the panel that says “Different molecules have different charge distribution” where the panel “Particle-level differences?” was, and remind students that this was the first thing we noticed that was different about the molecules of the different liquids.

Then remind students that from this we recognized something about the fields being generated around some parts of these molecules. Add the panel “Have different proportions and regions of polarity”. Emphasize as you do this that you are putting this next to “Fields generated by matter result in forces” to remind us that the red/blue coloration we saw on the molecules was a way to visualize the fields being produced at this scale. Add an arrow to reinforce the connection between these two ideas.



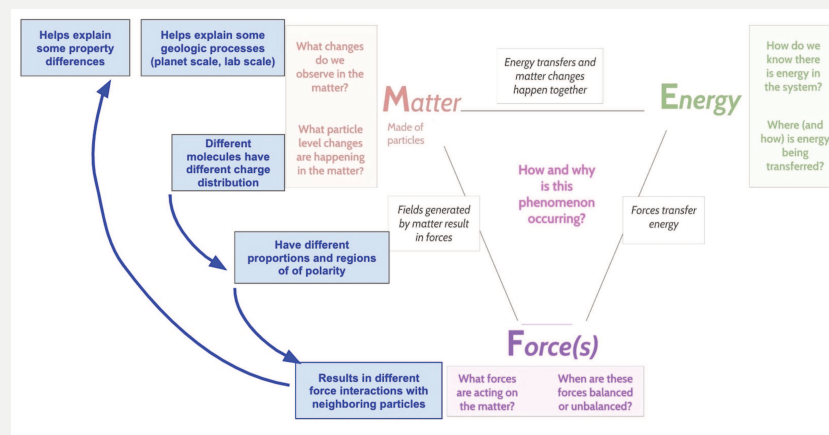
Now reference the Forces section of the poster, and emphasize that once we knew about these differences in fields, we started reasoning about how this would affect the force interactions between the molecules and other molecules near them. Add the panel “Results in different force interactions with neighboring particles”. Add the second arrow shown.



Point to the “Water’s Importance for Life and Chemical Reactions” poster from Lesson 2. Emphasize that force interaction thinking allowed us to start to explain some property differences in the liquids from the prior lesson, such as cohesion, adhesion, and surface tension.

Remind students that we decided that some of the property differences of water that we could see evidence of at a droplet or capillary-tube scale might be relevant to some of the differences we observed at a larger geologic scale, like the structure of the surface features that are formed when liquids flow over the surface of a moon or planet or when there is frost heaving below the surface.

Add the “Helps explain some property differences” panel and the last arrow.



Emphasize that the connections we made in this lesson on this half (Matter and Forces) of the M-E-F poster may be a helpful reference to return to in future lessons.

14 · UPDATE PROGRESS TRACKERS

5 min

MATERIALS: science notebook

Update Progress Trackers. Pause and give students five minutes to add these new ideas from their investigations and models to their Progress Trackers. Display **slide BB**. A sample Progress Tracker entry can be found in *Progress Tracker Key* from Lesson 2.

15 · COMPLETE AN ELECTRONIC EXIT TICKET AND NAVIGATE

10 min

MATERIALS: computer with internet access

ADDITIONAL GUIDANCE

See *Electronic Exit Tickets* for instructions on how to make the Electronic Exit Ticket using https://docs.google.com/forms/d/16uO5Lw_DiVaXHLQ6lhQY-O2Dv_vEiSDC-RIRnV422-s/copy.



Complete an exit ticket. Display **slide CC** and have students complete the Electronic Exit Ticket.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use **models** to make predictions about **bulk properties of substances**. (SEP: 2.4; DCI: PS1.A.3)
- Students relate a **substance's polarity to its ability to create erosion and frost heaves**. (CCC: 6.2)
- Students use **patterns in data** and **models** as **evidence to support their predictions**. (SEP: 2.4; CCC: 1.1)

What to do: See *Exit Ticket Key* for answers and explanations to the exit ticket questions, as well as how to support students during and after the exit ticket.

Building toward 4.B.2 Observe **patterns at multiple scales** to support **movement between multiple types of models** that use **molecular and submolecular structures that explain the properties of matter like water**. (SEP: 2.4; DCI: PS1.A.3; CCC: 1.1, 6.2)

The following section is an end-of-lesson navigation that will require about two minutes. If you are short of time, you can delay this navigation until the start of Lesson 5 – where similar questions are built into the start of that lesson.

If you do have time, problematize the lack of actual water on Mars's surface. Remind students that the images they have observed are of dry river beds. Ask students, *What happened to the water that formed these dry river beds? Where else besides the parts of the surface we examined might water be found on the planet now? Where else can it be found on Earth besides the surface?*

If students mention ice caps, follow up with the question, *Where else can water be found on Earth or where else could we look for it in these places beyond Earth?* Listen for ideas such as:

- Underground; we can send probes or drill for water.
- In the atmosphere; if we can see something like clouds, it might help us find water.

Suggest that we follow up on investigating these other parts of the planetary and moon systems next time.

Remove the expansion panels and arrows from the M-E-F poster if this is not the last class you are teaching.

LESSON 5: How can we tell what is in the atmosphere (and just below the surface) of objects in space?

PREVIOUS LESSON We investigated how liquids interact with surface materials and argued that surface features on Mars were likely made by water. We wondered what makes water different from other liquids and examined molecular models of them to compare their polarities. We read about how water causes surface features through erosion and freezing, and we modeled these processes. We completed an Electronic Exit Ticket.

THIS LESSON

INVESTIGATION

2 days

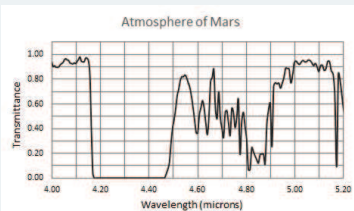


Image created using NASA Planetary Spectrum Generator (<https://psg.gsfc.nasa.gov/>)

We recall experiences with the interaction of sunlight with the air or clear materials. We build and use a projector-based spectrometer to investigate the absorption and transmission of light by solutions of pure substances and construct a way to graphically display this phenomenon. We examine infrared spectra of three gasses. We use reference spectra to identify gasses in simple mixtures and in the atmospheres of objects in space. We read about other ways spectroscopy is used to identify substances on objects in space.

NEXT LESSON We will examine element cards in order to develop an initial element tool. We will determine how many bonds or charges each element can form. The patterns we identify will help us create a class consensus model for an element tool.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, HS-ESS1-2, HS-ESS2-1, HS-ESS2-5



WHAT STUDENTS WILL DO

5.A Analyze, compare, and integrate empirical evidence to identify patterns in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer scientific questions about how we can identify which locations have the substances or elements needed to live and work in space. (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)

WHAT STUDENTS WILL FIGURE OUT

- Different substances absorb and transmit different colors of visible light and different wavelengths of non-visible light (e.g., infrared).
- Spectroscopy is the study of the light that is transmitted or emitted by different objects and is used to determine the presence of different gasses.
- Scientists can perform spectra analysis on the interactions of solids with sunlight to determine the presence of substances in the soil or ice.

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Lead a class discussion to recall where water was on Mars in the past and brainstorm other places to look for water on an object in space.	A-B	
2	3 min		CONSIDER CONNECTED EXPERIENCES Have students share experiences with Earth's atmospheric color as a class.	C	
3	6 min		OBSERVE SUNSET FROM THE ISS Orient students to the relative positions of objects in a video of sunset from the ISS, watch the video, and facilitate the sharing of observations as a class.	D-F	https://youtu.be/FoqKTkEGLa4
4	2 min		DEMONSTRATE DIFFRACTION Introduce the idea of spectra, poll students' experiences with this phenomenon, and demonstrate it using a projector.	G-H	Diffraction Demonstration
5	10 min		INVESTIGATE THE TRANSMISSION OF DIFFRACTED LIGHT BY SUBSTANCES Lead a demonstration to investigate the transmission of diffracted light by three unknown substances.	I-J	Light Spectra Demonstration Part I
6	4 min		DISCUSS PATTERNS IN TRANSMITTED LIGHT Lead a class discussion about the patterns students observed for the light transmitted through solutions of substances.	K	<i>Spectrum Observations</i>
7	7 min		GRAPH RELATIVE LIGHT INTENSITY VERSUS COLOR Co-construct a qualitative graph of light intensity versus light color for water and sample C. Have students add <i>transmission spectrum</i> and <i>spectroscopy</i> to their Personal Glossaries.	L-M	Light Spectra Demonstration Part II
8	5 min		ANALYZE TRANSMISSION SPECTRA OF DIFFERENT GASSES Have students turn and talk with a partner to analyze the transmission spectra of three gasses in Earth's atmosphere.	N	
9	3 min		NAVIGATE Have students individually complete an exit ticket.	O	sheet of loose-leaf paper
<i>End of day 1</i>					
10	5 min		NAVIGATE Lead a class discussion about how to use transmission spectra.	P	
11	8 min		ANALYZE AND INTERPRET TRANSMISSION SPECTRA FOR GAS MIXTURES Have students work with a partner to determine the composition of gas mixtures from reference spectra.	Q	<i>Transmission Spectra Library, Analyze Unknown Gasses</i>

Part	Duration		Summary	Slide	Materials
12	5 min		SHARE TRANSMISSION SPECTRA ANALYSIS Have partners share their transmission spectra analysis. Lead a class discussion around the strategies students used in their analysis.	R-S	<i>Transmission Spectra Library, Analyze Unknown Gasses</i>
13	15 min		ANALYZE SPECTRA FOR SPACE OBJECT ATMOSPHERES Analyze and interpret atmospheric spectra for objects in space with a partner using reference spectra. Have students work with a new partner to complete <i>Analyze Atmospheric Spectra</i> .	T-W	<i>Transmission Spectra Library, Analyze Atmospheric Spectra</i>
14	10 min		READ ABOUT OTHER WAYS TO FIND WATER WITH SPECTROSCOPY Have students individually read a set of excerpts from research papers about using spectroscopy to find substances in space.	X-Z	<i>Space Spectroscopy Studies</i>
15	2 min		NAVIGATE Have students add an entry to their Progress Tracker.	AA-BB	

End of day 2

Lesson 5 • Materials List

	per student	per group	per class
Diffraction Demonstration materials	science notebook		- diffraction grating - painter's tape - tabletop projector - C.3 Lesson 5 Transmission Spectra (optional)
Light Spectra Demonstration Part I materials	<i>Spectrum Observations</i> - indirectly vented chemical splash goggles - nitrile gloves - non-latex apron		- water sample - solutions of substances A-C - tabletop projector - diffraction grating - painter's tape - small box or book - C.3 Lesson 5 Transmission Spectra (optional)
Light Spectra Demonstration Part II materials	<i>Spectrum Observations</i> - science notebook		2 large pieces of grid paper prepared with <i>Spectrograph Grid Paper</i> - tape - chart paper markers - samples of water and solution C - tabletop projector - diffraction grating slide (between slide H and I)
Lesson materials	<i>Spectrum Observations</i> - sheet of loose-leaf paper - science notebook <i>Transmission Spectra Library</i> <i>Analyze Unknown Gasses</i> <i>Analyze Atmospheric Spectra</i> <i>Space Spectroscopy Studies</i>		https://youtu.be/FoqKTkEGLa4

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.

Test <https://youtu.be/FoqKTkEGLa4> to make sure you can play the video.

Make color copies of, or give students digital access to, the following handouts and reference:

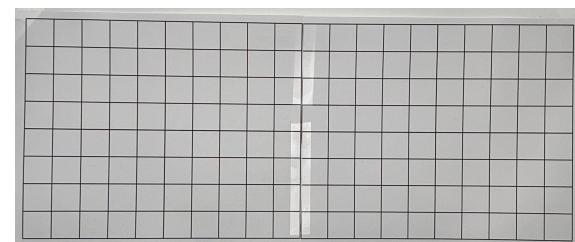
- Spectrum Observations*
- Transmission Spectra Library*
- Space Spectroscopy Studies*

Day 1: Diffraction Demonstration

- **Group size:** Whole class
- **Setup:** Gather the materials and have the tabletop projector located in a place in the classroom where the projection will be visible to the whole class. Have a computer connected to the tabletop projector with the white line slide projected. This is the slide in the slide deck between slide H and I.
- **Safety:**
 - Wear sanitized indirectly vented chemical splash goggles, nitrile gloves, and non-latex apron during the setup, hands-on, and takedown segments of the activities.
 - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
 - An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
 - Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
 - Hand sanitizer wipes must be provided for participant use at the completion of the activities.
 - Clean up any spills immediately using spill control containers for overflow of products produced. Oil spills require special attention.
 - Do not ingest any of the liquids used in the lab.
 - Before starting the activity in a darkened instructional space, remove any fragile equipment/furniture, sharps, etc. in the activity walkway to prevent trip/fall hazards.
 - Take care when taping and removing the diffraction grating slide to/from the tabletop projector to avoid burns as the light can get hot.
 - Do not put your face over an open chemical container. Chemicals used are harmful if ingested and can irritate skin.
 - Never consume any liquid in the lab for any reason.
 - Follow procedures set up by the instructor for disposal of materials.
 - Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
 - Any electrical cords must be off the floor to prevent trip/fall hazards.
 - Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
 - Direct supervision will be required during all aspects of these activities.
- **Disposal:** Dispose of tape in the trash.
- **Storage:** The diffraction grating can be stored and used again.

Day 1: Light Spectra Demonstration Parts I and II

- **Group size:** Whole class
- **Setup:** Gather the materials using the instructions found in *Spectra Demonstration Setup*. Prepare 2 large pieces of grid paper by printing 4 copies of *Spectrograph Grid Paper* in landscape orientation. Then, trim the margin off one short side of 2 pages. Use clear tape to attach the trimmed edge to an unaltered piece of grid paper to create one large sheet of grid paper. Repeat with the remaining pieces. See image below.
- **Notes for during the investigation:** Take a photo of the spectrum obtained for light passing through the diffraction grating without any sample, which you will use as the background spectrum in *Spectrum Observations*. Create this handout for your class by adding the image of your projected spectrum to each row. Use a digital copy of *Spectrum Observations* as a template. If your projected visible spectrum is not markedly different from the one in *Spectrum Observations*, you can use what is already in the handout.
- **Safety:**
 - Wear sanitized indirectly vented chemical splash goggles, nitrile gloves, and non-latex apron during the setup, hands-on, and takedown segments of the activities.
 - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
 - An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
 - Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
 - Hand sanitizer wipes must be provided for participant use at the completion of the activities.
 - Clean up any spills immediately using spill control containers for overflow of products produced. Oil spills require special attention.
 - Do not ingest any of the liquids used in the lab.
 - Before starting the activity in a darkened instructional space, remove any fragile equipment/furniture, sharps, etc. in the activity walkway to prevent trip/fall hazards.
 - Take care when taping and removing the diffraction grating slide to/from the tabletop projector to avoid burns as the light can get hot.
 - Do not put your face over an open chemical container. Chemicals used are harmful if ingested and can irritate skin.
 - Never consume any liquid in the lab for any reason.



- Follow procedures set up by the instructor for disposal of materials.
- Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
- Direct supervision will be required during all aspects of these activities.
- **Disposal:** Microchemistry solution bottles can be stored for later use. Ensure that they remain sealed and in a location where students will not have access. If you dispose of the solutions, follow the instructions in the material data safety sheets (SDS).
- **Storage:** The diffraction grating slide can be stored and used again.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students use light spectra to determine the presence of specific elements on objects in space. Students coherently build ideas related to the following disciplinary core ideas:

- **ESS1.A: The Universe and Its Stars.** The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.
- **PS4.B: Electromagnetic Radiation.** Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities.

Crosscut explanation: [ESS1.A.2](#) and [PS4.B.4](#) are fully developed in High School Physics *OpenSciEd Unit P.6: Why do stars shine and will they shine forever? (Stars)*.

Students leverage middle school understandings of stars, light, and color developed in the Middle School *OpenSciEd Unit 8.4: How are we connected to the patterns we see in the sky and space? (Space Unit)*. Additionally, students may bring in prior knowledge about non-visible light (e.g., infrared light) from High School Chemistry *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*.

Students share their prior experiences about changes in the color of Earth's atmosphere. Data collected from a demonstration using solutions of pure substances is used to help support students in developing understanding around the relationship between atoms and spectra for identification ([SEP: 4.1](#)). The data of water and one unknown solution is transformed into a graph to allow students to better identify patterns in the data ([CCC: 1.5](#)). Students then apply their understanding to evaluate transmission spectra of gasses found in Earth's atmosphere ([SEP: 4.1](#); [CCC: 1.5](#)). This understanding is applied a third time when analyzing atmospheric transmission spectra from solar system objects ([SEP: 4.1](#); [CCC: 1.5](#)). Students then read excerpts from peer-reviewed journal articles about other applications of transmission spectra analysis, including using other types of light spectra and interactions of solid materials with sunlight ([SEP: 8.2](#)). Emission light spectroscopy is mentioned in the excerpts, but is not a focus of this lesson.

Students engage in [SEP: 4.1](#) and [8.2](#) partially. For [SEP: 4.1](#): *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.* Students will fully develop crossed-out portions of this element in High School Chemistry *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*. For [SEP: 8.2](#): *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.* See this section in Lessons 2 and 4 for discussion of development of this element.

Students fully engage in [CCC: 1.5](#): *Empirical evidence is needed to identify patterns.* Students may need additional support in realizing that the data they collected and analyze are examples of empirical evidence. You may point this out to them as they engage with [CCC: 1.5](#) throughout the lesson.

In this lesson, students will co-construct a definition for the following words, which they should add to their Personal Glossaries: *visible spectrum, transmission spectrum, spectroscopy*. Terms should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Although the diffraction of white light into multiple colors is part of the demonstrations, students are not expected to develop a mechanistic understanding of this phenomenon. Diffraction is developed in High School Physics *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*. Additionally, although methane is used as one of the reference spectra, its impact on Earth's climate will not be addressed until *Fuels Unit*.

Students will build a partial model for spectroscopy and light in this lesson. Understanding is limited to transmission spectra, although the excerpts students read mention emission spectra. In this lesson, student understanding of spectroscopy is limited to the interaction of a substance with light as a unique property of a substance. Other applications of spectra and atomic spectra in particular (as opposed to molecular) will then be explored in High School Physics *OpenSciEd Unit P.6: Why do stars shine and will they shine forever? (Stars)*.

Discussion of wavelength is limited to the numerical value which corresponds to a color of visible light. Students also examine some spectral graphs that show numerical values of infrared light, but there is no further development of understanding of infrared light beyond what students developed in High School Chemistry *Polar Ice Unit*. In-depth development of the electromagnetic spectrum is covered in High School Physics *Microwave Unit*.

A detailed explanation for the absorption and transmission of particular wavelengths of light based on electronic transitions in the atom is beyond the scope of the unit and is beyond the targets for NGSS for high school. Because of this, students do not need to know the distinction between atoms absorbing or emitting light versus the constituent molecule they compose absorbing and emitting light.

LEARNING PLAN for LESSON 5

1 · NAVIGATE

5 min

MATERIALS: None

Navigate to the lesson by considering where we left off. Show slide A and use the prompts on the slide to facilitate a brief discussion.

Suggested prompt	Sample student response
<i>What did we figure out about finding water on Mars?</i>	We figured out that some of the surface features on Mars could have been created by flowing or freezing water. Water's properties, like polarity and expanding on freezing, can explain why those features formed.
<i>What are some limitations of our model?</i>	We didn't explain clouds or water in the air.
<i>Where else on Mars, besides on the surface, could we look for water?</i>	We could also find a way to figure out what's in a planet's or object's atmosphere (if they have one). We could drill down to see if water is under the surface, but we would have to go there to do it.

Discuss substances in atmospheres. Display slide B. Say, *Water is pretty important for our survival in space, but it's not the only substance we will need. Take a minute to turn and talk with a partner about the prompts on the slide.* After students have had a few minutes to discuss the prompts, invite students to share their ideas.

Suggested prompt	Sample student response
<i>What substances do we need that we might find in the atmosphere of a moon or planet?</i>	We definitely need oxygen to breathe! Carbon dioxide to hold in heat. Don't plants need nitrogen?
<i>How could we determine what substances are in an atmosphere?</i>	We could capture a sample of the atmosphere. We could test the properties of the gasses in the atmosphere. Accept all responses.

Say, *These are all great ideas! As we have discovered, it's challenging to send a mission into space, especially to places that are really far away. Scientists have figured out how to determine the composition of atmospheres using light and how it interacts with matter.*

2 · CONSIDER CONNECTED EXPERIENCES

3 min

MATERIALS: None

Share experiences with Earth's atmosphere. Display **slide C**. Remind students that our own atmosphere contains different gasses and particles, is about 96 km (60 mi) thick, and becomes less dense farther from Earth's surface. Suggest that our experiences with Earth's atmosphere might give us some ideas for how to figure out what other atmospheres are made of. Ask students to share their responses to the prompt on the slide.

Suggested prompts	Sample student responses	Follow-up questions
<i>Have you ever seen the color or brightness (intensity) of the sky change because of what was in the air?</i>	Pollution/smog makes the air hazy. Wildfires last summer made the air hazy and dangerous to breathe. Sunrise and/or sunset.	<i>Is that a change in intensity or color, or both?</i>

After a few students have shared their ideas, say, *I heard some of you mentioning sunrises or sunsets. If Earth's atmosphere wasn't there, would they look the same? Scientists have been able to determine just that from the International Space Station.*

3 · OBSERVE SUNSET FROM THE ISS

6 min

MATERIALS: <https://youtu.be/FogKtEGLa4>

Orient to sunset from the International Space Station (ISS). Remind students that the International Space Station (ISS) was on one of the mission cards they explored in *Space Missions Deck* during Lesson 1, and that it orbits Earth at an altitude of 330 km, well above Earth's atmosphere. Display **slide D** and use the diagrams on the slide to orient students to how the path of the sunlight they will see changes over the course of the video. It may be helpful to tell students to think of the video as being filmed from the rear window of the ISS as it orbits Earth at 28,000 km/h.

Watch the video of sunset from outer space. Share **slide E** and ask students to observe how the light from the Sun changes in color and intensity as it appears to set in the video. Play the entire video and expand it to fit the screen. At the beginning of the video, point out the thin blue glow that is Earth's atmosphere. Students may recognize this video from the *Middle School OpenSciEd Unit 8.4: How are we connected to the patterns we see in the sky and space? (Space Unit)*.

ADDITIONAL GUIDANCE

In the video, students will see some ray, rainbow, and polygonal artifacts around the bright light of the Sun due to lens flare. If students get distracted by this, explain that this is something that would not be seen with the naked eye but is due to the scattering of light by the camera's lens. Redirect students to focus on the color and intensity changes that occur between the 0:55 and 1:00 minute marks.

Discuss observations of how sunlight changes. Say, *The ISS is moving really fast, so that sunset happens quickly! I have a slide with still images at six points in time for us to look at.* Display **slide F** and discuss your observations as a class. Ask students to refer to specific images by number and connect their observations back to the position of the Sun and the path of sunlight. Revisit **slide D** as needed.

Suggested prompts	Sample student responses	Follow-up questions
<i>How would you describe the sunlight toward the start of the video?</i>	It starts out pretty white in image 1 and maybe a little yellow. The light is less intense from image 1 to 2 as the Sun moves behind Earth.	<i>Is the sunlight passing through Earth's atmosphere at that point?</i> <i>Is it the Sun that is moving so fast or is it us?</i>
<i>As the ISS moves farther around Earth, how does the light change?</i>	The light is less and less intense as more of the Sun is obscured by Earth. And as that happens, the color of the light becomes more orange in image 3 and even reddish in images 4 and 5.	<i>Is Earth itself the only thing obscuring the Sun's light?</i> <i>How does the path of the sunlight change as we see its color change from orange to red?</i>

Say, So the Sun's light looks really white or even blue from space, and when it interacts with things like our atmosphere, it might not stay white. Let's get a source of white light and see if we can understand some of these color and intensity changes; maybe it could help us figure out what substances are in different atmospheres.

4 · DEMONSTRATE DIFFRACTION

2 min

MATERIALS: Diffraction Demonstration

Poll students' experience with separating white light into a rainbow of colors. Show **slide G**. Explain that over the centuries, people and scientists noticed that when white light (like light from the Sun) passes through clear materials like glass or water droplets, it forms a rainbow of colors called a spectrum.* Ask students to raise their hands or indicate agreement in another way if they have ever experienced something similar. If time permits, you can ask a few students to share those experiences. Hold up the diffraction grating slide and say, *Phenomena like those led scientists to develop materials, like this diffraction grating slide, that break white light into its component colors. Let's try it out.*

Demonstrate the diffraction of white light. Explain to students that you have a projector with an intense white light that you will use to demonstrate diffraction. Display **slide H** and ask students to be ready to notice what happens when the white light from the projector passes through the diffraction grating slide.

ALTERNATE ACTIVITY

If you do not have access to the materials for the Diffraction Demonstration, use the images provided in C.3 Lesson 5 Transmission Spectra.

* ATTENDING TO EQUITY

Supporting Emerging Multilingual Learners. The plural of most words in English is simple: you just add an -s or -es to the end. However, "spectra" is the plural form and "spectrum" is the singular. This is an uncommon pattern in everyday English, although it is more common in biology and chemistry. It can be useful to teach spectra / spectrum as a pair of words so that students know they refer to the same thing. This -a / -um pattern is also true for a few other words students may have encountered by 10th grade:
bacteria / bacterium
mycelia / mycelium (related to fungus)
fora / forum

Darken the room and project the slide that follows slide H with your tabletop projector. Adjust the focus so the slit looks sharp.



Use painter's tape to attach the diffraction grating in front of the projector's lens.



You should see the narrow slit directly in front of the projector with mirror image rainbows on either side.



Ask, *What do we notice about the white light from the projector when it passes through the diffraction grating?* Ask a few students to share their noticings. Tell them that scientists refer to the colors we see in the rainbow as the visible spectrum. Turn on the lights and give students time to add *visible spectrum* to their Personal Glossaries.

5 • INVESTIGATE THE TRANSMISSION OF DIFFRACTED LIGHT BY SUBSTANCES

10 min

MATERIALS: Light Spectra Demonstration Part I

ADDITIONAL GUIDANCE

Demonstration instructions can be found on *Spectra Demonstration Setup*.

Prepare to view visible spectra for solutions of substances and water. Tell students that you have solutions of three different substances, and plain water, for the class to investigate and hold up the bottles of each substance for the class to observe. Display **slide I**, read the prompt aloud, and ask students to discuss it with a partner. Bring the class back together and use the prompts below to facilitate a quick share out.

Suggested prompts	Sample student responses	Follow-up questions
<i>If we hold one of these solutions A, B, C, or plain water in front of the light source, how will the visible spectrum projected on the wall change?</i>	Sample A is pretty dark blue so it will probably absorb a lot of light. The spectrum on the wall will look darker. From elementary school we know that the color we see with our eyes is what is reflected off something, and the other colors are absorbed, so maybe sample A absorbs all the colors but blue?	<i>So I hear you saying that the intensity will decrease, but what about the color?</i> <i>What do we mean when we say something absorbs light?</i>
<i>What did you think we would see for the other samples?</i>	Sample C looks light green/yellow so maybe it absorbs some of the other colors? Sample B is really light, it looks like water.	<i>Can we hear from a pair that thinks we will see something different?</i> <i>Oh yeah, these are solutions of pure substances in water!</i>
<i>Should we also test plain water? What will that tell us? *</i>	Well, all of the samples have water in them so we should make sure we know if/how water affects the visible spectrum.	<i>Does anyone remember what we call that kind of a test?</i>

Discuss how to record observations. Distribute a copy of *Spectrum Observations* to each student. Display **slide J** and explain that for each sample, there is a row with a faded version of the visible spectrum with the colors written below.* Instruct students to use a pencil to mark the changes they see when the sample is placed in front of the light source. Point out that there is also a place to write down other notes or observations.

* SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

You may elaborate or expand this section to include investigation design as desired. It is not a focal component of this lesson, but many students may benefit from revisiting “control” procedures and thinking through their findings. ([SEP: 3.1](#))

* ATTENDING TO EQUITY

Universal Design for Learning: The language underneath each spectrum indicates the name of the color to support students who are color-blind, but the labels also serve a broader purpose. Using the words under the spectra can be helpful to students who are learning English and can help the class have a discussion using shared language for blue, indigo, etc. These pieces of information help support *representation*.

SAFETY PRECAUTIONS

An **optional slide** after slide J is included, which shares the related safety considerations for the Light Spectra Demonstration.



 **Observe absorption spectra for water and samples A-C.** Make sure the lights are turned off so students can clearly see changes in the spectra for each sample.

Place a book or box in front of part of the diffraction grating on the projector lens to block the slit and one of the rainbows. Blocking the bright slit helps the eye better see changes in the projected spectrum.



Place the water control in front of the diffraction grating that is taped to the projector lens.



Center it so that the light passes through the center of the sample. If the light passes through the edge of the bottle, the spectrum may look dark or distorted. You may have to reposition the book or box to block the slit and second spectrum.



**ALTERNATE
ACTIVITY**

If you do not have access to the materials for the Light Spectra Demonstration, use the images provided in C.3 Lesson 5 Transmission Spectra.

Give students a few minutes to record their observations about the water control. Students should refer to the spectrum without a sample in the top row of *Spectrum Observations*, in addition to the faded version of that spectrum on each sample row. If necessary, remove and replace the sample in front of the light source so students can compare the light that comes through the sample to the control condition.

Replace the water control with samples A-C, giving students two minutes per sample to record their observations.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **analyze** the **spectra of unknown substances** by **comparing** them to **spectra of known substances**. (SEP: 4.1; DCI: PS4.B.4)
 - Students should notate differences such as position (color) and changes in brightness (intensity of light) between the spectra of the unknown samples and the printed spectra found on *Spectrum Observations*.

What to do: If students are not sure how to describe the differences in words, then encourage them to first shade in areas of their spectrum that look darker than the reference spectrum, and then describe what that represents in words under “other notes/observations.” Some students may benefit from switching back and forth in real time between the water (control) and the substance they are analyzing. This can help make the differences in the spectra more visible.

Building toward 5.A.1 **Analyze, compare, and integrate empirical evidence to identify patterns** in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer scientific questions about how we can identify which locations have the substances or elements needed to live and work in space. (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)

ADDITIONAL GUIDANCE

Students will wonder what the pure substances are in samples A-C. We do not recommend telling students because it introduces distracting information to the Space Survival-focused Storyline. Samples A-C are solutions of metal chlorides from regions of the periodic table that the class will not explore further in this unit, but they are extremely useful in showing how spectra reveal a unique “fingerprint” for substances.

For reference, the spectra observed for the water control and samples A-C in a very dark room are shown.

Water control	Sample A
 Image created using NASA Planetary Spectrum Generator (https://psg.gsfc.nasa.gov/)	 Image created using NASA Planetary Spectrum Generator (https://psg.gsfc.nasa.gov/)
Sample B	Sample C
 Image created using NASA Planetary Spectrum Generator (https://psg.gsfc.nasa.gov/)	 Image created using NASA Planetary Spectrum Generator (https://psg.gsfc.nasa.gov/)

6 · DISCUSS PATTERNS IN TRANSMITTED LIGHT

4 min

MATERIALS: *Spectrum Observations*

Discuss **spectral observations for different solutions**. Show **slide K** and ask students to take a moment to notice similarities and differences in the patterns of light that passed through each solution. Then facilitate a short share out of similarities and differences students noticed.

* SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Discussing the similarities here in the patterns of light students observed will aid students later in connecting the spectral patterns of known substances to unknown substances on *Analyze Unknown Gasses*. (CCC: 1.5)

Suggested prompt	Sample student response
<i>How were the patterns of light that passed through each substance similar? *</i>	Almost all of them had some form of pink or purple. All had green but in different intensities.
<i>How were they different?</i>	The pink/violet in sample C was very distinctive. The red is missing from sample A completely.

Summarize the discussion and say, *I hear you saying that each substance had dark areas but that those appeared in different places (blocking different color light) for different substances. If we tried to represent what we are seeing on a graph, what would that look like?*

7 · GRAPH RELATIVE LIGHT INTENSITY VERSUS COLOR

7 min

MATERIALS: *Light Spectra Demonstration Part II*

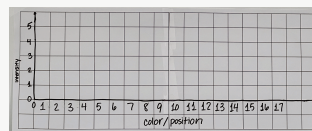
ADDITIONAL GUIDANCE	Be sure to have already prepared the two large pieces of grid paper using <i>Spectrograph Grid Paper</i> and the instructions included in the materials preparation section at the top of the Teacher Guide.
ALTERNATE ACTIVITY	If you do not have access to the materials for the Light Spectra Demonstration, use the images provided in C.3 Lesson 5 Transmission Spectra.

Graph the intensity of light across the visible spectrum. Explain that you have two pieces of graph paper with 1" squares to help us discuss the positions of the colors, and that as a class we will try to determine the relative light intensity we observe with our eyes for each position or square.

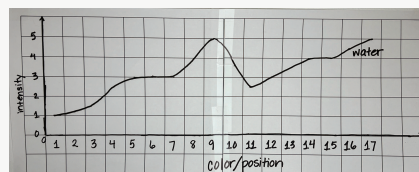
Return to the projector spectrometer, place the water sample in front of the light source, and tape the 1" graph paper on the wall in the middle of the spectrum. Number the squares that have the colors of the visible spectrum on them, starting with 1.



In a location near the projected spectrum, create the axes for an intensity vs. position graph on a second large piece of 1" graph paper or a whiteboard. Add 5 arbitrary levels of brightness to the y-axis and label it 'intensity'. Add the numbered 1" squares from the grid to the x-axis and label it 'color or position'.



Work with students to graph relative intensity points for each numbered square. It may be best to start with the brightest and darkest squares and assign them relative high (5) or low (0 or 1) intensity values. Once the class has assigned values for each numbered square, draw a curve through the points and label it 'water'. Depending on your projector, the graph may look something like this:



ADDITIONAL GUIDANCE

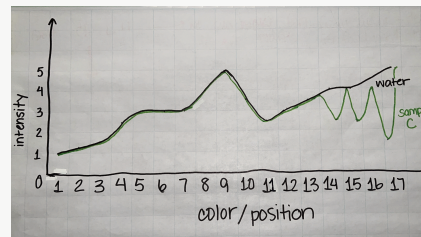
If students suggest using a light meter to measure light intensity versus position and you have one, feel free to give it a try. It is likely that the light meter you have will not be sensitive enough to detect the differences in intensity between bands for samples B and C that our eyes perceive as light and dark. Another option is to use a light meter application on a tablet or smartphone with a camera. A number of light meter apps are available for free.

Predict what an intensity plot for sample C would look like. Display slide L and give students two minutes to turn and talk with a partner about what they think an intensity graph like this would look like across the visible spectrum for light that passes through sample C. Remind students to refer to the observations they recorded on *Spectrum Observations*. If needed, you can place sample C in front of the diffraction grating that is taped to the projector lens.

Graph the intensity of light that passes through sample C across the visible spectrum. Invite partners to share what they discussed. Place sample C in front of the diffraction grating taped to the projector lens. Work with students' ideas to begin adding points for sample C to the intensity vs. position graph, preferably in a different color. It may be helpful to switch between the water control and sample C so students can note areas of difference. The major differences for sample C are in the indigo-purple end of the spectrum; in that region you may want to plot multiple points per numbered square to capture the detail. When you reach a dimmer area, ask students what number square it starts and ends at and how low the intensity drops on your scale of 1 to 5. Once the class has finished adding points, draw a curve through the points with the second color marker and label it 'sample C'. The chart you co-create should look something like this:

Define transmission spectrum. Display slide M and ask students, *What happens to the light as it passes through a substance (like sample C) to give the dark lines we see in the visible spectrum?* Leverage student ideas to come to consensus that the sample absorbs some colors of light while others pass through or are transmitted. Revisit the plots of light intensity vs. position (color of light) and tell students that this type of plot is called a *transmission spectrum*. Explain that the technique that we just used is known as *spectroscopy*. Give students time to add these terms to their Personal Glossaries.

Sample entries are shown below.



Transmission spectrum - a graph of intensity vs. light color (position) that represents the light that is transmitted through a sample.

Spectroscopy - the study of the absorption and emission of light by matter.

Say, *Scientists have collected transmission spectra (the plural of spectrum) for different substances using sensitive detectors to quantitatively measure light intensity with gasses. That is what we want to look for in an atmosphere, right? All you need is a source of light to go through the gas, and there is plenty of starlight to work with in space. Scientists called astronomers and spectroscopists look for patterns, just like you have done. Spectroscopists can detect wavelengths beyond the colors of light we can see with our eyes.*

ADDITIONAL GUIDANCE

OpenSciEd High School Chemistry *Polar Ice Unit* also referred to infrared light when we discussed how wavelengths can be absorbed “in the infrared”. You can also liken this to how dogs hear sounds that are “beyond” human-ear detectable sounds. *Note: This is not an extended lesson on wavelengths; that will be covered in High School Physics OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit).*

8 · ANALYZE TRANSMISSION SPECTRA OF DIFFERENT GASSES

5 min

MATERIALS: None

Analyze and interpret transmission spectra for three Earth gasses. Show **slide N**. Tell students these are the infrared transmission spectra for three gasses commonly found in our atmosphere on Earth: water, carbon dioxide, and ozone. Point out that since we cannot see infrared light, scientists refer to its “colors” using a number–wavelength–that has units of distance (1 micron = 1×10^{-6} m). Ask students to turn and talk with a partner about the similarities and differences they notice between the spectra for the three substances. Be prepared to answer any questions about the spectra and help students connect them to the graph the class co-created for sample C.

Share similarities and differences. Continue to project **slide N** and ask a few students to share some similarities and differences they discussed with their partner. Invite students to point out specific features on the projected spectra as they share out. Look for students to note the following:

- Different gasses transmit different wavelengths of light.
- The level of transmittance (intensity of light transmitted) is different at different wavelengths.
- The shape of peaks can be broader or sharper.

MATERIALS: sheet of loose-leaf paper



Assign an exit ticket. Share slide O and ask students to respond to the prompts on the slide on a sheet of loose-leaf paper.*

* ATTENDING TO EQUITY

Universal Design for Learning: Asking questions that tie back to the unit's "big question" is important for building coherence for learners and supporting *engagement*. A sense of coherence means that students know the purpose for their learning and it contributes to a broader motivation for learning, thereby increasing the ways students *access* the materials. Engaging students with the big question throughout the unit can also help them sustain effort and build resilience.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students identify and use **patterns** in **spectra of known substances** (**empirical evidence**) to **identify unknown substances**. (DCI: PS4.B.4; CCC: 1.5)

What to do: It is important that at this point in the lesson, students begin to connect how spectral lines and graphs of known substances can be used to identify unknown substances. If students do not make this connection, prompt them to think about how we could use the two sets of empirical data to make inferences about unknown substances. Ask, *How could we use the spectral graphs of the three gasses on Earth to help us identify the unknown samples we previously examined?*

Building toward 5.A.2 Analyze, compare, and integrate **empirical evidence** to **identify patterns** in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer **scientific questions** about **how we can identify** which locations **have the substances or elements needed** to live and work in space. (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)

End of day 1

10 · NAVIGATE

5 min

MATERIALS: science notebook

Discuss how we might use transmission spectra data. Display slide P.

Suggested prompt

How might this technique be used to determine what is in a mixture of gasses that make up an atmosphere?

It sounds like we get a pattern of transmitted light that is unique to a particular substance, like a signature or fingerprint. What else is unique to each substance?

We used light to measure these differences. What do you already know about how light interacts with different substances?

If substances interact uniquely with light, what data would we need to determine what is in a mixture of gasses that make up the atmosphere of an object in space?

Sample student response

We could compare the spectra of different elements or gasses we might expect to see with the spectra of what a satellite measured.

Well, we know each pure substance is made up of a certain type and number of atoms.

And substances have different polarities or charge distributions.

Light can travel through some substances.

Water can bend light to form rainbows.

If we know what color light a gas absorbs and transmits, maybe we could identify it by those peaks.

Yeah, we would need a reference of different gas spectra.

11 · ANALYZE AND INTERPRET TRANSMISSION SPECTRA FOR GAS MIXTURES

8 min

MATERIALS: *Transmission Spectra Library, Analyze Unknown Gasses*



Conduct unknown gas mixture investigation. Display slide Q. Distribute a copy of *Transmission Spectra Library* to each student. Explain that this reference is a library of transmission spectra obtained for eight different gasses. Point out that the names of the gasses and their chemical formulas are listed on the spectra.

Tell students that you have four unknown gas mixtures for partners to analyze and interpret using the reference spectra. Let them know that each pair of students will be assigned a different unknown. Distribute a copy of *Analyze Unknown Gasses* to each student. Assign each pair of students an unknown gas spectrum and tell them they have six minutes to identify the 1 to 3 reference gasses in their unknown. If students finish early, encourage them to try some of the other unknowns.

As groups work, circulate around the room and assist as needed.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **analyze** the **spectra of unknown substances** by **comparing** them to **spectra of known substances**. (SEP: 4.1; DCI: PS4.B.4)
- Students identify and use **patterns in spectra of known substances (empirical evidence)** to **identify unknown substances**. (DCI: PS4.B.4; CCC: 1.5)

What to do: If students are struggling to connect the two spectra images, encourage them to lay their unknown spectrum on top of the known spectra found on *Transmission Spectra Library*. Demonstrate how to overlay an unknown and reference spectrum so they can be held up to the light to look for patterns between them to aid in identification.

Building toward 5.A.3 **Analyze, compare, and integrate empirical evidence to identify patterns** in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer scientific questions about how we can identify which locations have the substances or elements needed to live and work in space. (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)

12 · SHARE TRANSMISSION SPECTRA ANALYSIS

5 min

MATERIALS: *Transmission Spectra Library, Analyze Unknown Gasses*

Share the identities of the gasses in the unknowns. Check in with students to see if they are ready to check their work by finding out what reference gasses were in each of the unknowns. Ask partners to share their analysis. Encourage pairs who analyzed the same unknown gas to show agreement or disagreement non-verbally.

Once you have built up some excitement, share slide R. Give students a minute to check their work.

Discuss data analysis and interpretation strategies. Display slide S.

Suggested prompts	Sample student responses	Follow-up questions
<i>What patterns helped you and your partner identify which gasses were in a mixture?</i>	We looked to see what wavelength a peak occurred at in the unknown and then looked for reference gasses with a peak there.	<i>Did others use a similar strategy? Or something different?</i>
<i>What kinds of patterns did you look for?</i>	And we also looked at the shapes of peaks in the unknown and reference gas. We considered the relative sizes and shapes of peaks clustered together.	<i>Can you describe an example for a specific reference gas?</i>
<i>Did the bands or peaks (use language students use) in the unknown mixture always look like they did in the reference spectrum?</i>	Well, they always seemed to be at the same wavelength position. But the transmittance value on the y-axis was different sometimes.	<i>How did you know it was a peak due to ____ gas in the unknown?</i> <i>What might cause those differences?</i>
<i>How might scientists analyze even more complex mixtures?</i>	If there's too many overlapping peaks at the same wavelength, it's probably not possible. Maybe they use computers or AI to help figure out what is in the mixture.	<i>These are great points. I bet they could also use different types of light, beyond the visible and infrared.</i>

13 · ANALYZE SPECTRA FOR SPACE OBJECT ATMOSPHERES

15 min

MATERIALS: *Transmission Spectra Library, Analyze Atmospheric Spectra*

Introduce transmission spectra for atmospheres. Recap why we started exploring spectroscopy. Say something like, *We started this lesson wondering if we could detect water on objects in space, and now we have this tool—spectroscopy--that we can use to detect water and other substances that we need to live and work in space.* Show **slide T** and use the diagram to explain how scientists use spectroscopy to determine what substances are in an object's atmosphere using the light from a star. Tell students that scientists have developed sophisticated instruments for this purpose, and that we will look at some data collected by NASA's James Webb Space Telescope (JWST, pictured on the slide). You can point out that the telescope uses a large mirror to collect light.

Display **slide U** and tell students that you have a set of four atmospheric spectra collected in this way for students to analyze and interpret. Explain that these spectra represent a snapshot of the gasses in each object's atmosphere at a specific point in time. These data also depend on the relative positions of the star (in our case, the Sun), the object (and its atmosphere), and the observer (the telescope) in three-dimensional space.



Analyze and interpret atmosphere data. Display **slide V** and distribute a copy of *Analyze Atmospheric Spectra* to each student. Ask students to work with a new partner to determine what gasses are present in the atmospheres of Earth, Mars, Venus, and Enceladus (a moon of Saturn). Point out that students can use the strategies that helped them identify the composition of the gas mixtures. Answer any

questions students may have about their task. Give students at least 10 minutes to work on this handout with a partner.

ADDITIONAL GUIDANCE

What to look/listen for in the moment:

- Students identify and use **patterns in spectra of known substances** (empirical evidence) to identify **unknown substances**. (DCI: PS4.B.4; CCC: 1.5)
- Students **analyze atmospheric spectra of objects in the solar system** to determine which gasses are present. (SEP: 4.1; DCI: ESS1.A.2)

What to do: See *Analyze Atmospheric Spectra Key* for additional support.

Building toward 5.A.4 Analyze, compare, and integrate empirical evidence to identify patterns in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer scientific questions about how we can identify which locations have the substances or elements needed to live and work in space. (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)

Discuss evidence for gasses in atmospheres. Display slide W and use the prompts to have students share what they figured out about the compositions of the objects' atmospheres from the spectral data.

Suggested prompts	Sample student responses	Follow-up questions
<i>Which reference gasses did we see supporting evidence for in the atmospheric spectra?</i>	The three planets all had carbon dioxide or CO ₂ . Enceladus might have CO ₂ , just a lot less.	<i>Which bands helped you determine that?</i> <i>What makes you think that?</i>
<i>What other gasses do we have strong evidence for?</i>	We saw a big band for ozone (O ₃) between 4.7–4.8 microns in Earth's atmosphere. Mars's spectrum seems to have some carbon monoxide bands between 4.6–4.8 microns.	<i>Did any other atmospheres have ozone or carbon monoxide? How do you know?</i>
<i>What gasses were clearly not present?</i>	We couldn't find any peaks for ammonia at 4.2 microns. Earth and Mars didn't seem to have any SO ₂ because if they did, we would see a broad band between 4.0–4.1 microns.	<i>Could the ammonia peak at 4.2 microns be overshadowed by CO₂?</i> <i>Did any object have SO₂ in its atmosphere?</i>

Suggested prompts	Sample student responses	Follow-up questions
<i>What gasses do we think we have inconclusive evidence for?</i>	We thought there might be some N₂O in Earth's atmosphere, especially the dip at 4.5-4.55 microns. It was really hard to see water. It seems to be the main substance that has bands between 5-5.2 microns, but if it is there, the bands are really small so maybe there is not a lot of it.	<i>Did others identify that?</i> <i>Yeah, there does not seem to be a lot of water in these atmospheres. Do you think spectroscopy could be used in other ways to look for water?</i>

14 · READ ABOUT OTHER WAYS TO FIND WATER WITH SPECTROSCOPY

10 min

MATERIALS: *Space Spectroscopy Studies*

Introduce the reading. Share slide X. Say, *It does not seem like there is much water in the atmospheres of objects in space, but what about on or under their surfaces? And could other substances we need be in those locations?* Tell students that scientists and engineers have found other ways to use spectroscopy to do this, and that we are going to read excerpts from research papers about the four objects shown on the slide. You can summarize the studies as follows:

- Analysis of light reflected from ice on Mars's south pole.
- Analysis of light emitted from material ejected from the Moon's surface when an empty rocket crashed into it.
- Analysis of light emitted from material spewed into space from below the surface of Enceladus.
- Analysis of light transmitted through the atmosphere of the exoplanet K2-18b.



Read about using spectroscopy to search for water. Display slide Y and distribute *Space Spectroscopy Studies*. Give students about six minutes to read research and answer questions about two of the objects in space. As students read, circulate around the room and assist as needed.

Discuss information from the reading. Display slide Z.

Suggested prompt	Sample student response
<i>What pieces of information in the excerpts help answer our question about how we can detect the presence of substances we need?</i>	Enceladus excerpt: They used other types of light to determine that there is water. Moon excerpt: They crashed objects into the surface of the Moon and analyzed how the soils interacted with sunlight. Mars excerpt: They used sunlight reflected off of Mars's polar ice caps to determine that they contain carbon dioxide and water. Hycean worlds excerpt: They measured atmospheric spectra of planets outside of our solar system.

Suggested prompt	Sample student response
<i>How does this information compare with the types of information we have analyzed in this lesson?</i>	They used different types of light, like near-infrared or ultraviolet spectra. They measured different types of matter, like soil and ice.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students compare information presented in different media to determine the presence of substances on objects in space. (SEP: 8.2; DCI: ESS1.A.2)

What to do: Encourage students to compare the color and graphic visualizations of the spectra data presented in this lesson. If students have difficulty comparing them, have students put *Spectrum Observations* and *Space Spectroscopy Studies* together to look at the color visualizations. Draw similarities between the visible portion of light and other portions of light discussed in the journal excerpts. Repeat this with *Analyze Atmospheric Spectra* to have students draw similarities with graphical representations of data.

Building toward 5.A.5 Analyze, compare, and integrate empirical evidence to identify patterns in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer scientific questions about how we can identify which locations have the substances or elements needed to live and work in space. (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)

15 · NAVIGATE

2 min

MATERIALS: science notebook



Update Progress Tracker. Display slide AA. Say, *Let's think about the different places on an object in space where scientists used spectroscopy to determine what substances are on it. You mentioned the atmosphere and solids like soil and ice. Using that, let's update our lesson question to move just beyond the atmosphere.* Give students the remaining class time to create a Progress Tracker entry.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Progress Tracker Key* in Lesson 2 for guidance.

What to do: See *Progress Tracker Key* in Lesson 2 for guidance.

Building toward 5.A.6 Analyze, compare, and integrate empirical evidence to identify patterns in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer scientific questions about how we can identify which locations have the substances or elements needed to live and work in space. (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)

Navigate. Display slide BB. Have students turn and talk with a partner about the prompt. If you have time, ask for a few volunteers to share their ideas. Accept all responses.

Additional Lesson 5 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

Students read excerpts from peer-reviewed scientific journals to determine what types of data were measured and the results of the data analysis. They compare this information to that presented earlier in the lesson to summarize the ways scientists use spectra data to determine the presence of substances on objects in space.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSS.IC.B.6: Evaluate reports based on data.

Students use data of known spectra to evaluate data of unknown spectra to determine which gas the unknown spectra represents.

LESSON 6: What patterns are there between the types of atoms and the number of bonds they form in the resources we need?

PREVIOUS LESSON We built and used a projector-based spectrometer to investigate the interaction of light with solutions of pure substances. We examined infrared spectra of three gasses, and used reference spectra to identify gasses in mixtures and the atmospheres of objects in space. We read about other ways spectroscopy is used to identify substances in space.

THIS LESSON
INVESTIGATION, PROBLEMATIZING

2 days



Atomic Composition	
Protons	13
Neutrons	14
Electrons	13

Al	
Aluminum	
Typical Mass (amu)	27
Bonds/Charges	3
Reactivity	Medium

Write "3" for 3 bonds

We examine element cards to figure out what makes elements different from one another in order to develop an element tool. We determine how many different bonds or charges each element can form. We add this information to our element cards and use it to revise our initial element tools, then create a class consensus element tool. We recall from an earlier unit that electrons are important for making bonds. We wonder why some elements, like carbon, form fewer bonds than they have electrons. So, we decide to figure that out next.

NEXT LESSON We will look back at our element tool to find patterns to help explain the missing carbon electrons. We will compare different atomic models and discuss which one is most helpful in answering our question. We will use a model to help us explain specific ratios in chemical formulas. We will complete an exit ticket.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, HS-ESS1-2, HS-ESS2-1, HS-ESS2-5



WHAT STUDENTS WILL DO

6.A Use patterns from empirical evidence to develop, revise, and evaluate merits and limitations of models of an element tool using subatomic particles and properties. (SEP: 2.3, 2.1; DCI: PS1.A.2; CCC: 1.5)

WHAT STUDENTS WILL FIGURE OUT

- Elements have varying numbers of protons, electrons, and neutrons which correspond to changes in typical mass and atomic number.
- Each element forms a specific number of bonds/charges when it combines with other elements.
- Elements are arranged on a table based on their repeating properties (numbers of bonds/charges formed, reactivity, composition, etc.).
- Patterns in elements' bonds/charges repeat (periodicity), while atomic mass and number of protons increase across rows.

Lesson 6 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	4 min		NAVIGATE Have students turn and talk with a partner and then share with the class to remind ourselves of where we left off last time.	A	<i>Materials for Survival</i>
2	4 min		REVISIT ATOMIC STRUCTURE AND COMPOSITION Have students talk with a partner about what they learned previously about atoms and subatomic particle interactions.	B	
3	4 min		INTRODUCTION TO ELEMENT DATA CARDS Have students turn and talk with a partner about patterns they notice within the data of three different element cards.	C	
4	9 min		ANALYZE AND ORGANIZE ELEMENT CARDS Have students meet with their group to organize their element cards using any type of information on the cards.	D	<i>Element Card Set</i>
5	6 min		DISCUSS INITIAL MODELS OF AN ELEMENT TOOL Have a class discussion to share student observations about different organizational models.	E	<i>Element Card Set</i>
6	8 min		IDENTIFY NUMBERS OF BONDS FORMED BY ELEMENTS Organize students in groups of four and distribute <i>Compound Representations</i> . Instruct groups to examine the cards and record patterns they notice.	F-G	<i>Materials for Survival, Compound Representations, chart paper, chart paper markers</i>
7	8 min		REORGANIZE ELEMENT CARDS Have students meet with their group to reorganize their element cards using the new information about numbers of bonds.	H	<i>Element Card Set</i>
8	2 min		UPDATE PERSONAL GLOSSARIES Have students update their Personal Glossaries.	I	
<i>End of day 1</i>					
9	10 min		SHARE MODELS OF ELEMENT TOOL Give groups a few minutes to revisit their element organizational models before having them share with other groups using the stay/stray protocol.	J	<i>Model Evaluation Support</i>
10	10 min		DISCUSS SIMILARITIES AND DIFFERENCES IN ORGANIZATIONAL MODELS Gather students in a Scientists Circle and lead a discussion around similarities and differences in groups' element card organizational models.	K-L	

Part	Duration		Summary	Slide	Materials
11	10 min		BUILD CLASS CONSENSUS ELEMENT TOOL Work with students in the Scientists Circle to co-construct an element tool using numbers of bonds or charges.	M	<i>Element Card Set</i> in page protectors, painter's tape
12	8 min		REFLECT ON CLASS CONSENSUS ELEMENT CARD ORGANIZATION Lead a Building Understandings Discussion to identify patterns in the element card organization.	N-O	class consensus element tool
13	7 min		UPDATE PROGRESS TRACKERS AND NAVIGATE Instruct students to update their Progress Trackers in their science notebooks. Navigate the class to the next lesson.	P-Q	class consensus element tool

End of day 2

Lesson 6 • Materials List

	per student	per group	per class
Lesson materials	- science notebook <i>Materials for Survival</i> <i>Model Evaluation Support</i>	<i>Element Card Set</i> <i>Compound Representations</i>	- chart paper - chart paper markers <i>Element Card Set</i> in page protectors - painter's tape - class consensus element tool

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.

Ensure students have access to either a printed or digital color version of *Materials for Survival* from Lesson 1.

Color print, cut out, and laminate (or put in sheet protectors) one set of *Element Card Set* per group of 3-4 students plus one additional set that will be used to develop the class consensus element tool. By laminating the cards (or using sheet protectors), you can reuse them between classes since students will be adding information to each element's card. Groups will use these cards again in the next lesson.

Lesson 6 • Where We Are Going and NOT Going

Where We Are Going

The goal of this lesson is for students to begin to identify some of the patterns used to organize the periodic table. This lesson is designed to coherently build ideas related to the following disciplinary core idea:

- **PS1.A: Structure and Properties of Matter.** 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.~~

Crosscut explanation: **PS1.A.2** is fully developed in Lesson 7 of this unit. In *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, students started to build out parts of the atomic structure but did not organize them into a table. This also builds on understandings developed in OpenSciEd Middle School unit *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*, where students used physical and chemical properties to identify pure substances and explore the idea of atoms as building blocks of substances.

Students revisit the results of a simulation from *Electrostatics Unit* to recall that each atom is composed of protons, electrons, and neutrons. Students also recall the effect that each particle had on the atom's overall charge. The patterns in atomic composition, state of matter, typical atomic mass, and general reactivity are used to make sense and begin organizing the element cards to possibly explain why we need more of certain elements (**CCC: 1.5**). Students revise their element tools after analyzing the number of bonds/charges each element formed within various molecules and compounds (**SEP: 2.3**). Allowing students to identify the merits and limitations of multiple groups' element tools will help to problematize how the elements are interacting in molecules (**SEP: 2.1**).

Students engage in **SEP: 2.1** and **2.3** partially. For **SEP: 2.1: 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.** Students previously developed this element in *Electrostatics Unit*. For **SEP: 2.3: 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 previously developed **SEP: 2.3** in the prior units *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*, *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*, *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*, *OpenSciEd Unit B.4: How does urbanization affect nonhuman populations, and how can we minimize harmful effects? (Urbanization Unit)*, *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, and *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. Students will fully engage with this element later in the unit as they revise their element tools and use the periodic table to predict relationships between compounds (components of a system) when they balance and write chemical equations.

In this lesson, students will encounter or co-construct a definition for the following terms, which they should add to their Personal Glossaries: *atomic number, compound, molecule*, and *periodicity*. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students might come into this unit already having an understanding of what the periodic table is and how it is used. The purpose of analyzing element cards of the first 20 elements is to support student understanding of the multiple patterns found among the elements on the periodic table in later lessons. This will also support students in identifying these patterns to make predictions of chemical reactions and bonding in future lessons and units.

At this point, students may wonder about the role of electrons and whether there is a pattern to how electrons are arranged in the atom. That is expected--students will develop this idea and consider electron shell configurations in Lesson 7.

The compounds on *Compound Representations* were carefully selected to allow students to readily identify generally typical trends in the number of bonds and charges that different elements form in compounds. Such a pattern is necessary to help students develop evidence of periodicity. However, one exception remains: sulfur, which can form additional bonds (as in sulfur hexafluoride, SF₆) due to involvement of *d*-orbitals. This idea is outside the scope of the DCIs in NGSS, so for the time being it is logical for students and the teacher to reason that sulfur can form two or four bonds, without clear explanation. VSEPR and orbital hybridization are addressed in college-level coursework, like AP Chemistry or university general chemistry. The force-and-matter models of the atom and bonding in Lesson Set 2 adequately prepare students for this coursework.

LEARNING PLAN for LESSON 6

1 · NAVIGATE

4 min

MATERIALS: science notebook, *Materials for Survival*

Briefly navigate into today's work. Say, *In the previous class we looked at what elements could be found on various cosmological objects. With an elbow partner, think about how we can use this data to help us prepare for future space missions.* Have students open their science notebooks to *Materials for Survival* from Lesson 1. Display **slide A** and have students discuss the prompts on the slide with a partner. After two minutes, ask for students to share what they discussed with the class.

Suggested prompt	Sample student response
<i>What are we looking for in space? Why?</i>	We are looking for the elements we need to survive. We need to know what's there because it takes too long to ship new stuff to another planet.
<i>Why is it necessary to know which elements are present or missing in other space objects?</i>	We need certain things to make the things we need. Without the starting materials, we can't make the things we need. If it's not there then we need to bring it with us.
<i>Other than the elements in water, are there any elements that seem to be needed more than others?</i>	Accept all answers; students may say carbon, hydrogen, and oxygen.

2 · REVISIT ATOMIC STRUCTURE AND COMPOSITION

4 min

MATERIALS: None

Revisit earlier atomic structure and composition learning. Display **slide B** and have students discuss the prompts on the slide with a partner. After two minutes, ask for students to share what they discussed.

Suggested prompt	Sample student response
<i>What do we remember about the parts of an atom?</i>	They are made of protons, neutrons, and electrons. Protons are positive. Electrons are negative. Protons and neutrons are in the nucleus. Electrons are found around the nucleus. Protons and neutrons both have a mass of 1 amu, while electrons have a much smaller mass.
<i>How do these components interact within the atom?</i>	Protons and electrons are attracted to each other. Protons repel each other. Electrons repel each other.
<i>How do these components result in some atoms carrying a neutral, positive, or negative charge?</i>	When an atom loses electrons it becomes more positive. If an atom gains electrons it becomes more negative. If an atom has the same number of protons and electrons it is neutral.
<i>What phenomena that we have investigated so far this year are the result of these charges?</i>	Accept all answers; students may say dissolving, lightning, polarization, attractive/repulsive forces, conductivity.
ALTERNATE ACTIVITY	If students struggle to recall the subatomic particles referred to or images used in slide B, then students can always return to the original simulation (https://lab.concord.org/embeddable.html#interactives/interactions/atom-builder.json) if you have time to access, project, and discuss it.

3 · INTRODUCTION TO ELEMENT DATA CARDS

4 min

MATERIALS: None

Continue the discussion by identifying elemental patterns in different molecules. Display slide C and say, *So we know that we need certain materials to survive and we know what elements they are made of, but why do we need more of certain elements and less of others? What makes these three elements in particular so special? Let's see if we can notice anything with how they look and act on Earth.* Have students turn and talk with a partner about the following prompts:

Suggested prompt	Sample student response
What types of data are on the element cards?	Number of subatomic particles. The element's appearance. The element's mass. The amount of reactivity it has. The symbol and name for the element.
What data might help us predict where electrons are in polar molecules?	Accept all answers.
What patterns might help us see which elements are more similar to each other?	Accept all answers.

4 · ANALYZE AND ORGANIZE ELEMENT CARDS

9 min

MATERIALS: Element Card Set

Notice patterns in element properties. Say, *I was able to gather some additional data about some other elements. Let's see if evidence of their properties can help us identify which elements are more similar to or different from each other.* Display **slide D**. Distribute a set of *Element Card Set* to each group of 3-4 students. Instruct students to individually read the questions on the slide. Next, have group members analyze the information on the element cards and consider which of the included data might help them organize the elements in some way.*

COLLABORATION



This may be an opportunity to have students choose a focal Community Agreement to attend to while they are working in their groups. Perhaps have students choose a sentence starter that will help guide their interactions with their peers (see "Routines and Tools to Support Peer Assessment" from the *OpenSciEd High School Teacher Handbook*).

As groups work, walk around the room and assist as needed. Ask clarifying questions, such as:

- What piece of information on the cards are you considering most important? Why?
- What evidence on the card is informing this decision?
- Is your group using a specific pattern to identify similar elements?

* SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Students may begin to notice and use patterns in evidence on the element cards as an organization scheme. Be sure to highlight these, without explicitly pointing to how those patterns are used to develop the periodic table. Later in this lesson, students will leverage these patterns to develop a class periodic table.

5 · DISCUSS INITIAL MODELS OF AN ELEMENT TOOL

6 min

MATERIALS: Element Card Set

Evaluate the element cards.* Display slide E, and have students share out what they noticed in their group work by responding to the prompts.

Suggested prompt	Sample student response
<i>Were there any patterns that seemed to be easier to organize by?</i>	Elements could easily be lined up using their typical mass. Numbers of electrons and protons seemed to go up by one with each element.
<i>Were there any patterns that we still are not accounting for within our model?</i>	Reactivity didn't change when the cards were lined up by mass or particles. The elements went from solid to gas, then back to solid.
<i>Do we have enough evidence to pick one of our models over another?</i>	Maybe, because some of them are more organized than others. No, because you can use lots of different information to organize. We need more evidence to help us decide on a structure that makes more of the patterns obvious.
<i>Are there any elements that might be able to do the things that carbon, hydrogen, and oxygen do?</i>	Oxygen and nitrogen have similar numbers of particles, are both clear, and are highly reactive. Hydrogen and fluorine are both clear and highly reactive. Carbon and boron are both shiny black materials with similar numbers of particles and mass.

Motivate a move toward compounds. Acknowledge that it is challenging to narrow down to one model or way of organizing the elements. Point out that the information we had was mainly related to a single atom of an element. Ask, *Do we usually see atoms by themselves, or with other atoms?* Students should note that atoms are usually together, in bonds. Suggest that this information might help us clarify our models.

* SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Students should use complex 3D learning as they share their *Element Card Set* organization and begin to [evaluate these models \(SEP: 2.1\)](#). Push students to consider that the [empirical patterns they used \(CCC: 1.5\)](#) to [develop their model](#) should also be used to [predict an element's atomic behavior \(SEP: 2.3; DCI: PS1.A.2\)](#). Students' models should vary at this point. Later in the lesson, students will revise their models.

6 · IDENTIFY NUMBERS OF BONDS FORMED BY ELEMENTS

8 min

MATERIALS: science notebook, *Materials for Survival*, *Compound Representations*, chart paper, chart paper markers

Identify patterns in compound structures. Say, *So we have seen a number of these elements in the materials we need to survive. Let's work together to determine whether there are any patterns in the way each element comes together to form molecules.* Distribute *Compound Representations* to each group and instruct students to locate *Materials for Survival* from Lesson 1 again in their science notebooks. Display slide F.

Go over the instructions on the slide with students. Stress that pairs within the group should look at one element at a time across the different compounds and try to identify a pattern for that specific element before moving on to the next one. Then, instruct partners to share their information with the other group members. Give groups about five minutes to identify and share patterns in the elements across

* SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Support groups in identifying patterns in the numbers of bonds and charges elements make with other elements. Students may notice that some elements do not show a bond with other elements; rather, they are

compounds. As groups work, circulate around the room and assist as needed. *

near to each other. Encourage students to note how many different elements are near to the one they are examining, and point out that this is also a pattern.

COLLABORATION



This may be an opportunity to have students choose a focal Community Agreement to attend to while they are working in their groups, such as *respect* or *equity*. Perhaps have students choose a sentence starter that will help guide their interactions with their peers.

Discuss patterns in the number of bonds made by each element. Say, *We have been talking about these bonds between elements that form different molecules and compounds.*

Display slide G. As students share the patterns they identified in the number of bonds for each element, record these on a piece of chart paper titled, "Numbers of Bonds/Charges Formed by Elements."

ADDITIONAL GUIDANCE

The sample table shows elements organized alphabetically. By organizing the elements alphabetically, students will not yet see emergent patterns, which is key for the next step in the lesson. If elements on the chart were organized by atomic number, students would likely notice patterns in the numbers of connections, and that should be avoided at this point.

Use the table below as a guide for the numbers of bonds students suggest.

Numbers of Bonds/Charges Formed by Elements			
Element Name & Symbol	# Bonds/Charges Formed	Element Name & Symbol	# Bonds/Charges Formed
Aluminum, Al	3	Lithium, Li	1
Argon, Ar	0	Magnesium Mg	2
Beryllium, Be	2	Neon, Ne	0
Boron, B	3	Nitrogen, N	3
Carbon, C	4	Oxygen, O	2
Chlorine, Cl	1	Phosphorus, P	3
Fluorine, F	1	Silicon, Si	4
Helium, He	0	Sodium, Na	1
Hydrogen, H	1	Sulfur, S	2 or 4

Once the table is complete, students will add these numbers to the dotted box on each of their group's element cards.

Atomic Composition
Protons: 5
Neutrons: 6
Electrons: 5

Al
Aluminum

Typical Mass
11 amu

Medium
Reactivity

Write "3" for 3 bonds

7 · REORGANIZE ELEMENT CARDS

8 min

MATERIALS: science notebook, *Element Card Set*



Reorganize element cards by different properties. Display slide H. Explain to the groups that they will add the number of bonds, or common ion charge, that each element forms to the element cards and then use this new information to update the organizational model they developed earlier. Say that groups will share their models with other groups, so they need to be able to explain how their group used the information on the cards to organize the elements. Give groups five minutes to reorganize their element cards.

As groups work, walk around the room and assist as needed. Ask clarifying questions, such as:

- *What piece of information on the cards are you considering most important? Why?*
- *What information on the card is informing this decision?*
- *Is your group using a specific pattern in the information on the cards to guide your organization process?*

Plan to share organizational models. Explain that tomorrow each group will have two minutes to share their organizational model with members from another group using the stay/stray protocol. Tell groups to take a moment to determine who will stay and share the model with other groups, who will stray to look at other groups' models, and how to plan the two-minute sharing of their model. Ensure that group members record the organizational model in their science notebooks. Alternatively, you may wish to take pictures of students' models and provide them digitally for later access.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use **patterns from empirical evidence** from the element cards to **support their organizational model**. (SEP: 2.3; CCC: 1.5)
- Empirical evidence** students provide can include:
 - numbers of protons/mass**, or
 - reactivity (chemical property)**, or
 - bonds and charges formed**. (DCI: PS1.A.2; CCC: 1.5)

What to do: If students do not state which pieces of evidence they used to help inform their decisions, prompt them to point out what information from the element cards aided in their decision. At this point, it is okay that students do not use the periodic table's organization scheme perfectly. Students will have opportunities to refine their organization.

Building toward 6.A.1 Use **patterns from empirical evidence** to **develop, revise, and evaluate merits and limitations of models of an element** using **subatomic particles and properties**. (SEP: 2.3, 2.1; DCI: PS1.A.2; CCC: 1.5)

8 • UPDATE PERSONAL GLOSSARIES

2 min

MATERIALS: science notebook

Update Personal Glossaries. Display **slide I**. Students will notice that the number of bonds is consistent for each element, but the numbers of elements in each molecule vary. Say, *What's different between these molecules and atoms? Let's co-construct some definitions in our Personal Glossaries.* Students will likely indicate that some of the molecules were made up of the same elements, and others were made up of different elements. Now is a good time to name *compounds* and add this to students' Personal Glossaries as well.

ADDITIONAL GUIDANCE

At this point, students may propose the following definitions:
Atom: one single nucleus with its electrons; "an atom of hydrogen"
Element: refers to all atoms of one type; "that element tends to have 3 bonds"
Molecule: a group of atoms that are bonded
Compound: a group of different atoms that are bonded

End of day 1

9 • SHARE MODELS OF ELEMENT TOOL

10 min

MATERIALS: *Model Evaluation Support*, science notebook

Navigate into the activity.* Display **slide J** and ask each group to nominate half of their group to be the first strayers. Explain that the strayers will spend four minutes visiting at least one other group before they come back and switch roles with the strayers. Give students a minute or two to re-identify roles and make sure they have an accessible copy of their group's model.

*** SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING**



Identify merits and limitations of models. Distribute a copy of *Model Evaluation Support* to each student. Tell students to use the prompts on *Model Evaluation Support* to guide their interactions while they participate in the activity.

Explain to students that when they are visiting other groups they should be looking for data patterns that follow their own organizational model, as well as for patterns that are different. Tell students to make a T-chart in their science notebooks to record patterns that are supported and contradicted within similar element groupings.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use the **merits and limitations of other groups' element tools**, which are based on **empirical evidence** from the element cards, to **consider revisions to their own element tool**. (SEP: 2.1; CCC: 1.5)
- **Empirical evidence** students provide can include:
 - **numbers of protons/mass**, or
 - **reactivity (chemical property)**, or
 - **bonds and charges formed**. (DCI: PS1.A.2; CCC: 1.5)

What to do: Visit each group and look at their model. If the “stayer” student is not talking to someone else, ask, *What evidence did you focus on to develop your organizational model? or, Are there any aspects from the evidence that aren't forming patterns within your model?* Note competing models, as students will have to come to consensus later in the lesson.

Building toward 6.A.2 Use **patterns from empirical evidence** to **develop, revise, and evaluate merits and limitations of models of an element tool** using **subatomic particles and properties**. (SEP: 2.3, 2.1; DCI: PS1.A.2; CCC: 1.5)

The purpose of this activity is to support students in seeing how the **merits and limitations they have evaluated from different element tools can be used to revise their own tools** (SEP 2.1). To make these evaluations, students will have to refine and apply their own thinking around **(sub)atomic properties and characteristics** (DCI: PS1.A.2) that they have developed using the **patterns observed in the empirical evidence** (CCC: 1.5). Students should be encouraged to use the sentence frames found in *Model Evaluation Support* to guide their thinking along the path of: (1) What has the empirical evidence shown me? (2) How did the other group use this evidence? (3) How does this thinking differ from mine? (4) What do these differences make me think about our group's model?

10 · DISCUSS SIMILARITIES AND DIFFERENCES IN ORGANIZATIONAL MODELS

10 min

MATERIALS: science notebook

ADDITIONAL GUIDANCE

As you have students move into a Scientists Circle, encourage them to sit near to their group members. This will encourage more collaboration between the group members as they share their notes from the stay/stray activity.

Discuss differences in element card organizational models in a Scientists Circle. Have groups examine their notes from the stay/stray activity. Display slide K. Give groups a few moments to discuss the prompts before asking for volunteers to share.

Suggested prompt

What were some similarities between the groups' models?

What were some differences between the groups' models?

Sample student response

We used either numbers of protons, bonds, or electrons to organize them.

Some of us also used neutrons.

We used protons and numbers of bonds.

* ATTENDING TO EQUITY

Universal Design for Learning: Highlighting the patterns that different groups used to organize their element cards helps to provide additional opportunities for *representation* to support student comprehension of the organization of elements on the periodic table. Comprehending these patterns now will help students later in the lesson as they figure out and articulate the meaning of periodicity.

Suggested prompt	Sample student response
<i>Based on the other ways you saw that groups organized the element cards, what changes would you make to your group's model? Why?</i>	Accept all responses.

Summarize students' observations by highlighting how groups approached the organization of the element cards either by considering a single property (e.g., number of protons) or by layering properties (e.g., number of protons and number of bonds). *

Determine which properties are most important for element card organization. Display slide L.

Suggested prompt	Sample student response
<i>Which property seems to be the most important to consider for organizing the element cards?</i>	Number of protons.
<i>Why?</i>	Because the number of protons tells you what type of atom it is.
<i>Which property seems to be second most important to consider?</i>	Number of bonds.
<i>Why?</i>	It lets us know when to start a new row, like how the number of bonds is similar for elements with different atomic numbers/numbers of protons.
<i>How does layering properties help inform our organization better than considering a single one?</i>	If we use two properties, that helps us see repeating patterns better. Like both hydrogen and lithium form one bond, and oxygen and sulfur form two bonds. So we know that those elements are related somehow.

Work with students to develop a definition for *atomic number*. Ask, *If the number of protons determines the type of atom, what term could we use to describe this number?* Look for students to suggest *atomic number*. Have students add the term to their Personal Glossaries.

11 • BUILD CLASS CONSENSUS ELEMENT TOOL

10 min

MATERIALS: *Element Card Set* in page protectors, painter's tape



Co-construct an element tool. Display slide M. Say, *Let's consider our approach of layering multiple characteristics to help organize the element cards. We agreed that the number of protons was the most important characteristic, so let's begin there.* * Start by posting the hydrogen element card on the board or wall. Then, add the helium card. Ask, *Where should we place lithium? I remember some of you saying that lithium and hydrogen both formed the same number of bonds.* Look for students to suggest placing lithium below hydrogen. Continue to work with the class to build out a class consensus organizational model. *

* ATTENDING TO EQUITY

Emphasize to students that when they work together to build consensus, everyone's ideas matter. Consensus does not necessarily mean that everyone must agree on everything. Rather, consensus is needed to

A sample consensus element tool is shown.



identify areas of common ground between ideas that may appear to differ. That way we have a better sense of where we all agree and where we do not agree.

* STRATEGIES FOR THIS CONSENSUS DISCUSSION

- It is important that, as you record student ideas for the element tool, you ask everyone to weigh in on each proposed idea--i.e., students should consider whether they had a similar idea.
- It is also important for students to work on restating and rephrasing the ideas that you record and to make sure each idea captures what everyone thinks is essential. Revise the ideas as students make suggestions.
- Do not have students write down ideas at this time. Have them work on listening and linking to the ideas other people share.

ADDITIONAL GUIDANCE

Keep the consensus element tool displayed after the final class of the day as you will annotate it in Lesson 7.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use **patterns from empirical evidence** from the element cards to **support their organizational model**. (SEP: 2.3; CCC: 1.5)
- **Empirical evidence** students provide can include:
 - **numbers of protons/mass**, or
 - **reactivity (chemical property)**, or
 - **bonds and charges formed**. (DCI: PS1.A.2; CCC: 1.5)
- Students suggest that:
 - **elements should be arranged by increasing numbers of protons and mass**, and
 - **new columns should begin based on numbers of bonds/charges formed**. (DCI: PS1.A.2; CCC: 1.5)

What to do: Ask students guiding questions, such as, *What information on the element card can help us determine the next element?* or, *If we look at the atomic number and number of bonds, what element would be next?*

Building toward 6.A.3 Use **patterns from empirical evidence** to **develop, revise, and evaluate merits and limitations of models of an element tool** using **subatomic particles and properties**. (SEP: 2.3, 2.1; DCI: PS1.A.2; CCC: 1.5)

12 · REFLECT ON CLASS CONSENSUS ELEMENT CARD ORGANIZATION

8 min

MATERIALS: science notebook, class consensus element tool

Lead a Building Understandings Discussion around larger-scale patterns in the class consensus element tool. Display slide N. *

* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

Suggested prompt	Sample student response	
<i>What patterns do you see in our class consensus element tool, from left to right?</i>	The number of bonds each element forms increases, then decreases. Reactivity seems to go down and then back up again.	As students share, encourage them to share evidence from their work with the element cards and <i>Compound Representations</i> to support the different patterns used to develop the class consensus element tool. By pushing students to use these different sources of evidence, they build understanding about the various patterns used to organize elements into the periodic table.
<i>What patterns do you see in our class consensus element tool, from top to bottom?</i>	They all form the same number of bonds or charges. Reactivity tends to decrease as you move down a column.	
<i>Has anybody ever seen anything like this?</i>	It's the periodic table with the middle portion missing.	
Develop a definition for periodicity. Display slide O. Have students turn and talk with a partner about the prompt on the slide. After a few minutes, ask students to share some of the experiences and ideas they discussed. Accept all suggestions. Say, <i>All of the examples you discussed describe something that occurs at a regular interval, or regularly. What are some terms or words you use to describe something that happens at a regular interval?</i> Accept all student ideas. Say, <i>One word that we use is to say these occurrences are periodic. The pattern we see with the number of bonds each element makes is an example of a periodic pattern. We call this periodicity.</i> Have students add the word <i>periodicity</i> and a definition to their Personal Glossaries.		

13 · UPDATE PROGRESS TRACKERS AND NAVIGATE

7 min

MATERIALS: science notebook, class consensus element tool

 Create a Progress Tracker entry to describe how patterns in element properties can be used to organize the elements into a chart or table. Say, *We have figured out so much using patterns in atomic number and number of bonds to help us organize the elements! How might knowing these patterns help us use chemistry to make the stuff we need to live beyond Earth?*

Look for students to suggest:

- We could predict which elements go together the best.
- We could predict which elements would dissolve in water because they form ions.

Say, *It seems like we have figured out some very important information that could help us use chemistry to live beyond Earth. Let's take a moment to record those understandings in our Progress Trackers.* Display **slide P**. Give students three to four minutes to create a Progress Tracker entry in their science notebooks. *

See *Progress Tracker Key* in Lesson 2 for a sample Progress Tracker entry.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students explain that **each element forms a specific number of bonds/charges when it combines with other elements.** (DCI: PS1.A.2)
- Students **identify patterns in empirical evidence to support their organizational model** as a way to **determine when to begin a new row.** (SEP: 2.3; CCC: 1.5)
- Students explain that **patterns in elements' bonds/charges formed repeat (periodicity), while mass/number of protons increases.** (DCI: PS1.A.2; CCC: 1.5)

What to do: If students do not identify the key understanding that patterns of increasing atomic number and periodicity (numbers of bonds) are used to organize elements into a chart/table, have them refer back to the class consensus element tool. Ask students to identify the patterns they see in the element card organization.

Building toward 6.A.4 Use **patterns from empirical evidence to develop, revise, and evaluate merits and limitations of models of an element tool** using **subatomic particles and properties** (SEP: 2.3, 2.1; DCI: PS1.A.2; CCC: 1.5)

Navigate to the next lesson by considering differences in numbers of electrons and numbers of bonds formed. Ask, *Think back to OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit). What part of the atom was most important when forming bonds between elements? Look for students to identify electrons.* Display **slide Q**. Say, *Let's take a moment to examine one element, carbon, because it is in so many things. What do you notice about the electrons and number of bonds in carbon? What do you wonder?* Give students a few minutes to individually reflect on the prompt before asking for volunteers to share.

* ATTENDING TO EQUITY

Remind students that the Progress Tracker is a thinking tool that is designed to help them keep track of important discoveries the class makes. 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, while 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 model in their Progress Tracker and indicate the sources of evidence, while making it clear that it is a class consensus model.

Suggested prompt	Sample student response
<i>What do you notice?</i>	Carbon has 6 electrons but forms 4 bonds.
<i>What do you wonder?</i>	Where are the 2 missing electrons?
<i>What type(s) of information would we need to answer our question?</i>	We need to find out more about the structure of the atom.
Summarize student ideas and say, <i>Great! It sounds like we know what we need to figure out in our next class.</i>	
ADDITIONAL GUIDANCE	If there is time, you might want to see if this is a pattern with other elements. Have students spend a few minutes looking at a few other elements, like beryllium or magnesium, to see that there is an emerging pattern of a discrepancy between numbers of electrons and bonds formed.

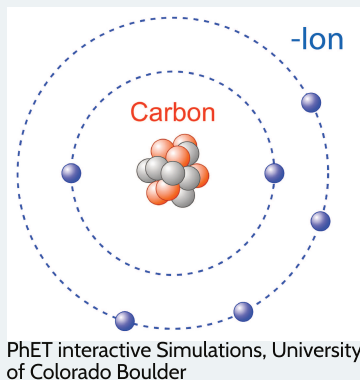
LESSON 7: Why is there a difference between the number of electrons an element has and the number of bonds an element forms?

PREVIOUS LESSON We examined element cards and developed an initial element tool, then determined how many bonds or charges each element can form. We reorganized the element cards and developed a class consensus element tool. We recalled that electrons are important in bonding and wondered why some elements form fewer bonds than they have electrons.

THIS LESSON

INVESTIGATION

2 days



We develop initial models of atomic structure to take stock of our current understanding. We look back at our class consensus element tool to find patterns that might help explain the missing carbon electrons. We use a simulation and compare different models of atomic structure, and then discuss which one best helps us answer our question. We use the electron shell model to help us explain specific ratios in chemical formulas. We complete an exit ticket and consider how patterns in the periodic table can help us predict element interactions (bonds).

NEXT LESSON We will predict and model the structure of a substance that could replace water. We will compare their properties and polarities. We will use a simulation to explore how electronegativity differences affect where electrons are in a bond, the bond characteristic, and its polarity.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, ESS1-2, ESS2-1, ESS2-5



WHAT STUDENTS WILL DO

7.A Develop, compare, and move between various models of atomic structures to explain and account for differences in the numbers of electrons and bonds formed by different atoms. (SEP: 2.4; DCI: PS1.A.1, PS1.A.2; CCC: 6.2)

7.B Determine which atomic model best illustrates patterns in atomic structures at the atomic scale, which can be used to predict interactions between elements. (SEP: 2.1; DCI: PS1.A.2; CCC: 1.1)

WHAT STUDENTS WILL FIGURE OUT

- Various models of atomic substructures can be used to try to account for differences in the numbers of electrons and connections formed by the element carbon.
- A model of atomic structure illustrating valence electrons is best for determining the number of interactions (connections) each element will have with other elements.

Lesson 7 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		NAVIGATE Have students turn and talk with a partner to remind the class of where we left off last time.	A	
2	12 min		DEVELOP INITIAL MODELS OF ATOMIC STRUCTURE Have students individually develop models of atomic structure. Organize students to meet with a partner to share their models.	B-C	
3	12 min		IDENTIFY PATTERNS BETWEEN NUMBERS OF ELECTRONS AND BONDS IN ELEMENTS Gather students in groups to analyze patterns using the class consensus element tool.	D	<i>Element Card Set</i> from Lesson 6 in page protectors, dry erase marker, class consensus organization of <i>Element Card Set</i>
4	10 min		BUILD UNDERSTANDING AROUND PATTERNS IN NUMBERS OF CONNECTIONS AND ELECTRONS Gather students in a Scientists Circle and lead a Building Understandings Discussion around patterns in the numbers of connections and electrons. Surface ideas around what these patterns can tell us about atomic structure.	E	<i>Element Card Set</i> from Lesson 6 in page protectors, class consensus organization of <i>Element Card Set</i> , dry erase marker
5	8 min		NAVIGATE Have students revise their initial atomic models, discuss differences between types of atomic models, and highlight how different representations of atomic structure may be helpful.	F-G	
End of day 1					
6	16 min		EVALUATE ANOTHER MODEL OF ATOMIC STRUCTURE Have students individually complete <i>Evaluate Another Model</i> . Lead a discussion around the patterns students noticed.	H-I	<i>Evaluate Another Model</i> , internet-connected device with access to https://phet.colorado.edu/en/simulation/s/build-an-atom
7	15 min		COMPARE FOUR MODELS OF ATOMIC STRUCTURE Have students complete <i>Compare Atomic Models</i> to consider the usefulness and limitations of different models of atomic structure. Work with the class to name each model.	J-O	<i>Compare Atomic Models</i>
8	12 min		USE VALENCE ELECTRONS TO EXPLAIN BONDS BETWEEN ELEMENTS IN COMPOUNDS Work with the class to demonstrate bonding in two compounds. Have students work with a partner and individually to model why elements in a compound form a specific number of bonds with each other.	P-S	<i>Periodic Table</i> , whiteboard, dry erase markers
9	3 min		NAVIGATE Have students turn and talk with a partner to re-evaluate how we are defining a bond.	T	
End of day 2					

Lesson 7 • Materials List

	per student	per group	per class
Lesson materials	- science notebook <i>Evaluate Another Model</i> - internet-connected device with access to https://phet.colorado.edu/en/simulations/build-an-atom <i>Compare Atomic Models</i> <i>Periodic Table</i>	<i>Element Card Set</i> from Lesson 6 in page protectors - dry erase marker - whiteboard - dry erase markers	- class consensus organization of <i>Element Card Set</i> - dry erase marker

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.

Have *Element Card Set* from Lesson 6 including the number of bonds formed information available for students. Place each element card in a page protector. You may also wish to have the class consensus element tool using *Element Card Set* displayed.

Check internet-connected devices to make sure they are able to play <https://phet.colorado.edu/en/simulations/build-an-atom>.

Have about 20 paper clips available (per group of 2 students) to support students in modeling how valence electrons can be used to explain and predict element combinations on day 2. These can be reused across classes.

Each student will use a whiteboard and dry erase marker on day 2.

Lesson 7 • Where We Are Going and NOT Going

Where We Are Going

The goal of this lesson is for students to compare multiple atomic models, assessing the merits and limitations of each. Students are given the periodic table. This lesson is designed to coherently use and build ideas related to the following disciplinary core ideas:

- **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.
- **PS1.A: Structure and Properties of Matter.** 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.

In *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, students used the paper-clip model as a way to explain movement of electrons between atoms. In Lesson 2, students used a simulation to build elements using the electron cloud model. These models did not consider valence electrons or electron configuration within the atom ([SEP: 2.1](#); [CCC: 1.1](#)). In this lesson, students use a simulation that uses the electron shell model as a way to explain differences in the total numbers of electrons and connections formed. Students develop their understanding of electron configuration and valence electrons through evaluating four different models ([SEP: 2.4](#)) to account for those differences and predict how elements will combine ([CCC: 6.2](#)).

At this point, students still may use the terms *connection* and *bond* interchangeably to describe how different atoms combine together to form molecules or compounds. In Lesson 8, students will develop an understanding of what occurs when these connections are made and update their definition of *bonds*.

Students engage with [SEP: 2.1](#) partially. For [SEP: 2.1](#): *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.* Students previously developed this element in *Electrostatics Unit*.

Students continue to build their proficiency using [CCC: 6.2](#) in this lesson. Now that they have a complete atomic model (structure), students are better equipped to explain bonding (function). In Lessons 8 and 9, students further build out the relationship between atomic structures and how they function to form bonds with other elements based on additional trends in the periodic table.

In this lesson, students will co-construct a definition for the following terms, which they should add to their Personal Glossaries: *electron shells* and *valence electrons*. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

Where We Are NOT Going

A full explanation of electron configuration is not developed in this lesson. Students may begin to identify patterns in the numbers of electrons found in each shell, but electron configurations (d, f, etc.) are not within the scope of the standards.

This lesson does not introduce the Aufbau principle, Hund's rule, or the Pauli exclusion principle.

LEARNING PLAN for LESSON 7

1 · NAVIGATE

3 min

MATERIALS: None

Navigate to the lesson by considering where we left off. Display **slide A** and have students turn and talk with a partner about the prompt on the slide. After a minute, ask for students to share their discussion with the class. Look for students to say that we wanted to figure out why there is a difference between the number of electrons and the number of bonds carbon makes, or more about the structure of the atoms.

2 · DEVELOP INITIAL MODELS OF ATOMIC STRUCTURE

12 min

MATERIALS: science notebook

ADDITIONAL GUIDANCE

As students work independently and compare with a partner, put up the class consensus organization of *Element Card Set* (from Lesson 6) for the remainder of the lesson in a place where the element tool will be visible during a Scientists Circle.

 **Develop initial models of atomic structure to take stock of our current understandings.** Display **slide B**. Say, *Let's take a moment to see where we are in our thinking about the structure of an atom before we try to figure out why there is a difference between the number of electrons an element has and the number of bonds an element forms. Since we are wondering about carbon, develop an initial model of a carbon atom and its structure that could explain these differences.* Give students about six minutes to individually develop their models.

After students have developed their models, have them meet with a partner and use the prompts on **slide C** to guide their discussion. After four minutes, lead a class discussion using the prompts below.

Suggested prompt	Sample student response
What sources of evidence did you use to develop your models?	I used the simulation where we built the atom, so I drew that the protons and neutrons were in the middle, and electrons floated around it. I remembered the model we drew in Electrostatics Unit, so I used that too (referring to the paper-clip model).
What similarities did you and your partner have in your models?	We both showed the protons and neutrons in the center and electrons around them.
What differences did you and your partner have in your models?	I showed all 6 electrons around the nucleus. I only showed 4 electrons around the nucleus and gave the carbon a charge.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **develop initial models**. The models should:
 - show the **substructure** of a **carbon atom**, and
 - try to **explain differences** in **electrons and connections formed**. (SEP: 2.4; DCI: PS1.A.1)
- The model should include:
 - 6 protons, or a nucleus
 - 6 neutrons, or a nucleus
 - 6 electrons surrounding the protons and neutrons
 - Any attempt to account for the difference between these numbers and the number of connections (4).

What to do: At this point, students may have many different ideas about the structure of the atom and how it can account for the differences in numbers of electrons and connections formed. Use this as an opportunity to gauge how varied students' ideas may be. If students are not clearly showing or explaining relationships among protons, neutrons, and electrons, ask clarifying questions.

Building toward 7.A.1 Develop, compare, and move between various models of **atomic structures** to explain and account for differences in the **numbers of electrons and bonds formed by different atoms**. (SEP: 2.4; DCI: PS1.A.1, PS1.A.2; CCC: 6.2)

Summarize differences in students' models and point out that by not showing the missing electrons, they developed models of a carbon ion rather than a carbon atom. Ask, *What other ions have we heard about?* Look for students to say sodium, chlorine, or others that they may have encountered in *Electrostatics Unit* or earlier in this unit.

Motivate returning to look at the element cards. Say, *So we have some ideas about ions and how they are missing, or have extra, electrons. Let's see if we can see some similar patterns in the numbers of bonds elements form with other elements. Let's revisit the element cards to see if we can find some patterns to help us make progress on our question.*

3 · IDENTIFY PATTERNS BETWEEN NUMBERS OF ELECTRONS AND BONDS IN ELEMENTS

12 min

MATERIALS: science notebook, *Element Card Set* from Lesson 6 in page protectors, dry erase marker, class consensus organization of *Element Card Set*

Analyze patterns between the numbers of bonds and electrons in atoms. Distribute a set of *Element Card Set* from Lesson 6 to each small group. Display **slide D**. Have the groups organize their set of element cards into the class consensus element tool developed in the previous lesson. Next, have students subtract the number of bonds formed from the number of electrons in each element and use a dry erase marker to record the difference on each element card. Then, have students work with their group to answer the questions at the bottom of **slide D** in their science notebooks. ✱ Give groups about 12 minutes to complete this task.

As groups work, circulate around the room and assist as needed. Listen to student discussions and ask probing questions, such as:

- What happens to the differences in bonds and electrons as you move across a row on your element tool?
- What happens to the differences in bonds and electrons as you move down a column on your element tool?

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Students are identifying patterns along the rows and columns of the class consensus element tool. Prompt students not only to examine patterns in the numbers of bonds as they move along rows and columns, but also to relate these patterns to the patterns in the numbers of electrons. Applying additional patterns will help students to identify areas where their current atomic models may need to be revised or to consider a new atomic model to explain why they are noticing these periodic patterns.

4 · BUILD UNDERSTANDING AROUND PATTERNS IN NUMBERS OF CONNECTIONS AND ELECTRONS

10 min

MATERIALS: science notebook, *Element Card Set* from Lesson 6 in page protectors, class consensus organization of *Element Card Set*, dry erase marker

ADDITIONAL GUIDANCE

It may be helpful to add the differences of the numbers of electrons and bonds formed to the class consensus element tool using a dry erase marker. A sample of the completed element tool is shown at the end of this activity. You might choose to have students add the differences to the element cards. Be sure to keep the element tool displayed for day 2 of the lesson.

Discuss patterns in the numbers of connections and electrons in the element card organization. After groups have noted the differences between the number of connections each element forms and the number of electrons, lead a whole-class discussion to share patterns and consider how to use those patterns to update our thinking about atomic models. Have the class gather in a Scientists Circle with their science notebooks. * Display slide E.

Suggested prompt

What patterns did you notice in the class consensus element tool?

Which pattern that you noticed could explain the differences in the numbers of electrons and bonds formed by elements?

How might we use this pattern to revise our models of atomic structure?

Sample student response

As you move across a row, the first four elements all have the same difference, but then it increases by 2 for the remaining four elements in the row.

As you move down a column, the difference is 8.

The difference in the top row and second row is 8 except for H and Li, which have a difference of 2.

I think as you move down a column, because it's always the same difference.

Maybe there are layers or levels of electrons, like some are more inside and some are more outside.

A sample class consensus element tool with notations of numbers of bonds formed (blue) and their differences with numbers of electrons (pink) is shown.

* SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Students observe the larger-scale pattern of differences between the numbers of electrons and bonds formed with their element cards to then try to explain the smaller-scale pattern of electron arrangement within the atom. The observation of the larger-scale patterns allows students to explain differences in the total numbers of electrons and bonds formed by developing the smaller-scale pattern of electron configuration within an atom.

Note: This table is a simplified version of the Element Cards in page protectors students annotate.

8 min

 **Make predictions about how the patterns might inform our ideas about atomic structure.** Have students look back at their initial models of the atomic structure of carbon. Display **slide F**. Give students a few minutes to update their models in their science notebooks. Then, have students show their models while in the Scientists Circle. Tell students to take a moment to look at the different models their classmates created.

Display slide G.

Suggested prompt	Sample student response
<i>How do our different models compare?</i>	We have a lot of different ideas! Some of us drew layers of electrons. Some of us color-coded electrons (or some other symbol).
<i>What are some advantages or disadvantages among our models?</i>	Accept all student responses.
<i>How does comparing models help us in explaining why there are differences between numbers of connections formed and numbers of electrons?</i>	We are showing different ways to think about how the electrons are organized. The other models we have looked at show electrons in different ways. Maybe by thinking about how electrons are moving around the atom, we can figure out where the missing ones are. Like they might be there, but we can't detect them.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **revise initial models** of a **carbon atom** to try to **explain differences** in **electrons and connections formed** by including some new way **to organize electrons** that may not have been in the initial model. (SEP: 2.4; DCI: PS1.A.1, PS1.A.2)
- Students **consider advantages or disadvantages of revised models**, particularly related to the **organization of electrons**. (SEP: 2.4; DCI: PS1.A.2)

What to do: Leverage the differences in students' models, but point out how each of those differences may help us work toward answering our question. Ask students to consider if they have ever used different models of the same phenomenon to account for different mechanisms. Invite students to share their prior experiences with moving between different mechanistic models of a phenomenon.

Building toward 7.A.2 Develop, compare, and move between various models of **atomic structures** to explain and account for differences in the **numbers of electrons and bonds formed by different atoms**. (SEP: 2.4; DCI: PS1.A.1, PS1.A.2; CCC: 6.2)

Say, I found a simulation we can use to help us examine some other ways scientists represent atomic structure. How might comparing some of their models help us make progress on our question? Look for students to say that scientists might have noticed structural differences in atoms that help explain differences in the connections formed. Comparing models is helpful because some models explain different things. Tell students that tomorrow, we will consider a new model of atomic structure.

End of day 1

6 · EVALUATE ANOTHER MODEL OF ATOMIC STRUCTURE

16 min

MATERIALS: *Evaluate Another Model*, internet-connected device with access to <https://phet.colorado.edu/en/simulations/build-an-atom>

Use a simulation to evaluate a new representation of electron structures within an atom. Remind students that yesterday, we decided to examine a different representation of an atomic model to help us make progress on our question, *Why is there a difference between the number of electrons an element has and the number of bonds an element forms?* * Display slide H. Distribute *Evaluate Another Model* and have students access the simulation <https://phet.colorado.edu/en/simulations/build-an-atom>. Give students about 10 minutes to complete the handout.

 Lead a Building Understandings Discussion around patterns in electron structures. Display slide I.

Suggested prompt	Sample student response
<i>What patterns did you see in these atomic models?</i>	The electrons were found in different areas, like different circles around the atom. The electrons were floating/moving around the protons and neutrons. The electrons were in a big space/cloud around the protons and neutrons. Each level only held a certain number of electrons. The first level only held 2 electrons, while the next level held 8 electrons.
<i>How do these patterns relate to the patterns we noticed in the differences between the numbers of electrons and bonds formed by elements?</i>	The different levels help explain the missing electrons. Like in the first row, we said that everything was missing 2 electrons, but those electrons were in the first level in the simulation.

*** SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS**

The Framework 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 (SEP: 2.4).* We have realized by now that our current atomic models are inadequate for explaining the differences between the numbers of electrons and connections that are made between elements. Here, we are presenting an additional model to students that can account for these differences.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students give examples of **various models that show different representations of the same structures (electrons)**. (SEP: 2.4)
- Students explain that **structures of electrons in atoms determine properties of atoms (how they connect with one another)**. (CCC: 6.2)
- Students point out that **electron structures (shells) are found in a repeating pattern on the periodic table**. (DCI: PS1.A.1, PS1.A.2)

What to do: If students do not identify different ways that the new simulation's representation of an atom can help us, ask them to consider how the models we have previously examined do or do not account for the missing electrons.

Building toward 7.A.3 Develop, compare, and move between various models of **atomic structures** to explain and account for differences in the **numbers of electrons and bonds formed by different atoms**. (SEP: 2.4; DCI: PS1.A.1, PS1.A.2; CCC: 6.2)

7 • COMPARE FOUR MODELS OF ATOMIC STRUCTURE

15 min

MATERIALS: *Compare Atomic Models*, science notebook



Compare models of atomic structure to consider electron shells. Say, *We have looked at many different atomic models, so let's take some time to compare them side by side.* Display **slide J**. Distribute *Compare Atomic Models* and give students about five minutes to individually complete the four questions on the handout. * Explain that after we talk about their responses, we will work as a class to name each of the atomic models. *

Discuss the merits and limitations of the atomic structure models. Display **slide K**.

Suggested prompt	Sample student response
<i>What similarities did you notice?</i>	They all showed electrons.
<i>What differences did you notice?</i>	Models 1, 2, and 3 showed protons, neutrons, and electrons. Model 3 showed electrons in different levels. Model 4 only showed a few electrons, which is equal to the number of bonds carbon forms.
<i>Which of the four models would best help us show and predict the numbers of bonds between atoms? Why?</i>	I think model 3 or 4 because they both show which electrons are involved in forming bonds.

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Individual time gives students an opportunity to synthesize evidence and formulate their ideas. This is important so that students are prepared to discuss which model they *selected that best fits the criteria* and to evaluate others' ideas when they share their determination in small groups and with the whole class (SEP: 2.1). As students work, circulate among them, prompting them to explain how the *electron shell model best fits the criteria* of showing the differences between the numbers of connections formed and electrons using evidence from the simulation and element cards *compared to the other models* presented in the handout.

* ATTENDING TO EQUITY

Universal Design for Learning: These four models provide different *representations* of atomic structures that can help us explain

Suggested prompt	Sample student response
<i>All models have limitations, so let's consider, what are some limitations of each model?</i>	Model 1 would make it seem like carbon would form six bonds because we would want to move all six paper clips. Model 2 makes it seem like carbon would form six bonds. Model 3 shows electrons in specific areas of the atom, and we know they move randomly. Model 4 only shows four of carbon's six electrons and doesn't show any protons or neutrons.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Compare Atomic Models Key* for guidance.

What to do: If students are struggling to figure out the relationship, have them look at an element card and compare it to the same element on <https://phet.colorado.edu/en/simulations/build-an-atom>. This will help them adjust their mental model for the structure of atoms from a “cloud” to a shell model.

Building toward 7.B.1 Determine which atomic model best illustrates patterns in atomic structures at the atomic scale, which can be used to predict interactions between elements. (SEP: 2.1; DCI: PS1.A.2; CCC: 1.1)

different interactions between and within elements. The goal of this activity is for students to identify that different *representations*, or models, can be used to explain different interactions, and that some may lend themselves to certain explanations better than others. Allowing students time to process differences among the *representations* will support evaluations of their usefulness in explaining different interactions between and within elements.

* SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

American scientist Gilbert Lewis (1875–1946) popularized electron dot diagrams in order to show patterns in the *structure and function* of atoms. There might be six electrons in the overall structure of a carbon atom, but only four of them are functionally useful to understanding its bonding patterns.

Work together to name the different models so we can keep track of them. Display slide L.

Suggested prompt	Sample student response
<i>What have we previously called the representation of an atom shown in Model 1?</i>	The paper-clip model.
<i>What is different between Models 2 and 3 that we can use to help name them?</i>	The way the electrons look. The way the electrons are organized.
<i>How would you describe the way the electrons are represented in Model 2?</i>	They move everywhere! There is a fuzzy area around the nucleus. It looks like a cloud.

Work with students to name and describe Model 2 as the *electron cloud model*, and encourage students to add this notation to where they have previously represented this model in their science notebooks.

ADDITIONAL GUIDANCE

Students can also choose to add *electron cloud model* to their Personal Glossaries. A possible definition may describe aspects of the model such as the electrons moving in an area, or cloud, around the nucleus of the atom.

Display **slide M**. Ask, *How would you describe the way the electrons are represented in Model 3?* Look for student responses such as:

- The electrons are on different orbits, like planets.
- The electrons are in layers.

Work with students to add the term *electron shells* to their Personal Glossaries. Say, *We call these layers or levels shells. What patterns did you notice in the numbers of electrons on each shell?* Look for students to say that the first level held only 2 electrons, and the other levels held up to 8 electrons.

Say, *Take a moment to record a definition for electron shells in your Personal Glossaries and include specific information about how many electrons are found in each shell.* Students may also add an entry for *electron shell model* at this time.

ADDITIONAL GUIDANCE

It is important for later discussions of element interactions (bonding) that students understand the arrangement of electrons in *electron shells*. A sample Personal Glossary entry is shown:

- *Electron shells:* A way to organize electrons into different levels surrounding the nucleus of an atom. Each shell holds a specific number of electrons. The first shell (closest to the nucleus) holds 2 electrons, and the other shells hold up to 8 electrons each.

Display **slide N**. Tell students to evaluate Models 3 and 4. Ask, *What is similar between them?* Look for students to suggest that Model 3 shows four electrons in the outside shell and that Model 4 shows just four electrons.

Explain that we call Model 4 a Lewis dot model, and that it represents just the electrons found in the outer shell of the atom. *

Check in with the class that we are in agreement that we would use either the electron shell or Lewis dot models to represent how atoms bond with each other.

Develop understanding of valence electrons. Say, *So it sounds like we have figured out why there is a difference between the numbers of electrons and the numbers of bonds formed in atoms. There is something special about the electrons in the outermost electron shell. Scientists call them valence electrons.* Display **slide O** and say, *Take a moment to add this term to your Personal Glossaries.*

ADDITIONAL GUIDANCE

A sample Personal Glossary entry for *valence electrons* is shown:

- *Valence electrons:* The electrons in the outermost electron shell. Valence electrons form connections with other atoms.

Note that students may have different definitions or representations of the term, and that is okay.

8 • USE VALENCE ELECTRONS TO EXPLAIN BONDS BETWEEN ELEMENTS IN COMPOUNDS

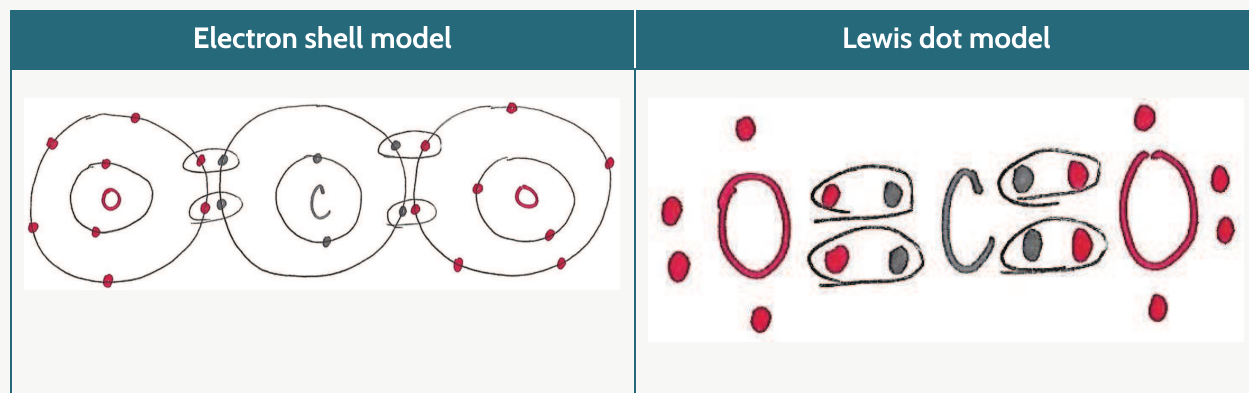
12 min

MATERIALS: *Periodic Table*, science notebook, whiteboard, dry erase markers

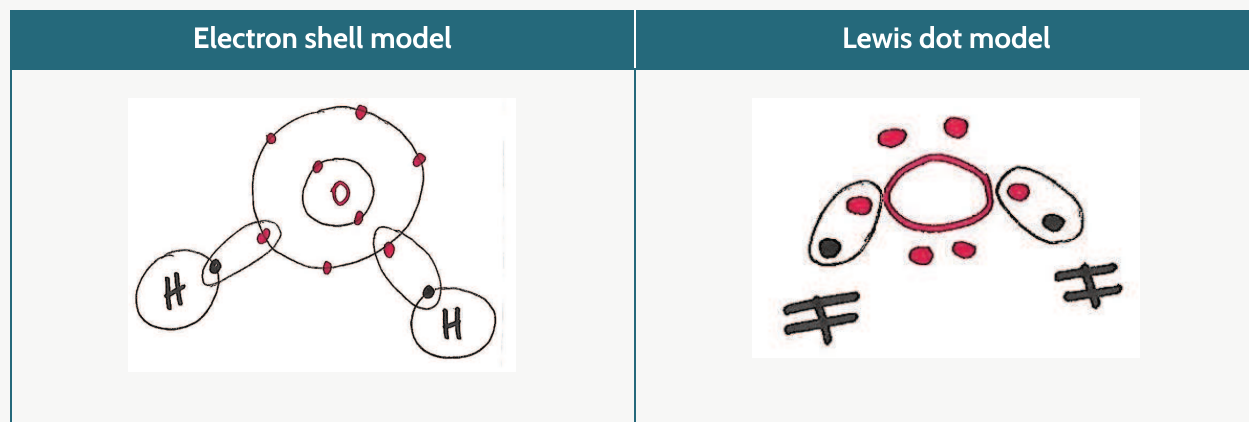
Introduce the periodic table. Point out that we have looked at only 18 elements with our class consensus element tool, but that there are over 100 more elements that scientists have identified. Display **slide P** and distribute *Periodic Table* to students. Say, *Notice that on the reverse side of the periodic table you have the electron shell and Lewis dot models of the first 18 elements we have examined. The patterns we have identified in the number of valence electrons going down a column are the same for the elements shown in the periodic table.*

Develop models of compounds using valence electrons. Say, *We have looked at and identified many different chemical compounds. How might knowing the numbers of valence electrons help us explain why there is a specific number of each type of atom found in a compound? Since we have focused on valence electrons in carbon, let's consider a compound using that element. For example, why does carbon dioxide contain 1 carbon atom and 2 oxygen atoms? Let's work together to model it using either the electron shell or Lewis dot model.*

Display **slide Q**. Work with the class to model how interactions between the valence electrons in carbon and oxygen result in the formation of two bonds between carbon and oxygen. Sample electron shell and Lewis dot models of carbon dioxide are shown.



 Display **slide R**. Say, *Let's practice this with a partner.* Give a whiteboard and two different colored dry erase markers to each pair of students. As partners work together, choose representations of both types of models to share with the class. Try to choose two models that resemble those shown in the table.



Have the pairs you have chosen share their models and explain their thinking. Point out areas where the models are in agreement, and summarize how each model illustrates that two of the valence electrons of oxygen are shared with the two hydrogen atoms. Ask, *How did you know how many electrons from hydrogen interact with the oxygen molecule?* Look for students to explain that they used the pattern of numbers of electrons in each shell of the electron shell model and that the outer shells contain either 2 or 8 electrons.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use either the electron shell or Lewis dot model to explain how valence electrons of two elements interact to form specific numbers of bonds with another element. (SEP: 2.1; DCI: PS1.A.2)
- Students show a structure with two bonds emerging at the scale of a single atom. (CCC: 1.1)

What to do: If students are struggling to model the interactions of valence electrons between elements in a compound, offer students paper clips to represent valence electrons on the element cards or suggest they use different colors or other representations to keep track of valence electrons.

Building toward 7.B.2 Determine which atomic model best illustrates patterns in atomic structures at the atomic scale, which can be used to predict interactions between elements. (SEP: 2.1; DCI: PS1.A.2; CCC: 1.1)



Practice explaining ratios in compounds. Display slide S. Have students individually develop one of two additional models in their science notebooks to explain the ratios of methane (CH_4) or oxygen gas (O_2). Sample student models are shown in the table.

Compound	Electron shell model	Lewis Dot model
CH_4 , methane		
O_2 , oxygen gas		

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use either the electron shell or Lewis dot model to explain how valence electrons of two elements interact to form specific numbers of bonds with another element. (SEP: 2.1; DCI: PS1.A.2)
- Students show a structure with two bonds emerging at the scale of a single atom. (CCC: 1.1)

What to do: If students are struggling to model the interactions of valence electrons between elements in a compound, offer students paper clips to represent valence electrons on the element cards or suggest they use different colors or other representations to keep track of valence electrons.

Building toward 7.B.3 Determine which atomic model best illustrates patterns in atomic structures at the atomic scale, which can be used to predict interactions between elements. (SEP: 2.1; DCI: PS1.A.2; CCC: 1.1)

9 · NAVIGATE

3 min

MATERIALS: None

Re-evaluate how we define bonds. Display slide T. Have students turn and talk with a partner about the prompts on the slide.

Suggested prompt	Sample student response
How has your definition of bond changed based on this new information?	It isn't all of the electrons in an atom responsible for forming a bond, just the valence electrons. A bond isn't when an electron moves.
What questions do you have now?	Accept all responses.

Highlight that we have a lot of different questions about what actually is happening in a bond and how that influences the properties of compounds. Tell students we will figure that out in our next class.

ALTERNATE ACTIVITY

For this Navigation activity, you could also go back to the DQB and ask students which questions are about bonds or can be answered by figuring out more about bonds. Suggest that we figure out those questions next.

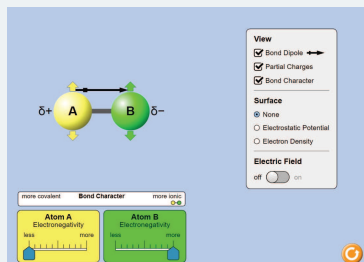
LESSON 8: Could another substance serve as a substitute for water for some of the processes we need to use it for in space?

PREVIOUS LESSON We developed initial models of atomic structure and looked back at our element tool to find patterns to help explain the missing carbon electrons. We used a simulation and compared different atomic models, and then discussed which one was most helpful in answering our question. We used the electron shell model to help us explain specific ratios in chemical formulas. We completed an exit ticket.

THIS LESSON

INVESTIGATION

2 days



PhET interactive Simulations, University of Colorado Boulder

We predict whether another substance could replace water for some processes and model the structure of water and hydrogen sulfide molecules. We predict and compare their properties and polarities. We explain why the electronegativities of O and S are different. We use a simulation to explore how electronegativity differences affect where electrons are in a bond, the bond characteristic, and its polarity. We update our periodic table to include trends in electronegativity.

NEXT LESSON We will describe bond characteristics and model the polarity for different substances. We will evaluate our progress on our DQB questions. We will consider how being able to make medicines on site would help our long-term plans for surviving beyond Earth. We will record new questions.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, ESS1-2, ESS2-1, ESS2-5



WHAT STUDENTS WILL DO

8.A Use the periodic table to identify atoms with similar bonding patterns and to explain how differences in atomic structure could contribute to differences in electronegativity. (SEP: 2.3; DCI: PS1.A.2; CCC: 1.1)

8.B Explain bond stability, differences in three properties, and differences in molecular polarity of two molecules based on the relative strength of forces between atoms and molecules. (SEP: 6.2; DCI: PS1.A.1, PS2.B.3; CCC: 6.2, 7.1)

WHAT STUDENTS WILL FIGURE OUT

- Differences in the polarity of H₂O and H₂S molecules help explain some of their property differences.
- Electronegativity is a measure of how strongly a nucleus is attracted to shared electrons. Greater electronegativity equals stronger attraction.
- Atoms of elements with more electron shells are larger. The size of an atom is called the atomic radius.
- Electronegativity is affected by an atom's atomic radius and amount of charge.

Lesson 8 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	6 min		NAVIGATE Discuss examples of substituting substances with similar properties and predict whether a substance that has similar properties as water could serve as a substitute for it.	A-B	
2	7 min		USE MODELS TO MAKE PREDICTIONS Have students identify the bonds in a water molecule and use the periodic table to identify a replacement atom for oxygen.	C-E	<i>Periodic Table</i> from Lesson 7, chart paper, chart paper marker, M-E-F poster
3	9 min		USE A MODEL TO EXPLAIN STABILITY IN A BOND Show a video of an inverter magnet and discuss interactions.	F	<i>Video Transcript</i> , https://youtu.be/ZSNU9GN-NJI , Substitution Reasoning poster, M-E-F poster with expansion panels, copy paper, painter's tape, chart paper marker
4	6 min		USE MODELS TO MAKE PREDICTIONS Have students use Lewis dot models to explain water molecule polarity and predict the polarity of hydrogen sulfide.	G-I	<i>Periodic Table</i> from Lesson 7, Substitution Reasoning poster, chart paper marker, copy paper, painter's tape
5	12 min		COMPARE POLARITIES AND PROPERTIES Have students compare the polarities and properties of H ₂ S and H ₂ O and explain some of those property differences using polarity differences.	J-K	<i>H₂O vs. H₂S</i> , Substitution Reasoning poster, M-E-F poster with expansion panels, painter's tape
6	5 min		EXIT TICKET Have students develop an initial explanation for differences in electronegativity in an exit ticket.	L	<i>Periodic Table</i> from Lesson 7, sheet of loose-leaf paper
<i>End of day 1</i>					
7	2 min		NAVIGATE Lead a class discussion to review some of the ideas raised in the exit ticket.	M	
8	6 min		DEVELOP INITIAL EXPLANATIONS Discuss how nuclear charge and atomic radius contribute to differences in electronegativity and connect these ideas to Coulomb's law.	N-P	M-E-F poster with expansion panels, Substitution Reasoning poster
9	10 min		MAKE PREDICTIONS USING A MANIPULATIVE AND EXPLORE A SIMULATION Have students work with a partner using a manipulative to make predictions about the location of shared electrons between atoms with different combinations of electronegativity. Explore these predictions with a simulation.	Q-X	Modeling Bond Polarity in 3D

Part	Duration		Summary	Slide	Materials
10	9 min		REPRESENT THE RESULTS AND MODEL ELECTRON SHIFTS Have students remain with their partners to discuss the results of the simulation and identify categories of bonds as existing along a polarity continuum.	Y-Z	M-E-F poster with expansion panels, Modeling Bond Polarity in 3D
11	4 min		CONSTRUCT AN EXPLANATION Have students explain the differences in molecular polarity of water and hydrogen sulfide molecules based on electronegativities of the atoms that make them up.	AA	sheet of loose-leaf paper
12	8 min		ADD ELECTRONEGATIVITY AND ATOMIC RADIUS TRENDS TO OUR PERIODIC TABLES Work with students to identify and annotate trends in electronegativity and atomic radius on their periodic tables.	BB	<i>Periodic Table</i> from Lesson 7, Substitution Reasoning poster, half sheets of copy paper, chart paper marker, painter's tape
13	5 min		NAVIGATE Prompt the class to brainstorm examples of substances that have some undesirable properties or side effects. Have partners consider how what we figured out could help us make substitutes for these, in at least some of the processes we need them for in space and on Earth.	CC	Substitution Reasoning poster, half sheets of copy paper, chart paper marker, painter's tape

End of day 2

Lesson 8 • Materials List

	per student	per group	per class
Modeling Bond Polarity in 3D materials		• https://www.openscienced.org/simulation/molecule-polarity/ • internet-connected device • 3D molecular model set containing the materials outlined in the lab preparation	• hot glue gun • hot glue stick
Lesson materials	• <i>Periodic Table</i> from Lesson 7 • <i>Video Transcript</i> • sheet of loose-leaf paper • science notebook	• <i>H₂O vs. H₂S</i>	• chart paper • chart paper marker • M-E-F poster • https://youtu.be/ZSNU9GN-NJl • Substitution Reasoning poster • M-E-F poster with expansion panels • copy paper • painter's tape • half sheets of copy paper

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.

Test these ahead of time:

- Video: <https://youtu.be/ZSNU9GN-NJl>
- Simulation: <https://www.openscienced.org/simulation/molecule-polarity/>

Ensure that at least one internet-connected device will be available for every two students.

Ensure that students have access to a color printed or digital version of *H₂O vs. H₂S*.

Prepare to add the following on day 1 to the M-E-F poster from Lesson 4:

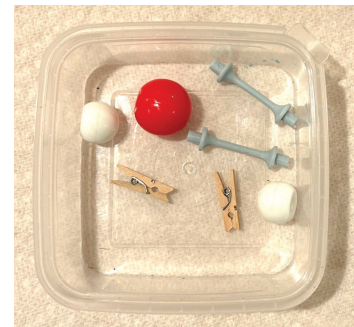
- A panel that says, "In a bond, balanced forces act on both atoms to keep them a relatively stable distance apart."
- A panel that says, "Electronegativity differences shift electrons in a bond."
- An arrow to connect both of these panels together.

Day 2: Modeling Bond Polarity in 3D

- **Group size:** 2 students
- **Setup:**
 - Do the following for 40 mini clothespins: Secure the spring to the wood of each clothespin with a dab of hot glue from a hot glue gun. This will help keep the spring more securely fastened to the clothespin. Though every pair of students will need only 2 clothespins, this set of 40 ensures a few extras to swap in, in case the spring does come out

during use.

- Prepare a 3D molecular model set in a small clear container or bag with the following structures inside, for every pair of students in your largest class:
 - 2 mini clothespins
 - From a molecular modeling kit:
 - 2 white atoms
 - 1 red atom
 - 2 long links/connectors
- **During the lab:** The small container or bag will support quick distribution and collection of the materials. Keep the hot glue gun plugged in to resecure/repair any spring on a clothespin that comes loose during use.
- **Safety:** There are no special safety concerns.
- **Disposal:** There is nothing to dispose of.
- **Storage:** All materials can be stored and reused from one year to the next.



Lesson 8 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students use data from a simulation to identify two additional trends on the periodic table: *electronegativity* and *atomic radius*. This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **PS1.A: Structure and Properties of Matter.** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- **PS1.A: Structure and Properties of Matter.** 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.
- **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.

Crossout explanation: Some of the crossed-out portions of **PS2.B.3** were developed in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. They do not address contact forces in this unit, as this idea is developed in the OpenSciEd High School Physics course in *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*.

In Lesson 7, students explored two new atomic models, the *electron shell model* and the *Lewis dot model*. Students developed definitions for *electron shells* and *valence electrons*, which are tied intimately to each element's place on the periodic table ([SEP: 2.3](#)).

In this lesson, students use their model of the periodic table to predict similarities in the number of bonds. They use a model of electrostatic forces (Coulomb's law) from *Electrostatics Unit* to explain how atomic radius and charge number affect the strength of these forces and contribute to changes in the patterns of electronegativity across the periodic table ([SEP: 2.3](#); [CCC: 1.1, 6.2](#)).

Students move between multiple models, including ball-and-stick manipulatives, Lewis dot models, magnetic models, the periodic table, Coulomb's law, and a simulation, to develop explanations for why bonds keep two atoms at a relatively stable distance from each other. Students synthesize the information from these models to explain how ionic and covalent bonds represent ends of a spectrum in which electrons may be transferred or shared, which affects the degree of bond polarity ([CCC: 1.1, 6.2, 7.1](#)).

Students partially engage in [SEP: 6.2](#). For [SEP: 6.2](#): Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. Students previously developed this element in OpenSciEd High School Biology *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)* and *OpenSciEd Unit B.4: How does urbanization affect nonhuman populations, and how can we minimize harmful effects? (Urbanization Unit)*.

Students engage with [CCC: 7.1](#) for the first time in the OpenSciEd High School Chemistry course. For [CCC: 7.1](#): Much of science deals with constructing explanations of how things change and how they remain stable. Students previously engaged with this CCC in OpenSciEd High School Biology *Natural Selection Unit* and *OpenSciEd Unit B.5: What will happen to Arctic bear populations as their environment changes? (Speciation Unit)*. Students use trends on the periodic table, including electronegativity and atomic radius, to explain stability and differences in atomic bonds.

This lesson begins to help students distinguish between polar bonds and *polar molecules*, which will be explored further in the next lesson.

In this lesson, students will develop a definition for the following terms, which they should annotate along with the corresponding trends on *Periodic Table* from Lesson 7 when the class is at **slide BB**: *atomic radius* and *electronegativity*. If you wish to have students record their own definitions for these terms, have them do so on *Periodic Table*. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

Students will encounter the following terms toward the end of the lesson: *nonpolar covalent bond*, *polar covalent bond*, *ionic bond*, and *dipole arrow*. Students will add these terms to their Personal Glossaries in Lesson 9. During the first half of the lesson, students will practice using the words to make predictions and by the end of day 1, these will become words that students earn.

Where We Are NOT Going

This lesson does not address valence shell electron pair repulsion (VSEPR) theory, as it is outside the bounds of the NGSS. In Lesson 10, students will develop their understanding of why certain bonds form and others do not, but the unit will not go any deeper in helping students think about why molecules are shaped the way they are. Instead, students will focus on provided structures and use their understanding of structure and intermolecular forces to predict bulk behavior.

Students also will not focus on exceptions in periodic trends, such as the lanthanides and actinides, as these tend to tie closely to aspects of quantum theory that are outside the bounds of the NGSS.

Students use Coulomb's law to approximate force differences as a proxy for electronegativity. The repulsive effects of the inner-shell electrons, however, are ignored in this simplification. Understanding of this mechanism is not necessary in this lesson, but if students raise questions about inner electrons, mention that they contribute to lowering electronegativity. This effect is referred to as electron shielding.

We are not introducing the idea that atomic radii decrease slightly from left to right across a row of the periodic table. Such an effect would also contribute to an increase in electronegativity. And while allocating additional instructional time to reason with Coulomb's law could help students figure out that increased positive charge in the nucleus would pull the electrons in the outer shell slightly inward, this additional detail is not needed to understand overall trends in electronegativity. Students also are not explaining or predicting differences in bond lengths in this unit, so it is not necessary to address differences in atomic radii across a row. Bond lengths are explained in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*.

Though electronegativity values do correspond to strength of forces on shared electrons, they are actually measures of the amount of energy needed to remove an electron from an atom. Understanding this distinction is not helpful in this unit. The distinction between strength of forces across a field and the amount of energy transferred between a particle and the field as the particle moves through it is a focus of the last unit of the course, *Fuels Unit*.

LEARNING PLAN for LESSON 8

1 · NAVIGATE

6 min

MATERIALS: None

Navigate. Ask the class what we identified as the top candidate substance that we are going to need for many processes to live and work in different places beyond Earth over many months. Students will say water.

Display **slide A**. Read the text on the top of the slide: *People often search for ways to find or make substitutes for substances when they are in short supply. To do this, they often consider what properties the substitute would need to have.* Point out that there are many examples of this in everyday life, and one that might be most familiar to students is related to cooking or preparing food. Have students consider the two prompts on the slide with a partner, and then discuss examples as a class.

*** ATTENDING TO EQUITY**

Connecting with students' home practices is important. This conversation about the properties of food in cooking provides the motivation to look at the properties of water.

Suggested prompt	Sample student response
[delete row]	
What is an example of a substance that you know some people use as a substitute ingredient when preparing/cooking food? *	Rice flour for wheat flour. Almond milk for dairy milk. Canola oil for butter. Zero calorie sweeteners for sugar.
What are some properties that are similar between the original substance and the substitute?	Taste / sweetness / sourness. Acidity. Oiliness / slipperiness. Smoke point (temperature at which it burns).

ADDITIONAL GUIDANCE

If students do not provide examples of substances with similar taste properties, or are not sure how to describe the properties that are similar, emphasize that it is often difficult to describe what is similar about the taste of different substances, since taste can be somewhat subjective. Follow up by asking students, *What are some substitutes that people use for vegetable oil that have similar properties?* and *What are some substitutes that your family has used for sugar that have similar properties?*

Recap the many uses of water. Display **slide B**. Refer students to any classroom artifacts that indicate all the uses of water we identified from prior lessons. Take a poll for the questions on the slide:

- If another substance had similar properties as water, could it serve as a substitute in at least some of the processes we use water for?
- Do you think this candidate substitute would have a similar structure as water?*

ADDITIONAL GUIDANCE

Mentioning cleaning or washing here may help students suggest examples of substitutes for water in these processes, such as alcohol or a different substance that dissolves stuff or carries away dirt easily. This provides an opportunity for students to connect back to some of their work in Lesson 4.

If there are conflicting predictions, foreground them. Either way, suggest that we start by trying to identify a substance that has a similar molecular structure to water to test our ideas against, by considering what we figured out about atoms and bonds in the last lesson.

2 · USE MODELS TO MAKE PREDICTIONS

7 min

MATERIALS: *Periodic Table* from Lesson 7, chart paper, chart paper marker, M-E-F poster

Identify the bonds in a water molecule. Display **slide C**. Discuss the question on the slide. Students should say that two bonds are being represented.

Problemalyze the bond “line.” Point out that nothing in the chemical formula itself tells us this, but the two models (ball-and-stick and Lewis dot) do. Ask how a single bond is represented in the Lewis dot model on the right. Students will say it is the two electrons in the overlapping dotted circles around each atom. Point out that the line representation in the ball-and-stick model makes it seem like there is a physical structure connecting the atoms, but we know that this representation is a simplification to show which two atoms are sharing electrons.



Identify a replacement atom. Display **slide D**. Ask the question on the slide, *What is another element that should produce the same number of bonds with two hydrogen atoms?* Point to the question marks shown in the new chemical formula and molecular models on the slide. Encourage students to refer to *Periodic Table* from Lesson 7 to identify a candidate. After giving a half minute to do this, have students share.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use the periodic table. (SEP: 2.3)
- Students identify a replacement atom that forms the same number of bonds as O (or any other atom in the column). (DCI: PS1.A.2; CCC: 1.1)

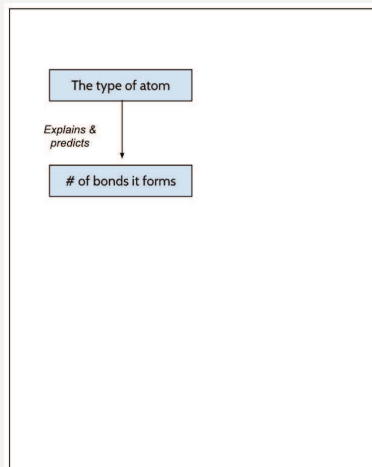
What to do: Ask students to work with a partner to find what other elements have the same number of electrons in their outer shell as oxygen.

Building toward 8.A.1 Use the periodic table to identify atoms with similar bonding patterns and to explain how differences in atomic structure could contribute to differences in electronegativity. (SEP: 2.3; DCI: PS1.A.2; CCC: 1.1)

Suggest that we keep track of these predictions in the form of a causal chain. Add the following diagram to the board.

If this is your last class, add it to a piece of chart paper, which will be referred to as the *Substitution Reasoning* poster for the rest of this lesson.

Suggest that we consider one of these substitutes, to see what we can predict and explain about it from similarities in its structure. Display **slide E**. Discuss the two questions on the slide and accept all responses. Foreground any areas of competing predictions that emerge.



Suggested prompt

Would these molecules have similar polarities?

Would these substances have similar properties?

Sample student response

They have similar structures, so I would think so.

Maybe similar polarity, but maybe not exactly the same.

Wouldn't the number of protons also affect its polarity?

Maybe.

If the properties are related to the polarity, then yes.

I don't know that they would have the exact same properties though.

ADDITIONAL GUIDANCE

Students may bring up that sulfur has more electron shells than oxygen, and that this difference in size may also affect its polarity. If they do, you can ask students to consult their periodic table to confirm this. If they do not bring up shell numbers now, that is okay; you will introduce that idea a bit later.

Suggest that we keep adding these predictions and any uncertainties we have identified in our reasoning so far to the model we started.

Add this question as the title to the top of the Substitution Reasoning poster: "Could another substance serve as a substitute for water for some of the processes we need to use it for in space?"

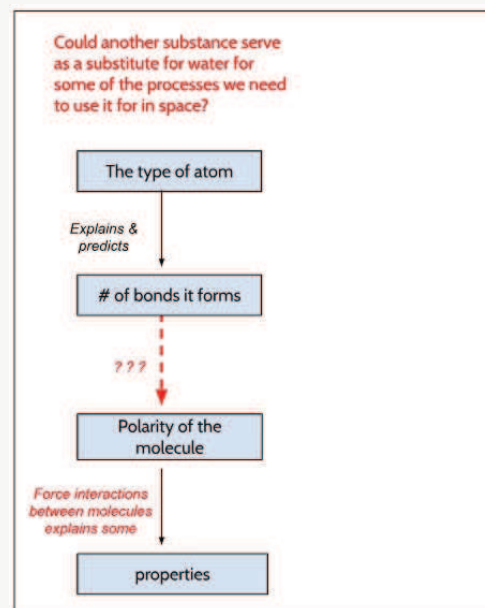
Place question marks and dotted lines in areas of less certainty, emphasizing the need for additional data to determine whether such relationships exist or to refute/support our predictions.

Ask students for an example of a property of water that is at least partly based on force interactions due to water's polarity. Listen for any example from Lesson 4 (e.g., adhesion, cohesion, ability to dissolve salt(s)).

Add "Force interactions between molecules explains some", next to the last arrow.

Refer to the M-E-F poster to highlight where the connections between the last two boxes on the Substitution Reasoning poster are located.

Point out that if forces due to water's polarity could explain some of its properties, then it would make sense for us to take a forces perspective when figuring out more about the box labeled "# of bonds it forms", since we know all charge interactions produce attractive and repulsive forces.



3 · USE A MODEL TO EXPLAIN STABILITY IN A BOND

9 min

MATERIALS: Video Transcript, <https://youtu.be/ZSNU9GN-NJI>, Substitution Reasoning poster, M-E-F poster with expansion panels, copy paper, painter's tape, chart paper marker



Watch and discuss a video depicting relationships between forces and charge. Reference the M-E-F poster to remind students that we can draw on our reasoning about the relationship between forces and charge that we developed in the prior unit to think about how we can use magnets to help us model the forces in a bond between two positive nuclei and two shared electrons. Before the video begins, you may tell students they will see a configuration of very strong magnets that represent two atoms.

Display slide F. Play <https://youtu.be/ZSNU9GN-NJI> and distribute Video Transcript. There are five discussion questions displayed as text during the video. When each question appears, pause the video and discuss. Sample student responses are shown in the table.

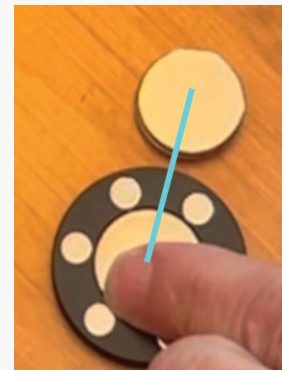
Discussion Question	Sample Student Response
Q1) If the two magnets represent two positively charged nuclei, what force interactions should we see evidence of as we bring them closer together? (Timestamp: 0:05)	They should be pushed apart from each other. Repulsion.
Q2) What does Coulomb's law predict will happen to the strength of the forces between charges as you bring them closer together? (Timestamp: 0:043)	The forces should get stronger.

Q3) <i>The smaller magnet is going to represent an electron. What force interactions should we see between it and the larger magnet (the nucleus) when we bring them closer together?</i> (Timestamp: 1:13)	They should come together. Attraction.
Q4) <i>If there are both attractive and repulsive forces being produced in the system, then what will we see happen when we bring the two parts of these two atoms together?</i> (Timestamp: 1:41)	Accept all predictions.
Q5) <i>What forces are causing the system to remain at a relatively stable distance apart?</i> (Timestamp: 1:58)	The attractive and repulsive forces.

Resume the video and discuss the follow-up questions. Return to any point in the video which may be helpful for the discussion.

Suggested prompt	Sample student response
<i>Which forces are stronger, the repulsive or attractive forces as the two parts of the system are pushed closer together than its stable bond length of 4 mm?</i>	The repulsive forces.
<i>Which forces are stronger, the repulsive or attractive forces as the two parts of the system are pulled farther apart than its stable bond length of 4 mm?</i>	The attractive forces.

Point out that in both cases – that of the magnets, and of atoms that form bonds – the bond itself is not an actual structure. Say something like, *We often try to visualize where the stable force interactions are occurring by drawing a line from the center of one atom to the center of another, between the two shared electrons in that bond.* Trace a line on the screen to show this.



ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students explain that **balanced force interactions** (repulsion between nuclei and attraction to shared electrons) exist to **cause two bonded nuclei to remain in a stable state at a certain distance from each other.** (DCI: PS2.B.3; CCC: 6.2, 7.1)

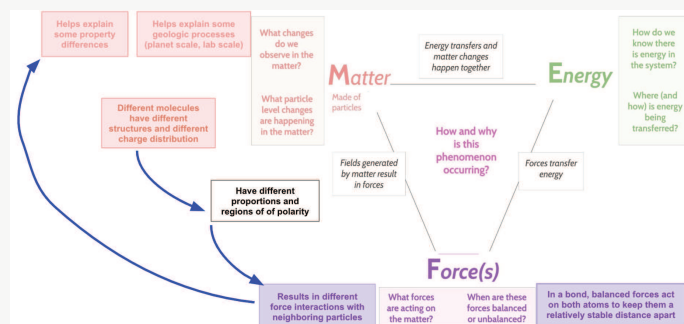
What to do: Revisit question 5 after discussing the follow-up questions.

Building toward 8.B.1 Explain **bond stability**, differences in three **properties**, and differences in **molecular polarity** of two molecules based on the **relative strength of forces between atoms and molecules.** (SEP: 6.2; DCI: PS1.A.1, PS2.B.3; CCC: 6.2, 7.1)

Revisit the “line” representation of bonds. Emphasize that the line is simply showing us the direction along which this stable state/connection forms. This is one way that we represent bonds when we draw molecules, but it is important to keep reminding ourselves that in reality, a bond is just a state in space where the force interactions from the different fields being produced by the different charges in the system are balanced.

Add an expansion panel to the right of “Forces” on the M-E-F triangle that says the following:

- In a bond, balanced forces act on both atoms to keep them a relatively stable distance apart.



4 · USE MODELS TO MAKE PREDICTIONS

6 min

MATERIALS: *Periodic Table* from Lesson 7, Substitution Reasoning poster, chart paper marker, copy paper, painter's tape

Use Lewis dot models to explain water molecule polarity. Suggest that we continue to investigate forces influencing the structure of a water molecule. Display **slide G**. Remind students to consult their *Periodic Table* from Lesson 7 as they turn and talk to answer the question on the slide.

After a minute or two, pause students and display **slide H**. Read the additional text on the slide: *There are 2 inner-shell electrons in the oxygen atom that are not shown. These, plus the 8 electrons in the outer shell, result in a total of 10 electrons in the red region.* Give partners an additional minute to discuss the question on the slide, and then discuss it as a class. Prompt for numbers in students' reasoning. Listen for these ideas:

- The blue regions of the water molecule are positive, because the charge closest to that end is +1 from the single proton in the nuclei of the H atoms.
- The red region of the water molecule is negative, because there is a total (net) charge of -2 in this space due to the two extra bonded electrons.

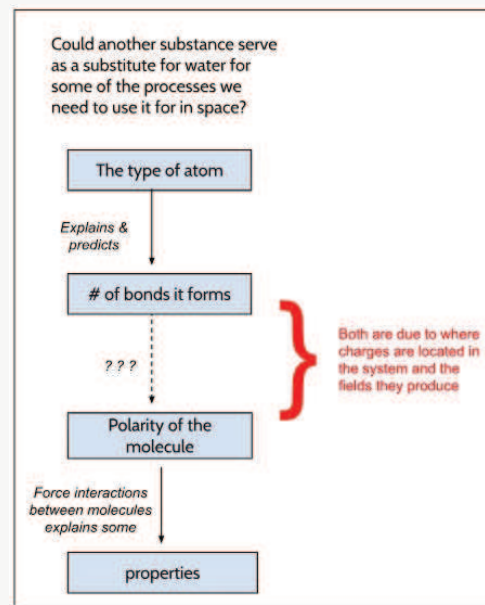
* SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

Charges and forces predict the structure and function of molecules. This is a great moment to highlight that the structure and function of all matter are determined by molecular forces and interactions (CCC: 6.2).

Refer back to the second and third boxes of the *Substitution Reasoning* poster. Emphasize to students that thinking about the charges and forces helps us better explain both how bonds form as well as the polarity of a water molecule.

Add a bracket with the following text to the diagram on the board (or to the *Substitution Reasoning* poster if this is your last class of the day): “Both are due to where charges are located in the system and the fields they produce”. You can also write this on a sheet of paper and tape it to the poster.

Use Lewis dot models to make predictions. Display slide I. Discuss the question on the slide as a class: *How should the polarity and properties of H₂S compare to those of H₂O?* Students likely will argue that the molecules should have the same polarity due to their similar structures.*



5 · COMPARE POLARITIES AND PROPERTIES

12 min

MATERIALS: *H₂O* vs. *H₂S*, Substitution Reasoning poster, M-E-F poster with expansion panels, painter's tape

Compare the polarities and properties of H₂S and H₂O. Display slide J. Distribute *H₂O* vs. *H₂S* to each pair of students and give them five minutes to discuss the question on the slide. Then discuss this question as a class. Follow up with the second question below.

Suggested prompt	Sample student response
<i>How do the patterns in the polarity and properties of H₂O and H₂S compare to your predictions?</i>	The same ends/sides/regions we predicted for water and hydrogen sulfide are positive and negative. Water has a redder and bluer region of polarity than hydrogen sulfide, so it must be more positive or negative in those regions. Most of the properties were very different. Density and characteristics of a solvent were more similar.

Suggested prompt	Sample student response
<i>Were there any properties that helped you figure out whether H₂S would be a good or safe substitute to use in any of the processes we use water for?</i>	Because it is poisonous and flammable, it does not seem like a very safe substance to be using for these processes.



Explain some property differences between H₂S and H₂O. Display slide K. Emphasize that it may be difficult to explain how and why hydrogen sulfide is poisonous without knowing more about the types of substances that make up different parts of our bodies, but we can probably explain other property differences. Discuss the three property differences highlighted on the slide. Suggested prompts include:

- How do differences in polarity help explain why water is more cohesive than hydrogen sulfide?
- How do these differences also help explain why water has a higher boiling point than hydrogen sulfide?
- How are these differences related to why, as liquids, water is better than hydrogen sulfide at dissolving more substances?

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students **explain** that: (SEP: 6.2)

- the **higher polarity** of H₂O molecules **exerts more pull (stronger forces)** on opposite ends of neighboring H₂O molecules; (DCI: PS2.B.3)
- **stronger pull causes more cohesion and higher boiling point** (it takes more energy to knock apart H₂O molecules into gas); (DCI: PS2.B.3; CCC: 7.1)
- the **higher polarity** of H₂O molecules (**structure**) **exerts more pull (stronger forces)** on oppositely charged particles nearby, making it **better at dissolving substances (function)**. (DCI: PS2.B.3; CCC: 6.2)

What to do: Prompt students to recall their explanations for the first two properties from Lessons 2 and 4. Encourage students to recall our model from the prior unit *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes?* (Electrostatics Unit) showing why water dissolves salts so well.

Building toward 8.B.2 **Explain bond stability, differences in three properties, and differences in molecular polarity** of two molecules based on the **relative strength of forces between atoms and molecules**. (SEP: 6.2; DCI: PS1.A.1, PS2.B.3; CCC: 6.2, 7.1)

Refer back to the arrow between the last two boxes on the *Substitution Reasoning* poster and point out that we are now able to explain some of the property differences based on the polarity differences in these two molecules.

Refer students to the M-E-F poster to highlight these connections there as well.

6 • EXIT TICKET

5 min

MATERIALS: *Periodic Table* from Lesson 7, sheet of loose-leaf paper



Introduce electronegativity. Display slide L. Read the text on the slide: *Electronegativity is a measure of how strongly a nucleus is attracted to shared electrons. Greater electronegativity corresponds to stronger attraction.* Give students the remaining time to individually write responses to the two questions on the slide as an exit ticket.

Give feedback. Review exit tickets by doing a quick sort based on students' responses to question 2, as described below. You will begin day 2 of the lesson by sharing a likely divergence: whether and how polarity is related to the intramolecular (inside the molecule) forces.*

* ATTENDING TO EQUITY

Universal Design for Learning: During this assessment opportunity you may hear a number of student ideas. Encourage students to write down their ideas or draw

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use the periodic table. (SEP: 2.3)
- **Question 1:** Students describe how sulfur (S) has one more electron shell than oxygen (O), making it bigger, and has more protons (and electrons). (DCI: PS1.A.2; CCC: 1.1)
- **Question 2:** Students state that the amount of positive charge and/or distance to the nucleus contribute to differences in electronegativity and/or how much the electrons are shifted in the molecule, which may be related to its polarity. (DCI: PS1.A.2)

What to do: For question 1, encourage students to reference their periodic table. Because question 2 is designed to support navigation to the start of day 2, it is okay if students do not make connections to polarity yet.

Building toward 8.A.2 Use the periodic table to identify atoms with similar bonding patterns and to explain how differences in atomic structure could contribute to differences in electronegativity. (SEP: 2.3; DCI: PS1.A.2; CCC: 1.1)

them. This supports students by providing multiple means of *representation* and *action & expression*. Many students still may prefer to share their ideas out loud. Following is a list of phrases that are on target for this stage of the lesson. First, listen for accurate expressed differences between sulfur and oxygen:

- Sulfur is bigger than oxygen.
- Sulfur has more protons and electrons than oxygen.
- Sulfur has one more electron shell.
- Oxygen has two electron shells, but sulfur has three.
- The valence electrons are farther from the center of sulfur.

If these ideas are stated incorrectly by more than 20% of your class, consider revisiting relevant parts of Lesson 7, or day 1 of Lesson 8, to learn periodic trends. If students are consistently stating the first three ideas, continue on to day 2.

Second, listen for students to attempt to predict how these differences might explain electronegativity. Encourage students to use their resources about forces to reason this through. (All ideas are valid; this question is a navigation question to day 2.) Students may say that either:

- Electronegativity is higher for sulfur because it is bigger, somehow making the pull greater.
- Electronegativity is higher for oxygen because it is smaller, somehow making the pull greater.

End of day 1

7 • NAVIGATE

2 min

MATERIALS: None

Review some of the ideas raised in the exit ticket. Display slide M. Reintroduce what electronegativity is a measure of by reading aloud the text on the slide. Discuss the question on the slide as a class. Listen for ideas that include:

- the number of charges in the nuclei
- the number of electron shells and/or the number of electrons in each shell
- the size of the atom (based on how many shells it has)

Suggest that we consider some of these differences, one at a time, with a partner over the next couple of slides.

8 · DEVELOP INITIAL EXPLANATIONS

6 min

MATERIALS: M-E-F poster with expansion panels, Substitution Reasoning poster

Consider the role of protons in the nucleus. Display **slide N**. Give students one minute to discuss the prompt on the slide with a partner. Listen for ideas about the higher charge “pulling harder” on electrons, which could add compelling uncertainty to the conversation. Do not dismiss this idea at this stage.

Consider the role of distance. Display **slide O**. Explain that atomic radius is the distance from the nucleus to the outer shell of the atom. Give students another minute to discuss the prompt on this slide with a partner, then discuss as a class.

Suggested prompt

Why would the combination of nuclear charge and atomic radius contribute to differences in electronegativity?

Sample student response

Greater charge number would produce stronger forces.

Greater distance would weaken forces.

Sulfur has both of these compared to oxygen, so one of these might be having a greater effect than the other.

But sulfur has twice the number of positive charges in its nucleus, and not twice the radius, so wouldn't the effect of charge outweigh the effect of distance?

Connect to Coulomb's law. Display **slide P**. Ask students to consider how this connects to Coulomb's law, which they developed in the prior unit, *Electrostatics Unit*. Reorient students to what the variables in the equation represent.* Listen for student ideas like:

- The effect of distance (r) on force is greater than the effect of charge, because r is squared.
- 100 squared (10,000) is more than twice as great as 60 squared (3,600), so the effect of atomic radius is greater than the effect of charge, which only doubled (8 to 16).

* SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

If some students are interested in calculating the force with Coulomb's law using the information on the slide, provide the following:

- $k = 2.3 \times 10^{-8}$ Newtons • angstroms² / e² (a constant conversion factor)
- q_A = the corresponding value from the table (each proton has a charge of +1 e)
- $q_B = -1$ e (the charge of a single shared electron)
- r = the corresponding value from the table (in angstroms)

The calculated force that Coulomb's law yields with these values will give a reasonable approximation for the differences in electronegativity. The repulsive effects of the inner-shell electrons, however, are ignored in this simplification. It is not necessary to introduce this additional mechanism to students. If, however, they raise questions related to this, you may include a brief mention that these electrons contribute to lowering electronegativity and that this effect is referred to as electron shielding.

Though relative differences in electronegativity values correspond to the relative strength of forces on shared electrons, they are actually measures of the

amount of energy needed to remove an electron from an atom. Understanding the difference between the strength of forces at a particular location in a field and the energy transferred between a particle and the field as the particle moves through it is a focus of the last unit of the course, *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?* (Fuels Unit), and is not a necessary distinction to explain the phenomena in this unit.

9 · MAKE PREDICTIONS USING A MANIPULATIVE AND EXPLORE A SIMULATION

10 min

MATERIALS: Modeling Bond Polarity in 3D

Introduce a manipulative. Suggest that we try to visualize how these differences in electronegativity might affect the bonded electrons. Distribute a 3D molecular model set to each pair of students. Display **slide Q**. Have students add the clothespin to the two bonded atoms as shown on the slide. Explain that this will represent the two shared electrons in the bond in the space between the two nuclei.

Make predictions. Display **slide R**. Point to the electronegativities shown on the slide and the three types of bonds in the table. Have partners explore and predict where the bonded electrons would be found relative to the two nuclei for each bond in the table by moving the clothespin to show either a) closer to one nucleus than another, or b) equal distance from both nuclei. Encourage students to communicate to their partner which atom in the model is which as they do this.

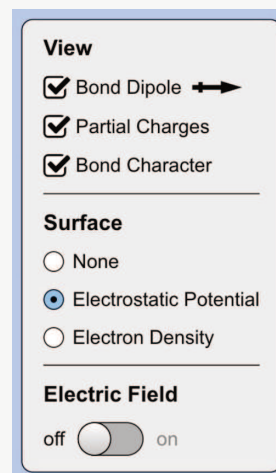
Test electronegativity predictions. Explain that students will test their predictions with a simulation. Display **slide S**. Share the simulation link with students: <https://www.openscienced.org/simulation/molecule-polarity/>. Have all students select the “Two atoms” option and, once it loads, adjust the settings on the simulation interface to match those shown on the slide.

Have students use their mouse to “grab” one of the atoms and move it slightly up and down to make the green and yellow “grab arrows” disappear from the field of view.

Display **slides T-W** to walk students through what they can change and what they should compare:

- **Slide T:** You can try different combinations of electronegativities.
- **Slide U:** Compare how electronegativity differences affect polarity, which will make the region around an atom bluer if it becomes more negative and redder if it becomes more positive.
- **Slide V:** Compare how electronegativity differences affect bond character.
- **Slide W:** Compare how electronegativity differences affect where the shared electrons are located in the space between the atoms. The double arrow, or dipole arrow, represents this. If there is no arrow showing, the electrons are not shifted at all and are equal distance from the nuclei. The larger the dipole arrow is, the greater the shift in the electrons (which corresponds to a greater shift of the clothespin in students’ 3D models).

Display **slide X** as a reference for students for the remaining minutes as they explore the simulation with a partner.



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10 · REPRESENT THE RESULTS AND MODEL ELECTRON SHIFTS

9 min

MATERIALS: Modeling Bond Polarity in 3D, M-E-F poster with expansion panels

Display **slide Y**. Have partner groups work with their manipulatives as you discuss the three bonds shown on the slide.

Ask students the following questions for each bond:

- Where are the shared electrons in this bond? Where should you put the clothespin in your manipulative?
- How did the representation of the dipole arrow change?
- What does this do to the bond character?
- What does this do to the overall polarity of the bond?

* SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Bond character should be taught as a continuum. Despite past pedagogy delineating bond character as ionic OR

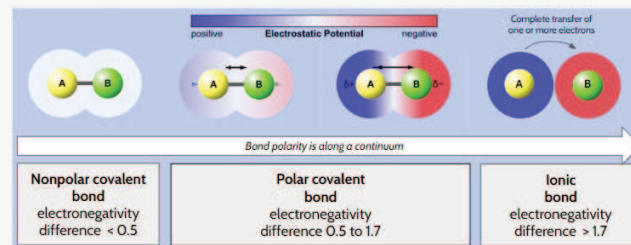
ADDITIONAL GUIDANCE

The visualizations of the polarity of the water and hydrogen sulfide molecules that students encountered on day 1 of this lesson, and of the liquids in Lesson 4, used red to represent regions of greater negative charge and blue to represent regions of greater positive charge. Such visualizations are sometimes referred to as Electrostatic Potential maps. This is the term that students will see used in the simulation to refer to the red-blue color gradient that represents shifts in the relative polarity of bonds.

Name the differences in bond character. Introduce the idea that scientists sometimes describe the two extremes based on where electrons end up in a bond. At one extreme, the word *covalent* means equally shared, which describes where the electrons are in the system, while the other extreme represents bonds that are ionic in character. Ask students what they recall about the meaning of *ion* and *ionic bond* from *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. Students will say:

- An ion is an atom that gains or loses electrons.
- An ionic bond is the result of the attraction of two oppositely charged ions.

Display **slide Z**. Identify the continuum and the three categories of bonds underneath that scientists use to distinguish how much shift there is in the electrons. Emphasize that bonds that fall within these categories can still fall along the continuum of “less” to “more”.*



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covalent, the NGSS require bond character to be modeled in terms of forces, energy, and relative positions of particles. If you are considering altering this lesson to include nomenclature quizzes, keep in mind that students benefit in the long term from a model of intermolecular forces that accounts for energy and matter. (DCI: PS2.B.3)

Remove the connector to model ionic bonding. Have partner groups model the ionic bond with their manipulatives by detaching the connector and transferring the clothespin all the way over to one of the two atoms. Emphasize that the removal of the connector represents that there is no longer a clear geometry line between the atoms along which they share electrons.

Suggested prompt

How is this similar to our paper-clip models of bonds in our previous unit, Electrostatics Unit?

How are these two atoms still bonded?

Sample student response

The paper clips “transferred” from one index card to another.

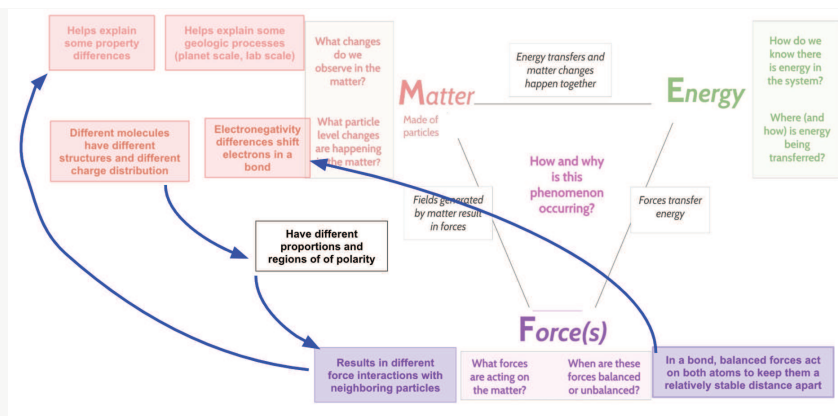
They are attracted because of their atom-to-atom charge.

One atom has a positive charge overall, and one has a negative charge overall.

They don’t have a “line” where the atoms hang out.

Update the M-E-F poster:

- Move the panel that says “Different molecules have different structures and different charge distribution” to the left to make room for a new expansion panel.
- Add the new expansion panel that says “Electronegativity differences shift electrons in a bond”.
- Add an arrow to this panel from the panel that says “In a bond, balanced forces act on both atoms to keep them a relatively stable distance apart”.



11 · CONSTRUCT AN EXPLANATION

4 min

MATERIALS: sheet of loose-leaf paper

Display **slide AA**. Point out that earlier, we predicted that both H_2O and H_2S were polar, but did not have an explanation for their differences in polarity when we first compared their molecular models on the slide – and that now we do. Give students this time to individually summarize an explanation for why H_2O molecules are more polar than H_2S molecules. Have students write their explanations on a sheet of loose-leaf paper and collect these as an assessment opportunity.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students **explain** that: (SEP: 6.2)

- the **higher electronegativity of O compared to S** means that **O atoms pull more strongly on the electrons** it shares in bonds with H than S atoms do, (DCI: PS1.A.1, PS2.B.3)
- leading to **a greater amount of shift in the electrons toward O than toward S**, (DCI: PS1.A.1; CCC: 6.2, 7.1)
- and these differences **in the structures of bonded atoms contribute to a higher degree of polarity** in some bonds vs. others and thus **differences in molecular polarity (function)** of H_2O compared to H_2S . (DCI: PS2.B.3; CCC: 6.2, 7.1)

What to do: Prompt students to recall their explanations for the first two properties from Lessons 2 and 4. Encourage students to recall our model from the prior unit *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes?* (Electrostatics Unit) showing why water dissolves salts so well.

Building toward 8.B.3 **Explain bond stability**, **differences in three properties**, and **differences in molecular polarity** of two molecules based on the **relative strength of forces between atoms and molecules**. (SEP: 6.2; DCI: PS1.A.1, PS2.B.3; CCC: 6.2, 7.1)

12 · ADD ELECTRONEGATIVITY AND ATOMIC RADIUS TRENDS TO OUR PERIODIC TABLES

8 min

MATERIALS: *Periodic Table* from Lesson 7, science notebook, Substitution Reasoning poster, half sheets of copy paper, chart paper marker, painter's tape

Annotate our periodic tables. Display slide BB. Have students take out their *Periodic Table* from Lesson 7. Ask students to describe what happens to atomic radius as we move down a column. Students should say that it increases. Have students add a downward-pointing arrow to the left side of their periodic table and label it “increasing atomic radius”.

Ask students how the electronegativities of oxygen and sulfur compare and then ask what should happen to electronegativity as atomic radius decreases. Students will say it should increase. Have students add an upward-pointing arrow to the right side of their periodic table and label it “increasing electronegativity.” Ask them how this is related to Coulomb's law.

Have students move across the second row of the periodic table and ask them what happens to the charge in the nucleus as they do so. Students will say it increases. Ask them why this would cause electronegativity to increase and how this is related to Coulomb's law. Then have students add a rightward-pointing arrow above their periodic table and label it “increasing electronegativity”.

Have students add an annotation to *electronegativity* to describe what it means in terms of the relative strength of force acting on electrons in the outer shell. Have them do the same for *atomic radius*.

ALTERNATE ACTIVITY

Electronegativity and *atomic radius* are terms that students have now earned. Having students add a personal meaning/definition for each term to their periodic table will probably make for a more useful reference than having students add them to their Personal Glossary. But you can give students that option if they prefer it.

ADDITIONAL GUIDANCE

Helping students to link a more fundamental mechanism for electronegativity is the reason we are asking them how Coulomb's law applies to these trends in the periodic table. We are only using differences in atomic radius between rows and differences in atomic charge across a row to do this.

We are not introducing the idea that atomic radii decrease slightly from left to right across a row of the periodic table. Such an effect would also contribute to an increase in electronegativity. And while additional reasoning with Coulomb's law could help students figure out that increased positive charge in the nucleus would pull the electrons in the outer shell slightly inward, this additional detail is not needed to understand overall trends in electronegativity. Students also are not explaining or predicting differences in bond lengths in this unit, so it is not necessary to address differences in atomic radii across a row. Bond length becomes important in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?* (Fuels Unit).

Ask students which corner of the table has atoms with the highest electronegativity values and which corner has atoms with the lowest. Students should indicate the top right for highest and the bottom left for lowest.

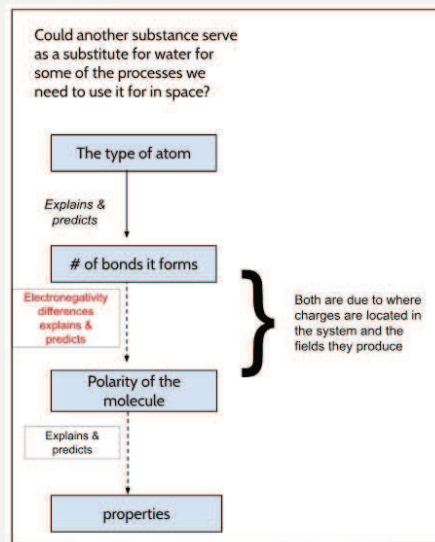
Ask, *How could we use these trends to predict and explain the characteristics of any bond?* Listen for students to share ideas like:

- Atoms farther apart on the periodic table will tend to form more polar or ionic bonds with each other.
- Atoms closer together on the periodic table will tend to form more nonpolar covalent bonds with each other.
- The same atoms will form nonpolar covalent bonds with each other.

Revisit the *Substitution Reasoning* poster. Tape a half sheet of copy paper that says “Electronegativity differences explain and predict” next to the second arrow.

Emphasize that with water and hydrogen sulfide, students had to consider only two bonds and their polarity differences to explain the overall polarity of each molecule. Suggest that we can continue to apply this thinking to more complex molecules in the next lesson.

Suggest that while some of those molecules could be the liquids we investigated earlier in the unit, like isopropyl alcohol or acetone, it might be interesting to include some new ones to see whether/how our ideas can be applied to any substance.



13 · NAVIGATE

5 min

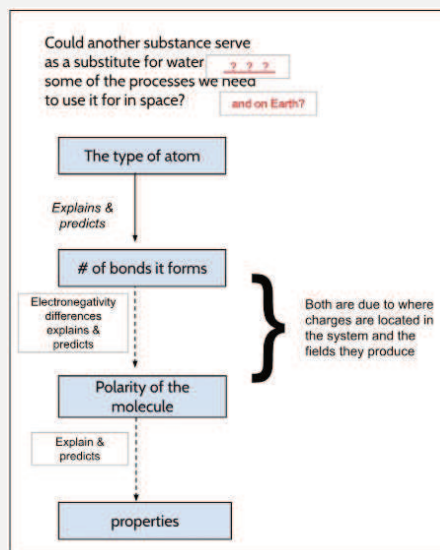
MATERIALS: science notebook, Substitution Reasoning poster, half sheets of copy paper, chart paper marker, painter's tape

Summarize what we have figured out. Emphasize that because of some of its property differences, like toxicity, we likely cannot use hydrogen sulfide to replace water in any of the processes we need it for. Tell students that the type of thinking we did today is what scientists do to try to find or create new substances that are better substitutes for what we currently use.

Foreground that there are many areas in which scientists are making rapid breakthroughs designing replacements for other substances, by using the type of thinking we did today – not just for living in space, but also for living and working on Earth.

Suggest that we broaden our lesson question, then, to consider other possible substitutes that we might make. On the Substitution Reasoning poster, make the changes shown in red and described below to indicate that we have broadened the application of our question.

- Tape a half sheet of copy paper with a blank line and question marks over the word “water” in the question title.
- Tape a half sheet of copy paper with the phrase “and on Earth?” over the question mark at the end of the question title.



Suggest that in preparation for looking into this further next time and filling in this blank in our question, you will give students a moment to record their own ideas in their science notebooks. Display **slide CC**. Give students the remaining class time to work with a partner to record their responses to the two prompts on the slide. Tell students they will share these out at the start of the next lesson.

Keep the *Substitution Reasoning* poster displayed for students to refer to the next class.

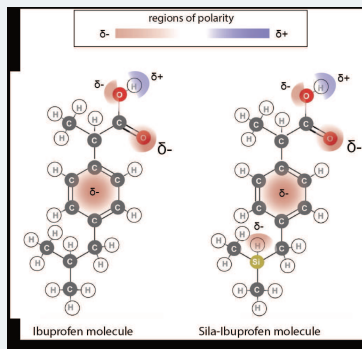
LESSON 9: How can the ideas we developed be applied to making a possible substitute for another substance?

PREVIOUS LESSON We predicted and modeled the structure of a substance that could replace water for some processes. We compared their properties and polarities. We used a simulation to explore how electronegativity differences affect where electrons are in a bond, the bond characteristic, and its polarity. We updated our periodic table to include trends in electronegativity.

THIS LESSON

PUTTING PIECES TOGETHER

2 days



Kleemiss, F., et al. (2020)

We describe bond characteristics in salt, wood, and metal and consider salt substitutes in our diets. We model the polarity for different substances. We explain how the ideas we developed could be applied to making a possible substitute for another substance. We evaluate our progress on our DQB questions. We consider how being able to make medicines on site would help our long-term plans for surviving beyond Earth. In a transfer task, we explain why one such replacement medicine has a similar structure to ibuprofen but different solubility in water. We record new questions.

NEXT LESSON We will read about how copper can be cleaned from water so that it can be used in various important processes. We will model this reaction and consider how molecular structures help determine how they react. We will wonder about other ways that water can be cleaned

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, HS-ESS1-2, HS-ESS2-1, HS-ESS2-5



WHAT STUDENTS WILL DO

9.A Use a variety of models and evidence (such as solubility and periodic trends in electronegativity and atomic radius) to a) describe the patterns and relationships between the parts of an atom and the bonds formed between atoms, b) predict polarity differences, and c) explain property differences based on the relative differences in the strength of forces between atoms and molecules. (SEP: 2.3; DCI: PS1.A.3, PS1.A.2; CCC: 1.1, 6.2)

WHAT STUDENTS WILL FIGURE OUT

- Some pairs of atoms can form double or triple bonds.
- The polarity of a molecule can be determined by comparing the relative polarities of bonds within it. Which can be determined from the difference in the electronegativities of the atoms that make up the bond.
- Some biochemistry and environmental chemists work on designing new substances, like medicines, that have more desirable properties or fewer side effects than those we use now.

Lesson 9 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE AND SELECT FOCAL AGREEMENTS Ask the class to consider how developing new substances could impact more sustainable living on Earth and beyond it.	A-B	Community Agreements, Substitution Reasoning poster from Lesson 8
2	9 min		USE A MODEL Orient students to a new electronegativity reference and re-introduce three models from a prior unit.	C-E	<i>Electronegativity Periodic Table</i>
3	12 min		IDENTIFY CANDIDATE SUBSTITUTES AND DETERMINE BOND CHARACTER AND POLARITY Have students use the periodic table and related electronegativities to identify substitute atoms and determine bond character and polarity of different molecules.	F-K	<i>Electronegativity Periodic Table, Modeling Polarity</i>
4	9 min		DETERMINE MOLECULAR POLARITY Orient students to use diagrams and manipulatives to visualize and predict the relative shifts of electrons in different bonds.	L-Q	hot glue gun, hot glue stick, Modeling Molecular Polarity in 3D
5	5 min		CONNECT TO OUR M-E-F POSTER Lead a class discussion to identify connections we made today through the lens of the M-E-F poster.	R-S	M-E-F poster with expansion panels, blue arrow
6	5 min		UPDATE PROGRESS TRACKERS AND INTRODUCE OPTIONAL HOME LEARNING Have students individually add a Progress Tracker entry. Introduce an optional home learning connected to dietary salts.	T-U	<i>Dietary Salts</i> (optional), M-E-F poster with expansion panels
<i>End of day 1</i>					
7	4 min		NAVIGATE Share some Progress Tracker entries as a class.	V	M-E-F poster with expansion panels
8	7 min		IDENTIFY QUESTIONS WE CAN NOW ANSWER Have partners take stock of the progress we have made on our DQB questions.	W	<i>Our DQB Questions</i> , DQB, panel for revised driving question
9	4 min		REFLECT ON COMMUNITY AGREEMENTS Have students reflect on their use of a focal Community Agreement.	X	Community Agreements
10	4 min		CONSIDER SUBSTITUTE SUBSTANCES IN MEDICINE Introduce the ideas that will be explored in the Mid-Point Assessment.	Y-Z	
11	26 min		COMPLETE A TRANSFER TASK AND ASK NEW QUESTIONS Have students use models to construct an individual explanation for how sila-ibuprofen could be a substitute medicine for ibuprofen. Record new questions we now have.	AA-CC	<i>Sila-ibuprofen Transfer Task</i> , 2 sticky notes (3" x 3"), permanent marker
<i>End of day 2</i>					

Lesson 9 • Materials List

	per student	per group	per class
Modeling Molecular Polarity in 3D materials	- science notebook <i>Electronegativity Periodic Table</i> <i>Modeling Polarity</i>	- clear container or bag 3D molecular model set containing the materials outlined in the lab preparation.	
Lesson materials	- science notebook <i>Electronegativity Periodic Table</i> <i>Modeling Polarity</i> <i>Dietary Salts</i> (optional) <i>Our DQB Questions</i> - Science Notebook <i>Sila-ibuprofen Transfer Task</i> 2 sticky notes (3" x 3") - permanent marker		- Community Agreements - Substitution Reasoning poster from Lesson 8 - hot glue gun - hot glue stick - M-E-F poster with expansion panels - blue arrow - DQB - panel for revised driving question

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.

Have the Community Agreements visible throughout this lesson.

Day 1 Preparation:

Ensure that students have access to a color printed or digital version of *Electronegativity Periodic Table*. Students should also keep a permanent copy of *Electronegativity Periodic Table* for reference in their science notebooks. It is okay to make students a printed black-and-white copy for this purpose.

Prepare to add the following to the M-E-F poster from the prior lesson:

- a blue arrow connecting the expansion panel that says “Electronegativity differences shift electrons in a bond” to the expansion panel that says “Different molecules have different structures and different charge distribution”.
- a panel that says “Helps explain some geologic AND biological processes”, which you will use to cover the panel that says “Helps explain some geologic processes (planet scale, lab scale)”.

You will add this arrow and panel during day 1 of the lesson and remove them at the end of each period before your next class. You will keep both of these on the M-E-F poster after your last class period on day 1.

Day 2 Preparation:

Prepare a copy of *Our DQB Questions* for each class period by pasting that class’s DQB questions into the notated portion of the handout.

Create a panel for an updated driving question to reflect our shift to thinking about Earth: *How can we find, make, and recycle the substances we need to live on and beyond Earth?*

Print *Sila-ibuprofen Transfer Task* in color if possible, as page 4 has a color image that students will need to reference as they complete the assessment. If you do not have access to a color printer, **slide BB** is provided as a color reference.

Have the *Substitution Reasoning* poster from Lesson 8 ready to refer to at the start of this lesson.

Day 1: Modeling Molecular Polarity in 3D

- **Group size:** 2 students
- **Setup:**
 - Do the following for 80 mini clothespins: Secure the spring to the wood on each clothespin with a dab of hot glue. This will help keep the spring more securely fastened to the clothespin. Though every pair of students will need only 4 clothespins, this set of 80 ensures a few extras to swap in, in case the spring does come out during use. Since you made 40 of these in the previous lesson, reuse them as part of this set of 80, checking first to see if they need any additional glue to resecure them.
 - Prepare a 3D molecular model set in a clear container or bag with the following structures inside, for every pair of students in your largest class:
 - 4 mini clothespins
 - A molecular model of methane, CH_4 (4 white atoms attached to 1 black atom with 4 long links/connectors)
 - 1 additional red atom with two holes
 - 3 additional atoms all the same color each with one hole in them. This should be a different color than black, white or red. But the color for each group can be different. For example one group can have all green for one group and all orange for another. You may need to use some of the blue atoms too in order to provide enough for every two students in your largest class. If you do then cover the extra holes on these atoms with blue painters tape so that only one hole is exposed.
- **During the lab:** The small container or bag will support quick distribution and collection of the materials. Keep the hot glue gun plugged in to resecure/repair any spring on a clothespin that comes loose during use.
- **Safety:** There are no special safety concerns.
- **Disposal:** Retain all materials for future use.
- **Storage:** All materials can be stored and reused from one year to the next.



Lesson 9 • Where We Are Going and NOT Going

Where We Are Going

Throughout the second lesson set of this unit, students have worked toward answering: *Why do we need certain types of atoms to create the substances we need?* The goal of this lesson is for students to develop understanding of the trends in the periodic table and how they can be used to explain differences in the types of bonds atoms form with other atoms. This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **PS1.A: Structure and Properties of Matter.** 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.
- **PS1.A: Structure and Properties of Matter.** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

Now that students have collected experimental evidence of water's unique properties compared to other liquids and hypothesized that these properties might be due to molecular-level differences, they actually look at molecular structures to tie observations from Lesson Set 2 back to chemical understandings developed in Lesson Set 1 ([CCC: 6.2](#)). Students figure out that differences in atomic electronegativity do not necessarily lead to polar molecules, as in Lesson 5, but can cause unequal sharing of electrons in individual bonds. In doing so, they build on the idea from *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)* that ions form when electrons are wholly transferred. Students develop the idea that ionic and covalent bonds represent ends of a spectrum in which electrons may be transferred or shared, with attraction between atoms resulting in either case ([SEP: 2.3](#); [CCC: 1.1](#)).

Students have engaged with the elements of all three dimensions in the lesson-level performance expectation in several prior lessons. The end of this lesson includes the *Sila-ibuprofen Transfer Task*, which serves as a summative assessment of a student's progress in using each of those three dimensions.

In this lesson, students will co-construct a definition for the following terms, which they should add to their Personal Glossaries: *nonpolar covalent bond*, *polar covalent bond*, *ionic bond*, and *dipole arrow*. Students are encouraged to notate *Electronegativity Periodic Table* with definitions of these terms. If students do that, it may not be necessary for them to add these words to their Personal Glossaries. Students will also encounter the terms *metallic bond*, *double bond*, and *triple bond*, which they may choose to add as well. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

Where We Are NOT Going

In this lesson students will work with manipulatives that will show the four bonds with carbon atoms in three dimensions. They will see computer visualizations of two carbon-based molecules in three dimensions as well for Question 6 of *Sila-ibuprofen Transfer Task*. The unit will not go any deeper in helping students think about why molecules are shaped the way they are.

Do not discuss why electronegativities of transition metals might not follow the expected trends and avoid modeling the shells of atoms that have *d*-orbitals, as these ideas fall outside the bounds of the NGSS.

Once students have had practice predicting reactions in Lesson 11, you may wish to have them use the paper-clip model to show how force interactions between bonded atoms and lone pairs cause them to repel as far apart as possible. This can be accomplished (with steric numbers up to four) by physically bending the cards to get the paper-clip electrons as far away from one another as possible. However, we recommend avoiding explicit thinking about orbitals and orbital hybridization because they cannot be explained using high school-level mechanisms. This unit does not address valence shell electron pair repulsion (VSEPR) theory, as it is outside the bounds of the NGSS.

LEARNING PLAN for LESSON 9

1 · NAVIGATE AND SELECT FOCAL AGREEMENTS

5 min

MATERIALS: science notebook, Community Agreements, Substitution Reasoning poster from Lesson 8

Refer to the *Substitution Reasoning* poster from last lesson and remind students that we ended last class wondering about what we might be able to substitute for substances we need, using the same type of thinking we did to compare water and hydrogen sulfide.

Consider how developing new substances could impact more sustainable living. Display **slide A**. Read the text at the top of the slide and discuss the question, *How could inventing new substances to serve as substitutes for some of the substances we use today help us live and work more sustainably beyond Earth and on it?* Listen for students to raise ideas about producing less waste, pollution, unwanted side effects, and negative impacts on biological systems, and/or developing more effective materials for their cost, strength, size, etc.

Select focal Community Agreements. Display **slide B**. Read the text at the top of the slide to highlight one of the goals of this lesson. Then say, *You will be asked to reflect on your contributions to our Community Agreements between now and the start of that assessment.**

* ATTENDING TO EQUITY

Here is an opportunity to further emphasize how lessons like this one, designed around the Putting Pieces Together routine, often have a similar end goal – preparing all members of our learning community to be successful on a transfer task. And since such an end goal involves an assessment that requires complex synthesis of knowledge and practices, the preparation for such work can always benefit from revisiting our Community Agreements.

You can emphasize how the type of teamwork students engage with today and at the start of class tomorrow, where the focus is on recapping and applying the key model ideas we need to use on such an assessment, can help to increase an individual student's success on the assessment.

2 · USE A MODEL

9 min

MATERIALS: science notebook, *Electronegativity Periodic Table*

Orient to a new electronegativity reference. Display **slide C**. Distribute a copy of *Electronegativity Periodic Table* to each student and have them add it to their science notebooks. Point out that this periodic table shows only the elements' electronegativities, and use the prompts to help students make connections to the bonds that atoms would form.

Suggested prompt	Sample student response
How do the electronegativities in this reference compare to the trends we predicted?	We said electronegativity should increase as you move across a row to the right, which this does in general. We said electronegativity should increase as you move up a column, which this does in general. There are some exceptions in groups 3-12.

Suggested prompt	Sample student response
<i>How can we use the electronegativities listed in this reference and the key below it to predict the bond character between two atoms?</i>	We would compare the electronegativities of the two types of atoms. We can calculate the difference between the electronegativities of the two atoms that form a bond.
<i>Which atoms pull more strongly on electrons in a bond, those with higher electronegativity or those with lower electronegativity?</i>	Higher.

Use two models from a prior unit. Display **slide D**. Remind students that we used the two models on the slide in *Electrostatics Unit*. Emphasize that we might use different representations now than we did then for the bonds that form. Encourage students to use *Electronegativity Periodic Table* as they think about the questions on the slide on their own for a minute. Then discuss students' responses for each question as a class.

Suggested prompt	Sample student response
<i>Which bonds in either substance shown would we now describe as ionic?</i>	The ones in the salt. The ones between Na^+ and Cl^- .
<i>Which bonds in either substance shown would we now describe as nonpolar covalent?</i>	The ones between two carbon atoms.
<i>Which bonds in either substance shown would we now describe as polar covalent?</i>	The ones between a carbon and an oxygen atom.

Evaluate a third model. Display **slide E**. Remind students that this model of copper wire was also one that we used in *Electrostatics Unit* to help explain why copper conducts electricity so well. Discuss the two questions on the slide as a class.

Suggested prompt	Sample student response
<i>Does this bonding seem more ionic or more covalent?</i>	Since it shows copper ions, it kind of seems more ionic.
<i>How is this bonding different from either ionic or covalent bonds?</i>	There is no negative ion. It looks like electrons are moving around rather than getting transferred to another atom/ion.

Describe metallic bonding behavior. Use the additional prompts to help students recognize the unique characteristics of electron behavior with metallic bonding.

Suggested prompt	Sample student response
What are the electronegativity values of the atoms in a metal like copper? Are they relatively high or low?	Low.
When an element has a low electronegativity, what tends to happen to its valence electrons when bonds are formed?	They tend to be pulled elsewhere. It does not hold on to them very strongly.

Point out that in ionic bonding, a higher-electronegativity element is pulling hard on the electrons, but there is no higher-electronegativity element in a metal. Elicit student ideas about how this might explain the behavior on the slide. Guide them toward the conclusion that valence electrons can move freely because no individual atom is pulling on them more strongly than a neighboring atom, leaving ions in a “sea of electrons.” Emphasize that this can only happen if the substance is mostly metal atoms, like a wire.

Tell students that we will not encounter metallic bonding-related phenomena in the assessment, but we may see them again in future lessons or units.

3 · IDENTIFY CANDIDATE SUBSTITUTES AND DETERMINE BOND CHARACTER AND POLARITY

12 min

MATERIALS: science notebook, *Electronegativity Periodic Table*, *Modeling Polarity*

 **Identify potential substitutes.** Display **slide F**. Have students read the text on the slide on their own and then discuss the prompts with a partner. Remind students to continue to reference *Electronegativity Periodic Table*. After two minutes for partner discussion, display **slide G**. The information on this slide will help students check their predictions. As you keep the slide projected for about half a minute, distribute *Modeling Polarity*.

ADDITIONAL GUIDANCE

The corresponding student self-assessment opportunities start now for the series of **slides F–G, H–I, J–K, L–O, and P–Q**, which provide incremental checkpoints for students to apply and check their understanding. A formative assessment opportunity occurs at **slide Q**. See the Assessment Opportunity box following **slide Q** for details on how to support students during this series of self- and formative assessment opportunities.

Use a model to determine bond character. Display **slide H**. Cue students to take two minutes to work on Part A of *Modeling Polarity*. After giving this time, display **slide I**. The information on this slide will help students check their predictions, so you will probably need to keep it projected for just half a minute.

Introduce double and triple bonds. Say, *Notice that if a line represents a bond in the model for HF, then the N₂ and CO₂ models appear to have more than one bond connecting their atoms together.* Point out that instead of sharing just two electrons to make a single bond, the atoms in N₂ are sharing six electrons to make three bonds, and the carbon atom in CO₂ is sharing four electrons to make two bonds with one oxygen atom and another four electrons to make two bonds with the other oxygen atom.

Use a model to determine bond polarity. Display **slide J**. Give students four minutes to work on Part B of *Modeling Polarity*. Then display **slide K**. The information on this slide will help students check their predictions, so keep it projected for about half a minute.

4 • DETERMINE MOLECULAR POLARITY

9 min

MATERIALS: Modeling Molecular Polarity in 3D, hot glue gun, hot glue stick

 **Use a model to determine molecular polarity.** Display **slide L**. Orient to the three different-sized purple arrow symbols at the bottom of the slide. Students can use these to represent the amount of shift of the electrons for each bond. Have students apply the dipole arrow convention used on the slide to all three molecules in Part C of *Modeling Polarity* with their partner, based on their work in Part B. After two minutes of partner work, display **slide M**. The information on this slide will help students check their predictions. As you keep the slide projected for about half a minute, distribute a molecular model set to each pair of students.

ADDITIONAL GUIDANCE

See the Assessment Opportunity box following **slide Q** for details on how to support students during this series of self- and formative assessment opportunities built over **slides F-G, H-I, J-K, L-O, and P-Q**.

Manipulate the 3D molecular models. Display **slide N**. Emphasize that students should try to model at least two of the electron shifts with their partner using the manipulatives in their set, by sliding the clothespins along each bond in different directions and indifferent amounts.

Compare to an alternate visualization. Display **slide O**. Explain that these images are output from a computer program that renders a visualization of the molecules in three dimensions. Use the prompt on the slide to discuss how close we came to predicting the overall polarity of these different molecules. Students will say that in general, we were able to predict many aspects of the overall polarity of the molecules.

Forecast that this sort of thinking is a part of the transfer task. Tell students that trying to visualize and predict polarity in a molecule with a drawing or manipulatives like they just did is something they will do again in the assessment, but only for a region of a few bonds within a much larger molecule.

Predict regions of polarity. Display **slide P**. Have students work individually for two minutes to label a part of each molecule toward which they expect to see a relatively strong shift of electrons, in Part D of *Modeling Polarity*. Collect molecular model sets as they are doing this. Then display **slide Q** so that students can check their predictions.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Modeling Polarity Key*.

What to do: Slides **G, I, K, M, O, and Q** provided incremental checkpoints for students to self-assess their understanding. Check in with students now to see how they are feeling. If students are struggling, ask them to circle the corresponding Part(s) of *Modeling Polarity* they feel they need more practice on. If so, then after **slide R**, provide that opportunity for practice with additional examples before administering *Sila-ibuprofen Transfer Task*.

Building toward 9.A.1 Use a variety of models and evidence (such as solubility and periodic trends in electronegativity and atomic radius) to a) describe the patterns and relationships between the parts of an atom and the bonds formed between atoms, b) predict polarity differences, and c) explain property differences based on the relative differences in the strength of forces between atoms and molecules. (SEP: 2.3; DCI: PS1.A.3, PS1.A.2; CCC: 1.1, 6.2)

5 · CONNECT TO OUR M-E-F POSTER

5 min

MATERIALS: M-E-F poster with expansion panels, blue arrow

Connect to prior work with properties. Display **slide R**. Discuss the question on the slide as a class: *What property differences did we previously explain using these differences in molecular polarity?* Students will refer to adhesion, cohesion, and/or ability to dissolve materials from their work in Lesson 4, or boiling point and ability to dissolve many different substances from Lesson 8.

ADDITIONAL GUIDANCE

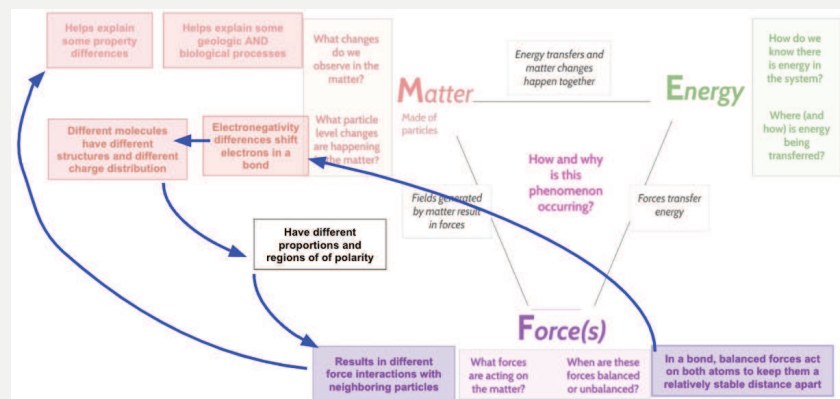
Students may benefit from additional practice in applying what they now know about the relationship between electronegativity differences and polarity, which is the focus of Questions 1-6 on *Sila-ibuprofen Transfer Task*. If you choose to use Question 7 (optional), students may also benefit from revisiting the relationships discussed on **slide R** to explain the properties listed above, as an additional assessment check before students engage with that question.

Recall similar connections with hydrogen sulfide and water. Point out that once we know the polarity differences, we can start thinking about how these would affect intermolecular forces between neighboring particles. Remind students that this is something we already did for hydrogen sulfide and water to help us explain differences in their boiling point, as well as differences in the many types of substances they can dissolve, and that after we did this, we organized our thinking in the context of the matter and forces portions of our M-E-F triangle.

Display **slide S**. Refer to the M-E-F triangle posted in the room. Point out that in each of the property examples we just mentioned, we were able to explain those properties by going all the way back to differences in the charge distributions in the different molecules, and we did all of that before we knew anything about electronegativity.

Emphasize that today we connected all of what we figured out about electronegativity differences to charge distribution—not just in a single bond, but in multiple bonds and ultimately in the entire molecule.

Add a blue arrow from the panel that says “Electronegativity differences shift electrons in a bond” to the panel that says “Different molecules have different structures and different charge distribution”.



Point out that we should now be able to reason about why properties might be similar or different for two different molecules, starting by looking at electronegativity similarities or differences in bonds. Emphasize that this is the type of thinking that scientists and engineers do to figure out how to make a possible substitute for another substance. Tell students that this is also the type of thinking they will be asked to apply next class to a possible substitute substance related to a biological process in our bodies.

6 · UPDATE PROGRESS TRACKERS AND INTRODUCE OPTIONAL HOME LEARNING

5 min

MATERIALS: science notebook, *Dietary Salts* (optional), M-E-F poster with expansion panels

Add to Progress Trackers. Display **slide T**. Have students set up a new page in their notebooks for the question shown on the slide, which they considered over the last two lessons, and then summarize what they figured out in their own words. See *Progress Tracker Key* in Lesson 2 for a sample Progress Tracker entry.

Offer the optional home learning. Display **slide U** and take half a minute to introduce the reading. Say, *We are starting to consider chemistry connections to diet and tomorrow will consider connections to medicine in our assessment, and this is an area many people consider as a career path. You are welcome to take a copy of Dietary Salts if you want to learn more about how the chemistry we are figuring out impacts body processes related to the dietary salts we consume.*

Remove the blue arrow and panels you added to the M-E-F poster if this is not your last class period for day 1 of the lesson.

End of day 1

7 · NAVIGATE

4 min

MATERIALS: science notebook, M-E-F poster with expansion panels

Share entries from Progress Trackers. Display **slide V**. Have a few students share their responses for their prior Progress Tracker entry. Listen for students to make connections to the annotations added to the M-E-F poster.

8 · IDENTIFY QUESTIONS WE CAN NOW ANSWER

7 min

MATERIALS: *Our DQB Questions*, DQB, panel for revised driving question

Take stock of our DQB questions. Display **slide W**. Distribute *Our DQB Questions* to each student or make available a digital copy they can annotate. Give students a few minutes to work with a partner to take stock of the questions that we have made additional progress on over the last few lessons.

At this point, suggest that we update our unit driving question to acknowledge that we are also concerned about finding, making, and recycling substances on Earth. Add the panel with the revised driving question: *How can we find, make, and recycle the substances we need to live on and beyond Earth?*

9 · REFLECT ON COMMUNITY AGREEMENTS

4 min

MATERIALS: Science Notebook, Community Agreements

Reflect on Community Agreements. Have the Community Agreements visible for the class. Display **slide X** and say, *The work we did yesterday and today was designed to prepare us to apply what we have figured out so far, so that everyone is ready for an individual assessment. Let's reflect on that work we did together.* Ask students to reflect individually in their notebooks.

10 · CONSIDER SUBSTITUTE SUBSTANCES IN MEDICINE

4 min

MATERIALS: None

ADDITIONAL GUIDANCE

The goal of this activity is two-fold. First, consider how being able to make any of the 20,000 prescription medicines (or safer substitutes) on site would help our long-term plans for living beyond Earth. Second, work to identify the intended purpose and side effects of two over-the-counter medicines.

Consider the role of medicines. Say something like, *Let's spend a few minutes more working together to orient ourselves to the phenomena you will explore on your own in the assessment.* Display **slide Y** and read the sentences at the top of the slide. Give students two minutes to discuss the prompts on the slide with a partner.

Orient to two medicines. Display **slide Z**. Discuss the two questions on the slide as a class.

Suggested prompt	Sample student response
<i>What are both of these medicines designed to do?</i>	They help with pain. Reduce headaches or fevers. Decrease swelling or soreness from injury.
<i>What are some side effects of either of these that you know of?</i>	Accept all answers.

11 • COMPLETE A TRANSFER TASK AND ASK NEW QUESTIONS

26 min

MATERIALS: *Sila-ibuprofen Transfer Task*, 2 sticky notes (3" x 3"), permanent marker, science notebook



Orient to what sila-ibuprofen is. Display **slide AA**. Give students a minute to read the information on the slide while you distribute two sticky notes, a permanent marker, and *Sila-ibuprofen Transfer Task* to each student.

Emphasize that students can use other references in their science notebooks to help them complete the assessment.

Provide a color image reference. Once students have finished reading slide AA, point out the diagram on *Sila-ibuprofen Transfer Task* to note that it is not in color and that students will need a color version to refer to. Display **slide BB**. Tell students you will keep this slide displayed for reference.

Give students most of the remaining time to individually complete the assessment.

Collect *Sila-ibuprofen Transfer Task*.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Transfer Task Key*.

What to do: See *Transfer Task Key*. Also note that Question 7 at the end of this assessment is designed to be an optional resource, with a variety of suggested uses, including remediation or extension opportunities. These uses are described at the end of the key. If there is time after students complete Questions 1-6, you may wish to encourage them to read the prompt on Question 7 to pique their interest in it, but keep in mind that there is not enough time allocated in the lesson for all students to complete Question 7. Therefore, make sure that you communicate to students how you intend to use Question 7, after the allocated class time for the rest of the assessment.

Building toward: 9.A.2 Use a variety of models and evidence (such as solubility and periodic trends in electronegativity and atomic radius) to a) describe the patterns and relationships between the parts of an atom and the bonds formed between atoms, b) predict polarity differences, and c) explain property differences based on the relative differences in the strength of forces between atoms and molecules. (SEP: 2.3; DCI: PS1.A.3, PS1.A.2; CCC: 1.1, 6.2)

Reserve two minutes to record new questions. Display slide CC. Cue students to record 1-2 new questions they now have on separate sticky notes and save them in their science notebooks.

LESSON 10: Why do we need water in so many reactions?

PREVIOUS LESSON We described bond characteristics and modeled the polarity for different substances. We evaluated our progress on our DQB questions. We considered how being able to make medicines on site would help our long-term plans for surviving beyond Earth. We explained why one such replacement medicine has a similar structure to ibuprofen but different solubility in water, and we recorded new questions.

THIS LESSON

PROBLEMATIZING

1 day



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We return to the different processes we encountered in Lesson 1, with more information about the reactions that are occurring. We notice that water is frequently involved and wonder how we can make sure the water is clean. We read about how copper can be cleaned from water by forming a precipitate, model this reaction, and recognize that the structures of molecules help determine how they react. We wonder about other ways that water can be cleaned.

NEXT LESSON We will decide we need more information about growing food in space. We will read about fertilizing plants and figure out that scientists can separate ammonium from urea instead of using ammonia fertilizer, and we will model these substances. We will read about perchlorate, another polyatomic ion, and model the chemical reaction of perchlorate decomposition.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, HS-ESS1-2, HS-ESS2-1, HS-ESS2-5



WHAT STUDENTS WILL DO

10.A Critically read scientific literature to identify the structures of different components and explain the transformations of matter with forces in a water-cleaning reaction. (SEP: 8.1; DCI: PS2.B.3; CCC: 6.1)

WHAT STUDENTS WILL FIGURE OUT

- Water is involved in many reactions and must be clean for them to work properly.
- Ions come together so that the substance formed is neutral.
- The intermolecular forces between water (a polar molecule) and certain ions allow for the observed cleaning reaction to occur.
- Some substances cannot be easily dissolved because their bonds are too strong.

Lesson 10 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	6 min		NAVIGATE Give students time to remember how they finished the last lesson and decide what information they need to know to understand how to make different substances.	A-B	Driving Question Board
2	7 min		EXAMINE DETAILED CHEMICAL REACTIONS Help students problematize the need for clean water in many different reactions associated with life and important materials.	C	<i>Key Chemical Reactions, Materials for Survival</i> from Lesson 1
3	22 min		READ ABOUT REMOVING METALS FROM WATER Set up, give time for, and lead discussion of a reading on using calcium-based compounds to remove copper from water. Then give students time to model and more fully explain the reactions highlighted in the article.	D-G	<i>Cleaning Metal-Contaminated Water</i> , cards from <i>Water Cleanup Modeling</i> , M-E-F poster
4	3 min		UPDATE PERSONAL GLOSSARIES Give students a few minutes to add <i>precipitate</i> and <i>intermolecular force</i> to their Personal Glossaries.	H	
5	7 min		NAVIGATE Return the class to key reactions from the unit and consider other substances that might have to be cleaned out of water.	I-J	<i>Key Chemical Reactions</i>

End of day 1

Lesson 10 • Materials List

	per student	per group	per class
Lesson materials	• <i>Key Chemical Reactions</i> • <i>Materials for Survival</i> from Lesson 1 • <i>Cleaning Metal-Contaminated Water</i> • science notebook	• cards from <i>Water Cleanup Modeling</i>	• Driving Question Board • M-E-F poster

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.

The first time you use this lesson, laminate and cut out (or ask students to cut out) the cards in *Water Cleanup Modeling* so that each pair of students has a complete set. Store each set of cards together in an envelope or with binder clips to allow for easy re-use.

Lesson 10 • Where We Are Going and NOT Going

Where We Are Going

This lesson starts off the third lesson set of this unit where students will develop understanding around the Law of Conservation of Matter and apply it to balancing chemical equations in an effort to answer the lesson-set question, *How can we make the substances we need to survive off of Earth using the existing matter in the solar system?* This lesson is designed to coherently build ideas related to the following disciplinary core idea:

- **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.~~

Crossout explanation: Students continue to build on work started in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)* to begin explaining chemical properties of matter, in addition to physical properties of matter. We do not address contact forces in this unit, as this idea is developed in the OpenSciEd High School Physics course in *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*.

Students figure out the ways in which forces at the atomic scale explain the role of water in the transformations of chemical reactions. This is done through the use of modified primary literature that examines different means of cleaning metal-contaminated water (**SEP: 8.1**). Students focus on these portions of **SEP:8.1: 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.** Students developed the crossed-out portions in prior units: *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*, *OpenSciEd Unit B.5: What will happen to Arctic bear populations as their environment changes? (Speciation Unit)*, and *Electrostatics Unit*.

Explaining the role of water in chemical reactions requires consideration of the way that its structure, and the structures of other substances in the reaction, lead to properties that allow for the reaction to take place (**CCC: 6.1**). For **CCC: 6.1: 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 their function and/or solve a problem.** This work builds on prior structure-function thinking developed in *Electrostatics Unit*. The "connections of components" emphasized in this lesson consist of force interactions between water molecules and ions.

In this lesson, students will encounter or co-construct a definition for the following terms, which they should add to their Personal Glossaries: *precipitate* and *intermolecular force*. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Reactions in this lesson are intentionally unbalanced. Students will develop the need to balance reactions in Lesson 11.

Students encounter examples of polyatomic ions like OH^- in this lesson, but they do not name or explain them. This is done in the next lesson.

Although students may have wonderings about how to balance the reactions featured in this lesson, they will also pursue these ideas further in Lesson 11.

Although this lesson includes an example of a single-replacement reaction, students do not name it as such. Reaction types are outside the bounds of the NGSS, but if you wish, you may name them as they arise. In Lessons 11 and 12, students will encounter a variety of synthesis and decomposition reactions. Double-replacement reactions play a key role in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)* and combustion reactions are introduced in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*.

Solubility rules are not addressed in the OpenSciEd High School Chemistry sequence, as they are outside the bounds of the NGSS.

LEARNING PLAN for LESSON 10

1 · NAVIGATE

6 min

MATERIALS: Driving Question Board

Reflection on the DQB check-in. Display **slide A** and have the Driving Question Board visible. Have students turn and talk with a partner to share the new questions they developed at the end of Lesson 9. Then share some examples with the whole class. Listen for these ideas:

- We wanted to figure out more about how people can make substitute substances.
- We wanted to understand more about how, or other ways, people could make different materials off of Earth.

Give students the opportunity to add their new questions to the DQB.

Generate specific pieces of information needed. Display **slide B** and point out that early in the unit we examined lots of different, important materials (like steel and glass) and processes (like photosynthesis). Ask, *What else do we have to know to understand how to actually make those things?* Listen for these ideas:

- We need to know how the substances are mixed.
- We need to know what devices are needed.
- We need amounts.

Say, I have an updated version of a resource we first used in Lesson 1 that might be able to help us out.

ADDITIONAL GUIDANCE

Students are likely to mention information that the handout does not provide, such as the equipment we might need. After students see the handout in the next step, have them record questions about unprovided information. Students will have opportunities to figure out the balanced reactions in Lessons 11 and 12 and will explore materials further in Lessons 13 and 14.

2 · EXAMINE DETAILED CHEMICAL REACTIONS

7 min

MATERIALS: *Key Chemical Reactions*, *Materials for Survival* from Lesson 1

Orient students to the updated reference. Distribute *Key Chemical Reactions* and display **slide C**. Explain to students that this reference has the same processes we encountered in the first lesson, but a little more information about each one. Point out that we now understand a lot more about the elements that make up different materials and the importance of water for life, so we may also recognize some patterns we did not before.

Give students a few minutes to examine the updated reactions with a partner, using the prompts on the slide to guide their thinking. Suggest that they take out *Materials for Survival* from Lesson 1 for direct comparison if they do not remember what is on it. Then ask pairs to share their thinking:

Suggested prompt	Sample student response
What do we notice that is new?	Instead of listing inputs and outputs, there is an arrow. The information looks more like equations with plus signs. There is more information about each process on the left side.
What common “ingredients” do we see? Why do we think that is?	A lot of the same elements are involved in different reactions (carbon, hydrogen, and oxygen). Carbon dioxide is involved in several reactions. Water is involved in almost every reaction, maybe because it is polar, dissolves stuff well, and has other special properties.

Problematize the need for clean water. Highlight that water is important in several of these processes and ask, *Is just finding any water good enough for all the purposes we need it for, like drinking, watering crops, and producing different materials?* Students should respond that clean water will be needed for at least some processes. Then ask, *How do we clean water?* Accept all responses at this time, but point out that beyond Earth, we may face more particular challenges in cleaning water.

Have students hang onto *Key Chemical Reactions*, as they will need it later in class.

3 · READ ABOUT REMOVING METALS FROM WATER

22 min

MATERIALS: *Cleaning Metal-Contaminated Water*, cards from *Water Cleanup Modeling*, M-E-F poster

Set up the reading. Display **slide D** and distribute *Cleaning Metal-Contaminated Water*. Explain to students that they have seen similar readings before in *Electrostatics Unit*, which are adapted from journal articles written by scientists. Highlight that each section is based on the scientists engaging with a different practice as they try to answer their question about how to clean water with chemical reactions.

Explain the reading strategy found on *Cleaning Metal-Contaminated Water* and **slide D**, then give students time to read.*
Summarize the new information about how the reactions discussed help clean water. Then record any new questions you have.*

ADDITIONAL GUIDANCE

The graph in *Cleaning Metal-Contaminated Water* shows that $\text{Ca}(\text{OH})_2$ is more effective when cleaning relatively high concentrations of copper, with CaCO_3 more effective when cleaning relatively low concentrations of copper. The explanation for this phenomenon is partially addressed in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*, when students will develop understandings of reaction energetics.



Debrief the reading. When students have had time to read and annotate, display **slide E** and lead a discussion about the reading. Accept all responses to the follow-up questions, as they are intended to help motivate modeling the reaction.

* ATTENDING TO EQUITY

Supporting emergent multilinguals: In the text, *precipitate* is used as both a noun and a verb. Making this explicit can help all learners participate in the language of science more readily.

* ATTENDING TO EQUITY

Universal Design for Learning: If you feel students need additional strategies in place to support reading before they summarize, consider the following:

- Underline places in the reading that connect to what we already know about water.
- Star new information about how the reactions discussed help clean water.

Suggested prompts	Sample student responses	Follow-up questions
<i>What is water doing?</i>	Pulls apart calcium hydroxide or calcium carbonate ions. Dissolves some ions, but not others. Helps break bonds.	<i>Do we already have evidence of or explanations for water doing these things?</i> <i>Water can help break bonds. How does it do that?</i>
<i>What are other substances doing?</i>	Calcium hydroxide or calcium carbonate dissolve. Copper ions bond with dissolved hydroxide or carbonate ions.	<i>What happened to the different substances' bonds in the process?</i>
<i>How are the substances different before and after the reaction?</i>	Copper hydroxide or copper carbonate don't dissolve. The new substance formed has bonds too strong to be broken by water.* A precipitate forms.	<i>How are the bonds different in the new substance compared to the old one?</i> <i>What do we mean by a precipitate?</i>

* SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

Explain to students that they are using structure and function to think about engineering design, working across multiple domains of science and engineering.

ALTERNATE ACTIVITY

Extension opportunity: If you have materials on hand, demonstrate this cleaning process by showing students any common precipitation reaction, such as that of copper sulfate and calcium hydroxide. If you do so, ensure that you follow all safety guidelines. If students are not directly handling the materials, they do not need gloves or chemical aprons if they have indirectly vented chemical splash goggles and are seated 15 feet away from the demonstration, behind a safety shield.

Prepare to model water's role in the reaction. Say, *This is all kind of confusing. We end up with water that is easy to clean and a clump of stuff, and water seems to play an important role in the process, but it is not clear how that works. Let's try to model it.* Display **slide F** and have students form pairs. Distribute a set of cards from *Water Cleanup Modeling* to each pair. Elicit any ideas about what is unusual about the cards. Students might say that several atoms are stuck together on some cards. Suggest that for now, we just treat those cards as one “thing” and pay attention to the negative charges like we have before.

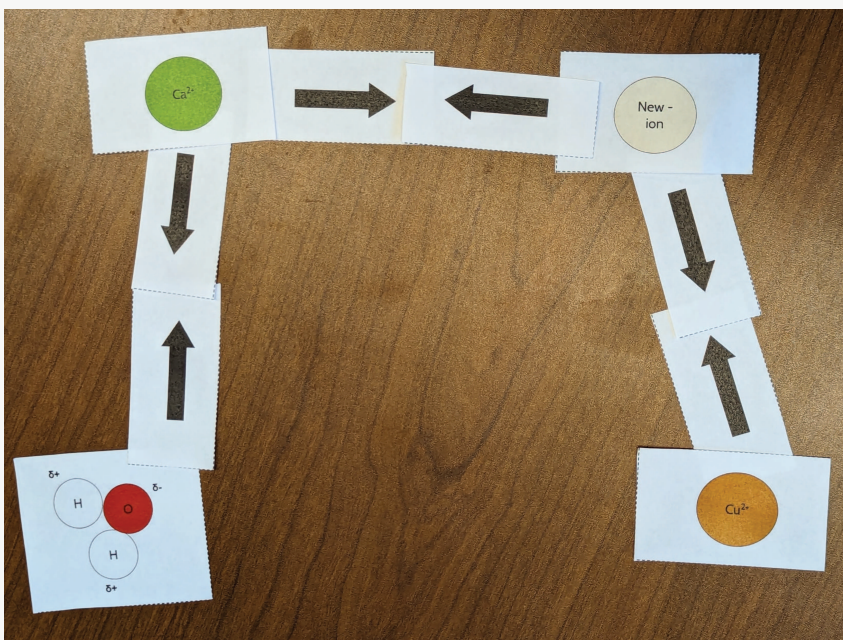
Display the M-E-F poster, noting that in the past we have found it to be a helpful tool in deciding what lens to use to understand a phenomenon. Elicit ideas for which of the three lenses might be most useful as we try to explain what is going on. Guide students toward *matter* and *forces*, since we have not thought much about what bonds have to do with energy. Point out that arrows are provided to help represent forces.

Model water's role in the reaction. Give partners five minutes to model. Tell half the pairs to assume that the “new ion” is carbonate (CO_3^{2-}) and the other half that it is hydroxide (OH^-). While students work, use the following prompts to ensure that students are fully considering the changes in matter and the role of forces in the reaction.

- What is different between the “before” and “during” steps? the “during” and “after” steps?
- Where might we see forces between ions? between water and ions?
- What ratio of negative and positive ions will form? Do we need just one negative ion for every positive ion, or more?

- What do forces have to do with bonds breaking and forming?
- Are all forces the same? How do we know?

The image gives an example of some of the forces students might identify.



Discuss the modeling. Display **slide G**. Start by having a pair from each half of the class (carbonate ion or hydroxide ion) share what they did. Then use the prompts to explain this phenomenon and the role of water in the reaction.

Suggested prompts	Sample student responses	Follow-up questions
<i>What is different when there is a carbonate ion compared to a hydroxide ion?</i>	There is only one carbonate ion for every calcium or copper ion, but there are two hydroxide ions for a positive ion.	<i>Why is that the case? What is different between those ions?</i> <i>How does that match up with what we know about what it means for a substance to be "neutral"?</i>

Suggested prompts	Sample student responses	Follow-up questions
<i>How could we model how water helps create a new substance?</i>	We can show bonds breaking and reforming. We can show water pulling on ions to dissolve them. We can show that water cannot dissolve some of the ions, which lets them precipitate out.	<i>How can our matter and force lenses help us understand how bonds are breaking and forming?</i>
<i>How do the structures of the substances help make the reaction “work”?</i>	Water is really polar, so it can pull apart ions and break those ionic bonds The ions are charged, so they are attracted to one of the ends of the water molecule.	<i>Is a bond also a force?</i> <i>How is a bond similar to or different from the force between a water molecule and nearby ions?</i>
Name intermolecular forces. Once students have established that there is a force between molecules that is different from a bond (which is between atoms in the same molecule), you can name this as an <i>intermolecular force</i>. Have students generate ideas about where they have seen the prefix “inter-”, such as “international.” Ask what these different terms have in common. Students should recognize that they all are describing relationships between different things of the same type.		
ADDITIONAL GUIDANCE	Prefixes are common in science, and in many cases different prefixes are used to describe related but opposing concepts. In this instance, it may be beneficial to introduce students to the related term <i>intramolecular forces</i> as describing the forces within a molecule or ionic compound. The force between ions in a compound can be described as either an ionic bond or an intramolecular force.	
ASSESSMENT OPPORTUNITY	What to look/listen for in the moment: - Students give accurate summaries of the text in discussion and when describing their models. (SEP: 8.1) - Students describe and explain the ways in which the structure of water (polarity) and strength of forces between different ions cause the observed transformation (reaction). (DCI: PS2.B.3; CCC: 6.1) What to do: You may assess individual students by collecting <i>Cleaning Metal-Contaminated Water</i> at the end of class and examining their personal summaries. Encourage students to return to the reading during discussion and while modeling to ensure that they are using it as a resource, along with prior force thinking as prompted by the M-E-F poster. Building toward 10.A.1 Critically read scientific literature to identify the structures of different components and explain the transformations of matter with forces in a water-cleaning reaction. (SEP: 8.1; DCI: PS2.B.3; CCC: 6.1)	

4 · UPDATE PERSONAL GLOSSARIES

3 min

MATERIALS: science notebook

Update Personal Glossaries. Display **slide H** and give students a few minutes to update their Personal Glossaries. They may want to add *intermolecular force* and *precipitate*, in addition to any other terms that they wish to recall easily in the future.

5 · NAVIGATE

7 min

MATERIALS: *Key Chemical Reactions*



Reflect on the original reactions. Have students take out *Key Chemical Reactions* and display **slide I**. Give partners a few minutes to reflect on the reactions using the prompts on the side, then discuss as a class:

- How is this cleaning process similar to the other reactions we saw at the start of the lesson?
- How is it different?
- How might the structures involved determine how similar or different the reactions are?

Listen for these ideas:

- Bonds break and form in all the reactions.
- Water is often involved, but not always.
- Several of the reactions seem to involve chunks of atoms together like we saw in this lesson's water-cleaning reactions.
- Some have three substances in the inputs.
- Water might be helpful in breaking apart ionic or other bonds.
- Many of the reactions with carbon seem to form really big molecules.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students connect the **structure of particles** and **force interactions to resulting reactions**. (DCI: PS2.B.3; CCC: 6.1)

What to do: Push students to use structure language (like *polar*) and force language (including *attract* and *pull*) to explain reactions generally. Ask them to consider specific, relatively simple examples if needed. If there is time, you may gather additional evidence by asking students to draw a model that predicts one of these simple reactions.

Building toward 10.A.2 Critically read scientific literature to **identify the structures of different components** and **explain the transformations of matter with forces** in a water-cleaning reaction. (SEP: 8.1; DCI: PS2.B.3; CCC: 6.1)

Navigate out of the lesson. Display **slide J**. Give students a minute to turn and talk about the prompts, then discuss these as a class.

Suggested prompt	Sample student response
<i>What other processes would we need to use water for on Mars?</i>	Accept all responses.
<i>What other substances may we need to remove from water before we could use it for those processes?</i>	Accept all responses.
<i>How might we use water to help us do that?</i>	It could break apart and help form new bonds so that we get something new that can be easily removed or is safer. It could react with something dangerous so it is safer.

Additional Lesson 10 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.2 Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

Students summarize important ideas from the reading--directly on the reading, in the class debrief, and as they model the reaction from the reading.

LESSON 11: How can we grow food in space?

PREVIOUS LESSON We noticed that water is frequently involved in important reactions and read about how copper can be cleaned from water so that it can be used in various processes. We modeled this reaction and recognized that the structures of molecules help determine how they react. We wondered about other ways that water can be cleaned.

THIS LESSON

PUTTING PIECES TOGETHER,
INVESTIGATION

2 days



We consider what we still need to know about living in space and decide we need more information about growing food. We engage in a reading about fertilizing plants and figure out that scientists can produce ammonium (NH_4^+) from urea instead of using ammonia (NH_3) fertilizer. We model the differences between ammonia and ammonium and develop a model for polyatomic ions. We also read about perchlorate, another polyatomic ion, and model the chemical reaction of perchlorate decomposition.

NEXT LESSON We will break down the chemical equation for photosynthesis and ensure there are equal numbers of elements on both sides of the equation. We will research which locations in the solar system contain the elements we need and read more about elements on Mars. We will balance an equation involved in cement production and read about making concrete on Mars without water. We will complete an Electronic Exit Ticket.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, HS-ESS1-2, HS-ESS2-1, HS-ESS2-5



WHAT STUDENTS WILL DO

11.A Critically read and determine central ideas of a text to develop a model that explains how using different reactants leads to the development of different fertilizers which can be used to grow plants off of Earth. (SEP: 8.1, 2.3; DCI: PS1.A.1, PS1.B.3; CCC: 6.2)

11.B Develop and revise a model based on evidence to show the relationship between reactant and product components and that atoms are conserved in a chemical reaction system. (SEP: 2.3; DCI: PS1.B.3; CCC: 5.1)

WHAT STUDENTS WILL FIGURE OUT

- To successfully grow plants off of Earth, nitrogen must be added to the soil. Two possible fertilizers, ammonia (NH_3) and ammonium (NH_4^+), could be added to the soil.
- NH_3 and NH_4^+ have different structures and charges. Ammonium could be made successfully in space.
- Polyatomic ions are substances that have many atoms but carry an overall net charge.

Lesson 11 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	7 min		NAVIGATE Have students recall what they have not yet figured out about surviving in space.	A-B	
2	21 min		READ ABOUT FERTILIZERS IN SPACE Have students read about different fertilizers that could be used to grow plants in space.	C-D	<i>Fertilizer from Urine</i>
3	15 min		MODEL AMMONIA AND AMMONIUM WITH A PARTNER Have partners develop models of ammonia and ammonium.	E-G	<i>Fertilizer from Urine</i> , molecular model kit (optional), chart paper, chart paper markers
4	2 min		NAVIGATE Have students recall why we were thinking about fertilizer.	H	
<i>End of day 1</i>					
5	10 min		DEVELOP CLASS CONSENSUS MODEL OF AMMONIA AND AMMONIUM Gather students in a Scientists Circle to develop a class consensus model of ammonia and ammonium.	I-J	chart paper, chart paper markers, 9 index cards (optional), 17 paper clips (optional)
6	7 min		IDENTIFY AND DEFINE POLYATOMIC IONS Have students analyze two data sets to identify and define polyatomic ions.	K-N	<i>Analyzing Chemical Formulas</i>
7	13 min		PROBLEMATIZE PERCHLORATE Read about another polyatomic ion that presents both obstacles and opportunities for living on Mars.	O-P	<i>Perchlorate on Mars</i>
8	12 min		MODEL CHEMICAL REACTIONS Have students use manipulatives to model chemical reactions and start thinking about conservation of matter.	Q-S	<i>Perchlorate on Mars</i> , individual whiteboard, dry erase marker, <i>Balancing Equations Molecules</i> , chart paper, chart paper markers
9	2 min		NAVIGATE Navigate students to the next lesson.	T	<i>Materials for Survival</i> from Lesson 1
<i>End of day 2</i>					

Lesson 11 • Materials List

	per student	per group	per class
Lesson materials	• <i>Fertilizer from Urine</i> • science notebook • <i>Analyzing Chemical Formulas</i> • <i>Perchlorate on Mars</i> • individual whiteboard • dry erase marker • <i>Materials for Survival</i> from Lesson 1	• molecular model kit (optional) • <i>Balancing Equations Molecules</i>	• chart paper • chart paper markers • 9 index cards (optional) • 17 paper clips (optional)

Materials preparation (35 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 and cut out the molecules and symbols from *Balancing Equations Molecules*. Ensure there are enough sets for students in your largest class to work in pairs.

Ensure students have access to either printed or digital color versions of *Fertilizer from Urine* (one per student), which is a reading about growing plants in space, and *Perchlorate on Mars*, which is about perchlorate in martian soil.

Have molecular model kits from Lessons 8 and 9 available to support students in modeling ammonia and ammonium.

Have index cards and paperclips available to develop paperclip models of ammonia and ammonium during class consensus model development.

Lesson 11 • Where We Are Going and NOT Going

Where We Are Going

This lesson focuses on what is needed to grow food in space. This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **PS1.B: Chemical Reactions.** The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- **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.

Students engage with two readings, each about a different “space food” process. The first, on day 1, explains the need for fertilizers to be added to soil to successfully grow plants in space. Students identify the central ideas of the reading and use them to develop questions around the two fertilizers discussed (SEP: 8.1). Students then co-develop a model illustrating the differences between NH_3 and NH_4^+ and compare their structures (SEP: 2.3; CCC: 6.2). The second reading, on day 2, introduces another polyatomic ion, perchlorate, and describes how it can be removed from martian soil and used to make breathable oxygen.

Students use their models of ammonium, as well as several other polyatomic ions they observe on the second day, to develop ideas around the structure and function of polyatomic ions (CCC: 6.2). Students also model chemical reactions using individual whiteboards and manipulatives to help them develop the idea of conservation of matter (SEP: 2.3).

Students engage in SEP: 8.1 and SEP: 2.3 partially. For SEP: 8.1: *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.* Crossed-out portions of this element were addressed in prior units. For more information, see this section in the Lesson 10 Teacher Guide. For SEP: 2.3: *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.* Crossed-out portions of this element were addressed in prior units. For more information, see this section in the Lesson 1 Teacher Guide.

Students engage in CCC: 6.2 and CCC: 5.1 partially. For CCC: 6.2: *The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.* In this lesson, students focus on the structure and function of naturally occurring substances. Students previously engaged with CCC: 6.2 in the OpenSciEd High School Biology unit, *Cancer Unit*. For CCC: 5.1: *The total amount of energy and matter in closed systems is conserved.* In this unit, students focus on conservation of matter. Students considered conservation of energy in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*. In the final unit of the OpenSciEd High School Chemistry course, *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*, students put together conservation of matter and energy.

Students should be familiar with ammonium (ammonium nitrate) from middle school. It is typically used to teach endothermic reactions (MS-PS 1-6). Students might also know that this compound is a common agricultural fertilizer. Ammonium nitrate can cause explosions and has been in the news in recent years for deadly blasts.

In this lesson, students will co-construct a definition for the following terms, which they should add to their Personal Glossaries: *polyatomic ion* and *law of conservation of matter*. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students might come into this unit with knowledge of how plants grow and how fertilizer is used. The purpose of this lesson is not to go into detail about photosynthesis and ideal growing environments for plants. Plants are used in this lesson because they are an essential material for human survival in space and the need for fertilizer leads us to examine polyatomic ions.

The Haber process (also called the Haber-Bosch process) is not an appropriate extension opportunity. This process is used for an assessment in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)* since it is a reversible reaction and requires ideas of collision and energy, which are not developed in this unit.

Students do not need to memorize the list of common polyatomic ions.

Students begin to balance a few simple chemical equations in this lesson; they will get more practice with this concept in the next lesson as well.

LEARNING PLAN for LESSON 11

1 · NAVIGATE

7 min

MATERIALS: None

Navigate. Display slide A. Say, *Last class we left off with thinking about other processes we need clean water for to live and work on Mars. What are some processes we said we might need clean water for?* Accept all answers. Highlight students who suggest producing food.

ADDITIONAL GUIDANCE

If students do not suggest growing food, have them refer back to *Materials for Survival* from Lesson 1.

After producing food has been identified, follow up by asking about the outputs of photosynthesis.

Suggested prompt	Sample student response
<i>Photosynthesis produces glucose. Is glucose the only nutritional need we have?</i>	No.
<i>What other substances do you think plants provide for us that we need for a healthy diet?</i>	Vitamins. Minerals, Fats. Proteins.

Problematize that these might require additional matter inputs for plants to produce. Display slide B and discuss the question on the slide, *What other matter inputs besides water and carbon dioxide do farmers provide their crops to ensure they grow and yield nutritious produce?* Students will likely suggest fertilizer. If students do not suggest fertilizer, ask, *What if the soil on Mars doesn't contain nutrients that plants need?* Once the class agrees that we may need fertilizer as well, ask students if they know what fertilizer is, or what the main ingredients of fertilizer are. Accept all responses.

Suggest that we collect some additional information to see if we can refine our ideas about this process to ensure that we can successfully grow nutritious food on Mars or other places beyond Earth.

2 · READ ABOUT FERTILIZERS IN SPACE

21 min

MATERIALS: *Fertilizer from Urine*



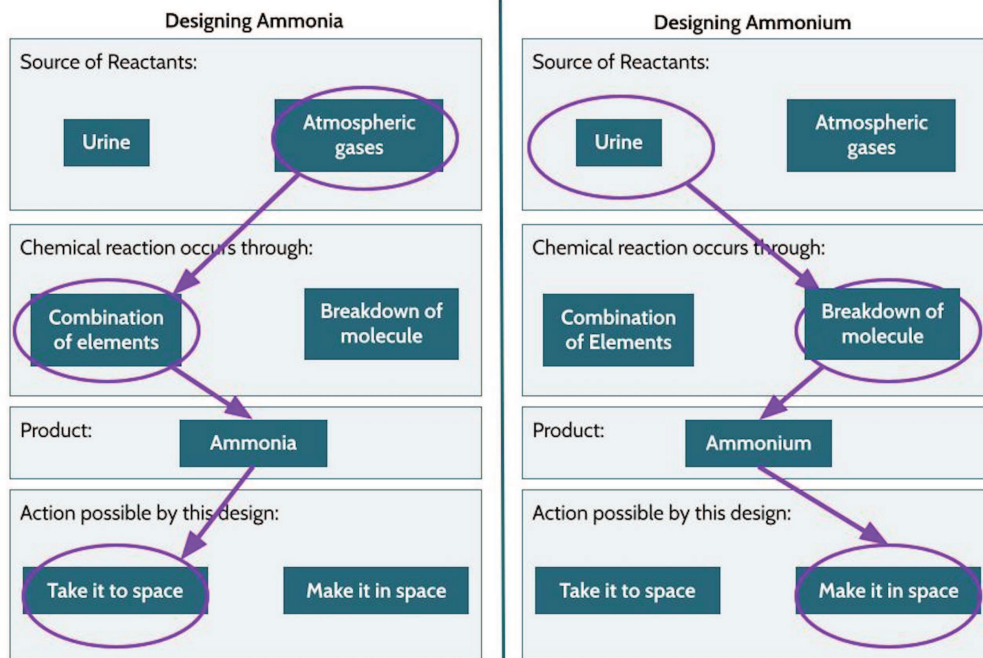
Read about growing plants in space. Display slide C. Distribute a copy of *Fertilizer from Urine* to each student. * Go over the instructions on the slide and check if students need any clarification. Give students about 10 minutes to read and complete the questions on *Fertilizer from Urine*. Circulate around the room and assist as needed.

* ATTENDING TO EQUITY

Universal Design for Learning. *Fertilizer from Urine* includes a diagram to help students put the pieces together and explain the differences between producing ammonia

Making Fertilizer in Space

Draw arrows to show the steps in two design processes that could be used to make fertilizer in space.
You will **not** use all the boxes for both sides.



Sample student map of processes to make fertilizers.

and producing ammonium. The diagram supports students in *representation*, as it guides information processing and visualization of the information contained in the reading.

Share ideas with a partner. Display **slide D**. Give students about three to four minutes to discuss the prompts on the slide with a partner. After that time, lead a class discussion.

Suggested prompt

What key ideas did you identify in the reading?

Should we use ammonia or ammonium as a fertilizer in space? Why?

Sample student response

Plants can be grown in space, but the soil needs more nutrients or fertilizer.

Ammonia is one kind of fertilizer, but requires a lot of nitrogen in the atmosphere.

Ammonium is another fertilizer. We can make it by breaking down urine.

We should use ammonium because we don't have to take it with us. We can make it using our urine.

Suggested prompt	Sample student response
<i>What new questions does this raise for you?</i>	What is in urine that lets us make ammonium but not ammonia? Could we also get the water out of urine? What is the difference between ammonium and ammonia?
ASSESSMENT OPPORTUNITY What to look/listen for in the moment: • Students critically read and determine central ideas about growing plants in space that can give us the materials needed for survival. (SEP: 8.1; DCI: PS1.B.3) • See <i>Fertilizer from Urine</i> Key for additional guidance. The key indicates levels of understanding for supporting struggling readers. What to do: Encourage students to underline only the key ideas in the reading. If a student has underlined most of the reading, you can provide assistance by reminding them about the questions we want to answer about the type of fertilizer we could use. If students need motivation, remind them that we are working to figure out “space food.” Building toward 11.A.1 Critically read and determine central ideas of a text to develop a model that explains how using different reactants leads to the development of different fertilizers which can be used to grow plants off of Earth. (SEP: 8.1, 2.3; DCI: PS1.A.1, PS1.B.3; CCC: 6.2)	

Highlight student questions about the differences between ammonia and ammonium. Say, *We have questions about what exactly ammonia and ammonium are; let's try to answer them.*

3 · MODEL AMMONIA AND AMMONIUM WITH A PARTNER

15 min

MATERIALS: science notebook, *Fertilizer from Urine*, molecular model kit (optional), chart paper, chart paper markers

Suggest looking at differences in ammonia and ammonium. Say, *We are wondering about the differences in the structures of ammonia and ammonium, since they have such different functions.* * Display **slide E**. Give students a few minutes to jot down any similarities and differences they notice about the chemical formulas, then lead a discussion with the prompts below.

Suggested prompt	Sample student response
<i>What similarities did you notice?</i>	They both contain nitrogen and hydrogen.
<i>What differences did you notice?</i>	Ammonia has three hydrogens and ammonium has four hydrogens. Ammonium has a charge.

* SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

Structure and Function are at the core of this conversation. Be sure to call out that the structures of these substances determine their different functions. Look at student responses to Question 3 in *Fertilizer from Urine* for ideas to make this discussion coherent. (CCC: 6.2)

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND

Prepare to model ammonia and ammonium. Say, *Let's take a closer look by modeling what is happening at the atomic scale that could explain the differences we see in ammonia and ammonium.* Display **slide F**. Work with students to develop a list of components and interactions to guide the development of the models. As students share ideas, add them to a T-chart on chart paper, similar to the one shown.

Modeling Ammonia & Ammonium	
Components	Interactions
- Nitrogen, N - Hydrogen, H - Protons - Electrons - Charge	- Valence electrons shared between elements - Bonds

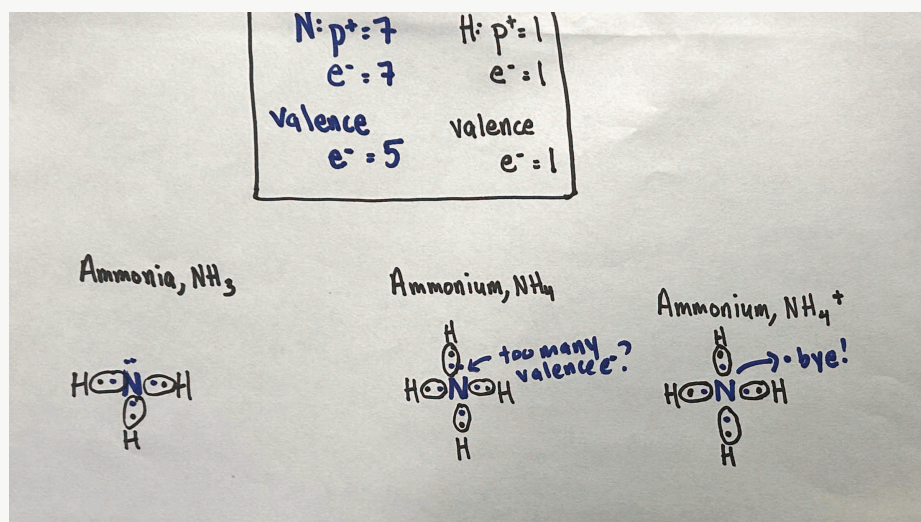
 **Model ammonia and ammonium with a partner.** Display **slide G**. Remind students that they have multiple means of modeling atomic structure to choose from; if needed, direct them back to *Compare Atomic Models* from Lesson 7 to review the various ways they can represent atoms. * Have students work with a partner to develop atomic-scale models of ammonia and ammonium. Tell groups they have about eight minutes to develop the two models. As groups work, circulate around the room and choose a few models to highlight at the beginning of the next class. It is okay if these models differ in how they account for the positive charge in ammonium. You can take photos of the models with your phone to upload to slides, or collect these models at the end of class or at the beginning of the next class.

ADDITIONAL GUIDANCE	Students may be unsure of what to do with the extra electron attached to the nitrogen atom in the ammonium model, and that is okay. When choosing student models to highlight, pick an example that raises this very question. Discussing what is happening with the extra electron attached to the nitrogen atom, and how to account for it, is important for the development of student understanding of polyatomic ions.
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ALTERNATE ACTIVITY	Students could also model ammonia and ammonium using molecular model kits. Have some available to support students who may benefit from using a different representation of the atoms involved while developing their models.
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USING MODELS

In this section, students should select an atomic model to reason through the similar structures of these two substances, especially the presence of an extra hydrogen on NH_4^+ . Students will illustrate the components (electrons) of each substance to predict their different functions. This is deeply integrated with crosscutting concepts of structure and function. ([SEP: 2.4](#))



Sample student model of ammonia and ammonium.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students develop models of NH₃ and NH₄⁺ based on evidence from the reading to predict the relationship between charge and number of electrons. (SEP: 2.3; DCI: PS1.A.1)
- Students show the atomic structures of NH₃ and NH₄⁺, including the number and charge of the protons, neutrons, and electrons. (DCI: PS1.A.1; CCC: 6.2)

What to do: At this point it is okay if students have areas of uncertainty. Encourage them to record their questions so that they remember them during the discussion to develop a class consensus model.

Building toward 11.A.2 Critically read and determine central ideas of a text to develop a model that explains how using different reactants leads to the development of different fertilizers which can be used to grow plants off of Earth. (SEP: 8.1, 2.3; DCI: PS1.A.1, PS1.B.3; CCC: 6.2)

4 · NAVIGATE

2 min

MATERIALS: science notebook

Navigate. Display slide H. Tell students, *Tomorrow we will decide how it might work to grow food in space.* Then take a moment to help students recall why they are thinking about fertilizer in the first place. Encourage students to look back in their science notebooks if they are unsure.

Suggested prompt	Sample student response
<i>Why do we need to think about fertilizer in the context of living in space?</i>	We will need to grow food in space. We might need fertilizer depending on what the soil is like.
<i>Why does it matter whether we use NH_3 or NH_4^+?</i>	We need to use a fertilizer we can make there so we don't have to take a lot with us.

End of day 1

5 · DEVELOP CLASS CONSENSUS MODEL OF AMMONIA AND AMMONIUM

10 min

MATERIALS: science notebook, chart paper, chart paper markers, 9 index cards (optional), 17 paper clips (optional)

Compare differences in ammonia and ammonium models. Have students gather in a Scientists Circle and bring their science notebooks. Display the 2-3 sample student models you identified at the end of last class. Display **slide I**. Give students a few minutes to compare the models and note any similarities and differences. After a few minutes, lead a class discussion.

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Using the Lewis dot models to represent valence electrons in atoms helps continue to support students in considering how to use different atomic models as they try to account for different mechanisms, such as bonding. ([SEP: 2.4](#))

Suggested prompt	Sample student response
<i>What similarities do you notice in our models?</i>	We all included one nitrogen atom and three hydrogen atoms for NH_3 . We all included one nitrogen atom and four hydrogen atoms for NH_4^+ . Ammonia has a full outer electron shell.
<i>What differences do you notice?</i>	Some of us added up the total numbers of protons and electrons. Some of us showed that there is an extra electron in ammonium, and some showed the electron flying off of the ammonium.
<i>What do we wonder about now?</i>	Why does ammonium have a positive charge? Why is ammonia less stable than ammonium?

 **Develop ammonia and ammonium class consensus models.** Say, *We have some different ideas about what happens to the electrons in the nitrogen atom of ammonium and why ammonia reacts or functions differently than ammonium. Let's develop class consensus models for these substances.* Display **slide J** and lead students in developing the class consensus models.

ADDITIONAL GUIDANCE

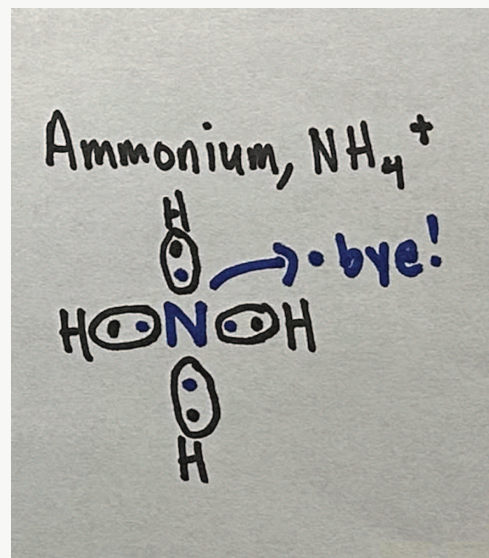
You can use index cards and paper clips or draw them on a sheet of chart paper. If using chart paper, color-coding the valence electrons in nitrogen and hydrogen may help students keep track of the movement of electrons in the molecules.

Say, *We all agree on the numbers of atoms and the numbers of protons and electrons in each model. It looks like we are in agreement about the ammonia model, but have some different ideas about the ammonium model. Let's quickly represent the ammonia model.* Draw the Lewis dot structure for ammonia on the chart paper and check in with students that they agree.

Say, *Now, let's consider the ammonium model. We agree on the overall structure, but have a question about how to represent the charges.* Take a moment to draw the structure of the ammonium model.

Say, *We saw that ammonium has a +1 charge on it. How could we account for that charge with our model?* Look for students to mention that there needs to be one more proton than electrons. Ask, *So what do you think is happening; which atom is losing an electron?* Look for students to suggest that it must be the nitrogen atom that loses an electron because hydrogen and nitrogen are bonded together. If students do not suggest this, ask, *If a hydrogen lost its only electron, would it be able to bond to the nitrogen?* Look for students to say that it would not. Add nitrogen's lost electron to the class consensus model.

Once the class consensus model is completed, ask students to consider what it is about ammonia that might help to explain why it is explosive. If students struggle, prompt them to think about what is different structurally about the two molecules. Look for students to point out that one side of the nitrogen atom is not bonded to hydrogen and so that side might be very negative. Highlight this on the class consensus model.



Sample class consensus model of ammonium.

Suggested prompt

How does this representation help us, or not help us, consider the differences between ammonia and ammonium?

*How does using Lewis dot models help explain how atoms of one element bond with atoms of another element to form molecules? **

Sample student response

Accept all student responses.

It's easier to keep track of the valence electrons.

We can have a visual record that is similar to our paper-clip models.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students develop models of NH_3 and NH_4^+ based on evidence from the reading to predict the relationship between charge and number of electrons. (SEP: 2.3; DCI: PS1.A.1)
- Students show the atomic structures of NH_3 and NH_4^+ , including the number and charge of the protons, neutrons, and electrons. (DCI: PS1.A.1; CCC: 6.2)

What to do: Use the suggested prompts embedded in the teacher guide to help students with areas of confusion.

Building toward 11.A.3 Critically read and determine central ideas of a text to develop a model that explains how using different reactants leads to the development of different fertilizers which can be used to grow plants off of Earth. (SEP: 8.1, 2.3; DCI: PS1.A.1, PS1.B.3; CCC: 6.2)

6 • IDENTIFY AND DEFINE POLYATOMIC IONS

7 min

MATERIALS: science notebook, *Analyzing Chemical Formulas*

Prepare to analyze polyatomic ions. Display slide K. Remind students that they saw groups of atoms with a charge, similar to ammonium, in the previous lesson. Say, *Now that we have seen a few of these, let's try to figure out what is going on with these substances.* Point out the brackets and the plus sign in the model on the slide. Prompt students to think about what the brackets may tell them about the charge of NH_4^+ .

Suggested prompt	Sample student response
What does the plus sign tell us?	It has a positive charge. It is an ion. It lost an electron.
What exactly is positive here?	The nitrogen. One of the hydrogens. All of it, everything inside the brackets.

Tell students, *It turns out there are a lot of substances like this. Let's take a look at a few more.*

Analyze different polyatomic ions. Display slide L. Give students a minute or two to examine the table. Then problematize these substances as neither molecules nor ions.

Suggested prompt	Sample student response
What information can we gather from the table?	There are other molecules like ammonium. Some molecules have the same charge as ammonium, but others have different charges.
Can someone remind us what we call a charged atom?	An ion.
How do you think these charged molecules would act in a compound? Would they bond as a whole group or separate?	I'm not sure. I think they would act together because the ammonium had a bracket around it.

Say, *I have some information that might help us figure out the structures and functions of these rule-breaker substances.* Display slide M. * Tell students that both of the tables on slides L and M are also on *Analyzing Chemical Formulas*. Give students a few moments to compare the two tables in the reference.

* SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

Comparing the formulas of the polyatomic ions to how they are found bonded with other elements (or other polyatomic ions) helps students to visualize that the structure of a polyatomic ion is similar to the structure of an atom or ion. This helps to reinforce thinking about ions developed in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)* and about ionic bonds developed earlier in this unit. Students can think about how this group of atoms functions as a single charged atom when bonded to other elements (or groups of atoms). (CCC: 6.2)

* ATTENDING TO EQUITY

Supporting emergent multilinguals: Encourage students to use their funds of knowledge to think of other words that relate to the *poly-* prefix. Here is a translanguage tip: *Poly-* in English is a cognate to *poli-* in Spanish. You can support Emerging Multilingual Learners and other language development by highlighting that the prefix *poly-* means "many," as in *polyglot* (someone who speaks multiple languages), *polygon* (a shape with many sides), and *monopoly* (one that owns too many related businesses).

Develop a definition for polyatomic ions. Display **slide N**. Tell students that these substances are called *polyatomic ions*. Ask students, *Looking at these formulas, can we see why they are called that?* Develop a definition for polyatomic ions by discussing with students that the group of atoms is acting like a single ion.

Suggested prompt	Sample student response
<i>What does the prefix poly- mean? *</i>	It means a lot. More than one.
<i>How do these pieces of data help us understand how the charged groups of atoms bond with other atoms?</i>	It shows that they act like a single atom. They are one ion made of more than one atom!

Have students add the term *polyatomic ion* to their Personal Glossaries. A sample glossary entry is shown.

Polyatomic ion – a group of atoms acting together as a single ion (charged atom) when bonded to other atoms or polyatomic ions.

7 · PROBLEMATIZE PERCHLORATE

13 min

MATERIALS: *Perchlorate on Mars*

Problematize perchlorate as a food-related toxin. Tell students that another polyatomic ion that is relevant to our conversation about growing food in space is perchlorate, ClO_4^- . Say, *Unlike ammonium, which can help us grow food and survive in places like Mars, perchlorates make survival more difficult. This means that in addition to adding something to the soil (NH_4^+), we also need to remove something from the soil. But how would we do that?* Display **slide O** and distribute *Perchlorate on Mars*. Give students seven minutes to read with a partner and answer the questions on the handout.

Discuss the reading as a class. Display **slide P**.

Suggested prompt	Sample student response
<i>What can be done about perchlorate in soil?</i>	It can be washed out with water. It can be combined with ammonium to make rocket fuel. It can be broken down to get oxygen.
<i>Why do we think perchlorate compounds are soluble in water?</i>	Charges in water attract charges in ions/ionic compounds. The ions separate in water.

Suggested prompt	Sample student response
<i>How can we model breaking apart perchlorate to get oxygen?</i>	Draw it. Write a chemical equation. Show atoms moving around.
ADDITIONAL GUIDANCE	Coherence. Use questions on the DQB about oxygen to motivate the need for this reaction.

8 • MODEL CHEMICAL REACTIONS

12 min

MATERIALS: science notebook, *Perchlorate on Mars*, individual whiteboard, dry erase marker, *Balancing Equations Molecules*, chart paper, chart paper markers

Model chemical reactions. Display **slide Q**. Tell students, *We can use a new model, called a chemical equation, to represent these processes that occur.* Ask students to work with a partner to write the chemical equation for the process described in *Perchlorate on Mars* on their individual whiteboards. Tell students to write big so that other students will be able to read from across the room. Give students a few minutes to do this, then ask all students to hold up their whiteboards at the same time.

It is likely that many students will have written something like: $\text{ClO}_4^- \rightarrow \text{Cl}^- + \text{O}_2$

Discuss these models with students. Start by asking whether the same elements are present on both sides of their chemical equation. Students should have chlorine and oxygen on both sides. Then ask students to count the number of each element on both sides of their equation to see if there are equal numbers. Students may have equal numbers for chlorine but not for oxygen. After students check their own chemical equation, have them compare with a neighbor.



Consider what happens to atoms in a chemical reaction. Point out to students that there seem to be more atoms on the reactants side than on the products side. Display **slide R**.

Suggested prompt	Sample student response
<i>Does it make sense that some of these oxygen atoms would just... disappear? Is that what we think happens?</i>	No, this isn't what happens.
<i>How should we show that these atoms are still there?</i>	We could write O_2 twice, like $\text{O}_2 + \text{O}_2$ We could draw two O_2 molecules
Distribute the molecules cut from <i>Balancing Equations Molecules</i> for either the decomposition of perchlorate or the synthesis of ammonia and give partners five minutes to model the reaction with the cutouts. Stress to students that they should have the same type and number of atoms on both sides of the arrow.	

ADDITIONAL GUIDANCE

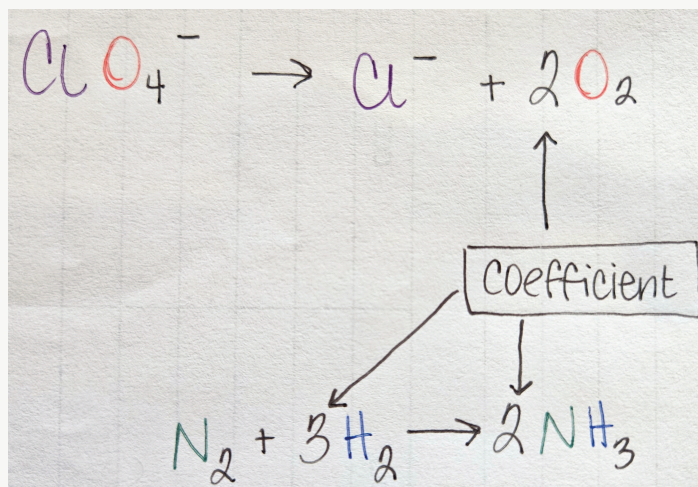
You can give half the students the cutouts to model the synthesis and half the students the cutouts to model the decomposition of perchlorate. You can also give everyone the same set of molecules and reserve the other set for students who finish quickly or who may benefit from extra practice.

Give feedback. Circulate and provide feedback to students by asking, *Is matter conserved on both sides? What is your evidence? How are you using mathematical thinking to figure this out?*

Once students have modeled balanced equations with the manipulatives, write the balanced equations on the board or a piece of chart paper. Circle or underline the coefficients and tell students that this is the accepted way to show multiple atoms or molecules of a substance in a chemical reaction.

Ask, *Why do we need to show the same number of each atom on both sides of the arrow?* Look for students to suggest:

- Because the atoms can't just disappear.
- Because we can't make new atoms.
- Because we need to show that all of the atoms are still there.



Sample balanced equations.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **develop models** of chemical reactions which show that **atoms are conserved** based on evidence from the reading. (SEP: 2.3; DCI: PS1.B.3)
- Students' **models illustrate** the **rearrangement and conservation of matter within the reaction system**. (SEP: 2.3; CCC: 5.1)

What to do: Encourage students to count each element symbol on both sides of the arrow of the chemical equation. If students are satisfied with unequal numbers, ask them if it makes sense that atoms should disappear or be created.

Building toward 11.B Develop and revise a model based on evidence to show the **relationship between reactant and product components** and that **atoms are conserved in a chemical reaction system**. (SEP: 2.3; DCI: PS1.B.3; CCC: 5.1)

Update Personal Glossaries. Display slide S. Tell students that models of chemical reactions must show the same numbers of atoms on the reactants side as on the products side, for the reasons they stated: that atoms cannot be created or destroyed. Then tell students that scientists have a name for this very important idea, the law of conservation of matter. Agree on a definition and give students a moment to update their Personal Glossaries. A sample definition is shown:

Law of conservation of matter - In a chemical reaction, the same number and type of atoms exist before and after the reaction, because atoms cannot be created or destroyed.

9 • NAVIGATE

2 min

MATERIALS: *Materials for Survival* from Lesson 1

Navigate. Celebrate everything we have figured out in this lesson, especially big questions about how to think like a chemical engineer to design an environment to grow food. Display **slide T** and have students refer back to *Materials for Survival* from Lesson 1.

Suggested prompt	Sample student response
<i>What other processes on the handout will we need to apply the law of conservation of matter to?</i>	All of them.
<i>Why do we need to apply this idea to these processes?</i>	Because the numbers of atoms in the matter inputs and outputs do not look like they match. We only looked at the atom type before. If we don't get the proportions right, we will not be able to make the products.

Additional Lesson 11 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. Students determine the central ideas of a reading about using fertilizers to grow plants in space. Students use their summary of the text to make a claim about which substance would be best to use to fertilize soil off of Earth. Students also determine the central ideas in a text about perchlorate ions in martian soil.
SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	CCSS.MATH.CONTENT.HSA-SSE.A.1.a: Interpret expressions that represent a quantity in terms of its context. a. Interpret parts of an expression, such as terms, factors, and coefficients. Students evaluate and choose coefficients to add to chemical formulas to ensure there are equal numbers of atoms on both sides of the chemical equation.

LESSON 12: Which location(s) in the solar system has the elements we need and what relative amount is required to make any substance?

PREVIOUS LESSON We decided we needed more information about growing food in space. We engaged in a reading about fertilizing plants and figured out that scientists can separate ammonium from urea instead of using ammonia fertilizer, and we modeled these substances. We also read about perchlorate, another polyatomic ion, and modeled the chemical reaction of perchlorate decomposition.

THIS LESSON

INVESTIGATION

2 days



Process	Reactants			Products	
Photo-synthesis	Carbon dioxide CO_2	Water H_2O		Glucose $\text{C}_6\text{H}_{12}\text{O}_6$	Oxygen O_2
Making steel	Iron Fe	Carbon C	Manganese Mn	Steel* $\text{Fe}_x\text{C}_y\text{Mn}_z$	
Making glass	Silica SiO_2	Sodium carbonate Na_2CO_3	Calcium carbonate CaCO_3	Glass* $(\text{Na},\text{Ca},\text{SiO}_2)_x$	Carbon dioxide CO_2
Making hardened cement	Titanium silicate Ca_2SiO_4	Dicalcium silicate Ca_2SiO_3	Titanium aluminate $\text{Ca}_3\text{Al}_2\text{O}_6$	Hardened cement* $(\text{CaO})_x(\text{H}_2\text{O})_y(\text{SiO}_2)_z(\text{Al}_2\text{O}_3)_w$	
Making plastic	Terephthalic acid $\text{C}_8\text{H}_6\text{O}_4$	Ethylene glycol $\text{C}_2\text{H}_4\text{O}_2$		Polyethylene terephthalate* $(\text{C}_{10}\text{H}_8\text{O}_2)_x$	Water H_2O

We break down the chemical equation for photosynthesis and figure out that we need to add more molecules of some reactants and products to ensure there are equal numbers of elements on both sides of the equation. We partner up to research which locations in the solar system contain the elements we need. We obtain information about additional elements on Mars from a reading and balance an equation involved in cement production. We realize that water is part of the structure of hardened concrete and read a paper about making concrete on Mars without water. We update our Progress Trackers and complete an Electronic Exit Ticket.

NEXT LESSON We will argue for how recycling many substances we need would impact our future plans for living and working beyond Earth and on it. We will synthesize information from a reading, two videos, and a series of molecular models to answer questions about why we recycle some of the substances we need but not others, and how this could apply to our long-term plans for living and working beyond and/or on Earth.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, ESS1-2, ESS2-1, ESS2-5



WHAT STUDENTS WILL DO

12.A Create balanced chemical equations (computational models) using mathematical representations of elements to demonstrate that matter is conserved. (SEP: 5.1; DCI: PS1.B.3; CCC: 1.4, 5.1)

12.B Gather, read, and interpret information presented in different formats and adapted from scientific literature to predict which object in space (system) would contain the quantities (large scale) of elements and compounds (atomic scale) needed to create the resources for survival. (SEP: 8.1, 8.2; DCI: PS1.B.3; CCC: 4.3)

WHAT STUDENTS WILL FIGURE OUT

- Since matter cannot be created or destroyed, balanced chemical equations must have equal numbers of each element in the reactants and products. This is done by adding coefficients to reactants and products in the chemical reaction.
- Mars has more of the elements needed to make the substances to live and work in space than any other location in the solar system.
- It is possible to develop processes to make the substances we need that utilize in situ resources if we know what elements are present on an object in space and their amounts.

Lesson 12 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	4 min		NAVIGATE Have students turn and talk with a partner and then share with the class to remind ourselves where we left off last time.	A	
2	16 min		DISCUSS PHOTOSYNTHESIS FROM A CHEMISTRY PERSPECTIVE Work with students to co-construct a balanced chemical equation for photosynthesis.	B-G	chart paper, chart paper markers
3	10 min		COLLECT DATA ABOUT ELEMENTS IN OUTER SPACE Organize students in pairs to determine how many atoms of each element we need and research where they are found in the solar system. Lead a class discussion to share results.	H-K	computer with internet access, <i>Substances for Survival</i> , <i>Search for Elements</i> , chart paper, chart paper markers
4	15 min		OBTAIN INFORMATION ON MARS'S SOIL Have students individually complete <i>Mars Rovers Research</i> .	L-O	<i>Mars Rovers Research</i> , <i>Substances for Survival</i>
<i>End of day 1</i>					
5	2 min		NAVIGATE Recap where we left off last time as a class.	P	
6	10 min		BALANCE A SECOND CHEMICAL EQUATION Lead the class in thinking about the chemical formula for cement. Then have students work with a partner to balance a chemical equation involved in making cement.	Q-S	individual whiteboard, dry erase markers
7	18 min		READ ABOUT SULFUR-BASED CONCRETE FOR MARS Have students individually read an adapted primary research paper. Lead a class discussion to debrief the reading and revisit the DQB.	T-W	<i>Sulfur-Based Concrete</i> , <i>Summarize a Reading</i> , Driving Question Board
8	5 min		UPDATE PROGRESS TRACKERS Have students update their Progress Trackers with what they have learned about balancing chemical equations.	X	
9	10 min		NAVIGATE Have students complete an Electronic Exit Ticket.	Y-Z	computer with internet access
<i>End of day 2</i>					

Lesson 12 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • computer with internet access • <i>Substances for Survival</i> • <i>Search for Elements</i> • <i>Mars Rovers Research</i> • <i>Sulfur-Based Concrete</i> • <i>Summarize a Reading</i>	• individual whiteboard • dry erase markers	• chart paper • chart paper markers • Driving Question Board

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.

Test to make sure the following links are working for students as they research locations in the solar system:

- <https://solarsystem.nasa.gov/planets/mars/in-depth/>
- <https://science.nasa.gov/moon/facts/>
- <https://solarsystem.nasa.gov/planet-compare/>
- <https://solarsystem.nasa.gov/planets/venus/in-depth/>, optional
- <https://solarsystem.nasa.gov/planets/mercury/in-depth/>, optional
- <https://solarsystem.nasa.gov/planets/saturn/in-depth/>, optional
- <https://solarsystem.nasa.gov/planets/jupiter/in-depth/>, optional
- <https://solarsystem.nasa.gov/planets/neptune/in-depth/>, optional

Ensure students have access to either a printed or digital color version of *Mars Rovers Research* (one per student), which is a reading about elements that rovers have found in martian soil, and *Sulfur-Based Concrete*, which is about sulfur concrete made with Mars soil simulant as a replacement for traditional concrete.

See *Electronic Exit Tickets* from Lesson 4 for instructions on how to make the Electronic Exit Ticket students will need at the end of this lesson using <https://docs.google.com/forms/d/1Tng1U2WcLUUecj-yEVWwHgbLGNsRcJBn1ECNeWjBN88/copy>.

Lesson 12 • Where We Are Going and NOT Going

Where We Are Going

The goal of this lesson is to have students engage with different types of media and a peer-reviewed journal article to determine the feasibility of living and working on Mars. This lesson is designed to coherently build ideas related to the following disciplinary core idea:

- **PS1.B: Chemical Reactions.** The fact that atoms are conserved, ~~together with knowledge of the chemical properties of the elements involved,~~ can be used to describe and predict chemical reactions.

Crossout explanation: Students previously addressed the crossed-out portion of **PS1.B.3** in Lesson 11. In the Lesson 15 unit assessment, students again use chemical properties such as electronegativity and valence electrons to predict outcomes of chemical reactions. The fourth High School Chemistry *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*, also addresses **PS1.B.3**.

In previous lessons, students focused on how individual atoms combine in specific ways to form molecules and compounds. This lesson builds upon that idea, but considers the importance of types and amounts of elements as they recombine in chemical reactions. Ideas from *Middle School OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* are reinforced when students develop ideas about conservation of matter. These ideas are further used to predict chemical reactions.

Students examine the unbalanced chemical equation for photosynthesis. They individually take account of the type and amount of each element on both the reactants and products sides of the equation. Students use this mathematical representation of the chemical equation to notice that the amounts of products and reactants are unequal (**SEP: 5.1; CCC: 1.4**). The class co-constructs a computational model of the process of photosynthesis, which results in a balanced chemical equation (**SEP: 5.1; CCC: 5.1**). Students continue to build the idea of accounting for elements (types and numbers) as they determine which substances we could successfully make in space using information from NASA websites (**SEP: 8.2; CCC: 4.3**).

Students read about research being conducted on Mars using rovers (**SEP: 8.1**). Students determine from the reading that Mars would be the best location for us to live and work off of Earth. Students work with a partner to balance a chemical equation for cement (**SEP: 5.1; CCC: 1.4, 5.1**). After identifying that making cement would be a limitation given the quantities of elements available on Mars, students read about research into alternatives for concrete production (**SEP: 8.1; CCC: 4.3**).

Students have previously engaged with **SEP: 5.1** in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*. Here students engage with **SEP: 5.1** partially: *Create and/or revise a computational model or simulation of a ~~phenomenon, designed device, process, or system~~*. See the Lesson 10 Teacher Guide for discussion of students' use of **SEP: 8.1**. See the Lessons 2, 4, and 5 Teacher Guides for discussion of students' use of **SEP: 8.2**.

This is the first time in this unit that students have engaged with **CCC: 1.4** and **CCC: 4.3**. Students previously developed **CCC: 1.4** in unit *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. Students engage with **CCC: 4.3** partially: *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*. Students have developed the crossed-out portions in *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)* and *Polar Ice Unit*.

Students engage with **CCC: 5.1** partially: *The total amount of ~~energy and matter~~ in closed systems is conserved*. See the discussion in the Lesson 11 Teacher Guide of this unit around when crossed-out portions are addressed.

In this lesson, students will co-construct a definition for the following terms, which they should add to their Personal Glossaries: *balanced chemical equation* and *coefficient*. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Students may have seen or balanced chemical equations in the past, but they may not be able to talk through the reasoning for why each coefficient was used. The purpose of intentionally talking through each step of balancing a chemical equation is to ensure students are exposed to the reasoning behind adding coefficients and what number to use for them. Students may benefit from additional practice with balancing chemical equations, but you should avoid having students balance equations outside of chemical formulas they have seen in this unit. In *Oysters Unit*, students will have additional practice with balancing chemical equations in later units.

We are not considering the properties of the elements involved when looking at which of Mars's soil substances we could use to build substances to survive there. It may be worthwhile to point out that we are theoretically determining if it *could* be possible, not that it *is* possible.

LEARNING PLAN for LESSON 12

1 · NAVIGATE

4 min

MATERIALS: None

Discuss what we figured out last class. Display slide A. Have students turn and talk with a partner about the prompts on the slide. After two minutes, ask students to share their discussion with the class.

Suggested prompt	Sample student response
What did we figure out we could do last class to survive in space?	We could grow plants. We can get fertilizer to grow plants. We can remove perchlorates from martian soil.
How do plants do that?	Photosynthesis!

Say, Great! Let's spend some time reminding ourselves of what is happening during photosynthesis, since we will definitely need it to grow plants to eat wherever we go in space.

2 · DISCUSS PHOTOSYNTHESIS FROM A CHEMISTRY PERSPECTIVE

16 min

MATERIALS: science notebook, chart paper, chart paper markers

Discuss what photosynthesis means. Ask, Where have you heard the word photosynthesis before? Look for students to suggest that they have heard it in other science classes. Display slide B. Say, Take a minute to quickly stop and jot your answers to the prompts on the slide in your science notebook. Give students a few minutes to record their ideas and then ask for volunteers to share.

Suggested prompt	Sample student response
What does photo- represent, or mean?	Light.
What does synthesis mean?	To put something together.
What does photosynthesis mean to you?	When plants take light and put together different molecules to grow.
What are the reactants in photosynthesis?	Water, carbon dioxide, light.
What are the products?	Sugar, oxygen.

* SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

This is a key lesson for the CCC: Matter and Energy. The fact that matter is conserved in chemical reactions serves as the basis for determining proportional relationships between reactants and products in a chemical equation. Listen carefully to students' ideas as they account for numbers and types of atoms on both sides of the equation and propose ways to balance them. (CCC: 5.1)

* ATTENDING TO EQUITY

Universal Design for Learning: Students rarely copy information into their science notebooks within the course, but this

Introduce the equation for photosynthesis. Say, *In the last lesson, we started to look at chemical equations as models of how atoms rearrange during chemical reactions. We also tried balancing some simple chemical equations because we know matter does not just disappear during a chemical reaction. * The equation for photosynthesis might be a bit more challenging to balance, so let's work on it together.*

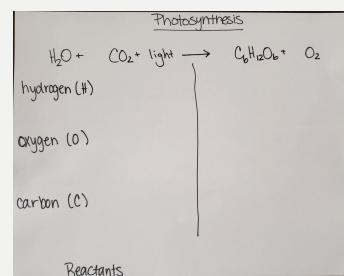
ADDITIONAL GUIDANCE

Although students may bring up energy (light) as necessary for photosynthesis, this unit focuses solely on matter transformations. Validate student ideas around energy as an important aspect of chemical reactions, and tell students that it is at the heart of the upcoming *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit).*

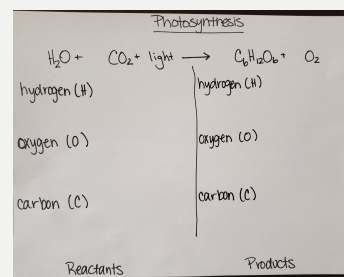


Balance the equation for photosynthesis. Display slide C. Write down an unbalanced equation for photosynthesis on a piece of chart paper and leave space to balance the equation. Tell students to write down the process in their science notebooks and to leave some space between each reactant or product.

Say, *We are going to count the different types of atoms on either side of the equation. As we do this, record what I write on the chart paper in your science notebooks. * What elements can we agree are on the reactants side?* Look for students to say hydrogen, oxygen, and carbon. Draw a line under the arrow in the equation and write hydrogen, oxygen, and carbon on the reactants side of the line.



Ask, *What elements can we agree are on the products side?* Look for students to say carbon, hydrogen, and oxygen. Say, *So we have the same elements in the products. Let's record them in the same order on the products side so we can compare how many of each there are.* Write hydrogen, oxygen, and carbon on the products side of the line.



representation of how to balance a chemical equation supports students in their comprehension. The visual representation, along with the verbalization of how to balance the chemical equation, increases students' comprehension of the iterative process of balancing chemical equations.

* ATTENDING TO EQUITY

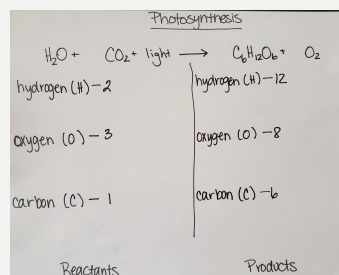
Universal Design for Learning: The goal in this moment is two-fold: (1) to support *representation* by providing students an opportunity to decode the symbols in the chemical equation, and (2) to have students think about how the chemical equation can be used as a model to explain phenomena or solve problems.

* SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Examples of prior work in ratio and proportional thinking that students would have developed through 6th- and 7th-grade CCSS mathematics include:

- Making scale draws and scaling up and down the relevant dimensions of a figure.
- Comparing part to part and part to whole in ratios of populations.
- Finding equivalent fractions.
- Scaling up and down ingredients in recipes.
- Calculating unit rates from proportions, and seeing these as equivalent ratios that are scaled to per 1.
- Calculating percentages, and seeing these as equivalent fractions that are scaled to per 100 ("per cento").

Display **slide D**. Have students individually count the number of each type of element on both the reactants and products sides of the equation. Then tell them to answer the two prompts on the slide. After a couple of minutes, ask for students to share out. * As students share, add the numbers next to each element on their respective sides of the chart.



Suggested prompt	Sample student response
<i>How many hydrogen atoms did you count on the reactants side?</i>	2
<i>How many oxygen atoms did you count on the reactants side?</i>	3
<i>How many carbon atoms did you count on the reactants side?</i>	1
<i>How many hydrogen atoms did you count on the products side?</i>	12
<i>How many oxygen atoms did you count on the products side?</i>	8
<i>How many carbon atoms did you count on the products side?</i>	6
<i>What do you notice?</i>	They do not match up. The amount of reactants is less than the amount of products.
<i>What do you wonder?</i>	Where do all of the extra atoms come from?

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use mathematical representations of the numbers of elements for evidence that the amount of matter on either side of a chemical equation is not equal. (CCC: 1.4; DCI: PS1.B.3)
- Students use a chemical equation (computational model) to account for amounts of elements. (SEP: 5.1; DCI: PS1.B.3)

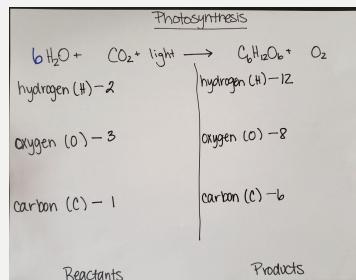
What to do: If students do not identify that the amounts of each element on either side of the equation should be added, work with them to find these totals. You may also write “before” and “after” above the equation so that students connect the abstract equation to the chemical change process and more readily see that in an unbalanced equation, matter seems to “appear” from nowhere. Stress that we need to consider the total numbers of atoms of different elements. At this point, students should identify that the numbers are not equal, which builds on ideas of matter conservation from Lesson 11 and *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*.

Building toward 12.A.1 Create balanced chemical equations (computational models) using mathematical representations of elements to demonstrate that matter is conserved. (SEP: 5.1; DCI: PS1.B.3; CCC: 1.4, 5.1)

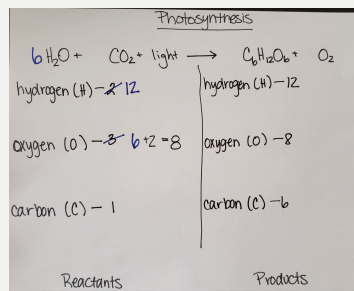
 Say, In our last class, we talked about conservation of matter. In order to represent this idea in a chemical equation, we need to make sure there are equal amounts of each element on both the reactants and products sides. We can do this by using multiplication to adjust the amounts of each atom on either side of the equation. Walk students through how to balance the equation for photosynthesis.

Say, Let's start with hydrogen, since we listed it first. When we are balancing equations, we want to examine just one element at a time, on both the reactants and products sides. So, for hydrogen, we have 2 atoms of it on the reactants side and 12 atoms of it on the products side. Think back to math class--what is the least common multiple of 2 and 12? Look for students to say 12.

Ask, If 12 is the least common multiple, what do we need to multiply the 2 by to get 12? Look for students to say 6. Write 6 in front of H₂O on the piece of chart paper.

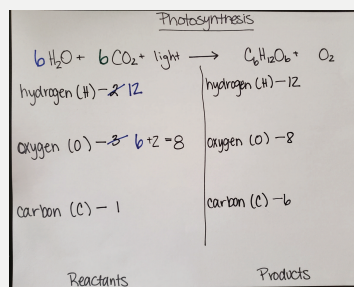


Say, Now that we have added the 6 in front of the H_2O , that means we need to multiply each element in the water molecule by 6. Under the reactants side, cross out the 2 for hydrogen and change it to 12. Then cross out the 3 for oxygen and change it to 8. Explain to students that when we said there was a total of 3 oxygen atoms, that was 1 from the water molecule and 2 from the carbon dioxide molecule. Say, So we now have 6 oxygen atoms in the water molecule and 2 in the carbon dioxide molecule, for a total of 8.

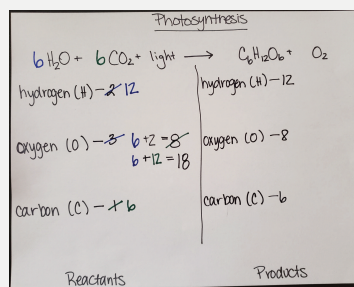


Say, Now look at our totals on each side. Which elements are balanced? Look for students to say that hydrogen and oxygen are balanced.

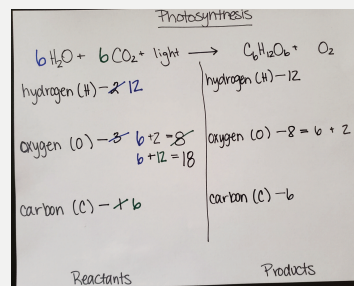
Say, Okay, now let's balance carbon using the same technique we used for hydrogen. What is the least common multiple of 1 and 6? Look for students to say 6. Write 6 in front of CO_2 on the piece of chart paper.



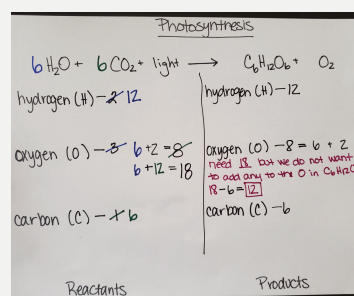
Say, Now that we have added the 6 in front of the CO_2 , that means we need to multiply each element in the carbon dioxide molecule by 6. Under the reactants side, cross out the 1 for carbon and change it to 6. Then cross out the 8 for oxygen and change it to 18. Explain to students that when we said there were 8 oxygen atoms, that was 6 from the water molecule and 2 from the carbon dioxide molecule. Say, So we now have 6 oxygen atoms in the water molecule and 12 in the carbon dioxide molecule, for a total of 18.



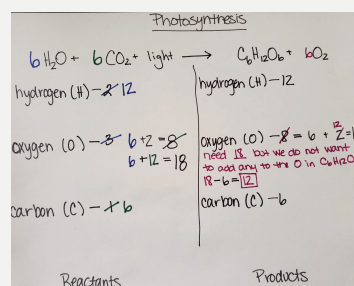
Say, Now, let's look at our totals again. Are all of the elements balanced on each side? Look for students to point out that oxygen is no longer balanced. Say, That sometimes will happen as we work to balance chemical equations. Let's try to figure out oxygen. Since the products side does not balance with the reactants side, let's look at where we got our total of 8 oxygen atoms. Point out that 6 are in the glucose molecule and 2 are in the oxygen molecule. Record this on the chart paper.



Say, In this case, it helps to split up the number because it may make it easier for us to balance the equation. Now, can someone remind us how many oxygen atoms we need on the products side to balance this equation? Look for students to say 18. Say, Okay, since we have hydrogen and carbon balanced, let's focus our attention on the oxygen. In order to do that, let's first remove the number of oxygen atoms in glucose from the total we need. Subtract 6 oxygen atoms from the 18 we need. Point out that we now need 12 oxygen atoms on the reactants side, and that these need to come from the oxygen molecule, O₂.



Say, Since 12 is the least common multiple of 2 and 12, what do we need to multiply the 2 by to get 12? Look for students to say 6. Write 6 in front of O₂. Say, Now that we have added the 6 in front of the O₂, that means we need to multiply the oxygen molecule by 6. Under the products side, cross out the 2 for oxygen and change it to 12. Finally, total the oxygen atoms on the products side to 18. Ask, Now, is our equation balanced? Look for students to agree that the equation is balanced.



Say, So we are pretty sure the equation is balanced, but it is always good to go through it one more time to do a final check. Add "final check" to the key in a fourth marker color. As you compare the numbers of each type of atom on the reactants and products sides of the equation, place a check mark on each total.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use mathematical representations of the numbers of elements for evidence that the amount of matter on either side of a chemical equation is not equal. (CCC: 1.4; DCI: PS1.B.3)
- Students use a chemical equation (computational model) to account for amounts of elements. (SEP: 5.1; DCI: PS1.B.3)
- Students use mathematical thinking to revise a chemical equation to show equal amounts of elements in products and reactants. (SEP: 5.1; DCI: PS1.B.3)

What to do: Since this is being co-constructed with students, check in with students for understanding. You may wish to have students balance several additional equations with a partner or individually. Other supports would be to display the images of the molecules on optional slide E to aid students in counting the numbers of each type of atom, or provide the physical manipulative models introduced in Lesson 8. At the end of the lesson, students will work with a partner to balance an equation for one of the reactions involved in the hardening of cement.

Building toward 12.A.2 Create balanced chemical equations (computational models) using mathematical representations of elements to demonstrate that matter is conserved. (SEP: 5.1; DCI: PS1.B.3; CCC: 1.4, 5.1)

Define the term coefficient. Display slide F. Point out the coefficients to students and remind them that we were introduced to this term in the last class. Ask students what the coefficients in the balanced equation for photosynthesis tell us. Look for students to say that they tell us how many of each molecule are needed in the reaction. Recap that coefficients are the numbers added in front of each chemical formula to help us balance the chemical equation. Say, *Now that we have more experience using coefficients to balance chemical equations, let's add those terms to our Personal Glossaries.*

Tell students to add the words *coefficient* and *balanced chemical equation* to their Personal Glossaries.

Sample student entries:

Coefficient - a number added to the front of a chemical formula for a molecule which shows the amount of the molecule needed to balance the chemical equation.

Balanced chemical equation - a chemical equation that includes multiplier coefficients to represent that the amounts and types of atoms on the reactants side are equal to those on the products side.

Debrief using proportion thinking. Keep slide F displayed. Prompt students to reflect on what the balanced equation for photosynthesis means for living and working in space. Say, *Let's think about what the balanced equation tells us. How many molecules of each reactant are needed to make one sugar molecule? How many oxygen molecules do we get for every sugar molecule produced?* Pose a couple of follow-up questions that ask students to consider multiples of these coefficients that use factors of 10, which is something students have done in the past. For example, *How many water molecules do we need to produce 10 molecules of sugar?* Emphasize that balancing equations is really just a way of thinking about ratio or proportion of parts, which students have used throughout their math classes in prior grades.*

Pivot from plants to other substances. Display slide G and point out that while we have been focused on how plants make glucose from carbon dioxide, water, and light, they use that glucose as a reactant in the other processes shown on the slide. This includes making other macromolecules such as proteins, nucleic acids, and fats. Summarize by saying, *As long as we provide plants with the inputs they need, they will use them in the right proportions to make lots of different molecules, like the fats and proteins our bodies need. Let's keep in mind what plants need, but shift our focus to other things we require that are not made by plants.*

ADDITIONAL GUIDANCE

The purpose of **slide G** is to point out that plants use glucose produced by photosynthesis as a reactant in many other chemical processes to make complex carbohydrates, fats, nucleic acids, and proteins. Because this unit focuses on matter changes, energy is not shown as an input for photosynthesis and as an output for respiration. Students have seen energy associated with these processes in *Middle School 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 7.4: Where does food come from, and where does it go next? (Maple Syrup Unit)*, and *High School Biology OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*. Students will explore energy associated with chemical reactions further in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*.

3 · COLLECT DATA ABOUT ELEMENTS IN OUTER SPACE

10 min

MATERIALS: computer with internet access, *Substances for Survival*, *Search for Elements*, chart paper, chart paper markers

Consider what we need to make other substances for survival off of Earth. Display **slide H**. Distribute *Substances for Survival* and *Search for Elements*. Cue students to think about the amounts of different elements we will need to make other substances for survival in space. Ask, *In addition to supplying plants with the elements to make glucose, what elements, and how many atoms of them, would we need to make steel? glass? cement? plastic? Work with a partner and use Substances for Survival to develop a list of elements we would need for each substance. Record this information in the table in Question 1 of Search for Elements.*

ADDITIONAL GUIDANCE

Students may notice that the tables on *Substances for Survival* look very similar to *Materials for Survival* and *Key Chemical Reactions*. In this instance, the images of the substances have been removed so that students focus on analyzing the chemical formulas for each of the substances needed for survival. Fats and proteins have been removed because we just confirmed that they can be made by plants and their synthesis is not easily represented by a single chemical reaction.

Share types and quantities of elements needed. After a couple of minutes, display **slide I** and ask students to share their results. As students share, list their findings on a piece of chart paper. See the sample chart provided.

Substance	Number of atoms of each element needed to make one molecule or unit of the substance								
	H	C	O	Na	Al	Si	Ca	Mn	Fe
Glucose	12	6	6						
Steel		1						1	59
Glass			14	2		6	1		
Hardened cement	76		115		2	20	34		
Plastic	8	10	4						

Say, *Okay, so now we have a list of elements and how many atoms of each we would need. Now, let's figure out where exactly we can find them.*



Research where we could find enough elements to make substances for survival. Display **slide J**. Ask partners to work together to determine which elements are found on the Moon and Mars. Explain that each person will research one of these locations. Tell students to use the website links provided on *Search for Elements* to research each location. Give pairs about 5 minutes to complete Questions 2-5 on the handout. As students work, circulate around the room and assist as needed.

ALTERNATE ACTIVITY

Extension opportunity: If students wish to research an additional location in the solar system, they can record their findings in the extra row provided in the table on *Search for Elements*. Students can access information about the following planets using the related links:

- Venus: <https://solarsystem.nasa.gov/planets/venus/in-depth/>
- Mercury: <https://solarsystem.nasa.gov/planets/mercury/in-depth/>
- Saturn: <https://solarsystem.nasa.gov/planets/saturn/in-depth/>
- Jupiter: <https://solarsystem.nasa.gov/planets/jupiter/in-depth/>
- Neptune: <https://solarsystem.nasa.gov/planets/neptune/in-depth/>

Discuss research findings. Display slide K and use the suggested prompts to facilitate a brief discussion.

Suggested prompt	Sample student response
<i>Based on your research, which location in space contains the elements required for photosynthesis and for us to make most of the substances we need for a permanent settlement?</i>	The Moon had a lot of the elements for cement but no carbon for photosynthesis. Mars had almost everything, including both reactants for photosynthesis--carbon dioxide and water. Mars is smaller than Earth so it might not have enough. It depends on how much we need.
<i>Which substances would be the most straightforward to produce? Why?</i>	Steel, because Mars has a lot of iron and steel requires only a little carbon and manganese.
<i>Which substances would be more difficult to produce? Why?</i>	Cement and glass, because both require silicon and only the Moon and maybe Jupiter's core have it. It said Mars is rocky, but we're not sure what elements are in those rocks.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **evaluate sources of information presented in different media** (websites) **or formats as well as in words to determine which location has the elements that could serve as the basis for the substances we need to live and work in space.** (SEP: 8.2; DCI: PS1.B.3)
- Students identify which object in space (**system**) contains the quantities (**large scale**) of **elements and compounds (atomic scale) needed to create the resources for survival.** (DCI: PS1.B.3; CCC: 4.3)

What to do: See guidance on *Search for Elements Key*. Additional support for students during this Jigsaw activity can be found on *UDL for Jigsaw Readings*.

Building toward 12.B.1 Gather, read, and interpret information presented in different formats and adapted from scientific literature to predict which object in space (**system**) would contain the quantities (**large scale**) of **elements and compounds (atomic scale) needed to create the resources for survival.** (SEP: 8.1, 8.2; DCI: PS1.B.3; CCC: 4.3)

4 • OBTAIN INFORMATION ON MARS'S SOIL

15 min

MATERIALS: *Mars Rovers Research, Substances for Survival*

Motivate the need for additional data about Mars. Say, *So far, we have found some information on the NASA websites about what elements are on the Moon and Mars. It seems like Mars has most of the elements to make the substances we need to live and work in space, but we are not sure if it has any silicon. And that is something we need to make cement and glass for building shelters.*

Ask students if they have ever heard of the Mars rovers. Show **slide L** and explain that the rovers are robotic vehicles equipped with scientific instruments capable of identifying elements and molecules using spectroscopy, and NASA has sent five rovers to Mars since 1997. Tell students that you have some data from rovers about the composition of rocks and soil on Mars.



Critically read about martian research. Display **slide M** and distribute *Mars Rovers Research* to each student. Give students eight minutes to read and annotate *Mars Rovers Research*, and to consider the implications that this new evidence has for building a permanent settlement on Mars by responding to the prompts at the end of the reading. *

Connect our findings to living in space. Display **slide N** and give students a few minutes to turn and talk with a partner about the implications of the rover data for living and working in space by sharing their responses to the prompts at the end of *Mars Rovers Research*.

Bring the class back together to share students' ideas. Display **slide O**.

* SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

Throughout this lesson, students are obtaining information from different sources of information to think about how chemical reactions can be used to address the unit question. Prior to this point in the lesson students have obtained information about what elements are present on the Moon and Mars from NASA websites (SEP: 8.2). The current reading, based on a paper presented at a conference, serves as a bridge between the websites and the upcoming adapted primary research paper (SEP: 8.1). Check in with students to gain insight into the support they might need later while reading the adapted research paper.

Suggested prompts	Sample student responses	Follow-up questions
What new evidence does the APXS data provide about rocks and soil on Mars?	It gives the elements present as oxides even though APXS directly detects only the element and not the oxide molecule. For each oxide or element, it also gives amounts as weight percents. There is a lot of silicon on Mars – its weight percent is higher than all the others.	Why is it reported that way? How accurate and precise do you think those values are? Roughly how much higher is it?
What additional substances in Substances for Survival might we be able to make based on that evidence?	Maybe steel? APXS found Fe and Mn, but not C . The Si could be used to make glass and cement. Except for water, the APXS data says all of the elements that are in glass and hardened cement as products are there – Na, Ca, Si, Al.	Do we have any evidence for carbon on Mars? How much of those elements did APXS find in the rocks and soil? How much will we need?
What does this mean for living and working in space?	Mars has the elements we need to build shelters that we can live and work in out of glass and cement!	

Conclude the day by saying something like, *We will need a lot of glass and cement if we are going to live and work on Mars. We should probably try balancing those equations to get a better idea of the quantities of each element we need. Let's pick up here next time.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students identify which object in space (system) contains the quantities (large scale) of elements and compounds (atomic scale) needed to create the resources for survival. (DCI: PS1.B.3; CCC: 4.3)
- Students determine the central ideas of scientific literature to determine the feasibility of living and working on Mars. (SEP: 8.1)

What to do: If students struggle to summarize the text found on *Mars Rovers Research*, see additional reading support in *The OpenSciEd High School Teacher Handbook*.

Building toward 12.B.2 Gather, read, and interpret information presented in different formats and adapted from scientific literature to predict which object in space (system) would contain the quantities (large scale) of elements and compounds (atomic scale) needed to create the resources for survival. (SEP: 8.1, 8.2; DCI: PS1.B.3; CCC: 4.3)

End of day 1

5 · NAVIGATE

2 min

MATERIALS: science notebook

Recap where we left off. Display **slide P** and use the prompt to discuss where we left off last time. Students should recall that the evidence we found indicated that Mars had the elements to make what we need but they are present in different amounts. If needed, ask students to take out their science notebooks and refer to *Search for Elements* and *Mars Rovers Research*.

Motivate the need to balance the cement equation. Say, *It sounds like Mars seems promising in terms of the elements required to make the substances we will need, but they are present in different amounts. How can we determine how much of each element we will need?* Students should suggest balancing the chemical equations. Suggest starting with cement because it is the most widely used construction substance on Earth and that based on its properties, it would probably protect us from the harsh environment on Mars.

6 · BALANCE A SECOND CHEMICAL EQUATION

10 min

MATERIALS: science notebook, individual whiteboard, dry erase markers

ADDITIONAL GUIDANCE

There are a wide variety of chemical formulas for cement. The ones presented here have been chosen because they are accessible and appropriate for student use.

Problematize water in hardened cement. Display **slide Q**. Tell students to look at a chemical formula for cement.

* SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

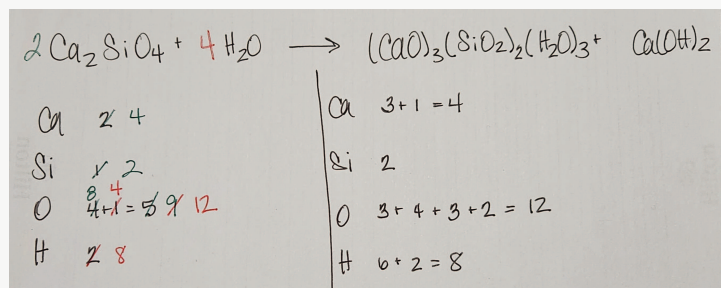
Students are about to engage with the crosscutting concept of system and system models by balancing a chemical equation. They will determine the coefficients needed to represent the conservation of matter during a chemical reaction. They will apply those proportional relationships to thinking about the feasibility of preparing cement from the amounts of elements or compounds available in other locations (closed systems) in the solar system.

Suggested prompt	Sample student response
<i>What do you notice about the chemical formula?</i> <i>What are you wondering?</i>	The water looks like it's part of the formula, but not. The parts of the formula are separated by parentheses. Cement is dry, so why is there water? Why are all of the different parts separated by parentheses?
ADDITIONAL GUIDANCE	If students do not yet bring up the way water is represented in the formula for cement, do so now. Say something like, <i>What struck me as unusual about the formula for hardened cement was the water in the formula. Hardened cement is dry!</i>
Say, <i>Let's take a closer look at the reaction for cement to see if we can answer some of our wonderings.</i> Examine the chemical reaction for cement more closely. Explain to students that the chemical formula on slide Q is one way scientists that study cement actually represent the chemical reaction that forms hardened cement from dry powdered cement and water. Point out that powdered cement is actually a mixture of the calcium-containing molecules shown on the reactants side, and that a complicated series of chemical reactions occurs when they are mixed with water. Give students time to examine the structure of the final product (hardened cement) and invite them to share what they notice. Look for them to point out the ordered structure, the caption indicating that the unit shown repeats throughout the substance, and the incorporation of water into the structure.	
ADDITIONAL GUIDANCE	This segue into cement occurs for two reasons. First, to quickly establish that making hardened cement is a water-intensive process as water is incorporated into the final structure. This will be leveraged later in the lesson as an obstacle on a desert planet like Mars. Second, it exposes students to the complexity of the chemical processes involved in making this ubiquitous material and provides students an opportunity to observe another important function of water.
ALTERNATE ACTIVITY	Extension opportunity: If students are interested in extended molecular structures of cement, they can check out the open-access chemical research paper: Mohamed, A.K., Moutzouri, P., Berruyer, P., Walder, B.J., Siramanount, J., Harris, M., Negroni, M., Galmarini, S.C., Parker, S.C., Scrivener, K.L, Emsley, L., & Bowen, P. (2020). The atomic-level structure of cementitious calcium aluminate silicate hydrate. <i>Journal of the American Chemical Society</i>, 142(25), 11060–11071. https://pubs.acs.org/doi/10.1021/jacs.OcO2988#. Figure 6 gives students an idea of how a single unit repeats to form a layered extended structure. Students should be invited to flip through the paper, and you can print and share copies with the class to familiarize them with the format of journal articles, including the abstract, introduction, methods, and results sections they have seen in other peer-reviewed papers presented in this unit. This extension opportunity further supports development of SEP: 8.1.

 **Balance a second chemical equation.** Say something like, *Given that cement doesn't "dry" as it becomes solid—water actually becomes part of the substance—and the fact that there does not appear to be a lot of water on Mars, it makes me wonder how much water it really takes to make cement. Let's see if we can figure that out now. **

Tell students that we will NOT be balancing the complex equation on **slide Q**; instead, we will balance the equation for one of the reactions responsible for cement's long-term strength. Display **slide R**. Distribute individual whiteboards and dry erase markers to each pair of students. Give groups about three minutes to balance the chemical equation on their whiteboards. Have the pairs of students show their balanced equations to the class and check for agreement. If students' work does not agree with others', ask partners to share the approach they used to balance the equation.

Here is the balanced equation:



ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use **mathematical representations of the numbers of elements for evidence that the amount of matter on either side of a chemical equation is not equal.** (CCC: 1.4; DCI: PS1.B.3)
- Students **use a chemical equation (computational model) to account for amounts of elements.** (SEP: 5.1; DCI: PS1.B.3)
- Students use **mathematical thinking to revise a chemical equation to show conservation of matter.** (SEP: 5.1; CCC: 5.1)

What to do: If students struggle to balance the chemical equation, encourage them to refer back to the notes they took in their science notebooks as the class balanced the equation for photosynthesis. Look for the accounting of elements on both sides of the chemical equation to ensure students calculated correctly.

Building toward 12.A.3 Create balanced chemical equations (computational models) using **mathematical representations of elements to demonstrate that matter is conserved.** (SEP: 5.1; DCI: PS1.B.3; CCC: 1.4, 5.1)

ADDITIONAL GUIDANCE

If students want or need more practice balancing equations, distribute copies of *Key Chemical Reactions* from Lesson 10 and ask them to try balancing some of the other chemical equations for making the substances we need to live and work in space.

Connect a balanced equation to prior data. Display **slide S**.

Suggested prompt	Sample student response
Why did we need to balance this equation for cement?	Mars has what we need to make cement but we want to know how much of each reactant we will need.
What did balancing the equation tell us?	If we want to live on Mars, we will need cement to build places to live and work.
How does that connect to what we know about the abundance of those reactants on Mars? (Ask students to refer to previous handouts if needed.)	To make one molecule of cement, we will need 2 molecules of Ca_2SiO_4 and 4 molecules of water.
	We have APXS evidence that Mars rocks and soil are about 50% by weight SiO_2 and 6-7% CaO . So there is enough of those substances.
	Water might be a problem. The NASA website said there is some ice, but it said more water was there in the past than now.

7 · READ ABOUT SULFUR-BASED CONCRETE FOR MARS

18 min

MATERIALS: *Sulfur-Based Concrete*, *Summarize a Reading*, Driving Question Board

Introduce a water-free alternative to traditional cement. Express your agreement with students that the lack of water on Mars is an issue for making cement, especially since we will have to rely on other processes that require water as well. Display **slide T**. Ask, *If water is not found in high quantities on Mars, what else have we figured out that could help us determine whether there is an alternative substance?* Students should recall Lesson 8 where they found that hydrogen sulfide (H_2S) was not a suitable substitute for water (H_2O). Say, *Researchers have been working to figure out how to make cement on Mars that does not require any water. I found a summary of a paper that we can read to learn more about this.*

Prepare to read about sulfur-based concrete. Display **slide U**. Distribute copies of *Sulfur-Based Concrete* and *Summarize a Reading*. Explain to students that they are about to read an adaptation of a paper in the journal *Construction and Building Materials* (Wan et al., 2016), and only minor changes have been made to the text. Point out that the structure of the reading mirrors that of the original paper, and use the bullet points on the slide to talk about each section. * Students have an expanded version of the slide content on *Summarize a Reading* for reference. Give students a few minutes to read over *Summarize a Reading* and ask any questions about the prompts. Point out that prompts like these can be used to help students understand any type of science or engineering paper.



Read about sulfur-based concrete. Display **slide V**. Give students time to annotate *Sulfur-Based Concrete* and answer the questions on *Summarize a Reading*. * Circulate around the room and assist as needed.

ADDITIONAL GUIDANCE

Students may notice connections to investigations they conducted in Lesson 4 to observe the interactions between liquids of different polarities and soil samples. They may also connect to Lesson 8 where they examined hydrogen sulfide as a possible substitute for water. Students may also wonder how the perchlorate they learned about in Lesson 11 may affect the properties of sulfur-based concrete.

* SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

Element **8.1** of the science and engineering practices states that, at the High School level, students must *critically read scientific literature adapted for classroom use to (...) obtain scientific and/or technical information to summarize complex evidence (...)*. *Summarize a Reading* is designed to help students summarize the complex evidence presented in *Sulfur-Based Concrete*. Additional reading support can be found in *The OpenSciEd High School Teacher Handbook*.

* ATTENDING TO EQUITY

Universal Design for Learning: *Sulfur-Based Concrete* includes a data table, images of the samples and testing equipment, a graph, and

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **determine the central ideas of scientific literature** to determine the feasibility of living and working on Mars. (SEP: 8.1)

What to do: If students struggle to summarize the text found on *Sulfur-Based Concrete*, see additional reading support in *The OpenSciEd High School Teacher Handbook*.

Building toward 12.B.3 Gather, read, and interpret information presented in different formats and adapted from scientific literature to predict which object in space (system) would contain the quantities (large scale) of elements and compounds (atomic scale) needed to create the resources for survival. (SEP: 8.1, 8.2; DCI: PS1.B.3; CCC: 4.3)

color microscale images of two samples. These multiple means of representation provide students with multiple means of engaging with the material. This supports students in *representation* by guiding information processing and visualization of the information contained in the reading. Provide additional support for complex texts by promoting the use of screen reader technology, online translators, and supported reading strategies (read aloud as a class, read aloud with a partner, work through the questions together).

Debrief the reading and revisit the DQB. Display slide W.

Suggested prompts	Sample student responses	Follow-up questions
<i>How would the explanation provided by the authors help address what we need to live and work permanently on Mars?</i>	They think the metals in the martian soil react with the sulfur and that it makes the concrete stronger. Sulfur concrete can also be recycled by melting it.	<i>What experimental evidence supports that?</i> <i>How would that be helpful on Mars or even on Earth?</i>
<i>What line(s) of questions on our Driving Question Board does this solution address?</i>	We had a group of questions about recycling. We also had questions about plastics.	

8 • UPDATE PROGRESS TRACKERS

5 min

MATERIALS: science notebook

Update Progress Trackers. Display slide X. Say, *Before we go, take a few minutes to organize your thoughts and update your Progress Tracker.* Give students five minutes to add new ideas to their Progress Trackers about which location in the solar system has the elements we need and what relative amount is required to make any substance. A sample Progress Tracker entry can be found in *Progress Tracker Key* in Lesson 2.

9 • NAVIGATE

10 min

MATERIALS: computer with internet access

Problematize the need for elemental sulfur. Display slide Y. Read through the slide and use it to problematize that although there is a lot of sulfur on Mars, it is mainly present as sulfate mineral hydrates and not as the elemental sulfur (S) needed to make sulfur concrete. Point out that from one hydrate, it is possible to make magnesium sulfate (MgSO_4) and water (H_2O), both of which can be used to ultimately make

elemental sulfur. Say, *In a moment you will complete an Electronic Exit Ticket. You will figure out how this is possible and use what we have been working on to figure out how to make another substance we will need: glass.*

ADDITIONAL GUIDANCE

See *Electronic Exit Tickets* in Lesson 4 for instructions on how to make the Electronic Exit Ticket using <https://docs.google.com/forms/d/1Tng1U2WcLUUecj-yEVWwHgbLGNsRcJBn1ECNeWjBN88/copy>.



Complete an Electronic Exit Ticket. Display slide Z. Have students complete the exit ticket.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Exit Ticket Key* for guidance.

What to do: See *Exit Ticket Key* for guidance.

Building toward 12.A.4 Create balanced chemical equations (computational models) using mathematical representations of elements to demonstrate that matter is conserved. (SEP: 5.1; DCI: PS1.B.3; CCC: 1.4, 5.1)

Additional Lesson 12 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

Students use the Jigsaw strategy and conduct research using information from scientific text to determine which elements are available on specific locations in the solar system.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSA-SSE.A.1.a: Interpret expressions that represent a quantity in terms of its context.
a. Interpret parts of an expression, such as terms, factors, and coefficients.

Students evaluate and choose (coefficients) to add to chemical formulas to ensure there are equal numbers of elements on both sides of the chemical equation.

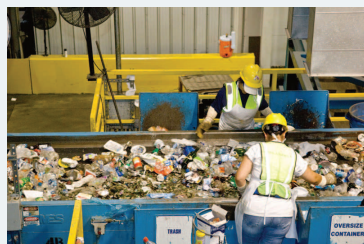
LESSON 13: Why can we recycle some of the substances we need and not others?

PREVIOUS LESSON We broke down the chemical equation for photosynthesis and figured out that we needed to ensure equal numbers of elements on both sides of the equation. We researched which locations in the solar system contain the elements we need and obtained more information about Mars from a reading. We balanced an equation involved in cement production and read about making concrete on Mars without water. We completed an Electronic Exit Ticket.

THIS LESSON

INVESTIGATION

2 days



US EPA

We argue for how recycling many substances we need would impact our future plans for living and working beyond Earth and on it. We identify some substances that we think can be recycled and consider what happens to them. We synthesize information from a reading, two videos, and a series of molecular models to answer questions about why we recycle some of the substances we need but not others, and how this could apply to our long-term plans for living and working beyond and/or on Earth.

NEXT LESSON We will recall the questions we have about materials we wish we could replace. We will read articles about different innovative materials technologies, share with a partner, and evaluate the articles' arguments. We will share our evaluations with a pair that investigated a different set of materials technologies.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, ESS1-2, ESS2-1, ESS2-5



WHAT STUDENTS WILL DO

13.A Compare and integrate information about the molecular structure, substructures, and bonding patterns of various materials from a text, experimental videos, and a series of molecular models to answer two scientific questions: 1) recyclability as a function of matter's interactions at the bulk scale, including atomic forces, and 2) how this informs new engineering solutions for living and working beyond and/or on Earth in the future. (SEP: 8.2; DCI: PS1.A.3, ESS3.C.2; CCC: 6.2)

WHAT STUDENTS WILL FIGURE OUT

- We can recycle some substances by melting, freezing, and reshaping
- Polymers are molecules with chains of repeating subunits (monomers).
- There are a variety of naturally and synthetically produced polymers that have different characteristic properties that make them well suited to specific uses.
- The structure of the polymer affects its properties.

Lesson 13 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	NAVIGATE Lead a class discussion of what was most surprising about the new kind of sulfur-based concrete students encountered in the last lesson.	A-B	Driving Question Board
2	3 min	DEVELOP AN INITIAL EXPLANATION Have the class discuss initial ideas about substances that can be recycled.	C	
3	11 min	IDENTIFY QUESTIONS AND SYNTHESIZE INFORMATION FROM A READING Prepare students to synthesize recycling information from different sources, starting with a reading.	D-E	<i>Recycling Ideas Organizer, Recycling Processes</i>
4	13 min	GATHER INFORMATION FROM TWO VIDEOS Orient students to two videos that demonstrate and explain thermoplastic and thermoset behavior.	F-G	<i>Transcript: Testing Plastics</i> (optional), recycled plastic pen, https://www.youtube.com/watch?v=-igxhoGEQFU&t=18s , https://youtu.be/pttxNzV_2U4
5	5 min	SYNTHESIZE INFORMATION FROM TWO VIDEOS Have students synthesize information from the two videos.	H	<i>Recycling Ideas Organizer</i>
6	8 min	COMPARE THE STRUCTURES OF THERMOPLASTICS Guide students to compare the molecular substructures of several thermoplastics.	I-J	<i>Materials for Survival</i> from Lesson 1
<i>End of day 1</i>				
7	9 min	COMPARE THE STRUCTURES OF THERMOPLASTICS Guide students to compare the molecular substructures of several thermoplastics.	K-Q	<i>Recycling Ideas Organizer, Polymer Molecular Models</i>
8	7 min	EXPLAIN PROPERTIES OF THERMOPLASTICS Lead the class in making connections between polarity and properties of thermoplastics using the M-E-F poster.	R	M-E-F poster, 3x3 sticky notes, permanent marker
9	4 min	EXAMINE THE STRUCTURE OF A THERMOSET Orient students to the molecular structure of a thermoset.	S-T	<i>Polymer Molecular Models</i>
10	4 min	EXPLAIN TWO PROPERTY DIFFERENCES Have students explain differences in strength and melting point for two types of rubber.	U-V	<i>Polymer Molecular Models</i>

Part	Duration		Summary	Slide	Materials
11	6 min		COMPARE PARTICLE-LEVEL CHANGES Guide students to compare the changes that happen at a particle level when thermoplastics vs. thermosets are heated.	W-X	<i>Polymer Molecular Models</i> , Driving Question Board
12	5 min		COMPARE STRUCTURES AND PROPERTIES OF OTHER POLYMERS Have students compare structures of other polymers and discuss the future of sustainable polymer research.	Y	<i>Polymer Molecular Models</i>
13	5 min		SYNTHESIZE INFORMATION FROM MOLECULAR MODELS OF POLYMERS Have students synthesize information from their exploration and discussion of molecular models of polymers.	AA	<i>Recycling Ideas Organizer</i> , <i>Polymer Molecular Models</i>
14	5 min		NAVIGATE Prompt the class to identify candidate substances for which more sustainable substitutes could be developed in the future.	BB	<i>Recycling Ideas Organizer</i>

End of day 2

Lesson 13 • Materials List

	per student	per group	per class
Lesson materials	• <i>Recycling Ideas Organizer</i> • <i>Recycling Processes</i> • <i>Transcript: Testing Plastics</i> (optional) • science notebook • <i>Materials for Survival</i> from Lesson 1 • <i>Polymer Molecular Models</i>		• Driving Question Board • recycled plastic pen • https://www.youtube.com/watch?v=-igxhoGEQFU&t=18s • https://youtu.be/pttxNzV_2U4 • M-E-F poster • 3x3 sticky notes • permanent marker

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.

Have the Driving Question Board visible for all students.

Have the annotated M-E-F poster from the end of Lesson 9 visible for all students.

You will need to have the recycled plastic pen from the materials list available to show students or pass around the classroom.

Test the related videos:

- <https://www.youtube.com/watch?v=-igxhoGEQFU&t=18s>
- https://youtu.be/pttxNzV_2U4

An optional resource, *Transcript: Testing Plastics*, is provided to accompany https://youtu.be/pttxNzV_2U4 if you wish to make it available.

Lesson 13 • Where We Are Going and NOT Going

Where We Are Going

The goals of this lesson are to apply and extend student thinking about the relationship between bulk scale properties and force interactions within and between molecules and to consider how we can develop new substances for living and working on and beyond Earth. This lesson is designed to coherently build new ideas related to the following disciplinary core ideas:

- **PS1.A: Structure and Properties of Matter.** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- **ESS3.C: Human Impacts on Earth Systems.** Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.

The work with **DCI: PS1.A.3** leverages students' ideas connecting atomic-scale forces and bulk-scale properties, which they developed through explicit connections to the M-E-F poster in Lessons 4, 8, and 9, to explain a new set of properties, melting point and strength. Students discuss the strengths of forces between particles when they consider the relatively low degrees of polarity in thermoplastics and the stronger and greater number of forces between cross-linked atoms in thermosets. Students use this to explain differences in the strength of the materials and why thermoplastics can be melted but thermosets decompose when heated.

The work with **DCI: ESS3.C.2** leverages student thinking about human impacts on Earth systems that was set up in Lesson 1. One of the two questions that students consider in *Recycling Ideas Organizer* is how the ideas they are figuring out inform new engineering solutions for living and working beyond and/or on Earth in the future. Students consider another version of this question at the end of the lesson with a partner – namely, how what we figured out can help people make new substances in the future that are more recyclable or produce less waste than some of those we use now. They identify candidate substances they think are important to develop substitutes for, to support more sustainable living beyond Earth and/or on it.

Students engage with **SEP: 8.2** partially: *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.* Students developed the crossed-out portions of the practice in the prior units *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* and *Electrostatics Unit*, and in Lessons 2, 4, 5, and 12 of this unit. This is the first time in the unit that students focus on the last part of **SEP: 8.2**, “solve a problem”. The student handout *Recycling Ideas Organizer* is designed to support this while also having students attend to a second question focussed on “address a scientific question”. The handout supports students in integrating ideas across both scientific questions and problems.

Students engage fully with **CCC: 6.2**: *The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.* Students continue their exploration of materials with a consideration of sustainability in the context of recycling materials, while still emphasizing the role of structure and function, comparing how the materials are shaped at a particle level (structure) to two bulk-scale functions (strength and response to heating). Students have previously engaged with **CCC: 6.2** in Lessons 1, 4, 7–9, and 11.

In this lesson, students will encounter the following terms, which they may choose to add to their Personal Glossaries: *thermoplastic*, *thermoset*, *monomer*, *polymer*, and *cross-link*. Students are encouraged to annotate *Polymer Molecular Models* with definitions of these terms. Students will also encounter a term that may be familiar to them from OpenSciEd High School Biology: *amino acid*, which they may choose to add as well. Words should be defined and recorded AFTER your class has developed a shared understanding of their meaning.

Where We Are NOT Going

This lesson focuses primarily on metals, glass, and plastics as materials that can be recycled. The next lesson expands the focus to include ceramics. Categories of materials beyond these are not explicitly considered, but students may wish to explore them as an extension after Lesson 14.

LEARNING PLAN for LESSON 13

1 · NAVIGATE

5 min

MATERIALS: Driving Question Board

Reflect on surprising aspects of sulfur-based concrete. Display **slide A**. Discuss the prompt on the slide as a class: *What was most surprising to you about the new kind of sulfur-based concrete you investigated in the last lesson?* Accept all answers.

If students do not mention that it was recyclable, ask the following question with a show of hands as a response: *How many of you also found the idea of making a new type of concrete that is recyclable also kind of surprising?*

Then say, *NASA has always had a mission of improving the lives of humans on Earth, too. A lot of NASA's work has directly supported human life down here, like these outer-space innovations that can reduce pollution and waste and negative impacts on ecosystems. Let's consider this connection to recycling a bit more.* *

* ATTENDING TO EQUITY

Universal Design for Learning: This lesson may be helpful and motivating for increasing relevance of this unit for students who are wary of space travel or whose interests in science are centered on the Earth's processes and systems, such as climate change.

ADDITIONAL GUIDANCE

In expanding the focus of the second question to explicitly refer to the types of contributions scientists and engineers can make to solving global problems on Earth, you are making this element of this DCI more explicit for students:

- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.

You are also reminding students of the broader scope/applications of the science concepts students are developing in the unit. For some students, the relevance of considering how to contribute to solving problems that currently exist on Earth, particularly for human impacts, pollution, and ecosystem degradation, will be very motivating.

Consider the impacts of developing more substitute substances. Display **slide B**. Discuss both questions on the slide as a class.

Suggested prompt	Sample student response
How could developing other types of substitute substances that are recyclable impact our long-term plans for living and working beyond Earth?	The more we can recycle, the better our chances will be of not running out of what we need. Once we are done using a substance like concrete for one particular purpose, like a structure, it could be recycled to make a new structure. We would need to find less of those substances in space.

Suggested prompt	Sample student response
<i>How could this also impact our long-term plans for living and working on Earth?</i>	It would reduce the amount of waste we send to landfills. We might need to mine, drill for, and harvest less resources. It could decrease our negative impacts on sensitive ecosystems. This could also slow down or stop climate change, because it also might decrease carbon dioxide production in any process where it is a product.

If students had questions about recycling on the Driving Question Board (which is likely), make reference to those now and/or ask students how both questions on **slide B** are related to the Driving Question of the unit: “How can we find, make, and recycle the substances we need to live on and beyond Earth?”.

2 · DEVELOP AN INITIAL EXPLANATION

3 min

MATERIALS: None

Individually reflect on prior knowledge. Display **slide C**. Give students at least a minute and a half to consider the three questions on the slide. Then discuss these as a class.

Suggested prompt	Sample student response
<i>What substances do you know of that we can recycle?</i>	Some plastics, glass, aluminum. Some other metals.
<i>What happens to those substances when they are recycled?</i>	They are sorted. They are ground up/broken up. They are melted and made into new objects.
<i>Why do you think we can recycle some substances but not others?</i>	Some things burn up or disintegrate. Some things are too greasy or dirty to recycle. Some pieces of stuff are too small to recycle (2" x 2" is the minimum size in most municipalities). Some things maybe don't "re-form," like you can't reconstitute dried modeling clay very easily.

ADDITIONAL GUIDANCE

If students suggest some examples of things that people recycle that are mixtures rather than substances, at this point in the lesson that is fine. An example might be paper or cardboard. The subsequent examples that students investigate further in this lesson will all be substances.

3 · IDENTIFY QUESTIONS AND SYNTHESIZE INFORMATION FROM A READING

11 min

MATERIALS: *Recycling Ideas Organizer*, *Recycling Processes*

Prepare to synthesize different information sources about recycling. Display slide D. Distribute a copy of both of these to each student:

- *Recycling Ideas Organizer*
- *Recycling Processes*

Orient to the three types of sources. Explain to students that we will complete *Recycling Ideas Organizer* by synthesizing information from a reading, two videos, and a series of molecular models.

Identify questions: Emphasize the different focuses of the two main questions at the top of the organizer. Point out that:

- the first question is what we were wondering about and is connected to the chemistry ideas we have been developing in this unit; and,
- the second question is designed to help us think like engineers, not just about the way things currently are, but about how we can apply our science ideas to create new materials that do not yet exist to sustainably live and work beyond and/or on Earth in the future.

Connect to the anchor: Ask students how making progress on the engineering question connects back to the Unit Question and/or what we thought about in the first lesson of the unit after viewing the Artemis video. Listen for ideas such as:

- If we are truly going to live on the Moon or Mars for a long time, we will need really good sustainability practices.
- If great inventions are made for the Moon, maybe they can help in places on Earth where we need more water or better soil.

Synthesize information from a reading. Display slide E. Give the remaining time (about 12 minutes) for students to work with a partner to complete row 1 of *Recycling Ideas Organizer* using *Recycling Processes*.

4 · GATHER INFORMATION FROM TWO VIDEOS

13 min

MATERIALS: *Transcript: Testing Plastics* (optional), recycled plastic pen, <https://www.youtube.com/watch?v=-igxhoGEQFU&t=18s>, https://youtu.be/ptvNzV_2U4

Orient to the next sources of information. Tell students that we will watch two videos next and discuss each of them briefly before adding to our organizer.

Introduce the type of object students will see being made in the first video. Hold up the recycled plastic pen and explain to students that most of its casing was made from recycled plastic bottles and that we will see how that sort of thing is done in the first video.

Watch and discuss the first video. Display slide F. Play these parts of <https://www.youtube.com/watch?v=-igxhoGEQFU&t=18s>:

- (0:18 - 1:01)
- (1:55 - 2:30)
- (4:08 - 4:55)

Then discuss the related questions on the slide.

Suggested prompt	Sample student response
<i>What is the evidence that the substance that is being recycled is going through a physical change, rather than a chemical change?</i>	It's still the same substance they started with. Breaking it into pieces and reshaping it is a physical change. Melting (and freezing) is a phase change because the same types of molecules are there throughout the change. No new substances are made in this process, so it's not a chemical change. No atoms are rearranged to make new molecules.
<i>How does this lend itself to the recycling process?</i>	You can make a different object in a different shape out of the same substance that was used to make the previous thing/object.

Watch and discuss the second video. Display slide G. Play https://youtu.be/pttxNzV_2U4. Then discuss the related questions on the slide.

ALTERNATE ACTIVITY

Distribute the optional, *Transcript: Testing Plastics* if you want to provide a transcript for students as they watch https://youtu.be/pttxNzV_2U4.

Suggested prompt	Sample student response
<i>Which objects were made of thermoplastics and went through physical change when heated?</i>	The ones that melted. It looked like the milk container and DVD case for sure. For a couple others it was hard to tell.
<i>What happens to the objects made of a thermoset when they were heated?</i>	They burned. They underwent a chemical reaction. Some of the solid that was formed had a different color (which is a property change). It produces toxic fumes (which is a new substance).
<i>Why would this prevent objects made of these types of plastics (thermosets) from being recyclable?</i>	You do not have the same substance you started with. The new thing you produced is not useful (or does not have the same properties as what you started with). It produced waste/pollution.

ADDITIONAL GUIDANCE

Students who have completed the following OpenSciEd Middle or High School Biology units will have developed the idea that burning is a chemical reaction:

- Middle School *Inside Our Bodies Unit*
- Middle School *Maple Syrup Unit*
- High School Biology *Fires Unit*

5 · SYNTHESIZE INFORMATION FROM TWO VIDEOS

5 min

MATERIALS: *Recycling Ideas Organizer*, science notebook

Synthesize information from the videos. Display **slide H**. Give students this time to work individually to complete row 2 of *Recycling Ideas Organizer*. Have students keep the organizer in their science notebooks for next period.

6 · COMPARE THE STRUCTURES OF THERMOPLASTICS

8 min

MATERIALS: *Materials for Survival* from Lesson 1, science notebook

Orient to a synthetic thermoplastic. Display **slide I**. Remind students that the thermoplastic that is described on the slide is the same one we saw in the first video and is one of the plastics we learned about in the reading. Give students a minute to read the text on slide I on their own. Point out to students that this plastic is also shown in the matter outputs of the PET chemical process on *Materials for Survival* from Lesson 1.

Orient to the molecular structure of PET. Display **slide J**. Ask students to find the one subunit shown on the slide in the matter outputs on *Materials for Survival* from Lesson 1. Remind students of any questions they had about the “n” in this model, or point it out now if they did not have questions before. Emphasize the following different scales. Then ask students to talk briefly with a partner about what they notice and wonder about the models shown on the slide.

- The subunit is made of 10 carbon atoms, 6 hydrogen atoms, and 4 oxygen atoms.
- A single subunit is called a *monomer*.
- There are parentheses around the monomer with a tiny “n”.
- The subtext says that “n = multiple repeating units in a chain”.

Give a volunteer an opportunity to come up and show where these monomers “connect” or begin to repeat. Ask the volunteer how they know where to start. Point to the parentheses as a representation for where the monomer “links up” to other monomers. Ask, *So how long do you think this goes?*

ADDITIONAL GUIDANCE

Mono- means “one” across chemistry usage. It is a cognate to the *mono-* prefix in Spanish (e.g., monolingüe/monolingual). This English usage also extends to economics (monopoly) and art (monogram, monochrome).

Poly- means “many” across chemistry usage.

Describe polymers. Let students share their interpretations for how these monomers fit together in a polymer. ✱ Listen for or highlight these ideas:

- PET molecules are thousands of these chained together.
- Showing this structure then means we cannot show individual atoms anymore.

✱ ATTENDING TO EQUITY

Universal Design for Learning: This lesson emphasizes multiple *representations*. Making sense of multiple *representations* allows for more equitable access because students can have multiple entry points to recognize and engage with polymers and recycling. The idea of using multiple *representations* and synthesizing their meaning also supports student engagement with [SEP 8](#).

- Polymers are a super long chain of monomers—so long that even showing it on the slide would require us to fold up the ends of it to indicate this.
- A *polymer* is the general name for this type of repeating structure of monomers in a molecule.

End of day 1

7 · COMPARE THE STRUCTURES OF THERMOPLASTICS

9 min

MATERIALS: *Recycling Ideas Organizer*, *Polymer Molecular Models*, science notebook

Reorient to our two main questions. Display **slide K**. Ask students to refer to their copy of *Recycling Ideas Organizer* to review the questions on it for half a minute before continuing.

Reorient to a synthetic thermoplastic. Display **slide L**. Remind students that the thermoplastic that is shown on the slide is the same one we saw in the first video and is one of the plastics we learned about in the reading last time.

Reorient to the molecular structure of PET. Display **slide M**. Use the slide to review what monomers and polymers are from last period.

Provide a reference for this molecular model and others. * Display **slide N**. Distribute *Polymer Molecular Models*. Explain that because we will see many different molecular models on the next slides, and each slide will be displayed for only a couple of minutes, this handout will be useful for students as they look for patterns, particularly once we are ready to complete row 3 of *Recycling Ideas Organizer*.

Compare three other synthetic thermoplastics. Display **slide O**. Refer students to table B on *Polymer Molecular Models*. Ask, *What do the triangles with arrows indicate?* Students will say that these substances are recyclable.

Point out that all of these are thermoplastics that melt as they saw in the video, and that just like PET, they are made of repeating chains thousands of monomers long. Ask, *What do you notice is similar about the structure of each of the monomers?* Students will say that they all have carbon and hydrogen atoms in them.

Then emphasize that the bonds between neighboring carbon atoms provide the backbone structure of the polymer, and that this is a common structural feature across the molecules that make up all thermoplastics.

Orient to a natural thermoplastic. Point out that all of the examples we have looked at so far are synthetic thermoplastics produced in the lab, but there are also some examples of thermoplastics that are produced from living things. One of these is natural rubber produced by the rubber tree. * Display **slide P**. Give students a minute to read the text on the slide and share any observations with the class.

Compare the structure of natural rubber molecules. Display **slide Q**. Have students refer to table C on *Polymer Molecular Models*. Ask, *How does the structure of this molecule compare to the synthetic thermoplastics we have examined?*

Listen for these ideas:

- This molecule is also a repeating chain of subunits (monomers).
- Carbon atoms bonded to carbon atoms also make up the “backbone” of this polymer.

Students may also notice:

- Hydrogen atoms were also present in the other polymers’ subunits.
- The total numbers of each type of atom and the bonds (single vs. double) are different in this subunit compared to the others.
- The carbons form a “chain” that zigzags in shape.

* ATTENDING TO EQUITY

Universal Design for Learning: This lesson emphasizes multiple *representations*. Making sense of multiple *representations* allows for more equitable access because students can have multiple entry points to recognize and engage with polymers and recycling. The idea of using multiple *representations* and synthesizing their meaning also supports student engagement with [SEP 8](#).

* SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

Multiple Domains. Crosscutting concepts help students think across the traditional domains of biology, chemistry, and physics. While this unit is extremely interdisciplinary, incorporating the [structure and function](#) of rubber tree sap into the unit can provide students meaningful connections to previous learning and biology interests. ([CCC: 6.2](#))

8 · EXPLAIN PROPERTIES OF THERMOPLASTICS

7 min

MATERIALS: M-E-F poster, 3x3 sticky notes, permanent marker

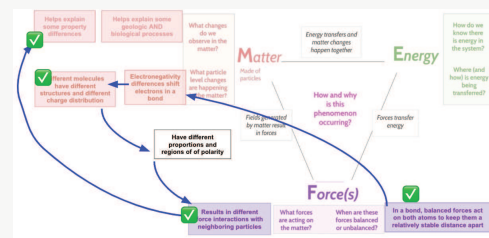
Connect polarity to properties. Display slide R. Read the sentence at the top of the slide: *Thermoplastics have low polarity across most of the polymer.*

Give students two minutes to turn and talk with a partner about the questions on the slide, then discuss as a class.

Suggested prompt	Sample student response
Why would low polarity make for weaker attraction between neighboring molecules?	Low polarity means there are not very many or not very strong fields being produced on different parts of the molecule.
Why would low polarity give these substances a relatively low strength and a low melting point?	There would not be parts of the molecules that are very strongly attracted to each other. They would break apart from each other more easily. So as you increase the temperature, the molecules move faster, which also would lead them to break away from each other more easily (at a lower temperature).

If time permits, reference the M-E-F poster from the end of Lesson 9 to help students see the similar connections they just made. Tag the four sections of the poster (shown here with green check marks) by using temporary 3x3 sticky notes with check marks written on them in permanent marker, to foreground the four connections students are making in this discussion:

- We compared structures (1) of molecules.
- We considered bonds (2), particularly the number of them.
- We thought about force interactions (3) for explaining different properties (4)—for example, the forces between molecules for one property (melting point), and the force interactions within a molecule for others (increases in strength, decomposition upon heating).



Problematize natural rubber for use in outer space. Emphasize that these properties limit some of the potential uses of natural rubber in outer space and even on Earth, since it would need to be stronger or not melt if the temperature got too high.

9 · EXAMINE THE STRUCTURE OF A THERMOSET

4 min

MATERIALS: Polymer Molecular Models

Introduce vulcanized rubber. Display **slide S**. Say, *Thermosets, like the plastic that burned black and didn't melt in the video, work well for tires.* Give students a minute and a half to read the information on the slide. Then point out that the chemical reaction on the slide simply involves the addition of sulfur atoms, which react with natural rubber to make this new substance that has properties that allow it to be used in tires for cars, trucks, and even airplanes. Say, *Thermosets can handle a lot of heat and braking friction. But thermosets are chemically very special, too.*

Examine the structure. Display **slide T**. Have students refer to table D on *Polymer Molecular Models*. Work together to identify where new bonds are formed between two molecules of polyisoprene (natural rubber) when vulcanized rubber is made.

10 · EXPLAIN TWO PROPERTY DIFFERENCES

4 min

MATERIALS: *Polymer Molecular Models*

Explain the strength increase for vulcanized rubber. Display slide U. Have students keep out *Polymer Molecular Models* to reference. Have students discuss the prompt with a partner for two minutes: *Why would the addition of C-S-C bonds across these chains of monomers increase the strength of the rubber so much?*

Introduce cross-linking. Display slide V and read aloud the bulleted text. Ask, *Why might these bonds make it so that a thermoset like vulcanized rubber does not melt?* Accept all ideas.

Connect to designed materials in the engineering disciplines. Say, *Chemical engineers work really hard to design materials like vulcanized rubber that provide improved properties for the uses we need the materials for. We have figured out some pretty big structural stuff that results in functional changes in substances, many of which make our lives better—we have rubber that doesn't melt when it gets hot, which transforms the way we work and live.*

11 · COMPARE PARTICLE-LEVEL CHANGES

6 min

MATERIALS: *Polymer Molecular Models*, Driving Question Board

Compare particle-level changes when heating substances. Display slide W. Have students refer to table E on *Polymer Molecular Models*. Ask, *What happens to a molecule of a thermoset when it is overheated?* Students will say it breaks apart into smaller pieces.

Ask students what this tells us about what is produced in the process of overheating—are these different-sized and -shaped particles all the same substance, or are they different substances? Students will say that they are different substances.

Identify some toxic by-products. Display slide X. Explain that there are many substances that are produced when a thermoset degrades from overheating, and the slide shows just a few examples of harmful by-products of burning vulcanized rubber. Give students a minute to consider the question on the slide and then discuss it as a class. Students will say that toxic products could negatively affect their health.

Connect to the Driving Question Board. Point to portions of the DQB where students have questions about designing new materials. Say, *Maybe with what you are figuring out, you can be a part of the next generation of scientists and engineers that design new materials with useful properties we need, like the high strength and elasticity of vulcanized rubber, but that are also more recyclable or do not produce harmful by-products. That sort of work seems important for figuring out not only how to live beyond Earth, but also how to live differently on Earth in the future.*

12 · COMPARE STRUCTURES AND PROPERTIES OF OTHER POLYMERS

5 min

MATERIALS: *Polymer Molecular Models*

Highlight structural patterns across polymers. Display slide Y. Give students one minute to read the slide on their own. Then point out that the three structures shown are general categories of polymers, and that every variation in bonding or monomer can result in a shift in properties. This leads to millions of possible polymers that we know of and even more that we have yet to discover in nature or figure out how to synthesize. Some polymers can break down in nature and sustainable polymer research is a field very rich with possibilities!

Compare some examples of these polymers. Display slide Z. Have students refer to table F on *Polymer Molecular Models*. Ask, *What do you notice and wonder about these different examples?* Accept all responses.

ADDITIONAL GUIDANCE

Students who have completed OpenSciEd High School Biology may already know about the 20 amino acids and all the ways they can combine to make many different types of proteins. Here is an opportunity to encourage students to think about how biochemical engineers might make progress in the future by figuring out how to synthesize new proteins from different combinations of amino acids that do not yet exist.

13 · SYNTHESIZE INFORMATION FROM MOLECULAR MODELS OF POLYMERS

5 min

MATERIALS: *Recycling Ideas Organizer*, *Polymer Molecular Models*, science notebook

Synthesize information. Display **slide AA**. Give students this time to work individually to complete row 3 of *Recycling Ideas Organizer*.

Have students add *Polymer Molecular Models* to their science notebooks. Consider having students annotate this handout with the definitions for the following terms (sample definitions shown; expect student definitions to vary):

- Thermoplastic: a plastic that softens or melts when heated and then can be molded into different shapes
- Thermoset: a plastic with cross-links between polymer chains; will undergo a chemical change when overheated
- Monomer: a small unit of a repeating chain OR a subunit of a polymer
- Polymer: a long chain of repeating monomers OR a component strand of plastics OR a molecule with thousands of repeated subunits
- Cross-link: a bond or a short sequence of bonds that links one polymer chain to another

14 · NAVIGATE

5 min

MATERIALS: *Recycling Ideas Organizer*



Identify some candidate substances. Display **slide BB**. Read the text at the top of the slide and then have students discuss the related prompt with a partner for two minutes. Then discuss these candidate substances as a class.

Point out that if we are hopeful to see scientists and engineers develop substitutes for some of these substances in the near future, then maybe some of them are already in development today. Ask, *How can we find out if they are?* Students will suggest that we do some additional research on these topics.

Work with the class to commit to doing just that in the next lesson – looking into what new developments are underway – based on our different areas of interest.

Collect *Recycling Ideas Organizer* for assessment.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See sample student responses in *Recycling Organizer Key*.

- Students have accurate responses in column 1 showing they have **integrated information from several diverse multimedia sources**. (SEP: 8.2)
- Students indicate **substructures of plastics, especially polymers, monomers, and cross-linking**, in column 1, row 2. (DCI: PS1.A.3; CCC: 6.2)
- Students refer to the strength of materials (**forces at a bulk scale**) and/or **strength/number of forces between molecules (intermolecular) or atoms (bonds)**. (DCI: PS1.A.3)
- Students indicate in column 2 that **new engineering solutions will require goals of (or will potentially impact) sustainability and human survival (especially non-toxicity of plastics), and/or students raise questions about what potential solutions are being developed or researched**. (DCI: ESS3.C.2)

What to do: If students struggle with the first three bullet points, give them an opportunity to collect additional research on the bonding patterns in graphite vs. diamond and how these are related to differences in their properties. If students have few ideas for the fourth bullet point, ask them to gather information from people in their community or about a specific area of interest. This can be something you extend past the next lesson too.

Building toward 13.A Compare and integrate information about the **molecular structure, substructures, and bonding patterns of various materials** from a text, experimental videos, and a series of molecular models to answer two scientific questions: 1) **recyclability as a function of matter's interactions at the bulk scale, including atomic forces**, and 2) **how this informs new engineering solutions for living and working beyond and/or on Earth in the future**. (SEP: 8.2; DCI: PS1.A.3, ESS3.C.2; CCC: 6.2)

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

Students gather information from a scientific text (*Recycling Processes*) to determine what is common across different recycling processes.

Students also *partially engage* in the following learning target:

CCSS.ELA-LITERACY.RST.11-12.7: Integrate ~~and evaluate~~ multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

Students integrate information from a reading, two videos, and a series of molecular models to answer questions about why we can recycle some of the substances we need but not others, and how this informs new engineering solutions for living and working beyond and/or on Earth in the future.

LESSON 14: What are some more sustainable approaches we are developing to help us make the things we need off of Earth and on it?

PREVIOUS LESSON We argued for how recycling many substances we need would impact our future plans for living and working beyond Earth and on it. We synthesized information from a reading, two videos, and a series of molecular models to answer questions about why we recycle some of the substances we need but not others, and how this could apply to our long-term plans for living and working beyond and/or on Earth.

THIS LESSON

INVESTIGATION

1 day



NASA, Bill Stafford

We recall the questions we had at the end of last class about materials that we wish we could replace or produce more sustainably. We use the Jigsaw strategy to read articles about different innovative materials technologies. We share with a partner and evaluate the arguments made in the articles. Then we share our evaluations with a pair that investigated a different set of materials technologies. We reflect on what we have figured out and how that relates to human survival in space and on Earth.

NEXT LESSON We will evaluate competing arguments about human survival in space in light of matter conservation and the chemical structures of molecules and atoms, trade-offs, and ethics. We will model the transformation of substances on Mars into necessary survival materials for humans. Then we will close out the DQB and take an assessment.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, ESS1-2, ESS2-1, ESS2-5



WHAT STUDENTS WILL DO

14.A Synthesize multiple methods to compare arguments for the sustainable properties of materials based on the forces that determine bulk-scale interactions. (SEP: 7.1, 8.4; DCI: PS1.A.3; CCC: 6.1)

WHAT STUDENTS WILL FIGURE OUT

- New technologies may allow for common materials (or replacement materials) to be more sustainable.
- A given material must have the right microscopic structures and resulting forces in order to produce the desired bulk-scale interactions.
- Technologies that could aid living off of Earth could make life on Earth more sustainable, but in general using less of a given material is best.

Lesson 14 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	4 min		NAVIGATE Help students recall their ideas from Lesson 13 about developing better substitute materials.	A-B	
2	12 min		READ ABOUT INNOVATIVE MATERIALS Help students organize into pairs based on interests and give time to read a short article and record ideas from it.	C-D	<i>Synthesis and Evaluation, CO2 Plastics/Bioplastics (1/2 of class), 3-D Printing/Geopolymer Concrete (1/2 of class), internet connected device</i>
3	13 min		SYNTHESIZE INFORMATION AND EVALUATE CLAIMS Give students time and support as they work in pairs to synthesize information across articles and evaluate the articles' claims.	E	<i>Synthesis and Evaluation, CO2 Plastics/Bioplastics or 3-D Printing/Geopolymer Concrete</i>
4	12 min		SHARE EVALUATIONS Give students a structure to share their evaluations with a pair that examined a different materials technology.	F	<i>Synthesis and Evaluation, CO2 Plastics/Bioplastics or 3-D Printing/Geopolymer Concrete</i>
5	4 min		NAVIGATE Lead a discussion to reflect on the implications of what students figured out in this lesson.	G	

End of day 1

Lesson 14 • Materials List

	per student	per group	per class
Lesson materials	• <i>Synthesis and Evaluation</i> • <i>CO2 Plastics/Bioplastics</i> (1/2 of class) • <i>3-D Printing/Geopolymer Concrete</i> (1/2 of class) • internet connected device • <i>CO2 Plastics/Bioplastics</i> or <i>3-D Printing/Geopolymer Concrete</i> • science notebook		

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.

Make copies of *Synthesis and Evaluation* for all students.

Ensure there are enough copies of each of the following for half of the class, plus a few extras:

- *CO2 Plastics/Bioplastics*
- *3-D Printing/Geopolymer Concrete*

The articles in these readings are intentionally written at different difficulty levels. Consider whether you want to give students choice or assign groups based on students' reading proficiencies. In both readings, Article 1, which is written in a popular style, is more accessible than Article 2.

Each student (or pair of students) will need an internet connected device to check sources, when possible. You may wish to provide digital versions of the readings so that students can click directly on links to sources, instead of having to type them.

Lesson 14 • Where We Are Going and NOT Going

Where We Are Going

The goal of this lesson is for students to engage in evaluating research around sustainable manufacturing practices. This lesson is designed to coherently build new ideas related to the following disciplinary core idea:

- **PS1.A: Structure and Properties of Matter:** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

Students continue their exploration of materials with a consideration of sustainability, while still emphasizing the role of structure and function (CCC: 6.1). They build understandings through a jigsawed set of articles that they summarize (SEP: 8.4), building on prior work in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. Students also engage in SEP: 7.1 for the first time in the Chemistry course, and will have opportunities to return to it in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)* and *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*. This lesson provides an opportunity for students to continue to think about the ways in which the microscopic structures of ceramics (cement and concrete) and plastics result in macroscopic properties--properties which must be maintained even as the specific materials are modified to make them more sustainable.

Where We Are NOT Going

This lesson focuses primarily on the mechanical properties of materials, since these are most readily explained by forces at the molecular and atomic levels. Students do not explicitly consider other categories of materials beyond plastics and ceramics, although students could explore other categories of materials as an extension.

Students do not evaluate the validity and reliability of claims in articles fully (SEP: 8.4) due to lack of access to all peer-reviewed publications, instead focusing their evaluation on considerations of known explanations, constraints, and ethical issues as described in SEP: 7.1. Students will have more opportunities to evaluate competing design solutions in *Fuels Unit*.

LEARNING PLAN for LESSON 14

1 · NAVIGATE

4 min

MATERIALS: None

Reflect on the end of Lesson 13. Display slide A. Ask, *What were some types of materials we hoped to see scientists and engineers develop substitutes for in the near future?* Give students a moment to turn and talk, then share with the class. Acknowledge all student ideas, but listen for these in particular:

- Water
- Non-recyclable plastics / rubber
- Concrete/cement
- Metals
- Glass
- Fuels

Elicit ideas about replacements. Display slide B. Ask, *What do you think could make replacement materials better than the ones we have now?* Listen for these ideas:

- They could be easily recyclable.
- Maybe they could be made with fewer emissions or less harsh chemicals.
- They could last longer so that we don't have to replace them as often.

Say that these are all excellent ideas--ones that scientists and engineers are exploring now. Note that many involve making materials more *sustainable*--that is, able to be used in the long run without harming ecosystems, human systems, and the environment. Suggest that we check out some materials that will help us learn more about them.

2 · READ ABOUT INNOVATIVE MATERIALS

12 min

MATERIALS: *Synthesis and Evaluation*, *CO2 Plastics/Bioplastics* (1/2 of class), *3-D Printing/Geopolymer Concrete* (1/2 of class), internet connected device

Form pairs based on the readings. Display slide C. Briefly explain the two categories of readings to students. Have them identify which one they wish to read, then pair them off within these groups or give them the opportunity to self-select pairs. Alternatively, pre-assign pairs, then give each pair the opportunity to select the reading they will both engage with.

Give instructions and reading time. Display slide D and distribute *Synthesis and Evaluation* to all students and one of *CO2 Plastics/Bioplastics* or *3-D Printing/Geopolymer Concrete* to each student. Explain to students that they will read the introduction with their partner, then each read one of the two articles in the reading. They should use *Synthesis and Evaluation* numbers 1-2 to support their thinking before and during reading. Ensure that students are comfortable with checking sources. Emphasize that they can skim available source articles if these are short, or at least check the abstract for articles that are longer or behind a paywall.*

Then, give students the rest of the activity time to read individually. The *Synthesis and Evaluation* key gives an idea of what might come up in their reading and discussion.

* SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

Checking data and sources is an important part of critically evaluating information. Given time constraints, encourage students to focus on the abstract of a source to ensure alignment with stated claims in the article they read. If there is time, push students to go further with [SEP: 8.4](#) and check the reliability of sources. It may be helpful to return to *OpenSciEd Unit C.2: What causes lightning and why are some places safer than*

ALTERNATE ACTIVITY

Extension opportunity: If students are interested in materials other than ceramics (like concrete) or polymers, such as metals, electronic materials, or composites, you may wish to have them research these materials. Students can still use *Synthesis and Evaluation* to summarize findings and evaluate arguments, although additional time will need to be allowed for research.

Additionally, these articles intentionally reference careers such as *materials scientist*, *chemical engineering*, *food technology*, and *biochemical engineering*. You may have students research these and related careers through the Bureau of Labor Statistics Occupational Outlook Handbook: <https://www.bls.gov/ooh/>.

others when it strikes? (Electrostatics Unit)
Lesson 11 to review how students might go about evaluating sources more carefully.

3 · SYNTHESIZE INFORMATION AND EVALUATE CLAIMS

13 min

MATERIALS: *Synthesis and Evaluation*, *CO2 Plastics/Bioplastics* or *3-D Printing/Geopolymer Concrete*



Set students up to discuss with partners. Display **slide E** and explain the task to students. Highlight that they should first take a few minutes to synthesize across articles, meaning partners will help each other complete the table in number 3 of *Synthesis and Evaluation* and note similarities and differences. Then, partners should use number 4 to help evaluate the claims made in the articles. Highlight that our key question when we read pieces like this should be: *How does the claim match up against our understanding of scientific evidence and of the problem being addressed?*

Give work time. Circulate as students work, encouraging partners to compare across articles and consider scientific understandings, their understanding of the problem, and ethics as they write their evaluations.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **synthesize both articles' claims and check that at least one of the provided references supports the claims.** (SEP: 8.4)
- Students identify the ways in which the **particle-level structure of the material** and the **force interactions at this level result in material properties.** (DCI: PS1.A.3; CCC: 6.1)
- Students' **evaluations consider their current scientific evidence and understandings about material properties, problem-based considerations, and ethics.** (SEP: 7.1; DCI: PS1.A.3)

What to do: Ensure that students are comfortable in their synthesis before moving on to evaluation. Use targeted questions to help students narrow in on key ideas in their synthesis; for example, *If we are trying to understand what happens at the particle level, we often think about bonds. What is bonding like in this material?* If you are unable to listen in on all pairs, continue listening in the next activity.

Building toward 14.A.1 Synthesize multiple methods to compare arguments for the **sustainable properties of materials** based on the **forces that determine bulk-scale interactions.** (SEP: 7.1, 8.4; DCI: PS1.A.3; CCC: 6.1)

4 · SHARE EVALUATIONS

12 min

MATERIALS: *Synthesis and Evaluation*, *CO2 Plastics/Bioplastics* or *3-D Printing/Geopolymer Concrete*



Prepare students to share their evaluations. Bring the class together and point out that other pairs examined different materials, so we can all learn from each other. Display **slide F** and facilitate pairs in (ideally) finding another pair who examined something different. If any groups involve only students who examined the same articles, encourage them to focus on the differences between their evaluations.

Ensure that each pair has five minutes to share their evaluations and answer questions before switching roles.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students identify the ways in which the **particle-level structure of the material** and the **force interactions at this level result in material properties**. (DCI: PS1.A.3; CCC: 6.1)
- Students' **evaluations consider their current scientific evidence and understandings about material properties, problem-based considerations, and ethics**. (SEP: 7.1; DCI: PS1.A.3)

What to do: Ensure the first evaluation share-out does not go too long and encourage students to make comparisons between materials when the second pair has finished sharing.

You may collect students' handouts if you wish to individually assess their work. Provide feedback around students' connections to ideas from class about matter-force properties and structure-function thinking, and around the depth of their evaluations. The *Synthesis and Evaluation* key gives an idea of what students might say.

Building toward 14.A.2 Synthesize multiple methods to compare arguments for the **sustainable properties of materials** based on the **forces that determine bulk-scale interactions**. (SEP: 7.1, 8.4; DCI: PS1.A.3; CCC: 6.1)

5 • NAVIGATE

4 min

MATERIALS: science notebook

Reflect on implications. Display **slide G**. Give students three minutes to update their Progress Trackers.

Return to the question of space survival. Ask students, *Given what we know now, do we think people could live and work off of Earth, or should try?* Take a couple of responses, then acknowledge that this is a big question we should return to next time.

Additional Lesson 14 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.

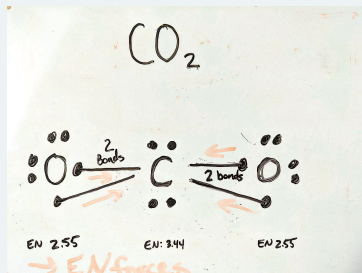
Students evaluate the authors' claims for two articles based on scientific understandings they have developed through evidence and on reasoning (relationships to human needs and ethical considerations).

LESSON 15: What is the full impact of going to space?

PREVIOUS LESSON We had questions about materials we wish we could replace, so we read articles about different innovative materials technologies. We shared with a partner and evaluated the arguments made in the articles. We shared our evaluations with a pair that investigated a different set of materials technologies. We reflected on what we have figured out.

THIS LESSON

PUTTING PIECES TOGETHER



We evaluate competing arguments about human survival in space in light of matter conservation and the chemical structures of molecules and atoms, trade-offs, and ethics. We model the transformation of substances on Mars into necessary survival materials for humans. Then we close out the DQB, take an assessment, and individually reflect on our Community Agreements.

NEXT LESSON There is no next lesson.

BUILDING TOWARD NGSS

HS-PS1-1, HS-PS1-2, HS-PS1-3, HS-PS2-6, HS-ESS1-2, HS-ESS2-1, HS-ESS2-5



WHAT STUDENTS WILL DO

15.A Evaluate competing arguments about human survival in space in light of matter conservation and the chemical structures of molecules and atoms, trade-offs, and ethics. (SEP: 7.1; DCI: PS1.B.3; CCC: 1.2)

15.B Create balanced and accurate chemical equations (computational models) uniting mathematical and molecular representations of covalently-bonded molecules to ensure matter is conserved. (SEP: 5.1; DCI: PS1.B.3; CCC: 5.1)

Transfer Task PE: 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. (SEP: 2.3; DCI: PS1.A.1, PS1.A.2; CCC: 1.1)

Transfer Task PE: HS-PS1-2 Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. (SEP: 6.2; DCI: PS1.A.2, PS1.B.3; CCC: 1.1)

WHAT STUDENTS WILL FIGURE OUT

- There are competing science and ethics arguments about human survival in space.
- The elements available to us in outer space limit what we can build on another planet. Matter cannot be gained or lost in a chemical reaction.
- Soap scum is formed as a result of interactions between polyatomic ions and other ions that are dissolved in water.

Lesson 15 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Have students examine data from a final location in space.	A-B	<i>Another Planet's Data</i>
2	30 min		BUILD UNDERSTANDING Have students read about different scales of space travel issues.	C-E	<i>Space Travel Perspectives, Four Corners Labels</i> , painter's tape
3	8 min		DISCUSS FINAL THOUGHTS ABOUT SPACE TRAVEL Organize students in a Scientists Circle to share their thoughts about ethics and trade-offs.	F	<i>Discussion Map</i>
4	2 min		NAVIGATE Have students review the DQB and prepare for the next day.	G	Driving Question Board
<i>End of day 1</i>					
5	10 min		BUILD A SUBSTANCE ON MARS Guide students to choose and model a chemical reaction on Mars.	H	<i>Substances on Mars</i> , individual whiteboard, dry erase markers
6	10 min		BUILD A FINAL MODEL Support students in modeling a compound they can create on Mars.	I	
7	25 min		EVALUATE AND DISCUSS DQB QUESTIONS Lead students in evaluating their final progress on the DQB.	J-L	permanent marker, updated <i>Our DQB Questions</i> from Lesson 9, Driving Question Board
<i>End of day 2</i>					
8	30 min		TAKE THE END-OF-UNIT ASSESSMENT Have students complete the end-of-unit assessment independently.	M	<i>Soap Scum Transfer Task</i>
9	15 min		REFLECT ON THE UNIT Have students reflect on their learning throughout the unit.	N	Community Agreements
<i>End of day 3</i>					

Lesson 15 • Materials List

	per student	per group	per class
Lesson materials	• <i>Another Planet's Data</i> • science notebook • <i>Space Travel Perspectives</i> • permanent marker • updated <i>Our DQB Questions</i> from Lesson 9 • <i>Soap Scum Transfer Task</i>	• <i>Substances on Mars</i> • individual whiteboard • dry erase markers	• <i>Four Corners Labels</i> • painter's tape • <i>Discussion Map</i> • Driving Question Board • Community Agreements

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.

Print copies of *Another Planet's Data* and *Space Travel Perspectives* for each student.

Prepare copies of *Substances on Mars* for each set of partners.

Update DQB questions on *Our DQB Questions* from Lesson 9 with any new DQB questions students have added. Make copies of the updated handout for each student.

Print one copy of *Four Corners Labels*, cut out the headings, and use painter's tape to post them around the room for the Four Corners activity.

Review the teacher information for the final assessment: *SoapScum Transfer Task Key*.

Print a copy of *Soap Scum Transfer Task* for each student.

Have the Community Agreements visible.

Lesson 15 • Where We Are Going and NOT Going

Where We Are Going

The goal of this lesson is to have students think about the ethical considerations of trying to live and work in space; e.g., should we try? This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **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.
- **PS1.A: Structure and Properties of Matter.** 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.
- **PS1.B: Chemical Reactions.** The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.

Throughout the unit, we have built ideas about how atoms are structured (DCI: PS1.A.1), how to use the periodic table to predict their structures, how their valence structures and electronegativities predict their interactions with other atoms (DCI: PS1.A.2), and how the law of conservation of matter can be used to predict and balance chemical reactions (DCI: PS1.B.3).

Students construct a balanced chemical equation (computational model) to demonstrate their understanding of restructuring matter that ultimately answers the lesson question: *What is the full impact of going to space?* (SEP: 5.1; CCC: 1.2) To do so, they must evaluate arguments (SEP: 7.1; CCC: 1.2), use the periodic table as a model (SEP: 2.3; CCC: 1.1), and use different strategies to model how molecules' structure determines their function (SEP: 2.3, 6.2; CCC: 1.1, 5.1).

This lesson culminates in an assessment task about how changing the types of substances dissolved in water affects the formation of soap scum.

Where We Are NOT Going

This unit attempts some speculation about what substances are possible to create, but it does not reason about the energy required (or given off) by chemical reactions, nor does it consider the reaction mechanisms required for substances' formation. DCIs related to energy and enthalpy are foundational to models built in High School Chemistry *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?* (Fuels Unit).

LEARNING PLAN for LESSON 15

1 · NAVIGATE

5 min

MATERIALS: *Another Planet's Data*, science notebook

Remind ourselves what we were thinking about last time. Display slide A.

Suggested prompt	Sample student response
<i>What are some more sustainable approaches we are developing to help us make the things we need off of Earth and on it?</i>	Accept all answers from the research students completed in the last lesson. Students may also bring up new things they have heard about in the news.
<i>What does this tell us about future possibilities for using science to try to live and work beyond Earth?</i>	On Earth, we can have less of a negative impact both through new technology and by not making things we don't need. In space, we could get by with less and with the help of new materials.

Determine an optimal place to live. Display slide B and make sure students have *Another Planet's Data* available. Say, *Here is some information about another planet we did not look at before.* Tell students to stop and jot their thinking about the prompt on the slide in their science notebooks.

After a couple of minutes, ask for a few volunteers to share their ideas with the class. Look for students to say that this planet is the better option compared to the others we examined because it contains everything we need in its atmosphere and crust.

Say, *The data you just examined was for planet Earth!*

2 · BUILD UNDERSTANDING

30 min

MATERIALS: *Space Travel Perspectives*, science notebook, *Four Corners Labels*, painter's tape

Share current thinking. Display **slide C**. Give students a few minutes to individually consider the prompts on the slide. Ask for a few volunteers to share their thinking about trade-offs and ethical concerns with the class. Accept all student ideas.

Say, It sounds like we have a lot of different ideas about what we should do. Let's consider some other perspectives before we decide what we should do.

Read about other perspectives on space travel. Display **slide D** and distribute *Space Travel Perspectives*. Give students 10-15 minutes to read the four perspectives and answer the three questions on the slide in their science notebooks. As students are reading, tape the perspective headings/labels from *Four Corners Labels* so they are visible for grouping students in the next discussion.

Reorganize the class. Display **slide E**. Instruct students to go to the part of the classroom with the heading that represents their personal priority. The choices are: “Colonization Concerns,” “Concerns for Our Earth Systems,” “Helping Earth Through Space,” and “Safety Concerns.” *

Discuss prioritized perspectives with like-minded classmates. Give students 10 minutes to discuss the prompts on **slide E** in their groups. As groups discuss, circulate around the room and listen in on the discussions.

After the 10 minutes, ask for each group's spokesperson to share why their group's perspective should be prioritized over others. Accept all answers and ask groups to share the evidence they used to make their decision.

*** ATTENDING TO EQUITY**

Universal Design for Learning allows students of all abilities to stay *engaged* with a range of movement. Make sure that students can access the four corners you designate. Consider body size, furniture that might be in the way, and mobility supports such as wheelchairs or crutches as you decide where to place the labels.

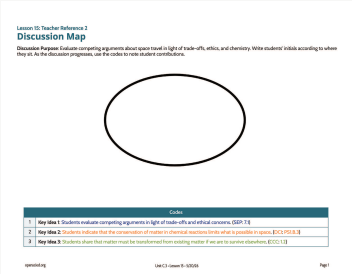
3 · DISCUSS FINAL THOUGHTS ABOUT SPACE TRAVEL8 min

MATERIALS: science notebook, *Discussion Map*

Figure out where we stand after hearing our classmates' ideas. Display **slide F**. Have students form a Scientists Circle.

In the Scientists Circle, tell students: *We are going to sum up our conversation about the larger social concerns about going to space. I will be listening for each of you to think about our conversation. Take a moment to write your thoughts about these questions in your science notebook. We will move through these questions as a class, and you will build on each other's ideas as we reflect on that conversation.*

 Use *Discussion Map* to track students' responses. See *The OpenSciEd High School Teacher Handbook* for more guidance on how to use *Discussion Map* as a formative assessment opportunity.



Suggested prompt	Sample student response
Is there a set of priorities that would satisfy all of us?	No. We all care about science, but we all have concerns for the Earth, too. There is no perfect answer.

Suggested prompt	Sample student response
How can discussing hot issues in terms of trade-offs, ethics, and science be helpful?	It keeps our conversation focused. We understand better why we disagree. It doesn't get reduced to personal opinion.
What role does chemistry play in our priorities?	It's important to understand what is actually possible from a matter and molecules standpoint. We should let go of ideas about building a perfect "Earth-like" environment. Survival would be really difficult off of Earth.

Summarize students' ideas and/or comment on any themes that begin to emerge, especially about the professional nature of science and engineering discourse. When we disagree, we have to characterize the disagreement and attempt to understand each other's perspectives.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **evaluate competing arguments in light of trade-offs and ethical concerns.** (SEP: 7.1) (Key Idea 1)
- Students **indicate that the conservation of matter in chemical reactions limits what is possible in space.** (DCI: PS1.B.3) (Key Idea 2)
- Students **share that matter must be transformed from existing matter if we are to survive elsewhere.** (CCC: 1.2) (Key Idea 3)

What to do: Use *Discussion Map* to evaluate the conversation in terms of these numbered key ideas. You can use teacher prompts, such as *Who can sum up what they are saying?*, to encourage students to do the intellectual work of the conversation. If students are not indicating these three key ideas, you can give them more time to write and reflect on their own and return to this conversation the next day.

Building toward 15.A Evaluate competing arguments about human survival in space in light of **matter conservation and the chemical structures of molecules and atoms, trade-offs, and ethics.** (SEP: 7.1; DCI: PS1.B.3; CCC: 1.2)

4 · NAVIGATE

2 min

MATERIALS: science notebook, Driving Question Board

Celebrate our progress. Display slide G. Say, *Let's take a moment to celebrate our progress! Look over the Driving Question Board and think to yourself about what questions we can now answer. Next class, we will spend some time closing out the DQB for this unit.* If students choose, they can jot down a few questions in their science notebooks for discussion next class.

5 • BUILD A SUBSTANCE ON MARS

10 min

MATERIALS: *Substances on Mars*, individual whiteboard, dry erase markers

 **Revisit how we could make the things we need.** Display slide H. Organize students into pairs and distribute *Substances on Mars*, a whiteboard, and dry erase markers to each group. Students may benefit from having access to multiple colors of dry erase markers while balancing chemical equations.

*Say, We came to the conclusion that we will need to make the things we need to survive beyond Earth because taking them all is just not possible. During the unit, we have found out how atoms in substances can rearrange into different substances. You should notice that Substances on Mars contains information from some of our prior lessons. With your partner, examine Substances on Mars to see what substances are available on Mars, and then choose one simple compound, or one monomer of a polymer, to build on Mars. **

Support students in balancing equations and using mathematical models, including coefficients, to show what substances are possible to build on Mars. Clarify to students that the equations they will develop most likely do not represent how the substances form naturally. Stress that the chemical equations students are developing are hypothetical based on the materials, and that students should only represent the formation of a monomer.

Note: Formation of all of the substances listed on *Substances on Mars* will not be possible. Proteins, fats, wood, and plastic are possible given the elements available on Mars. Questions about energy necessary for reactions will be the major content of *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*, so do not give away this important detail. The current lesson focuses on the conservation of matter.

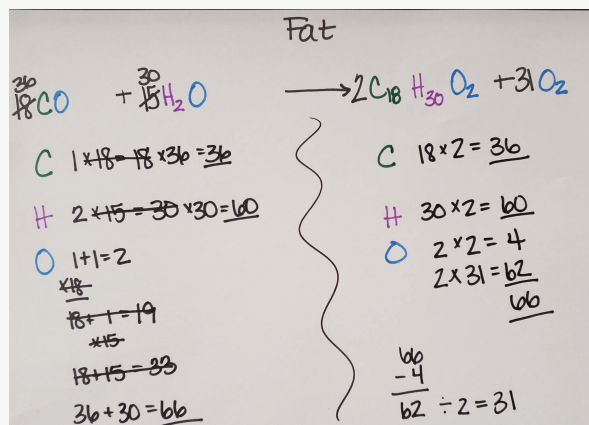
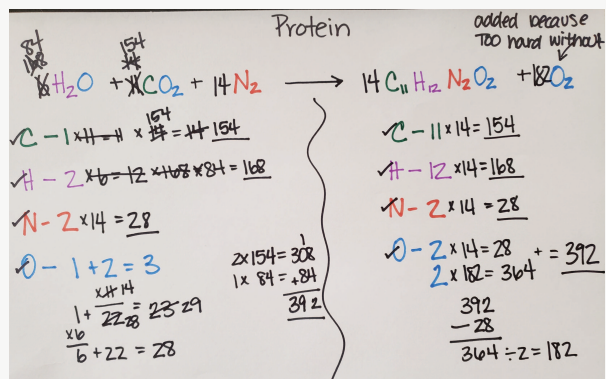
Give partners about 10 minutes to develop a balanced chemical equation on their whiteboard. As groups are working, circulate around the room. Assist as needed and make sure partners show how they are balancing their equation. As you visit groups, choose two to three different balanced chemical equations to display for the class. Fats and proteins are good candidates for this, as they can be built from the components of carbon monoxide or dioxide, nitrogen, and other organic compounds. Steel is a mixture, not a compound, so it cannot be modeled in this way. Students may also realize that they have too many reactants, so some additional substances might be formed.

The following table shows sample balanced chemical equations:

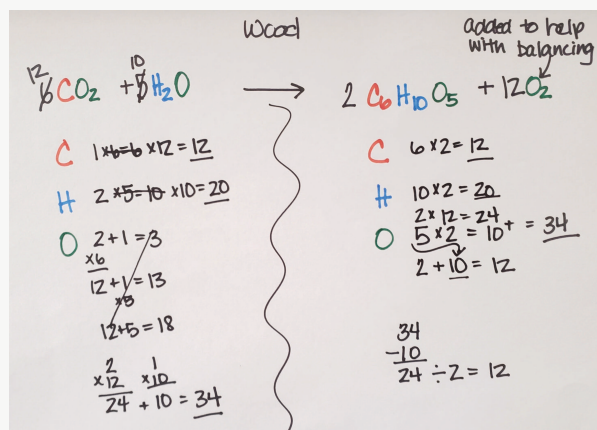
Protein	Fat
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* ATTENDING TO EQUITY

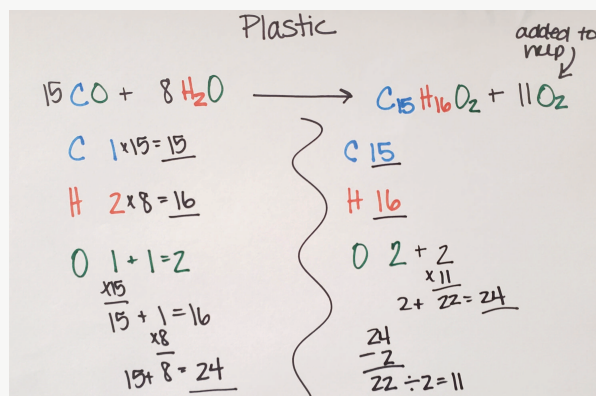
Universal Design for Learning: Student choice is an important component to support *engagement*. Providing choice gives students an excellent opportunity to model a substance of interest to them. Students may choose a substance like wood or plastic that they have experienced in their daily lives, which helps support *representation*. These substances may be more materially interesting to some students because they can be seen and felt. This supports students' comprehension by allowing them to use their background knowledge.



Wood



Plastic



ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **explain** how **an equation is balanced** using **coefficients and molecular formulas** as **evidence**. (SEP: 5.1; DCI: PS1.B.3)

What to do: If students do not identify that the numbers of like elements on either side of the chemical equation should be added, work with them to find the totals on both sides of the equation. If students are struggling to balance the equation with just the substance they chose, tell them to consider adding additional products, such as oxygen, to aid in their balancing. Point out that when they balanced the chemical equation for photosynthesis in Lesson 11, there were additional products besides glucose.

Building toward 15.B.1 Create balanced and accurate chemical equations (computational models) uniting mathematical and molecular representations of covalently-bonded molecules to ensure matter is conserved. (SEP: 5.1; DCI: PS1.B.3; CCC: 5.1)

ALTERNATE ACTIVITY

Extension Opportunity: The assessment boundary of the related NGSS Performance Expectation, HS-PS1-2, limits assessments to main group elements and combustion reactions (DCI: PS1.B.3). To keep within this assessment boundary, limit students to investigating N₂, O₂, CaO, SiO₂, or Al₂O₃.

The unit materials have prepared students to balance larger compounds, if you wish to extend student thinking beyond this boundary.

In the next activity, students will select a substance to model from one of the chemical equations, linking instruction in Lesson Sets 1-3 to Lesson Set 4.

ALTERNATE ACTIVITY

You can also choose not to select any equations for display and instead have students join together to form larger groups of two to three pairs to compare and evaluate their balanced chemical equations.

6 • BUILD A FINAL MODEL

10 min

MATERIALS: science notebook

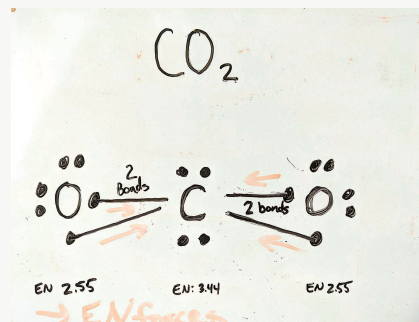
Share balanced chemical equations. Display slide I. Say, *We have mathematical models (balanced chemical equations) for these substances, but can we also show how they are structured? Let's revisit how this molecular stuff works by modeling one of the substances you used!* Allow students to select one of the simple compounds (longer chains and rings will be too complicated) they used in their balanced chemical equations from the previous activity. It can be a reactant or a product. *

Share a list of requirements for the model. Point out that students should show atoms, valence electrons, and electronegativity “pulling” on electrons in their model. Circulate around the room and give formative feedback tied to the positions of electrons, the use of the periodic table, and the pulls that students represent in their molecular models. Reference students’ balanced equations from the previous step, as well.

A sample student model is shown.

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

An alternative to providing the list of requirements for the molecular model is to construct the checklist together as a class with a public representation of the ideas the class agrees should be part of the consensus model. If you modify the current activity,



keep in mind the following important components to make this activity a productive one:

- The process should be collaborative and involve students arguing based on evidence for their ideas.
- There should be a public record, or artifact, of the ideas that students agree to include in their model.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' models indicate that **no matter is gained or lost during a chemical reaction** (conservation of matter). (SEP: 5.1; DCI: PS1.B.3; CCC: 5.1)

What to do: Check students' molecular models to ensure they are drawing on electronegativities and valence electron patterns to show the ways the forces are working to hold the atoms together.

Building toward 15.B.2 Create balanced and accurate chemical equations (computational models) uniting mathematical and molecular representations of covalently-bonded molecules to ensure matter is conserved. (SEP: 5.1; DCI: PS1.B.3; CCC: 5.1)

7 · EVALUATE AND DISCUSS DQB QUESTIONS

25 min

MATERIALS: science notebook, permanent marker, updated *Our DQB Questions* from Lesson 9, Driving Question Board

Reflect on what we've accomplished. Direct students to the Driving Question Board. Say, *Wow, we have figured out so many different pieces to help answer our big question: How can we find, make, and recycle the substances we need to live and work beyond Earth and on it? Let's take some time to revisit the DQB to see how many more of our own questions we have answered.*

Evaluate what questions the class has answered from the DQB with a partner. Display slide J. Provide students with an updated copy of *Our DQB Questions*, which you started in Lesson 9, containing all of the students' DQB questions. Have students mark additional questions they think the class has answered:

- We did not answer this question or any parts of it yet: ○
- 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: ✓+

Answer our questions using evidence. Have partners select a question and write an answer with supporting evidence. Students will use this in the Consensus Discussion.

Mark questions on the classroom DQB. ✱ Display slide K. Students should walk up to the DQB and place a check mark on five questions they think the class has made progress on.

Reflect on answered questions in a Scientists Circle. Display slide L and lead students in the following Consensus Discussion.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Use this opportunity to encourage students' *action* and *expression* by allowing them to physically move to the DQB and use a marker or pen to show their ideas. Be sure to seat students near the DQB if movement in the classroom due to body size or disability would be a barrier.

Suggested prompt	Sample student response
<i>What did you notice as you looked at the Driving Question Board?</i>	We have made progress on most of the questions! Not all of the questions are answered.
<i>Which questions have we made the most progress on?</i>	Accept all responses.
<i>What have we figured out?</i>	Students should talk about the question they chose and wrote a response for using supporting evidence.
<i>What questions do you have about any of the ideas that have been shared?</i>	Accept all responses. Work through any confusion or partial understandings students may have.

Prepare students for the end-of-unit assessment. Say, *We have had a chance to figure out so many things about how we could use chemistry to build the materials we need to survive off of Earth. I think we are ready to demonstrate what we have learned on an assessment next class.*

End of day 2

8 • TAKE THE END-OF-UNIT ASSESSMENT

30 min

MATERIALS: Soap Scum Transfer Task

 **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 a different problem that we can solve using what we have figured out about molecules, atoms, and bonds.* Distribute Soap Scum Transfer Task. Allow students to work on the assessment for about 30 minutes or until all students are done.

ADDITIONAL GUIDANCE

Question 3a on the *Soap Scum Transfer Task* is framed to have students consider differences in electronegativity to explain why water molecules are able to dissolve sodium stearate. This does not consider differences in the sizes or concentrations of the water molecules and stearate ions. In *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*, students will consider how concentration affects particle-level interactions between ions and water molecules.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *SoapScum Transfer Task Key*.

What to do: See *SoapScum Transfer Task Key*.

Transfer Task PE: 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. (SEP: 2.3; DCI: PS1.A.1, PS1.A.2; CCC: 1.1)

Transfer Task PE: HS-PS1-2 Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. (SEP: 6.2; DCI: PS1.A.2, PS1.B.3; CCC: 1.1)

If students finish the assessment early, you can have them start on the reflection questions on **slide N**.

Provide assessment feedback to students in the form of written comments if possible, and in as timely a manner as you can.

9 · REFLECT ON THE UNIT

15 min

MATERIALS: science notebook, Community Agreements

Complete self-reflection on the unit. Display **slide N**. Direct students to complete a quick write in their science notebooks about any or all of the questions on the slide, then discuss them as a class.

Additional Lesson 15 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSA-SSE.A.1.a: Interpret expressions that represent a quantity in terms of its context.
a. Interpret parts of an expression, such as terms, factors, and coefficients.

Students evaluate and choose coefficients to add to chemical formulas to ensure there are equal numbers of elements on both sides of the chemical equation.



Unit C.3 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	<i>Day 1 Exit Ticket</i> <i>Day 1 Exit Ticket Key</i> <i>Initial Reaction Model</i> <i>Initial Model Key</i> Driving Question Board <i>DQB Assessment Guidance Key</i>	Pre-Assessment The student work in Lesson 1 available for assessment 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 <i>Day 1 Exit Ticket</i> and <i>Day 1 Exit Ticket Key</i> developed on day 1 is a good opportunity to pre-assess students understanding the problem that defines the driving question for the unit by having students identify some of the criteria and constraints of supporting living and working off Earth for a longer period of time. The <i>Initial Reaction Model</i> and <i>Initial Model Key</i> developed on day 2 of Lesson 1 is a good opportunity to pre-assess student understanding of what happens to the atoms in a chemical reactions and their experience modeling the matter inputs (reactants) and matter outputs (products). The Driving Question Board is another opportunity for pre-assessment. Reinforce for 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. <i>DQB Assessment Guidance Key</i> is provided to show examples of the type of questions students raised in the pilot of the anchor for this unit, and is a general guide for the type of questions the scope of questions that you can expect - largely focused on finding, recycling and making the resources needed for living and working off Earth (and on it) - subsequent lessons will end up delivering on these.
Lesson 2	<i>Focal Community Agreement</i>	Self-Assessment + Peer Feedback This handout provides students with an opportunity to choose a focal Community Agreement prior to working in a group. After completing the group work, they share their focal agreement and receive feedback from their peers around how well the student attended to it during the investigation. This feedback is connected to engaging in SEP8, which is a focal practice for the unit. Use the revisitation of Community Agreements to determine if students would benefit from additional opportunities to do this, beyond the subsequent two built into the unit (lesson 4 and 9).

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 4	<i>Lesson 4 Exit Ticket (Electronic Exit Ticket)</i> <i>Exit Ticket Key</i>	Formative + Summative + Community Building This Electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations (LLPEs) for Lesson 4. The first Electronic Exit Ticket allows relatively quick individual assessment of students on a key LLPE. Teachers can quickly check students' understanding of the relationship between molecular polarity, atomic structure, and molecular structure to explain liquid interactions with surface materials. Additionally, students have an opportunity here to reflect on their own experiences with unexpected interactions of liquids with materials, how they used science and engineering practices and crosscutting concepts in sensemaking, and the value of their classmates in supporting their learning.
Lesson 5	<i>Analyze Atmospheric Spectra</i> <i>Analyze Atmospheric Spectra Key</i>	Formative + Summative During the lesson, students developed an understanding about how light interacting with atoms and molecules results in characteristic patterns in the visible and infrared portions of the light spectrum. Students worked with partners to analyze the spectra of gasses in Earth's compared to known samples to determine an unknown. In <i>Analyze Atmospheric Spectra</i>, students work with a different partner to interpret atmospheric data for solar system objects, determining the presence or absence of referenced gasses.
Lesson 6	Element Tool Model <i>Model Evaluation Support</i> Consensus Element Tool Model	Formative + Peer Feedback Students develop small-group element tools on day 1 to organize a set of element cards. On day 2, they give and receive peer feedback and revise their work. Formative + Summative + Community Building Students develop a consensus model element tool.
Lesson 7	<i>Compare Atomic Models</i> <i>Compare Atomic Models Key</i>	Formative Students examine a third atomic model, electron shell model, and compare that to previous atomic models they have seen in <i>Electrostatics Unit</i>: paper clip model and electron cloud model. They are given a fourth atomic model, Lewis dot model. Students identify the merits and limitations of each to explain differences in bonds formed and electrons in atoms to develop understanding of the role of valence electrons.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 9	<i>Modeling Polarity</i> <i>Modeling Polarity Key</i> <i>Lesson 9 Exit Ticket: Community Agreement Reflection</i> <i>Sila-ibuprofen Transfer Task</i> <i>Transfer Task Key</i>	Self-Assessment + Formative <i>Modeling Polarity</i> and the related slides that provide students with answers for each of their predictions, provide students multiple self-assessment opportunities in day 1 and that start of day 2 of this lesson. A more formal check-in with the teacher occurs on slide Q, to determine if additional practice is needed in any area, before launching the individual transfer task, they are about to engage in: <i>Sila-ibuprofen Transfer Task</i>. Community Building Students will reflect on their Community Agreements using an electronic form, related to the work they engaged in with their partner and how it helped prepare both of them for the individual transfer task they are about to engage in: <i>Sila-ibuprofen Transfer Task</i>. Summative <i>Sila-ibuprofen Transfer Task</i> provides a key summative assessment on the ideas developed across lessons 6-9, including patterns in the periodic table and bonding, connections to Coulomb's law, electronegativities, and overall molecular polarity. An optional question provides an opportunity for students to connect in ideas about differences in intermolecular forces due differences in molecular polarity and a resulting property that they developed in lesson 4,
Lesson 11	<i>Fertilizer from Urine</i> <i>Fertilizer from Urine Key</i>	Formative Students read, annotate, and answer questions about the <i>Fertilizer from Urine</i> reading. They discuss these with a partner before participating in a class discussion.
Lesson 12	<i>Search for Elements</i> <i>Search for Elements Key</i> <i>Lesson 12 Exit Ticket (Electronic Exit Ticket)</i> <i>Exit Ticket Key</i>	Formative <i>Search for Elements</i> provides an opportunity to evaluate students' use of a focal practice (SEP8) and give them an opportunity to practice balancing chemical equations. Formative + Summative + Community Building This Electronic Exit Ticket and <i>Exit Ticket Key</i> addresses 3-D elements associated with the lesson-level performance expectations (LLPEs) for Lesson 12 and is an important formative assessment opportunity related to balancing chemical equations. The last question on the Electronic Exit ticket has students reflect on what another person in their community did to help move their thinking forward.
Lesson 13	<i>Recycling Ideas Organizer</i> <i>Recycling Organizer Key</i>	Formative Students engage in a focal practice (SEP: 8), when they synthesize information from a reading, two videos, and a series of molecular models to answer two questions in <i>Recycling Ideas Organizer</i>.
Lesson 14	<i>Synthesis and Evaluation</i> <i>Synthesis and Evaluation</i>	Formative + Community Building Students individually choose a topic and related article to read. They complete a table summarizing the information from the article. Students then meet with and synthesize ideas from the articles with three other students.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 15	<i>Soap Scum Transfer Task</i> <i>SoapScum Transfer Task Key</i>	Summative End-of-Unit Transfer Task Students will have the opportunity to demonstrate their competence with a Transfer Task, where they will develop models explaining the formation of soap scum due to the presence or absence of specific ions in water. This task is robust and will take approximately 30-45 minutes. The ideas, crosscutting concepts, and practices students engage with as part of completing this assessment can be found at the top of the Scoring Guidance (key). Please use scoring that works for your class and your requirements. We strongly recommend that you encourage students to use their notebooks as a resource for completing all assessments.
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.
Occurs in several lessons	Progress Tracker <i>Progress Tracker Key</i>	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, 4, 5, 6, 9, 12, 14.
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 <i>OpenSciEd Teacher Handbook: High School Science</i>. In addition to the self-assessment moments described above, this tool's use is suggested as an alternate activity at the end of Lessons 2 and 9.

When	Assessment and Scoring Guidance	Purpose of Assessment
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 <i>OpenSciEd Teacher Handbook: High School Science</i>. In addition to the peer assessment moments described above, this tool's use is suggested as an alternate activity at the end of Lessons Lessons 2 and 6.

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 Define some of the criteria for living and working in places beyond Earth for longer periods of time and the constraints for taking all of the substances/materials we would need, and identify possible solutions for obtaining these substances/materials. (SEP: 1.8, DCI: ESS3.A.1, ESS3.C.2, PS1.B.3; CCC: 3.1) 1.B Develop and use a model to represent atom-level compositions of products and reactants and the changes and interactions that occur between the atoms in a chemical reaction that help explain why specific products form and not others. (SEP: 2.3; DCI: PS1.B.3; CCC: 3.1, 6.2) 1.C Ask questions that arise from careful observation of images (at different scales) of solar system objects and particle-level models for different chemical process/reactions and/or ask question to clarify/seek additional information and relationships about ways to find, recycle, and/or make enough of the substances we need to live and work beyond Earth and on it. (SEP: 1.1, 1.2; DCI: ESS3.A.1, ESS3.C.2, PS1.B.3; CCC: 6.2)	1.A When to check for understanding: At the end of day 1, when you collect <i>Day 1 Exit Ticket</i>. (slide L) What to look/listen for during the opportunity: See <i>Day 1 Exit Ticket Key</i>. 1.B When to check for understanding: At the end of day 3, after students complete <i>Initial Reaction Model</i>. (slide AA) What to look/listen for during the opportunity: See <i>Initial Model Key</i>. 1.C When to check for understanding: When students post their sticky notes to the Driving Question Board. (slide GG) What to look/listen for during the opportunity: See <i>DQB Assessment Guidance Key</i>.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 2	2.A Compare, integrate, and communicate information presented in different media or formats to identify patterns in water's ability to: absorb, store, and release large amounts of energy through its specific heat; transmit sunlight; and dissolve and transport materials. (SEP: 8.2, 8.5; DCI: ESS2.C.1, PS2.B.3; CCC: 1.5)	2.A When to check for understanding: 1. As students work in small groups to complete the station investigations. (slide G) 2. As students work in their group on day 1 to prepare ways to share their station findings. (slide H) 3. As students work in their group on day 2 to prepare ways to share their station findings. (slide J) 4. As groups communicate their station findings to their peers. (slide K) 5. As the class co-creates the "Water's Importance for Life and Chemical Reactions" poster. (slide L) What to look/listen for across opportunities 1-5: • Students should identify patterns in different sources of information, including temperature data (or CODAP data) and investigation data. (SEP: 8.2; CCC: 1.5) • Students use and integrate information presented in various media to explain and identify properties of water including water's ability to: absorb, store, and release large amounts of energy through its specific heat; transmit sunlight; and dissolve and transport materials. (SEP: 8.2; DCI: ESS2.C.1) • Students who visit Stations 1 and 3 communicate information about the role of attraction of water and other liquids to materials in order to explain the properties of cohesion and adhesion. (SEP: 8.5; DCI: PS2.B.3) • Students collaborate with peers in their group to develop a list of talking points to effectively communicate with other peers in the class. (SEP: 8.5) • Students communicate information orally and/or visually about properties of water which may include water's ability to: absorb, store, and release large amounts of energy through its specific heat; transmit sunlight; and dissolve and transport materials; as well as the role of attraction of water and other liquids to materials in order to explain the properties of cohesion and adhesion. (SEP: 8.5; DCI: ESS2.C.1, PS2.B.3) • Students integrate information presented in various media to explain the importance of properties of water to life and chemical reactions. (SEP: 8.2; DCI: ESS2.C.1, PS2.B.3)
Lesson 3	3.A Make and defend a claim about the geologic processes that were most likely responsible for the formation of different surface features on Earth and other solar objects, using evidence from satellite images at different scales. (SEP: 7.5; DCI: ESS1.C.2; CCC: 1.1)	3.A When to check for understanding: 1. As students work to build the "Surface Features and Causes" poster. (slides E-F) 2. As groups defend their claims about which geologic processes formed the surface features in the satellite images they examined on either <i>Satellite Set A</i> or <i>Satellite Set B</i>. (slides L-M) 3. As students develop and defend claims about geologic processes that could have formed surface features on the Moon and Mars on <i>Evaluate Satellite Images</i>. (slides N-O) What to look/listen for across opportunities 1-3: • Students use patterns in geologic features across different scales to identify possible causes, or geologic processes, which form the features. (DCI: ESS1.C.2; CCC: 1.1) • Students' claims include evidence (e.g., similar or different structures visible in the images) of different regions of Earth at different scales from either <i>Satellite Set A</i> or <i>Satellite Set B</i>. (SEP: 7.5; CCC: 1.1) • Students' claims reference patterns that are similar between surface features in different data sources across both <i>Satellite Set A</i> and <i>Satellite Set B</i>. (SEP: 7.5; CCC: 1.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 4	4.A Design and conduct an investigation to determine the patterns to use as causal evidence to explain the interaction of water with Earth's surface compared to substances with similar properties. (SEP: 3.1; DCI: ESS2.A.1, ESS2.C.1; CCC: 1.1) 4.B Observe patterns at multiple scales to support movement between multiple types of models that use molecular and submolecular structures that explain the properties of matter like water. (SEP: 2.4; DCI: PS1.A.3; CCC: 1.1, 6.2) 4.C Compare, integrate, and evaluate information from a reading, models, and an investigation to explain how water's polarity results in its unique bulk properties. (SEP: 8.2; DCI: PS1.A.3; CCC: 6.2)	4.A When to check for understanding: 1. When students plan their investigations using <i>Erosion Investigation</i> on day 1. (slides E-H) 2. When students discuss their investigation results on day 2. (slides N-O) What to look/listen for across opportunities 1-2: • Students' investigation plans include sufficiently controlled variables to enable them to compare water's impact on surface materials to other liquids' impacts. (SEP: 3.1; DCI: ESS2.A.1, ESS2.C.1) • Students' investigations will help students observe patterns at the observable scale to provide evidence for causality of landform creations by various liquids. (SEP: 3.1; CCC: 1.1) • Students' plan and conduct investigations which will help them revise their models of how water creates surface features on Earth. (SEP: 3.1; DCI: ESS2.A.1, ESS2.C.1) • Students reason that alcohol also causes erosion sometimes, but that the overall pattern is that water has a greater impact. (DCI: ESS2.A.1, ESS2.C.1; CCC: 1.1) • Students describe the results of their investigations that show how water exhibits stronger force interactions than other liquids in the stream table erosion investigation. (SEP: 3.1; DCI: ESS2.A.1, ESS2.C.1) • Students articulate how patterns of water's interactions with surface materials at the classroom investigation scale can help explain landforms on Earth and Mars. (DCI: ESS2.A.1, ESS2.C.1; CCC: 1.1) 4.B When to check for understanding: 1. When students create models of the lab results using <i>Molecule Cutouts</i> on day 2. (slide T) 2. When students complete the Electronic Exit Ticket on day 3. (slide CC) What to look/listen for across opportunities 1-2: • Students use investigation data to develop models, which includes how water erodes surface materials because water molecules are polar (an idea that originated in <i>Electrostatics Unit</i>). (SEP: 2.4; DCI: PS1.A.3) • Students relate patterns in investigation data to patterns in molecular models. (SEP: 2.4; CCC: 1.1) • Students use models to make predictions about bulk properties of substances. (SEP: 2.4; DCI: PS1.A.3) • Students relate a substance's polarity to its ability to create erosion and frost heaves. (CCC: 6.2) • Students use patterns in data and models as evidence to support their predictions. (SEP: 2.4; CCC: 1.1) 4.C When to check for understanding: During the Building Understandings Discussion on day 3. (slide AA) What to look/listen for during the opportunity: • Students use the reading and molecule cutouts to develop models that include: as water freezes, the molecules line up, resulting in its expansion; this leads to cracks in the ground (experimental level). (SEP: 8.2; CCC: 6.2) • Students reason that: • the "pull" of water on surface materials is due to its polarity, and • water expands when it freezes because the molecules arrange themselves in a regular pattern, due to its polarity. (DCI: PS1.A.3)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 5	5.A Analyze, compare, and integrate empirical evidence to identify patterns in the interaction (study) of a star's light or other light spectrum with substances present in a sample or on an object in space to answer scientific questions about how we can identify which locations have the substances or elements needed to live and work in space. (SEP: 4.1, 8.2; DCI: ESS1.A.2, PS4.B.4; CCC: 1.5)	5.A When to check for understanding: 1. As students record their observations during the Light Spectra Demonstration on <i>Spectrum Observations</i>. (slide J) 2. When students complete an exit ticket at the end of day 1. (slide O) 3. As students work with a partner to complete <i>Analyze Unknown Gasses</i>. (slide Q) 4. As students work with a new partner to complete <i>Analyze Atmospheric Spectra</i>. (slide V) 5. When students read and discuss <i>Space Spectroscopy Studies</i>. (slides Y-Z) 6. As students add to their Progress Trackers. (slide AA) What to look/listen for across opportunities 1-6: • Students analyze the spectra of unknown substances by comparing them to spectra of known substances. (SEP: 4.1; DCI: PS4.B.4) • Students identify and use patterns in spectra of known substances (empirical evidence) to identify unknown substances. (DCI: PS4.B.4; CCC: 1.5) • Students analyze atmospheric spectra of objects in the solar system to determine which gasses are present. (SEP: 4.1; DCI: ESS1.A.2) • Students compare information presented in different media to determine the presence of substances on objects in space. (SEP: 8.2; DCI: ESS1.A.2)
Lesson 6	6.A Use patterns from empirical evidence to develop, revise, and evaluate merits and limitations of models of an element tool using subatomic particles and properties. (SEP: 2.3, 2.1; DCI: PS1.A.2; CCC: 1.5)	6.A When to check for understanding: 1. As students reorganize element cards on day 1. (slide H) 2. As students share models of their element tool on day 2. (slide J) 3. As students build a class consensus element tool on day 2. (slide M) 4. As students create a Progress Tracker entry on day 2. (slide P) What to look/listen for across opportunities 1-4: • Students use patterns from empirical evidence from the element cards to support their organizational model. (SEP: 2.3; CCC: 1.5) • Empirical evidence students provide can include: • numbers of protons/mass, or • reactivity (chemical property), or • bonds and charges formed. (DCI: PS1.A.2; CCC: 1.5) • Students use the merits and limitations of other groups' element tools, which are based on empirical evidence from the element cards, to consider revisions to their own element tool. (SEP: 2.1; CCC: 1.5) • Students suggest that: • elements should be arranged by increasing numbers of protons and mass, and • new columns should begin based on numbers of bonds/charges formed. (DCI: PS1.A.2; CCC: 1.5) • Students explain that each element forms a specific number of bonds/charges when it combines with other elements. (DCI: PS1.A.2) • Students identify patterns in empirical evidence to support their organizational model as a way to determine when to begin a new row. (SEP: 2.3; CCC: 1.5) • Students explain that patterns in elements' bonds/charges formed repeat (periodicity), while mass/number of protons increases. (DCI: PS1.A.2; CCC: 1.5)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 7	7.A Develop, compare, and move between various models of atomic structures to explain and account for differences in the numbers of electrons and bonds formed by different atoms. (SEP: 2.4; DCI: PS1.A.1, PS1.A.2; CCC: 6.2) 7.B Determine which atomic model best illustrates patterns in atomic structures at the atomic scale, which can be used to predict interactions between elements. (SEP: 2.1; DCI: PS1.A.2; CCC: 1.1)	7.A When to check for understanding: 1. As students develop initial models of a carbon atom. (slides B-C) 2. As students compare and use their models to make predictions. (slides F-G) 3. As the whole class builds understanding around patterns in atoms. (slide I) What to look/listen for across opportunities 1-3: • Students develop initial models. The models should: • show the substructure of a carbon atom, and • try to explain differences in electrons and connections formed. (SEP: 2.4; DCI: PS1.A.1) • Students revise initial models of a carbon atom to try to explain differences in electrons and connections formed by including some new way to organize electrons that may not have been in the initial model. (SEP: 2.4; DCI: PS1.A.1, PS1.A.2) • Students consider advantages or disadvantages of revised models, particularly related to the organization of electrons. (SEP: 2.4; DCI: PS1.A.2) • Students give examples of various models that show different representations of the same structures (electrons). (SEP: 2.4) • Students explain that structures of electrons in atoms determine properties of atoms (how they connect with one another). (CCC: 6.2) • Students point out that electron structures (shells) are found in a repeating pattern on the periodic table. (DCI: PS1.A.1, PS1.A.2) 7.B When to check for understanding: 1. As students discuss their responses to <i>Evaluate Another Model</i>. (slides J-K) 2. As students work with a partner to model valence electron interactions in water. (slide R) 3. As students individually model valence electron interactions in either methane or oxygen gas. (slide S) What to look/listen for across opportunities 1-3: • See <i>Compare Atomic Models Key</i> for guidance. • Students use either the electron shell or Lewis dot model to explain how valence electrons of two elements interact to form specific numbers of bonds with another element. (SEP: 2.1; DCI: PS1.A.2) • Students show a structure with two bonds emerging at the scale of a single atom. (CCC: 1.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 8	8.A Use the periodic table to identify atoms with similar bonding patterns and to explain how differences in atomic structure could contribute to differences in electronegativity. (SEP: 2.3; DCI: PS1.A.2; CCC: 1.1) 8.B Explain bond stability, differences in three properties, and differences in molecular polarity of two molecules based on the relative strength of forces between atoms and molecules. (SEP: 6.2; DCI: PS1.A.1, PS2.B.3; CCC: 6.2, 7.1)	8.A When to check for understanding: 1. On day 1, as students identify a substitute atom for oxygen. (slide D) 2. As students complete question 1 of the exit ticket on day 1. (slide L) What to look/listen for across opportunities 1-2: • Students use the periodic table. (SEP: 2.3) • Students identify a replacement atom that forms the same number of bonds as O (or any other atom in the column). (DCI: PS1.A.2; CCC: 1.1) • Students describe how sulfur (S) has one more electron shell than oxygen (O), making it bigger, and has more protons (and electrons). (DCI: PS1.A.2; CCC: 1.1) • Students state that the amount of positive charge and/or distance to the nucleus contribute to differences in electronegativity and/or how much the electrons are shifted in the molecule, which may be related to its polarity. (DCI: PS1.A.2) 8.B When to check for understanding: 1. On day 1, as students discuss the prompts in the video. (slide F) 2. On day 1, as students discuss how the differences in polarity explain differences in three properties. (slide K) 3. On day 2, as students individually respond to the question, <i>How can electronegativities help explain why H₂O molecules are more polar than H₂S molecules?</i> (slide AA) What to look/listen for across opportunities 1-3: • Students explain that balanced force interactions (repulsion between nuclei and attraction to shared electrons) exist to cause two bonded nuclei to remain in a stable state at a certain distance from each other. (DCI: PS2.B.3; CCC: 6.2; 7.1) • Students explain that: (SEP: 6.2) • the higher polarity of H₂O molecules exerts more pull (stronger forces) on opposite ends of neighboring H₂O molecules; (DCI: PS2.B.3) • stronger pull causes more cohesion and higher boiling point (it takes more energy to knock apart H₂O molecules into gas); (DCI: PS2.B.3; CCC: 7.1) • the higher polarity of H₂O molecules (structure) exerts more pull (stronger forces) on oppositely charged particles nearby, making it better at dissolving substances (function). (DCI: PS2.B.3; CCC: 6.2) • Students explain that: (SEP: 6.2) • the higher electronegativity of O compared to S means that O atoms pull more strongly on the electrons it shares in bonds with H than S atoms do, (DCI: PS1.A.1, PS2.B.3) • leading to a greater amount of shift in the electrons toward O than toward S, (DCI: PS1.A.1; CCC: 6.2, 7.1) • and these differences in the structures of bonded atoms contribute to a higher degree of polarity in some bonds vs. others and thus differences in molecular polarity (function) of H₂O compared to H₂S. (DCI: PS2.B.3; CCC: 6.2, 7.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 9	9.A Use a variety of models and evidence (such as solubility and periodic trends in electronegativity and atomic radius) to a) describe the patterns and relationships between the parts of an atom and the bonds formed between atoms, b) predict polarity differences, and c) explain property differences based on the relative differences in the strength of forces between atoms and molecules. (SEP: 2.3; DCI: PS1.A.3, PS1.A.2; CCC: 1.1, 6.2)	9.A When to check for understanding: 1. As students incrementally complete <i>Modeling Polarity</i>. (slides F-G, H-I, J-K, L-O, and P-Q) 2. When students complete <i>Sila-ibuprofen Transfer Task</i>. (slides AA-CC) What to look/listen for across opportunities 1-2: • See <i>Modeling Polarity Key</i>. • See <i>Transfer Task Key</i>.
Lesson 10	10.A Critically read scientific literature to identify the structures of different components and explain the transformations of matter with forces in a water-cleaning reaction. (SEP: 8.1; DCI: PS2.B.3; CCC: 6.1)	10.A When to check for understanding: 1. As students debrief the reading and model the reaction from it. (slides E-G) 2. As students revisit the reactions from the start of the lesson. (slide I) What to look/listen for across opportunities 1-2: • Students give accurate summaries of the text in discussion and when describing their models. (SEP: 8.1) • Students describe and explain the ways in which the structure of water (polarity) and strength of forces between different ions cause the observed transformation (reaction). (DCI: PS2.B.3; CCC: 6.1) • Students connect the structure of particles and force interactions to resulting reactions. (DCI: PS2.B.3; CCC: 6.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 11	11.A Critically read and determine central ideas of a text to develop a model that explains how using different reactants leads to the development of different fertilizers which can be used to grow plants off of Earth. (SEP: 8.1, 2.3; DCI: PS1.A.1, PS1.B.3; CCC: 6.2) 11.B Develop and revise a model based on evidence to show the relationship between reactant and product components and that atoms are conserved in a chemical reaction system. (SEP: 2.3; DCI: PS1.B.3; CCC: 5.1)	11.A When to check for understanding: 1. As students annotate and discuss questions on <i>Fertilizer from Urine</i> on day 1. (slides C-D) 2. As students develop models of ammonia and ammonium with a partner. (slide G) 3. As students develop consensus models of ammonia and ammonium as a class. (slide J) What to look/listen for across opportunities 1-3: • See <i>Fertilizer from Urine Key</i> for additional guidance. • Students critically read and determine central ideas about growing plants in space that can give us the materials needed for survival. (SEP: 8.1; DCI: PS1.B.3) • Students develop models of NH_3 and NH_4^+ based on evidence from the reading to predict the relationship between charge and number of electrons. (SEP: 2.3; DCI: PS1.A.1) • Students show the atomic structures of NH_3 and NH_4^+, including the number and charge of the protons, neutrons, and electrons. (DCI: PS1.A.1; CCC: 6.2) 11.B When to check for understanding: 1. As students model chemical reactions on day 2. (slide Q) What to look/listen for during the opportunity: • Students develop models of chemical reactions which show that atoms are conserved based on evidence from the reading. (SEP: 2.3; DCI: PS1.B.3) • Students' models illustrate the rearrangement and conservation of matter within the reaction system. (SEP: 2.3; CCC: 5.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 12	12.A Create balanced chemical equations (computational models) using mathematical representations of elements to demonstrate that matter is conserved. (SEP: 5.1; DCI: PS1.B.3; CCC: 1.4, 5.1) 12.B Gather, read, and interpret information presented in different formats and adapted from scientific literature to predict which object in space (system) would contain the quantities (large scale) of elements and compounds (atomic scale) needed to create the resources for survival. (SEP: 8.1, 8.2; DCI: PS1.B.3; CCC: 4.3)	12.A When to check for understanding: 1. As students identify the types and total numbers of elements on either side of the chemical equation for photosynthesis. (slides C-D) 2. As students work together with the class to balance the chemical equation for photosynthesis. (between slides D-F) 3. As students work with a partner to balance a chemical equation for cement. (slide R) 4. On day 2 as students complete an Electronic Exit Ticket. (slide Z) What to look/listen for across opportunities 1-4: • Students use mathematical representations of the numbers of elements for evidence that the amount of matter on either side of a chemical equation is not equal. (CCC: 1.4; DCI: PS1.B.3) • Students use a chemical equation (computational model) to account for amounts of elements. (SEP: 5.1; DCI: PS1.B.3) • Students use mathematical thinking to revise a chemical equation to show equal amounts of elements in products and reactants. (SEP: 5.1; DCI: PS1.B.3) • Students use mathematical thinking to revise a chemical equation to show conservation of matter. (SEP: 5.1; CCC: 5.1) • See <i>Exit Ticket Key</i> for guidance. 12.B When to check for understanding: 1. As students work with a partner to complete <i>Search for Elements</i> and discuss with the class. (slides J-K) 2. On day 1 as students complete <i>Mars Rovers Research</i> and discuss with the class. (slides M-O) 3. On day 2 as students complete <i>Summarize a Reading</i> using the reading on <i>Sulfur-Based Concrete</i>. (slide V) What to look/listen for across opportunities 1-3: • Students evaluate sources of information presented in different media (websites) or formats as well as in words to determine which location has the elements that could serve as the basis for the substances we need to live and work in space. (SEP: 8.2; DCI: PS1.B.3) • Students identify which object in space (system) contains the quantities (large scale) of elements and compounds (atomic scale) needed to create the resources for survival. (DCI: PS1.B.3; CCC: 4.3) • Students determine the central ideas of scientific literature to determine the feasibility of living and working on Mars. (SEP: 8.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 13	13.A Compare and integrate information about the molecular structure, substructures, and bonding patterns of various materials from a text, experimental videos, and a series of molecular models to answer two scientific questions: 1) recyclability as a function of matter's interactions at the bulk scale, including atomic forces, and 2) how this informs new engineering solutions for living and working beyond and/or on Earth in the future. (SEP: 8.2; DCI: PS1.A.3, ESS3.C.2; CCC: 6.2)	13.A When to check for understanding: When you collect students' completed <i>Recycling Ideas Organizer</i>. (slide BB) What to look/listen for during the opportunity: - Students have accurate responses in column 1 showing they have integrated information from several diverse multimedia sources. (SEP: 8.2) - Students indicate substructures of plastics, especially polymers, monomers, and cross-linking, in column 1, row 2. (DCI: PS1.A.3; CCC: 6.2) - Students refer to the strength of materials (forces at a bulk scale) and/or strength/number of forces between molecules (intermolecular) or atoms (bonds). (DCI: PS1.A.3) - Students indicate in column 2 that new engineering solutions will require goals of (or will potentially impact) sustainability and human survival (especially non-toxicity of plastics), and/or students raise questions about what potential solutions are being developed or researched. (DCI: ESS3.C.2)
Lesson 14	14.A Synthesize multiple methods to compare arguments for the sustainable properties of materials based on the forces that determine bulk-scale interactions. (SEP: 7.1, 8.4; DCI: PS1.A.3; CCC: 6.1)	14.A When to check for understanding: - As students synthesize claims and evaluate arguments with a partner. (slide E) - As students share their evaluations with another pair. (slide F) What to look/listen for across opportunities 1-2: - Students synthesize both articles' claims and check that at least one of the provided references supports the claims. (SEP: 8.4) - Students identify the ways in which the particle-level structure of the material and the force interactions at this level result in material properties. (DCI: PS1.A.3; CCC: 6.1) - Students' evaluations consider their current scientific evidence and understandings about material properties, problem-based considerations, and ethics. (SEP: 7.1; DCI: PS1.A.3)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 15	15.A Evaluate competing arguments about human survival in space in light of matter conservation and the chemical structures of molecules and atoms, trade-offs, and ethics. (SEP: 7.1; DCI: PS1.B.3; CCC: 1.2) 15.B Create balanced and accurate chemical equations (computational models) uniting mathematical and molecular representations of covalently-bonded molecules to ensure matter is conserved. (SEP: 5.1; DCI: PS1.B.3; CCC: 5.1) Transfer Task PE: 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. (SEP: 2.3; DCI: PS1.A.1, PS1.A.2; CCC: 1.1) Transfer Task PE: HS-PS1-2 Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. (SEP: 6.2; DCI: PS1.A.2, PS1.B.3; CCC: 1.1)	15.A When to check for understanding: As students discuss the merits of different perspectives and argue using trade-offs, ethics, and science ideas in the Scientists Circle. (slide F) What to look/listen for during the opportunity: - Students evaluate competing arguments in light of trade-offs and ethical concerns. (SEP: 7.1) - Students indicate that the conservation of matter in chemical reactions limits what is possible in space. (DCI: PS1.B.3) - Students share that matter must be transformed from existing matter if we are to survive elsewhere. (CCC: 1.2) 15.B. When to check for understanding: - As students build balanced computational models (chemical equations). (slide H) - As students model the molecules they choose. (slide I) What to look/listen for across opportunities 1-2: - Students explain how an equation is balanced using coefficients and molecular formulas as evidence. (SEP: 5.1; DCI: PS1.B.3) - Students' models indicate that no matter is gained or lost during a chemical reaction (conservation of matter). (SEP: 5.1; DCI: PS1.B.3; CCC: 5.1) Soap Scum Transfer Task: In this lesson you will administer the <i>Soap Scum Transfer Task</i> task. This assessment is not building toward a lesson-level performance expectation. It is designed to assess progress toward two performance expectations from the NGSS (HS-PS1-1 and HS-PS1-2). See <i>SoapScum Transfer Task Key</i> for details.

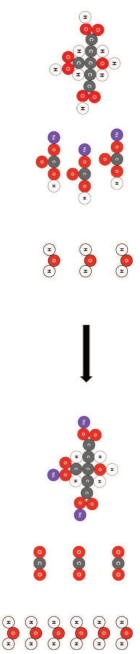


Lesson-Specific Teacher Materials

Lesson 1: Teacher Reference

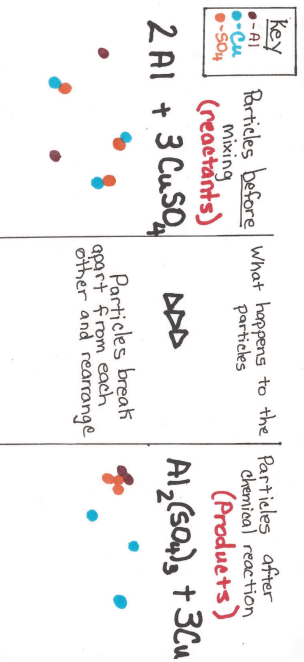
Prior Chemical Reactions

What are some prior models of chemical reactions that students will have developed in OpenSciEd middle school units?

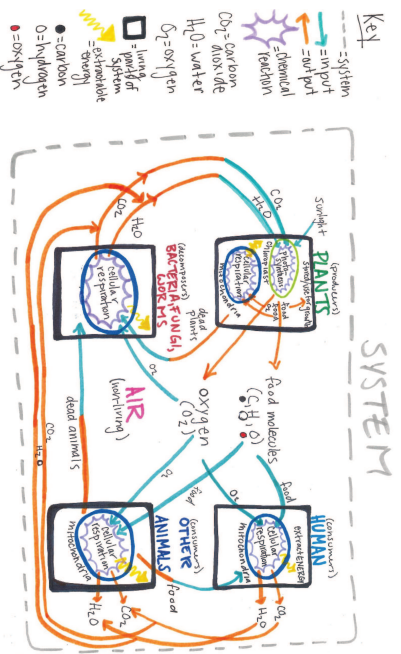


In unit *OpenSciEd Unit 7.1: How can we make something new that was not there before?* (Bath Bombs Unit), which occurs first in the sequence of OpenSciEd 7th grade science courses, students model and describe that atoms of hydrogen and oxygen combine to make a “compound particle” of water. The forces and relative masses are not important to this model in *OpenSciEd Unit 7.1: How can we make something new that was not there before?* (Bath Bombs Unit), but students develop the ideas that particles like molecules can be broken down and rearranged to make new particles, and the smaller particles that rearrange to do this are atoms. The anchoring phenomena, which includes production of a gas in a bath bomb, is explained by developing models of chemical reactions that look like the one shown to the right.

In unit *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem?* (Homemade Heater Unit), which is the second unit in the sequence of OpenSciEd 7th grade science courses, students work with chemical reactions to design an MRE (meal ready to heat). Students optimize the ratios of reactants for the weight constraints of the design, by collecting empirical data on energy transfer to the surroundings. They do not work with molar masses, nor balancing equations to solve this design problem. The type of chemical reaction models that students will have developed in this unit, look like the one shown to the right.



In the third unit in the 7th grade OpenSciEd course sequence, *OpenSciEd Unit 7.3: How do things inside our bodies work together to make us feel the way we do?* (Inside Our Bodies Unit), students develop a model of cellular respiration at a particle, cellular, and organism level. In the fourth unit, *OpenSciEd Unit 7.4: Where does food come from, and where does it go next?* (Maple Syrup Unit), students develop a model of photosynthesis at these different levels and connect photosynthesis to it, to explain the flow of matter that occurs at a particle level between different types of organisms (animals, plants, decomposers) and the atmosphere. The representations that are integrated into these models, look like the one shown to the right.



Lesson 1: Answer Key 1

Day 1 Exit Ticket Key

Building toward: 1.A Define some of the criteria for living and working in places beyond Earth for longer periods of time and the constraints for taking all of the substances/materials we would need, and identify possible solutions for getting these substances/materials. (SEP: 1.8, DCI: ESS3.A.1, ESS3.C.2, PS1.B.3; CCC: 3.1)

3D Elements
Asking Questions and Defining Problems. Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations. (SEP: 1.8)
Natural Resources. Resource availability has guided the development of human society. (DCI: ESS3.A.1)
Human Impacts on Earth Systems. Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (DCI: ESS3.C.2)
Chemical Reactions. The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (DCI: PS1.B.3)
Scale, Proportion, and Quantity. The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (CCC: 3.1)

This rubric is provided as guidance for the types of responses students may have on *Day 1 Exit Ticket*. It is **not suggested** that you grade these items.

Criteria:

- What types of substances/materials will we need at any of the places off Earth that you looked at today in order to live and work or a longer amount of time?
- What additional substance/materials would we need to work productively and live happily there as well?

Constraints: Based on what we figured out today, what factors will limit the amounts of those substances/materials that we can take with us (crewed) or send (uncrewed) to our chosen destination?

Solutions: What else could we do to get these substances/materials if we can not bring them with us nor have them sent from Earth? *Possible solutions should use our current technologies.*

	Foundational Understanding	Linked Understanding	Organized Understanding
3D Elements	What to look for in students' responses: Students identify more than one criteria (substances/materials) people will require in order to live and work in a place beyond Earth. Students identify a constraint. Students identify a solution that uses ideas around human impacts on Earth systems or chemical reactions: - finding the needed substances on site and/or mining/separating/extracting once a reservoir of a substance is found - recycling the materials we have - making/manufacturing substances we do not have (through chemical process)	What to look for in students' responses: Students identify a few criteria (substances/ materials) people will require in order to live and work in a place beyond Earth. Students use scale thinking to identify a constraint. Students identify multiple solutions that use ideas around human impacts on Earth systems or chemical reactions: - finding the needed substances on site and/or mining/separating/extracting once a reservoir of a substance is found - recycling the materials we have - making/manufacturing substances we do not have (through chemical process)	What to look for in students' responses: Students identify multiple criteria (substances/ materials) people will require in order to live and work in a place beyond Earth and what those substances/materials are made of. Students use scale thinking to identify more than one constraint. Students identify multiple solutions that use ideas around human impacts on Earth systems and chemical reactions: - finding the needed substances on site and/or mining/separating/extracting once a reservoir of a substance is found - recycling the materials we have - making/manufacturing substances we do not have (through chemical process)
Example	Criteria: We will need to have air, food, and shelter. Constraints: We need to think about what stuff we need to take with us, the rockets we would use, and where we would go. Solutions: We could also reuse the parts on the spacecraft we take to get to the place, since we wouldn't need it to leave.	Criteria: We will need to have water, oxygen, food, shelter, medicine, and soap. Constraints: We need to think about one of these constraints - how long it takes to get to these places - how far away these places are - the speed of our rockets - how much we can carry on the rocket (payload) - cost or cost per lb. - temperature range of the place we are going to Solutions: We could search for the raw substances/materials that we need. We could also reuse the parts on the spacecraft we take to get to the place, since we wouldn't need it to leave.	Criteria: We will need to have water, oxygen, food, shelter, medicine, and soap. To build shelters we will need concrete, wood, steel, glass, plastic, and something for insulation. Constraints: There are several constraints that we need to think about, like: - how long it takes to get to these places - how far away these places are - the speed of our rockets - how much we can carry on the rocket (payload) - cost or cost per lb. - temperature range of the place we are going to Solutions: We could search for the raw substances/materials that we need, and then mine them. For some substances/materials, we could just use them as they are, like water. We could also reuse the parts on the spacecraft we take to get to the place, since we wouldn't need it to leave. We could use chemical reactions to make some products we need to survive.

Feedback / What to do	<i>Linking:</i> Invite students to think about what substances/materials go into making the designed structures (shelter). Invite students to expand on how the constraints they listed would be impacted if we considered scale, proportion, or quantity. Invite students to think about additional solutions to finding enough substances/materials to support us in living and working beyond Earth.	<i>Organizing:</i> Invite students to think about what the substances/materials they have identified could be broken down into. Invite students to list additional constraints that would be impacted if we considered scale, proportion, or quantity. Invite students to list an additional solution that would use an idea around human impacts on Earth systems or chemical processes.	<i>Extending:</i> Encourage students to identify what the substances/materials are made of at the atomic scale. Encourage students to identify whether the constraint is a result of scale (time/space), proportion (ratio thinking), or quantity. Encourage students to connect ideas around human impacts on Earth systems and chemical processes.
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	Foundational Understanding	Linked Understanding	Organized Understanding
Ideas for Instruction	Break down designed structures into the substances/materials which form their composition. Ask students to think about how scale, proportion, or quantity would impact the types of decisions and/or solutions we would need to make.	Give students a chance to revise their Exit Ticket responses before discussing them as a class on day 2. This could be done by pairing up students to compare their responses.	Invite students to list the atoms/elements that would be essential to find on the planet/moon we want to live and work on. What atoms would be the most important to find? Why those atoms?

Lesson 1: Answer Key 2

Initial Model Key

Building toward: 1.B Develop and use a model to represent atom-level compositions of products and reactants and the changes and interactions that occur between the atoms in a chemical reaction that help explain why specific products form and not others. (SEP: 2.3; DCI: PS1.B.3; CCC: 3.1, 6.2)

3D Elements

SEP: 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)

DCI: Chemical Reactions. The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (DCI: PS1.B.3)

CCC: Scale, Proportion, and Quantity. The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (CCC: 3.1)

CCC: Structure and Function. The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. (CCC: 6.2)

This rubric is provided as guidance for the types of representations students may have on *Initial Reaction Model*. It is **not suggested** that you grade these initial models.

Choose a reaction described by one of the processes on *Materials for Survival*.

Write the name of the process here: _____

- What happens to the matter inputs at a particle level in the reaction you chose? Represent any particle-level changes that occur. Use words and/or pictures to illustrate your thinking.
- What particle-level interactions occur during the reaction?
- Why do these specific products form from the reactants, and not different products?

A description or representation of:

- at least two types of particles – e.g., atoms or molecules (also may include ions, electrons)
- atoms or ions breaking apart from the other particles they were connected to in the reactants
- those same types of atoms or ions coming back together (connecting back together) in new arrangements when they form the products

At least one proposed reason for why the particular products are the result of a reaction between the particular reactants, that draws on an idea from *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, such as:

- The same types of atoms have to be there.
- Certain atoms go with others.
- There are directionality or strength differences in attractive forces between some atoms.
- Some electrons move off of and on to other atoms.
- Certain atoms can bond with others.
- Some sort of structure enables atoms to be connected together.

- It has something to do with what those atoms are made of (electrons, protons, neutrons).

Lesson 1: Answer Key 3

DQB Assessment Guidance Key

Building toward: 1.C Ask questions that arise from careful observation of images (at different scales) of solar system objects and particle-level models for different chemical process/reactions and/or ask question to clarify/seek additional information and relationships about ways to find, recycle, and/or make enough of the substances we need to live and work beyond Earth and on it. (SEP: 1.1, 1.2; DCI: ESS3.A.1, ESS3.C.2, PS1.B.3; CCC: 6.2)

3D Elements
Asking Questions and Defining Problems. Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. (SEP: 1.1)
Asking Questions and Defining Problems. Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships. (SEP: 1.2)
Natural Resources. Resource availability has guided the development of human society. (DCI: ESS3.A.1)
Human Impacts on Earth Systems. Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (DCI: ESS3.C.2)
Chemical Reactions. The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (DCI: PS1.B.3)
Structure and Function. The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. (CCC: 6.2)

The sample questions are provided as guidance for the types of questions students may develop during the lesson. It is **not suggested** that you grade these questions.

On slide R, students developed questions on blue sticky notes related to finding or extracting resources we need, that arise from careful observation of images (at different scales) of solar system objects (SEP: 1.1; DCI: ESS3.A.1, ESS3.C.2; CCC: 6.2). The following list represents the types of questions you should expect to see on these blue sticky notes related to finding resources:

- Where in the system (e.g., underground, on the surface, in the atmosphere) can deposits/reservoirs of a particular substance be found?
- Can surface features suggest the presence of a particular substance(s)?
- What properties (e.g., color, density) can help us identify what a substance might be?
- What might be the states of matter of a substance on different moons/planets and/or at different temperatures?
- How do the compositions of different moons/planets compare?
- Can we mine the planet for what we need?
- Does the Moon or Mars have water below the surface or at the ice caps?

On slide DD, students developed questions on yellow sticky notes related to recycling or making the resources we need, that arise from careful observation of particle-level models for different chemical processes/reactions (SEP: 1.2; DCI: ESS3.C.2, PS1.B.3; CCC: 6.2). The following list represents the types of questions you should expect to see on these yellow sticky notes related to recycling resources:

- Can we clean/filter/distill the used dirty water and reuse it?
- How do they recycle air on the ISS?
- Why are some plastics recyclable but others are not?

- *Can we use our waste (feces, urine) as fertilizer for growing plants?*
- *What will we do with all the garbage we produce in these places in space?*
- *Don't plants help with recycling oxygen and carbon dioxide between the air and us?*
- *Do we recycle metal by melting it?*
- *How can we recycle food? Won't that take too long?*
- *Is special equipment required to recycle stuff?*
- *Are some materials more recyclable than others?*
- *Are there better options for some stuff than recycling it?*
- *Can we build everything we need out of recyclable materials?*
- *Do you always need heat, fuel, or fire to recycle things?*
- *What are the steps you need to do to something to recycle it (or parts of it) into a new object?*

The following list represents the types of questions you should expect to see on these yellow sticky notes related to making resources:

- Why are so many of the things people need made of C, H, and O?
- What atoms make up plastic?
- What reactants are available on other objects to make substances people need?
- Are there types of substances we can make that we have not discovered yet?
- How could people use materials from other objects to make needed substances?
- Is there some rule for which atoms will react together?
- What causes a chemical reaction to happen with some things and not others?
- How can we make oxygen out of carbon dioxide?
- Can we make water?

What to do: Some students may list specific substances (e.g., glucose, water, copper), while others may list classes of materials (e.g., metals, food, ceramics). Some of the latter may include mixtures or composites. All of these are evidence of students considering that there are different types of matter that will be needed. If students list types of designed structures only (e.g., shelter, vehicles, space suits), leave a sticky-note question that asks, *What type(s) of substances/materials are these made of?* Keep in mind that this is a good pre-assessment of students' engineering thinking. So, any feedback you provide at this point should simply encourage engineering thinking. Avoid "correcting" students' answers during anchoring phenomenon lessons so that students are encouraged to enter the new unit with whatever assets they bring.

Lesson 2: Teacher Reference 1

Station Investigation Setup

The table below outlines the print and physical materials that each station requires. Below the table is station-specific setup information. To accommodate larger classes, it is recommended that you build duplicates of Stations 1, 3, 4 and 5 so that students can spread out around the lab and access all the materials at each station without the need to share with other groups.



Safety Notes:

- Wear sanitized indirectly vented chemical splash goggles, nitrile gloves and non-latex apron during the setup, hands-on, and takedown segments of the activities.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
- Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
- Hand sanitizer wipes must be provided for participant use at the completion of the activities.
- Spill control containers for overflow of products produced.
- Follow procedures set up by the instructor for disposal of materials.
- Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Keep flammable liquids (e.g. acetone, alcohol) away from active flames or sparks to prevent fire.
- Use caution when working with a hot kettle! Can burn skin on direct contact.
- Use caution when working with glassware or plasticware - can break and cut/puncture skin.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
- Given there is use of flammable liquids, the instructional space must have appropriate ventilation. The ventilation system in the instructional space must meet the needs relative to removing the flammable vapors produced. Use of a fume hood is also a viable alternative.
- Direct supervision will be required during all aspects of these activities.

Station #	Station Name	Description	Required Materials (in addition to <i>Water's Properties Investigations</i>)
1	Stickiness to Itself	Students carry out the drops-on-a-penny investigation. Students read about cohesion and surface tension.	• <i>Water Is Sticky</i> • paper towels • soapy water soak bin • ruler • 4 250-mL beakers, 1 of each containing: water, acetone, rubbing alcohol, vegetable oil • 4 droppers or pipettes labeled with corresponding liquid • 12 clean pennies per group • indirectly vented chemical splash goggles, nitrile gloves and non-latex apron

2	Interactions with Light	Students read about water's interactions with light and how this explains differences in zones of living things in the ocean.	• <i>Ocean, Light, & Life</i>
3	Stickiness to Other Stuff	Students complete an investigation using capillary tubes. Students read about adhesion and capillary action.	• <i>Liquids Are Sticky</i> • paper towels • ruler • 4 glass capillary tubes in a transfer cup per group • 4 250-mL beakers, 1 of each containing: water, acetone, rubbing alcohol, vegetable oil. • sharps disposal container • indirectly vented chemical splash goggles, nitrile gloves and non-latex apron
4	Dissolving Salt	Students carry out an investigation to see which liquids are able to dissolve salt.	• permanent marker • digital scale • soapy water soak bin • 4 plastic test tubes with caps per group, each containing 5 g table salt (NaCl) • 4 250-mL beakers), 1 of each containing: water, acetone, rubbing alcohol, vegetable oil • 4 droppers or pipettes labeled with corresponding liquid • indirectly vented chemical splash goggles, nitrile gloves and non-latex apron
5	Energy Transfer / Storage	Students measure temperature differences of substances to develop ideas about heat capacity. Students examine specific heat values for common materials.	• <i>Energy Transfer/Storage</i> • 3 sets of submersion weights (each with 18" fishing line with 5 steel nuts tied on one end and 1 steel nut tied on the other) • 3 binder clips (1" wide) • electric tea kettle, $\frac{3}{4}$ filled with water • infrared thermometer • 3 labeled styrofoam cups, each containing 50 mL of a different liquid: water, rubbing alcohol, and vegetable oil • 3 styrofoam cup lids • soapy water soak bin • indirectly vented chemical splash goggles, nitrile gloves and non-latex apron
6	Temperature Data	Students identify patterns or trends in temperature data from different cities in the United States.	• <i>Seasonal City Temperatures</i> • Alternate: If using CODAP, students will need a computer with internet access and https://www.openscienced.org/simulation/temp-data/

Station-Specific Setup Information:

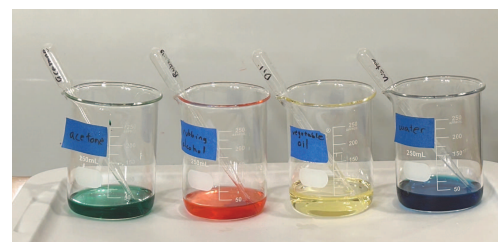
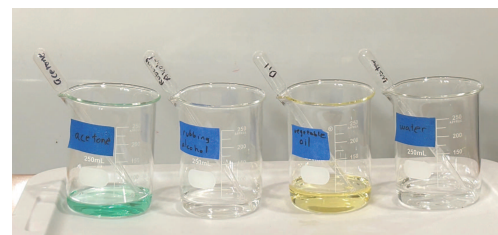
Station 1: Stickiness to Itself

- Label each beaker with its corresponding liquid (water, acetone, rubbing alcohol, vegetable oil). You should need a total of about 50 mL of each liquid for 6 class periods.
- Label a dropper or pipette for each liquid and place it in the corresponding beaker.
- Ensure you provide each group with relatively shiny, clean pennies. Avoid reusing pennies from prior groups unless you wash, rinse, and dry them before the next class. Residual liquids and grime on the penny surface can skew results.
- Prepare a soapy water soak bin for students to place the used pennies. This will provide a prewash of the pennies to make cleaning and reusing them between class periods/years easier.



Station 3: Stickiness to Other Stuff

- Place 4 glass capillary tubes in a single transfer cup for every group that will visit this station across all of your class periods. The transfer cup provides a safe way to distribute these fragile items to and from stations. You can recycle the cups, but make sure that students dispose of all used glass capillary tubes in a sharps disposal container in your room.
- Label each beaker and add 25 mL of the corresponding liquid: water, acetone, rubbing alcohol, vegetable oil. The 250-mL-size beaker is recommended for this lab, as it will allow students to lean the capillary tube against the spout of the beaker while they wait for the liquid to move up the tube.
- Add two drops of the following food coloring to each liquid:
 - Add green to acetone.
 - Add red to rubbing alcohol.
 - Add blue to water.
- Do not add food coloring to the vegetable oil as it will not mix in; its natural yellow tint should suffice.



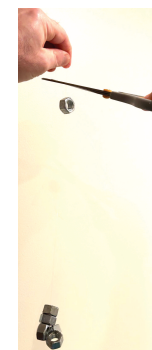
Station 4: Dissolving Salt

- Use a funnel to transfer 5 g of table salt (NaCl) into each of 4 plastic test tubes for every group that will visit this station across all of your class periods. Cap each test tube.
- Label each beaker with its corresponding liquid (water, acetone, rubbing alcohol, vegetable oil). Each group that visits this station will use about 10 mL of each liquid, so fill each beaker accordingly, for the number of classes you have.
- Label a dropper or pipette for each liquid and place it in the corresponding beaker.



Station 5: Energy Transfer/ Storage

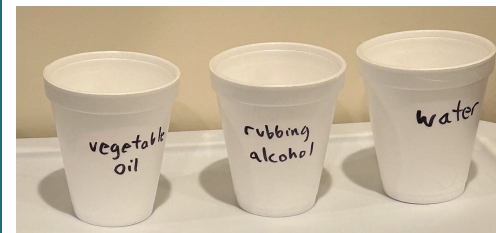
- Make 6 sets of submersion weights for each station to reuse across class periods. Three sets will be in use at the lab station until the end of the period, when students will exchange their cleaned sets with you for 3 new sets of submersion weights to set up the station for the next class. The directions for making one set of these submersion weights is as follows:
 - Cut 18" of fishing line.
 - Thread one end of the fishing line through 5 steel nuts and double-knot it to secure them together.
 - Thread the other end through 1 steel nut and double-knot it so that the distance between this nut and the other 5 is 1 foot.
 - Trim off the excess fishing line.



- Label 3 8-oz styrofoam cups and add 50 mL of the corresponding liquid: water, rubbing alcohol, vegetable oil. Make a set of these and three lids for each station. These can be reused across class periods.



Safety: Do not use acetone at all for this station (Station 5) as it dissolves styrofoam.



- Set up an electric tea kettle $\frac{3}{4}$ filled with water at each station.
- Hang the group of 5 steel nuts on each set of submersion weights in the water so that they are fully submerged but not touching the metal plate at the bottom of the kettle. Binder clip the fishing line to the edge of the kettle at this position and drape the single steel nut over the outside edge of the kettle.
 - *Note: This will ensure that the steel nuts heat relatively evenly from water-bath conduction alone, and will allow students to grab the single steel nut to remove each set of weights from the water.*
- Leave an infrared thermometer at the station.
- Prepare a soapy water soak bin for students to place the used submersion weights. This will provide a prewash of the weights to make cleaning and reusing them between class periods/years easier.



Station Investigation Directions

Station 1: Stickiness to Itself

Materials at this station:	
• <i>Water Is Sticky</i> • paper towels • soapy water soak bin • ruler	• 12 clean pennies per group • 4 250-mL beakers, 1 of each containing: water, acetone, rubbing alcohol, vegetable oil • 4 droppers or pipettes labeled with corresponding liquid • indirectly vented chemical splash goggles, nitrile gloves and non-latex apron

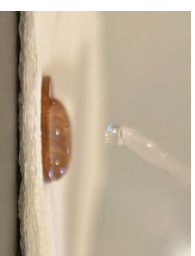


Safety:

- Wear sanitized indirectly vented chemical splash goggles, nitrile gloves and non-latex apron during the setup, hands-on, and takedown segments of the activities.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
- Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
- Hand sanitizer wipes must be provided for participant use at the completion of the activities.
- Spill control containers for overflow of products produced.
- Follow procedures set up by the instructor for disposal of materials.
- Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Keep flammable liquids (e.g. acetone, alcohol) away from active flames or sparks to prevent fire.
- Use caution when working with a hot kettle! Can burn skin on direct contact.
- Use caution when working with glassware or plasticware - can break and cut/puncture skin.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
- Given there is use of flammable liquids, the instructional space must have appropriate ventilation. The ventilation system in the instructional space must meet the needs relative to removing the flammable vapors produced. Use of a fume hood is also a viable alternative.
- Direct supervision will be required during all aspects of these activities.

Procedure:

1. Arrange clean pennies several inches apart in three rows and four columns on top of a paper towel. Label the top of each penny column on the paper towel with the name of the liquid you will add to that column -- acetone, rubbing alcohol, vegetable oil, and water.
2. Use the dropper to slowly place 1 drop at a time of the first liquid onto the first penny in the corresponding column, from about 1 cm above the penny. Count how many drops you are able to place on the penny before the "bubble" bursts and the liquid runs onto the paper towel. Record the number of drops in your data table for Trial 1.
3. Repeat the previous step two times, using the same liquid for the second penny (Trial 2) and for the third penny (Trial 3). Return the dropper to the correct beaker.



4. Repeat Steps 2 and 3 for the other liquids.

5. Calculate the average (mean) number of drops for each liquid.

6. Cleanup:

- a. Place the used pennies in the soapy water bin.
- b. Make sure all droppers are in their corresponding beakers.
- c. Use another paper towel to wipe down the table.
- d. Throw away all used paper towels on your way to the next station.
- e. Get 12 new clean pennies from your teacher and leave them at the station for the next group of students.

7. Read *Water Is Sticky*.

8. Discuss and answer the questions for **Station 1** on *Water's Properties Investigations* with your group.

Station 2: Interactions with Light

Materials at this station:

Ocean, Light, & Life

Procedure:

1. Read *Ocean, Light, & Life*.
2. Discuss and answer the questions for **Station 2** on *Water's Properties Investigations* with your group.

Station 3: Stickiness to Other Stuff

Materials at this station:

- | | |
|--|--|
| <ul style="list-style-type: none">• <i>Liquids Are Sticky</i>• paper towels• ruler | <ul style="list-style-type: none">• 4 glass capillary tubes in a transfer cup per group• 4 250-mL beakers, 1 of each containing: water, acetone, rubbing alcohol, vegetable oil• sharps disposal container• indirectly vented chemical splash goggles, nitrile gloves and non-latex apron |
|--|--|

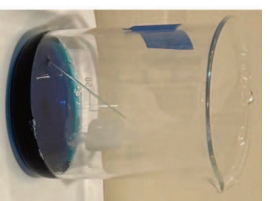
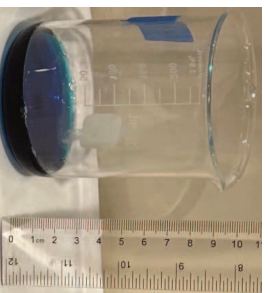


Safety:

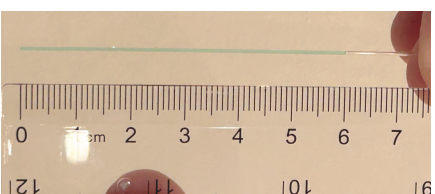
- Wear sanitized indirectly vented chemical splash goggles, nitrile gloves and non-latex apron during the setup, hands-on, and takedown segments of the activities.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
- Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
- Hand sanitizer wipes must be provided for participant use at the completion of the activities.
- Spill control containers for overflow of products produced.
- Follow procedures set up by the instructor for disposal of materials.
- Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Keep flammable liquids (e.g. acetone, alcohol) away from active flames or sparks to prevent fire.
- Use caution when working with a hot kettle! Can burn skin on direct contact.
- Use caution when working with glassware or plasticware – can break and cut/puncture skin.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
- Given there is use of flammable liquids, the instructional space must have appropriate ventilation. The ventilation system in the instructional space must meet the needs relative to removing the flammable vapors produced. Use of a fume hood is also a viable alternative.
- Direct supervision will be required during all aspects of these activities.

Procedure:

1. A drop of food coloring has been added to three of the liquids to make them easier to measure. Place a ruler along the side of each beaker to measure and record the height of the liquid in it.
2. Place a clean glass capillary tube into each liquid, so that the tube rests at an angle from the bottom edge of the beaker to the spout on the top opposite edge. You will see the liquid move up into the capillary tube. Wait 30 seconds.
3. Tilt the first glass capillary tube upright so that it is vertical. Wait 10 seconds.
4. Lift the capillary tube out of the beaker, keeping it vertical. Hold a ruler next to the capillary tube to measure and record the height of the liquid in it.
5. Determine how high the liquid was pulled up the capillary tube by calculating the difference of the two heights you measured in Steps 1 and 4.



6. Place the used capillary tubes in the transfer cup to prepare to dispose of them.
7. Repeat Steps 3-6 for the remaining three liquids.
8. Cleanup:
 - a. Using the transfer cup to transport them, dispose of the used capillary tubes in the appropriate sharps container.
 - b. Return the transfer cup to your teacher.
9. Read *Liquids Are Sticky*.
10. Discuss and answer the questions for **Station 3** on *Water's Properties Investigations* with your group.



Station 4: Dissolving Salt

Materials at this station:

- | | |
|---|---|
| <ul style="list-style-type: none">• permanent marker• ruler• soapy water soak bin | <ul style="list-style-type: none">• 4 plastic test tubes with caps per group, each containing 5 g table salt (NaCl)• 4 250-mL beakers, 1 of each containing: water, acetone, rubbing alcohol, vegetable oil• 4 droppers or pipettes labeled with corresponding liquid• indirectly vented chemical splash goggles, nitrile gloves and non-latex apron |
|---|---|



Safety:

- Wear sanitized indirectly vented chemical splash goggles, nitrile gloves and non-latex apron during the setup, hands-on, and takedown segments of the activities.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
- Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
- Hand sanitizer wipes must be provided for participant use at the completion of the activities.
- Spill control containers for overflow of products produced.
- Follow procedures set up by the instructor for disposal of materials.
- Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Keep flammable liquids (e.g. acetone, alcohol) away from active flames or sparks to prevent fire.
- Use caution when working with a hot kettle! Can burn skin on direct contact.
- Use caution when working with glassware or plasticware - can break and cut/puncture skin.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
- Given there is use of flammable liquids, the instructional space must have appropriate ventilation. The ventilation system in the instructional space must meet the needs relative to removing the flammable vapors produced. Use of a fume hood is also a viable alternative.
- Direct supervision will be required during all aspects of these activities.

Procedure:

1. Use the permanent marker to label each test tube for a different liquid – water, acetone, rubbing alcohol, and vegetable oil.
2. Use the corresponding dropper to fill each test tube with liquid to 2 cm below the top of the tube.
3. Cap each test tube. Keep your thumb over the cap as you shake each tube for 30 seconds.
4. Hold each test tube up to a ceiling light to compare how much, if any, solid salt remains visible in the liquid to get a relative measure of how much salt dissolved in each liquid. Record your observations.
5. Cleanup:
 - a. Empty the solution in each test tube into the sink.
 - b. Place the used test tubes and caps in the soapy water bin.
6. Discuss and answer the questions for **Station 4** on *Water's Properties Investigations* with your group.

Station 5: Energy Transfer / Storage

Materials at this station:

• <i>Energy Transfer/Storage</i> • 3 binder clips • 3 styrofoam cup lids • infrared thermometer • soapy water soak bin	• 3 labeled styrofoam cups, each containing 50 ml of a different liquid water, rubbing alcohol, and vegetable oil • 3 sets of submersion weights (each with 18" fishing line with 5 steel nuts tied on one end and 1 steel nut tied on the other) • electric tea kettle, $\frac{3}{4}$ filled with water • indirectly vented chemical splash goggles, nitrile gloves and non-latex apron
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Safety:

- Wear sanitized indirectly vented chemical splash goggles, nitrile gloves and non-latex apron during the setup, hands-on, and takedown segments of the activities.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
- Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
- Hand sanitizer wipes must be provided for participant use at the completion of the activities.
- Spill control containers for overflow of products produced.
- Follow procedures set up by the instructor for disposal of materials.
- Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Keep flammable liquids (e.g. acetone, alcohol) away from active flames or sparks to prevent fire.
- Use caution when working with a hot kettle! Can burn skin on direct contact.
- Use caution when working with glassware or plasticware - can break and cut/puncture skin.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
- Given there is use of flammable liquids, the instructional space must have appropriate ventilation. The ventilation system in the instructional space must meet the needs relative to removing the flammable vapors produced. Use of a fume hood is also a viable alternative.
- Direct supervision will be required during all aspects of these activities.

Procedure:

1. Check the electric kettle to make sure that there are 3 sets of submersion weights in the water. Each set should have a group of 5 steel nuts fully submerged in the water but not touching the metal plate at the bottom of the kettle. The binder clip on the edge of the kettle can be adjusted to hold the weights in the correct position. The other end of the fishing line should have 1 steel nut hanging over the outside edge of the kettle. Make note of this setup, as you will make a similar setup at the end of your investigation so that it is ready for the next group of students.



2. Check to see that the electric kettle is turned on. If it is not, turn it on now. Leave the weights in the heated water until the water boils, and then turn the kettle off.
3. While you are waiting for the water in the kettle to heat up, measure the temperature of each of the three liquids in the styrofoam cups by pointing the infrared thermometer toward the center of the bottom of the cup and pressing the trigger. Record these initial temperatures.
4. Pick up a submersion weight by the end with the single steel nut, lift the other end with the 5 nuts out of the heated water, and lower them into one of the liquids, leaving the single steel nut outside the cup. Place a lid over the cup.



5. Repeat the previous step for the other two liquids.
6. Wait 2 minutes. Then gently swirl each cup for 10 seconds.
7. Remove the lid from the first cup you covered. Measure the temperature of the liquid by pointing the thermometer toward the center of the bottom of the cup and pressing the trigger. Record the new temperature for that liquid.
8. Repeat the previous step for the other two liquids.
9. Calculate and record the temperature increase for each liquid.
10. Cleanup:
 - a. Carry each cup to the soapy water bin first. Lift the submersion weights out of each liquid and place them completely in the soapy water.
 - b. Remove the submersion weights from the soapy water and rinse them under running water.
 - c. Empty the used liquids into the sink.
 - d. Return the used styrofoam cups to your teacher.



11. Exchange your cleaned submersion weights with 3 new sets of submersion weights from your teacher and create the same setup with the electric kettle that you found in Step 1, for the next group of students.
12. Read *Energy Transfer/Storage*.
13. Discuss and answer the questions for **Station 5** on *Water's Properties Investigations* with your group.

Station 6: Temperature Data

Materials at this station:

Seasonal City Temperatures

Procedure:

1. Examine *Seasonal City Temperatures* on your own for a minute or so.
2. Look for patterns or trends in the coastal locations and record them in your chart.
3. Look for patterns or trends in the inland locations and record them in your chart.
4. Share the patterns you have observed with your group.
5. Discuss and answer the questions for **Station 6** on *Water's Properties Investigations* with your group.

Station 6 Alternate: Temperature Data

Materials at this station:

- computer with internet access
- <https://www.openscienced.org/simulation/temp-data/>

Procedure:

1. Examine <https://www.openscienced.org/simulation/temp-data/> on your own for a minute or so.
2. Using the graph function, drag attributes from the gray table headers to the graph to help you complete Steps 3 and 4. See <https://youtu.be/bZsmczFH-bI?si=rMbBs7XOl4USlpJG> for assistance.
3. Look for patterns or trends in the coastal locations and record them in your chart.
4. Look for patterns or trends in the inland locations and record them in your chart.
5. Share the patterns you have observed with your group.
6. Discuss and answer the questions for **Station 6** on *Water's Properties Investigations* with your group.

Lesson 2: Answer Key

Progress Tracker Key

The Progress Tracker is a formative and self-assessment tool that is designed to help students keep track of important discoveries that the class makes while investigating the phenomena, and to help them figure out how to prioritize and use those discoveries to focus on explaining the phenomenon they're working on. The Progress Tracker is a metacognitive tool requiring students to 1) look back at what we have done, 2) make decisions about where we are going next, and 3) consider what we don't know. Metacognitive strategies like these support students in deepening learning and building agency (Bransford, Brown & Cocking, 2000; Zohar & Barzilai, 2013). Students will refer back to the tracker regularly to revise or build on their models, explanations, and/or designs for their current thinking about the phenomenon. Further, students, and the class as a whole, will use the tracker as a way to think with others about what is important in their models, explanations, and/or designs.

It is important to note that this tool is designed to be a dynamic resource that students can use to progressively make sense of their ideas. OpenSciEd suggests that teachers use this tool to support progressive sensemaking throughout the unit, and avoid using this tool as a simple note-taking activity. In the teacher guidance for each lesson that uses Progress Trackers, suggestions are given for supporting students in using the tracker to identify and use discoveries to continually revisit, revise, and prioritize ideas. In order to avoid Progress Tracker fatigue, teachers should not have students use the tracker every day in the same way, but rather, use it to further the sensemaking when applicable.

The structure of the Progress Tracker will vary across units to address different goals for student reflection, but here are some common features you will see across units:

- The Progress Tracker is a handout that students can put in their binders.
- The Progress Tracker organizes entries by lesson. Some trackers allow for multiple entries per lesson.
- Every Progress Tracker includes a column that asks some form of the question, "What have we figured out?"
- The Progress Tracker is not intended as something to be graded -- it is a record of changing student thinking over the course of a unit, and should be a place where students feel comfortable reflecting on what they do not know or do not yet understand.
- Progress Tracker entries are either reflective of individual thinking in the moment, or co-constructed by the class. Lesson questions and science ideas are never filled in for students.

Please note that while this Progress Tracker key is written in text, you should look for student ideas in writing, images, models, and other formats chosen by your students that they think best explain their thinking. Additionally, these ideas will vary based on your students' ideas about the phenomenon in each lesson. This key is just a guide to help show some possible student ideas seen in the field test of this unit.

**Note: All sample Progress Tracker entries contain a "Source of evidence" column, but this is not a requirement. We have provided this information so that if students have incomplete, or are struggling to complete, Progress Tracker entries, you can use the examples listed to support these struggling students. Point students back to the sample "Sources of evidence" and incorporate any assessment guidance found in that lesson's Teacher Guide.*

Unit Driving Question(s)

Lesson 1: *How can we find, make, and recycle the substances we need to live and work beyond Earth?*
Updated in Lesson 9: *How can we find, make, and recycle the substances we need to live on and beyond Earth?*

*Note: These questions are generated by the class and will vary based on your classroom.

Lesson 2

Question	Source of evidence
How does water support life and chemical reactions?	• Station investigation data • “Water’s Importance for Life and Chemical Reactions” poster
What I figured out in words and pictures	
Water has several properties which help to support life: high specific heat, transparency to light, ability to dissolve substances, stickiness to itself (cohesion) and other materials (adhesion). The ability of water to dissolve substances also explains its importance for chemical reactions.	

Lesson 4

Question	Source of evidence
How could the structures of liquids explain their interactions with surface materials?	• Erosion Investigation data • Mars Landforms reading • Molecular Structures
What I figured out in words and pictures	
Water is a polar molecule, which means that the ends of the water molecule have different charges. This lets parts of the water molecule become attracted to particles in the land around the water. As the water moves downstream, it is able to pull the particle away with it, causing erosion. Because positive sides of one water molecule attract to negative sides of other molecules, the molecules line up when water freezes, which causes expansion and frost heaving.	

Lesson 5

Question	Source of evidence
How can we tell what is in the atmosphere (and just below the surface) of objects in space?	• Transmission spectra of reference gasses and the atmospheres of objects in space • Space Spectroscopy Studies reading
What I figured out in words and pictures	
We can figure out what substances are in an object’s atmosphere, surface, or subsurface based on the way the substance interacts with light (spectroscopy). The atmospheres of Mars and Venus contain a lot of carbon dioxide but not much water. Researchers have used spectroscopy in different ways to identify water in the plumes of Enceladus, multiple elements on the Moon (including some water), water ice at the poles of Mars, and oceans of hydrogen and molecules that might indicate biologic activity on an exoplanet.	

Lesson 6

Question	Source of evidence
How are elements different from each other? How do these elements combine to form the resources we need?	- Compound Representations reference - Element Cards
What I figured out in words and pictures	
We can organize elements using their atomic number and number of bonds. Each element forms a specific number of bonds when it combines with other elements, which is a periodic pattern we can use to make predictions about which elements combine best with others. 	

Lesson 9

Question	Source of evidence
How can the ideas we developed be applied to making a possible substitute for another substance?	- Electronegativity data - Polarity visualizations - Properties
What I figured out in words and pictures	
Differences in some properties of substances can be explained in terms of differences in the polarity of the molecules. The polarity of a molecule can be determined by comparing the relative polarities of bonds within it. The relative polarity of a bond can be determined from the difference in the electronegativities of the atoms that make up the bond.	

Lesson 12

Question	Source of evidence
Which location(s) in the solar system has the elements we need and what relative amount is required to make any substance?	- NASA website information about elements on different objects in the solar system - Mars rover paper about elements present in rocks and soil - Research paper about making sulfur concrete on Mars
What I figured out in words and pictures	

Since mass is conserved during a chemical reaction, chemical reactions must be balanced to have equal numbers of each element in the reactants and products. Coefficients are numbers in front of a chemical formula that show the amount of each molecule needed to balance the equation. Basic math can be used to determine the coefficients. Mars has most of the elements required to make the substances we need. If researchers know what elements are at a destination, they can explore how to use them to make substances.

Lesson 14

Question	Source of evidence
What are some more sustainable approaches we are developing to help us make the things we need off of Earth and on it?	• CO₂ Plastics/Bioplastics reading • 3-D Printing/Geopolymer Concrete reading
What I figured out in words and pictures	
We could engineer materials more sustainably on Earth that would be more likely to be workable off of Earth. There are a lot of alternatives to plastics and building materials that we could use in space or on Earth. Even new versions of materials need some similar properties/functions and particle-level structures. Using fewer materials is always better.	

References

Bransford, J., Brown, A., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience, and school* (Expanded ed.). National Academy Press.

Zohar, A., & Barzilai, S. (2013). A review of research on metacognition in science education: current and future directions. *Studies in Science Education*, 49(2), 121–169. <https://doi.org/10.1080/O3057267.2013.847261>

Erosion Investigation Guidance

Erosion Investigation Setup

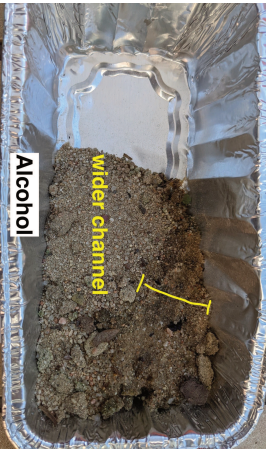
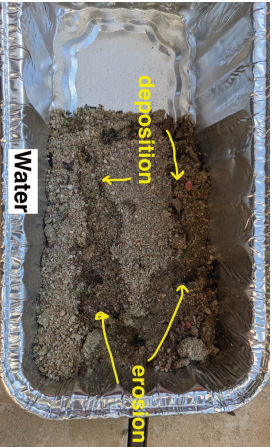
Have the following materials available for each group:

- approximately 115 g of very dry sand (or other Mars-like material)
- 2 small pans or trays
- 2 straws or pipettes for releasing liquids
- 2 paper cups for two of the following:
 - 50 mL water
 - 50 mL vegetable oil
 - 50 mL isopropyl alcohol
 - 50 mL acetone
- 2 index cards
- indirectly vented chemical splash goggles, nitrile gloves and non-latex apron for each student

Erosion Investigation Suggested Procedure

1. Distribute materials.
2. To control for confounding variables, we will have to (procedures may vary, depending on what students decide):
 - a. build similar “landforms” in each tray in the class;
 - b. use a straw to consistently drip (and not “blast”) the liquid, since the force needs to be held constant (see video in slides);
 - c. use equal amounts of liquid in every group;
 - d. mark our straws so that we have equal amounts of liquid in each drop;
 - e. release the liquid down the same place in each tray.
3. Place sand in the trays in desired shapes. (Landforms will vary; support students in controlling steepness.)
4. Place the straw in the designated liquid the group is testing.
5. Place a finger on one end of the straw to seal it, holding the liquid in the straw.
6. Position the straw over the “landforms” of sand.
7. Release the liquid by removing your finger from the end of the straw.
8. Repeat until the designated amount of liquid has been allowed to run down the sand.
9. Observe the patterns formed by the liquid’s interactions with the sand.

Anticipated Results

	Anticipated Results	
Oil		
Isopropyl alcohol		

**Safety**

- Wear sanitized indirectly vented chemical splash goggles, nitrile gloves and non-latex apron during the setup, hands-on, and takedown segments of the activities.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
- Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
- Hand sanitizer wipes must be provided for participant use at the completion of the activities.
- Clean up any spills immediately using spill control containers for overflow of products produced. Oil spills require special attention.
- Do not ingest any of the liquids used in the lab.
- Do not put your face over an open alcohol or acetone container. Isopropyl alcohol and acetone are harmful if ingested and can irritate skin.
- Do not put your mouth on the straws. Never consume any liquid in the lab for any reason.
- Follow procedures set up by the instructor for disposal of materials.
- Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Keep flammable liquids (Isopropyl alcohol and acetone) away from active flames or sparks to prevent fire.
- Given there is use of flammable liquids, the instructional space must have appropriate ventilation. The ventilation system in the instructional space must meet the needs relative to removing the flammable vapors produced. Use of a fume hood is also a viable alternative.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.

- Direct supervision will be required during all aspects of these activities.

Lesson 4: Teacher Reference 2

Electronic Exit Tickets

Why student Electronic Exit Tickets?

Student Electronic Exit Tickets are a great tool for collecting data from students to inform instruction. Having students take these exit tickets electronically helps to quickly aggregate data so that students can analyze results to guide and inform the direction of their future work.

How to use student Electronic Exit Tickets

1. Select the link for the survey that corresponds with the lesson you are teaching. In *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)* there are two Electronic Exit Ticket assessments, in Lessons 4 and 12. Additionally, there is an electronic option for a Community Agreements reflection in Lesson 9.

- Lesson 4: https://docs.google.com/forms/d/16uO5Lw_DiVaXHLQ6lhQY-O2Dv_VEISDC-RIRnV422-s/copy.
- Lesson 12: <https://docs.google.com/forms/d/1Tng1U2WcLUUecj-yEWWwHgblGNsRcJBrIECNEwJBN88/copy>.
- Spanish Lesson 4: https://docs.google.com/forms/d/18gkCIT_9pR3DtB-iVHgOTSAvsI2yo-yv9-QzvmrQ/copy.
- Spanish Lesson 12: <https://docs.google.com/forms/d/1BhEmti3EPCXV1bEjYrIwmMTW7QZeI2XIEjYNOQfidk/copy>.

2. When you select the link, you will be asked to make a copy in your own Google Drive.

Copy document

Would you like to make a copy of **Family and Friends MRE Survey?**

Make a copy



3. The student survey will open in your own Google Drive.

Family and Friends MRE Survey ☆

Questions Responses

Family and Friends MRE Survey

Send

4. Select the “Send” button in the upper-right corner to get a link to give to students.

Family and Friends MRE Survey ☆

Questions Responses

Family and Friends MRE Survey

Send

5. In the “Send via” panel, select the middle icon if you wish to send the survey via a link.

Send form

☐ Collect email addresses

Send via



6. Copy the link provided 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.

Link

<https://forms.gle/9YFjGS5FQhY3P7V/R6>



Shorten URL

Press Ctrl+C to copy

Cancel

Copy

7. Once students submit responses these will appear in your Google Form under "Responses". Google will automatically provide you with some visualizations of the responses.

The screenshot shows the 'Responses' tab of a Google Form. At the top, it says '0 responses'. Below this, there is a toggle switch labeled 'Accepting responses' which is currently turned on. To the right of the toggle is a green plus icon and a three-dot menu icon. At the bottom of the tab, it says 'Waiting for responses'.

8. If you want to view the data in a spreadsheet format, click the sheet icon to create a Google Sheet. It will automatically populate when students respond to the survey.

9. For each survey, you will need to repeat the process above. You can choose to make a copy of the survey for each of your classes, or use one survey for all of your classes.

Exit Ticket Key

4.B Observe patterns at multiple scales to support movement between multiple types of models that use molecular and submolecular structures that explain the properties of matter like water. (SEP: 2.4; DCI: PS1.A.3; CCC: 1.1, 6.2)

Where these elements are addressed in this assessment	2.4 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.	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.	6.2 Structure and Function The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of their various materials.	1.1 Patterns Mathematical representations are needed to identify some patterns.
Q1			X	
Q2	X	X		
Q3	X		X	
Q4	X			X
Q5		X	X	

Question 1

Which statement best explains the relationship between polarity and cohesion/adhesion observed in the Erosion Investigation?

- Polar molecules stick to each other/other objects better because the partial charges create attractions between particles.
- Nonpolar molecules stick to each other/other objects better because the neutral charges create attractions between particles.
- Polar molecules do not stick to each other/other objects well because the partial charges create repulsions between particles.
- Nonpolar molecules do not stick to each other/other objects well because the neutral charges create repulsions between particles.

Correct response: Polar molecules stick to each other/other objects better because the partial charges create attractions between particles.

Rationale for distractors:

Nonpolar molecules stick to each other/other objects better because the neutral charges create attractions between particles - is what students might select if they do not know that polar molecules have partial charges or that partial charges create attractions. Polar molecules do not stick to each other/other objects well because the partial charges create repulsions between particles - is what students might select if they do not know that it is polar molecules that are more likely to stick together. Nonpolar molecules do not stick to each other/other objects well because the neutral charges create repulsions between particles - is what students might select if they have the misconception that neutral charges result in repulsions.

What to do:

Ensure students read the answer choices carefully. Encourage them to think about which substances showed the most cohesion and adhesion in the Water's Properties Investigation, and then encourage students to consider what they learned about in this lesson.

Question 2

How did using multiple models of atomic and molecular structure help you make sense of **what is happening at the particle level to cause the interactions** between liquids and surface materials?

What to look for in response:

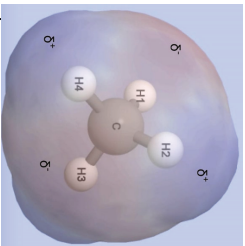
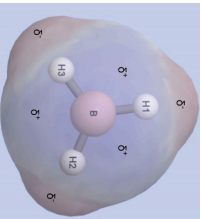
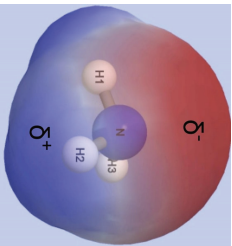
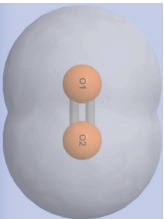
- Students refer to the presence of color coding or partial charges in molecular models as evidence of polarity.
- Students relate polarity to the interactions between liquids and surface materials.

What to do:

Encourage students to consider how the models help them determine **which molecules are more polar, and then to consider which liquids interacted more with surface materials.**

Question 3

Which substance do you think would be the most likely to **cause erosion or frost heaving**?

• CH₄		• BH₃	
• NH₃		• O₂	

Correct response: NH₃ is the most polar substance of the options provided.

Rationale for distractors:

CH₄ and BH₃ models indicate some partial charge, but less than NH₃.

O₂ is a nonpolar molecule with no partial charges shown.

What to do:

Encourage students to use the color coding and/or partial charges to draw conclusions about the polarity of the substances, and to use the polarity to reason about which substance could **cause the same effects** on landscapes that water does.

Question 4

What **patterns** from the investigation and molecular models you observed made you select that option?

What to look for in response:

- Students connect patterns in the Erosion Investigation data to patterns in polarity of the molecular models of liquids.
- Students compare patterns in polarity in the answer choices to the substances used in the Erosion Investigation.

What to do:

Encourage students to compare the **patterns** in polarity of the **molecular models** in the answer choices to the **molecular models** from the lesson.

Question 5

Multiple Science Domains: Where have you seen **different liquids behave (function)** unexpectedly, or where have you seen **liquids affect other materials**, that you can now better **explain with details** about their **structure**?

What to look for in response:

- Students identify a liquid other than one they investigated today, or identify a different interaction between a liquid and another material or substance.
- Students make claims about the structure or polarity of the liquid based on observed interactions or properties.

What to do:

Encourage students to consider whether their observed interaction suggests that the liquid is polar. Then, based on whether or not they think the liquid is polar, encourage them to make a claim about the liquid's molecular structure. The claims do not have to be so specific as to name elements, but should give some explanation of polarity or charges.

Question 6

Looking ahead: What are the limitations to our model for finding water via riverbeds? If there is not currently liquid water on Mars, where else in the planetary system might it be stored (consider all possible places)? What data might help us?

What to look for in response:

- Students propose anywhere else on Mars that water might be found.
- Students propose any type of data collection to find water.

What to do:

Accept all responses. Validating these responses engages students in activating **interest** in these issues, which can motivate future questions.

Question 7

Did you contribute an idea to class today? Did you feel that your idea was heard?

What to look for in response:

- Students select that they contributed and their idea was heard by a small group or the whole class.

What to do:

Depending on student responses, it may be beneficial to revisit the Community Agreements.

- If many students select that they did not share or that their idea was not heard, spend time revisiting the Community Agreements to ensure that students are using the agreements as they work together to make progress on figuring out science ideas.

Spectra Demonstration Setup

Preparing for the Light Spectra Demonstration

1. Gather materials. You will need:

1. A tabletop projector with an easily accessible lens about the size of the diffraction grating slide that can be connected to your computer. It is assumed that you will have access to a portable, tabletop projector somewhere in your school.
 2. Painter's tape
 3. A diffraction grating slide
 4. 4 50-mL microchemistry solution bottles (4" H x 1 3/8" W x 15/16" D) with caps
 5. 50-75 mL of each of the following aqueous solutions:
 - a. 1 M copper (II) chloride solution (sample A)
 - b. 0.1 M erbium chloride solution (sample B)
 - c. 0.1 M praseodymium chloride solution (sample C)
 6. Tap water
 7. A small box or book to block part of the light coming through the diffraction grating
2. Label the bottoms of the microchemistry solution bottles with a permanent marker with the substances listed in 5.a-c; label the remaining bottle 'water'.
 3. Transfer solutions 5.a-c to the corresponding labeled microchemistry solution bottles. Top off with tap water as needed to fill each bottle. Cap and invert each bottle a few times to mix. Fill the remaining bottle with tap water.
 4. Make any adjustments needed to make the classroom or lab as dark as possible. Be prepared to pull down shades or blinds, cover the door window with paper, etc.



Safety Notes

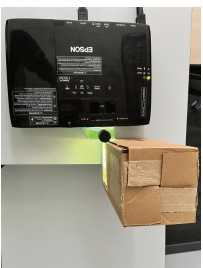
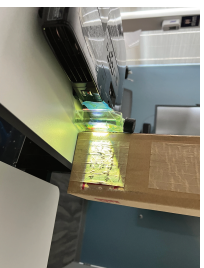
- Wear sanitized indirectly vented chemical splash goggles, nitrile gloves, and non-latex apron during the setup, hands-on, and takedown segments of the activities.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
- Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
- Hand sanitizer wipes must be provided for participant use at the completion of the activities.
- Clean up any spills immediately using spill control containers for overflow of products produced. Oil spills require special attention.
- Do not ingest any of the liquids used in the lab.
- Before starting the activity in a darkened instructional space, remove any fragile equipment/furniture, sharps, etc. in the activity walkway to prevent trip/fall hazards.
- Take care when taping and removing the diffraction grating slide to/from the tabletop projector to avoid burns as the light can get hot.
- Do not put your face over an open chemical container. Chemicals used are harmful if ingested and can irritate skin.
- Never consume any liquid in the lab for any reason.
- Follow procedures set up by the instructor for disposal of materials.
- Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
- Any electrical cords must be off the floor to prevent trip/fall hazards.
- Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
- Direct supervision will be required during all aspects of these activities.

Conducting the Light Spectra Demonstration

The steps listed below walk you through the demonstration and are also found in the body of the Teacher Guide. Please note that additional text from the Teacher Guide is not included here. *Italicized text is unique to this document for your reference.*

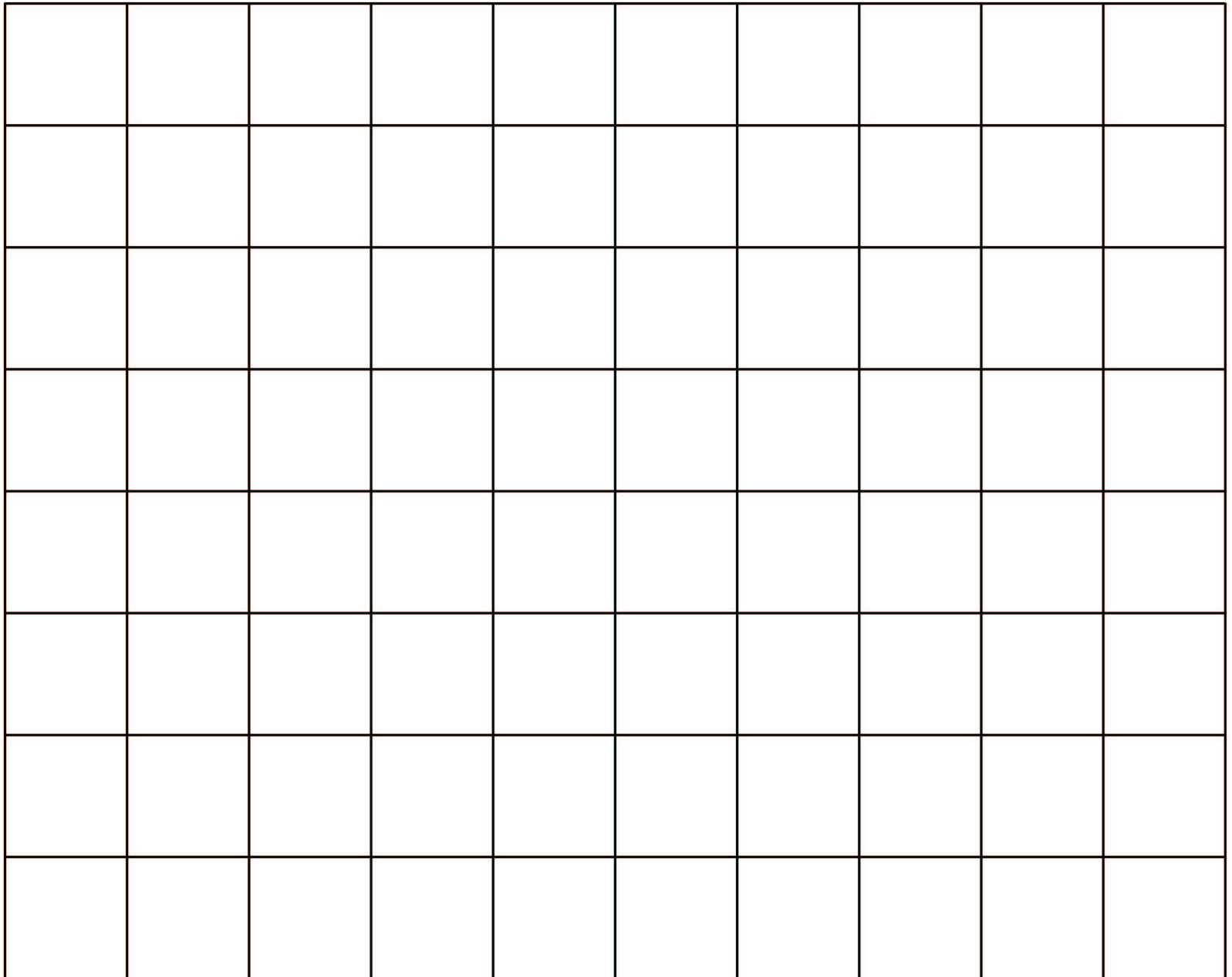
Darken the room and project the slide that follows slide H with your tabletop projector. Adjust the focus so the slit looks sharp. • <i>Be prepared to adjust the distance between the projector and a blank space on the wall to optimize the appearance of the projected spectrum.</i> • <i>A narrow slit is needed to obtain spectra through the diffraction grating. The optical physics of this process is beyond the scope of the unit, but if students wonder about the slit, you can tell them that the slit is needed to lower the intensity of the projected light.</i>	
Use painter's tape to attach the diffraction grating in front of the projector's lens. You should see the narrow slit directly in front of the projector with mirror image rainbows on either side. As mentioned above, the optical physics behind the production of mirror image first-order spectra on either side of the slit is beyond the scope of the unit.	
Place a book or box in front of part of the diffraction grating on the projector lens to block the slit and one of the rainbows. Blocking the bright slit helps the eye better see changes in the projected spectrum. <i>Take a photo of your projected spectrum to use as the background spectra in the Spectrum Observations handout.</i>	

Place the water control in front of the diffraction grating taped to the projector lens. Center it so that the light passes through the center of the sample. If the light passes through the edge of the bottle, the spectrum may look dark or distorted. You may have to reposition the book or box to block the slit and second spectrum.



Replace the water control with samples A-C, giving students 2 minutes per sample to record their observations.

Spectrograph Grid Paper



Analyze Atmospheric Spectra Key

- The images below show how students may annotate the spectra. For all atmospheric spectra, expect students to be confident that certain gasses are present or not present, as well as to have uncertainty about some gasses.

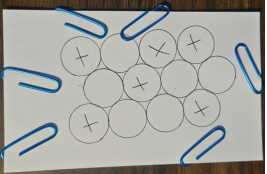
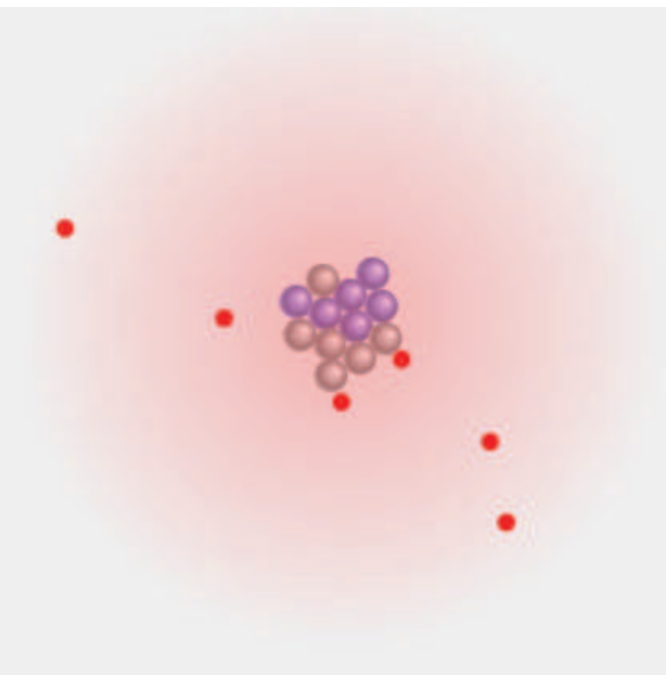
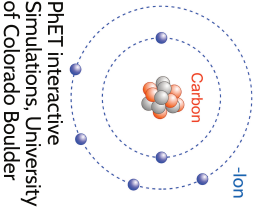


Scoring Guidance: The table below shows what gasses students should be able to identify in the object's atmosphere using the reference spectra provided in *Transmission Spectra Library*. Note that although other gasses may be present, evidence for them is not easy to identify because of their low concentration or because they are buried under bands from other substances.

Object	Reference Gasses							
	H ₂ O Water	CO ₂ Carbon dioxide	O ₃ Ozone	CO Carbon monoxide	NH ₃ Ammonia	N ₂ O Nitrous oxide	CH ₄ Methane	SO ₂ Sulfur dioxide
Earth	✓	✓	✓	X	X	✓	X	X
Mars	?	✓	X	✓	X	?	X	X
Venus	?	✓	?	✓	X	?	X	✓
Enceladus	?	✓	X	X	X	?	X	X

Compare Atomic Models Key

- Students identify that there are merits and limitations for all models. (SEP: 2.1)
- Students identify that **valence electrons determine the number of interactions (connections)** each element will have with **other elements**. (DCI: PS1.A.2)
- Students identify:
 - **patterns in electron configurations**, as shown in the electron shell model; and
 - **how they can be used to explain the numbers of bonds between elements**. (DCI: PS1.A.2; CCC: 1.1)

Atomic Model #1	Atomic Model #2	Atomic Model #3	Atomic Model #4
	 Images generated using Atom Builder (https://lab.concord.org/embeddable.html#interactives/interactions/atom-builder,json), developed at the Concord Consortium.	 PHET interactive Simulations, University of Colorado Boulder	
Model name: Paper-clip model	Model name: Electron cloud model	Model name: Electron shell model	Model name: Lewis dot model

1. What similarities do you see among the four atomic structure models?
Every model shows electrons.

2. What differences do you see among the four atomic structure models?

Models 1, 2, and 3 also show protons and neutrons.

Model 3 organizes electrons into different levels.

Model 4 only shows some electrons. This is equal to the number of bonds carbon forms.

3. Which of the four models might be more useful in helping us show and predict the numbers of bonds between atoms?
Why? (SEP: 2.1; DCI: PS1.A.2; CCC: 1.1)

Model 3, because it shows all of the parts of the atom and organizes the electrons into different levels.

Model 4, because I think it shows the electrons that are involved in forming bonds.

4. What are some limitations of the model that you chose in question 3? (SEP: 2.1)

Model 3 shows electrons staying in the same location, and models we've already looked at show electrons moving around.

Model 4 doesn't show all of the electrons found in an atom, so we might not have all of the information we need.

Scoring Guidance:

Use this handout as a pre-assessment of students' current understanding of the relationships between electrons and bonds formed between elements. This is the first opportunity for students to develop understanding about electron structure, so do not penalize students if they do not name *valence electrons*. Later in the lesson, students will fully develop DCI: PS1.A.2 and CCC: 1.1 portions of the lesson-level performance expectation 7.B: Determine which *atomic* model best illustrates patterns in *atomic structures* at the *atomic scale*, which can be used to predict interactions between *elements*. (SEP: 2.1; DCI: PS1.A.2; CCC: 1.1)

The goal here is to compare the different atomic models that students have had exposure to in the prior High School Chemistry *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)* and in the current unit. Students should identify both the merits and limitations of each of the four atomic models. (SEP: 2.1)

Lesson 9: Answer Key 1

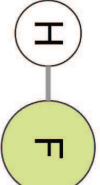
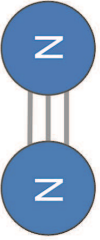
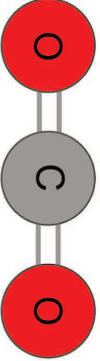
Modeling Polarity Key

This key breaks down how student self-assessment opportunities are built over the course of several slides toward developing an understanding of the Lesson 9 LLPE: **9.A** Use a variety of models and evidence (such as solubility and periodic trends in electronegativity and atomic radius) to a) describe the patterns and relationships between the parts of an atom and the bonds formed between atoms, b) predict polarity differences, and c) explain property differences based on the relative differences in the strength of forces between atoms and molecules. (SEP: 2.3; DCI: PS1.A.3, PS1.A.2; CCC: 1.1, 6.2)

Sample student responses are shown in purple.

Slides H-I

Part A:

	Hydrogen fluoride	Nitrogen gas	Carbon dioxide
Chemical formula	HF	N ₂	CO ₂
Molecular structure			
Electronegativity difference	1.78	0	0.89
Bond character: a) nonpolar covalent b) polar covalent c) ionic	b	a	b

What to look/listen for in the moment:

- Students use models showing molecular structure to predict polarity differences. (SEP: 2.3; DCI: PS1.A.3)
- Students use electronegativity trends in the periodic table (model) to predict polarity differences. (SEP: 2.3; DCI: PS1.A.2, PS1.A.3)

Slides J-K

Part B:

Bond	Electronegativity difference	Rank in order of relative polarity (1 = most 3 = least)	Are the shared electrons in this bond pulled toward carbon (C) or away from it?
C-H	(2.55 - 2.20) = 0.35	3	toward C
C=O	(2.55 - 3.44) = -1.11	1	away from C
C-Cl	(2.55 - 3.16) = -0.61	2	away from C

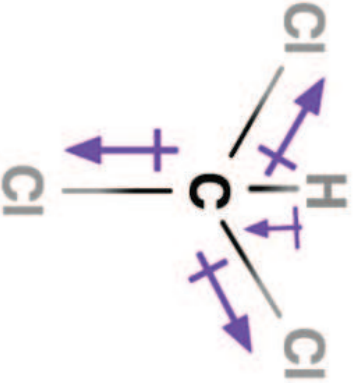
What to look/listen for in the moment:

- Students use electronegativity trends in the periodic table (model) to predict polarity differences. (SEP: 2.3; DCI: PS1.A.2, PS1.A.3)

- Students identify patterns based on differences in electronegativity to explain relationships between parts of bonded atoms. (DCI: PS1.A.3, PS1.A.2; CCC: 1.1)

Slides L-O

Part C:

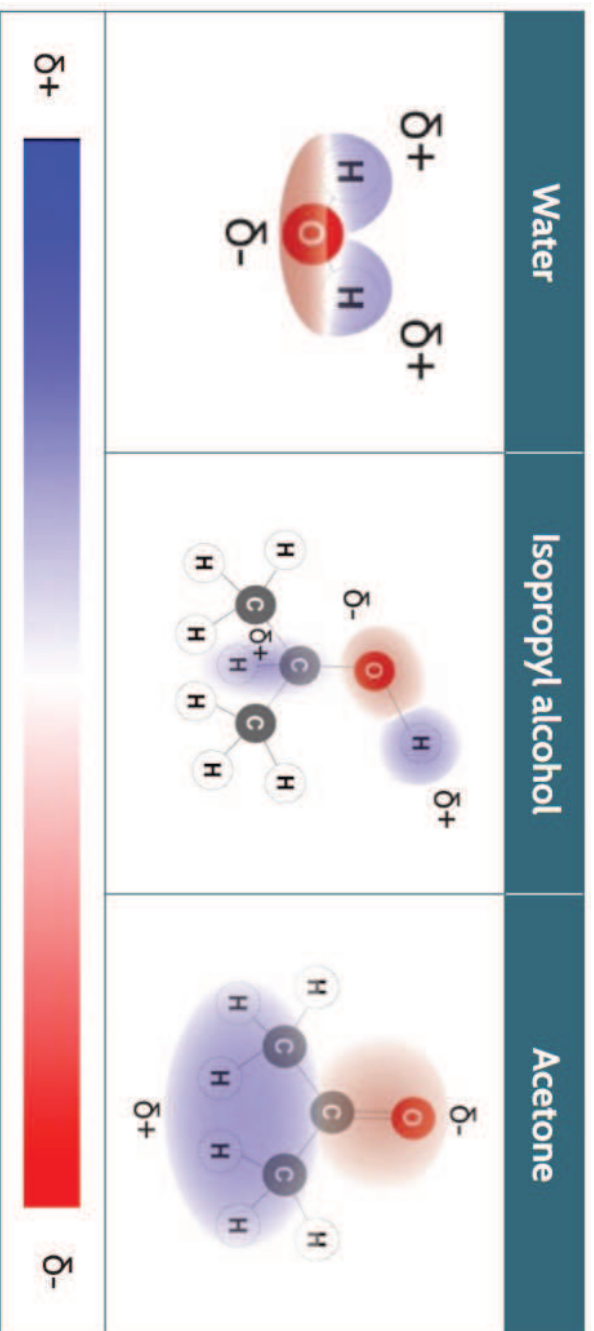
Methane CH_4	Chloroform CHCl_3	Formaldehyde CH_2O
		
Use different sizes and directions of dipole arrows to represent the relative shift of the electrons in each bond. 		

What to look/listen for in the moment:

- Students revise molecular models to show the strength of forces between atoms. (SEP: 2.3; DCI: PS1.A.2)

Slides P-Q

Part D:



What to look/listen for in the moment:

- Students show the **relative** differences in the **strength** of forces between atoms and molecules. (DCI: PS1.A.2; CCC: 6.2)

Lesson 9: Answer Key 2

Transfer Task Key

This assessment targets the following lesson-level performance expectation (LLPE):

9.A. Use a variety of models and evidence (such as solubility and periodic trends in electronegativity and atomic radius) to a) describe the patterns and relationships between the parts of an atom and the bonds formed between atoms, b) predict polarity differences, and c) explain property differences based on the relative differences in the strength of forces between atoms and molecules. (SEP: 2.3; DCI: PS1.A.3, PS1.A.2; CCC: 1.1, 6.2)

3D Elements	Question #						
	1	2	3	4	5	6	7*
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			X	X	X
Structure and Properties of Matter. 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. (DCI: PS1.A.2)	X	X		X			
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)			X	X	X	X	X
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)	X	X		X			
Structure and Function. The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. (CCC: 6.2)		X	X	X	X	X	X

***NOTE:** Question 7 at the end of *Sila-ibuprofen Transfer Task* is designed to be an optional resource, with a variety of suggested uses, including remediation or extension opportunities. These uses are described at the end of this key. If there is time after students complete Questions 1-6, you may wish to encourage them to read the prompt on Question 7 to pique their interest in it, but keep in mind that there is not enough time allocated in the lesson for all students to complete Question 7. Therefore, make sure that you communicate to students how you intend to use Question 7, after the allocated class time for the rest of the assessment.

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.

Scientists continue to research ways to develop better medicines that are more effective, have a lower cost or environmental impact, or have fewer side effects.

One recent example of an effort to develop a better medicine is an attempt to find a replacement for ibuprofen, due to its side effects. When taken too frequently or in too high dosages, ibuprofen can lead to thinning of the stomach lining, causing ulcers and gastro-intestinal bleeding. Because our kidneys have to metabolize these drugs, taking too much for too long can lead to decreased

kidney output or kidney failure.

To address this problem, biochemists developed a new substance, sila-ibuprofen, to use in place of ibuprofen. They reported on their findings in the *Journal of Medical Chemistry* (Kleemiss et al., 2020). They claim to have found that substituting a single silicon (Si) atom for a carbon (C) atom in the ibuprofen molecule results in a medicine that is equally effective but at a lower dosage.

References

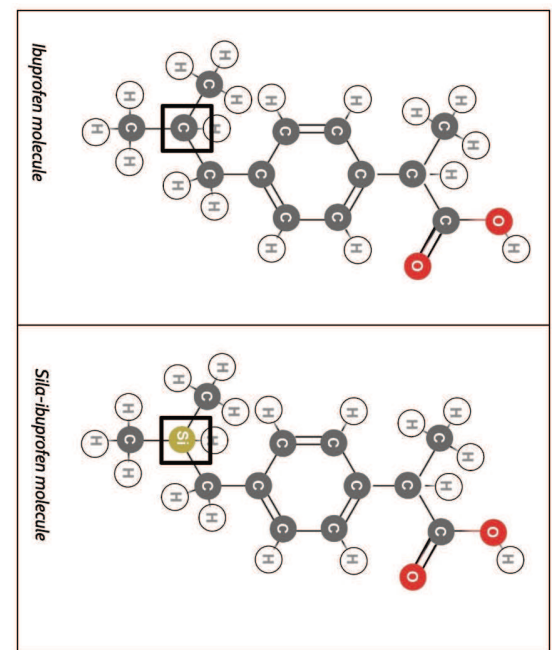
Kleemiss, F., Justies, A., Duvinage, D., Waterman, P., Ehrke, E., Sugimoto, K., Fugel, M., Malaspina, L. A., Dittmer, A., Kleemiss, T., Puylaert, P., King, N. R., Staubitz, A., Tzschentke, T. M., Dringen, R., Grabowsky, S., & Beckmann, J. (2020). Sila-ibuprofen. *Journal of Medicinal Chemistry*, 63(21), 12614–12622. <https://doi.org/10.1021/acs.jmedchem.0c00813>

A silicon (Si) atom is able to replace a carbon (C) atom at the location shown in the highlighted square in each molecule, and still produce the same number of bonds in the overall molecule.

Question 1. What pattern(s) at the atomic scale can you use from your periodic table model to help you explain this similarity in the bonding patterns?

Key elements:

- + Elements in the same column of the periodic table have the same number of valence electrons.
- + Both C and Si are in the same column of the periodic table.
- + The number of valence electrons determines the number of bonds an element can typically form.
- + Both C and Si have four valence electrons, so they both will form four bonds.



Sample student response:

Elements in the same column of the periodic table have the same number of valence electrons. Both C and Si are in the same column of the periodic table and therefore have four valence electrons. This number of valence electrons determines the number of bonds each element can typically form, which is four.

What to do: If students incorrectly identify a reason for a similar number of bonds, ask them to draw Lewis dot models for the three types of atoms involved in these bonds (C, H, and Si). Have students draw these separately at first to help them establish how many electrons are in the outer shell of each atom. Next, have students draw the five atoms involved in the four bonds in each molecule using Lewis dot models again. Once students have developed these models, ask them to put into words the structures that they represented and how these are related to patterns in the periodic table.

Differences in the structures and electronegativities of three different atoms found in the two medicines are shown in the table.

Atom	Atomic radius (pm)	# of protons in the nucleus	Electronegativity
H, hydrogen	25	1	2.20
C, carbon	70	6	2.55
Si, silicon	114	14	1.90

Question 2. The atomic radius of a silicon (Si) atom is larger than that of a carbon (C) atom. What pattern(s) in your periodic table model help you explain this difference in their atomic-level structures?

Key elements:

- + Atomic radius is the distance from the nucleus to the electrons in the outer shell of the atom.

- + The number of shells that the electrons are in for each element increases by one as you move down one row in the periodic table. The number of electrons also increases by 8 (for the elements we are familiar with).

- + Silicon is one row below carbon in the periodic table.
- + Silicon has one more electron shell than carbon.

Sample student response:

Since silicon is one row below carbon in the periodic table, silicon has an extra electron shell that its valence electrons are in compared to carbon. This additional shell increases the radius of the atom.

What to do: If students incorrectly identify differences in atomic radii, have them refer to their annotated periodic table from Lesson 8. If they need more help, have students build an electron shell model by first determining the total number of electrons in each oxygen atom, and then adding the electrons one at a time until they fill the corresponding shell around the atom. Then ask students to determine how many additional electrons are in a silicon atom. Have them make a copy of the model they drew for the oxygen atom and then add these additional electrons to it until its shell is filled, and then ask students where these additional electrons end up. Have them draw these after identifying that they go into a new shell farther away from the nucleus. Pause here and have students revise their original response to this question, using the models they developed and referencing where these atoms are found in the periodic table.

Question 3. What is it about the structures of the atoms in the table above that helps explain why the electronegativity of silicon (Si) is lower than that of carbon (C)? Be sure to use *force thinking* in your response.

Key elements:

- + Increases in distance between charges decrease the strength (magnitude) of electrical forces between them.
- + As atomic radius increases, the electrons in the outer shell are farther away from the positive charges in the nucleus.
- + Lower electronegativity corresponds to electrons in the outer shell that are easier to pull away from the atom.

Additional accurate elements not essential to this item:

- ++ The effects predicted by Coulomb's law of increasing the positive charges (number of protons in the nucleus) are less than the effects of increasing the distance between the charges (atomic radius squared).
- ++ The increased number of electrons in a silicon atom (particularly the ones in the shell closest to the outer shell) contributes some repulsive force on like charges (electrons in the outer shell), or decreases some of the effects of the net attractive force from the protons in the nucleus.

Sample student response:

The greater distance to electrons in the outer shell of a silicon atom would decrease the strength of the electrical forces produced by the positive charges in its nucleus, which would result in a lower electronegativity.

What to do: If students incorrectly identify the role of distance in affecting electronegativity, recall how distance affects the strength of forces between charges by sketching a graph of the nonlinear relationship students discovered in *Electrostatics Unit*. Then provide them a reference to Coulomb's law, such as the one on slide P from Lesson 8, shown here. Have students then describe:

- which variable represents distance between charges and which variable represents strength of forces;
- what happens to the strength of the forces when the distance between the charges doubles; and
- how this is related to atomic radius differences and electronegativity differences.



With your class

- How does this connect to Coulomb's law?

$$F = k \cdot \left(\frac{q_A \cdot q_B}{r^2} \right)$$

Question 4. How will the electronegativities of the atoms involved impact any shift in the shared electrons and any differences in the relative polarity across the four bonds that differ between ibuprofen and sila-ibuprofen? Each row in the following table will help you think about one of these bonds.

Key elements:

- + Bond character is on a continuum. Nonpolar covalent bonds have electronegativity differences less than 0.5, ionic bonds have differences greater than 1.7, and polar covalent bonds have differences between these.
- + Correctly ranked order of relative polarity for all four bonds.

- + A calculation of the electronegativity difference **between the two atoms in each bond**.
- + A shift of electrons toward the atom with higher electronegativity occurs in all bonds between two different elements.
- + No shift of electrons toward either atom occurs in the bond that forms between the same element.

- + Differences in the relative **pull or strength of forces** acting on electrons in the outer shell predict/explain why there is a shift of the bonded electrons toward one atom.
- + Equality/similarity in the relative **pull or strength of forces** acting on electrons in the **outer shell** predicts/explains why there is no shift of the bonded electrons toward either atom.

Sample student response:

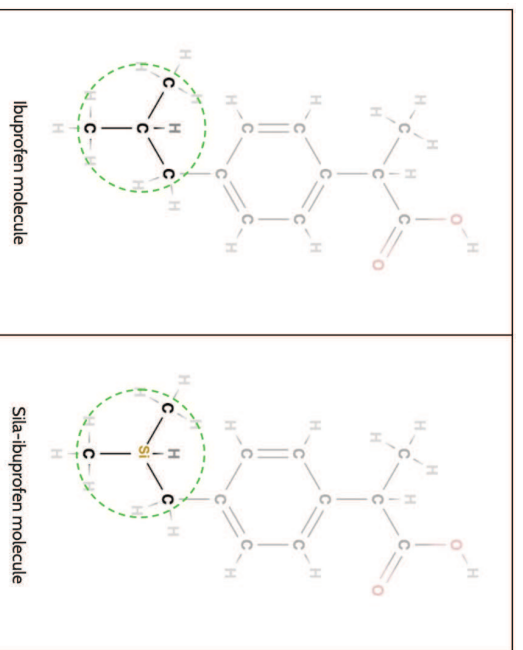
Bond	Show the calculation you use to determine your answers in the next two columns.	Bond character (choose one): a) nonpolar covalent b) polar covalent c) ionic	Rank the relative polarity of each bond. (1 = most 4 = least)	Which atom (if either) are electrons shifted toward? Explain your thinking.
C - C	$(2.55 - 2.55) = 0$	a	4	The shared electrons are not shifted toward either atom; since the atoms have the same electronegativity, they pull just as strongly on electrons in their outer shells.
C - H	$(2.55 - 2.20) = 0.35$	a	2	The shared electrons are shifted toward carbon because it has a higher electronegativity due to greater/stronger attraction of the electrons in its outer shell.
Si - H	$(2.20 - 1.90) = 0.30$	a	3	The shared electrons are shifted toward hydrogen because it has a higher electronegativity due to greater/stronger attraction of the electron in its outer shell.
C - Si	$(2.55 - 1.90) = 0.65$	b	1	The shared electrons are shifted toward carbon because it has a higher electronegativity due to greater/stronger attraction of the electrons in its outer shell.

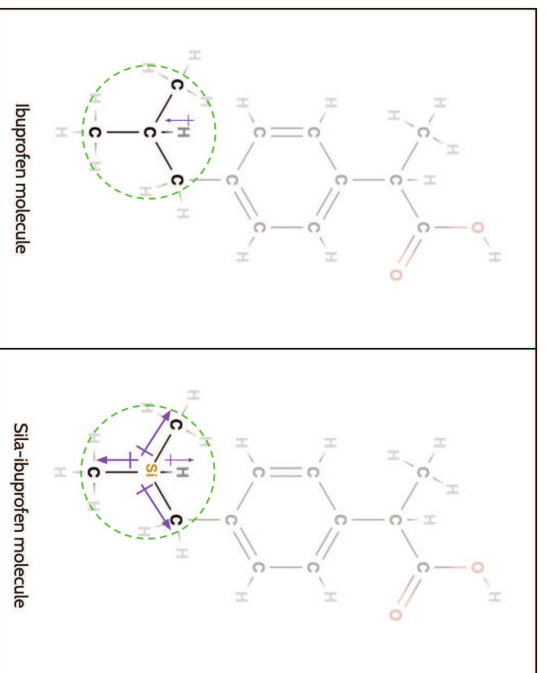
What to do: If students struggle with any parts of this table, have them review and then summarize what they did in Part B of *Modeling Polarity*. Then ask students to apply the same thinking to this question.

Question 5. Use the **bond polarities** from Question 4 as evidence to annotate each model to illustrate the relative shifts of the shared electrons in the four bonds around the carbon and silicon atoms. Your illustrations should use dipole arrows, as in *Modeling Polarity*.

Key elements:

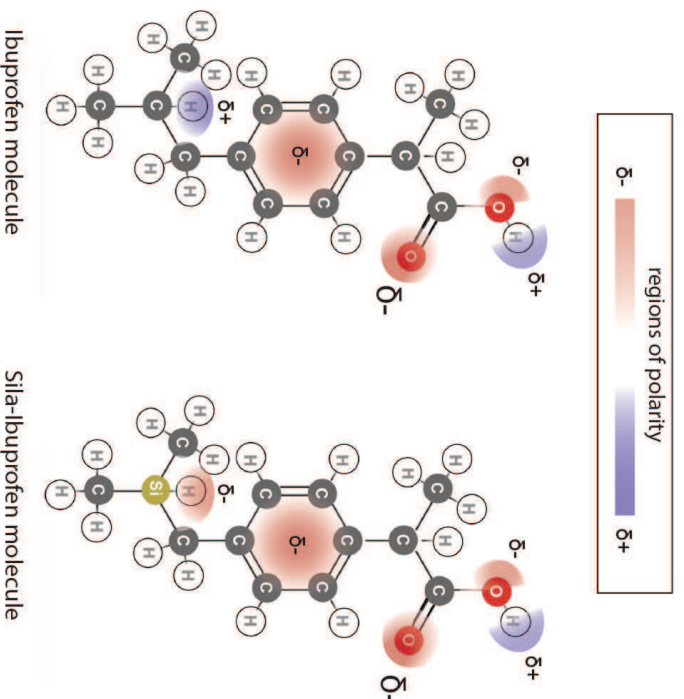
- + Dipole arrows illustrate the direction that shared electrons shift along a bond.
- + The relative size of the dipole arrow illustrates the relative amount of shift of the shared electrons, which can be predicted by **differences in bond polarities**.
- + No dipole arrow along a bond illustrates no shift of the shared electrons, which is what occurs **when the bonded atoms have the same electronegativity**.
- + The direction of the dipole arrow illustrates which atom the electrons are shifted toward.





What to do: If students struggle with using dipole arrows to illustrate their thinking, provide them with the physical manipulatives they used on day 1 of this lesson to represent the relative shifts. Then have students describe in words what they did, and why.

Computer visualizations of the overall polarity of the ibuprofen and sila-ibuprofen molecules were included in the journal article by the authors that published this discovery. Similar visualizations are shown below.



- Question 6.** Use the **ideas** you have developed so far to explain the differences in polarity predicted by the computer visualizations in the region around the corresponding hydrogen atoms in ibuprofen vs. sila-ibuprofen. In your response, be sure to include:
- how **electrons shift** in the four bonds at the location where the silicon (Si) atom replaces the carbon (C) atom;
 - how these **shifts** contribute to the overall shift in charge in that region; and
 - how this overall shift in charge impacts the **polarity of the electric field** in the space around this region of the molecule.

	Foundational Understanding	Linked Understanding	Organized Understanding
3D Elements	Makes one of these connections: Connects field representations from the computer visualization to shifts of electrons toward or away from those places in space around the molecule. Connects shifts of electrons toward or away from a place in space to changes in at least one of the new bonds that is formed. Connects differences in the direction that electrons in bonds shift to the atom in the bond that has greater electronegativity.	Makes two of the three connections: Connects field representations from the computer visualization to shifts of electrons toward or away from those places in space around the molecule. Connects shifts of electrons toward or away from a place in space to changes in at least one of the new bonds that is formed. Connects differences in the direction that electrons in bonds shift to the atom in the bond that has greater electronegativity.	Makes all three connections: Connects field representations from the computer visualization to shifts of electrons toward or away from those places in space around the molecule. Connects shifts of electrons toward or away from a place in space to changes in at least one of the new bonds that is formed. Connects differences in the direction that electrons in bonds shift to the atom in the bond that has greater electronegativity.
Sample student response	In the ibuprofen molecule the hydrogen atom is positively charged because both electrons shared in the bond between hydrogen and carbon are shifted toward carbon. In the sila-ibuprofen molecule the hydrogen atom is negatively charged because both electrons shared in the bond between hydrogen and silicon are shifted toward hydrogen and away from silicon.	In the ibuprofen molecule the field around this hydrogen atom shows a positive charge (indicated by the blue color visualization and $\delta+$ symbol). This is because both electrons shared in the bond between hydrogen and carbon are shifted toward carbon. In the sila-ibuprofen molecule the field around this hydrogen atom shows a negative charge (indicated by the red color visualization and $\delta-$ symbol). This is because both electrons shared in the bond between hydrogen and silicon are shifted toward hydrogen and away from silicon.	In the ibuprofen molecule the field around this hydrogen atom shows a positive charge (indicated by the blue color visualization and $\delta+$ symbol). This is because both electrons shared in the bond between hydrogen and carbon are shifted toward carbon, giving the region around (or on the other side of) the hydrogen atom a positive polarity. In the sila-ibuprofen molecule the field around this hydrogen atom shows a negative charge (indicated by the red color visualization and $\delta-$ symbol). This is because both electrons shared in the bond between hydrogen and silicon are shifted toward hydrogen and away from silicon, giving the region around the hydrogen atom a negative polarity.
Feedback / What to do	Linking: Have students consider which parts of Questions 4 and 5 are asking about particles (parts of the atom or the atoms themselves), which parts are asking about fields produced by the matter, and which parts are about force interactions.	Organizing: Encourage students to make connections to the M-E-F triangle to consider the role of forces and where electrons are in the system, and the fields produced by differences in the net charge in that particular region of the molecules.	Extending: Encourage students to consider why changes in the four bonds being considered would also have subtle, minor effects on the polarity of the molecule in regions far away from where the four bonds are located.

Ideas for Instruction	Foundational Understanding	Linked Understanding	Organized Understanding
	Review the responses to [C.R.L9.HO2] with students and ask them to articulate which of the Parts A-D are asking students to use ideas that correspond to Questions 4 and 5 on this assessment task. Provide physical manipulatives that they used on day 1 of this lesson to model the shifts in electrons for Question 5.	Have students compare responses with a partner, working to identify strengths and weaknesses in each. Then have students work individually to develop revised responses to this assessment task or to develop a response to Question 7.	Encourage students to pick one corresponding portion of both molecules that has a subtle, minor change in polarity, far away from where the four bonds are located. Encourage students to draw the slight shift of electrons in the nearest bonds in that region that might have been affected, and then argue what chain of cause and effect across the intervening bonds in the molecule might have resulted in this shift.

***NOTE:** Question 7 has various uses, described in greater detail in the "What to do," including:

- as a re-assessment or remediation opportunity for **Question 6**. In this case, provide only after students have had other opportunities to receive and use feedback from the assessment task to improve their understanding. You may wish to review Lesson 4 with students so that they are not surprised by the re-introduction of dissolution.
- as an extension opportunity to connect back to Lesson 4. In this case, be explicit with students that they will have to build on what they did in **Question 6** as well as use ideas about dissolution from Lesson Set 1.

One drawback of ibuprofen is its low solubility in water, which means it does not dissolve easily. This limits its use to pill form and prevents it from being administered through an intravenous solution (an IV) directly into the bloodstream, which would be helpful for patients who are recovering from sedation after surgery.



Ibuprofen pill form



An IV

The solubility of sila-ibuprofen is 83 mg/L, meaning that up to 83 milligrams of sila-ibuprofen dissolve in 1 liter of water. This is compared to 21 mg/L for ibuprofen. This increased solubility of sila-ibuprofen allows enough of it to be dissolved in water and administered to patients through an IV.

Question 7. Explain how differences between these molecules result in sila-ibuprofen being more soluble in water. In your response, use:

- patterns and structure-function relationships that you identified in prior questions;
- reasoning with the M-E-F triangle and models that you developed in the unit; and
- force interactions between molecules of the medicines and neighboring water molecules.

Key elements:

- + The field produced around a region is due to the charges in that region. This is indicated by the red/blue color visualization and related δ^- and δ^+ symbols.
- + Polar regions and the resulting fields that are produced are due to shifts of electrons toward or away from that region of the molecule.
- + The atom that is replaced in ibuprofen vs. sila-ibuprofen forms four different bonds.
- + The electrons in all four bonds are being pulled away from the replacement silicon atom, rather than not being pulled, or being pulled toward the original carbon atom.
- + The fields around polar regions of a molecule produce force interactions with polar regions on neighboring particles.
- + There are many different polar regions in different areas of a large molecule like ibuprofen or sila-ibuprofen, as shown in the models.
- + There are just three different polar regions in a smaller water molecule – a negative region around the oxygen end and two positive regions around the hydrogen ends, as shown in the models.
- + In solid form, neighboring molecules of ibuprofen or sila-ibuprofen are next to each other.
- + When a molecule of ibuprofen or sila-ibuprofen is dissolved in water, many neighboring water molecules surround and pull on it.

Sample student response:

The substitution of one type of atom for another in a molecule affects the polarity of bonds it forms with neighboring atoms. This affects the overall charge in a region of the molecule. This in turn affects the fields produced around the molecule. Ibuprofen and sila-ibuprofen have multiple regions where the polarity of these regions varies because of the different bonds in those regions (e.g., O=C in some places and not others). Each of these fields can produce force interactions with polar regions of neighboring particles. Because the polarity of one region flips in sila-ibuprofen due to substitution of one atom, the strength and/or number of the force interactions with neighboring molecules must also change. Such a change must make it easier for water to pull sila-ibuprofen molecules away from other sila-ibuprofen molecules and surround it than it is to pull ibuprofen molecules away from other ibuprofen molecules.

What to do:

If you are using this as a **Re-assessment Opportunity**, provide students with similar feedback as in **Question 6**.

If you are using this as an **Extension Opportunity**, do the following:

Encourage students to describe how either changes in relative strength OR in the number of attractive forces between neighboring molecules could explain these outcomes. This may lead students to argue that there are either:

- weaker or a fewer number of attractive forces between neighboring sila-ibuprofen molecules compared to neighboring ibuprofen molecules; or
- stronger or a greater number of attractive forces between water molecules and neighboring sila-ibuprofen molecules compared to water molecules and neighboring ibuprofen molecules.

You may also ask students to argue how changes in repulsive force interactions could contribute to these effects. This may lead students to argue that there are either:

- stronger or a greater number of repulsive forces between neighboring sila-ibuprofen molecules compared to neighboring ibuprofen molecules; or
- weaker or a fewer number of repulsive forces between water molecules and neighboring sila-ibuprofen molecules compared to water molecules and neighboring ibuprofen molecules.

Ask students to consider why there would be a limit to how much sila-ibuprofen can dissolve in water. This is an excellent preview of concentration thinking at a particle level and what might be affecting that, which will be a focus of the next unit, *OpenSciEd Unit C.4*:

Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit).

Lesson 11: Answer Key

Fertilizer from Urine Key

Key ideas from each paragraph have been underlined. This helps to address the following portions of **11.A** Critically read and determine central ideas of a text to develop a model that explains how using different reactants leads to the development of different fertilizers which can be used to grow plants off of Earth. (SEP: 8.1, 2.3; DCI: PS1.A.1, PS1.B.3; CCC: 6.2):

- Students critically read and determine central ideas about growing plants in space that can give us the materials needed for survival. (SEP: 8.1; DCI: PS1.B.3)

Urine: An outer-space fertilizer?

One idea that scientists are investigating is using human urine to make fertilizer for growing plants in space. Plants have been found to grow in soil from the Moon, but the plants did not last very long. (Keeter, 2022). Scientists indicated that any space plants will require high-quality fertilizer engineering processes. Two fertilizers we use on Earth, *ammonia* and *ammonium*, have been identified as something we could potentially use. These fertilizers could be used to enrich the soil on the Moon or elsewhere so that plants might grow. But, what are the trade-offs of using one of these fertilizers over the other?

Ammonia

Ammonia is often used as a fertilizer here on Earth and is common in U.S. farming. It is a liquid that farmers spray on their fields to supply plants with nutrients. Ammonia is created by combining nitrogen gas from the atmosphere with hydrogen gas. However, there are some issues with using ammonia in space. Most places that humans could travel to do not have nitrogen-rich atmospheres, so it would be difficult to make ammonia there. Another concern is that ammonia storage can be hazardous. It is corrosive to metal, so it can damage the containers it is stored in and explode. Recently, a large explosion of stored ammonia-based fertilizer killed 15 people in Texas (Chappell, 2013). Ammonia is also harmful to human tissues and causes irritation to the eyes, nose, and throat, breathing difficulty, wheezing, and chest pain. It can also cause buildup of fluid in the lungs, skin burns, and liquid frostbite (Centers for Disease Control, 2019).

Ammonium

Ammonium ions are a second option for fertilizing plants in outer space. Ammonium ions can be made when an acid called urea is broken down, but ammonium does not tend to exist on its own. Urea is a component of urine. Recently, a team of scientists and fertilizer engineers in Japan developed the first tool that can convert urea into ammonium suitable for fertilizer (Tokyo University of Science, 2020). This was a breakthrough development. It means that we can potentially recycle human urine into plant fertilizer using a tool.

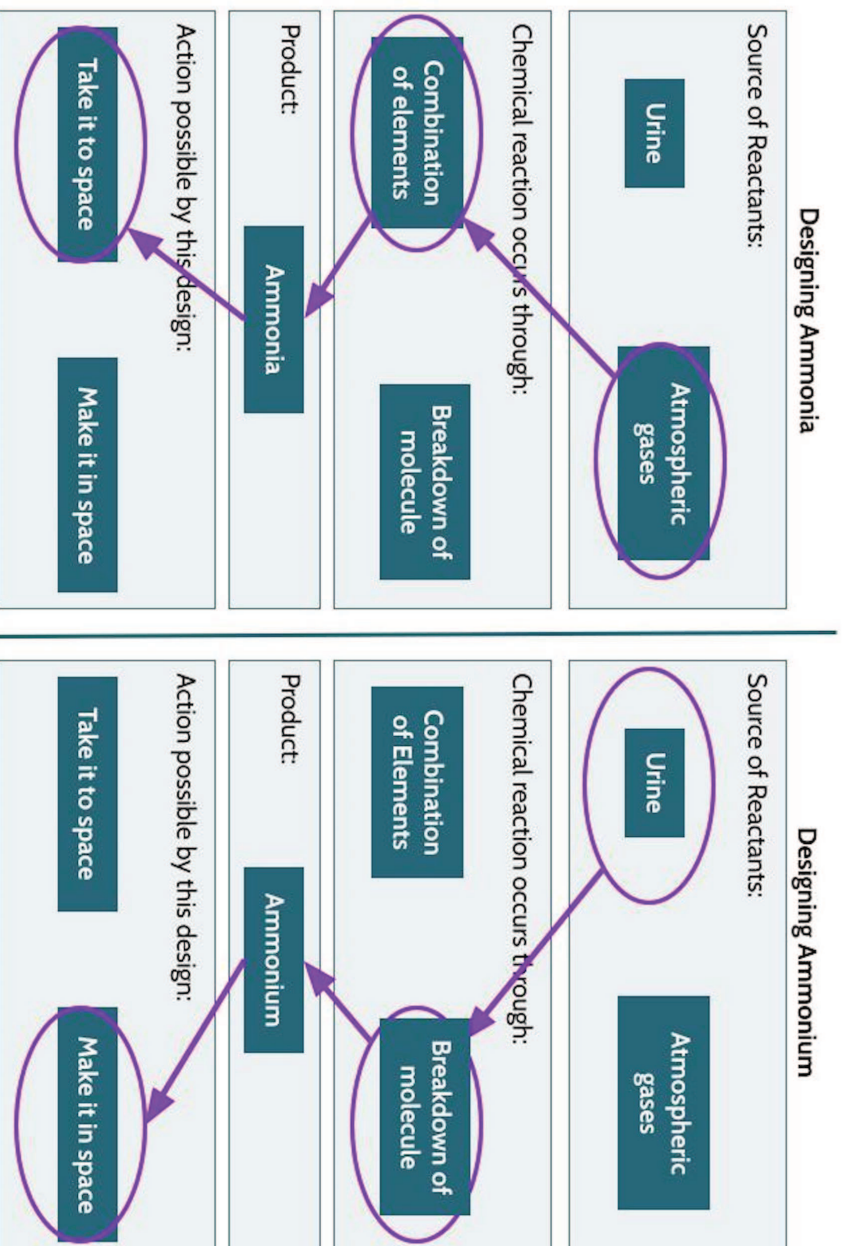
References

- Centers for Disease Control and Prevention. (2019, October 30). CDC - NIOSH Pocket Guide to Chemical Hazards - Ammonia. Centers for Disease Control and Prevention. Retrieved September 8, 2022, from <https://www.cdc.gov/niosh/npg/npgd0028.html>
- Chappell, Bill (April 23, 2013). *Death Toll in West, Texas, Fertilizer Explosion Rises to 15*. NPR. Retrieved September 8, 2022, from <https://www.npr.org/blogs/thetwo-way/2013/04/23/178678505/death-toll-in-west-texas-fertilizer-explosion-rises-to-15>
- Keeter, B. (2022, May 12). *Scientists grow plants in lunar soil*. NASA. Retrieved August 31, 2022, from <https://www.nasa.gov/feature/biological-scientists-grow-plants-in-soil-from-the-moon>
- Tokyo University of Science. (2020, December 14). *One's trash, another's treasure: Fertilizer made from urine could enable space agriculture*. ScienceDaily. Retrieved August 31, 2022, from <https://www.sciencedaily.com/releases/2020/12/201214123520.htm>

1. Map out the two different processes for making fertilizers.

Making Fertilizer in Space

Draw arrows to show the steps in two design processes that could be used to make fertilizer in space.
You will not use all the boxes for both sides.



2. Should we use ammonia or ammonium as a fertilizer in space? Why?

We should use ammonium to make fertilizer in space because we won't have to take it with us. The reading said that there is a tool we can use to convert the urine we produce to make ammonium for plants that will help them grow in the soil.

Look for students to:

- identify ammonium;
- reference that we can make ammonium using urine and a special tool in space, or that we cannot make ammonia in space.

Students who do the following may need additional support, such as using a screen reader or having the text read aloud:

- Do not note the differences between ammonia and ammonium.
- Overlook the dangers of storing ammonia.
- Do not note that there are possibilities for making fertilizer out of urine.

3. What new questions does this raise for you about their structure or function?

Look for students to raise questions about the elements found in ammonia or ammonium, the differences between the two fertilizers, or the processes (chemical reactions) that make them.

UDL for Jigsaw Readings

Engagement	Representation	Action & Expression
Purposeful & Motivated	Resourceful & Knowledgeable	Strategic & Goal-Directed
Recruit Interest: Allow students to choose readings. Sustain Effort: Jigsaws are social, and all participants are treated as experts.	Perception: Electronic format supports screen reading; images support background knowledge. Language & Symbols: We pay attention to structure and text features. Comprehension: Students access key information relevant to the big question.	Physical Action: Using computers optimizes access to translation/screen readers. Expression & Communication: The lesson encourages use of text features. Executive Function: Students have a distinct goal/purpose for reading and use handouts to organize ideas.

Here are some text structures and design features that benefit **all readers** in this lesson, and can be applied to other texts your students may encounter:

1. **Images and graphics:** There is a reason “a picture is worth a thousand words.” Images help readers engage with the text on a sensory level before the reading activity begins. An image that is closely related to the text’s main content can activate sensemaking that includes students’ previous experiences, cultural funds of knowledge, and curiosity.
2. **Short sentences and paragraphs:** If a reader has to decode a lot of words in a sentence, it is hard for them to remember the concepts from previous parts of the sentence to string together. One way to alleviate this is with shorter sentences that maintain the meaning of an idea or paragraph.
3. **Titles, subtitles, and other section names:** Titles highlight the purpose of the text and “set the stage” for students to make conceptual connections to the text. Students can use their background knowledge and cultural funds of knowledge to connect with the reading right away.
4. **Language register:** Science articles can take on different registers of language depending on the audience and purpose. Articles written for youth may have more colloquial language, while articles written for professionals will have more highly specialized language. While specificity is important, it should not come at the expense of general comprehension for any audience. One general guideline is the 90% rule: If 1 in 10 words is unfamiliar to students, the reading or text is not easily comprehensible.

Additionally, these text design features may be available when using online-based text:

1. **Interactive features:** Online reading has the advantage of including interactive features inside or alongside the text, such as video, simulations, and graphics. These features help offer an introduction point for the text that is not solely based on reading comprehension. Additionally, online features are excellent support for multilingual learners or students with specific reading disabilities (e.g., dyslexia).
2. **Translator access:** Another advantage of online reading is the ability to use an electronic translator to help translate specific words or phrases. If you are able to copy-paste the text, you can usually pop it into a translating service. Examples of text that cannot be copy-pasted might be those from pictures or low-quality PDFs.

The articles in this lesson have the following embedded features:

Reading	Universal Design Features	Differentiation Guidance
Mars https://solarsystem.nasa.gov/planets/mars/in-depth/	- Graphics - Interactive map - Section titles - Relatively concise sentences - Short paragraphs	This is a good article to assign to students who struggle with reading long sentences in English because 1) its topic is familiar to most students (background knowledge about Mars), and 2) its sentences are very short. The article itself is long because of the depth of understanding we have about Mars, so encourage students to look for important headers.
The Moon https://science.nasa.gov/moon/facts/	Short overall length	This reading is short but very dense and requires some highly-specialized vocabulary. Assign it to capable readers. Point students to paragraph 2 for the needed information.
Venus https://solarsystem.nasa.gov/planets/venus/in-depth/	- Colloquial language - Compelling images - Section titles	Point students to the section subtitled “Atmosphere.” The information is difficult to locate without guidance, and the text is comparatively long.
Mercury https://solarsystem.nasa.gov/planets/mercury/in-depth/	- Concise sentences - Colloquial language - Graphics 3D model - Short paragraphs	Topic sentences throughout this article can help students skip through irrelevant information. The key information is in the “Atmosphere” section.
Saturn https://solarsystem.nasa.gov/planets/saturn/in-depth/	- Short paragraphs - Section titles - Interactive graphic	Specialized vocabulary and passive voice are potential barriers to comprehension. Composition information is in the “Atmosphere” section. Have students or screen reader technology read the paragraphs aloud if you anticipate difficulty.
Jupiter https://solarsystem.nasa.gov/planets/jupiter/in-depth/	- Compelling interactives “Quick facts” table	Long sentences with winding clauses may make it difficult for students to get the main idea. Encourage them to read aloud to themselves or with a partner because “hearing” the text can increase comprehension. The information needed is in the “Atmosphere” section, paragraphs 1 and 2.

Neptune https://solarsystem.nasa.gov/planets/neptune/in-depth/	• Section titles • Table of moons • Images • 3D model	The needed information is in the “Structure” and “Atmosphere” paragraphs, which are written in very concise form. Other sections contain less accessible sentence structures and obscure vocabulary (axial, eccentric).
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Note: The Google versions of these articles are accessible to screen reading technology and online translator services.

References

CAST (2018). *Universal design for learning guidelines* (Version 2.2). <http://udlguidelines.cast.org>

Name: _____ Date: _____

Lesson 12: Answer Key 1

Search for Elements Key

1. Use *Substances for Survival* to determine the numbers of atoms required to make each substance needed for survival.

In the table below, enter the total number of atoms of each element needed to make one molecule or unit of each substance.

Substance	Number of atoms of each element needed to make one molecule or unit of the substance								
	H	C	O	Na	Al	Si	Ca	Mn	Fe
Glucose	12	6	6						
Steel		1						1	59
Glass			14	2		6	1		
Hardened cement	76		115		2	20	34		
Plastic	8	10	4						

If students do not find the total number of each type of element, remind them to combine the amounts of elements across the chemical formula or compound.

2. Research the two locations our class thinks are reasonable candidates for where we can live and work in space – the Moon and Mars – to figure out what elements are present there. Each partner will research one location to determine whether it has the elements required to make the substances we need for survival. Record the information in the table. Information coded in red in the table below is provided to help you point out to struggling students where to look in each of the websites. Students may or may not include this information in their tables.

Candidate location and link	Element present (Y or N) and amount (A lot, Some, or A little)								
	H	C	O	Na	Al	Si	Ca	Mn	Fe
The Moon https://science.nasa.gov/moon/facts/	Water on the Moon, 2nd paragraph: Y, a lot		Water on the Moon, 2nd paragraph; Structure, 3rd and 4th paragraph: Y, a lot		Structure, 4th paragraph: Y, Some	Structure, 3rd paragraph; Structure, 4th paragraph: Y, A lot	Structure, 4th paragraph: Y, Some		Structure, 2nd paragraph; Structure, 3rd and 4th paragraph: Y, A lot

Mars https://solarsystem.nasa.gov/planets/mars/in-depth/	Surface, 6th paragraph: Y, Some	Atmosphere, 1st paragraph: Y, Some	Surface, 1st and 6th paragraph; Atmosphere, 1st paragraph: Y, A lot		Structure, 1st paragraph: Y, Some		Structure, 1st paragraph: Y, Some		Structure, 1st paragraph: Y, A lot
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Note: If students have time, you can prompt them to look up the chemical formulas for each of the minerals mentioned in Structure.

If students choose to explore other planets, use the table below to help students in their research.

Candidate location and link	Element present (Y or N) and amount (A lot, Some, or A little)								
	H	C	O	Na	Al	Si	Ca	Mn	Fe
Venus https://solarsystem.nasa.gov/planets/venus/in-depth/		Atmosphere : Y, A lot	Atmosphere : Y, A lot						Potential for Life, 3rd paragraph; Structure, 1st paragraph: Y, A lot
Mercury https://solarsystem.nasa.gov/planets/mercury/in-depth/	Atmosphere : Y, A little		Atmosphere : Y, A little	Atmosphere : Y, A little					
Saturn https://solarsystem.nasa.gov/planets/saturn/in-depth/	Introduction, 1st paragraph; Structure, 1st paragraph: Y, A lot								Structure, 1st paragraph: Y, A little

Jupiter https://solarsystem.nasa.gov/planets/jupiter/in-depth/	Introduction , 1st paragraph; Structure: Y, A lot		Introduction , 1st paragraph; Atmosphere , 1st paragraph: Y, A lot						
Neptune https://solarsystem.nasa.gov/planets/neptune/in-depth/	Structure, 1st and 2nd paragraphs; Surface; Atmosphere , 1st paragraph:: Y, A lot	Structure, 1st paragraph; Surface; Atmosphere , 1st paragraph:: Y, A lot	Structure, 1st and 2nd paragraphs; Surface; Atmosphere , 1st paragraph:: Y, A lot						

3. Compare the tables you and your partner completed in Question 2 to the table you completed together in Question 1. Which location in space contains the elements required for photosynthesis and for us to make most of the substances we need for a permanent settlement?

Mars, because there is carbon as carbon dioxide which plants need for photosynthesis. It's missing sodium so we can't make glass, and it's missing silicon which means we can't make cement either.

If students suggest the Moon, point out that there was no evidence of carbon on the Moon. This means that we would not be able to grow plants, since they need carbon for photosynthesis.

4. Which substances would be the most straightforward to produce? Why?

Glucose by photosynthesis, and maybe plastic, because all of the elements we need are on Mars. Maybe steel, because there seems to be a lot of iron and it only needs a little manganese, so maybe we could bring that.

5. Which substances would be more difficult to produce? Why?

Glass and cement, because both need a lot of silicon and there isn't any on Mars. Glass also needs sodium, and that is not on Mars either.

Lesson 12: Answer Key 2

Exit Ticket Key

12.A Create balanced chemical equations (computational models) using mathematical representations of elements to demonstrate that matter is conserved. (SEP: 5.1; DCI: PS1.B.3; CCC: 1.4, 5.1)

Additionally, one **ESS** disciplinary core idea, **ESS3.C.2**, is incorporated into this assessment. See discussion in the Lesson 1 Teacher Guide around the use of **DCI: ESS3.C.2** to move students' thinking forward. **DCI: ESS3.C.2** is included as part of students' learning in the next lesson.

Where these elements are addressed in this assessment	5.1 Using Mathematics and Computational Thinking Create and/or revise a computational model or simulation of a phenomenon; designed device, process, or system.	PS1.B.3: Chemical Reactions The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	ESS3.C: Human Impacts on Earth Systems Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.	5.1 Energy and Matter: Flows, Cycles, and Conservation The total amount of energy and matter in closed systems is conserved.	1.4 Patterns Mathematical representations are needed to identify some patterns.
Q1a	X	X			
Q1b	X				
Q2		X	X		
Q3a		X			X
Q3b					X
Q4	X			X	

Questions 1a and 1b

A common substance on Mars is magnesium sulfate (MgSO_4), and researchers are exploring ways to obtain the elemental sulfur (S) needed to make sulfur-based concrete. One potential approach involves the reaction of hydrogen gas (H_2) with sulfate minerals in a two-step process represented by the overall equation shown:



The hydrogen gas reactant (H_2) can be obtained from the electrolysis of water, which also produces oxygen gas (O_2).

Assuming that both reactions occur in closed systems, how many molecules of hydrogen gas would be needed to react with 100 molecules of magnesium sulfate (MgSO_4)?

- 300
- 150
- 100
- 30

How did you use mathematics and computational thinking to help you figure out your answer? Explain the steps you took.

Correct response: 300
 $(100/1) = (x/3) = 300$

First I balanced the chemical equation that shows how to make elemental sulfur, S. This told me that you need 3 molecules of H_2 to react with 1 molecule of $MgSO_4$. Then I used ratio thinking, 1:3, and multiplied 100 by 3 to get 300.

Rationale for distractors:

150 is obtained by students also balancing the water electrolysis equation and using an additional ratio for H_2 : $100 \times (3/2)$.
100 is obtained by not balancing the first equation.
30 is obtained by incorrectly calculating the ratio: $100/3$.

What to look for:

- Students refer to balancing the first chemical equation.
- Students use ratio thinking.

What to do:

Ensure students are using matter conservation thinking when determining their solution. Ask, *How can we first make sure the atoms in the reaction are conserved?*

Support students in using ratio thinking. Ask, *What information did you use to set up your ratio?* This aspect of Using Mathematics and Computational Thinking returns in Lesson 15.

Follow up with students who consistently attend to only one dimension at a time throughout this assessment. For example, highlight the use of **mathematics** to support understanding of **conservation of matter** in this prompt, then ask students to explain their use of different dimensions together in other prompts.

Question 2

Multiple Science Domains: In the *Sulfur-Based Concrete* handout, you read about how scientists and engineers are able to recycle sulfur-based concrete. Look back at the **two-step process to make elemental sulfur**, S, proposed in Question 1:



The hydrogen gas reactant (H_2) can be obtained from the electrolysis of water, which also produces oxygen gas (O_2), according to the following equation:



We are pretty sure that **water on Mars will be a limited resource**. In **what ways could scientists and engineers design a system to reduce the amount of water needed to carry out this two-step process?**

What to look for in response:

- Students identify that water is a product of the process to make elemental sulfur from $MgSO_4$.
- Students postulate that the water produced in the reaction could be used in the electrolysis process to make H_2 .

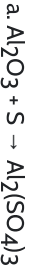
What to do:

Encourage students to look back at how they have thought about the role of water in essential reactions throughout the unit. Then, ask them to think about how water is both used as a reactant and produced as a product in chemical reactions. Have students consider how this may impact the ways in which we could use by-products of a chemical reaction. Point out the cyclical nature of water, glucose, and carbon dioxide in the reactions for photosynthesis and cellular respiration. The OpenSciEd High School Chemistry course threads ideas of the impacts of increasing carbon dioxide on Earth systems throughout each of the units. In the next two units, students will use engineering thinking (**DCI: ETS**) and concepts of chemistry (**DCI: PS**) to find solutions to reduce human impacts on Earth systems (**DCI: ESS**).

Questions 3a and 3b

In the *Sulfur-Based Concrete* handout, to account for the enhanced strength of sulfur concrete made with a simulated martian soil, the authors propose that metal compounds like aluminum oxide (Al_2O_3) in the simulated soil react with melted sulfur (S) during mixing to form aluminum sulfate, $\text{Al}_2(\text{SO}_4)_3$.

Two possible unbalanced chemical equations for the formation of aluminum sulfate, $\text{Al}_2(\text{SO}_4)_3$, are shown.



Which **chemical equation** most likely describes the process? Use **ideas about the conservation of matter and mathematical representations of the chemical equations** to help you.

- A
- B
- Neither
- Both

How did using **mathematical representations of the chemical equations** help you?

Correct response: B

Both of the possible chemical equations contained the correct types of atoms: Al, S, and O. It wasn't until I tried to balance both of them that I could choose the correct answer. There was no way to balance the first chemical equation, but I was able to balance the second one.

Rationale for distractors:

A is obtained if students incorrectly balance the chemical equation.

Neither is obtained if students incorrectly balance both chemical equations.

Both is obtained if students do not attempt to balance both chemical equations and rely only on the correct types of atoms appearing on both sides of the chemical equations.

What to look for:

- Students identify the need to balance the chemical equations because the correct types of atoms are found on both sides of the chemical equations.

What to do:

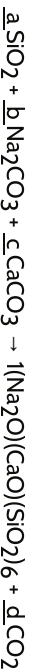
Ensure students are using matter conservation thinking when determining their solution. Ask, *How can we first make sure the atoms in the reaction are conserved?*

Support students in using mathematical representations to make predictions. Ask, *How might using a mathematical representation of each equation help us to determine whether the equations follow what we know about matter conservation?*

Some students may become frustrated with trying to balance chemical equation A. Encourage them to try chemical equation B and then go back to A. At that point, students should conclude that chemical equation A cannot be balanced.

Question 4

In addition to concrete, glass is another material people might need to establish a permanent settlement on Mars. On Earth, glass is made according to the following chemical reaction:



The coefficient for the final product, glass ($(\text{Na}_2\text{O})(\text{CaO})(\text{SiO}_2)_6$), is 1. Which set of **coefficients** below would lead to a **balanced chemical equation**?

- a = 6, b = 2, c = 1, d = 2
- a = 6, b = 1, c = 1, d = 2
- a = 6, b = 1, c = 2, d = 3
- a = 12, b = 2, c = 2, d = 4

Correct response: $a = 6, b = 1, c = 1, d = 2$

Rationale for distractors:

$a = 6, b = 2, c = 1, d = 2$ is obtained if students incorrectly balance for carbon.

$a = 6, b = 1, c = 2, d = 3$ is obtained if students incorrectly balance for oxygen.

$a = 12, b = 2, c = 2, d = 4$ is obtained if students do not reduce the coefficients.

What to do:

Support students in balancing a more difficult chemical equation. Point out that because we know the coefficient of glass is 1, we know that the **elements found in glass on the products side of the equation cannot be changed**. Encourage students to highlight these elements on the reactants side as they work to balance the chemical equation.

Question 5

Did you contribute an idea to class today? Did you feel that your idea was heard?

What to look for in response:

- Students select that they contributed and indicate that their idea was heard by a small group of students or the whole class.

What to do:

Depending on students' responses, it may be beneficial to revisit the Community Agreements.

- If many students select that they did not share or that their idea was not heard, spend time revisiting the Community Agreements to ensure that students are using the agreements as they work together to make progress on figuring out science ideas.

Lesson 13: Answer Key

Recycling Organizer Key

Source of information	Why can we recycle some of the substances we currently need and not others? What clues are there in the structure and properties of these materials?	How does this inform sustainable engineering solutions for living and working beyond and/or on Earth in the future?
#1 Recycling Processes reading	Aluminum It needs to be heated and is easy to recycle. Steel It just needs to be heated but mining is difficult. Plastic It just needs to be heated, except the thermoset kind. Glass It just needs to be heated with tiny chunks of glass present.	Maybe we should stick with aluminum, glass, and steel as key sources of materials! Plastics seem different from the other three materials. They don't seem as durable.
#2 Thermoplastic and Thermoset demonstration videos	Thermoset plastics burn toxic fumes. Other plastics would melt really fast on Mars. We don't know how these substances do that.	Plastics are tricky; thermosets are more durable and good under heat so they would be more ideal on Mars. But they release really toxic chemicals when recycled, so I wouldn't want to use them.
#3 Polymer molecular models	Polymers are really complex and engineers are developing new ones all the time. The "cross-link" of carbon chains makes plastics stronger and is what makes vulcanized rubber.	The problem with using polymers that are vulcanized is still true because they can burn toxic fumes and you can't recycle them, but maybe engineers have a better idea of what we can do. Steel, glass, concrete, and aluminum seem to be better materials for building things. But maybe for concrete we can switch to using a recyclable version of it, in the future, like we learned about in the last lesson.

Synthesis and Evaluation

Before you read

1. Briefly explain why you picked this topic and article. What questions do you have that you hope it will answer?

Accept all responses. Examples:

CO₂ Plastics/Bioplastics: How can we make plastics more sustainably for outer space?

3-D Printing/Geopolymer Concrete: How can concrete be generated so that it doesn't produce greenhouse gases?

While you read

2. Complete the table for your article.

CO ₂ Plastics/Bioplastics Article 1	
Article Topic: CO ₂ plastics	
What is the sustainable engineering solution being described?	
Making plastics out of captured CO ₂ .	
How does the engineered material <i>work</i> at the particle level? Use structure/function and matter/force thinking.	
CO ₂ is taken from the atmosphere, and then “artificial photosynthesis” happens: CO ₂ reacts with H ₂ O (and energy input) to make polymer chains. The chains are made of small atoms but because they are so long and link with one another, the material is fairly strong.	
What claims does the article make about what the material could be used for?	
Any plastic, or the ones that make up mattresses.	
How did you verify that the claims in at least one of the references match this reading? (The references that are publicly available have a * in front. If an article is behind a paywall, you can still examine its abstract and check that the journal is a reliable source.)	
I skimmed the BBC Earth reference. It is clear and echoes claims in the article. The BBC is a credible news site with low bias.	
CO ₂ Plastics/Bioplastics Article 2	
Article Topic: Bioplastics and circular economy	
What is the sustainable engineering solution being described?	
Making plastics using materials other than fossil fuels. Bacteria can help with that or with recycling certain plastics.	
How does the engineered material <i>work</i> at the particle level? Use structure/function and matter/force thinking.	
Chemical reactions are used to form long chains of plastic from things that are not fossil fuels; bacteria eat plastic to make monomers that can be chained together (bond) to form new plastic.	
What claims does the article make about what the material could be used for?	
There are different plastics that can be used for different purposes like packaging.	
How did you verify that the claims in at least one of the references match this reading? (The references that are publicly available have a * in front. If an article is behind a paywall, you can still examine its abstract and check that the journal is a reliable source.)	
One article is from <i>Nature Reviews Materials</i> . I looked it up and saw that it is a peer-reviewed journal. The abstract indicated general agreement with the article I read.	

3-D Printing/Geopolymer Concrete Article 1

Article Topic: 3-D printed homes

What is the sustainable engineering solution being described?

Using regolith on Mars to make 3-D printed homes.

How does the engineered material *work* at the particle level? Use structure/function **and** matter/force thinking.

Concrete works because of ionic bonds. There are also bonds in the 3-D printed structure, but they are not as strong, particularly between layers.

What claims does the article make about what the material could be used for?

It could be used for shelter if the “sharp dust” doesn’t break the 3-D printer.

How did you verify that the claims in at least one of the references match this reading? (The references that are publicly available have a * in front. If an article is behind a paywall, you can still examine its abstract and check that the journal is a reliable source.)

I checked the NASA website. It talked about the 3-D printed homes being tested on Earth, just like in the article I read. NASA is a reliable source because of its experts.

3-D Printing/Geopolymer Concrete Article 2

Article Topic: Geopolymers

What is the sustainable engineering solution being described?

Using concrete that is made of polymer-like chains.

How does the engineered material *work* at the particle level? Use structure/function **and** matter/force thinking.

The rock must be dissolved in a solvent and atoms linked into long, polymer chains. The covalent bonds in these chains provide strength that is similar to the ionic bonds in concrete.

What claims does the article make about what the material could be used for?

It is very strong! It could be used for structures because the data are really clear that it can be stronger than conventional concrete while releasing less CO₂.

How did you verify that the claims in at least one of the references match this reading? (The references that are publicly available have a * in front. If an article is behind a paywall, you can still examine its abstract and check that the journal is a reliable source.)

The Wang article is in Nature’s *Scientific Reports*, which is a real peer-reviewed journal, and the abstract says the study examined the things that the article said it did.

After you read - with your partner

3. Synthesize information across articles with your partner. Both partners should complete both tables.

4. Evaluate the arguments together. How promising are the technologies in this area for promoting sustainability? Consider:
- what we know about the structure and properties of materials and how forces affect particle-level interactions;
 - what we know about people’s survival needs in space and on Earth;
 - ethical issues like impacts on the environment (living and nonliving) and the humans who live in it.

Accept all thorough responses that use all three dimensions. Sample response:

My partner and I looked at the concrete alternatives. We thought both technologies have some promise on Earth because they release less carbon dioxide than regular concrete does. We were concerned about the 3-D printing on Earth, or maybe even on Mars or the Moon, because the bonds in the structure aren’t as strong as in regular concrete. We were less worried about geopolymer

concrete, because it sounds like the long chains result in covalent bonding that makes it as strong or stronger than regular concrete. We also think geopolymer concrete might be a better option in space or on Earth than 3-D printing because it does not seem to involve as many toxic substances, and the water could be recovered and reused.

Concerns for Our Earth Systems

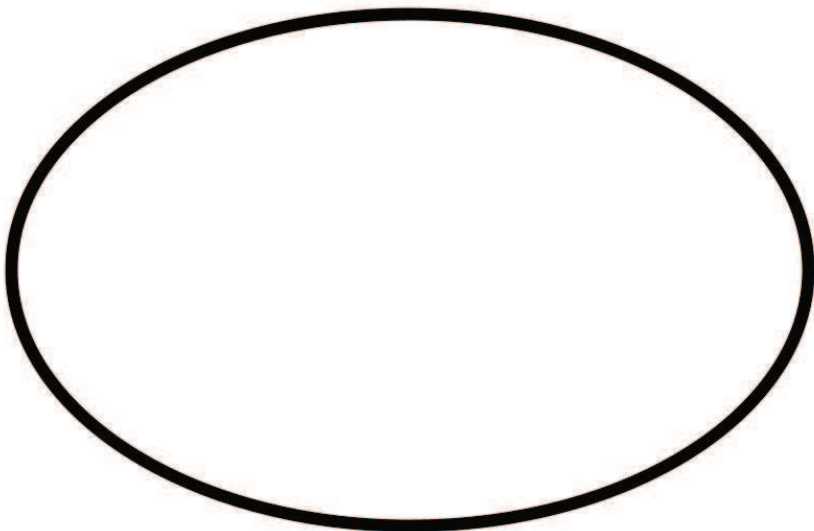
Safety Concerns

Colonization Concerns

Helping Earth Through Space

Discussion Map

Discussion Purpose: Evaluate competing arguments about space travel in light of trade-offs, ethics, and chemistry. Write students' initials according to where they sit. As the discussion progresses, use the codes to note student contributions.



Codes	
1	Key Idea 1: Students evaluate competing arguments in light of trade-offs and ethical concerns. (SEP: 7.1)
2	Key Idea 2: Students indicate that the conservation of matter in chemical reactions limits what is possible in space. (DCI: PS1.B.3)
3	Key Idea 3: Students share that matter must be transformed from existing matter if we are to survive elsewhere. (CCC: 1.2)

Lesson 15: Answer Key

Soapscum Transfer Task Key

NGSS performance expectations being addressed:

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. (SEP: 2.3; DCI: PS1.A.1, PS1.A.2; CCC: 1.1)

HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. (SEP: 6.2; DCI: PS1.A.2, PS1.B.3; CCC: 1.1)

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 #					
	1	2	3a	3b	3c	4
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				
Constructing Explanations and Designing Solutions. Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (SEP: 6.2)			X	X	X	X
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. (DCI: PS1.A)						X
Structure and Properties of Matter. The periodic table orders elements horizontally by the number of protons in the atoms nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (DCI: PS1.A)	X			X	X	X
Chemical Reactions. The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (DCI: PS1.B)	X	X	X		X	
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)				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.

Have you ever washed your hands and thought that they did not feel clean? It may be that something formed on your hands called soap scum! Soap scum forms when you wash your hands using some bar-shaped soaps with hard water. Hard water is water that

contains high amounts of dissolved minerals, such as calcium bicarbonate, $\text{Ca}(\text{HCO}_3)_2$, common in rocks like limestone.

Calcium bicarbonate is an ionic compound that breaks apart into two ions when it dissolves in water: Ca^{2+} and HCO_3^- .

Having hard water not only can affect how clean your skin feels, it can also lead to serious issues with your home plumbing. Hard water can cause soap scum and other deposits to build up on the inside of pipes. This can lead to clogs in pipes and provide surfaces for bacterial growth.

Question 1. Develop an initial model to explain what you think might be happening between calcium bicarbonate and water before **soap scum** forms on the sink drain. Be sure to include the following components of the system and their interactions in your model:

- drain surface
- **water molecules, including partial charges**
- calcium and bicarbonate ions

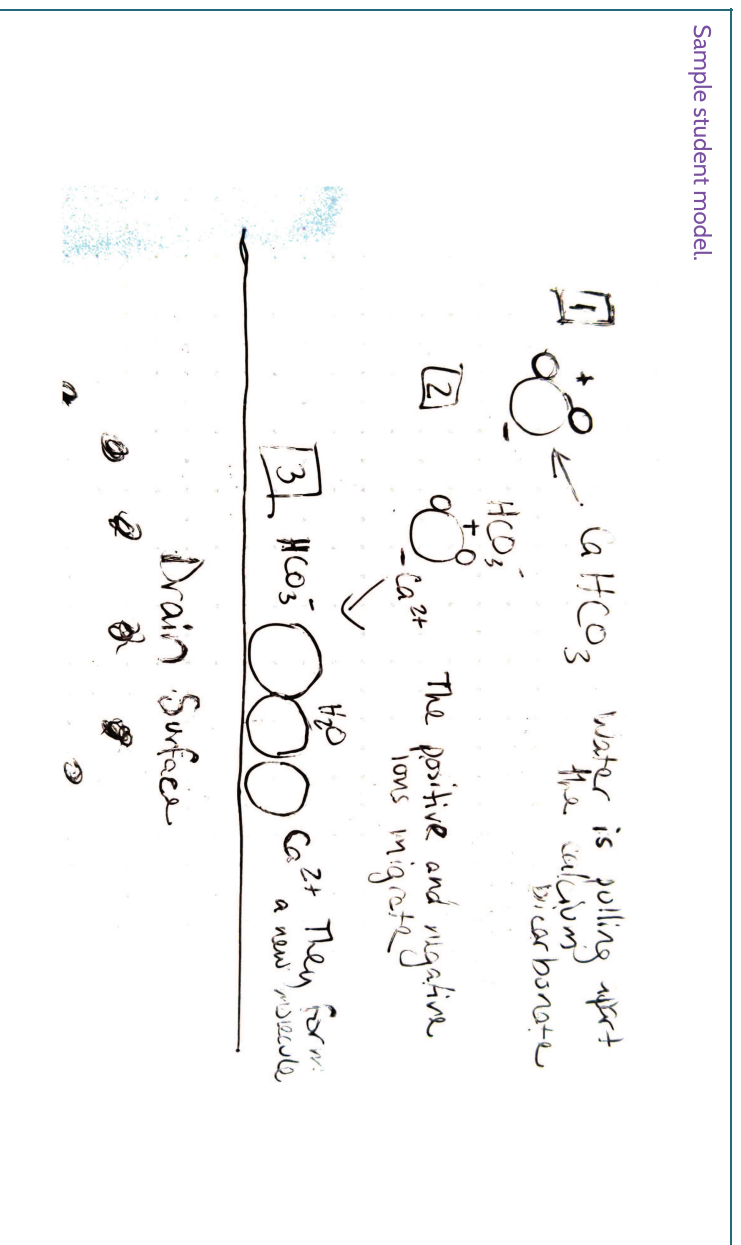


Soap scum on sink drain.



Hard water deposits on faucet head.

Sample student model.



Key elements:

+ model predicts and illustrates interactions between components of the system

+ shows **interaction between water and calcium bicarbonate to form ions**

Additional accurate element not essential to this item:

++ shows **force interactions between water and calcium bicarbonate to form ions**

Sample student response:

See sample student model above.

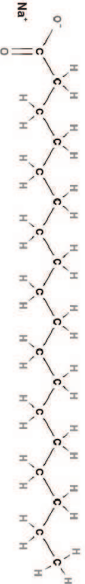
What to do: Use this item as a pre-assessment of students' understanding about interactions of polar water molecules with ionic compounds.

Use *Periodic Table* from Lesson 7 and *Electronegativity Periodic Table* from Lesson 9 as you answer the items to figure out:

- How do the particle-level structures help further explain what causes soap scum?

How do the particle-level structures help further explain what causes soap scum?

Bar soaps typically contain a compound called sodium stearate, $\text{NaC}_{18}\text{H}_{35}\text{O}_2$, which is soluble in water. When water has high quantities of dissolved calcium bicarbonate, $\text{Ca}(\text{HCO}_3)_2$, the calcium ions (Ca^{2+}) can replace the sodium ions (Na^+) to form calcium stearate or soap scum, $\text{Ca}(\text{C}_{18}\text{H}_{35}\text{O}_2)_2$. This substance is insoluble (cannot dissolve) in water and gets stuck on hands and in pipes.

Compound and name	Solubility in water
$\text{NaC}_{18}\text{H}_{35}\text{O}_2$, Sodium stearate (soap)	Soluble
Model	
	

Compound and name	Solubility in water
$\text{Ca}(\text{C}_{18}\text{H}_{35}\text{O}_2)_2$, Calcium stearate (soap scum)	Insoluble
Model	
	

Question 2. *Balance* the chemical equation for this reaction by *adding coefficients* on the provided lines. Use the table to help you keep track of atoms as you are balancing the chemical equation.



Elements	Reactants	Products
Ca, calcium	1	1
HCO_3 , bicarbonate	2	42
Na, sodium	42	42
$\text{C}_{18}\text{H}_{35}\text{O}_2$, stearate	42	2

Key elements:

+ chemical equation (model) has correct *coefficients added*

Sample student response:

See sample student responses on the equation and in the table above.

What to do: If students incorrectly balance the chemical equation, have them refer back to *Balancing Equations Molecules* from Lesson 11 or the work they did in Lesson 12. Help students think about how to handle the polyatomic ions when balancing chemical equations by pointing out how the polyatomic ion is acting as a single element in each compound shown in the chemical equation. If students do not recall what the parenthetical states of matter in the chemical equation relate to, refer students back to *Key Chemical Reactions* from Lesson 10.

The chemical equation you balanced in **Question 2** summarized the overall process to form soap scum. It did not illustrate the process of sodium stearate, $\text{NaC}_{18}\text{H}_{35}\text{O}_2$, being dissolved in water. The sodium is attracted to the oxygen portion of the stearate ion. You know from prior lessons that the oxygen portion of a water molecule also has a negative charge.

The following table provides information about atomic radius and electronegativity of the atoms to help explain differences in polarity of the water molecules, H_2O , and stearate ions, $\text{C}_{18}\text{H}_{35}\text{O}_2^-$.

Atom	Radius (pm) 1 billion pm = 1 mm	Electronegativity of elements
Na, sodium	180	0.93
H, hydrogen	25	2.22
C, carbon	70	2.55
O, oxygen	60	3.44

Question 3a. How is it possible that the **oxygen atom in the water molecule is able to pull the sodium ion away from the oxygen atom in the stearate ion**? Construct an explanation of this phenomenon using differences in electronegativity between the atoms in water molecules and stearate ions. You may wish to use the following table to help you think through your evidence.

Bond	Difference in electronegativity
O - H (in water molecule)	$3.44 - 2.22 = 1.22$
O - C (in stearate ion)	$3.44 - 2.55 = 0.89$
O - Na (O in water, Na in sodium stearate)	$3.44 - 0.93 = 2.51$

Key elements:

- + explanation includes evidence from the given table (or periodic table)
- + uses **differences in electronegativity (chemical property)** to reason why **sodium is more attracted to oxygen**

Sample student response:

The electronegativity difference between the O-H bonds in water is greater than between the O-C bonds in the stearate ion. This means that the water molecule is more polar than the stearate ion. So when sodium stearate is added to water, the sodium ion is more attracted to the oxygen atom in the water molecule than to the oxygen in the stearate ion.

What to do: If students struggle to remember the relationship between electronegativity differences and polarity, refer them back to their work on *Electronegativity Periodic Table* and *Sila-ibuprofen Transfer Task* from Lesson 9.

Another process in the chemical equation you balanced in **Question 2** was not shown. Just as sodium stearate, $\text{NaC}_{18}\text{H}_{35}\text{O}_2$, dissolves in water, so does calcium bicarbonate, $\text{Ca}(\text{HCO}_3)_2$. The free-floating stearate ions, $\text{C}_{18}\text{H}_{35}\text{O}_2^-$, and calcium ions, Ca^{2+} , are able to bond with each other to form calcium stearate, $\text{Ca}(\text{C}_{18}\text{H}_{35}\text{O}_2)_2$.

Question 3b. Why does the **calcium ion attach to two stearate ions**? Construct an explanation using **evidence from patterns in the periodic table** and information presented in this assessment as support.

Key elements:

- + explanation includes evidence from patterns in the periodic table and information in the assessment
- + states number of valence electrons in a calcium atom, or the charge of a calcium ion
- + states charge of a stearate ion
- + explains that to have a stable compound, the charges need to balance

Additional accurate element not essential to this item:

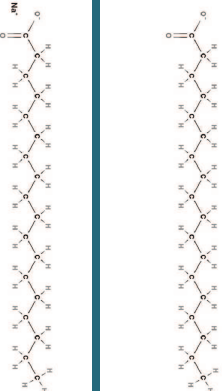
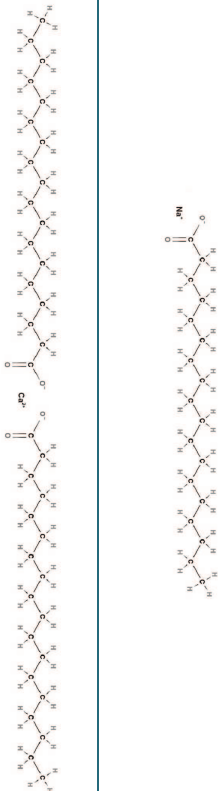
++ compares numbers of valence electrons in sodium and calcium to explain differences in stearate compound structures

Sample student response:

Calcium has two valence electrons. This means that calcium has a 2+ charge, because it gives up the two valence electrons when it bonds with other elements. The stearate ion has one valence electron, which we know because it has a - charge. So, in order to have a stable compound, there needs to be a second stearate ion.

What to do: Help students think about how the number of valence electrons in the atom corresponds to the charge on the ion. You can have students do this by referring to the Lewis dot models in the periodic table in *Periodic Table* from Lesson 7. Alternatively, encourage students to visually represent this using the Lewis dot model for calcium and then creating a Lewis dot model for stearate ions, which should be modeled after atoms that have a - charge.

Question 3c. The following table includes information about the **stearate ion**, **electronegativities of its elements**, and images of calcium stearate and sodium stearate. Use this information and patterns in the periodic table to explain why the **sodium or calcium ion** is likely to be closer to the oxygen atoms in the stearate ion rather than the portion containing carbon and hydrogen.

Ion/molecule and name	Radius (pm) 1 billion pm = 1 mm	Electronegativity of elements
$\text{C}_{18}\text{H}_{35}\text{O}_2^-$ Stearate ion	> 4000	C = 2.55 H = 2.22 O = 3.44
$\text{NaC}_{18}\text{H}_{35}\text{O}_2$ Sodium stearate		
$\text{Ca}(\text{C}_{18}\text{H}_{35}\text{O}_2)_2$ Calcium stearate		

Key elements:

- + explanation includes evidence from the given table and patterns in the periodic table
- + oxygen has greater electronegativity, so sodium/calcium are more attracted to it
- + discusses differences in electronegativity between sodium/calcium and oxygen, carbon, and hydrogen

Sample student response:

The sodium or calcium ions are closer to the oxygen end because it is the more polar end of the stearate ion. Oxygen has the highest electronegativity of the atoms found in the stearate ion. So that end should be more polar than the end containing carbon and hydrogen atoms. The electronegativities of sodium and calcium are pretty close to each other. There's a greater difference in the electronegativities of sodium/calcium and oxygen compared to sodium/calcium and hydrogen or sodium/calcium and carbon. Because of this, sodium/calcium is more attracted to oxygen.

What to do: Prompt students to think about differences in electronegativity between sodium/calcium and oxygen, carbon, and hydrogen. Point them back to *Electronegativity Periodic Table* and *Modeling Polarity* from Lesson 9 or their related Progress Tracker entry. Ask, *How might differences in electronegativities between the different atoms explain why one part of the stearate ion is more attractive to sodium or calcium than the other?*

Hard water can also contain other dissolved minerals which can lead to the formation of soap scum. Chemical engineers are studying two minerals and their likelihood to cause damage to pipes: potassium carbonate, K_2CO_3 , and magnesium bicarbonate, $Mg(HCO_3)_2$.

Question 4. Which mineral, potassium carbonate or magnesium bicarbonate, would most likely form soap scum by combining with stearate ion(s) to form an insoluble compound? Why?

- Use evidence from patterns in the periodic table and information presented in this assessment as support for your explanation.



Hard water buildup in a pipe.
Александр Юрьевич
Лебедев

	Foundational Understanding	Linked Understanding	Organized Understanding
3D Elements	Incorrectly predicts that potassium carbonate, or that both ionic compounds, will form soap scum. Written explanation ties back to the model or includes scientific information from sources students used during the unit. Relates that because potassium and calcium are next to each other in the periodic table, potassium will form an insoluble compound.	Predicts that magnesium bicarbonate will form soap scum. Written explanation mentions the model and references scientific information from sources students used during the unit. Relates that because magnesium and calcium are in the same column of the periodic table, magnesium will form an insoluble compound.	Predicts that magnesium bicarbonate will form soap scum. Written explanation explicitly ties back to the model and references scientific information from sources students used during the unit. Relates that because magnesium and calcium are in the same column in the periodic table, both will need to combine with two stearate ions, resulting in an insoluble compound.
Example	Potassium carbonate will form soap scum if it is dissolved in water. Potassium and calcium are next to each other/in the same row of the periodic table. That means they will both form insoluble compounds.	Magnesium bicarbonate will form soap scum if it is dissolved in water. Its atomic structure is most like calcium carbonate. You can also look at its location in the periodic table: calcium and magnesium are in the same family/column, so they will have similar chemical properties. Since calcium forms an insoluble compound with stearate, so will magnesium.	Magnesium bicarbonate will form soap scum if it is dissolved in water. Its atomic structure is most like calcium carbonate. You can also look at its location in the periodic table: calcium and magnesium are in the same family/column, so they will have similar chemical properties. For example, they both have two valence electrons. Since we know that calcium bonds to two stearate ions, making it insoluble in water, we can assume that magnesium will do the same.

Feedback / What to do	<i>Linking:</i> Have students think about the differences in the valence electron configurations of the atoms and how those differences explain why one would form an insoluble stearate compound. Ask, <i>What is different about the atomic structures of the potassium and magnesium atoms? How are they similar to or different from the atomic structures of sodium and calcium atoms?</i>	<i>Organizing:</i> Have students explicitly link their written explanation to their models. Ask, <i>How do your models support your explanation?</i>	<i>Extending:</i> Encourage students to move beyond atomic structure (e.g., valence electrons) to incorporate forces thinking to explain why two bonds might result in a more stable, insoluble compound, using ideas they developed related to cross-linking in polymers.
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Ideas for Instruction	Foundational Understanding	Linked Understanding	Organized Understanding
	Review the electron shell or Lewis dot models of the first 18 elements on <i>Periodic Table</i> from Lesson 7 with students. Help them use trends in the periodic table to think about the structure of calcium, which is not shown in either of those two examples. Encourage students to revisit their Progress Trackers.	Review the assessment with students to help them connect their model to their explanation.	Invite students to consider the role of forces in forming soap scum. Encourage students to think about differences in electronegativity and/or polarity of the ionic compounds involved.