PHYSICS

Electromagnetic Radiation

How do we use radiation in our lives, and is it safe for humans?

OpenSciEd

HIGH SCHOOL SCIENCE

TEACHER EDITION

How do we use radiation in our lives, and is it safe for humans?

Electromagnetic Radiation: Microwaves

OpenSciEd Unit P.5

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TABLE OF CONTENTS

UNIT P.5 How do we use radiation in our lives, and is it safe for humans?

UNIT OVERVIEW

How do we use radiation in our lives, and is it safe for humans?

This unit is anchored by a short news article explaining that some people are using their microwave ovens to store electronics. This is followed by a series of in-class demonstrations using a microwave oven, including playing music on a Bluetooth speaker from a device inside the oven and heating a plate of nachos (or a similar food).
In the first lesson set (L1-8) they investigate wave properties and their relationships, and learn about the production of electromagnetic radiation from electricity using a magnetron. They use a simulation to understand how moving a charged particle back and forth will create ripples in the electric field surrounding it that propagate through space as electromagnetic waves. They design investigations to better understand how microwaves, a type of electromagnetic wave, are contained in the oven, and find evidence to build an explanation of wave reflection. Students use simulations to investigate how particles of different materials (water, plastic, metal) interact with changing electric fields, and connect this particle-scale evidence to macroscopic evidence about materials heating up in the microwave oven. They also use simulations to make sense of wave interference to explain the hot and cold spots produced by the microwave oven. By the end of this lesson set, students are ready to explain how a microwave oven uses the principles of wave behavior to transfer energy into food, but they still have questions about the safety of this technology, and how other forms of radiation are used.
In the second lesson set (L9-13), students build out the electromagnetic spectrum, read about the dual nature of electromagnetic radiation, and consider the safety of different radiation technologies. In the transfer task, students use their understanding of EM radiation and its associated technologies to evaluate two social media posts about 5G radiation, and use the model for EM radiation to argue from evidence about whether this technology is safe.

Throughout the unit, students will do the following:

- Use simulations to model and understand field interactions to transfer energy across space through electromagnetic radiation (waves).
- Plan and conduct investigations to provide evidence to explain the interactions of microwave radiation with matter.
- Construct explanations and develop claims using evidence from a variety of sources including student's own data, readings, models to identify relationships between material interactions and electromagnetic radiation.
- Obtain and communicate information about the uses of electromagnetic radiation, its safety, and ways to protect ourselves.

Building Toward NGSS Performance Expectations

HS-ESS2-4:
Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS-PS2-5:
Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

HS-PS4-1:
Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

HS-PS4-2:
Evaluate questions about the advantages of using digital transmission and storage of information.

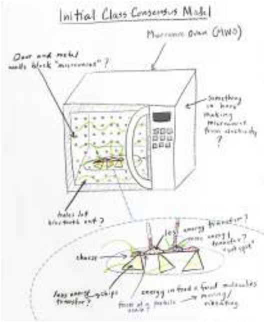
HS-PS4-3:
Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

HS-PS4-4:
Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

HS-PS4-5:
Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.*

UNIT STORYLINE

Unit Question: How do we use radiation in our lives, and is it safe for humans?

Lesson Set 1: How does a microwave oven heat up food?			
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 Lesson Set 1 3 days **How do microwave ovens function, and why does their structure affect wireless signals?** Anchoring Phenomenon 	 *Wireless communication signals are affected when they pass through the walls and door of a microwave oven. The microwave oven cooks food quickly and without an obvious heat source.*	We read an article about an interesting trend: people are storing their phones, keys, and other electronic devices in their microwave ovens. We observe a Bluetooth speaker paired to a device inside a closed microwave oven, read the *Microwave Oven Manual*, and then safely heat food and make additional observations. We model the structure and function of the microwave oven, build a Driving Question Board, and brainstorm future investigations and data we need. We figure out: ● The structure of a microwave oven blocks or somehow affects wireless signals, but not completely. ● The function of a microwave oven is to heat (transfer energy into) liquid/food. ● Using a microwave oven requires attention to safety.	

⇓ **Navigation to Next Lesson:** We have a lot of questions about microwave ovens and wireless technology, and a lot of ideas for investigations we want to do to answer our questions.

LESSON 2
Lesson Set 1

1 day

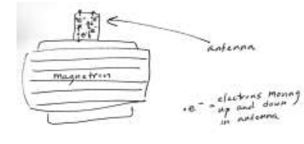
How does a microwave oven use electricity to produce microwave radiation?

Investigation

When a microwave oven is taken apart, we find a magnetron with an antenna. This antenna probably changes fields inside the cooking area, but to be sure we need to know more about how the magnetron works.

We integrate information from our *Microwave Oven Manual*, a video of a magnetron being dissected, a reading, and a brief investigation to identify a relationship between moving electrons and changing electric fields. We figure out:

- Electrons vibrate inside the antenna of a magnetron.
- Vibrating charged particles change electric fields.
- Changing electric fields carry energy across space.
- The microwave oven is designed so the magnetron antenna changes electric fields near the oven's cooking area. This energy transfers across space and somehow reaches the food.



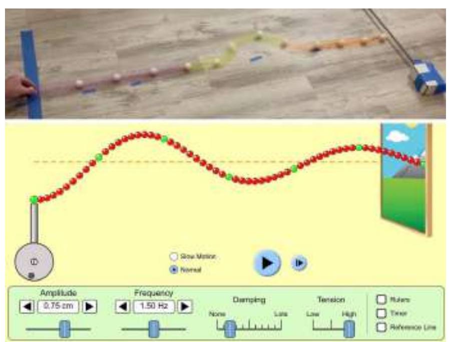
⇓ **Navigation to Next Lesson:** We have many ideas about how the changing electric fields emitted from the magnetron transfer energy from the antenna to the food. We recognize that we need to know more about waves to investigate these ideas in more detail.

LESSON 3
Lesson Set 1

3 days

How does energy transfer through a wave?

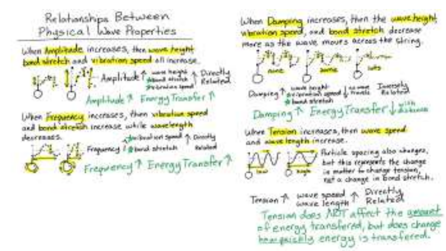
Investigation



Shaking the end of a slinky creates a wave pattern. A computer simulation of a wave on a string produces similar patterns.

We recall examples of physical waves and produce waves with a spring. We develop a model of how physical waves transfer energy through solids. We use a computer simulation to plan and carry out four investigations. Using our results, we make claims for how various wave properties affect energy transfer. We develop a mathematical model of the relationship between some of these properties. We figure out:

- Energy is transferred through waves on a string by the stretching of electric fields (bonds) and by the forces between these fields and the matter of the string.
- A larger amplitude transfers more energy along the wave.
- A larger frequency transfers more energy along the wave.
- The wavelength of a wave can be determined by the wave speed across the



medium and its frequency.

⇓ **Navigation to Next Lesson:** We think that the multiple perspectives (M-E-F) we have used to explain energy transfer in physical waves could also help us make sense of how energy transfers from the magnetron to the food inside the microwave oven.

LESSON 4

Lesson Set 1

2 days

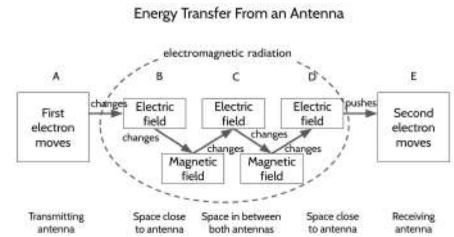
How does an antenna transfer energy to matter at a distance?

Investigation

Electromagnetic radiation can be visualized as changing electric and magnetic fields rippling outward from a moving charge.

We investigate how moving electrons in an antenna cause energy to transfer. We use and evaluate different representations of electromagnetic radiation propagating through space, and read about the mechanism that generates electric and magnetic fields from a vibrating charged particle. We develop a mechanistic explanation of electromagnetic radiation and use it to predict its interactions with matter inside the microwave oven. We figure out:

- Moving electrons create electric fields that change.
- These changing electric fields, in turn, create changing magnetic fields, which generate changing electric fields again. This wavelike cycle continues, resulting in the formation of electromagnetic radiation.
- Electromagnetic radiation can travel through empty space without needing matter to move through.
- The energy in changing electric and magnetic fields spreads out as waves travel, becoming weaker the farther they go.



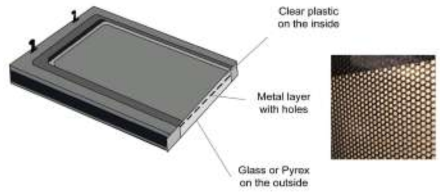
⇓ **Navigation to Next Lesson:** We figured out how electromagnetic waves transfer energy through space, but we wonder how microwaves interact with the matter inside the microwave oven.

LESSON 5
Lesson Set 1

3 days

How does radiation interact with the parts of the microwave oven system?

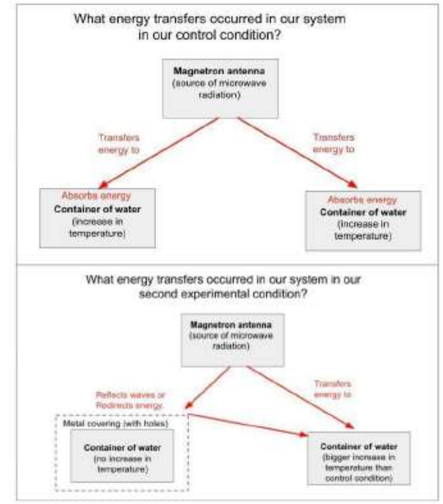
Investigation



When bowls of water wrapped in foil or in foil with small holes are in a running microwave oven for 15 seconds, their temperature does not increase.

We argue for, plan, and carry out investigations to determine what happens to microwave radiation when it reaches the material(s) in the microwave oven door and walls. We develop a model to explain the results of our investigations, showing what happens to the energy transferred by these waves when they interact with these parts of the system. We figure out:

- The energy transferred by microwave radiation can be absorbed (food heating up), reflected (off metal walls), and/or transmitted by matter.
- We all have an ethical responsibility to consider the possible personal, societal, and environmental impacts of any scientific investigation we plan or engineering solution we design.
- The window in the microwave oven door transmits one type of EM radiation (visible light) through it, but transmits none (or very little) of another type of EM radiation (microwave radiation).



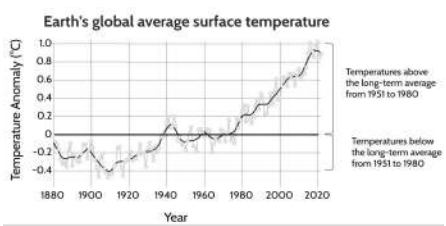
⇓ **Navigation to Next Lesson:** Though we were able to determine how microwave radiation interacts with some materials, we still have questions about why it interacts the way it does and how other materials (e.g., different foods) interact with it.

LESSON 6
Lesson Set 1

1 day

How can we use interactions between matter and electromagnetic radiation to explain the increase in global temperatures?

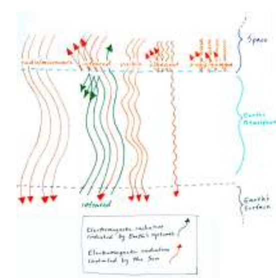
Putting Pieces Together



Greenhouse gases and global temperatures have increased over the last century, but the amount of solar radiation has not.

We add new questions to the Driving Question Board and use our science ideas about the interactions of different types of EM radiation with different types of matter to explain how an increase in greenhouse gases could be contributing to the overall increase in global temperatures. We figure out:

- EM radiation is emitted by the Sun.
- A percentage of that EM radiation is absorbed, reflected, or transmitted when it enters Earth's atmosphere.
- After EM radiation reaches Earth, matter on the surface absorbs it and then emits infrared radiation that is more readily



- absorbed by the greenhouse gases in the atmosphere.
- Because of the prevalence and longevity of carbon in the atmosphere, carbon has contributed to the increased temperatures globally and will continue to do.

⇓ **Navigation to Next Lesson:** We revisited our Driving Question Board and realized we still have many questions about other types of EM radiation, their safety, and their interactions with various types of matter, such as food and other objects.

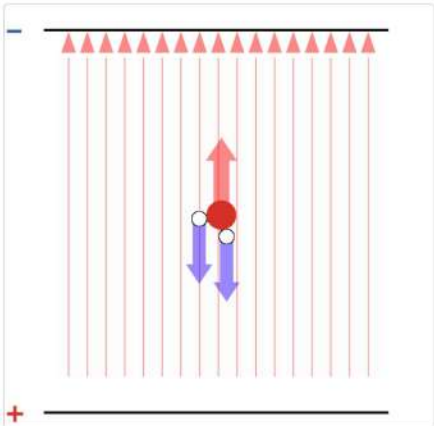
LESSON 7

Lesson Set 1

2 days

Why do some substances heat up faster than other materials in a microwave oven?

Investigation, Putting Pieces Together



Different materials respond differently when heated inside the microwave oven. Water heats up, plastic doesn't, and aluminum foil creates sparks.

We use simulations to model how matter of different materials (water, plastic, metal) interact with changing electric fields of different frequencies. We connect this particle-scale evidence to macroscopic evidence about materials heating up in the microwave oven, then model our understanding. We read articles to consider whether metal in the microwave oven is safe, and consider the validity and reliability of these claims. We figure out:

- The forces from changing electric fields in the microwave oven will cause polar molecules, like water, to rotate in the direction of the fields.
- The interaction between the microwave radiation and the water molecules will transfer energy out of the fields and into thermal or kinetic energy of the water.
- Electrons can move inside conductors like metal when pushed by changing electric fields in microwave radiation, which can cause reflection, or dangerous arcing in some cases.

⇓ **Navigation to Next Lesson:** We wonder what causes the patterns of melted and unmelted cheese when we heat nachos in the microwave oven.

LESSON 8

Lesson Set 1

3 days

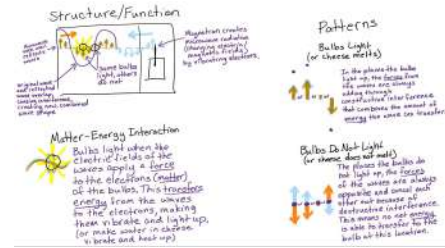
Why do we see patterns of hot and cold spots in the microwave oven?

Investigation, Putting Pieces Together

When many small light bulbs are placed across the microwave oven while it is running, some light up and some do not.

We observe a pattern when light bulbs are placed in the microwave oven. We use simulations to make sense of wave interference. We model wave interference from an energy perspective to explain hot and cold spots in the microwave oven. We revise our initial consensus model from the anchor phenomenon and our Driving Question Board. We figure out:

- When two waves meet in space, they can produce a new wave through either constructive or destructive interference, but the total combined energy of the original waves is conserved.
- The microwave oven produces hot and cold spots due to constructive and destructive wave interference between the waves emitted from the magnetron and those reflected off of the oven's interior walls.
- The turntable in the microwave oven is designed to move food between hot and cold spots to provide more even heating.



⇓ **Navigation to Next Lesson:** We can explain how electromagnetic radiation can transfer energy to food in a microwave oven, but we cannot explain how it can be used to transfer information between wireless devices.

Lesson Set 2: How do we use electromagnetic radiation safely in our lives?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it

LESSON 9
Lesson Set 2

2 days

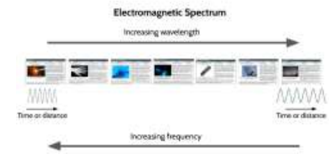
What other types of EM radiation are there, and how do we use them?

Investigation, Problematizing

The electromagnetic spectrum includes various types of radiation with a wide range of frequencies, wavelengths, and uses, such as communication and medical imaging, but some types can also pose health risks.

We examine the remaining categories of DQB questions and construct the EM spectrum using the wavelength and frequency of various types of EM radiation. We write an argument about the relationship between the frequency and wavelength of EM radiation and its interactions with matter, and how this relationship helps explain some of the uses of EM radiation. We add new questions to the DQB. We figure out:

- The EM radiation spectrum is arranged from high- to low-frequency (short to long wavelength) EM waves.
- Different types of EM radiation have different interactions with matter, including heating it up, ionizing it, or breaking apart its molecules.
- These interactions can be harnessed for various applications, such as medical imaging, telecommunications, and energy production.
- Ionizing radiation can harm living organisms.



⇓ **Navigation to Next Lesson:** We are wondering why some types of EM radiation can damage or kill living organisms and others do not.

LESSON 10
Lesson Set 2

2 days

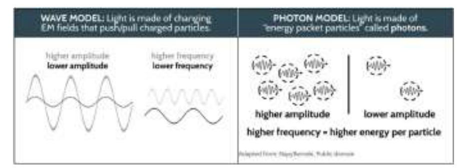
Does all electromagnetic radiation cause damage?

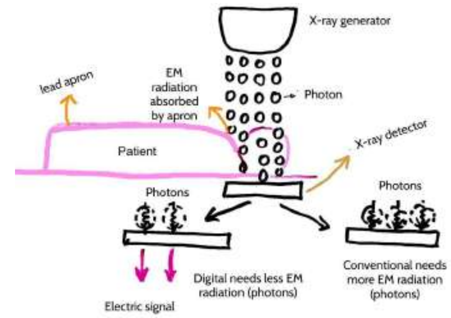
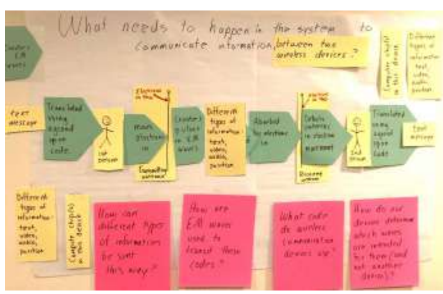
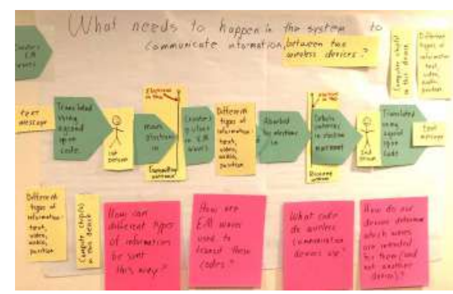
Investigation

Not all frequencies and amplitudes of light are linked to skin cancer.

We question whether higher frequency or higher amplitude EM radiation leads to an increase in skin cancer. We use multiple sources of evidence to try to identify patterns in frequency, amplitude, and skin cancer. We use both a wave model and a photon model to try to explain our evidence. We figure out:

- The photons of high-frequency EM radiation have enough energy to knock out electrons, causing changes in the molecular structure of the DNA molecule.
- More high-frequency, ionizing radiation puts you at greater risk of cancer, but how much the risk increases depends on the type of radiation and the total exposure



		time. ● The photon model of EM radiation can better explain the interactions of high-frequency EM radiation and matter.	
⇓ **Navigation to Next Lesson:** We wonder about why we still use high-frequency radiation in multiple technologies if it is so dangerous.			
LESSON 11 Lesson Set 2 1 day **How can we use EM radiation to create and store digital images?** Investigation	 *Digital radiography uses electronic detectors to capture X-rays for creating and storing digital images of our bodies' internal structures.*	We wonder how EM radiation is used to create and store digital images. We read about how the interactions of X-rays with matter can be harnessed to create images of the internal structure of our body, and about the advantages and disadvantages of digital versus conventional radiography. We wonder how EM radiation is used in wireless communication to transmit information. We figure out: ● Sensors that respond to EM radiation are very sensitive and can trigger electric currents that can be used to create digital images. ● Digital images can be reliably stored in our computers. ● Digital technologies can reduce the time of exposure to the ionizing radiation necessary in medical applications.	
⇓ **Navigation to Next Lesson:** We figure out that the interactions of X-rays with matter can be harnessed to create digital images for medical applications while reducing the time of exposure needed, and thus, reducing the potential harm they can cause us. We wonder how the interactions between EM radiation and matter are used in communication technologies.			
LESSON 12 Lesson Set 2 2.5 days **How are our wireless electronic devices designed to use EM waves to reliably communicate different types of information?**		We develop ways to send messages with EM waves using a simulation. We develop a model for how this system works and compare it to digital communication systems. We gather information from multiple sources in various formats from four different stations. We integrate this information with our model to summarize how our wireless electronic devices are designed to use EM waves to reliably communicate various types of information. We figure out:	

Investigation

Pulses of sound, light, and other EM waves have been used in the past to communicate text messages over long distances.

- The majority of modern wireless communication uses binary code (digital transmission) to represent information, such as text, audio, photos/video, and location.
- Binary code is a combination of “on” and “off” states; it can be represented in EM radiation by varying the energy in the wave, using changes in the wave’s amplitude or frequency to communicate “on” and “off”.
- If a wireless message is encrypted, only the intended receiver can decode the information.

⇓ **Navigation to Next Lesson:** We consider the argument that scientists and engineers are making that using even higher frequency EM radiation in future wireless communication technologies could provide some advantages. We can already see some trade-offs related to doing this.

LESSON 13

Lesson Set 2

1.5 days

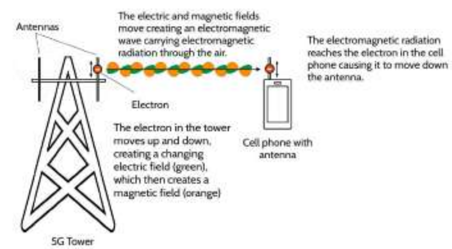
Is communication technology that uses radiation safe?

Putting Pieces Together

EM radiation affects different materials in different ways.

We return to the Driving Question Board to take stock of where we have been and what questions we have answered. We work through an assessment task in which we evaluate two social media posts about 5G radiation, and we use our model for EM radiation to argue from evidence about whether this technology is safe. We figure out:

- We have answered many of our questions about EM radiation.
- 5G technology is most likely not dangerous because it is not a form of ionizing radiation, but long-term exposure could lead to potential health consequences.



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

LESSONS 1-13

27 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 fifth in the OpenSciEd High School Physics course sequence. It is designed to build on student ideas about energy transfer and forces from previous units, and apply these ideas in the context of waves and electromagnetic radiation. In the first unit of the course, *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*, students develop ideas around energy transfer and conservation in the context of charged particles (electrons) colliding with other electrons (electricity) to transfer energy across great distances. In the second unit of the Physics course, *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*, a sudden rip in Earth's crust motivates the need to consider forces to explain our observations. In the third unit, *OpenSciEd Unit P.3: What can we do to make driving safer for everyone? (Vehicle Collisions Unit)*, students develop a more robust understanding of forces as vectors and use conservation of momentum to make predictions about the outcomes of collisions. In the fourth unit, *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*, students expand their model of forces to include the force of gravity at great distances, using ideas about fields developed in the first unit to understand the relationships between gravity and energy transfer. In this unit, *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*, students use energy transfer, electromagnetism, wave mechanics, and forces at a distance to explain how food heats up in a microwave and how this technology might be dangerous for humans (and also save lives). In the final unit, *OpenSciEd Unit P.6: Earth's History and the Big Bang (Cosmology Unit)*, students will explore cosmology and the Big Bang, applying ideas about forces and energy from all five previous units on the largest scale.

What is the anchoring phenomenon and why was it chosen?

This unit is anchored by a short news article explaining that some people are using their microwave ovens to store electronics. This is followed by a series of in-class demonstrations using a microwave oven, including playing music on a Bluetooth speaker from a device inside the oven and heating a plate of nachos (or a similar food). Students draw on their personal experiences of heating food to make predictions about how to transfer energy quickly into matter. The use of a microwave oven both to block wireless signals and to heat food provides the context in which to investigate the nature of energy transfer through waves, properties of waves, the interactions of electromagnetic (EM) radiation with various particles, the use of EM radiation in our daily lives, and safety considerations when using those technologies.

The microwave oven anchoring phenomenon was chosen from a group of phenomena aligned with the target performance expectations based on the results of two focus groups with high schoolers from across the country, and in consultation with external advisory panels that included teachers, subject matter experts, and state science administrators. This unit was adapted from a previous unit, and therefore did not follow the same selection process as other OpenSciEd HS units. The microwave oven anchor was chosen for the following reasons:

- Teachers and administrators saw high relevance to students' everyday experiences.
- Students found the phenomenon compelling and had dozens of relevant questions.
- Explaining how the microwave oven heats food addresses all the DCIs in the bundle at a high school level.
- Students have a unique opportunity to generate observable EM radiation in the classroom with a microwave oven and use it to investigate the interactions between EM radiation and matter.
- The microwave oven shares components with many other forms of technology that are relevant to students' lives.

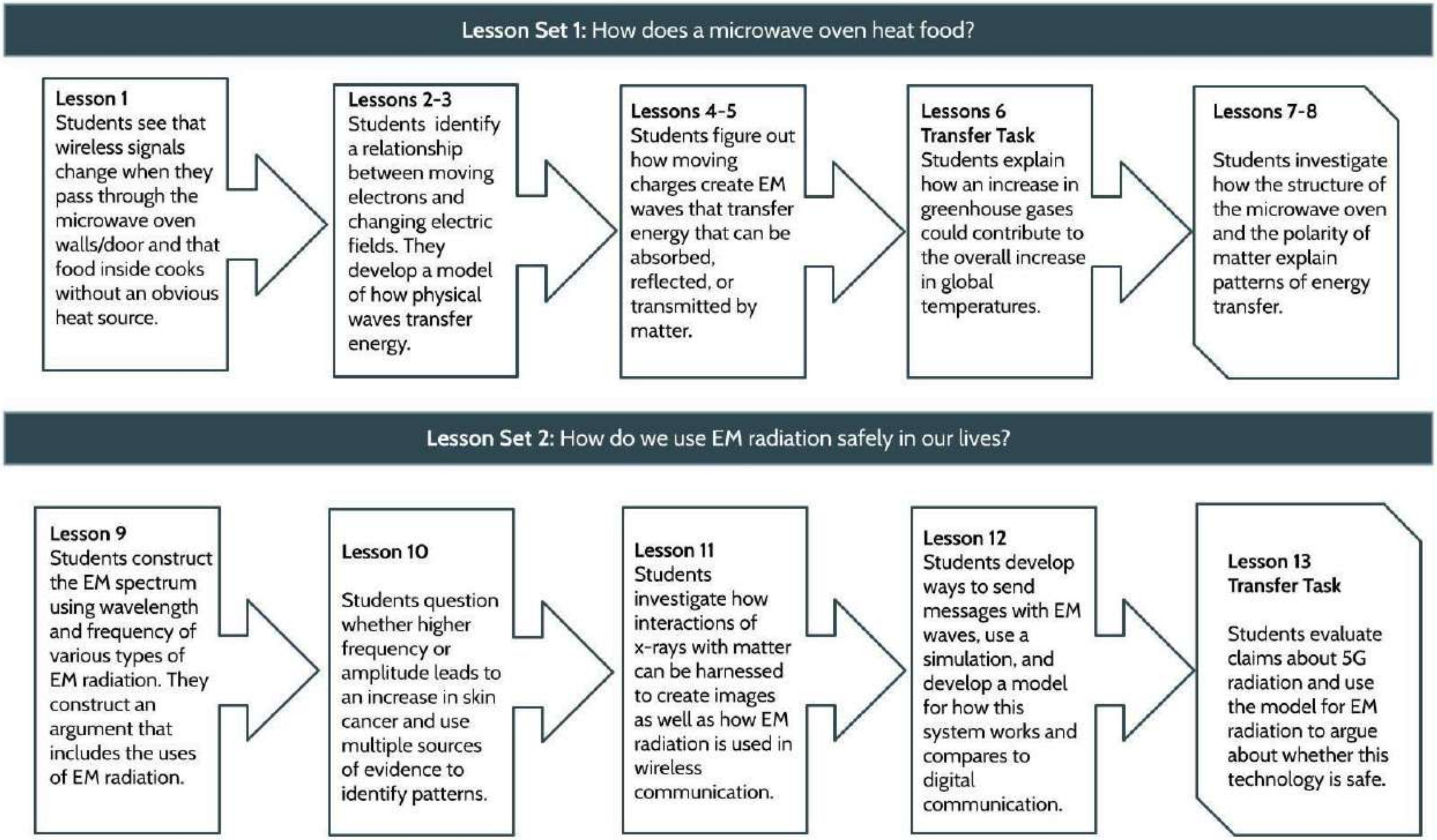
How is the unit structured?

The unit is organized into two main lesson sets. Lesson Set 1 (Lessons 1-8) focuses on developing science ideas about energy transfer through waves and changing electric and magnetic fields. These lessons also cover how the structure of the microwave oven and the type of substance within the oven influences how well a material absorbs wave energy. Lesson Set 2 (Lessons 9-13) shifts the focus to examining other types of EM radiation, their uses, interactions with various materials, and safety considerations based on what is learned in Lesson Set 1 about wave and particle interactions. Students apply these ideas in a transfer task in Lesson 13.

In the **first lesson set** (Lessons 1-8), students notice patterns when heating food in a microwave oven, and develop models for how the structure of a microwave oven affects energy transfer to the food inside of it and how it can affect wireless signals. They watch a dissection of a microwave oven and learn that this device is designed so the magnetron antenna changes electric fields near the oven's cooking area. They investigate wave properties using a string in a simulation, as well as waves on a physical spring, to determine how waves can transfer energy. This leads them to wonder about the nature of the waves in a microwave oven and what could be producing them. They investigate how moving electrons in an antenna can cause changing electric fields that travel through space, and measure the magnetic field around a current-carrying wire to understand the relationship between electric and magnetic fields. They then design an investigation to determine what happens to the microwave radiation when it reaches the material(s) in the door and walls, and find evidence suggesting that energy transferred by microwave radiation can be absorbed, reflected, and/or transmitted by matter. For the mid-unit assessment, students use the science ideas they have developed about the interactions of different types of EM radiation with different types of matter to explain how an increase in greenhouse gases could be contributing to the overall increase in global temperatures.

In the last two lessons of the first lesson set, students will use simulations to investigate how particles of different materials (water, plastic, metal) interact with changing electric fields, and connect this particle-scale evidence to macroscopic evidence about materials heating up in the microwave oven. They will use these ideas to consider the validity and reliability of claims about the safety of using metal in the microwave oven. Finally, they use simulations to make sense of wave interference to explain the hot and cold spots produced by the microwave oven. By the end of this lesson set, students are ready to explain how a microwave oven uses the principles of wave behavior to transfer energy into food, but they still have questions about the safety of this technology, and how other forms of radiation are used. This lesson set builds toward the DCI elements associated with the following performance expectations: **HS-PS2-5***, **HS-PS4-1**, **HS-PS4-5**, and **HS-ESS2-4†**.

In the **second lesson set** (Lessons 9-13), students build out the electromagnetic spectrum after organizing different forms of radiation in a card sort, and argue about how the properties of EM radiation and its interactions with matter can help explain its uses. They use multiple sources of evidence to try to identify patterns in frequency, amplitude, and skin cancer, and read about the dual nature of EM radiation as a way to explain ionizing radiation. Students wonder about other uses of EM radiation, and read about digital and conventional radiography to explain the advantages and disadvantages of storing information digitally. Students develop a system to send messages with EM waves using a simulation, and use these ideas together with information from multiple sources to explain how wireless electronic devices are designed to use EM waves to reliably communicate different types of information, adding to their understanding of wave behavior associated with HS-PS4-5. In the transfer task, students use their understanding of EM radiation and its associated technologies to evaluate two social media posts about 5G radiation, and use the model for EM radiation to argue from evidence about whether this technology is safe. The lesson set builds toward the DCI elements associated with the following performance expectations: **HS-PS4-2, HS-PS4-3**, and **HS-PS4-4**.



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

This unit is designed to introduce students to the concept of electromagnetic radiation in a relevant and familiar context. Developing and using models is **intentionally developed** in this unit, as students model energy transfer through electromagnetic radiation. Students model how moving charged particles cause changing electric fields, that in turn cause changing magnetic fields, to understand how EM radiation can transfer energy to matter at a distance. Students model energy flow inside a microwave oven to explain how the structure of the microwave oven is designed to create patterns of constructive and destructive interference. Students also model particle-level interactions with changing fields to explain why some substances heat up more than others in the microwave oven. Students evaluate the merits and limitations of the wave model and photon model to explain the interactions of high-frequency EM radiation and matter. Finally, they integrate different sources of information to model how wireless electronic devices use EM waves to reliably communicate different types of digital information. To support using these energy models to make sense of EM radiation, energy and matter and cause and effect are both **intentionally developed** throughout the unit.

Planning and carrying out investigations is **intentionally developed** in this unit, beginning in Lesson 1 when students brainstorm investigations that they would like to do to answer their questions about the microwave oven and related technology. They plan and conduct an investigation to support their claims about how frequency and amplitude affect how much energy a wave can transfer. Students also plan an investigation collaboratively to produce data to determine what happens to the energy transferred by microwave radiation when it reaches different parts of the microwave oven structure. As can be noted, structure and function **is intentionally developed** as students consider not only how the structure of the microwave oven affects energy transfer, but also how the charge distribution at the particle level can help explain why some substances heat up more than others in the microwave oven.

Obtaining, evaluating, and communicating information **is intentionally developed** over the entire unit. Students evaluate multiple claims from advertisement media to determine the validity and reliability of claims made about the safety of technologies that use EM radiation, and about the interaction of matter with electromagnetic radiation. Students also have multiple opportunities to integrate multiple sources of information **to explain** how different applications of modern technologies use principles of electromagnetic radiation and its interaction with matter.

Cause and effect is **intentionally developed** in this unit. Students use computer models to explore how moving electrons can cause energy transfer through changing electric and magnetic fields, and how the forces from changing electric fields in the microwave oven cause polar molecules to vibrate. They also use the photon and wave models of light to explain how high-frequency radiation can cause damage to living organisms.

This unit builds toward these performance expectations:
HS-PS2-5* Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current. **HS-PS4-1** Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. **HS-PS4-2** Evaluate questions about the advantages of using digital transmission and storage of information. **HS-PS4-3** Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other. **HS-PS4-4** Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. **HS-PS4-5** Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. **HS-ESS2-4†** Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. *This performance expectation is developed across multiple units.

†This performance expectation is developed across multiple courses.

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts
This unit **intentionally develops** students' engagement in these practice elements: **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. ● 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. **Planning and carrying out investigations** ● 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. ● Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. ● Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts.	**PS2.B: Types of Interactions** ● Forces at a distance are explained by fields (~~gravitational,~~ electric, and magnetic) permeating space that can transfer energy through space. Magnetics or electric currents can cause magnetic fields; electric charges or changing magnetic fields can cause electric fields. (HS-PS2-5) **PS3.A: Definitions of Energy** ● These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as either motions of particles or energy stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2) **PS4.A: Wave Properties** ● The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the types of wave ~~and the medium through which it is passing~~. (HS-PS4-1) ● Waves can add or cancel on another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. (HS-PS4-3) ● Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. (HS-PS4-2, HS-PS4-5)	This unit **intentionally develops** students' engagement in these crosscutting concept elements: **Cause and effect** ● 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 require revision when information from smaller or larger scales is introduced, thus requiring improved investigations and experiments. **Energy and matter: Flows, cycles, and conservation.** ● The total amount of energy and matter in closed systems is conserved. ● Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. ● Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems.

	PS4.B: Electromagnetic Radiation ● Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. (HS-PS4-3) ● When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, x-rays, gamma rays) can ionize atoms and cause damage to living cells. (HS-PS4-4) ● Photovoltaic materials emit electrons when they absorb light of a high-enough frequency. (HS-PS4-5)	

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts
This unit **intentionally develops** students' engagement in these practice elements: **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. ● Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source. ● Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible. Elements from the following practices are also **key to the sensemaking** in this unit: ● Asking Questions and Defining Problems ● Analyzing and Interpreting Data ● Using Mathematics and Computational Thinking ● Building Explanations and Designing Solutions ● Engaging in Argument from Evidence	**PS4.C: Information Technologies and Instrumentation** ● Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. (HS-PS4-5) **ESS2.D Weather and Climate** ● The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption~~, storage, and redistribution among the atmosphere, ocean, and land systems~~, and this energy's re-radiation into space.	**Structure and function.** The way in which an object or living thing is shaped, and its substructure, determine many of its properties and functions. The following elements of this crosscutting concept are intentionally developed across this unit: ● 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. Elements from the following crosscutting concepts are also **key to the sensemaking** in this unit: ● Patterns ● Systems and Systems Models

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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 Investigations Use a Variety of Methods. Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge.	In Lesson 3, the teacher reminds students that their work throughout this lesson using physical models and simulations is a reflection of the nature of science: physical models allow scientists to directly observe changes in a system that results from manipulating variables of interest, such as the amplitude and frequency, and simulations enable them to study complex phenomena, such as particle behavior on a string, to further their understanding. In Lessons 8 and 13, the teacher reminds students that their work throughout this unit has been a reflection of the nature of science: Scientists work to answer questions they have about natural phenomena, such as the way microwave ovens work. These questions motivate the need to use different methods, such as investigations, simulations, or discussions to gather and evaluate data that could help them make sense of various phenomena. In this unit, student questions motivate a set of explorations to build and refine models that could better explain their questions about how EM waves work.
Scientific Knowledge Is Based on Empirical Evidence. Science disciplines share common rules of evidence used to evaluate explanations about natural systems.	In Lesson 8, after students develop a model of energy transfer inside the microwave oven, the teacher reminds students that one way to test the power of their model is to use it to make predictions about energy transfer in the microwave oven when matter is heated using the turntable.
Scientific Knowledge Is Open to Revision in Light of New Evidence. Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.	In Lesson 10, when students identify the limitations of the wave model of light to explain their observations, the teacher mentions that historically, scientists believed that light was purely a wave phenomenon, but that similarly to our experience, this model did not match their observations, which led them to revise their ideas about the behavior of light.

Connections to Engineering, Technology, and Applications of Science (ETS)	
Which elements of ETS are developed in the unit?	How are they developed?
Influence of Science, Engineering, and Technology on Society and the Natural World. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.	In Lesson 11, students read about digital and conventional radiography and learn about how advances in technology have enabled the use of ionizing radiation while decreasing costs and risks.

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

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

This unit uses and builds upon the following **Disciplinary Core Ideas (DCIs)** and other science ideas that students should have previously developed in the **OpenSciEd High School Biology and Chemistry courses** and previous units in **this Physics course**:

- Energy is conserved. (*OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*, *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, *OpenSciEd Unit C.5: Which fuels should we design our next generation vehicles to use? (Fuels Unit)*)
- Like particles repel one another through electric forces. (*OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*)
- Electrons move toward different charges and away from like charges, transferring electrical energy, and move particularly easily through metals. (*OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*)
- Energy can be transferred into and out of, and be stored in, magnetic and electric fields. (*OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, *OpenSciEd Unit C.5: Which fuels should we design our next generation vehicles to use? (Fuels Unit)*)

This unit also reinforces and builds upon the following **DCI elements** from the **OpenSciEd Middle School sequence**:

- Magnets have invisible fields through which objects can interact and energy can transfer without contact. (*OpenSciEd Unit 8.3: How can a magnet move another object without touching it? (Magnets Unit)*)
- Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding human behavior and applying that knowledge wisely in decisions and activities. (*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)*)
- Digitized signals (sent as wave pulses) are a more reliable way to encode and transmit information. (*OpenSciEd Unit 6.5: Where do natural hazards happen and how do we prepare for them?(Tsunami Unit)*)
- Electromagnetic radiation: A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. However, because light can travel through space, it cannot be a matter wave, like sound or water waves. (*OpenSciEd Unit 8.4: How are we connected to the patterns we see in the sky and space? (Space Unit)*)
- When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. (*OpenSciEd Unit 6.1: Why do we sometimes see different things when looking at the same object? (One-way Mirror Unit)*, *OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*, *OpenSciEd Unit 8.4: How are we connected to the patterns we see in the sky and space? (Space Unit)*)

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

- Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. (HS-PS4-3)
- When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.(HS-PS4-4)

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 Chemistry** and will continue to build in future units. The progressions of these practices and concepts across the program are as follows:

	Questions	Models	Investigations	Data	Math	Explanation	Argument	Obtaining
Biology	*Cancer Unit*	*Serengeti Unit, Fires Unit*	*Fires Unit, Natural Selection Unit*	*Natural Selection Unit, Cancer Unit*	*Serengeti Unit*	*Fires Unit, Cancer Unit, Natural Selection Unit*	*Speciation Unit*	*Cancer Unit, Speciation Unit*
Chemistry	*Polar Ice Unit, Oysters Unit*	*Electrostatics Unit, Space Survival Unit*	*Polar Ice Unit*	*Fuels Unit*	*Polar Ice Unit, Oysters Unit*	*Fuels Unit*	*Fuels Unit*	*Electrostatics Unit, Space Survival Unit*

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

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

What are some common ideas that students might have?

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

Some relevant ideas that students may come into the unit with include the following:

1. Radiation of all kinds is dangerous and/or causes cancer.
2. Radiation is a kind of matter.
3. Radiation is radioactivity or causes radioactivity.
4. Radiation is unnatural and can only be caused by man-made technologies.
5. Light waves are made up of energy.
6. Energy transfers either through radiation, conduction, or convection, never as a combination of the three.

7. Energy is only associated with heat, so a piece of cold food “has no energy.”
8. Energy of motion (kinetic energy) is only associated with macroscopic motion (i.e., pressing hard on a wall does not transfer energy because we do not see the wall move, when in fact the matter is compressed on a particle scale).
9. Energy causes things to happen (when in fact it is a force that is causal).
10. All EM technology is digital.
11. Some kinds of radiation act like waves, while others act more like particles.

In reality, radioactivity is a type of radiation, but it is made up of particles. This unit focuses on electromagnetic (EM) radiation, which is not made up of particles, but rather of changing fields that, in turn, generate changing fields. The changing electric fields from oscillating electrons produce magnetic fields, which also change as the electric fields continue to change. These changing magnetic fields produce more electric fields, which produce more magnetic fields. These fields continue to ripple outward into space. Depending on its frequency, this EM radiation manifests as radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, or gamma rays. Waves of EM radiation will travel through empty space forever until they interact with matter and transfer energy to the particles in that matter. Energy is the ability of something to make something move through a force, with or without contact. And when the work is done to impart that motion through a force, energy is transferred. The forces at play in EM radiation are applied to the particles in matter by the electric and magnetic fields propagating through space as part of the wave. Although this model for understanding radiation characterizes EM radiation as waves, there are many phenomena that require us to model radiation as particles. In reality, radiation is not a wave or a particle, but manifests characteristics of both.

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 building a scientific identity, it improves science learning across the board. For example, in Lesson 4, students explore the idea that light waves transfer energy through a medium. In fact, light waves do not require a medium to propagate. The idea of the “ether” through which light must move may not be scientifically accurate, but it is a productive idea that was tested extensively by physicists in the 19th century, leading to a more complete understanding of how light moves through space without a medium. Following the history of these ideas, and building explicitly from these ideas to draw connections, is a productive pedagogical tool that helps students construct a new, more accurate conceptual model for radiation.

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

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

- If taught before OpenSciEd High School Chemistry, supplemental teaching of the particle model of matter will be required, including conceptual understanding of the nature of electrons, nuclei, atoms, molecules, and polarity. You will also need to review the nature of thermal energy and thermal energy transfer.
- If taught earlier in the school year, supplemental teaching of the relationship between energy and forces, the nature of forces at a distance, basic properties of mechanical waves, and the fundamentals of electricity will be required.
- If taught as part of an AP Physics course, be prepared to provide students with additional support around equations that are not treated in depth.

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:

- Lesson 5: Instead of providing time for small groups to design their investigations at the end of day 2, you can have the class develop an investigation plan together. This approach will limit students' individual engagement in planning and carrying out investigations, but it will save you time as groups won't need to argue for their plans in front of the class and reach a consensus on which investigations to focus on.
- Lessons 6 features the first transfer task of the unit, which includes an ESS Performance Expectation. If this is not a priority for your school or district, you can skip this assessment. We suggest you design an alternative assessment with an equally complex phenomenon, as this is an ideal moment in the unit to assess students' understanding about absorption, reflection, and transmission of EM radiation.

To extend or enhance the unit, consider the following:

- Lesson 2: Cavity magnetrons are very complicated, and the science ideas needed to explain in detail how they work are far beyond what is expected of high school students. However, some students may be eager to explore circuits and magnetrons or be more engaged by university-level physics topics. As an extension activity, you can ask them to research capacitors and inductors (they can search for information about LC oscillations), or allow them to safely experiment with capacitors and inductors on a breadboard connected to an oscilloscope to produce LC oscillations. They will gain a much more nuanced understanding of the magnetron, as well as the ability to make connections back to the circuitry they worked with in *Electricity Unit*.
- Lesson 3: Give students extra time to test the mathematical model. See teacher guide for additional information.
- Lesson 5: Give students additional materials and time to carry out their own investigations. This will require additional time assessing the safety of each of the investigations students will carry out, but it will give students the opportunity to gather data they considered as appropriate to answer their own questions. You may also want to consider taking an extra period for classes in which there is student engagement around the need for additional tests beyond the three defaults outlined in the lesson.
- Lesson 6: Spend more time on evaluating the interactions of EM radiation with greenhouse gases. You could accomplish this by discussing the ways students answered the questions to the transfer task.
- Lesson 7: Investigate how different food types (proteins, carbohydrates, fats) interact with microwave radiation, drawing connections between the polarity of the molecules and their

ability to absorb energy.
- Lessons 7 and 12: Provide students with the opportunity to obtain information on the internet about claims regarding the safety of microwave radiation (Lesson 7) and the safety of wireless communication (Lesson 12), and evaluate their validity and reliability.
- All lessons: Remove scaffolds provided with Science and Engineering Practices (SEPs) as a way to give students more independent work with the elements of these practices.

What mathematics concepts will students engage with in the unit?

This unit requires knowledge of how to solve algebraic equations, but it is not math-intensive. In addition, students need to use numbers expressed in scientific notation to make sense of the range of frequencies and wavelengths of EM radiation.

During the **first lesson set**, students investigate wave properties and how they relate to energy transfer. During Lesson 3, students use a physical manipulative to help identify where energy is stored and transferred as a wave moves across a spring. These identified quantities are then used to build a descriptive model of how energy is transferred in a wave. Students also identify the mathematical relationships between frequency, cycles, time, and distance. For example, students express period as time/cycle to make sense of the inverse relationship between frequency and period. They use these relationships to develop a mathematical model that shows how an emergent property of the system (wavelength) is related to two variables: a property of the medium (wave speed) and an independent input property of the wave (frequency).

In the **second lesson set**, students use scientific notation to compare the magnitude of the difference in wavelength and frequency between the different types of EM radiation. This is an 8th grade CCMS. To provide additional practice, teachers are encouraged to remove the values written in scientific notation from the *Unknown material with identifier: pr.l9.ref* and ask students to express the values in scientific notation.

This unit does not assume fluency with the mathematical practices listed below; rather, 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 listed below:

Category	Code	Domain and Heading	Standard	Relevant Lessons
Number and Quantity	CCSS.MATH.CONTENT.HS.N-Q.2	**Quantities:** Reason quantitatively and use units to solve problems.	Define appropriate quantities for the purpose of descriptive modeling.	3
Algebra	CCSS.MATH.CONTENT.HS.A-SSE.3c	**Seeing Structure in Expressions:** Write expressions in equivalent forms to solve problems	Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression: Use the properties of exponents to transform expressions for exponential functions.	3

Expressions & Equations	CCSS.MATH.CONTENT.8.EE.A.3	**Expressions and Equations**: Work with radicals and integer exponents.	Use numbers expressed in the form of a single digit times an integer power of 10 to estimate very large or very small quantities, and to express how many times as much one is than the other.	9

See individual lessons referenced above for details.

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 that are integrated throughout the OpenSciEd routines and are intended to increase relevance and provide access to science learning for all students. These equity goals are supported 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) offering specific strategies for supporting emerging multilingual students in science classrooms.

Many of these strategies are highlighted in the *Teacher Guides* in sidebar callout boxes with these headings:

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

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

The OpenSciEd instructional model casts the teacher as a member of the classroom community, supporting students motivated by their own questions about phenomena to figure out scientific ideas. 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 the lessons also builds incrementally. Throughout the unit, we provide just-in-time science content background for you that is specific to the Disciplinary Core Ideas (DCIs) figured out in each lesson. Places to find this guidance include the “Where we are going” and “Where we are not going” sections of the lesson’s *Teacher Guide*. The expected student responses, keys, and rubrics also illustrate important science ideas that should be developed. The K-12 Science Framework is another great resource for learning more about the DCIs in this unit (**PS2.B: Types of Interactions**, **PS3.A: Definitions of Energy**
PS4.A: Wave Properties, PS4.B: Electromagnetic Radiation, PS4.C: Information Technologies and Instrumentation, ESS2.D Weather and Climate), 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 this unit's phenomena and Performance Expectations bundle.

- To learn more about how electromagnetic radiation-based technologies work, as well as their safety:
    - **Microwave Oven - How does it work?** https://www.youtube.com/watch?v=D9_2qtD8flo
    - **The FDA's website on microwave ovens:** https://www.fda.gov/radiation-emitting-products/resources-you-radiation-emitting-products/microwave-ovens
    - **Electromagnetic Fields and Cancer (National Cancer Institute):** https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/electromagnetic-fields-fact-sheet
- To learn more about how electromagnetic waves are produced and how they propagate through space:
    - **Anatomy of an Electromagnetic Wave (NASA Science):** https://science.nasa.gov/ems/02_anatomy
    - **The electromagnetic spectrum (Hubble site):** https://hubblesite.org/contents/articles/the-electromagnetic-spectrum
- To learn more about the uses of electromagnetic radiation in communication
    - **How radio works:** https://electronics.howstuffworks.com/radio.htm
    - **Digital versus analog signals:** https://serpmedia.org/scigen/assets/e5t2-digital.pdf
    - **Waves and information transfer (Museum of Science):** https://www.mos.org/sites/dev-elvis.mos.org/files/docs/offerings/mos_educator-guide_nasa_waves-and-information-transfer.pdf
    - **How does an Antenna work?** https://www.youtube.com/watch?v=ZaXm6wau-jc
- To learn more about the DCIs in this unit:
    - **PS2.B: Types of Interactions: https://youtu.be/U-uJ8KhRQIc**
    - **PS3.A: Definitions of Energy: https://youtu.be/DGVtH5xmb9M**
    - **PS4.A: Wave Properties: https://youtu.be/4S-MevRKGZs**
    - **PS4.B: Electromagnetic Radiation: https://www.youtubeeducation.com/watch?v=dzyPT7kxp8M**
    - **PS4.C: Information Technologies and Instrumentation: https://www.youtubeeducation.com/watch?v=uxK_Fg1_mE0**
    - **ESS2.D Weather and Climate: https://youtu.be/gLT1J8je5lo**

How do I support students' emotional needs?

EM radiation is a complex phenomenon, and it has inspired a large body of online information about the risks of using cell phones or microwave ovens. Because this information is easily accessible, some students might experience anxiety about EM radiation and believe that exposure from sources like Wi-Fi, cell phones, power lines, and other electronic devices poses a serious risk to their health.

Make space for students to process information, and validate their feelings and reactions. Be aware that students who are struggling may demonstrate a variety of behaviors, including but not limited to: fidgeting, withdrawal, disruption or distraction, rapid breathing, holding their breath, change in body language or tonation. If you notice a student might be struggling, share what you are observing and ask whether they need some help.

Relationship skills: In order for students to openly communicate their feelings and ideas about EM radiation, it is important that instruction supports an environment where students feel safe sharing their thoughts with others. Throughout the unit, structures and scaffolds are in place to facilitate students' interactions with each other. Particular examples include the use of Scientists Circles to promote equitable discussions, peer feedback in Lesson 1 to help students provide useful and respectful feedback, and Lesson 4 work in jigsaw groups to share and make sense of all group members' observations.

For more support around Social and Emotional Learning, visit https://casel.org.

Guidance for Developing Your Personal Glossaries

This unit refers to two categories of academic language (i.e., vocabulary). Most often in this unit, students have experiences with and discussions about science ideas before they know the specific vocabulary word that names that idea. After students develop 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 co-construct that definition and can add the specific term to a Personal Glossary in their science notebook. 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 only 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		antenna, Bluetooth, wireless, microwave oven, microwave radiation, electromagnetic radiation, arc
L2		magnetron
L3	amplitude, frequency, wavelength, wave speed	damping, tension
L4	electromagnetic waves, electromagnetic radiation	
L5	reflection, absorption, transmission	
L6		
L7		polar molecule
L8	interference, constructive interference, destructive interference	
L9	electromagnetic spectrum	
L10	ionizing radiation, photon, photovoltaic material	
L11	digital information	
L12	binary code, encryption, digital signal	bits, amplitude-shift keying, frequency-shift keying, Global Positioning System (GPS), unicode (universal code), metadata
L13		5G

ASSESSMENT SYSTEM OVERVIEW

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the “Assessment Icon” in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	Initial individual models Driving Question Board	**Pre-Assessment** The student work available for assessment in Lesson 1 should be considered a pre-assessment. It is an opportunity to learn more about the ideas your students bring to this unit. Revealing these ideas early can help you be more strategic in building from and leveraging student ideas across the unit. The initial model is a good opportunity to pre-assess student understanding of wave properties and energy transfer across space. The Driving Question Board is another opportunity for pre-assessment. Reinforce students in generating open-ended questions, such as how and why questions, to post to the board. However, any questions students share--even close-ended questions--can be valuable. Make note of any close-ended questions and use navigation time throughout the unit to have students practice turning them into open-ended questions when they relate to the investigations underway.
Lesson 2	*The Magnetron* Exit ticket	**Formative** Both *The Magnetron* and the exit ticket ask students to integrate ideas from a reading and a video to recognize the role of electric fields produced by moving electrons in transferring energy through space. Use these opportunities formatively to modify instruction if students need to spend more time with the ideas in the reading before moving on.
Lesson 3	Electronic Exit Ticket, *L3 Electronic Exit Ticket Key*	**Summative**

		This Electronic Exit Ticket addresses 3D elements associated with the lesson-level performance expectations from Lesson 3. The first three questions are designed to make it easy to gather information about where students are still struggling to understand wave characteristics. **Formative** The last two questions in the Electronic Exit Ticket are designed to provide formative information for how to navigate into the next lesson. Guidance is provided in the accompanying key and the *Teacher Guide*.
Lesson 4	*Static Field Visualization*, *Arrows and Line Field Visualization*, or *Full Field Visualization*, *Field Visualization Key*	**Formative** Students evaluate different representations of electromagnetic radiation propagating through space and record changes in electric fields using one of three handouts. The accompanying key provides guidance for what to look for in student responses. Students examine alternative representations in modeling fields, waves, and forces. They identify limitations of the various representations and choose one representation to move forward into future models to explain what is happening in the space between the magnetron and food in a microwave oven.
Lesson 5	*Oven Investigation Plan*, *Oven Investigation Key* *Explaining What Happened*	**Formative** Students work in small groups to plan and conduct an investigation around the role of the metal mesh in the door of a microwave oven. Collect *Oven Investigation Plan* and use the accompanying key to provide targeted feedback. Students then use the data from their investigation to revise their models of the interactions of microwave radiation with materials (metal mesh) in the microwave oven. Model revisions should show that the metal mesh does not absorb or transmit microwave radiation; rather, it reflects or refracts the radiation into other parts of the oven. *Explaining What Happened* provides guidance for what to look for in the revised models.
Lesson 6	*Explaining Temperature Rise Transfer Task*, *Lesson 6 Assessment Scoring Guidance*	**Summative** Students apply what they have figured out about interactions of EM radiation and materials to design ways to explain global temperature rise over the past several decades. This assessment addresses **HS-ESS2-4**. The ideas, crosscutting concepts, and practices students engage with in this assessment are shown at the top of the accompanying key. We strongly recommend that you encourage students to use their science notebook as a resource for completing all assessments.
Lesson 7	*Field-Particle Interactions*, *Field-Particle Interactions Key*	**Formative**

	Exit ticket	Students use a simulation and manipulatives to model the interactions of polar molecules (water) with microwave radiation as a way to explain why water moves in response to a changing electric field. Collect *Field-Particle Interactions* and use the accompanying key to provide targeted feedback. The exit ticket on day 1 serves as a check to see where students are in understanding the basics of why water heats up in response to microwave radiation. On day 2, students will create a consensus model of water in the microwave oven. Use the exit ticket responses to gauge how challenging this task will be for them, and adjust the differentiation supports for day 2 accordingly.
Lesson 8	*Wave Interactions*, *Wave Interactions Key* Electronic Exit Ticket	**Formative** Students use *Wave Interactions* to investigate a simulation of wave interference. Collect the handout and use the accompanying key to provide targeted feedback. **Summative** The Electronic Exit Ticket addresses 3-D elements associated with the lesson-level performance expectations from Lessons 7 and 8. This assessment is designed to make it easy to gather information about students' current understanding.
Lesson 13	*Evaluating 5G Safety Transfer Task*, *Evaluating 5G Safety*	**Summative** At the end of this final lesson, students have the opportunity to demonstrate their competence with a transfer task. This task is robust and takes approximately 45 minutes. This assessment addresses **HS-PS4-4**. The ideas, crosscutting concepts, and practices students engage with as part of completing this assessment can be found at the top of the accompanying key. The scoring on this assessment represents our recommendation for how to weigh questions. Please use scoring that works for your class and your requirements. Similar to Lesson 6, encourage students to use their science notebook as a resource for completing all assessments.
Occurs in several lessons	Lesson-Level Performance Expectation Assessment Guidance	**Formative Assessment** Use this document to see which parts of lessons or student activity sheets can be used as embedded formative assessments.
Occurs in several lessons	*Progress Tracker*	**Formative and Self-Assessment** Progress Trackers are thinking tools designed to help students (1) keep track of important discoveries that the class makes while investigating phenomena and (2) figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what students write in their tracker reflect their own thinking at that particular moment. In this

		way, the tracker can be used throughout the unit to formatively assess individual student progress or for students to assess their own understanding. Because a tracker is meant to be a thinking tool, we strongly suggest that it not be collected for a summative "grade" other than to note its completion. In this unit, students add to their Progress Tracker in Lessons 4, 5, 7, 8, 9, and 11. Examples of models and ideas that students may include in this tracker are embedded in these lessons.
Occurs in several lessons	Student Self-Assessment Discussion Rubric	**Self-Assessment** This resource is available in the unit's front matter. It can be used anytime after a discussion to help students reflect on their participation in class that day. Use this at least once every other week or even weekly. Initially, you might give students ideas for what they can try to improve on next time, such as sentence starters for discussions. As they gain practice and proficiency with discussions, ask for their ideas about how classroom and small-group discussions can be more productive.
Occurs in several lessons	Peer Feedback Facilitation: A Guide	**Peer Feedback** This resource is available in the front matter. There will be times when helping students exchange feedback will be very valuable for their three-dimensional learning as well as for learning to give and receive feedback from others. We suggest incorporating peer review at least two times per unit. This document is designed to give you options for how to support this in your classroom. It also includes student-facing materials to support giving and receiving feedback, along with self-assessment rubrics in which students can reflect on their experience with the process. Peer feedback is most useful when complex and diverse ideas are visible in student work and not all work is the same. Student models or explanations are good times to use a peer feedback protocol. These do not need to be final pieces of student work; rather, peer feedback is more valuable to students if they have time to revise after receiving it. This should be a formative, not summative, assessment. It is also necessary for students to have experiences with past investigations, observations, and activities that they can use as evidence for their feedback. In addition to this flexible resource, peer feedback has been written directly into the unit in Lessons 1 and 10.

For more information about the OpenSciEd approach to assessment and general program rubrics, visit the OpenSciEd Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every OpenSciEd lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to Science and Engineering Practice(s), alignment to Cross-Cutting Concept(s), and alignment to the Disciplinary Core Ideas.

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 1	**1.A** Develop and revise a model of a microwave oven that explains how the components of the system function to heat liquid/food, and how and why these structures could affect a Bluetooth signal. (SEP: 2.3; CCC: 6.2; DCI: PS4.B.2, PS4.C.1) **1.B** Ask questions and brainstorm investigations about the structure and function of technologies and phenomena that rely on electromagnetic radiation to transfer energy. (SEP: 1.4, 3.1; CCC: 5.2, 6.2; DCI: PS4.B.2, PS4.C.1)	**1.A.1 When to check for understanding:** On day 2, when students make their initial models and revise them using peer feedback. **What to look for/listen for in the moment:** Look for students to give feedback specifically around matter, energy, and forces in the model, and then focus on these elements in their revision (SEP: 2.3): ● matter changes (liquid/food heating up) (DCI: PS4.B.2) ● energy transfer (into liquid/food, maybe through waves, radiation, or particles) (DCI: PS4.B.2) ● forces (most likely, that they are missing from the model) **1.A.2 When to check for understanding:** On day 2, when the class is developing the initial consensus model. **What to look for/listen for in the moment:** Listen for students to suggest the following components and interactions as parts of the model (SEP: 2.3): ● a structure that creates microwave radiation inside the microwave oven (CCC: 6.2; DCI: PS4.C.1) ● liquid/food heating up, represented as energy transfer or particles of matter speeding up (the function of the microwave oven) (CCC: 6.2; DCI: PS4.B.2) **1.B.1 When to check for understanding:** On day 3, when students are developing the Driving Questions Board (DQB). **What to look for/listen for in the moment:** ● questions about related phenomena or technology (e.g., the Sun, a radio, a bad cell phone signal, an X-ray machine, something else that generates radiation) (SEP: 1.4; DCI: PS4.B.2, PS4.C.1) ● questions that use energy and matter to seek a mechanistic explanation (e.g., "How does a microwave oven transfer energy to food?") (SEP: 1.4; CCC: 5.2)

		• questions that relate the structure of the microwave oven (or a related technology) to its function (e.g., "How do the holes in the door help the microwave oven work?" or "What structures in the microwave oven make radiation?") (SEP: 1.4; CCC: 6.2; DCI: PS4.B.2, PS4.C.1) • questions about how distance affects microwave radiation or wireless signals (SEP: 1.4; DCI: PS4.B.2, PS4.C.1) **1.B.2 When to check for understanding:** At the end of day 3, after students complete the exit ticket. **What to look for/listen for in the moment:** Look for students to recognize that structure and function are different by suggesting: • an investigation related to what is inside the microwave oven (e.g., dissecting a microwave oven, studying the schematics, looking at a Faraday pouch) (SEP: 3.1; CCC: 6.2) • an investigation related to what the microwave oven does (e.g., running the microwave oven and measuring the temperature of liquid/food inside, measuring the radiation, doing more investigations with wireless signals) (SEP: 3.1; CCC: 6.2)
Lesson 2	**2.A** Integrate multiple sources of information to analyze how the designed structure of a magnetron causes the generation of changing electric fields inside the cooking area of a microwave oven. (SEP: 8.2; CCC: 4.1, 6.1; DCI: PS4.B.1)	**2.A.1 When to check for understanding:** As students fill out and discuss *The Magnetron* and make sense of how electric fields cause a transfer of energy both inside and outside the magnetron. **What to look for/listen for in the moment:** Look and listen for students to integrate ideas from the reading and the video (SEP: 8.2) to: • Identify that electrons vibrate inside the magnetron antenna. This represents a foundational understanding. (CCC: 4.1, 6.1; DCI: PS4.B.1) • Note that charged particles create electric fields, and they also can feel a push from electric fields. This represents a connected understanding. (SEP: 8.2; DCI: PS4.B.1) • Refer to the designed structure of the magnetron (cavity, antenna) to describe how moving electrons in the antenna cause electric fields to change inside the cooking area. (CCC: 4.1, 6.1; DCI: PS4.B.1) • Students with an organized understanding may also note that the direction of electric fields in the microwave oven changes rapidly because electrons are vibrating rapidly in the antenna. (DCI: PS4.B.1) **2.A.2 When to check for understanding:** While reading through students' exit tickets, completed and turned in at the end of class. **What to look for/listen for in the moment:** Students' descriptions and/or drawings should show or describe electric fields. Look for students to:

		• Identify that electric fields change near the magnetron antenna. (CCC: 4.1, 6.1; DCI: PS4.B.1) • Refer to evidence from the light bulb experiment and/or the magnetron reading as evidence of these changes in the electric field. (SEP: 8.2; DCI: PS4.B.1) • Show or describe the antenna near the cooking area. (CCC: 4.1, 6.1)
Lesson 3	**3.A** Plan and conduct an investigation to produce data to serve as evidence to support claims about how certain wave properties affect energy transfer in waves. (SEP: 3.2, 6.1; CCC: 5.2; DCI: PS3.A.4, PS4.A.1, PS4.B.1) **3.B** Use algebraic techniques to develop a mathematical model to identify and test the relationship between frequency, wave speed, and wavelength. (SEP: 5.3; CCC: 1.4; DCI: PS4.A.1)	**3.A.1 When to check for understanding:** On day 2, while students use *Wave Variable Cards* to make predictions and fill out the first three columns on the *Wave Property Relationships* handout. **What to look for/listen for in the moment:** Listen/look for students to: • Use the cards to predict how certain wave properties will affect each other. (SEP: 3.2; DCI: PS4.A.1, PS4.B.1) • Plan how to investigate the relationships between wave properties, including energy, by selecting independent variables and dependent variables to test. (SEP: 3.2; CCC: 5.2; DCI: PS4.A.1, PS4.B.1) **3.A.2 When to check for understanding:** At the end of day 2, while the class discusses the findings from investigating amplitude. **What to look for/listen for in the moment:** Listen for students to: • Use their data to make claims about how increasing amplitude increases bond stretch and vibration speed. (SEP: 6.1; DCI: PS3.A.4, PS4.B.1) • Use bond stretch and vibration speed data to claim that increasing amplitude increases the energy transferred by a wave. (SEP: 3.2, 6.1; CCC: 5.2; DCI: PS3.A.4, PS4.B.1) **3.A.3 When to check for understanding:** At the end of day 3, while students review the connections to energy transfer that they saw in the lab, and after you collect *Wave Property Relationships* to review student responses. **What to look for/listen for in the moment:** Listen/look for students' verbal and written responses to: • Show planning of the investigation within the table of wave property variables and predicted outcomes, including connections to energy transferred by the wave. (SEP: 3.2; CCC: 5.2; DCI: PS4.A.1, PS4.B.1) • Document the process of the investigation, including how and what data was collected and observations used as evidence for the conclusion statements on the back. (SEP: 3.2) • Make claims about how wave properties that affect the energy transferred by the wave are connected to and supported by the data from the investigation. (SEP: 3.2, 6.1; CCC: 5.2; DCI: PS4.B.1) • Make claims about how energy transferred by the wave is connected to the vertical motion of particles and energy

		in stretched fields in bonds. (SEP: 6.1; CCC: 5.2; DCI: PS3.A.4, PS4.B.1) **3.B When to check for understanding:** On day 2, while the class constructs the Physical Wave Properties poster. **What to look for/listen for in the moment:** Listen for students to discuss how to: ● Represent frequency, wavelength, and wave speed mathematically in terms of a fraction or equation (e.g., frequency = cycles/time). (SEP: 5.3; CCC: 1.4; DCI: PS4.A.1) **Electronic Exit Ticket:** The Electronic Exit Ticket is designed to address elements related to both lesson-level performance expectations from this lesson. This assessment is designed to make it easy to gather information about where students are still struggling to apply ideas about wave characteristics and energy transfer, and use algebraic techniques.
Lesson 4	**4.A** Use and ask questions about multiple models of electromagnetic radiation to refine a mechanistic explanation for patterns of energy transfer through changing electric and magnetic fields, applying empirical evidence from an in-class investigation. (SEP: 1.4, 2.4; CCC: 1.5, 2.2; DCI: PS4.B.1) **4.B** Examine smaller-scale mechanisms of changing electric and magnetic fields to construct an evidence-based explanation about energy transfer through electromagnetic radiation. (SEP: 6.2; CCC: 2.2; DCI: PS4.B.1)	**4.A.1 When to check for understanding:** On day 1, when students work individually to complete Part 1 of their assigned handout (*Static Field Visualization*, *Arrows and Line Field Visualization*, or *Full Field Visualization*). See the *Field Visualization Key* for sample responses. **What to look for/listen for in the moment:** ● Use evidence from the simulation about magnitude and direction to describe the patterns of changing electric fields as energy transfers from the antenna. (SEP: 2.4; CCC: 1.5; DCI: PS4.B.1) ● Use evidence from the simulation about the motion of electrons and the magnitude of forces over distance to suggest decreases in energy transferred from the transmitting antenna. (SEP: 2.4; CCC: 1.5; DCI: PS4.B.1) ● Identify evidence and gaps in the model to draw cause-and-effect relationships between parts of the system to explain how energy transfers from the antenna. (SEP: 2.4; CCC: 1.5; DCI: PS4.B.1) **4.A.2 When to check for understanding:** On day 1, when students work in small groups to summarize the findings from the field visualizations they explored. **What to look for/listen for in the moment:** As you walk around the classroom, pay attention to how students integrate the different dimensions to make sense of energy transfer as they answer Questions 1-4 in Part 2 of their handout. See the *Field Visualization Key* for sample responses. **Question 1:** See the example of a filled table. **Question 2:**

		- Connect different parts of the system through arrows that describe the interactions between the two components. (CCC: 1.5) - Describe observable changes in electric fields at each location. (CCC: 1.5; DCI: PS4.B.1) - Add question marks to highlight gaps in the model that are hard to explain with the current evidence. (SEP: 1.4; CCC: 2.2) **Question 3:** - Mention the usefulness of the radiated field visualizations to help explain some of the changes that happen between both antennas. (SEP: 1.4; CCC: 2.2) - Mention the usefulness for observing different behaviors of the electric field (static and radiated). (SEP: 2.4; CCC: 1.5; DCI: PS4.B.1) - Identify the similarities in both radiated field visualizations as evidence of a mechanism behind energy transfer. (SEP: 2.4; CCC: 1.5, 2.2) **Question 4:** - Questions that aim to fill cause-and-effect gaps that can help explain some of the patterns we observed in the change in electric fields. (SEP: 1.4; CCC: 1.5, 2.2; DCI: PS4.B.1) - Questions that look to clarify the role of components of the system or their interactions in causing energy transfer. (SEP: 1.4; CCC: 2.2; DCI: PS4.B.1) **4.B. When to check for understanding:** On day 2, when students revise the model in the Energy Transfer from an Antenna poster. **What to look for/listen for in the moment:** - Add changing magnetic fields as part of the mechanism that can help explain how energy transfers through electromagnetic radiation. (SEP: 6.2; CCC: 2.2; DCI: PS4.B.1) - Describe energy transfer using cause-and-effect language that connects changes in electric and magnetic fields to the difference in motion of both electrons. (SEP: 6.2; CCC: 2.2; DCI: PS4.B.1) - Name this system of changing magnetic and electric fields as electromagnetic radiation. (DCI: PS4.B.1)
Lesson 5	**5.A** Plan investigations to safely produce data that would help determine whether the energy of the microwave radiation is	**5.A When to check for understanding:** On day 2, in small-group planning discussions and in students' individual recording of these ideas on the *Oven Investigation Plan* handout.

	reflected, absorbed, or transmitted when it reaches the materials (matter) in the door and walls of the microwave oven (SEP: 3.1, 3.3; CCC: 5.1; DCI: PS3.A.1, PS4.B.2) **5.B** Revise a model of what happens to the path of some of the microwave radiation when it interacts with various materials (matter) in the microwave oven, and use the model to support an explanation for why some of those materials heated up (energy) more than others. (SEP: 2.3; CCC: 5.1, 5.2; DCI: PS3.D.1, PS4.B.2)	**What to look for/listen for in the moment:** Students should discuss and ultimately document investigation plans that address each of these four categories of ideas: (1) data collection, (2) experimental versus control conditions, (3) eliminating the effect of confounding variables, and (4) meeting safety criteria. These are further detailed in the *Oven Investigation Key* key. **5.B When to check for understanding:** On day 3, in the individual explanations and model revisions that students document on a separate sheet of paper. **What to look for/listen for in the moment:** See the *Explaining What Happened* key for the model revisions and the key ideas in the cause-and-effect chain that students should use in their explanations.
Lesson 6	**6.A** Ask questions about how the structure of the matter in a microwave oven affects reflection, absorption, and transmission of energy in the oven. (SEP: 1.2; CCC: 6.2; DCI: PS4.B.2) **Transfer Task PE: HS-ESS2-4** Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. (SEP: 2.4; CCC: 5.2, 2.1; DCI: ESS2.D.1, ESS2.A.3, PS4.B.2)	**6.A When to check for understanding:** When students return to the DQB and develop/share questions with the class. **What to look for/listen for in the moment:** Students posting and sharing the following: ● Questions that arise from study of the Lesson 5 models about how reflective properties of the inner surfaces of the microwave oven affect electromagnetic radiation absorption, reflection, and/or transmission. (SEP: 1.2; CCC: 6.2; DCI: PS4.B.2) ● Questions that seek additional information about various types of matter and why/how they interact with electromagnetic radiation within the context of the microwave oven system. (SEP: 1.2; CCC: 6.2; DCI: PS4.B.2) **Warming Global Temperatures Transfer Task:** When you score *Explaining Temperature Rise Transfer Task*, administered in this lesson. This assessment does not build toward a lesson level performance expectation. It is designed to assess progress toward a performance expectation from the NGSS (HS-ESS2-4). See the accompanying *Simulation Investigation Key* for details. This transfer task **does not** assess this performance expectation completely; rather, it gives students the opportunity to apply new ideas from this unit to their understanding of climate phenomena from previous courses, filling in the gaps in their understanding.
Lesson 7	**7.A** Develop and revise a model to illustrate absorption of microwave radiation as movement of charged particles in response to particle-level forces from changing	**7.A.1 When to check for understanding:** On day 1, when students use manipulatives and simulations to develop a model of the interaction of water molecules with changing electric fields on the *Field-Particle Interactions* handout.

	electric fields. (SEP: 2.3; CCC: 2.2; DCI: PS2.B.2, PS4.B.2) **7.B** Evaluate multiple claims from advertisement media to determine the validity and reliability of claims made about the relationship between the structure, shape, and molecular substructure of aluminum foil and its interaction with electromagnetic radiation. (SEP: 8.4; CCC: 6.2; DCI: PS2.B.2)	**What to look for/listen for in the moment:** See Part 1 of the *Field-Particle Interactions Key* for additional guidance. (SEP: 2.3; CCC: 2.2; DCI: PS2.B.2, PS4.B.2) **7.A.2 When to check for understanding:** At the end of day 1, while looking through student work on the *Field-Particle Interactions* handout. **What to look for/listen for in the moment:** See Part 2 in the *Field-Particle Interactions Key* for additional guidance. (SEP: 2.3; CCC: 2.2; DCI: PS2.B.2, PS4.B.2) **Note:** The exit ticket on day 1 serves as a check to see where students are in understanding the basics of why water heats up in response to microwave radiation. On day 2, students will create a consensus model of water in the microwave oven. Use the exit ticket responses to gauge how challenging this task will be for your students, and adjust differentiation supports for day 2 accordingly. **7.B When to check for understanding:** On day 2, when students evaluate the validity and reliability of the *Metal in Microwave Ovens* reading using the *Evaluating Information Checklist*. **What to look for/listen for in the moment:** Listen for students to: ● Mention specific pieces of evidence used by the author to justify whether the claims in the reading are valid. (SEP: 8.4) ● Mention specific investigations or ideas developed by the class that provide evidence of validity for claims about the interactions of charged particles within aluminum foil and electromagnetic radiation. (SEP: 8.4; CCC: 6.2; DCI: PS2.B.2) ● Consider particle-level interactions in the aluminum foil structure with changing electric fields to determine whether the claims are valid. (SEP: 8.4; CCC: 6.2; DCI: PS2.B.2) ● Describe an investigation that can be carried out with materials in the classroom to test the reliability of claims about the role of aluminum foil in influencing electromagnetic radiation within the microwave oven. (SEP: 8.4; CCC: 6.2; DCI: PS2.B.2)
Lesson 8	**8.A** Develop, revise, and use a model of wave interactions using an energy, matter, and forces lens to explain how reflection and interference cause patterns of energy transfer into materials in the microwave	**8.A.1 When to check for understanding:** After day 1, review collected student work on the *Wave Interactions* handout. **What to look for/listen for in the moment:** Look for student work on the handouts to: ● Identify that the total energy is the same at all points in time for the wave interaction. (CCC: 2.2, 5.3; DCI: PS4.A.3) ● Show that the waves add up to a larger wave shape when they are both up (Interaction A) and cancel when one is

	oven without creating or destroying energy. (SEP: 2.3; CCC: 2.2, 5.3; DCI: PS4.A.3, PS4.B.1) **8.B** Collaboratively revise a model of a microwave oven to explain how the components of the system function to heat food, and how and why these structures could affect a Bluetooth signal. (SEP: 2.3; CCC: 5.2, 6.2; DCI: PS4.A.3, PS4.B.1, PS4.B.2, PS4.C.1) **8.C** Ask questions about the structure and function of technologies and phenomena that rely on electromagnetic radiation (including energy transfer). (SEP: 1.4; CCC: 5.2, 6.2; DCI: PS4.B.2, PS4.C.1)	up and the other is down (Interaction B). (DCI: PS4.A.3) ● Show that the wave shapes and directions return to their original state after the waves have passed through each other, showing the energy is unchanged. (CCC: 5.3; DCI: PS4.A.3) ● Use logic about how forces act on the particles of the string in a way that pulls the particles up or down, and how these forces add or cancel based on their relative directions (cause) to result in a new wave shape while the waves meet in space (effect). (CCC: 2.2; DCI: PS4.A.3) **8.A.2 When to check for understanding:** At the end of day 2, when students revise their initial group models from the light bulb investigation. **What to look for/listen for in the moment:** Look for students' revised models (SEP: 2.3) to: ● Show how the microwave oven's structure serves to create and reflect microwave radiation in order to cause wave interference. (SEP: 2.3; CCC: 2.2; DCI: PS4.A.3) ● Illustrate how interference causes the wave heights/forces/energy of the microwave radiation to combine, creating new wave shapes with lots of energy in some places and little to none in others. (SEP: 2.3; CCC: 2.2; DCI: PS4.A.3) ● Explain how the bulbs lighting up (or the cheese melting) is caused by energy transfer to them from the microwave radiation through the electric fields of the waves applying forces to the electrons (matter) in the bulbs (or in the water in the cheese), causing them to vibrate. (SEP: 2.3; CCC: 2.2, 5.3; DCI: PS4.B.1) ● Show how in places where the bulbs light up, constructive interference causes the forces/energy of the interfering waves to add together, creating larger forces/energy that light the bulbs. (SEP: 2.3; CCC: 2.2, 5.3; DCI: PS4.A.3) ● Show how in places where the bulbs do not light up, destructive interference causes the forces/energy of the interfering waves to cancel out, creating little to no forces/energy that cannot light the bulbs. (SEP: 2.3; CCC: 2.2, 5.3; DCI: PS4.A.3) **8.B When to check for understanding:** On day 3, while students revise the initial consensus model from the anchor phenomenon. **What to look for/listen for in the moment:** Look for the revised consensus model (SEP: 2.3) to include these elements: ● Electromagnetic waves transfer energy across space via changing electric (and magnetic) fields. (CCC: 5.2; DCI: PS4.B.1) ● The structure of the magnetron creates microwave radiation inside the microwave oven by vibrating electrons that change electric fields. (CCC: 6.2; DCI: PS4.C.1) ● The structure of the metal walls of the microwave oven reflects microwave radiation (including from the magnetron and the cell phone) inside the oven. (CCC: 6.2; DCI: PS4.C.1)

		• Reflected waves add to or cancel each other with the waves coming out of the magnetron to cause uneven transfer of energy to matter, creating hot and cold spots in the microwave oven, which is structured with a turntable to minimize the effects of cold spots. (CCC: 5.2, 6.2; DCI: PS4.A.3, PS4.B.2) • Liquid/food heats up, represented as energy transfer from microwave radiation to polar water molecules in the form of thermal energy (the function of the microwave oven). (CCC: 5.2, 6.2; DCI: PS4.B.2) • Less microwave radiation gets from the phone to the Bluetooth speaker than when the phone isn't in the microwave oven, because some of the radiation is reflected back into the oven due to the oven's structure. (CCC: 6.2) **8.C When to check for understanding:** At the end of day 3, while students add new questions to the Driving Question Board. **What to look for/listen for in the moment:** • questions about related phenomena or technology (e.g., the Sun, a radio, a bad cell phone signal, an X-ray machine, something else that generates radiation) (SEP: 1.4; DCI: PS4.B.2, PS4.C.1) • questions that use energy and matter to seek a mechanistic explanation (e.g., "How does a microwave oven transfer energy to food?") (SEP: 1.4; CCC: 5.2) • questions about how distance affects microwave radiation or wireless signals (SEP: 1.4; DCI: PS4.B.2, PS4.C.1) • questions about how electromagnetic radiation may be dangerous (SEP: 1.4; DCI: PS4.B.2) • questions about other types of electromagnetic radiation and their uses, and the structure of devices that use them (SEP: 1.4; DCI: PS4.C.1, CCC: 6.2) **Electronic Exit Ticket:** The Electronic Exit Ticket at the end of this lesson is designed to address the lesson-level performance expectations from Lessons 7 and 8. This assessment is designed to make it easy to gather information about where students are still struggling to put the pieces together. See *Electronic Exit Ticket Key*.
Lesson 9	**9.A** Develop an argument about why EM radiation can be used in multiple technologies to do specific tasks based on its frequency, wavelength, and interactions with matter. (SEP: 7.4; CCC: 4.1; DCI: PS4.B.2, PS4.C.1)	**9.A.1 When to check for understanding:** At the end of day 1, when students complete their work in small groups using *EM Radiation Applications* and the *Unknown material with identifier: pr.l9.ref*. **What to look for/listen for in the moment:** Look for students to draw connections between the use of EM radiation and its frequency, wavelength, and interactions with matter. These are some example arguments they can make: • EM radiation types used for communication (radio waves, IR, microwave radiation, visible light) are part of the EM spectrum with lower frequency and longer wavelength. All these EM radiation types can cause electrons to move,

	9.B Ask questions that arise from examining a model of the electromagnetic spectrum related to the uses and material interactions of different types of electromagnetic radiation. (SEP: 1.2; CCC: 4.1; DCI: PS4.B.2, PS4.C.1)	and when electrons move, they produce electric current. Other types of EM radiation can knock electrons out of atoms, so this does not seem to be useful in communication. (SEP: 7.4; CCC: 4.1; DCI: PS4.B.2, PS4.C.1) ● EM radiation types used for killing microorganisms or cancer cells are part of the EM spectrum with higher frequency and shorter wavelength. All these EM radiation types can ionize matter by knocking electrons out of atoms or breaking molecules. This interaction is harmful to living cells, so this is probably why these types of EM radiation are used for this purpose. (SEP: 7.4; CCC: 4.1; DCI: PS4.B.2, PS4.C.1) ● EM radiation types used for detecting defects in metal (gamma rays, X-rays) are the two types of EM radiation with the highest frequency and shortest wavelength. Unlike other types of EM radiation, gamma rays and X-rays can pass through dense materials, such as metal, so this is probably why they can be used for this purpose. (SEP: 7.4; CCC: 4.1; DCI: PS4.B.2, PS4.C.1) **9.A.2 When to check for understanding:** On day 2, after students have shared their argument with a peer. **What to look for/listen for in the moment:** See the previous Assessment for the types of arguments students could make. See the *EM Radiation Applications Key* for additional guidance. **9.B When to check for understanding:** On day 2, as students discuss what they noticed and wondered after examining the model of the electromagnetic spectrum, and add new questions to the Driving Question Board. **What to look for/listen for in the moment:** ● Questions that seek additional information about the uses of different types of EM radiation (e.g., "Why does wireless communication seem to rely on microwave radiation?" or "Could we use X-rays for wireless communication?"). (SEP: 1.2; CCC: 4.1; PS4.C.1) ● Questions that seek to clarify the relationship between the frequency and wavelength of EM radiation with its safety (e.g., "Why do EM radiation types that can cause harm have higher frequencies?"). (SEP: 1.2; CCC: 4.1; DCI: PS4.B.2)
Lesson 10	**10.A** Use data about the effect of EM radiation on human beings and solar cells to look for patterns at a macroscopic scale to revise our working explanation of the types of EM radiation that can cause damage to living cells. (SEP: 4.5; CCC: 1.1; DCI: PS4.B.2)	**10.A.1 When to check for understanding:** At the end of day 1, in the completed exit tickets (**slide L**). **What to look for/listen for in the moment:** ● The risk of damage increases when both amplitude and frequency are increased, but the pattern for frequency and damage is stronger than the pattern for amplitude and damage. (CCC: 1.1) ● The slinky activity provided evidence for increased energy due to increases in amplitude and increases in frequency. (SEP: 4.5; DCI: PS4.B.2)

	10.B Evaluate the merits of the wave and photon models of EM radiation to determine which reasoning better explains how high-frequency EM radiation can cause ionization of atoms and emission of electrons from a solar cell. (SEP: 7.2; CCC: 2.2; DCI: PS4.B.1, PS4.B.2, PS4.B.3)	• The information in the *Amplitude/Frequency Evidence* and the subsequent organization of data to identify patterns in the chart provide evidence that increases in frequency can increase damage. (SEP: 4.5; CCC: 1.1; DCI: PS4.B.2) • Although there is evidence that increased energy due to increased frequency can cause more damage through the emission of electrons, students cannot explain--based upon the evidence and their slinky activity--why increasing frequency causes more damage than an increase in amplitude. (SEP: 4.5; DCI: PS4.B.2) **10.A.2 When to check for understanding:** At the start of day 2, as students evaluate a water wave analogy for explaining the effect of EM radiation on matter. **What to look for/listen for in the moment:** • A water wave analogy is useful because the frequency and amplitude of water waves affect their energy just like EM radiation, and both water waves and EM radiation transfer energy. (SEP: 4.5; DCI: PS4.B.2) • The water wave analogy doesn't match the patterns in our qualitative evidence because larger amplitude waves would destroy the sandcastle more quickly than higher frequency waves. (SEP: 4.5; CCC: 1.1) • The patterns in the data about EM radiation suggest that UV frequencies or higher are needed to cause skin cancer in humans and that visible light frequencies or higher are needed to cause electron emission from a solar cell. For both, the patterns show that amplitude only matters if frequency is high enough. (SEP: 4.5; CCC: 1.1; DCI: PS4.B.2) **10.B.1 When to check for understanding:** In the middle of day 2, as students consider which model is better for explaining various examples of EM radiation interacting with matter, as they work through the *Photon Model*. **What to look for/listen for in the moment:** See 10.B.2 and the *Photon Model Key*. **10.B.2 When to check for understanding:** At the end of day 2, as students come to consensus on which model is better for explaining various examples of EM radiation interacting with matter. **What to look for/listen for in the moment:** • See the *Photon Model Key* for detailed responses. • Some evidence, such as cold spots from destructive interference in the microwave oven, is better explained by a wave model because waves can interfere and cancel out (Question 3a). (SEP: 7.2; DCI: PS4.B.1) • Other evidence is better explained by a photon model. (SEP: 7.2; DCI: PS4.B.1) • A photon model better explains why only visible light or higher frequency radiation can cause electron emission from photovoltaic material in a solar cell, because IR photons don't have enough energy to eject electrons (Question 3b). (CCC: 2.2; DCI: PS4.B.1, PS4.B.3)

		● A photon model better explains why only UV or higher frequency radiation can cause ionization. (CCC: 2.2; DCI: PS4.B.1, PS4.B.2) ● Some evidence (reflection, water heating up in the microwave oven) can be explained by both models. (SEP: 7.2)
Lesson 11	**11.A** Critically read scientific literature adapted for classroom use to determine the advantages and disadvantages of creating X-ray images using digital transmission and storage of information. (SEP: 8.1; CCC: 6.1; DCI: PS4.A.2, PS4.C.1)	**11.A When to check for understanding:** When students complete the *Radiography: Conventional versus Digital* reading. **What to look for/listen for in the moment:** Look for students to: ● Use information from the reading to describe in their own words how the patterns of absorption and transmission of X-rays are used to create images of the internal structure of our body. (SEP: 8.1; CCC: 6.1; DCI: PS4.C.1) ● Use information from the reading to describe how electronic detectors are used to absorb X-ray radiation and create digital images. (SEP: 8.1; CCC: 6.1; DCI: PS4.A.2, PS4.C.1) ● Use information from the reading to identify the advantages of digital radiography over conventional radiography based on the interactions of different components to reduce the time of radiation exposure, image processing, and image storage. (SEP: 8.1; CCC: 6.1; DCI: PS4.A.2, PS4.C.1) ● Use information from the reading to identify the disadvantages of digital information, such as data loss or security risks. (SEP: 8.1; DCI: PS4.C.1)
Lesson 12	**12.A** Integrate information from multiple sources in various formats (manipulatives, diagrams, text, and a model) to communicate how modern electronic devices use the principles of wave behavior and wave interactions with matter to transmit and capture so much and so many different types of information reliably. (SEP: 2.6, 8.2; CCC: 2.3, 4.3; DCI: PS4.A.2, PS4.C.1)	**12.A When to check for understanding:** On day 3, when students turn in the *Communicate Information* and *Gather Station Information* handouts (**slide R**). **What to look for/listen for:** See *Summarizing Stations Key*.
Lesson 13	**13.A** Integrate information from various resources to answer Driving Question Board questions about cause-and-effect relationships and structure and function in the EM spectrum and related technologies.	**13.A When to check for understanding:** As students discuss which Driving Question Board questions we have answered. **What to look for/listen for:** ● Students should incorporate evidence from prior investigations and build on each other's ideas. (SEP: 8.2) ● Listen for ideas framed by structure and function and cause and effect. (CCC: 2.2, 6.1)

	(SEP: 8.2; CCC: 2.2, 6.1; DCI: PS4.A.1, PS4.B.1, PS4.B.2, PS4.C.1) **Transfer Task PE: HS-PS4-4.** Evaluate the validity and reliability of claims in published materials about the effects that various frequencies of electromagnetic radiation have when absorbed by matter. (SEP: 7.3, 8.4; CCC: 2.2; DCI: PS4.B.2)	• Listen for students to incorporate ideas about EM radiation and related technologies from throughout the unit to accurately answer their Driving Question Board questions. (DCI: PS4.A.1, PS4.B.1, PS4.B.2, PS4.C.1) **5G Transfer Task:** In this lesson you will administer the *Evaluating 5G Safety Transfer Task* task. This assessment is not building toward a lesson-level performance expectation. It is designed to assess progress toward a performance expectation from the NGSS (HS-PS4-4). See *Evaluating 5G Safety* for details.

HOME COMMUNICATION

Dear Guardian,

Your student's high school physics class is starting a unit called *How do we use radiation in our lives, and is it safe for humans?* as part of the OpenSciEd science curriculum. This unit develops science ideas around electromagnetic radiation, such as radio waves, visible light, and X-rays, and how it interacts with matter. Students design and carry out investigations to explain and model how various technologies in our lives use electromagnetic radiation to function.

Students draw on their personal experiences of heating up food to make predictions about how to transfer energy quickly into matter. The use of a microwave oven to heat up food provides the context for investigating the nature of energy transfer through waves, properties of waves, the interactions of electromagnetic radiation and various materials and particles, how electromagnetic radiation is used in our daily lives, and safety considerations when using those technologies.

Students may come home with questions about cooking, microwave ovens, and other technology. Share your experiences, ideas, and questions with them.

Your student will be conducting experiments using a microwave oven in class. **IMPORTANT: DO NOT USE YOUR MICROWAVE OVEN TO CONDUCT INVESTIGATIONS AT HOME, OR ALLOW YOUR STUDENT TO DO SO. This can be very dangerous if done incorrectly.**

Helping your student make sense of their learning:

- There is no need to teach your student any related vocabulary before the unit, because many words have multiple meanings, and new terms are often easier to remember once students have had some experience with them.
- Encourage your student to expand their thinking by asking them to give you examples or to say more about their ideas.
- Ask how your student arrived at a particular conclusion.
- Ask your student to recall what other students have said in class, and what about those ideas they agreed or disagreed with.
- Repeat, rephrase, or paraphrase what your student says as a way to clarify their ideas.

Having conversations about science:

- Encourage your student's curiosity through talking about their noticings and wonderings.
- Ask your student to explain how other electromagnetic technology works as you encounter it, such as X-ray machines, 5G cell phone towers, or radios.
- Have honest conversations with your student about balancing the risks and benefits of such technologies.