Electromagnetic Waves

Level	
High School	

Time Required	Lesson Summary
175 min (3.5- 50 min. class periods)	In this lesson, students will learn how electromagnetic waves are created. They will also participate in four learning stations to help them better understand the creation and properties of these waves. Lastly, they will make a 3-D model of an electromagnetic wave that they will use as a learning tool.

Standards

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

PS4.B**:** Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons.

Vocabulary	Objectives
photon electric field magnetic field induction electromagnet	• Students will understand the basis of the wave and particle models of electromagnetic waves. • Students will be able to describe the relationship between the magnetic and electric fields that make up an electromagnetic wave. • Students will calculate wave properties using the wave equation • Students will create a 3-D model of an electromagnetic wave that they will use to explain the propagation of these waves.

Materials

- electromagnet activity: 28, 30, or 32 gauge magnet wire, D battery holders, D batteries, iron nails, paper clips, sandpaper

- electromagnetic induction activity: 24 or 26-gauge magnet wire, galvanometer, a bar magnet, sandpaper
- electromagnetic modeling activity: index cards, pipe cleaners, tape, cardboard, scissors, and paper board (these supplies are not included in the kit)

Pre-Requisites

Students should be able to identify parts of a transverse wave.

Safety Considerations

There is a shock risk during the electromagnetic station if students do not follow the instructions. Students must connect the wires to the battery holder BEFORE adding the battery.

Pacing Notes

This lesson requires three and a half 50-minute class periods.

Day 1: Introduction quiz, introduction to a different type of wave, present the two fields, explain expectations for stations, students complete one station.

Day 2: Students complete two stations

Day 3: Students complete the last station, whole class discussion, direct instruction

Day 4 (1/2 of the period) Students create an electromagnetic wave model and instruct peers.

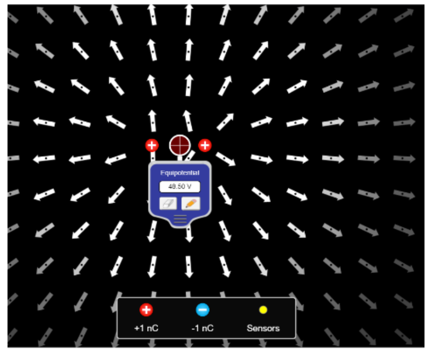
Before the Lesson

Check if your computer will run the Phet simulations charges and fields the week before teaching this lesson. If your IT department blocks it, talk to the person responsible for your school and ask for it to be unblocked. Alternatively, you could download the program on your personal computer and transfer it to your school computer via an external hard drive.

Cut several pieces of copper wire of various lengths and strip the ends before the learning stations activity. Alternatively, you could allow students to do this during class. However, it may lead to material waste and longer activity times.

Assessments	**Classroom Instructions**
Pre-Activity Assessments	Introduction
Students can complete this quiz on paper, or you could use an electronic delivery system such as your LMS, Kahoot, or Quizlet. After grading the quizzes, reteach those concepts most students struggled to understand.	Have students start the day by demonstrating what they know about the components of a wave through a short quiz. A quiz has been created for you but feel free to modify it to meet your students' needs.
Activity Embedded Assessments	Activities
This activity will demonstrate students' personal experience with electromagnetic waves.	1. Introduction to a different kind of wave a. Conduct a stand-up, sit-down survey using the following questions. If a student has experience with something, they stand up. If they don't, they stay seated. **Ask**: Have you ever had an X-ray? Spend a minute or two allowing students to share stories **Ask**: Have you ever listened to an FM radio station? **Ask**: Have you ever listened to an AM radio station? **Ask**: Have you ever used a microwave? **Ask**: Have you ever been sunburned? **Ask**: Have you ever seen green grass? **Say**: If you stood up for any of these things, you have experience with electromagnetic waves. 2. Present the two fields **Say**: All of those events depend on a different kind of wave – an electromagnetic wave. This wave differs from the mechanical waves we have discussed in the past, but it is also the same in some ways. **Say**: First of all, this wave is comprised of two fields. These fields are not like the ones we grow crops in (show a picture) but are fields of electric energy and magnetic force. a. Go to https://phet.colorado.edu/en/simulation/charges-and-fields (last

During this activity, walk around as much as possible to observe the students as they work. Are all students participating in the activity? If not, ask why not and attempt to engage them in the activity. Pay close attention to the reasoning students use. It is possible for them to make a correct prediction but have faulty reasoning. If this happens, ask questions to guide students to an appropriate reason. Allow different students to share with the class each time. This technique will allow more students to be actively engaged in the activity. It will also let you check the understanding of a more significant portion of the class.	accessed 6/24/23) Note: If you are unable to project this simulation, please see the accommodations sections for alternatives b. Once the simulation opens, project your screen on the board for the students to see. - Place a single positive change in the middle of the black field. The arrows pointing away from this charge represent the electric field. - **Say:** This simulation shows us an electric field made by a single positive charge. - Point out to students that the field travels in all directions from the charge. (If the arrows are pointed at strange angles, it is due to the positioning of the charge on the simulation grid. If you want to see the arrows just like a diagram in a textbook presents them turn on the grid and place the charge when the darker horizontal and vertical lines cross). - Have students draw what they see on a sheet of paper. Tell students to include a written explanation under the drawing. - **Ask**: What would the electric field look like if I used a negative charge? Have students share their answers with the person sitting next to them. - Remove the positive change and drag a negative charge into the black field. - **Ask**: Who predicted this result? Allow students to share their reasoning for their choice. Then, have students draw what they see on their paper. - **Ask:** What do you think will happen if I add another negative charge? Have students draw what they think will happen below their first drawing. - Add a second negative charge near the first. **Ask**: How many of you predicted this change? Allow students to share their reasoning both for making this prediction or for predicting something else. Talk about how the second charge affected the field created by the initial charge. Have students make a drawing of what is displayed on the screen. Instruct them to include a written explanation under their picture. - Select the voltmeter and position it between the charges. The number displayed is the voltage produced by the combination of those charges.



- **Ask**: Do you think the number will change if I move the voltmeter? Allow students to give a response either verbally or by shaking their heads.
- **Ask**: How so? Do you think the number will increase or decrease? Have students share their answers with the person sitting next to them.
- Now move the voltmeter further away from the charges.
- **Ask**: Who predicted that would happen?
  Allow students to share their reasons for their choice. Then, discuss the logic the students used to make an incorrect prediction and help them understand why this happened.
- Clear one negative charge and the voltmeter from the black field.

- **Ask**: What will happen to the electric field if I place a positive charge just to the left of the negative charge?
  Have students share their predictions with the person next to them.
- Place the positive change in the field.
- **Ask**: Who predicted that would happen?
  Allow students to share their reasoning. Then, have students draw what they see and write a caption on their paper.
  Say: This simulation allowed us to see how electrical fields move away from charged particles, what happens to the voltage as the distance from the charged particle increased, and the effect of oppositely charged particles on the electric field. This information will be vital to us as we learn about electromagnetic waves. Now let's talk about the second part of these waves, the magnetic field.

c. Magnetic field introduction
   Ask: How many of you know that magnets have poles?
   Allow students to share stories with the class. At least one student will likely talk about how sometimes the ends of magnets will stick together and other times push away.

   Say: That observation is possible because each magnet has a north and a south pole. Opposite poles attract while the same poles repel. So, when you try to make two identical poles touch, you can feel the two magnetic fields pushing against each other.

- Pass around as many pairs of strong bar magnets as you have available. Allow students to experience this phenomenon for themselves. *** Caution *** Instruct students to keep magnets away from computers and cell phones, as magnets can damage these devices. Also, tell students to keep a tight hold on magnets when pushing the poles together. If the magnets are strong enough, they can snap together with enough force to produce a painful pinch.

  Note. Students may ask if they can do this with refrigerator magnets. While these magnets do have poles, two characteristics prevent these interactions. First, they are relatively weak magnets, and second, the direction the poles are oriented prevent them from attracting or repelling other magnets.

  While students are quietly passing around the magnets
  Say: The Earth is a large magnet. The magnetic field around the Earth is used for navigational systems. It also protects the Earth from the Solar winds.

  Spoiler alert: Students will hopefully ask how these magnetic fields are created. Avoid answering this question by telling students they will discover this information for themselves in the next activity.

  If you have iron shavings, an extension activity will allow students to see the lines of the magnetic field. See the Extension section at the bottom of this document for details.

3. Learning Stations
   Students should be working in pairs. As a group, they will move from station to station. Each station should be approximately the same amount of time.

   a. Hand out the student pages and go over the directions for each station. Then, stress the safety concerns with the electromagnet station.

   b. Electromagnet station teacher notes
   Pay special attention to the groups at this station to be sure the battery is not in the holder when they are setting up or taking apart their apparatus. The stripped ends of the wires must be touching for students to get a current.

   c. Induction station teacher notes
   Remind students that the ends of the wires must be stripped to get a reading.

As the students are participating in the stations walk around the room. Observe students as they work. Are all students

actively engaged in the learning activities? If not, approach that student and ask questions about the learning station. Then, make the necessary adjustments to engage the student in the learning. Due to safety considerations, pay special attention to the electromagnetic induction and electromagnet station. **Ask**: Can you tell me what you are doing? Why are you doing that? **Ask**: What have you observed? What is your explanation for that event? For the math groups **Ask**: How did you solve that problem? **Ask**: Is there anything you don't understand about this assignment? For the reading groups **Ask**: What did you just read about? **Ask**: Is there anything in this reading you don't understand?	Tell students to make sure the clip is in contact with the metal of the post. They can do this by either putting the clip into the hole on top or unscrewing the plastic piece enough to expose the metal post. Please see the training video if you have questions. d. Math station teacher notes An answer guide is included in this lesson folder. e. Reading station There has been a controversy about whether electromagnetic energy travels as waves or particles. More recently, there has been a new theory of the wave/particle duality of this type of energy. Therefore, during their time in this reading station, students need to read the evidence for both the wave and the particle nature of electromagnetic energy. This can be from your textbook or the reading supplied in the *Educator Resources* section below. After reading the selections, students should write a one-page position paper supporting either a wave or particle model. This paper should support their choice with evidence from the readings.

As you work through this discussion, pay attention to the students answering questions and those listening. Do all students seem to be following the conversation? If not, ask those individuals to answer a question. Do the students' explanations make sense? If students do not have correct reasoning to back up their statements, ask a series of questions to guide them to the accurate evidence. Be sure to stop frequently during this time to ask students questions. An excellent way to	4. Whole class discussion After the students have finished the learning stations, discuss the learning with the students. **Ask**: What was the most exciting thing you learned from these activities? **Ask**: Do you have any questions after these activities? For the following questions, request students to elaborate on answers if they only provide short responses. Also, allow other students to add to or challenge parts of other student's responses. **Ask**: Can someone describe what happened during the electromagnet station? (Tell students you are interested in the mechanism that caused the magnetism) **Ask**: What did you do to increase the magnetism? Give several groups a chance to share. **Ask**: Can someone describe what happened during the induction station? (Tell students you are interested in the mechanism) **Ask**: How did you increase the voltage? Give several groups a chance to share. **Ask**: What was the most challenging part about the wave math? Be sure students can overcome these challenges and complete the assignment. Spend time addressing student questions and concerns about this part of the learning activity. **Ask**: How many of you support the idea that an electromagnetic field travels as a wave? Let a student or two explain why they support this model. **Ask**: How many of your support the idea that an electromagnetic field travels as particles? Let a student or two explain why they support this model. **Ask**: Does anyone have another opinion? Allow students to share their views on how an electromagnetic field travels. Then, request they provide evidence for their opinions. 5. Direct instruction on the creation and movement of an electromagnetic field. Present information to your students in the method which is most comfortable to you. Please include the following during your instruction:

engage students during direct instruction is to stop and have them discuss something you just said with a peer. You can walk around and listen to conversations as they are doing that. This technique allows you to determine if they understand the information you share.	Source of this field – A changing electric field causes a changing magnetic field which causes a changing electric field. This phenomenon continues creating a wave that moves away from the starting location. A charge oscillating back and forth creates a changing electric field. This changing field could create a changing magnetic field. Alternatively, a changing magnetic field can be created by an oscillating current. This field, in turn, can create an electric field. This wave is similar to a physical transverse wave because it has a crest, trough, wavelength, amplitude, and frequency. Therefore, the wave equation also holds for these waves. This wave differs from physical waves in that it does not require a medium with particles the energy can bounce off of to move from place to place. Electromagnetic waves can move through a vacuum where the electric and magnetic fields are the only thing moving. The electric and magnetic fields occur at a 90-degree angle to each other (see the image sheet for pictures you can use in your instruction).
Post Activity Assessments	*Closure*
Walk around while students are creating their models. Observe what they are doing. **Ask**: How do you plan to make your model? **Ask**: Why did you make that choice? **Ask**: Is your model realistic? Why or why not? **Ask**: Rate your model	**Creation of a Wave Model** 1. To solidify their knowledge of electromagnetic waves, students should conclude this lesson by building a 3-D model of an electromagnetic wave. Please provide them with the materials listed on the student sheet and give them time to create a wave. Students can construct models in many ways, so please avoid giving specific instructions. Budget approximately 20 minutes for creating models. 2. After students have completed their models, have them explain the creation and movement of an electromagnetic wave to a peer. They should use their model to help them explain this information. Students should be encouraged to question their partner if the model or explanation does not make sense. Students should work together to develop a thorough understanding of the phenomena.

from one to 10, with one not representing an electromagnetic wave and 10 representing a wave perfectly. Why did you rate your work in that manner?	

Accommodations

If you cannot use the Phet simulation due to a lack of technology or access to the internet, you may complete it by drawing on the board. Please see the *Alternative to the Phet simulation page* for directions.

Allow ELL students to use translating software during the activities. This will allow them to understand what you expect them to accomplish.

Follow all student IEPs. Make the appropriate modifications to the learning activities.

Allow ELL students to work in groups with native-speaking peers. This social interaction will allow them to refine their knowledge.

Educator Resources

Readings for the stations' activity

Wave theory

https://www.olympus-lifescience.com/en/microscope-resource/primer/java/doubleslitwavefronts/ (last accessed 6/24/23)

Particle theory

https://openstax.org/books/physics/pages/21-2-einstein-and-the-photoelectric-effect (last accessed 6/24/23)

Background information

You can learn about electromagnetic waves by going to these web pages.

https://www.khanacademy.org/science/physics/light-waves/introduction-to-light-waves/v/electromagnetic-waves-and-the-electromagnetic-spectrum (last accessed 6/24/23)

https://www.weather.gov/jetstream/electro (last accessed 6/24/23)

https://scholar.harvard.edu/files/david-morin/files/waves_electromagnetic.pdf (last accessed 6/24/23)

Optional Extension Activities

- Magnetic field visualization with Iron Filings

1. Place a bar magnet on a piece of white paper. Next, sprinkle iron filings on the sheet. Give the paper a little jiggle if the filings don't automatically line up on the magnetic field lines.

2. Use a document camera or have students walk past to see the field. Then, ask them to sketch what they see on paper.

3. Put the iron filings back into the container. Now arrange two bar magnets on the piece of paper. The magnets should be in a straight line with opposite poles facing but far enough apart that the magnets are stationary.

4. Repeat the process of sprinkling iron filings around the magnets. Again, give the paper a jiggle if the filings don't immediately arrange along the magnetic field line.

5. Again, have students draw what they see either by observing the image when it is projected or by walking past it.

6. Have students predict what will happen to the magnet field if you turn one of the magnets, so it is 90 degrees from the other.

7. Turn the magnet and show students the results. Have them sketch what they see and write if their hypothesis was correct or incorrect.

- The following article discusses one scientist's work to make objects invisible using electromagnetic frequencies. While the story is interesting, it will be above the reading level of many students. Therefore, you might consider rewriting a portion of it to meet the needs of your students.

https://www.popularmechanics.com/technology/a10042/how-far-away-are-active-invisibility-cloaks-16466686/ (last accessed 6/24/23)

Acknowledgments

This is the second lesson in a nine-lesson series intended to increase student understanding of radio frequencies. You are welcome to just use this lesson but if you are interested in this topic consider checking out the others in the series.

Lesson One: Mechanical Waves
Lesson Two: Electromagnetic Waves
Lesson Three: Electromagnetic Spectrum
Lesson Four: Argumentation and Radio Waves
Lesson Five: Investigating Spectrum Users
Lesson Six: Aircraft and Newton's Second Law of Motion
Lesson Seven: Weather Forecasting and Radio Waves
Lesson Eight: Satellites and Society
Lesson Nine: Spectrum Management

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