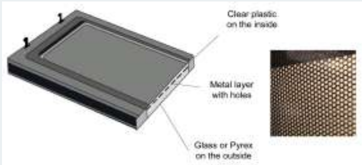
Lesson 5: How does radiation interact with the parts of the microwave oven system?

Previous Lesson *We investigated how moving electrons in an antenna cause energy transfer. We used and evaluated different representations of electromagnetic radiation propagating through space, and read about how a vibrating charged particle generates electric and magnetic fields. We developed a mechanistic explanation for electromagnetic radiation and used it to predict interactions with matter inside the microwave oven.*

This Lesson

Investigation

3 days



We inspect the structure of a microwave oven door and wonder about how it interacts with two forms of EM radiation (visible light and microwave radiation). We plan an investigation to determine what happens to the energy transferred by these waves when they reach the oven door and walls. We carry out a consensus investigation, then argue for and carry out additional consensus investigations for the door and walls. We develop a model of what happens to the energy transferred by microwave radiation when it interacts with these parts of the system, and we generate new questions.

Next Lesson *We will revisit the Driving Question Board and add new questions. We will complete an assessment to explain that an increase in greenhouse gases in the atmosphere contributes to the overall increase in global temperatures because of the gases' absorption of electromagnetic radiation.*

BUILDING TOWARD NGSS

HS-PS2-5, HS-PS4-1, HS-PS4-2, HS-PS4-3, HS-PS4-4, HS-PS4-5, HS-ESS2-4

What students will do

5.A Plan investigations to safely produce data that would help determine whether the energy of the microwave radiation is 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 students will figure out

- The energy transferred by microwave radiation can be absorbed, reflected, and/or transmitted by matter.
- We can detect the absorption of microwave radiation by measuring for increases in temperature.
- 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 metal walls of the microwave oven reflect microwave radiation.
- 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).

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Connect to the models from the end of Lesson 4. Consider the interaction of microwave radiation with matter in the microwave oven system.	A	exit ticket from Lesson 4, class consensus model from Lesson 4
2	10 min		**DETERMINE INTERACTIONS OF LIGHT WITH MATTER IN THE CLASSROOM** Look for examples of light interacting with objects in the classroom. Determine what the light is doing as it interacts with various objects, and construct a model of each type of interaction.	B-C	chart paper, markers, *EM Radiation Interactions*
3	18 min		**CONSIDER THE INTERACTIONS OF EM RADIATION WITHIN THE MICROWAVE OVEN SYSTEM** Revise individual models to show possible interactions of EM radiation with parts of the microwave oven system. Use materials comparable to parts of the system to predict these interactions.	D-F	EM Radiation Interactions Chart, Orientation to Available Materials
4	4 min		**IDENTIFY AREAS OF UNCERTAINTY** Discuss which interactions in the microwave oven system we are less certain about, and mark these on the EM Radiation Interactions Chart.	G	EM Radiation Interactions Chart, markers
5	4 min		**UPDATE INDIVIDUAL MODELS** Revisit individual models and update them with new ideas about reflection, absorption, and transmission of microwave radiation.	H	exit ticket from Lesson 4, EM Radiation Interactions Chart
6	4 min		**NAVIGATE** Independently generate investigation questions.	I	
					End of day 1
7	8 min		**NAVIGATE** Review the recorded questions from the last class in partners. Develop shared investigation questions for the microwave oven walls and door as a class.	J	
8	8 min		**DETERMINE A KNOWN ABSORBER**	K-L	

		Discuss how water (a known absorber of microwave radiation) can be used to indicate whether non-visible radiation is being reflected or transmitted.		
9	12 min	**BRAINSTORM SAFETY CONSIDERATIONS FOR POTENTIAL INVESTIGATIONS** Brainstorm initial safety concerns for investigations. Review the *Microwave Oven Manual* and develop a Safety Constraints poster as a class.	M-N	*Microwave Oven Manual*, chart paper, markers
10	17 min	**OUTLINE AN INVESTIGATION PLAN AND COLLECT DATA ON A CONTROL CONDITION** Orient to the investigation materials. Use the *Oven Investigation Plan* handout to plan an investigation in small groups.	O-P	*Oven Investigation Plan*, Safety Constraints and Protocols poster, Control Condition Investigation
				End of day 2
11	8 min	**DETERMINE AND CONDUCT A CONTROL CONDITION INVESTIGATION PLAN** Develop an investigation plan for a control condition and carry out the investigation as a class.	Q-R	Safety Constraints and Protocols poster
12	10 min	**ARGUE FOR THE PROPOSED WALL AND DOOR INVESTIGATION PLANS** Hear groups' proposals for investigating the oven walls and door. Through a Consensus Discussion, negotiate and agree upon a single investigation plan for each, including control variables, to carry out as a class.	S-T	*Oven Investigation Plan*, digital images of each group's investigation plan from the *Oven Investigation Plan* handout, computer, projector
13	4 min	**CARRY OUT THE WALL INVESTIGATION PLAN** Think about hypotheses for the planned investigations. Carry out the wall investigation plan for the microwave oven system.	U-V	*Oven Investigation Plan*, Microwave Oven Wall Investigation
14	4 min	**CARRY OUT THE DOOR INVESTIGATION PLAN** Briefly consider hypotheses for the investigation of the door of the microwave oven system in light of new data. Carry out the investigation plan.	W-X	Microwave Oven Door Investigation
15	5 min	**DEVELOP AN ENERGY TRANSFER MODEL FOR THE CONTROL INVESTIGATION** Gather in a Scientists Circle to develop an initial energy flow diagram to explain the results of the control investigation.	Y	chart paper, markers

16	8 min		**MODEL THE MICROWAVE RADIATION INTERACTIONS IN THE WALL OR DOOR TEST** Individually create a revised model to show what happened to the radiation in either the wall or door investigation.	Z-AA	sheet of notebook paper
17	4 min		**UPDATE THE PROGRESS TRACKER** Individually update the *Progress Tracker* to summarize how the materials in the walls and door of the microwave oven interact with microwave radiation.	BB	*Progress Tracker* from Lesson 4
18	2 min		**GENERATE AND RECORD NEW QUESTIONS** Record questions on sticky notes to be used next time.	CC	3” x 3” sticky notes, marker, EM Radiation Interactions Chart, Driving Question Board

End of day 3

Lesson 5 • Materials List

	per student	per group	per class
Orientation to Available Materials materials			• 2 sheets heavy-duty aluminum foil (~8" x 12") • 2 sheets hole-punched heavy-duty aluminum foil (~8" x 12") • 1 gallon room-temperature tap water • microwave oven (with the turning plate/track/plastic gearing mechanism removed for now) • 8 microwave-safe glass bowls (100-250 mL) with plastic lids • 1 graduated cylinder (100 mL) • microwave-safe plastic wrap
Control Condition Investigation materials			• 1 gallon room-temperature tap water • microwave oven (with the turning plate/track/plastic gearing mechanism removed for now) • 8 microwave-safe glass bowls (100-250 mL) with plastic lids • 1 graduated cylinder (100 mL) • microwave-safe plastic wrap • 2 oven mitts
Microwave Oven Wall Investigation materials	• indirectly vented chemical splash goggles • science notebook		• 2 sheets of heavy-duty aluminum foil (~8" x 12") • 1 gallon tap water at room temperature • microwave oven (with the turning plate/track/plastic gearing

			mechanism removed for now) ● 4 microwave-safe plastic bowls (1" tall) ● 3 microwave-safe plastic cutting boards ● IR thermometer ● 8 microwave-safe glass bowls (100-250 mL) with plastic lids ● 1 graduated cylinder (100 mL) ● microwave-safe plastic wrap ● 2 oven mitts
Microwave Oven Door Investigation materials	● indirectly vented chemical splash goggles ● science notebook		● 2 sheets hole-punched heavy-duty aluminum foil (8" x 12") ● 1 gallon room-temperature tap water ● microwave oven (with the turning plate/track/plastic gearing mechanism removed for now) ● 4 microwave-safe plastic bowls (1" tall) ● 3 microwave-safe plastic cutting boards ● IR thermometer ● 8 microwave-safe glass bowls (100-250 mL) with plastic lids ● 1 graduated cylinder (100 mL) ● microwave-safe plastic wrap ● 2 oven mitts
Lesson materials	● exit ticket from Lesson 4 ● science notebook ● *Microwave Oven Manual*		● class consensus model from Lesson 4 ● chart paper

	• *Oven Investigation Plan* • sheet of notebook paper • *Progress Tracker* from Lesson 4 • 3" x 3" sticky notes • marker		• markers • *EM Radiation Interactions* • EM Radiation Interactions Chart • Safety Constraints and Protocols poster • digital images of each group's investigation plan from the *Oven Investigation Plan* handout • computer • projector • Driving Question Board

Materials preparation (45 minutes)

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

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

Three-hole-punch all handouts so they can be added to students' notebooks.

Make sure each student has a copy of the *Microwave Oven Manual* (used previously in Lessons 1 and 2 of this unit).

Review *Additional Safety Guidelines*. This teacher reference shows the safety guidelines from a student's perspective and the corresponding parts of the *Microwave Oven Manual*. As the class develops a list of safety considerations, make sure these guidelines are recorded on the Safety Constraints poster.

Create the **Investigation 1 Chart:** Prior to day 3, write the agreed-upon investigation question **for the microwave oven walls** at the top of a piece of chart paper. Leave plenty of room below it to record an agreed-upon consensus investigation plan.

Create the **Investigation 2 Chart:** Prior to day 3, write the agreed-upon investigation question **for the microwave oven door** at the top of a piece of chart paper. Leave plenty of room below it to record an agreed-upon consensus investigation plan.

Day 1: Orientation to Available Materials

- **Group size:** Whole group.
- **Setup:**
    - Prepare 4 sheets of heavy-duty aluminum foil (~8" x 12"), 2 with and 2 without hole-punches, and test that they can be wrapped around a microwave-safe glass bowl on an insulated platform (described and shown below) as indicated in *Foil/Platform Preparation* and https://www.youtube.com/watch?v=9Ldx_Vm5X5c. Prepare a set of sheets for each separate class of students.
    - Fill a gallon container with tap water and leave it out for a day to ensure it reaches room temperature. Prepare a gallon for each separate class of students.
    - Lay out these investigation materials for students to see when you reach this activity:
        - 8 microwave-safe glass bowls (100-250 mL) with plastic lids
        - 1 graduated cylinder (100 mL)
        - microwave-safe plastic wrap
        - 2 sheets heavy-duty aluminum foil (~8" x 12")
        - 2 sheets hole-punched heavy-duty aluminum foil (~8" x 12")
        - 1 gallon room-temperature tap water
        - microwave oven (with turning plate/track/plastic gearing mechanism removed for now)
        - IR thermometer
        - 4 microwave-safe plastic bowls (1" tall)
        - 3 microwave-safe plastic cutting boards
    - The cutting boards serve as platforms to place on top of the plastic bowls used as spacers. Because a container of water placed in the microwave oven heats up, it also heats the spot below it on the platform via conduction. Having multiple boards on hand allows you to swap in a room-temperature board for each test while the previously used board cools off. An alternative is a lid from a plastic storage container (shown here). If you plan to use such a material, test a small piece in the oven ahead of time to make sure it doesn't heat up when tested alongside (but not in contact with) a bowl of water.

    - Students may suggest other materials in their investigation plans, which you can also bring in if they justify them. Examples might include:
        - Nest the glass bowl of water wrapped in hole-punched foil within a larger empty glass/Pyrex bowl to better simulate the outer glass layer of the window in the oven door.
- **Storage:** Store materials in a cabinet in the classroom.

Day 2: Control Condition Investigation and
Day 3: Microwave Oven Wall Investigation and Microwave Oven Door Investigation

- **Group size:** Whole group.
- **Setup:**
    - Carry out tests as outlined later in this *Teacher Guide* before you do the same with your first class of students; confirm that the tests produce the expected results.

- **Notes for during the lab:**
    - The extra plastic cutting boards allow you to swap in room-temperature boards for any that might have heated up during the tests.
- **Safety:**
    - Follow all the safety protocols outlined in *Foil/Platform Preparation* and *Additional Safety Guidelines*.
    - Keep a fire extinguisher handy.
    - You and your students should wear indirectly vented chemical splash goggles during the setup, hands-on activities, and take-down phase of this investigation.
    - You should be the one to place the setup into the microwave oven, remove it, and handle the containers. Use oven mitts to do this.
    - Poke a small hole in any plastic wrap or lid you use to cover a bowl filled with water.
    - Volunteers can take turns using the IR thermometer for quick temperature measurements of the parts in the system.
    - If the platform or other parts of the system get wet, dry them thoroughly with paper towels before reusing in another test. Foil must not be reused; see Storage below.
    - Use caution when working with glassware or plasticware--it can break and cut/puncture skin.
    - Use caution when working with sharps--they can cut/puncture skin.
    - Immediately wipe up any spilled liquids--they are a slip/fall hazard.
    - Never eat any food items used in a lab activity.
    - Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
    - Any electrical power cords used near water must be plugged into a GFCI-protected circuit. Presenters need to provide a GFCI temporary power cord or power strip for this use.
- **Storage:** Dispose of the used foil after every test. Reusing it could create spaces and chads, which could lead to arcing in the microwave oven system. It is safe to throw away in a trash can, but make sure that is where students cannot collect and reuse it. If recycling is available, consider recycling it. All other materials can be reused. Store materials in a cabinet in the classroom.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

In previous lessons, students built a model that explains how microwave radiation is generated and how the waves propagate through space. In this lesson, they start considering how microwave radiation interacts with various materials in the microwave oven. More specifically, they explore how reflection caused by certain materials affects the way energy transfers from the magnetron to other parts of the microwave oven system.

In Lesson 4, students began to create a model of how microwave radiation interacts with the parts of the microwave oven system, which they refine in this lesson. This gives them experience in engaging with science and engineering practice (SEP) 2.3 over time, using their models to make predictions about the relationships between parts of the system, and revising their models based on data collected in their investigations.

- SEP 2.3: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Students argue for investigation plans, carry out those investigations, and develop models to explain the results. During this process, students engage in SEP 3.1 and SEP 3.3, which allows them to generate data to more deeply engage in SEP 2.3 (above).

- SEP 3.1: Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems.
- SEP 3.3: 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~~.

Through this process of developing and carrying out multiple investigations, data collection, and model refinement, this lesson is designed to target the following disciplinary core ideas (DCIs):

- **PS3.A.1** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.
- **PS3.D.1** Although energy cannot be destroyed, it can be converted to less useful forms--for example, to thermal energy in the surrounding environment.
- **PS4.B.2** 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.~~

Guidance is also provided in day 3 of the learning plan for how and why you may want to consider taking an extra instruction period for those classes in which there is student engagement around the need for additional tests beyond the three defaults described.

Students will co-develop definitions for *reflection, absorption,* and *transmission*. They should also have developed preliminary definitions for these terms, related to sound or visible light, in middle school. **Do not** post any words or ask students to add them to their Personal Glossaries until after the class has developed a shared understanding of their meaning.

Where We Are NOT Going

This lesson is not about why certain materials do or do not interact with different types of microwave radiation, nor is it about electrostatics. No attempt is made to distinguish whether the hole-punched heavy-duty aluminum foil is reflecting versus refracting microwave radiation, though the latter term would imply (incorrectly) that the radiation still passes through the window in the oven door.

LEARNING PLAN for LESSON 5

1 · NAVIGATE

5 min

MATERIALS: exit ticket from Lesson 4, class consensus model from Lesson 4

SAFETY PRECAUTIONS

This lesson uses heavy-duty aluminum foil in a microwave oven. Make sure to read *Foil/Platform Preparation* and this *Teacher Guide* in full before teaching this lesson.

Look back. Point to the class consensus model produced in Lesson 4, and ask for volunteers to summarize what electromagnetic radiation is. Listen for them to say that it consists of changing electric and magnetic fields transferring energy across space.

Say, *Though EM waves are different in some ways from physical waves, like sound or water, thinking about how sound or water waves interact with different types of matter may help us identify what is happening in our microwave oven system.* ✱ Remind students that as our exit ticket out of the last class, we produced models to predict what we thought was occurring when microwave radiation interacted with matter like food or liquid. Return the exit tickets to students.

Consider types of wave and matter interactions. Present **slide A**. Pose the prompts as a Turn and Talk to have students consider interactions with different types of matter:

- *What did you predict the EM radiation would do when it encounters different types of matter that we might put in the microwave oven?*
- *How is your model similar to or different from your partner's model?*

After 2 minutes, elicit student ideas in a whole-group share-out. Listen for the following ideas:

- Microwave radiation might go through food to heat it up, or be absorbed by the food.
- Microwave radiation might hit the sides/floor/walls of the microwave oven, bouncing off or being absorbed. Maybe some of it gets through the sides as well.
- Microwave radiation may be going through the oven door, but it's unclear if and how this happens.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

In this lesson, the microwave oven is referred to as "the microwave oven system" to make it explicit for students how parts and interactions in the system affect the function of the system as a whole. When students consider the total amount of energy transferred (Energy of a wave = reflected + absorbed + transmitted), the system's boundaries must be established to accurately describe the electromagnetic wave inputs and outputs, as well as the interactions that occur with the matter and electromagnetic waves.

Models across partner pairs might show uncertainty or conflicting ideas.

Reintroduce the terms *absorption*, *reflection*, and *transmission*. Point out that the microwave radiation seems to be either bouncing, getting absorbed, or going through something in our models. Remind students that we used three terms in elementary/middle school to discuss the interactions of waves with matter: *absorption, reflection,* and *transmission*.

Explain that there is a general rule for how these three ways of interacting should add up to the total energy of a wave. This is true not only for electromagnetic waves, but for all other types of waves, including physical waves, like sound. If students have experienced the *Earth's Interior Unit* unit, help them make connections across disciplines by asking them what seismic waves do when they encounter matter.

Connect light waves and other EM waves. Say, *Because we can't really see what this type of EM radiation is doing, we may need to consider other types of EM waves that interact with matter in these three ways. The Light as a Wave reading explained that visible light is made of changing electric and magnetic fields, like the waves generated by a magnetron. And in prior grades, we explained lots of phenomena related to how visible light interacts with matter. So let's try to use the same patterns of interaction that we can see with light waves to make predictions about EM radiation interactions that we can't see.*

2 · DETERMINE INTERACTIONS OF LIGHT WITH MATTER IN THE CLASSROOM

10 min

MATERIALS: chart paper, markers, *EM Radiation Interactions*

Consider interactions of light waves with matter. Project **slide B**. Have students take a silent moment to look around the classroom and consider where light is being absorbed, reflected, or transmitted by different types of matter.

Interaction Models	**Visible Light** interacting with matter in our classroom	**Microwave radiation** interacting with matter in the oven
Absorption (energy is absorbed)		
Reflection (energy bounces off)		
Transmission (energy passes through)		

As they do this, create a poster of a T-chart with three rows, each labeled with a type of interaction (absorption, reflection, transmission). Title it "EM Radiation Interactions Chart". Do not draw the accompanying models yet; this will be done with the class in the next step. See *Unknown material with identifier: pm.l5.tref2* for a larger example of a completed chart.

Then ask students to share out. Anticipated responses include these:

- Absorption: dark-colored materials that have increased in temperature due to light shining on them
- Reflection: mirrors, anything we can see, shiny desks or equipment
- Transmission: glass, anything we can see through

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

This is an explicit reference to prior use of these two related elements of this crosscutting concept. Such references can help students recognize the utility of this concept across different contexts:

- 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

As students share, ask if others agree, and then record their examples in the second column of the chart.

ADDITIONAL GUIDANCE	If students ask about *scattering* or *refraction*, validate these ideas. Tell them that scattering is a form of bouncing off in lots of directions, so it is considered reflection. Tell them that refraction is a change in direction that waves take when they pass from one medium into another and go through that new medium, so it is considered a form of transmission.

After recording a few examples in each row, turn students' attention to the first column. Suggest that if we model these examples of the three ways light interacts with matter, maybe we can use our models to think about how similar interactions may happen with microwave radiation in our microwave oven system.

Create models of how light is absorbed, reflected, and transmitted. Project **slide C**. Direct students to look at the examples in the first row and consider how light is interacting as it is absorbed by the identified items. Create a model similar to the example shown. Move on to create models for reflection and transmission, following the same process. Have students add these terms to their Personal Glossaries as well.

Interaction Models	**Visible Light** interacting with matter in our classroom	**Microwave radiation** interacting with matter in the oven
Absorption (energy is absorbed)	Black cloth - gets warm and can't see the color of it.	
Reflection (energy bounces off)	White cloth - see it via light in my eyes. Aluminum foil - shines light back at me.	
Transmission (energy passes through)	Clear plastic, window, anything translucent - I can see through it. The light passes through it.	

Connect to energy conservation in any process. Remind students that in prior units, we developed ways to show that all of the energy in a system must be accounted for, and also when energy transfers from one system to another, so it might be important to capture that important concept for waves, too. ✱ Suggest that one way to express that energy relationship between these three different matter interactions could be this equation:

- Energy of a wave (that reaches a new material) = energy reflected + energy absorbed + energy transmitted

Add this relationship equation to the bottom of the EM Radiation Interactions Chart.

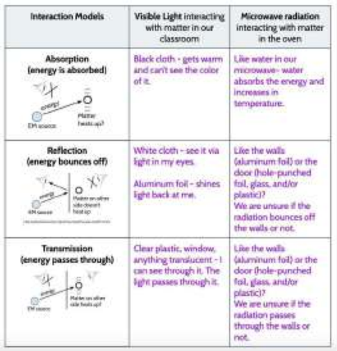
of energy and matter flows into, out of, and within that system.

3 · CONSIDER THE INTERACTIONS OF EM RADIATION WITHIN THE MICROWAVE OVEN SYSTEM

18 min

MATERIALS: Orientation to Available Materials, EM Radiation Interactions Chart

Introduce models as a way of understanding EM radiation interactions. Turn students' attention back to the microwave oven. Explain that now that we have considered what is happening when light interacts with matter in these three ways, maybe we can use these models to consider how EM radiation interacts with the parts of our microwave oven system.



Interaction Models	**Visible Light** interacting with matter in our classroom	**Microwave radiation** interacting with matter in the oven
Absorption (energy is absorbed)	Black cloth - gets warm and can't see the color of it.	Like water in our microwave- water absorbs the energy and increases in temperature.
Reflection (energy bounces off)	White cloth - see it via light in my eyes. Aluminum foil - shines light back at me.	Like the walls (aluminum foil) or the door (hole-punched foil, glass, and/or plastic)? We are unsure if the radiation bounces off the walls or not.
Transmission (energy passes through)	Clear plastic, window, anything translucent - I can see through it. The light passes through it.	Like the walls (aluminum foil) or the door (hole-punched foil, glass, and/or plastic)? We are unsure if the radiation passes through the walls or not.

Turn and talk about possible interactions of EM radiation within the system. Project **slide D**. Have students turn and talk about the prompts:

- *What types of materials are part of the microwave oven system (when it's in use)?*
- *How do we think the microwave radiation is interacting with these different materials?*

While partners discuss, label the chart's third column "Microwave radiation interacting with matter in the oven".

Discuss parts of the system and potential EM radiation interactions. Project **slide E**. Ask students to share out their ideas, starting with the first prompt:

- *What types of materials are part of the microwave oven system (when it's in use)?*

As students share, add their ideas to the next two columns. Continue the conversation using the table below.

Suggested prompt	Sample student response
What types of materials are part of the microwave oven system (when it's in use)?	Metal walls, a glass spinning tray, a door made of metal mesh and plastic (or glass), food or liquid and the containers that hold them (plastic, paper, or glass).
We identified the metal walls and floor--I have some aluminum foil, which is also metal. We could use the foil to think about how microwave radiation interacts with the walls. Do you think it interacts with metals like this the same way light does?	Light reflects off of metal, so microwave radiation might reflect off of it, too.
We identified that containers can be made of plastic or glass. Do we think microwave radiation interacts with these materials the same way light does?	(Continue the conversation, allowing students to add their ideas and build off of each other.)

During this conversation, use the following materials to represent each part of the system:

- Aluminum foil (without holes punched)--This can represent the oven's walls, ceiling, or floor, because it is made of metal.
- Water--This can represent both water and food.
- Glass bowl--This can represent different types of containers/dishes for holding liquid or food.
- Door--See separate guidance below.

Students might also list parts such as:

- Liquid in a drink--Relate this back to the water listed above.
- Floor of the microwave oven--Relate this back to the oven's metal walls.
- Spinning tray--Relate this back to the glass bowl listed above.

Focus attention on the oven door. Suggest we consider the door more closely, as it appears to be made of more than one type of material. Display **slide F**. Elicit student ideas in response to the prompts:

- *What types of materials is this structure made of?*
- *What material might represent the mesh?*
- *Does microwave radiation interact with these materials the same way light does?*

Use the diagrams on the slide to help students determine what materials make up the door. If needed, they could come up to inspect the actual microwave oven door.

Point out that we already made some predictions about the glass/plastic in the door, because it would interact the same way that we reasoned through the glass bowl earlier, but we haven't considered the metal mesh. Hold up a sheet of hole-punched aluminum foil and suggest that we could use this metal foil, which has a similar structure, to investigate how microwave radiation interacts with it.

Ask students to predict whether they think microwave radiation interacts with these materials the same way light does. Anticipate controversy around this, because light both reflects off of glass/plastic and transmits through it, and if microwave radiation behaves similarly, then some of that energy might be coming out of the oven like light does.

4 · IDENTIFY AREAS OF UNCERTAINTY

4 min

MATERIALS: EM Radiation Interactions Chart, markers

Identify areas where we are lacking evidence. Display **slide G**. Discuss the questions as a class:

- *What material interactions do we disagree on?*
- *Where do we need more evidence to explain what is occurring when the waves interact with these materials?*

Anticipate the following areas of uncertainty, and indicate them with question marks on the EM Radiation Interactions Chart when they come up in the discussion:

- We aren't sure if the solid metal surfaces (e.g., walls, ceiling, and floor) are transmitting or absorbing any microwave radiation.
- We aren't sure if the metal with holes in it in the door is reflecting and/or transmitting microwave radiation.

5 · UPDATE INDIVIDUAL MODELS

4 min

MATERIALS: science notebook, exit ticket from Lesson 4, EM Radiation Interactions Chart

Update models with how light interacts with the microwave oven system. Present **slide H**. Ask students to look back at their model from Lesson 4 (discussed at the start of the period) and revise that model, as needed, to show how they now think microwave radiation is interacting with all the different materials in the microwave oven system.

If there is time, allow students to quickly share their models with a partner and give each other feedback on the potential interactions.

6 · NAVIGATE

4 min

MATERIALS: science notebook

Generate initial investigation questions. Present **slide I**. Say, *Now that we have identified what interactions we are uncertain about, let's see if we can frame some questions to guide the investigations we want to design.* Give students a few minutes to individually consider what question(s) best captures what we are trying to figure out about the microwave oven walls and door, and to record their investigation question in their science notebooks. This may be two separate questions (e.g., one for the walls and one for the door) or one overall question for both.

Ask for a few volunteers to share their questions, and allow students to modify the questions they recorded in their notebooks. Tell them we will carry out some tests with our oven and try to figure out the answers to our questions in the next class.

End of day 1

7 · NAVIGATE

8 min

MATERIALS: science notebook

Review investigation questions. Project **slide J**. Have students share their questions from last time with a partner. After a few minutes, bring the class together and ask students to share out. For each suggested question, workshop its phrasing to ensure it reflects what everyone thinks best represents what the class has been considering. Ask other students to repeat the question and weigh in on how it is phrased.

The goal here is to develop one investigation question for the oven walls and another for the oven door. Once the class settles on a version for each that everyone likes, write it on the board as reference for the next steps. ✱ Some possibilities that your classes might land on are listed below.

For the walls:

- Does some, none, or all of the microwave radiation get reflected off of the oven walls?
- Does any of the microwave radiation get transmitted through the oven walls?
- Does any of the microwave radiation get absorbed by the oven walls? (Students may be uncertain whether absorption was happening at the walls.)

For the door:

- Does any microwave radiation get out of the oven?
- Does some, none, or all of the microwave radiation pass through the holes in the window in the door?
- Are the materials in the door designed to make sure that microwave radiation cannot get through?

✱ STRATEGIES FOR THIS CONSENSUS DISCUSSION

Establishing a shared question that everyone agrees represents the main question the class has been narrowing in on is a useful form of consensus building, and it will drive the investigations for the remainder of this lesson. It is important to use the language of the classroom to represent this jointly developed question, so all students can understand the question and the joint goal of the classroom community's investigations. Consider asking students to rephrase or revoice this question once it is written to reinforce that joint goal.

8 · DETERMINE A KNOWN ABSORBER

8 min

MATERIALS: None

Determine how we know whether microwave radiation is absorbed. Project **slide K**. Remind students that last time, we determined that microwave radiation interacts with matter in three ways: absorption, reflection, and/or transmission. Say, *Though we can't see this type of radiation, we knew it was in use in our oven system. How did we know that?* Point to the first prompt on the slide:

- *How have we detected the absorption of microwave radiation so far?*

Guide students to conclude that we have evidence of microwave radiation being absorbed in the system, because food or water inside the oven increases in temperature when we run the oven.

Consider evidence for other interactions. Point to the second prompt:

- *Do we have a way of knowing if these non-visible waves are being reflected or transmitted by the walls or door of the microwave oven?*

Ask a few students to share out. Listen for the following observations:

- We have no evidence for reflection, because we haven't yet figured out if the radiation has been reflected off of or transmitted through any items.
- We have no evidence for transmission, because the radiation would go through it without any increase in temperature.

If students have trouble thinking of whether we have evidence for reflection or transmission, hold up the materials representing each part of the system and briefly discuss them using the table below.

Suggested prompt	Sample student response	Follow-up question
Do we have evidence of microwave radiation reflecting off of continuous metal surfaces like the walls, similar to the foil, in our oven?	The food gets hot, but the walls don't. I'm not sure if the radiation is bouncing off or going through the walls.	*How would we be able to detect the microwave radiation or know where it is going if it is indeed reflecting off of a continuous metal surface, like foil?*
Do we have evidence of microwave radiation transmitting through the type of materials in our oven door, such as glass, clear plastic, or a metal mesh like this hole-punched foil?	We don't have evidence of it transmitting, but light transmits. It doesn't warm up, so maybe it's going through. Or it could also be reflected.	*So, if it transmits like light, what would happen on the other side of the glass or hole-punched foil? What would the waves do to something on the other side?* *How would we be able to detect that microwave radiation goes through the glass and hole-punched foil?*

Determine that water can be used to indicate whether transmission or reflection occurs. Present **slide L**. At this point, students may have surmised that water can be placed in different locations in the oven to determine whether the microwave radiation is reflecting or transmitting. If they have not, press for the idea that water can be used as a detector for these two types of energy transfer. Say, *How could we detect where the waves go? What material do we have that shows a clear interaction with microwave radiation?*

Help students reach the conclusion that water, a known absorber, would be the most consistent material and could be used in the following ways:

- Water could be put on the other side of an object that we think is transmitting microwave radiation, and the water would increase in temperature if the waves were transmitted.
- Water could be put in the space where we think reflection is happening, and the water would increase in temperature if the waves were reflected.

9 · BRAINSTORM SAFETY CONSIDERATIONS FOR POTENTIAL INVESTIGATIONS

12 min

MATERIALS: science notebook, *Microwave Oven Manual*, chart paper, markers

Raise the issue of safety concerns. Project **slide M**. Say, *We're considering ways to use water to investigate our microwave oven system to collect evidence for reflection or transmission. Before we start testing materials, like foil, let's consider how we can safely use the oven with something like metal in it. What safety concerns do we have, and how could we address them?*

Validate any and all safety concerns that students have raised so far. Emphasize this line of thinking as a crucial aspect of the work of scientists and engineers. Say, *Trying to anticipate safety concerns ahead of time is an important responsibility for scientists and engineers to always be considering--including the possible personal, societal, and environmental impacts of any scientific investigation or engineering design solution.*

Relate safety considerations to ethics. Refer to any versions of this principle that you have posted in the classroom since the start of the year. If an explicit statement isn't already posted from prior work in *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*, add this now to chart paper to keep in the room:

- *Each of us individually, and our entire class, has an ethical responsibility to consider the possible personal, societal, and environmental impacts of any scientific investigation we plan and carry out or engineering design solution we design.*

Identify where to find safety information. Project **slide N**. Ask, *Where could we find safety information about our microwave oven system?* Guide students to say that we could find it in the *Microwave Oven Manual*. Have them look at their copies of the manual from Lesson 1; distribute a copy to anyone who needs one.

Brainstorm and record ideas for safety concerns and possible protocols. Assign students to small groups. Give them 5 minutes to look through the manual and discuss the questions on the slide. Then pull the class back together to discuss each question.

Remind students of the materials we identified as representing the parts of our system (e.g., foil with and without holes, water, glass bowl, plastic bowl). Say, *What safety considerations should we keep in mind and what protocols should we have in place when designing our investigations?* Examples are shown in the table below. List any ideas that arise on a piece of chart paper labeled "Safety Constraints and Protocols".

Suggested prompt	Sample student response	Follow-up question
What are some safety concerns we should consider before testing any of the materials that your group may have been considering testing in the microwave oven? What are some precautions we could take?	We should be careful using aluminum foil. We should wear goggles in case there are sparks. We should have a fire extinguisher in case it overheats.	*What did the manual say to address that concern?* *Did the manual suggest anything else?* *Are there any safeguards we could use to help keep it from overheating in the first place?* *What could we use to absorb that microwave radiation?*

Guide students to pull out the following information from the manual, which is also in *Additional Safety Guidelines*:

- A platform must be created at the bottom of the microwave oven to prevent the foil from touching the floor.
- There should be no exposed edges, seams, or gaps showing in the foil before using it in the microwave oven.
- Make sure there are no spaces in between the pieces of foil.
- To prevent overheating, each test should be limited to only 15 seconds on high power.
- The microwave oven should not be run without a known absorber inside of it.
- Students should not use any items from the Limited Use category in microwave ovens outside of the classroom.

10 · OUTLINE AN INVESTIGATION PLAN AND COLLECT DATA ON A CONTROL CONDITION

17 min

MATERIALS: Control Condition Investigation, *Oven Investigation Plan*, Safety Constraints and Protocols poster

Individually record investigation questions. Say, *Now that we have determined what safety guidelines should be followed, let's develop some investigations to explore the answers to our questions!* Present **slide O**. Distribute *Oven Investigation Plan* to each student. Have them write their question (or two questions) in Part A of their handout.

ADDITIONAL GUIDANCE	At this point, the class will have a question (or two) about the oven walls and door reflecting and/or transmitting microwave radiation. If you have two questions (door versus window), then determine how you would like to make small groups to create investigation plans to tackle one of the questions. Otherwise, all groups can work on the larger question.

Summarize the goal and display the investigation materials. Show **slide P**. Tell students they will need to pick materials and establish a procedure that is specific to their investigation question.

Display the materials for the class to see:

- 8 microwave-safe glass bowls (100-250 mL) with plastic lids
- microwave-safe plastic wrap (or lids) to lay on top of the glass bowls
- 2 sheets of heavy-duty aluminum foil (~8" x 12")
- 2 sheets of hole-punched heavy-duty aluminum foil (~8" x 12")
- 1 gallon of room-temperature tap water
- 3 microwave-safe plastic cutting boards to serve as a platform
- 4 microwave-safe plastic bowls (1" tall) to serve as spacers under the cutting board
- IR thermometer
- 1 graduated cylinder (100 mL)

Construct investigation plans in small groups. Reorient students to the handout to answer its remaining questions with their group. Emphasize that you will collect the plan they are constructing as a formative assessment. Explain that they should be prepared to present and argue for their plan to the class as a candidate investigation next time.

Give students most of the remaining time to discuss and record their plan, but reserve the last 2-3 minutes to have them do the following:

- Upload an image of the group's investigation plan as a digital artifact, along with the group members' names.
- Turn in their handouts so you can provide individual feedback (as an assessment).

SAFETY PRECAUTIONS 	**As students leave, remind them that they are not allowed to do any experiments at home with a microwave oven. This would be against the guidelines of the *Microwave Oven Manual* and the Safety Constraints list developed and agreed on as a class.**

ASSESSMENT OPPORTUNITY	**What to look for:** See the *Oven Investigation Key* key for guidance on what to look for in all three dimensions. **What to do:** See the *Oven Investigation Key* key for suggested feedback. **Building toward: 5.A** Plan investigations to safely produce data that would help determine whether the energy of the microwave radiation is 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)

ADDITIONAL GUIDANCE	Make sure you have digital images of all groups' investigation plans to project for discussion on day 3. If any are missing, make digital images (one for each group) of the handout they turned in.

End of day 2

11 · DETERMINE AND CONDUCT A CONTROL CONDITION INVESTIGATION PLAN

8 min

MATERIALS: Safety Constraints and Protocols poster

Meet in a Scientists Circle. Have the class bring their chairs and notebooks to the circle. Return the *Oven Investigation Plan* handouts. Make sure the Safety Constraints and Protocols poster is prominently displayed.

Establish the need for a baseline absorption reading. Remind students that although we want to do several investigations, we all need to compare each condition to the same baseline, or control condition. Point out that most of the investigation plans you reviewed proposed a two-bowl system with changes to the foil around one bowl.

Develop a control condition investigation plan. Project **slide Q**. Discuss the prompts on the slide to converge on a consensus investigation plan for the control condition. Establish the setup described in the Key Ideas box below. These additional prompts may help support this discussion:

- *If we manipulate the foil around one bowl and observe temperature changes, how could we tell if these were caused by the foil and not something else?*
- *How would we know if adding the foil was actually affecting the energy transfer and if the foil was absorbing, reflecting, or transmitting the microwave radiation?*

KEY IDEAS

Purpose of this discussion: To establish an investigation plan for a control condition.

Listen for these ideas:

- A test should be conducted with two bowls with the same amount of water used in each, but without any aluminum foil covering them.
- An adequate amount of water (at least 100 mL) should be measured into each bowl to avoid accidentally overheating the water in any condition.
- The temperature of the water in each bowl should be taken both before and after the 15-second test. (Agree on a unit of measure. It is suggested to use °F, as it provides a greater degree of graduation and is likely more familiar, but you can use °C if students argue for it for a different reason.)
- Each bowl should be at least 1 inch from all sides of the oven.
- A platform must be used to keep the bowls off of the oven floor (as specified in the *Microwave Oven Manual*). This can be made by placing the plastic bowls as spacers under the cutting board. All bowls of water will be placed on the cutting board platform.
- Optional: students may say that it is important to have a plastic covering over the top of the bowls of water (to prevent convection of steam, which would transfer energy to the oven walls).
- Optional: students may also suggest taking the temperature of the oven walls, ceiling, floor, platform, or door.

Suggest that we carry out this control condition investigation before deciding what additional conditions to test and how we would do that.

Prepare notebooks to record results. Project **slide R**. Direct students to turn to a blank page in their notebooks and draw a T-chart to record the initial and final temperature of each bowl. If they would also like to track the temperature of other parts of the system, have them create a separate area for those parts below their bowl chart. Establish which bowl is A and which is B.

Assemble for the investigation. Have everyone put on their indirectly vented chemical splash goggles, bring their handout and notebook, and position themselves in a semicircle around the investigation area. Each person should be 15 feet or more from the oven when it is running, so everyone can watch it.

Conduct the investigation and record results. If there is time, consider doing several trials of this control investigation, running the oven for only 15 seconds each test. Quickly do this investigation with the class, using the IR thermometer to take the temperature of the bowls (and any other agreed-upon parts). Be careful **not** to make contact with the water, as it may be hot. Record the before and after temperatures in a highly visible place for reference during future investigations. Have students also record the results in their notebooks.

SAFETY PRECAUTIONS	Follow all previously outlined safety protocols as you set up materials inside the microwave oven. Run the oven for no more than 15 seconds at a time. Wear oven mitts to remove the bowls and the platform from the oven. **Never** handle any materials that have been in the oven without wearing oven mitts.

12 · ARGUE FOR THE PROPOSED WALL AND DOOR INVESTIGATION PLANS

10 min

MATERIALS: science notebook, *Oven Investigation Plan*, digital images of each group's investigation plan from the *Oven Investigation Plan* handout, computer, projector

Reorient to investigating the oven walls and door. Say, *Now that we have baseline data from our control condition, let's consider how we can investigate the oven walls and door and collect data to compare to these results.*

Project **slide S**. Ask a volunteer to restate the two related questions we want to investigate about the walls and door. Tell students we will test both parts of the system, but we will start with the walls.

Establish the participation structure for choosing an investigation plan. Emphasize that our goal is to come to agreement on a single plan, but we are going to engage in argument first to make sure the wall investigation plan we agree on represents the ideas that we all determine have the most merit, and then do the same for a door investigation plan. ✱

✱ STRATEGIES FOR THIS CONSENSUS DISCUSSION

This is considered a Consensus Discussion because the proposals must be negotiated and agreed upon by everyone to have a single investigation plan to carry out as a class.

Select volunteers to report out their group's proposed plan. Present **slide T**. Have the class use the slide as a discussion guide as proposals are presented. As a volunteer from each group presents, project/display Parts A-D from the first page of the group's handout (e.g., a digital photo of this) as a visual anchor point for the class.

Encourage students to work with the ideas presented. Emphasize that you want the class to work with each new proposal by asking questions where needed and asking who can restate it (all hands should go up at these points, to indicate that everyone is listening for understanding). ✱ Explain that each presenter should ask for a show of hands of those who had a similar idea, and follow up by asking for feedback/evaluation, including suggestions about whether we should adopt some, none, or all of the proposal, or wait a bit and hear from more groups before deciding.

You will likely need to hear from a few groups before a consensus emerges on the best approach. That approach will likely be a hybrid of ideas presented by multiple groups, and may include more than three tests.

KEY IDEAS	**Purpose of this discussion:** To come to agreement on a single set of tests to carry out as a class, and to provide multiple opportunities for every student to weigh in on and converge on this plan.
	• **Ideas you should hear for keeping these variables constant:**
	  • Use two bowls with the same amount of water in each, as in the control condition.
	  • Take the temperature of the water in each bowl before and after the 15-second test.
	  • Each bowl should be at least 1 inch from all sides of the oven.
	  • A platform must be used to keep the bowls off of the oven floor (as specified in the *Microwave Oven Manual*). This can be done by placing the plastic bowls as spacers under the cutting board. All bowls of water will be placed on the cutting board platform.
	• **Ideas you may hear for modifying the setup:**
	  • Nest the glass bowl of water wrapped in hole-punched foil within a larger empty glass/Pyrex bowl to better simulate the outer glass layer of the window in the oven door.
	  • Cover the top of the bowl with plastic wrap with at least one small hole poked in it to minimize thermal energy loss to the surroundings.
	• **Ideas you may hear for alternate conditions to test:**
	  • Place a bowl of water wrapped in hole-punched foil on one side of the platform and an unwrapped bowl of water on the other side. Refer to this as test 1.
	  • Swap the locations of the two bowls (wrapped and unwrapped). Refer to this as test 2. Its purpose

Point out the second bullet on **slide S**, and emphasize that there are many ways to contribute. Students who prefer not to talk have the responsibility of carefully considering each idea presented. Everyone should feel comfortable seeking clarification if they missed something or aren't sure what is meant, even if they are doing more listening than talking. Students who volunteer to share should also be ready to restate the most recently shared idea in their own words before weighing in on whether they agree with it.

✱ SUPPORTING STUDENTS IN ENGAGING IN ARGUMENT FROM EVIDENCE

Listening for understanding helps all students engage in academically productive talk. Other aspects of argumentation hinge on this happening first. This whole-class discussion provides an opportunity for all students to give both verbal and nonverbal feedback showing they are engaging in this aspect of the practice.

To achieve this, you can reinforce the active listening role this requires from everyone; even if every student doesn't present an investigation plan, every student can voice what they agree or disagree with on various aspects of any plan that is being discussed.

is to confirm that location isn't a confounding variable.

- Any other conditions to test that the class deems necessary, which meet the safety requirements and are supported with adequate reasoning, can be referred to as test 4, test 5, and so forth.
- Measure the temperature of the oven walls and floor before and after each test.

Agree on measurements to take and variables to control. Once the tests are agreed upon, take a brief second pass through the plan for these tests, asking new students to verbally share their responses from Parts C and D of the handout. This discussion should be faster-moving and easier to establish consensus on. Ask for volunteers to record the agreed-upon tests and any related data from subsequent tests on the board.

KEY IDEAS

Purpose of this part of the discussion: Reinforce the role of control variables and identify a few key controls to keep in mind. Give new students an opportunity to weigh in on modifications to the experimental design that help refine this as they emerge.

Key ideas to listen for:

- Measure the temperature of the water in both bowls, before and after running the microwave oven.
- Measure the temperature of other things (e.g., the metal foil, the platform).
- Important controls include:
  - the size and material of the bowls
  - the amount of water in each bowl
  - the starting temperature of the water in each bowl
  - the distance of each bowl from the edge of the platform and/or the location of each bowl within the system across each test
- Optional: students may say a plastic covering over the top of the bowls of water is important (to prevent convection of steam, which would transfer energy to the walls); if you use a covering, poke a small hole in it.
- Optional: students may also suggest taking the temperature of the oven's walls, ceiling, floor, platform, or door.

13 · CARRY OUT THE WALL INVESTIGATION PLAN

4 min

MATERIALS: Microwave Oven Wall Investigation, science notebook, *Oven Investigation Plan*

Consider hypotheses for the investigations. Say, *We now have two investigations planned: one for the oven walls and one for the oven door.* Project **slide U**. Ask students to quietly reflect on the questions:

- *Look back at what you wrote in Part G of your investigation plan handout* (*Oven Investigation Plan*)*. Do you feel more certain about your predictions for one investigation versus the other? Why or why not?*

Take a poll and share hypotheses. Quickly poll students with a show of hands to see whether they are more certain about their predictions for the wall investigation or the door investigation. Ask a few students who chose the wall and a few who chose the door to share their reasons. Suggest that because more students seem to agree on or feel more confident about their predictions for the solid foil investigation, we might want to start with that one first, before trying the hole-punched foil investigation.

Set up notebooks for the wall investigation. Project **slide V**. Have students draw a T-chart for the measurements for bowls A and B, as shown on the slide. Determine which bowl will be the experimental bowl, and direct students to denote this in their notebooks. If they would also like to keep track of the temperature of other parts of the system, have them create a separate area below their bowl chart to record this data.

Double-check that students are following safety guidelines. Have everyone put their goggles back on and make sure they are 15 feet or farther from the microwave oven.

Collect initial measurements before running the test. These will likely be the temperature of the water in both bowls. They may also include the temperature of the oven walls and floor. If so, make sure to take the temperature using the IR thermometer before and after this test.

Prepare the foil-wrapped bowl and the insulation platform. Measure 100 mL of water, pour it into one of the bowls, and enclose the bowl with aluminum foil. Make sure this foil is wrapped tightly with no gaps between the pieces, and is molded to the shape of the bowl with nothing sticking out anywhere. Place the cutting board on top of the plastic spacers to create a platform inside the oven (as specified in the *Microwave Oven Manual*).

Conduct the investigation. Place both bowls (one foil-covered and one not covered) on the platform. **Follow all safety protocols outlined previously as well as those mentioned in the advance preparation section of this *Teacher Guide*** as you set up these materials. Run the oven for 15 seconds. Wear oven mitts to remove the bowls and the platform and to unwrap the covered bowl. Make sure to wear the mitts when handling anything that has been inside the oven, as it may be hot.

Collect final measurements. Have students record the final temperature measurements of the foil and water in their notebooks. These measurements will show:

- No temperature increase (or a very slight increase) in the water in the bowl wrapped in foil (e.g., ~1°F increase or less).
- No temperature increase (or a very slight increase) of the foil itself.
- Substantial temperature increase in the water in the bowl not wrapped in foil (e.g., ~40°F increase for 50 mL of water). This will be higher than either bowl in the control condition.
- No temperature increase (or a very slight increase) for the walls and floor of the microwave oven.

Conduct tests with varied locations of items (if needed). Students may suggest that the temperature increased due to the arrangement of items in the oven (e.g., the uncovered bowl was on the side of the magnetron and the covered bowl was on the other side). If this occurs, suggest running a test with the bowls in opposite places.

As with all tests before and after this one, make sure all safety precautions are followed. Using a new bowl set, new foil, and fresh room-temperature water, conduct a test in which the location of the two bowls is switched. Take a final temperature measurement of each bowl; again, always use mitts to handle anything that has been in the oven. Quickly compare this test to the previously conducted test to verify that the location doesn't seem to matter and the results were very similar.

14 · CARRY OUT THE DOOR INVESTIGATION PLAN

4 min

MATERIALS: Microwave Oven Door Investigation

Consider the impact of new data. Project **slide W**. Say, *Let's think about how the new data from our last investigation might impact our hypotheses about what will happen in this investigation.* Give students a moment to consider the question on the slide:

- *Based on our new data, how do you think the EM radiation will interact with the hole-punched foil?*

Elicit ideas and accept all. As students share, ask them why they think the hole-punched foil will interact in the ways that they predict. Tell them we will investigate this interaction next.

Set up notebooks for the door investigation plan. Present **slide X**. Tell students to add a section for the wall investigation results in their notebooks, as shown on the slide. Determine whether bowl A or B will be the experimental bowl covered with hole-punched foil, and direct students to record that in their notebooks. If they would also like to keep track of the temperature of other parts of the system, have them create a separate area below their bowl chart to record this data.

Collect initial measurements. These will likely be the temperature of the water in both bowls. They may end up including the temperature of the inside of the oven and the hole-punched foil as well. Students may also want to take the temperature of the oven door before and after the test.

SAFETY PRECAUTIONS	Run the microwave oven for 15 seconds for this test. Wear oven mitts to remove all items from the oven and when removing the foil from the bowl.

Set up materials and conduct the investigation. Follow all previously outlined safety protocols as you set up the materials inside the oven. Use new bowls and water and swap in a new platform to ensure these items are starting at room temperature.

Carefully wrap the hole-punched foil around the designated bowl, making sure not to spill any water. Inspect to make sure there are no gaps, hanging chads, or foil that is not tightly molded to the bowl. Place the wrapped bowl carefully onto the platform and ensure that it is at least 1 inch from the oven walls. Make sure to place the unwrapped bowl of water (the absorber) 1 inch or more from this bowl and at least 1 inch from the walls before starting the test.

Collect final measurements. Have students record the final measurements in their notebooks. These will show:

- No temperature increase (or a very slight increase) in the water in the bowl wrapped in hole-punched foil (e.g., ~1°F increase or less).
- No temperature increase (or a very slight increase) of the hole-punched foil itself.
- A substantial temperature increase in the water in the bowl not wrapped in hole-punched foil (e.g., ~40°F increase). This will be higher than either bowl in the control condition.
- No temperature increase (or a very slight increase) for the oven walls, floor, or door.

15 · DEVELOP AN ENERGY TRANSFER MODEL FOR THE CONTROL INVESTIGATION

5 min

MATERIALS: chart paper, markers

Motivate modeling as a way of explaining our results. Convene a Scientists Circle. Say, *Now that we've completed our investigations, let's consider the data we collected. Some of it may be surprising. Let's try to explain what happened by modeling the control results together. Then maybe we can use the control results to try to explain what happened with the bowls covered in solid and hole-punched foil.*

Develop an energy flow diagram to explain the control condition results. Present **slide Y**. Title a piece of chart paper "Where did the energy in the system come from to increase the temperature of the matter in our control condition?" Co-develop a model with the class to explain this, using the table below. Add the corresponding part of the model to the poster as you get each response.

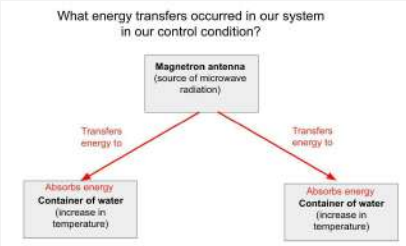
Suggested prompt	Sample student response
Where did the energy in the system come from to heat up the water in both bowls in our control condition?	From the magnetron. From the antenna of the magnetron.
How did the amount of energy being transferred into the water in each bowl compare to the one bowl that absorbed energy in test 1?	It was less.
How did it compare to test 2?	It was less.

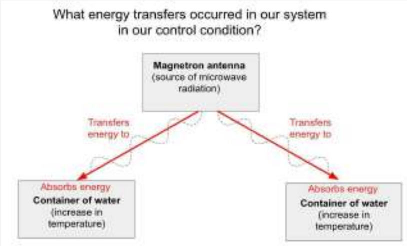
Remind students of what we know about the microwave radiation, based on our tests:

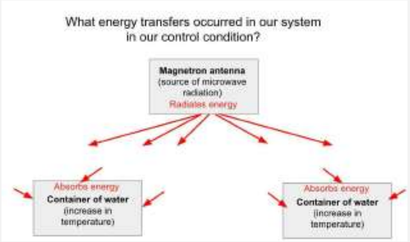
- Energy that the waves transferred eventually reached the bowls after the waves left the magnetron.
- Based on our model of light and the related models we developed for microwave radiation, we argued that both of these waves travel in a straight line until they interact with other matter.

Suggest adding a representation in the model of the radiation coming from the magnetron and reaching the bowls. Continue to add that the waves travel in a straight line until they interact with the bowls. Students may suggest adding wavy lines over the straight lines to emphasize the fluctuating EM fields.

If students argue that we don't know whether the radiation follows a straight path from the source to the water, or that we don't know whether it is also reflecting off the walls, then the class could modify the diagram to show the waves coming to the water from multiple directions (different from the direction they were traveling out of the magnetron). Three possible models are shown below, depending on what your class argues for.







Motivate modeling the door and wall interactions with microwave radiation. Return to emphasizing the results of the wall and door tests, to motivate an additional question that begs explanation, from either investigation. Say, *Why did one bowl in the ______ investigation increase in temperature more than either bowl in our control condition, and the second bowl didn't increase in temperature at all (or very very little)?*

Write this question under the newly developed model. Say that we should take some time to model the matter and energy interactions of the microwave radiation in our wall and door tests to explain the patterns in our data.

16 · MODEL THE MICROWAVE RADIATION INTERACTIONS IN THE WALL OR DOOR TEST

8 min

MATERIALS: sheet of notebook paper

Revise the class model to explain the foil results. Present **slide Z**. Distribute a piece of notebook paper to each student. Explain that we can now add, remove, or change the components and interactions in our class model of the control condition to explain the results of our tests with either the solid or the hole-punched foil. Give students 4 minutes to revise the control model on their paper, including the question at the bottom, for one of the two investigations. Tell them this paper will be handed in at the end of class.

(If time permits) Share and get feedback on models in partners. Project **slide AA**. After 4 minutes, ask students to stand up and find a partner to compare their representations, as shown on the slide. As they do this, encourage them to add any annotations or written explanations to their model that would help make their thinking more visible around the question they just discussed with their partner.

ASSESSMENT OPPORTUNITY	**What to look for:** See the *Explaining What Happened* key for the model revisions and key ideas in the chain of cause that students should use in their explanation. **What to do:** If students struggle with the idea of energy being redirected by the foil (hole-punched or solid), here are two options: ● Ask students to use their model to predict how different the data would be if we test a bowl of water partially wrapped with foil. ● Have students sketch a series of surfaces or geometry of surfaces that could be designed to reflect microwave radiation from a single source to a small spot using hole-punched foil. Ask them to think about how mirrors might be laid out to do the same for another type of EM radiation, visible light. Have them draw an energy transfer model of their design proposal and use it to predict where in the system the transfer would increase the temperature of the food the most, and why it would do so at that location much faster than if that geometry of hole-punched foil surfaces was not built into the system. **Building toward: 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 explain why some of those materials increased in temperature (energy) more than others. (SEP: 2.3; CCC: 5.1, 5.2; DCI: PS3.D.1, PS4.B.2)

ALTERNATE ACTIVITY	You may 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 this guide. Watch for and respond to any classes that: ● Express strong skepticism about the results of only three tests, and argue for a fourth test (or more) to convince themselves of what they can infer from the results. ● Express strong excitement about carrying out a fourth test to confirm a prediction based on the prior results (e.g., that nearly complete but not full shielding of water or food with the hole-punched aluminum foil may result in partial heating of that water or food). Consider differentiating the path that different classes follow from this point onward to respond to such genuine engagement. Following student thinking to carry out a fourth test (or more) will require a fourth class period. To get the most out of allocating an additional day of instruction, consider having students draft an

argument for how additional tests will help answer the class's new or remaining questions. The structure of such an argument could include arguing for what the different possible outcomes might show us:

- If this test(s) produces results X, then that would show us that ...
- If this test(s) produces results Y, then that would show us that ...

A repeated round of investigation planning, arguing for what the results would tell us, carrying out the investigation, and developing a model to account for those results provides an additional opportunity to engage both lesson level performance expectations (LLPEs) 5.A and 5.B.

17 · UPDATE THE PROGRESS TRACKER

4 min

MATERIALS: science notebook, *Progress Tracker* from Lesson 4

Help students see that we have sufficient data to make a claim. Reference the equation for the total energy of a wave that you wrote on the board earlier: Energy of a wave = energy reflected + energy absorbed + energy transmitted. Say, *Let's try now to use this science idea in combination with our results so far to make some inferences.*

Update the *Progress Tracker*. Present **slide BB**. Give students a few minutes to use their *Progress Tracker* to record their ideas for explaining how the materials in the oven door and walls interact with microwave radiation.

18 · GENERATE AND RECORD NEW QUESTIONS

2 min

MATERIALS: 3" x 3" sticky notes, marker, EM Radiation Interactions Chart, Driving Question Board

Generate more questions. Present **slide CC**. Direct the class to reference our EM Radiation Interactions Chart and our Driving Question Board to consider what questions we still have about different materials and matter-and-energy interactions related to microwave radiation. Distribute 4 sticky notes and a marker to each student. Have them use 1-2 sticky notes right now to record questions as shown on the slide. Tell them to store these in their notebooks to reference and share in our next class period.

Make sure students turn in their revised models before they leave.