5. Electricity and Magnetism

In this 5E segment, students will analyze and investigate Coulomb's Law, transfer of Charge, electric potential energy, electric circuits, Ohm's Law, and electromagnetism.	
Student Science Performance	
Grade or course: Physics	**Title:** Electricity and Magnetism
Topic: Electricity and Magnetism	

Performance Expectation for GSE:

SP5. Obtain, evaluate, and communicate information about electrical and magnetic force interactions.

a. Develop and use mathematical models and generate diagrams to compare and contrast the electric and gravitational forces between two charged objects.

b. Plan and carry out investigations to demonstrate and qualitatively explain charge transfer by conduction, friction, and induction.

c. Construct an explanation based on evidence of the behavior of charges in terms of electric potential energy.

d. Plan and carry out an investigation of the relationship between voltage, current, and power for direct current circuits.
(*Clarification statement:* Application of Ohm's Law to different circuit configurations, not limited to parallel and series, and calculations of equivalent resistance are expected.)

e. Plan and carry out investigations to clarify the relationship between electric currents and magnetic fields.
(*Clarification statement:* This includes coils and their importance in the design of motors and generators.)

Performance Expectations for Instruction:

- Students will be able to compare and contrast the electric and gravitational forces between two objects.
- Students will be able to explain charge transfer in conduction, friction and induction.
- Students will design and implement an investigation about the relationship between voltage, current and power for direct current circuits.
- Students will design and implement an investigation to clarify the relationship between electric currents and magnetic fields.

Additional notes on student supports

Materials

- Transparent tape
- Electroscopes
- Electrostatic lab supplies
- Van de Graaff generator (if available)
- Magnets (various size)
- Circuit equipment
- Power sources (or batteries)
- Computers for student use

Students will continuously obtain, evaluate, and communicate information. This is not a linear process. Students will communicate through writing and discussions to allow for formative assessment. This benefits the teacher, student, and whole group to guide instruction to clarify misconceptions or extend content.

Engaging Learners	**Phenomenon** Two pieces of tape when quickly removed from a surface will attract or repel each other.

	Obtaining Guiding question: What is causing the tapes to be attracted/repelled? *Teacher Notes: transparent tape should be used for the demonstration (not masking or other types of tape); only certain brands of transparent tape work, so test in advance. Also, different surfaces from which the tape is removed will cause the two pieces to be either repelled or attracted.* Use electroscopes to investigate and develop a model of charge transfer to explain the situation. • Have multiple materials available for students to use to investigate the charge transfer and distribution (e.g. wool, felt, fur, plastic, balloons, etc.). • During the investigation, students should develop models for charging by friction, induction, and conduction. The PhET simulation Balloons and Static Electricity can be used as a follow-up or to help scaffold. (Attribution: PhET Interactive Simulations, University of Colorado Boulder; https://phet.colorado.edu)
	Evaluating As students go through the investigation, some questions to ask to help them develop their models include: • *If the charged object is brought closer/farther away, what happens to the leaves of the electroscope?* • *What would happen if an object touched the electroscope?* • *What would happen if your hand touched the electroscope?*
	Communicating Students will whiteboard and present their models in a gallery walk; after discussing the models and seeing other students' models, they will formalize their model for assessment.
Exploring	*Obtaining* Students continue investigating charge transfer and behavior in the Electrostatic Lab; the student lab sheet is attached. This lab is centered around the big idea/phenomenon that electrical charges can be transferred. Students investigate at different stations conduction, friction, and induction. They will generate diagrams and models to show how the particles are responding to changes. Students could be given materials with little or no prescribed steps as they should be designing the investigation. The following stations are suggestions. **Station 1**: 2x4 and charged rod [induction; friction] a charged rod is brought near the board, and the board will begin to rotate. Students discuss reasons and must develop diagrams as part of an explanation for the reaction.

	Guiding questions: Do all objects have charged particles? Is wood a conductor? Where do the charges come from that cause the motion? What forces are overcome to cause rotation? Set-up: Charge a plastic rod (or ruler) by rubbing with fur, fleece, or fabric. Surprisingly, the rod can make a 2x4 (3-4 feet long) rotate. Set the piece of wood on a stool balancing on a watch glass. Students do not think of wood as having charged particles because they already know it is an insulator. Bring the charged rod on the side of the board near one end and it will begin to rotate. Extension: if the rod is move to the other side, the rod can make the 2x4 rotate in the other direction. **Station 2:** pith balls suspended from ring stand. If pith balls are not available, you can use small chunks of paper or Styrofoam pieces with strings. Two balloons can be tied to strings and suspended as well, PVC or plastic tubing can work for the charged object. Suspend balls the same height; when a charged rod is brought near the balls will separate. This shows a collection of like charges on the sides of the balls facing each other. Students have heard "like charges repel"; students see in this station that there is an actual force present. **Station 3: Charge research** Students describe charge, charge units, and measurement, but more importantly they develop an analogy to better explain charge behavior. Students also are challenged to compare electric and gravitational forces between charged objects using diagrams and mathematical models. **Station 4:** Van De Graaff Generator [conduction, grounding] students see how charges are gathered on the VDG generator. An older generator taken apart might help students so they can see how the charge is built up. They must determine what must happen for someone's hair to stand up. *Guiding question: what is charge grounding?* Extension: lightning rods. **Station 5:** magic wand [friction]. A long thin piece of plastic tube or PVC is charged with felt or fur. A ring of plastic (from a thin plastic bag) or ring made of Styrofoam packing paper is also charged with the fur. The ring can be made to "levitate" above the tube. Guide students to determine how charges are balanced, and what happens as the rod is moved to different sides of the plastic. *Guiding question: why does the magic wand not last forever?* Videos can be found online of examples and set up. **Station 6:** balloons and aluminum drink can. Students rub the balloon on hair or fabric and make the can move. Guide them to investigate how charge is arranged (is the can neutral, positive, negative?) is their attraction or repulsion? Students design a min-experiment to investigate. They can put water in the can to find out how strong the force is, try different hair or charging materials, or size of balloons, etc.

	Station 7: electroscope. A pre-made electroscope works for this station, or a home-made one works well too. Homemade electroscope Video Link. Students can easily cause the metal leaf to separate by bringing a charged object (balloon or rod) close to the top. One difficult part of induction in this set up is for students to understand that charges (positive or negative) do not actually leave the balloon or rod and deposit on the wire or metal leaf. The particles that were already in the wire or leaf are moved by the charged object. The charged object simply causes the electroscope to be "polarized" where charges separate on opposite ends. When students address part c, guide them to understand that if electrons or protons are continually being added from an outside source—that the mass would increase in the metal leaf.
	Communicating Students communicate findings in this segment through lab sheets, diagrams, and class discussions. Student groups will make presentations of findings. As stations are completed, students (or in groups) should return to their initial models and conclusion from the gallery walk and make any improvements.
	Evaluating Student diagrams and lab responses are evaluated based on describing charge transfer and force comparison. Written responses and models are included in the evaluation.
	Formative Assessment of Student Learning
Explaining Finalizing Model	*Obtaining* Students obtain information about electric fields and charge behavior using the PhET simulation Electric Field Hockey. The simulation Charges and Fields could also be used; the Electric Field Hockey student lab sheet is attached. (Attribution: PhET Interactive Simulations, University of Colorado Boulder; https://phet.colorado.edu)
	Evaluating Students may re-visit initial models and predictions from the first segment. Students should now have conceptual models of charge behavior (including charge transfer and electric potential energy). Before continuing with electric circuits and magnets, students should demonstrate clear understanding of electric charges.
	Communicating Students communicate explanations using written responses and models.
Elaborating Applying Model to Solve a Problems	**Phenomenon 1:** Some holiday lights when a bulb is removed from a strand, the whole strand will go out and with other types of strands the remainder of the strand will remain lit. **Phenomenon 2:** magnetic and electric fields interact in various ways

	Obtaining For phenomenon 1: multiple strands of non-LED holiday lights (or other stranded/wired together lights) are necessary; one strand should have lamps wired in parallel and one strand should have lamps wired in series. Alternately, a single strand of lights can be used that has series sections wired in parallel. *Guiding question: Why do some of the strands remain lit while others do not when individual lamps are removed?* • Students will design and carry out an investigation using resistors to model the behavior of the lamps in various configurations (series, parallel, combination). • When carrying-out their investigation, students to determine the relationship between voltage, current, and resistance. *Teacher Notes: multimeters would be necessary to collect data. If using digital multimeters, caution should be used when measuring current to avoid blowing the fuse.* For phenomenon 2: students plan investigations to determine the relationship between magnetic and electric fields. This can be completed in lab-challenge format: Electricity and Magnetism Lab Student Sheet *Teacher Notes:* **For challenge 1:** Students can test number of coils, current, diameter of coil, different size wire, with or without the iron core, and others. At the end of this section, students can share data with other groups so designs can be re-tested. **For challenge 2:** Students will quickly see that a wire with current will produce a three-dimensional magnetic field around the wire. A compass will easily show this. **For challenge 3:** A small current will be induced with this set-up. The multimeter should be set on milliamps. Students should discover that only a moving magnet will create this. They can experiment with different sized magnets, coils, speed of magnet, which pole of the magnet is brought near loop, and others. An alternative set-up is to use a strong bar magnet, cardboard tube, 4 meters of insulated wire, and compass. Wrap one end of wire about 5 times around compass. Leave about 24 inches of wire from compass to tube, wrap tube around 5 times. Connect wires. When the magnet is brought into the tube, the compass dial will move.

	For challenge 4: Students can alter several factors, such as the current, the number of coils, the type of wire, the type or strength of magnet. I have attached a file on the crowdsourcing site with instructions, background, and great follow-up questions. *Teacher Notes: various simulations can be found online to provide for reference or scaffolding.*
	Evaluating Students are evaluated based on their developed models, investigation plans and results, and written responses.
	Communicating Students completed diagrams and lab results are used to conduct another gallery walk.
Evaluation	***Assessment of Student Learning***
	Students are assessed throughout unit with lab results, whiteboard sharing sessions, student writing, calculations, and diagrams.
SEP, CCC, DCI	**Science Essentials**
Science and Engineering Practices	• Developing and using models • Planning and carrying out investigations • Constructing explanations
Crosscutting Concepts	• Patterns • Energy and Matter • Cause and Effect • Scale, Proportion, and Quantity
Disciplinary Core Ideas	From *A Framework for K-12 Science Education:* • PS2B: Types of Interactions • PS3A: Definitions of Energy • PS3B: Conservation of Energy and Energy Transfer • PS3C: Relationship Between Energy and Forces

Additional Supports for struggling learners:

The following supports are suggestions for this lesson and are not the only options to support students in the classroom. These supports target students that struggle with science material, this lesson or a previous lesson. These are generalized supports and do not take the place of IEP accommodations as required by each student's Individualized Education Program.

General supports for the following categories:

Reading:	Writing:	Math:
1. Provide reading support by reading aloud or doing partner reads 2. Have the teacher model what they are thinking when reading the text 3. Annotate the text with students so that they may refer to it as they work through the lab	1. The teacher can provide a sentence starter for the students. 2. The teacher can give students an audience to write to (i.e. Write a letter to your sibling explaining this topic). 3. The teacher can provide constructive feedback during the writing process to help students understand the expectations.	1. Provide calculators as needed. 2. Provide graph paper as needed.

Supports for this specific lesson if needed:

Performance expectations for instruction:

1. The teacher should provide information to students in various formats to reach as many students as possible.
2. The students should be given adequate time to complete each part of the lesson.
3. The students should be allowed to express their knowledge in various formats.
4. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material.

Engage:

1. The teacher should consider showing the demo more than once to allow students to make observations.
2. The teacher should consider providing students with an organizer to plan their investigation.
3. The teacher should show students the materials that they may use in the investigation to assist in the planning process.
4. The teacher should consider using guiding questions to assist students in the planning process.
5. The teacher should consider using the PhET simulations to scaffold and assist in the planning process.
6. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material. These formats could include diagramming, drawing, writing or verbally explaining.
7. The teacher should consider providing students with multiple ways to share their work. These formats could include using technology, gallery walks or presentations.
8. Students may need additional time to complete their assignment.

9. Students should be given the opportunities to revise their model after the students share their work.

Exploring:

1. The teacher should consider ensuring that students have ample opportunities at each station.
2. The teacher should consider providing students with an organizer to design and carry out their investigation.
3. The teacher should consider providing students with an organizer to assist students in generating a model.
4. The teacher should be prepared to repeat directions as needed.
5. The teacher may need to use guiding questions to assist students at the different stations.
6. The teacher may need to consider showing videos more than once as needed for students to make observations.
7. Students may need additional time to complete their assignment.
8. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material. These formats could include diagramming, drawing, writing or verbally explaining.
9. The teacher should consider providing students with multiple ways to share their work. These formats could include using technology, gallery walks or presentations.
10. The teacher should consider providing a rubric so that students can self-assess their work. This will increase student ownership of their work.
11. The teacher should have clear and consistent guidelines for discussion. These guidelines should help students feel more comfortable and be more likely to participate.

Explaining:

1. The teacher should consider providing students with an organizer to record research and observations from the PhET simulations.
2. The teacher should consider a formative assessment to determine which students need re-teaching, reviewing or enriching.
3. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material. These formats could include diagramming, drawing, writing or verbally explaining.
4. Students may need additional time to revise their models.

Elaborating:

1. The teacher should consider showing the demo more than once as needed for students to make observations.
2. The teacher should consider providing an organizer to plan and carry out an investigation.
3. The teacher should consider using videos and simulations to assist students in completing the challenges.
4. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material. These formats could include diagramming, drawing, writing or verbally explaining.
5. Students may need additional time to complete their assignment.
6. The teacher should consider providing students with multiple ways to share their work. These formats could include using technology, gallery walks or presentations.

Evaluating:

1. The teacher should consider giving students multiple formats to communicate their knowledge. This could be drawing, writing or designing a presentation.
2. Students may need additional time to complete their assignments.

Electrostatic Lab Student Sheet

Station 1: 2x4 and rod

Set up the materials at this station: upside-down watch glass on stool, 2x4 balanced on watch glass.

Part 1: Take the plastic rod and place on the side of the board near one end without making contact. Record observations.

Par 2: Make the wood rotate using the rod—but the rod must NOT make contact with the wood. (Wind power is not allowed). Teacher hint available.

Discussion: with your group explain what is happening in BOTH parts. Diagrams must be included.

Station 2: Pith Balls

Can charged particles exert a force? Provide evidence from this station. Diagrams are required in your explanation. What particles are involved here?

Station 3: What is charge?

Through research and discussion, answer the following questions:

a. What is charge? How is it measured and what are the units?
b. So, you found the definition for charge—but so what? You and your group describe a comparison or analogy to explain the idea of charge. Your task—how could you explain "charge" to a third grader?
c. How does the electric force compare to the gravitational force between two charged objects? Make initial predictions. Diagrams and calculations should be used here.
d. Take good notes here!

Station 4: Van de Graaff Generator.

Turn on the VDG generator.

Part 1: How are charges being gathered on the sphere? Look at the VDG generator that has been taken apart for you.

Part 2: What must happen to make a group member's hair stand up? Explain—and yes, with a diagram.

Station 5: Magic Wand

Use two charge objects, a piece of plastic pipe and a ring of plastic, see if you can get them to repel each other. Discussion: what is "magic" about the wand? How long can the "magic" last? Why not forever? Diagrams are a must!

Station 6: Balloons and Can

Challenge: with charge only (no contact) make a balloon move the empty can. Design an experiment to investigate. Your teacher must approve; provide a description and diagrams. For this mini experiment, report your predictions, observations, and conclusions.

Station 7: Electroscope

Can you cause the metal leaf to separate inside the electroscope without contact? How? Address the following:

a. With a diagram, show how happens with the charged particles.
b. How do charges move in this scenario? What kind of charges must the metal leaves have?
c. Do charges move from the charged object to the electroscope? Explain you answer with evidence.

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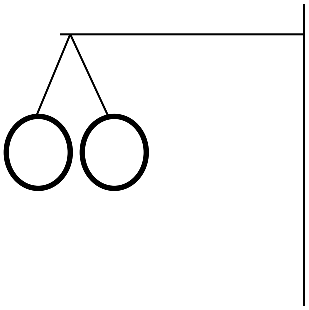
Electric Field Hockey

Directions: Answer the following questions using the simulation found here.

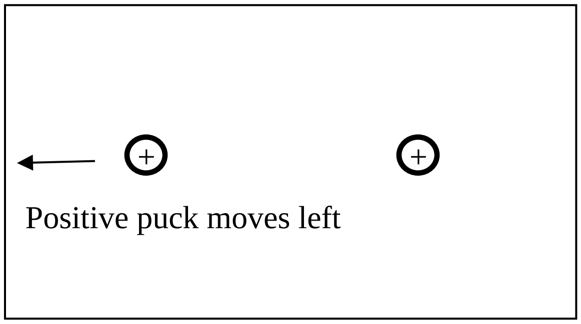
1. Prediction: (simulation not needed). You have most likely done a few things with static electricity, such as rubbing balloons on your hair. Consider this: you have two equal size balloons suspended by separate strings on a ring stand.



1. Before the balloons are touched, what will they look like suspended? Draw a diagram and explain.
2. You rub the balloons on your hair with one in each hand. After letting go, what will the balloons look like? Draw a diagram and explain.

2. With the simulation, what variables or parameters can be changed?
3. When you place a positive charge near the puck what happens? Why?
4. When you place a negative charge near the puck what happens? Why?
5. **Practice Mode:** Make the puck go into the goal. Draw what your screen looks like? How did you determine this set-up?
6. **Practice Mode:** Reset all of your charges and click the "Field" button so that the electric field shows. Place a single positive charge somewhere. Draw what the field looks like and how the puck moved as a result.
7. **Practice Mode:** Use the same set-up as #6, click the "Puck is Positive" to make the puck have a negative charge. Draw what the field looks like and how the puck moved as a result.
8. **Practice Mode:** Explain how charges are influenced by the created electric fields. Experiment with different charges, number of charges and locations. Your explanation must be based on evidence from the simulation.
9. **Practice Mode:** Reset the simulation and leave the puck positive. Using a single positive charge, answer the following: If potential energy is the "capacity to do work", what influences the potential energy of the charge? How does the puck respond when you make these changes? What happens to potential energy if more charges are added in the same vicinity?
10. **Difficulty 1:** Get the puck into the goal; draw a diagram of your screen. Explain your strategy. How many different scenarios did you try?
11. **Difficulty 2:** Get the puck into the goal; draw a diagram of your screen. Explain your strategy. How many different scenarios did you try? How does your solution illustrate electric potential energy?
12. **Difficulty 3:** Get the puck into the goal; draw a diagram of your screen. Explain your strategy. How many different scenarios did you try?
13. Based on your experimentation with the simulations, what is the relationship between electric fields and electric potential energy?
14. Based on your experimentation with the simulations, summarize how electric charges behave. Your statements must be based on evidence.

Example: Positive charges are repelled by other positive charges; the evidence for this is a positive charge will force the positive puck to move in the opposite direction:



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Electricity and Magnetism Lab

Challenge 1: How do you build the best electromagnet?

Your task is to test several designs of an electromagnet to determine how to create the strongest electromagnet.

Supplies:

Each group will have:

- Power supply (or batteries)
- Copper wire
- Small paper clips or staples
- Iron nail

You must test at least 5 designs. For each design, your group must record the prediction as to how strong the electromagnet will be. Only test one variable at a time! For each design, describe thoroughly what variable you are altering. Record your data.

Draw a diagram of the best design that your group made.

Challenge 2: Magnetic Field Direction

Your task is to determine what kind of magnetic field is created by a wire that has electrical current running through it.

Supplies:

Each group will have:

- Compass
- Power supply
- Wire

For starters: How does a compass work to find direction? Explain.

With current passing through a straight portion of the wire, determine:

1. How the compass needle is affected by the wire.
2. How far away the compass needs to be to feel this influence.
3. The shape of the magnetic field. Draw several diagrams and viewpoints of compass positions.

Challenge 3: Create Electricity

Your task is to determine how electric current can be created with a magnet.

Supplies:

Each group will have:

- Multimeter
- Magnet
- Wire coil

Hook the wire coil to the leads of the multimeter. Be sure it is set-up to measure current. Describe what happens as the magnet is brought near the wire coil. Design several investigations to find out more about this relationship.

Challenge 4: Build a Motor

Your task is to design and build an electric motor that will cause a wire coil to rotate. Your teacher will show a basic set-up. Your challenge is to create a motor that will rotate the coil at the greatest speed.

You must test at least 5 designs. Record your group's predictions for each design. Explain and draw a diagram of the set-up that rotated the coil the fastest. Explain why this design worked the best.

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