Lesson 7: Answer Key

Field-Particle Interactions Key

As students work through this handout, consider their work as a formative assessment in modeling a few different core ideas, including:
- Electric fields cause force on charged particles. (SEP: 2.3; CCC: 2.2, DCI: PS2.B.2)
- Waves interact with matter: they absorb, transmit, and/or reflect. (SEP: 2.3; DCI: PS4.B.2)
- Increased particle movement means increase in temperature. (SEP: 2.3; DCI: PS4.B.2)

While using the guidance below in class, be careful not to “hover” over students’ work or intervene too early. At this point in the unit, and even in the year, students should be proficient enough with the modeling practice that they are able to depict their own ideas and observations clearly. By intervening too early or too often, we deny students the opportunity to reflect on their own work themselves.

Part 2 of the key describes feedback that can be given in writing on this same handout after it has been submitted as an exit ticket. If you’re unsure whether to make a comment about an individual student’s work in class, consider whether that comment can wait until the exit ticket. Consider how delivering that feedback in writing may enhance student agency over their own work, then use your best judgment.

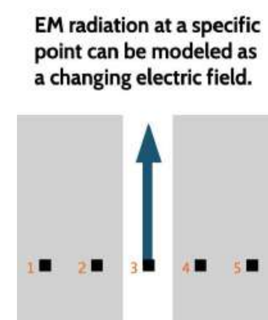
Part 1 of Key: To be used in class (continues on pages 2-4).

1. Consider what we know about electric fields and EM radiation. What would you expect to see in the electric field in a computer simulation designed to model EM radiation?

The electric field at one point would change direction and magnitude up and down.

2. Press **"setup"** and **"go/pause"**. What do you notice? Does this match what you expected in Question 1?

All the arrows flip at once--the field changes direction, but I don’t think it’s changing magnitude.



3. Try changing the **frequency-of-flip** using the dropdown menu. What do you notice about the electric field?

The time in between field flips changes--higher frequency means the arrows flip more quickly.

What to look for in the moment: Electric field changes up and down at a specific frequency chosen in the computer model. (SEP: 2.3; DCI: PS2.B.2)

4. The simulation allows you to investigate 3 types of particles. For each, use words and/or pictures to describe what you notice about (a) the force on the particle and (b) any changes in motion that occur. (Click the **show-force-arrows** button to see forces.)

What to look for in the moment: In words and/or pictures: (SEP: 2.3; CCC: 2.2; DCI: PS2.B.2, PS4.B.2)

- Electric fields cause force on charged particles.
- Combined forces cause the water molecule to rotate because the forces on the two ends are unbalanced.
- Combined forces cause the plastic molecule to remain still, because the forces balance.
- Changing the direction of the field changes the direction of force, causing a charged particle to change speed and direction.

Note: Organized assessment consists of three different components: force, motion, and field. Each of these pieces is an element of foundational understanding. If you see a student using only one or two components, encourage them to consider how another piece can be brought in to make their model more complete.

What to do (Question 4): If students in some groups struggle to see the interactions of specific molecules and changing electric fields, direct them to the water molecule cutouts.

Assign two students to push with a finger on the positively charged and negatively charged parts of the molecule, respectively. Agree on a direction for the electric field. Say, *Let's assume that the electric field points toward the whiteboard. Let's see what happens to the motion of the molecule.*

Then direct students' attention to the plastic molecule. Say, *Now try the same thing with the plastic molecule. What differences do you see?*

5. For each matter type, does the motion of the particle suggest that energy from microwave radiation is being absorbed, reflected, or transmitted? Explain your thinking. **If you notice any limitations of your model or explanation, write a ? to show this.**

What to look for in the moment: The interaction between the field and the water molecule suggests that waves absorb into the water, because energy transfers to the particle motions. The interaction with the plastic molecule suggests that waves transmit through the plastic because no motion results.

water molecule	ethylene plastic molecule
I think the results about water could indicate that energy has been absorbed, because particle motion means higher temperature, so the water's energy increases.	I think the results about plastic could indicate that energy has been transmitted through, because there is no effect on the plastic at all.

What to do (Questions 5 and 6): If students struggle to put their thinking into words, consider providing them with this sentence frame: *"I think the results about (water / plastic / electrons) could indicate that energy has (absorbed / transmitted / reflected) because..."*

If students in some groups struggle to see the connection between the particle-level model and wave behaviors (absorb, transmit, reflect), help reground their thinking in energy. Say, *Considering energy, what does it mean for EM radiation to be absorbed into something? What about transmitted through?* If students struggle to use macroscopic temperature evidence, use questioning to remind them. Point to the Matter Changes in the Microwave Oven Investigation poster and say, *What did we see when we put these two materials in the microwave oven last class? How could our particle model help explain this result?*

If students do not have ideas about how electron movement may cause reflection, do not press this point. Encourage them to write a ? in that box, and move on. This will be revisited on day 2 of the lesson.

6. For each matter type, use the questions to connect the conclusions we reached about energy transfer at a macroscopic scale to the observations you made in the simulation. **If you notice any limitations of your model or explanation, write a ? to show this.**

a. What happens on a macroscopic scale to matter of each type when we expose it to EM radiation in the microwave oven?
b. What particle-scale observations from the simulation help us explain this observation?

What to look for in the moment: Motion of water molecules in our model indicates an increase in temperature on a macroscopic scale. The lack of motion of plastic in our particle model indicates no increase in temperature.

Note: Organized understanding shows a connection between an increase in particle motion and an increase in temperature, whereas foundational understanding may show one or the other.

You can encourage students who are ready to select "particle-type" as "electrons in aluminum" in the simulation. Because aluminum was a material tested in class, this may encourage them to try modeling how electron movement helps to explain why aluminum reflects microwave radiation. The class will visit this part of the simulation near the end of day 2, to consider the reliability of a reading about metal in the microwave oven.

7. a. How do different particles respond when you increase or decrease the frequency of flipping the electric field?
b. We have seen in the past that higher frequency in a wave transfers more energy when amplitude stays the same. Does this previous model agree with the new model of matter interactions we've seen in this simulation? Why or why not?

What to look for in the moment:

- Electric field changes up and down at a specific frequency, selected in the computer model. Smaller frequencies mean that the electric field points in the same direction for more time.
- If the flipping frequency is too fast, the field does not cause much motion because the field direction changes too quickly for the particle to change speed.

a. The motion of the water and the electron usually match the frequency of the flipping electric field. But if the frequency is too fast, then the particle doesn't actually move much. It needs time to get some speed, so if the direction changes quickly, it never builds up any speed.

b. It's hard to say, because higher frequency could still mean higher energy. Faster flipping could mean hotter temperatures for particles. But for the water especially, it seems like the most motion is at medium frequencies, not high frequencies, because we can get the speed of rotation going really fast if the timing is right. This would mean that the new model doesn't match the old model exactly.

Part 2 of Key: To be used outside class, on exit ticket feedback.

Look for the following key ideas as you formatively assess student understanding on exit ticket Questions A and B, whether or not students circled a relevant section of their own work. Give feedback as described in the "What to do" section below.

What to look for in the moment: (SEP: 2.3; CCC: 2.2; DCI: PS2.B.2, PS4.B.2)

Exit ticket Question (A) Why does water heat up in the microwave oven?

For water, students should circle or create a drawing that shows:

- Arrows for the electric field pointing in two different directions.
- Arows for force on the water molecule **or** some indication of rotation or motion of the water molecule (such as "whoosh" lines or the like) caused by the forces.

Or students should circle or write an explanation that describes:

- The electric field pushes on charged particles, and the water is charged.
- When the water feels a force, this causes it to rotate. If the electric field changes direction, the water can keep spinning.

Exit ticket Question (B) Why doesn't the microwave-safe plastic heat up in the microwave oven?

For plastic, students should circle or create a drawing that shows:

- Arrows for the electric field pointing in two different directions.
- Arrows for force on the water molecule showing balanced force or no arrows at all. Some indication of zero movement (such as a label).

Or students should circle or write an explanation that describes:

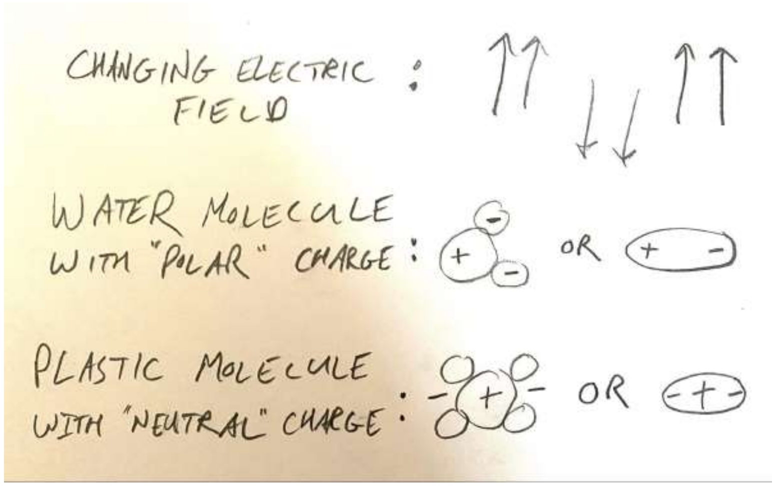
- The electric field pushes on charged particles. The charges in the plastic balance out because plastic is neutrally charged.
- The balanced charges / balanced force on the plastic causes it to stay still.

What to do:

• Place a checkmark next to parts of student models or explanations that contain the ideas above. In the class discussion at the beginning of day 2, ask *Who has a check mark next to a model or explanation that they would be willing to share with the class?*
• Write a ? next to parts of student models or explanations that don't make sense or seem inconsistent with the findings in the simulation. If you notice that many students have missed the fundamental ideas listed above, take time at the beginning of day 2 to revisit the simulation as described below and in the Assessment callout for this exit ticket.

To help students make sense of key ideas needed to explain why a microwave oven heats up food but not plastic, take additional class time to try the following strategy:

- At the beginning of day 2, answer the second bullet of **slide M** as a class, drawing images of key components, as shown in the image here. Make sure to include: *changing electric fields, water molecule with polar charge, plastic molecule with neutral charge.*
- Brainstorm and record a list of key ideas. Ask questions to prompt the following: *electric field pushes charged particles, unbalanced forces can make particles move, faster moving molecules means heating up.*
- Provide students with a chance on day 2 to work individually or in partners to sketch a model of why water heats up in the microwave oven and why plastic does not heat up.



After students have made models individually or in partners, move on to the class consensus model, using ideas students generated through their own models.