Lesson 2: How does a microwave oven use electricity to produce microwave radiation?

Previous Lesson *We read about an interesting trend--people are storing phones, keys, and other electronic devices in their microwave ovens. We observed a Bluetooth speaker paired to a device inside a closed microwave oven, read the Microwave Oven Manual, and then safely heated food and made additional observations. We modeled the structure and function of the microwave oven, built a Driving Question Board, and brainstormed future investigations and data.*

This Lesson

Investigation

1 day

rgouveia, Pixabay

We study the Microwave Oven Manual and infer that a part called a magnetron produces microwave radiation. We watch a video showing the inside of a magnetron. We read about the magnetron and use energy transfer models to connect new ideas about fields to our prior understanding. We wonder how the changing electric fields connect to waves, and then decide to look into waves in more detail.

Next Lesson *We will model energy transfer in waves on a spring. We will use a simulation to do four investigations to make claims about how various wave properties affect energy transfer. We will develop a mathematical model of the relationship between some of these properties.*

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

2.A Integrate multiple sources of information to analyze how the designed structure of a magnetron causes the generation of changing electric fields inside the cooking area of a microwave oven. (SEP: 8.2; CCC: 4.1, 6.1; DCI: PS4.B.1)

What students will figure out

- Electrons vibrate inside the antenna of a magnetron.
- Vibrating electrons change electric fields.
- Changing electric fields carry energy across space.

- The microwave oven is designed so the magnetron antenna changes electric fields near the oven's cooking area. This energy transfers across space and somehow reaches the food.

Lesson 2 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	4 min		**NAVIGATE** Study a diagram of the structure of the microwave oven in the *Microwave Oven Manual*. Create individual Notice and Wonder charts.	A	*Microwave Oven Manual*, 8.5" x 11" paper
2	10 min		**WATCH A VIDEO OF A MAGNETRON DISSECTION** Watch a video of a magnetron dissection and continue to record noticings and wonderings. Volunteers look inside a microwave oven and describe what they see (optional).	B	https://youtu.be/3JLRCEjF6uA
3	20 min	☑	**READ ABOUT A MAGNETRON AND DISCUSS HOW IT WORKS** Read *The Magnetron* and build understanding about how a magnetron is designed to generate changing electric fields.	C-G	*The Magnetron*
4	7 min		**(SAFELY) HEAT A LIGHT BULB IN THE MICROWAVE OVEN** Heat a light bulb in the microwave oven to test for electric fields.	H-I	Lighting a Bulb in the Microwave Oven Demonstration
5	4 min	☑	**NAVIGATE: EXIT TICKET** Consider how energy transfers from the magnetron antenna to the light bulb.	J	8.5" x 11" paper

End of day 1

Lesson 2 • Materials List

	per student	per group	per class
Lighting a Bulb in the Microwave Oven Demonstration materials	• indirectly vented chemical splash goggles		• incandescent light bulb • microwave-safe glass bowl (100-250 mL) • water • microwave oven • oven mitts
Lesson materials	• science notebook • *Microwave Oven Manual* • 8.5” x 11” paper • *The Magnetron*		• https://youtu.be/3JLRCEjF6uA

Materials preparation (20 minutes)

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

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

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

(Optional) Look Inside the Microwave Oven

- **Group size:** Whole class, with 3-4 student volunteers to make direct observations.
- **Setup:** Have a microwave oven available, unplugged. Remove the shiny cardboard piece from inside the oven so the magnetron antenna is visible.
- **Safety:** Do not lift or reposition the oven while looking inside. Be careful not to damage the shiny cardboard, so it can be put back.

Lighting a Bulb in the Microwave Oven Demonstration

- **Group size:** Whole class.

- **Setup:** Test the procedure with the incandescent bulb in the microwave oven ahead of time, following all safety precautions. For class, have a microwave-safe glass bowl (100-250 mL) that can be filled with water and heated in the microwave oven.
- **Safety:** Be sure the metal part of the light bulb is submerged in the water. Do not heat the light bulb for more than 15 seconds at a time. Use indirectly vented chemical splash goggles and oven mitts to handle heated objects. Keep students who are not wearing protective equipment at a safe distance (a minimum of 15-20 feet).
- **Disposal:** Dispose of the light bulb safely or save it for future use. For disposal, securely wrap the bulb in a thick, sealable bag so nobody will be cut if it shatters.

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

In *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*, students reviewed the ideas that electrons are negatively charged particles and that electrons move in a wire when energy transfers through an electrical circuit. In that unit, students worked with simulations showing (1) electrons moving in a single direction (DC current) around a circuit powered by a battery and (2) electrons vibrating in a wire (AC current) for a circuit powered by a generator.

The focus of investigating charged particles in this unit is to explain their role in creating and changing electric fields. Atomic structure is not a focus of this unit. Students may or may not identify positive particles in the atom as protons; it is OK if they do, or if they simply refer to positively charged particles. Naming those specific particles is not important.

Students encounter a definition for the term *magnetron* in this lesson. **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 highlights basic ideas that students need to model electromagnetic radiation in a microwave oven. Students do not develop a complete understanding of how the magnetron works. The "right-hand rule" (sometimes used to determine vector directions in electricity and magnetism) is not discussed. Neither is the resonant behavior of the electrons, nor the capacitance and inductive properties of certain shapes within the magnetron.

In this lesson, students do not investigate how changing electric and magnetic fields move through space; they will figure that out in Lesson 4. Modeling electromagnetic radiation as changing fields is the focus of multiple future lessons, though some students may have initial ideas and lots of questions about it by the end of this lesson.

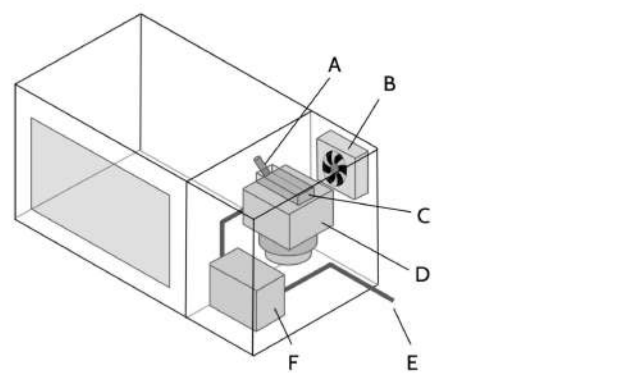
LEARNING PLAN for LESSON 2

1 · NAVIGATE

4 min

MATERIALS: science notebook, *Microwave Oven Manual*, 8.5” x 11” paper

Look at the diagram of the internal parts of a microwave oven. Say, *In the last class, we had so many ideas we wanted to investigate. Many of us were wondering where this “microwave electromagnetic radiation” we read about comes from. Where in the manual could we look to get a better idea about that?* Listen for students to suggest the diagram (pictured at right).



Present **slide A**. Distribute a piece of paper to each student. Say, *Let’s take a closer look at this diagram to help figure this out. Make your own chart to record what you notice and wonder about the diagram.*

After 1-2 minutes, ask for a few volunteers to share out. Here are some possible noticings:

- The waveguide is attached to the antenna and the magnetron.
- There is an antenna in the microwave oven.
- A wire connects the high-voltage transformer to the magnetron.
- A wire connects to the outlet outside the microwave oven.

Here are some possible wonderings:

- Does the magnetron have magnets in it?
- How does the magnetron make electromagnetic radiation?
- How does the magnetron make the microwave oven work?
- What does the magnetron do?
- Why is there an antenna in the microwave oven?

2 · WATCH A VIDEO OF A MAGNETRON DISSECTION

10 min

MATERIALS: science notebook, https://youtu.be/3JLRCEjF6uA

Watch a video of a magnetron dissection. Say, *I have a video showing a magnetron dissection that might give us a few clues.* Present **slide B**. Tell students to continue recording what they notice and wonder as they watch the video. Emphasize the question on the slide:

- *What parts or materials seem especially important?*

Show https://youtu.be/3JLRCEjF6uA. Then ask students what parts they identified. Listen for them to mention some or all of the following (these are listed roughly in order of importance to the lesson):

- antenna
- heated filament
- copper metal
- two permanent magnets
- beryllium oxide
- resonant cavity
- wire

(Optional) Look inside the microwave oven. Say, *Let's look inside the oven for any visible evidence that our magnetron is similar to the one in the video. What parts of the magnetron would you expect to be able to see from the oven's cooking area?* Listen for students to say antenna or waveguide. Note: This is not possible with all microwave ovens. You may need to remove the shiny cardboard piece that covers the waveguide and antenna.

Ask for a few volunteers to look in the oven and describe what they see where the cardboard was. You may need to stick a phone camera through the gap to see it clearly. Make sure the oven is unplugged. Do not lift the oven, or allow students to lift it, as it is heavy and can injure someone if dropped.

Whether or not students see the antenna, direct their attention to the picture on the slide. Ask, *What part do we think is shown here?* Listen for them to identify the antenna or call attention to the beryllium oxide insulator ring. ✱

Surface student ideas. Ask, *How might these parts work together to produce electromagnetic radiation?* Accept all answers.

SAFETY	• Never operate the microwave oven without the shiny cardboard piece in place.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

The crosscutting concept of Structure and Function is intentionally developed across this unit. Structure and function are complementary properties. The NGSS points out that "understanding how a bicycle works is best addressed by examining the structures and their functions at the scale of, say, the frame, wheels, and pedals." In the example of the microwave oven, students will develop an understanding that the antenna, the magnetron, and the cooking area are intentionally placed to achieve a desired outcome: heating food quickly and safely using microwave radiation.

PRECAUTIONS

- Never touch or disturb the antenna, even when the oven is unplugged. The beryllium oxide insulator on the antenna is extremely toxic if disturbed or scratched.
- Do not lift the oven, or allow students to lift it, as it is heavy and can injure someone if dropped.
- **Do not ever disassemble the microwave oven to investigate its internal structure!**

3 · READ ABOUT A MAGNETRON AND DISCUSS HOW IT WORKS

20 min

MATERIALS: *The Magnetron*, science notebook

Surface questions to motivate the reading. Present **slide C**. Pose the question as a Turn and Talk:

- *How might the parts of the magnetron work together to produce electromagnetic radiation?*

Read about how a magnetron functions. Present **slide D**. Say, *Let's see whether we can use a reading to figure out how all the parts we saw in the magnetron might be interacting to produce electromagnetic radiation.* Distribute *The Magnetron* to each student. Ask for a volunteer to read the first paragraph aloud.

Give students 30-60 seconds to answer the questions in the box in Part I:

- Where have you seen parts or materials with these names before (magnets, copper, antenna, filament)?
- What have they been used to do?

Then ask for volunteers to share their ideas. Accept all answers, but listen for these:

- Magnets can attract or repel each other.
- Magnets can affect electricity, like in a generator.
- Copper is often used when electricity needs to get through the material, like in a wire.
- An antenna is used to broadcast or receive signals, like for a phone tower, Wifi, or radio.
- Some light bulbs have a filament--it gets very hot.

Complete the handout in partners. Present **slide E**. Say, *With a partner, continue through the rest of the reading. Answer the questions in the boxes.* Allow students about 10 minutes to complete the reading and questions in Part II and Part III of *The Magnetron*.

The upcoming class discussion focuses on Part III before Part II. As some students reach Part III, glance at their answers to see whether anyone mentions the key ideas in the Assessment callout below. If you can, give some students a heads-up that you like their answer, and ask if they'd mind sharing out. This informal check for understanding serves as the beginning of a formative assessment on this lesson's main objective. Students who haven't mentioned the ideas shown in the callout may need more support in making sense of the reading during the discussion.

Discuss how electric fields affect energy transfer inside and outside the magnetron. Present **slide F**. Lead a Building Understandings Discussion of the questions from Part III. Use the prompts from the slide and reading, and the strategies in the Building Understanding callout at right, ✱ to get students talking about their ideas:

✱ STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

Use probing questions such as, *What do you mean when you say ___?* to get students to elaborate. Ask other students whether they agree, disagree, or have something to add, and encourage them to respond to their classmates' ideas.

Listen for students to connect ideas from the reading to develop possible explanations. Refer to the M-E-F poster from *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)* to elicit ideas about changes in the system that involve energy transfer, such as unbalanced forces or changes in matter.

✱ SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

As students engage with this fairly technical reading, encourage them to go back to the language in the reading itself in their discussion. If the discussion gets off topic, go back to the reading. Ask, *What new information from the reading could help answer our questions about how the microwave*

- *IIIa: How do moving charged particles affect electric fields?*
- *IIIb: Where might electric fields cause energy to transfer, either inside or outside the magnetron?* ✱
- *IIIc: How might the magnetron's design affect the electric field inside the oven's cooking area?*

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Look and listen for students to integrate ideas from the reading and the video (SEP: 8.2) to:

- Identify that electrons vibrate inside the magnetron antenna. This represents a foundational understanding. (CCC: 4.1, 6.1; DCI: PS4.B.1)
- Note that charged particles create electric fields, and they also can feel a push from electric fields. This represents a connected understanding. (SEP: 8.2; DCI: PS4.B.1)
- Refer to the designed structure of the magnetron (cavity, antenna) to describe how moving electrons in the antenna cause electric fields to change inside the cooking area. (CCC: 4.1, 6.1; DCI: PS4.B.1)
- Students with an organized understanding may also note that the direction of electric fields in the microwave oven changes rapidly because electrons are vibrating rapidly in the antenna. (DCI: PS4.B.1)

What to do: If students do not identify the relationships between moving charged particles and the formation of electric fields, ask, *What changes are needed inside the antenna to change electric fields nearby?* or, *If I can get an electron moving down a copper wire, what would happen?* If they are still stuck, ask whether any passages in other parts of the reading can help answer our questions. Specifically, the last sentence in Part II helps to answer Question IIIb: "As the electrons in the magnetron antenna move back and forth quickly, energy moves away from the antenna and through space by transferring from the antenna's moving electrons to electric fields."

Building toward: 2.A.1 Integrate multiple sources of information to analyze how the designed structure of a magnetron causes the generation of changing electric fields inside the cooking area of a microwave oven. (SEP: 8.2; CCC: 4.1, 6.1; DCI: PS4.B.1)

Consider how to confirm whether electric fields are changing in the oven. Present **slide G**. Give students a minute to turn and talk about the prompts. Then lead a brief discussion (see table below) heading toward how we could test our ideas so far: by using a light bulb to test for electric fields.

oven heats food? When students summarize a passage, push for more by asking, *What does that mean?*

Suggested prompt	Sample student response
What ideas or questions do you have about how electric fields transfer energy from the magnetron antenna into the matter inside the microwave oven?	(Accept all ideas.)
What objects have we worked with that could show us evidence of electric fields changing inside the oven's cooking area?	We know that electric fields can change in wires, and that wires can heat up if electrons move through them. We know that light bulbs glow when electrons move through them.

If needed, guide students to consider experimenting with light bulbs. If students aren't coming up with ideas, ask, *We've seen light bulbs light up when electrons move through them. So, what might happen with a light bulb if it's near an electric field?* Listen for them to say that the electric field might push electrons through the bulb, and that the bulb might light up if electrons are moving through it.

4 · (SAFELY) HEAT A LIGHT BULB IN THE MICROWAVE OVEN

7 min

MATERIALS: Lighting a Bulb in the Microwave Oven Demonstration

Introduce the demonstration. Say, *So, we think that if electric fields are in the microwave oven, they could push electrons around inside the light bulb so it glows.*

Present **slide H**. Say, *I'd love to try this out, but we need to be sure we're doing the experiment safely. I pulled a few safety concerns from the manual to help us check our ideas on how to do that.* Use the table below to elicit student ideas.

Suggested prompt	Sample student response
The manual says, "Always operate the microwave with food or liquids that you know will absorb some of the microwave electromagnetic radiation." How can we do this for our light bulb test?	We can put something that we know absorbs microwave radiation in there with the bulb, like water.
How can we ensure that metal objects aren't within 1 inch of the oven's walls, floor, or ceiling?	We can raise it up on something, so the metal in the bulb isn't anywhere near the sides.
How can we ensure that objects inside the oven do not reach dangerous temperatures?	We can run the oven for only a few seconds at a time, so it won't get too hot.

Say, *Let's try putting the bulb in a cup of water, which will raise the bulb and keep its metal part away from the oven's floor, walls, and ceiling. Then we can run the oven--for no more than 15 seconds at a time--to see what happens!*

Use a light bulb to test for electric fields in the oven. Mostly fill a microwave-safe glass bowl (100-250 mL) with water, and place the bulb metal-side-down into the water. The bulb should float, with the glass globe and filament sticking out above the surface. Note: if the filament is underwater, the microwave radiation may absorb into the water without reaching the filament.

Place the container with the light bulb into the oven **just off-center, closer to the side that does not contain the antenna**. Have students gather around the oven so they can see if the bulb begins glowing. Ask them to confirm that the metal part isn't within 1 inch of the walls, floor, or ceiling, and then close the oven door.

Run the oven at normal power. **Do not heat the bulb for more than 15 seconds (see Safety callout below).** The bulb should begin glowing within about 5 seconds of being heated.

SAFETY PRECAUTIONS

- Only the teacher should operate the equipment; this experiment should **not** be replicated at home.
- Use an incandescent bulb, **not** an LED or fluorescent bulb.
- Make sure the bulb base is submerged in the water, at least 1 inch from the oven's walls, floor, or ceiling.
- Never heat the bulb for more than 15 seconds at a time--longer could cause it to shatter.
- Use oven mitts to remove heated materials from the microwave oven.

Debrief the light bulb experiment. Present **slide I**. Elicit answers to the questions in the table below.

Suggested prompt	Sample student response
What do you notice happens to the bulb when the microwave oven is running?	The bulb starts glowing.
What does this evidence tell us is happening in the middle of the microwave oven?	It could mean there are electric fields getting from the antenna to the middle of the oven.

Say, *So, we think vibrating electrons in the magnetron antenna affect electric fields and somehow enable energy transfer in the oven. I definitely think we should investigate to figure out how this happens.*

5 · NAVIGATE: EXIT TICKET

4 min

MATERIALS: 8.5" x 11" paper

Problematize what is happening between the antenna and the light bulb. Present **slide J**. Ask, *We know electric fields are changing in the microwave oven, and we think electrons moving in the antenna cause that change. But for me, this just raises more questions about how those electric fields are related to microwave radiation, and how this transfers energy to heat the food.*

Administer the exit ticket. Distribute a piece of paper to each student. Say, *On your exit ticket, use words or pictures to jot down your thoughts about the question on the slide: What do you think is happening between the magnetron antenna and the light bulb to transfer energy all the way across the microwave oven? We'll use your ideas to figure out where we should investigate further.*

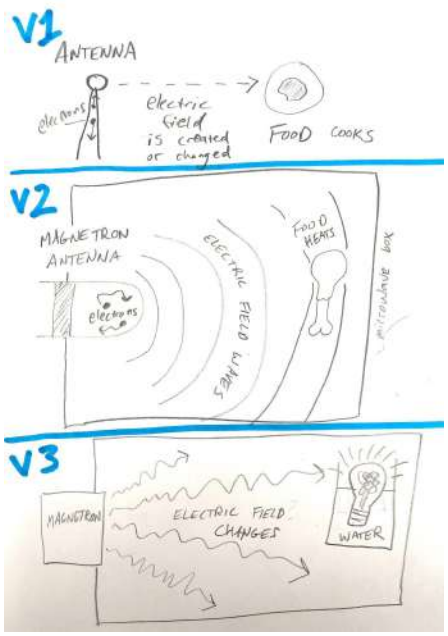
Have students turn in their exit tickets as they leave class.

ADDITIONAL GUIDANCE	Expect diverse ideas and uncertainty to emerge when students jot down initial ideas about how the antenna transfers energy through space, how to visualize this, and what exactly the structure of a microwave oven is. Celebrate students who are willing to take risks with their work. Say something like, *Shout out to ___ and ___ , who are writing some fascinating ideas. It takes courage to jot down ideas when we're not sure, but we need that courage to make progress.*

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Students' descriptions and/or drawings should show or describe energy transfer. Look for students to:

- Identify that electric fields change near the magnetron antenna. (CCC: 4.1, 6.1; DCI: PS4.B.1)
- Refer to evidence from the light bulb experiment and/or the magnetron reading as evidence of these changes in the electric field. (SEP: 8.2; DCI: PS4.B.1)
- Show or describe the antenna near the oven's cooking area. (CCC: 4.1, 6.1)



What to do: Expect students to depict "changing electric fields" visually as wavy lines, rings, or dashed lines. Don't push them to go too deeply with showing a sophisticated understanding of electric fields from the antenna. Instead, encourage creative modeling and intellectual risk-taking.

If students' explanations or sketches do not include electric fields in any way, emphasize electric fields during the navigation into

	the next lesson. If many sketches show wavy lines or mention "waves" with no reference to electric fields, ask the class explicitly about this at the beginning of Lesson 3. If models show electric fields incompletely or incorrectly (see image), this is fine for now, perhaps even positive. Subsequent lessons will build the idea of how changes in electric fields move through space and ultimately interact with charged particles in food. At this stage, it is not necessary for that idea to be fully developed. We simply want students to consider the electric field as an essential component in energy transfer from the antenna. **Building toward: 2.A.2** Integrate multiple sources of information to analyze how the designed structure of a magnetron causes the generation of changing electric fields inside the cooking area of a microwave oven. (SEP: 8.2; CCC: 4.1, 6.1; DCI: PS4.B.1)
ALTERNATE ACTIVITY	**Extension:** Cavity magnetrons are very complicated, and the science ideas needed to explain in detail how they work are far beyond what is expected of high school students. However, some students may be eager to explore circuits and magnetrons or be more engaged by university-level physics topics. As an extension activity, you can ask them to research capacitors and inductors (they can search for information about LC oscillations), or allow them to safely experiment with capacitors and inductors on a breadboard connected to an oscilloscope to produce LC oscillations. They will gain a much more nuanced understanding of the magnetron, as well as the ability to make connections back to the circuitry they worked with in *Electricity Unit*. For safety reasons, **do not disassemble the microwave oven to investigate its internal structure!** **Extension-level understanding of a cavity magnetron:** Electrons are emitted from a heated piece of metal (filament cathode) and move toward the outer metal ring of the magnetron, which is positively charged (anode). Because of the powerful magnets sandwiching the device, the electrons feel a pulling force away from the anode (following the right-hand rule), forcing those electrons to move in a spiral shape around the magnetron's core. Meanwhile, the "spokes" pointing inward from the outside of the magnetron form something like miniature coils of wire and capacitors. Circuits of capacitors and coils have a distinctive "resonant frequency"; a magnetron is precisely tuned to the frequency of the microwave radiation it is designed to produce: 2.45 GHz. As the electrons in a cavity whiz past the spokes of the copper structure, electrons in the cavity around the

	filament move away from that negative charge, ultimately moving in and out along the spokes; in other words, they oscillate at the resonant frequency. Energy from these moving electrons is transferred into the electrons in an antenna attached to the copper structure, and the electrons in the antenna then oscillate at the same frequency as in the spokes. These vibrating electrons in the antenna emit electromagnetic radiation at the desired frequency into the cooking area of the microwave oven.

Additional Lesson 2 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-LITERACY.RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. As students read about how energy is transformed and transferred inside the microwave oven, they need to synthesize the process that leads to the generation of electric fields.