8 Transforming Energy At-a-Glance:

In the last unit, students learned about how all living things interact with and depend on other living things and their environment for survival. In this unit, students connect their explorations of Earth and life sciences with physical sciences with an exploration into the relationship between magnetism and electricity. They investigate magnetic fields and electromagnets, and then apply their scientific knowledge to design a wind turbine.

Common Misconceptions:

- **Misconception**: All metals are attracted to magnets.
  - ✓ **Fact**: Magnets attract some metals, including iron, nickel, and cobalt. However, many metals, including copper, silver, and gold, are not attracted to magnets.
- **Misconception**: Electric charges and magnetic poles are the same thing so magnets can be attracted to or repulsed by electric charge.
  - ✓ **Fact**: Electric charges are different from magnetic poles, and do not affect magnets or magnetic materials.

A Breakdown of the Lesson Progression:

1 Magnetism and Energy

In the first lesson, students explore how magnets can exert a force on other magnets and magnetic materials without coming into contact with each other. They first investigate the relationship between the number of magnets in a system and the size of the magnetic field produced, and then investigate how the amount of potential energy stored within a system of interacting magnets can change when the distance between the magnets changes.

2 Electric and Magnetic Interactions

Once students understand the basic principles of magnetism, they build simple electric motors using permanent magnets and electromagnets and test the factors that affect how fast the motor spins.

3 Engineering Wind Turbines

In the third lesson, students apply what they know about magnets, forces, energy transfer, and generators to engineer a vertical-axis wind turbine that generates a specific amount of electrical energy in both low and high wind speeds.

Unit 8: Transforming Energy

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Transforming Energy

Overview:

Dolphins navigate using Earth's magnetic field.

Scientists believe various animals, including dolphins, sea turtles, bats, spiny lobsters, and many insects, navigate using Earth's magnetic field. However, scientists cannot say for sure how animals do this. One hypothesis is that they have tiny magnetic particles in their cells that react with Earth's magnetic field, somehow signaling the nervous system in a way that guides the animals as they travel around the planet.

Magnetic fields are also helpful for people because magnets can exert a force on other magnets or magnetic materials without coming into contact with them. Magnetic fields are also closely related to electric fields and can be harnessed to convert energy from one form to a different form that can do work.

In this unit, students are introduced to magnetic and electric fields as they explore how objects can interact with other objects without coming into contact with them. Students begin with an exploration into magnetic interactions and then apply what they know to investigate the relationship between magnets and electricity with electromagnets. Students use electromagnets to build a simple motor, and then apply scientific concepts to design wind turbines that use a generator to produce electricity.

Unit Goals:

1. Observe how magnetic fields exist between objects and exert forces on each other.
2. Use evidence to compare electric and magnetic forces.
3. Describe how energy converts from one form to another in electric motors and generators.

Applying Next Generation Science Standards

This unit covers the following **Next Generation Science Standards**. Each standard includes where it is found in the unit, as well as how it applies the relevant crosscutting concepts (listed in green) and disciplinary core ideas (listed in orange). **Note: Science and engineering practices are listed separately because all of the practices are incorporated into every unit.*

Focus Standards:

MS-PS2	**Motion and Stability: Forces and Interactions**
MS-PS2-2.	**Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.** **Students are introduced to this standard in this unit. They will continue to explore it in the next unit.* ▪ **Forces and Motion:** Students observe the relationship between the mass of their blades and the amount of force needed to make them spin. Lesson 3 ▪ **Stability and Change:** Students explore stability and change with their wind turbine designs, examining what makes their prototypes stable and how forces can be applied to cause change. Lesson 3
MS-PS2-3.	**Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.** ▪ **Types of Interactions:** In Lesson 1, students investigate how increasing the number of magnets in a system affects the size of the system's magnetic field and how different amounts of potential energy can be stored in a system of interacting magnets. In Lesson 2, students build electric motors and test the factors that affect how fast the motor spins. Lessons 1 and 2 ▪ **Cause and Effect:** In Lesson 1, students ask questions to explore the cause-and-effect relationship between the number of magnets in a system and the size of a magnetic field. In Lesson 2, students explore ways they can cause their motor to spin more quickly. Lessons 1 and 2

MS-PS2	Motion and Stability: Forces and Interactions
MS-PS2-5.	**Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.** ▪ **Types of Interactions:** In Lesson 1, students begin with an investigation to gather evidence that magnetic fields exist between magnetic materials by observing the change in motion of a magnetic material when it comes into a magnet's magnetic field. In Lesson 2, students observe how electromagnets become magnetized and interact with permanent magnets without coming into contact with them. Lessons 1 and 2 ▪ **Cause and Effect:** Students use evidence from their investigations and experiment to explain the cause-and-effect relationship between the interactions of different objects that aren't in contact with one another. Lessons 1 and 2

MS-PS3	Energy
MS-PS3-2.	**Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.** ▪ **Definitions of Energy:** Students use their knowledge of potential and kinetic energy to explain how the amount of potential energy stored in the system changes when the distance between magnets interacting at a distance changes. Lesson 1 ▪ **Relationship Between Energy and Forces:** Students model how forces can transfer energy into systems by applying a force to their system of interacting magnets and measuring the distance they move as a result. Lesson 1 ▪ **Systems and System Models:** Students use what they know about systems to explain how two interacting magnets form a system, and the amount of potential energy stored in the system can change. Lesson 1

MS-ETS1	Engineering
MS-ETS1-1.	**Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.** ▪ **Defining and Delimiting Engineering Problems:** Students describe a problem they will solve, including its criteria and constraints, with a technology that efficiently converts wind energy into electrical energy. Lesson 3 ▪ **Influence of Science, Engineering, and Technology on Society and the Natural World:** Students describe how engineers apply scientific knowledge to the challenges of energy generation. Lesson 3
MS-ETS1-2.	**Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.** ▪ **Developing Possible Solutions:** Students systematically evaluate their design solutions based on the energy efficiency of their wind turbine blades. Lesson 3 ▪ **Influence of Science, Engineering, and Technology on Society and the Natural World:** Students use their scientific knowledge of electromagnetism and energy conversion to help them in their wind turbine designs. Lesson 3
MS-ETS1-3.	**Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.** ▪ **Developing Possible Solutions:** Students test each of their wind turbine prototypes, collecting and analyzing data on how well each one met the criteria and constraints of the problem and evaluating the strengths and weaknesses of each prototype's design. Lesson 3

- **Influence of Science, Engineering, and Technology on Society and the Natural World:** Students evaluate their data, using their data analysis to help them make informed decisions about how to improve their prototype so it better meets the criteria and constraints of the problem. Lesson 3

MS-ETS1-4. **Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.**

- **Optimizing the Design Solution:** Students work in teams to design and build their prototype, and then follow a procedure for testing it to gather data they can use to evaluate their design for how well it meets the criteria and constraints of the problem. Lesson 3
- **Influence of Science, Engineering, and Technology on Society and the Natural World:** Students work to achieve an optimal design for their wind turbine prototype. Lesson 3

Supporting Standard:

MS-PS3	**Energy**
MS-PS3-5.	**Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.** ▪ **Conservation of Energy and Energy Transfer:** In all three lessons, students explore how energy is transferred into or out of objects or systems by force. Lessons 1, 2, and 3 ▪ **Energy and Matter:** Students explore how forces can transfer energy into different objects or systems. Lessons 1, 2, and 3

Science and Engineering Practices

Students use the following science and engineering practices in the unit's lessons.

Lesson 1: Magnetism and Energy

1. Asking questions (for science) and defining problems (for engineering)

- This lesson has two investigations. In the first investigation, teams use a model to answer the question: "How does increasing the number of magnets in a system affect how far the system's magnetic field extends beyond the magnets?"
- In the second investigation, teams use a different magnet system to answer the question: "How does changing the distance between repelling magnets in a system affect the amount of potential energy stored in the system?"

2. Developing and using models

- In the first investigation, students model how magnets have a magnetic field that exerts a force on other magnets without coming into contact with them.
- In the second investigation, students model how magnets exert forces on each other that transfer energy that can be stored within the system.

3. Planning and carrying out investigations

- In the first investigation, students use their magnet models to observe magnetic fields.
- In the second investigation, use their magnet models to compare the distance that a set of free-moving magnets moves when the distance between those magnets and fixed magnets changes.

4. Analyzing and interpreting data

- In the first investigation, students collect and analyze data on how the number of magnets in a system affects how far the system's magnetic field extends beyond the magnets.
- In the second investigation, students collect and analyze data on the distance the repelled magnets travel up a dowel when placed at different starting positions from the fixed magnets.

6. Constructing explanations (for science) and designing solutions (for engineering)

- In the first investigation, students use their observations from the model to construct an explanation about how a magnet's magnetic field exerts a force on other magnets or magnetic materials, causing their motion to change.
- In the second investigation, students use the data they gathered to construct an explanation (conclusion) that either supports or rejects their hypothesis

about the relationship between the amount of potential energy stored in a system of interacting magnets and the distance between the interacting magnets.

7. Engaging in argument from evidence

- In both investigations, students engage in argument within their teams. Student teams then come together as a class to respectfully present their results to the class, using their data from the investigations as evidence to support their claims about magnetic interactions. Students work through any points of disagreement or confusion.

8. Obtaining, evaluating, and communicating information

- Students use information from the investigations, background reading, and any personal experiences to communicate how magnets are able to exert a force on other magnets or magnetic materials without having to come into contact with each other and how a system of interacting magnets can store different amounts of potential energy.

Lesson 2: Electric and Magnetic Interactions

1. Asking questions (for science) and defining problems (for engineering)

- Student teams work together to ask questions about the factors that affect how fast an electric motor spins.

2. Developing and using models

- Students create a model electric motor that uses electromagnets and permanent magnets to convert electrical energy into mechanical energy that causes the motor to spin.

3. Planning and carrying out investigations

- Student teams work collaboratively to predict how different factors will affect the speed of their electric motor, and then carry out an investigation to test their predictions.

4. Analyzing and interpreting data

- Students make observational data about how the speed of their electric motor is affected by different numbers of magnets, the orientation of the magnets, the distance between the magnet and the coil, and the strength of the voltage flowing through the motor.

6. Constructing explanations (for science) and designing solutions (for engineering)

- Students use their observational data to construct an explanation about how the strength of an electric motor is affected by a variety of different factors.

7. Engaging in argument from evidence

- Students engage in argument within their teams as they build and then test their electric motors, and then student teams come together as a class to respectfully present their results to the class, using their observations as evidence to support their argument about the factors that affect how fast the motor spins. Students work through any points of disagreement or confusion.

8. Obtaining, evaluating, and communicating information

- Students use information from the investigation, background reading, and any personal experiences to explain how electric motors use interactions between magnets and electricity to generate mechanical energy.

Lesson 3: Engineering Wind Turbines

1. Asking questions (for science) and defining problems (for engineering)

- Students define a design problem that they will solve to generate a specific amount of electrical energy in low and high wind speeds. They identify the criteria and constraints of the problem to help them come up with a design solution.

2. Developing and using models

- Students create a visual model (scientific diagram) of their proposed wind turbine prototype. Students use the model to visualize and later develop a physical prototype model of their design that they can test to see how well it solves the problem.

3. Planning and carrying out investigations

- Students build their wind turbine and then carry out tests to evaluate its electrical output in high and low wind speeds.

4. Analyzing and interpreting data

- Students analyze their data on the electrical output of each prototype in low wind speeds and high wind speeds. They use the data to evaluate the efficiency of their wind turbine prototypes in both high and low wind speeds.

6. Constructing explanations (for science) and designing solutions (for engineering)

- Students use the data they gathered from their prototypes to explain how well their prototypes solved the problem, and how they would revise their design to improve its ability to solve the problem.

7. Engaging in argument from evidence

- Student teams review the data produced by each of their design solutions to analyze which prototype best solved the problem (met the criteria and constraints), and which modifications positively or negatively impacted the prototype designs. They use the data to make recommendations for the replication of their solution, or to support additional testing.

8. Obtaining, evaluating, and communicating information

- Students use information from their lab manuals and class discussion, along with their scientific knowledge of energy transformation and energy generation, to evaluate how engineers use scientific concepts and knowledge to design technologies that solve problems.

* Unit connections to Common Core Math practices: MP.2, MP.4, and MP. 6.

Unit 8 Pacing Guide Example

All KnowAtom units are designed to take approximately one month. Lessons may span one or two weeks. This pacing guide provides one example for how to break down the lessons in this unit over a month. **Breakdown in this guide is based on 45- to 55-minute class periods.** Communities that have longer or shorter class periods or schedules where science class occurs more frequently can modify this guide accordingly.

Any days in this guide that appear unused take into account months with holidays, vacations, or times when a lab and/or investigation takes longer to complete. Note that at the beginning of the school year, when the engineering and scientific processes are new to students, labs may take longer to complete.

Unit 8: Transforming Energy				
Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**
Week 1				
Lesson 1 **Start:** As a class, read Section 1 of the KnowAtom student lab manual.* **Final Goal:** Transition to the Socratic dialogue.	**Lesson 1** **Start:** Socratic Dialogue 1. **Final Goal:** Transition to the Magnetic Fields Investigation.	**Lesson 1** **Start:** Teams carry out the Magnetic Fields Investigation. **Final Goal:** Teams complete the investigation analysis and conclusion. Wrap up and transition to Socratic Dialogue 2.	**Lesson 1** **Start:** Socratic Dialogue 2. **Final Goal:** Transition to the Repelling Magnets Investigation.	**Lesson 1** **Start:** Students begin the Repelling Magnets Investigation. **Final Goal:** Students carry out the majority of the Repelling Magnets Investigation.
Week 2				
Lesson 1 **Start:** Teams complete the investigation analysis and conclusion. **Final Goal:** As a class, review conclusions, wrap up the investigation, and debrief.	**Non-Science Day**	**Non-Science Day**	**Lesson 2** **Start:** As a class, read Section 2 of the KnowAtom student lab manual.* **Final Goal:** Transition to the Socratic dialogue.	**Lesson 2** **Start:** Socratic dialogue. **Final Goal:** Transition to the hands-on portion of the investigation.

Week 3				
Lesson 2 **Start:** Students assemble electric motors. **Final Goal:** Wrap up motor assembly portion of investigation. Transition to Electromagnetic Forces Investigation.	**Lesson 2** **Start:** Teams use their motors to carry out the Electromagnetic Forces Investigation. **Final Goal:** Teams collect and analyze data for Questions A and B of the investigation.	**Lesson 2** **Start:** Teams collect and analyze data for Questions C and D of the investigation. **Final Goal:** Wrap up the investigation and debrief.	**Lesson 3** **Start:** As a class, read Section 3 of the KnowAtom student lab manual.* **Final Goal:** Transition to the Socratic dialogue.	**Lesson 3** **Start:** Socratic dialogue. **Final Goal:** Transition to the engineering lab (Lab 11) scenario/problem.
Week 4				
Lesson 3 **Start:** Recap engineering problem. **Final Goal:** Teams complete the lab problem through possible solutions steps of the lab with check-ins.	**Lesson 3** **Start:** Teams complete lab development and begin prototype testing. **Final Goal:** Teams complete Prototype 1 testing.	**Lesson 3** **Start:** Teams build and test Prototypes 2-3. **Final Goal:** Teams analyze test data and evaluate results.	**Lesson 3** **Start:** Teams analyze data and begin lab conclusions. **Final Goal:** Teams complete lab conclusions.	**Lesson 3** **Start:** As a class, review lab conclusions, wrap up the lab, and debrief. **Final Goal:** Review assigned assessment questions (optional).

Pacing Guide Notes

* As the school year progresses, students are expected to come to class having already read the lab manual so they can actively participate in the Socratic dialogue. When students read the lab manual outside of class time, this time can be used for deeper Socratic dialogue.

Science Words to Know:

This unit's vocabulary is divided into three lessons. Use a blank concept map visual to connect vocabulary once the unit is complete. An example concept map is displayed in Appendix 3.

Lesson 1

1. **attract** – to pull toward

2. **magnet** – an object that produces a magnetic field

3. **magnetic field** – the invisible area around a magnet that attracts or repels other magnets and magnetic materials such as iron

4. **repel** – to push away

Lesson 2

5. **circuit** – the circular path that electrons travel in a negative to positive direction

6. **current** – a measure of the rate that an electric charge passes through a point in an electric circuit over time; measured in amps

7. **electric conductor** – a material that electrons can easily pass through

8. **electric field** – an area around a charged particle that attracts or repels other charged particles

9. **electric insulator** – a material that electrons do not pass through easily

10. **electricity** – the flow of electrons through a conductor

11. **electromagnet** – a tightly wound coil of wire that produces a magnetic field when electricity passes through the wire

12. **motor** – a machine that transfers an input of electrical energy into an output of mechanical energy

13. **permanent magnet** – an object that stays magnetized without electricity

14. **voltage** – a measure of the difference in electric charge between two points

Lesson 3

15. **generator** – a machine that converts an input of mechanical energy into an output of electrical energy

16. **wind** – moving air molecules

17. **wind turbine** – a device that converts mechanical energy from the wind into electrical power

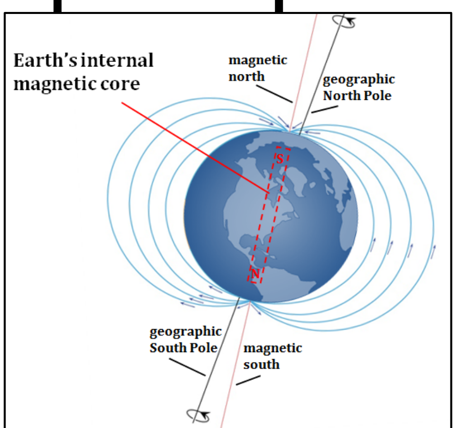
Teacher Background

Earth's Magnetic Field

Earth is a giant magnet. **Magnets** are objects that produce a **magnetic field**, which is the invisible area around a magnet that attracts or repels other magnets and magnetic materials such as iron. Earth has a magnetic field that is created in Earth's molten iron core and extends far into space.

The magnetic field acts as a shield against harmful particles given off by the sun's solar winds, which would otherwise enter our atmosphere. Earth's magnetic field changes in strength day to day and completely switches direction (inverts) every few thousand years.

Understanding how Earth's magnetic field could help animals navigate begins with the basic rules of magnetism. Magnets exert a force on other magnets or magnetic materials. A force is a push or pull that acts on an object, changing its speed, direction, or shape. Magnets either repel or attract other magnets or magnetic materials. To **repel** means to push away. To **attract** means to pull toward.



Earth's geographic and magnetic poles

All magnets have a north pole and a south pole. The north pole of one magnet always attracts the south pole of another. However, two north poles will always repel each other, as will two south poles.

Because Earth is a magnet, it has a magnetic north pole and a magnetic south pole. However, these poles are actually opposite the geographic North and South Poles, which are the northernmost and southernmost fixed points on Earth. People sometimes refer to Earth's magnetic north, which is near the geographic North Pole, but this magnetic north is actually a magnetic south pole. This is why the north pole of a compass is attracted to it. In the same way, people sometimes refer to Earth's magnetic south, which is near the geographic South Pole, but this is actually a magnetic north pole.

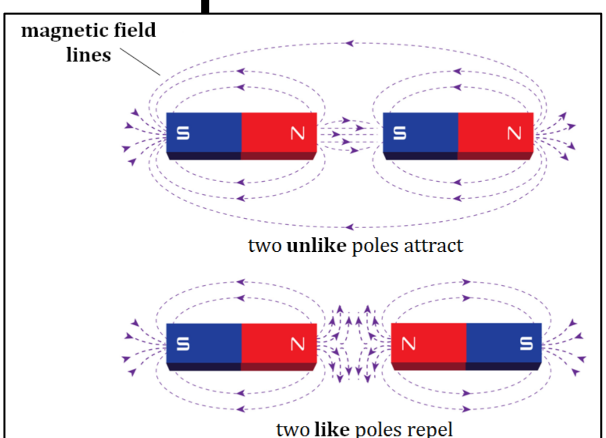
Using Earth's Magnetic Field to Navigate

Scientists have been conducting various studies to learn more about how animals use Earth's magnetic field. In 2014, a team of scientists from France announced that bottle-nosed dolphins have the ability to sense magnets because they swam toward magnetic objects much faster than they swam toward the demagnetized objects.

This experiment answers just one small question that is part of the much larger question of how many animals use Earth's magnetic field to navigate. More research will be needed to definitely answer that larger question. For example, the experiment didn't tell scientists that dolphins could sense Earth's magnetic field because the magnets used by the scientists had a much stronger magnetic field than Earth's own magnetic field. Scientists still don't know whether dolphins can sense Earth's weaker magnetic field and if this is how dolphins navigate.

A compass's magnetic north pole points toward Earth's internal magnetic south pole (near the geographic North Pole).

People can also use Earth's magnetic field to navigate with the help of a compass, which is an instrument that aligns with Earth's magnetic poles. The red tip of the compass needle is a magnetic north pole. Because north poles are attracted to south poles, the red tip always points toward Earth's internal magnetic south pole (near the geographic North Pole).



how magnets interact

As these examples of navigation show, magnets are useful because they can attract or repel other magnets or magnetic materials without touching them. Whenever a magnet or a magnetic material is within another magnet's magnetic field, the field exerts a force that either attracts or repels the magnet or magnetic material.

Forces and Energy

Imagine you have two magnets. When they are within each other's magnetic fields, they form a system because they interact with one another by exerting a force on each other. For example, if you orient the magnets so that their like poles are facing each other, they will repel, pushing away from each other.

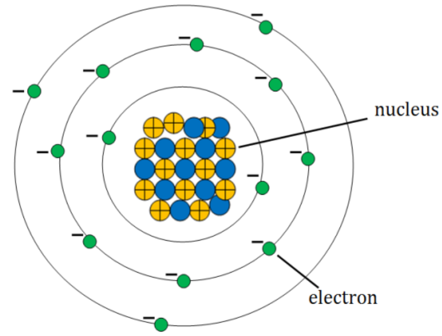
Now imagine that you push those repelling magnets toward each other. You have to use mechanical energy to overcome that repelling force to move them together. Mechanical energy is the energy of a substance or system due to its motion. As you push them, you apply a force to the system that transfers the energy from your hands into the system. In other words, your pushing force provides an input of mechanical energy into the system.

That input of mechanical energy is stored in the system as potential energy. You can see evidence of this potential energy when you let go of the two magnets and they move apart from one another. The potential energy stored in the system has been changed back into mechanical kinetic energy.

If you change the distance between the interacting magnets, you change how much energy is transferred into the system. For example, the closer you push two repelling magnets together, the more energy you need to use. This means more energy is transferred into and stored within the system. This will cause the magnets to move farther apart when you release them.

In a perfect system, the total amount of energy is always conserved as it changes from one form to another. In other words, however much potential energy the system of interacting magnets has, that same amount of energy will change into mechanical kinetic energy as the magnets are released and move away from one another. However, in the real world, some of that energy is transferred out of the system. When energy is transferred, it moves into or out of an object or system. For example, if the magnets are on the ground, friction will transfer some of the energy out of the system. Friction is a force that slows motion whenever two objects rub against each other by turning mechanical energy into heat.

Kinds of Magnets

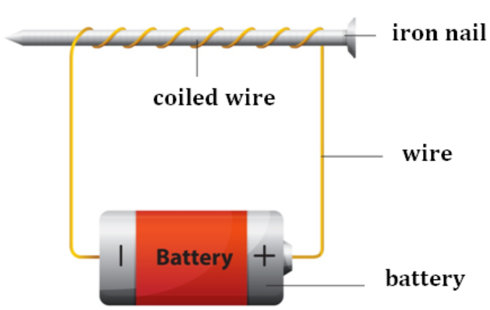


This is a model of an atom.

Whether an object is a magnet is one property of matter. An object has magnetic properties if its electrons are behaving in a specific way. Remember that all matter is made of tiny particles called atoms. Atoms are made up of even smaller particles, including protons, neutrons, and electrons. Protons and neutrons are found in the nucleus, and electrons orbit the nucleus at different distances called shells. Protons have a positive charge (+), and electrons have a negative charge (-).

In non-magnets, electrons randomly spin clockwise or counterclockwise. In contrast, magnets have electrons that mostly spin in the same direction.

People can cause objects to become magnetized. For example, if you repeatedly rub an iron-containing object, such as a paper clip or a nail, with an active magnet, it causes that object's electrons to align temporarily.



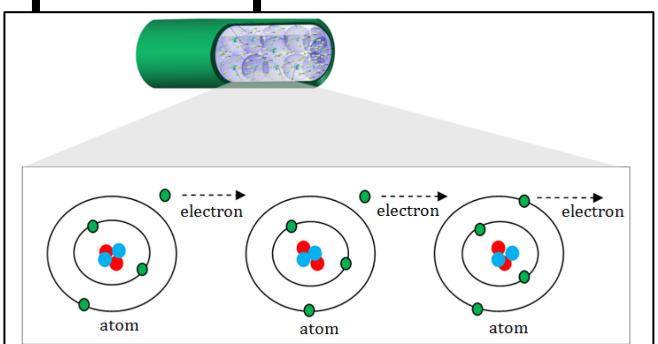
This is a simple electromagnet.

Magnets can also be created with the use of **electricity**, the flow of electrons through a conductor. **Electromagnets** are tightly wound coils of wire that produce a magnetic field when electricity passes through the wire. They are useful in various technologies because the magnet can be turned off and on. This is different from **permanent magnets**, which stay magnetized without electricity.

Electricity and Magnetism

Electricity is closely linked to magnetism. Charged particles change the space around them. They produce an **electric field**, which is the area around a charge that can exert a force on other charged particles. Similar to magnets, charged particles either attract or repel one another. Particles that have an opposite charge attract one another within their electric field, while particles with the same charge repel each other within their electric field. Electrons are kept in orbit in their shells because the positive charge of the protons in the nucleus attracts the negatively charged electrons.

The strength of the field weakens with distance. Because of this, electrons in shells closest to the nucleus are tightly bound, while electrons in the outermost shell are much more loosely bound. When a force is applied, electrons in the outer shells can be pushed from one atom to another. Once that first electron has been pushed away from its atom, it moves to another atom. This movement of electrons causes electrons to all move in the same direction as one another.



This diagram shows electricity moving through a conductor. The green outer covering of the wire is an insulator.

Electrons can move more easily through some materials than others. **Electric conductors** are materials that allow electrons to pass through them easily. Metals such as copper and aluminum are electric conductors because they have electrons that are loosely held and therefore can easily be pushed from their shells by an outside force.

Electric insulators are materials that do not allow electrons to pass through easily because electrons do not easily separate from their atoms. Rubber and plastic are both good electric insulators. This is why electrical cords are covered in rubber or plastic. The electricity cannot travel through the rubber or plastic and is forced to follow the path on the aluminum or copper wires. Some materials are semiconductors, which means they can sometimes act as a conductor, depending on what other molecules are around.

Electro-magnets and Circuits

Because electromagnets are made with electricity, they can be demagnetized when the electricity is turned off. This is possible because electromagnets form a circuit. A **circuit** is the circular path that electrons travel in a negative to positive direction.

All circuits have the same basic parts, including an energy source such as a battery. The battery has stored chemical energy that converts to electrical energy. This energy provides the input of force that pushes the electrons in the conductive material through the circuit. A battery's voltage affects how much it can push and pull electrons through a circuit. **Voltage** is a measure of the difference in electric charge between two points. A high voltage pushes and pulls electrons with more force than a low voltage. Voltage is measured in volts (v).

Circuits also have wires, which are the paths that electrons travel in the circuit. Energy moves from the battery through the conductors inside the wires. The wires in a circuit are attached to an object that can convert electrical energy to do work (any change in position, speed, or state of matter due to force). All circuits must include something that can do work. Without this part, the electricity will cause danger by overheating the circuit. This is called a "short circuit."

For example, a light bulb is an object that does work. When electrons reach the light bulb in a circuit, they transfer electrical energy. The light bulb changes the electrical energy into outputs of light energy and heat. In a perfect system, the same amount of energy that was transferred through the circuit would be available to light up the bulb because of the conservation of energy. However, in the real world, some of the energy transfers out of the system due to resistance, which is the force opposing the current. The electrons then continue on their path. They return to the opposite side of the battery.

Finally, most circuits have switches. The switch opens and closes the circuit. Electrons flow when a circuit is closed. This is "on." A closed circuit will cause the light bulb to light up. Electrons cannot flow when a circuit is open. This is "off." No work can be done in an open circuit.

Magnetic Trains

The way a circuit is put together affects the amount of electric current that can do work. **Current** is a measure of the rate that electric charge passes through a point in an electric circuit over time. It is measured in amps (A). The amount of work that can be done increases as current increases. For example, a fast current will cause a light bulb to be brighter than a slow current. This is because more electrons reach the bulb in the same amount of time.

As electrons in a conductor move in the same direction as one another, their movement produces a magnetic field around the wire conductor. The magnetic field around a straight wire is not very strong. However, if the wire is wrapped in a coil, the fields produced in each turn of the coil add up to create a stronger magnetic field. This is the idea behind an electromagnet: a tightly coiled wire produces a magnetic field when electricity passes through the wire. The electromagnet becomes magnetized when the circuit is closed. It becomes demagnetized when the circuit is open.

Electromagnets are found in many technological applications, including at the bottom of high-speed trains, called "maglev" trains, short for magnetic levitation. Maglev trains are designed with electromagnets on the bottom that produce a powerful magnetic field. The track, called a guideway, has loops of conductive materials, such as aluminum.

As the train passes over the loops, magnetic repulsion between the electromagnets on the train and the magnetic loops keeps the train a certain distance from the guideway. Magnetic attraction propels the trains forward.

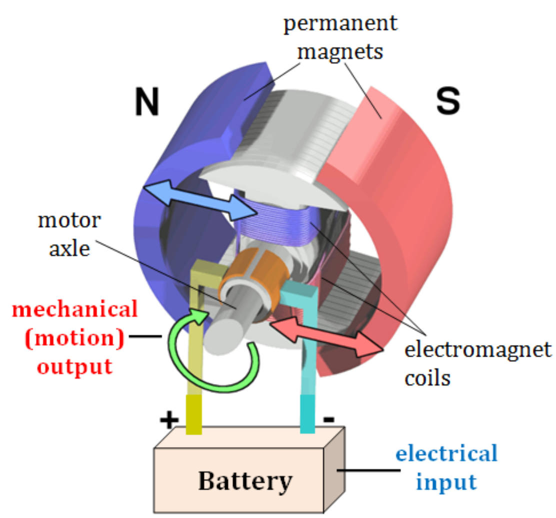
Floating above the tracks offers the trains a significant advantage: there is very little friction to slow the trains down. Engineers in the United States are discussing using maglev trains to connect the East and West Coasts.

Magnets in Electric Motors

Electromagnets are not just found at the bottom of high-speed trains. They are an important part of electric motors, which are found in a wide range of household items, including electric screwdrivers, washing machines, automatic can openers, fans, electric toothbrushes, and many toys that move.

A **motor** is a machine that transfers an input of electrical energy into an output of mechanical energy.

An electromagnetic motor has two parts: an outside permanent magnet and an inside electromagnet. The electromagnet becomes magnetized when the circuit it is part of is closed.



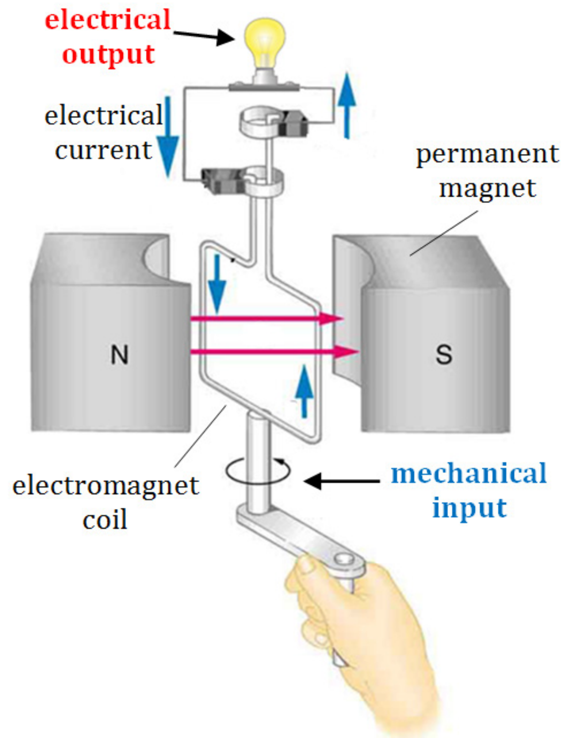
an electric motor

If the electromagnet is positioned so that its north pole is near the north pole of the permanent magnet, the two magnets will repel each other, and be attracted to each other's south pole. These attracting and repelling forces cause the electromagnet to rotate, generating mechanical energy. This is the same basic concept behind maglev trains. If a gear is attached to the spinning electromagnet, the gear can be made to do work.

There are different ways to change the speed that a motor spins. The more coils an electromagnet has, the stronger magnetic field it will have. Because the electric current is so connected to the magnetic field, this stronger magnetic field causes the current to flow even faster. A faster current means that the electrons are moving faster. That faster movement creates a stronger magnetic field, which then causes the current to move even faster.

Wind Turbines

Generators are also machines that use permanent magnets and electromagnets. A **generator** is a machine that converts an input of mechanical energy into an output of electrical energy. The generator uses the same principles of electromagnetic force as an electric motor, but it works in reverse. A generator uses mechanical energy to move a magnet near a wire conductor, which creates a flow of electrons, generating electricity.



a simple hand-powered generator

Engineers can use generators in various technologies that generate energy, including **wind turbines**, which are devices that convert the wind's mechanical energy into electrical energy. The **wind** has mechanical energy because it is moving air. Wind turbines can be as tall as a 20-story building and have blades that are 60 meters (200 feet) long. Basic wind turbines have three parts: blades, a drive shaft, and a generator.

The generator is able to move because the blades of a wind turbine capture the wind's kinetic energy. The wind pushes on the blades, transferring some of its own mechanical energy of motion to the blades. The blades are connected to a drive shaft, which is a long bar of steel that can rotate. As the wind moves the blades, the blades rotate the drive shaft. That rotating motion moves the electromagnet in the generator, which produces electricity.

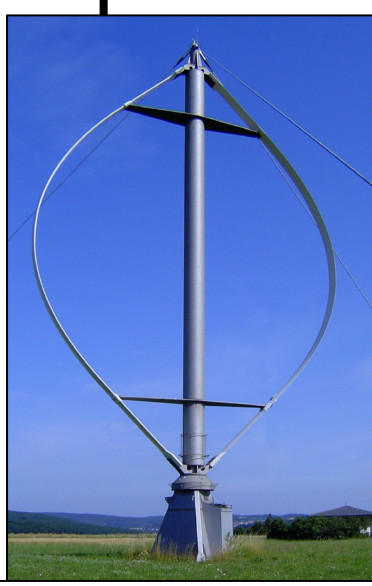
Types of Turbines

Engineers experiment with different blade shape and size depending on the specific environmental conditions. There are two basic designs: vertical-axis wind turbines and horizontal-axis wind turbines.

horizontal-axis wind turbines

Horizontal-axis turbines are much more common because they are generally more efficient at converting the wind's mechanical energy into electricity. They look like massive airplane propellers on a pole.

However, horizontal-axis wind turbines work most efficiently when the wind flows at a right angle to the blades. This means that the main rotating shaft and electrical generator must be pointed into the wind. They are also very tall, with long, heavy blades. The more mass the blades have, the more force is needed to turn them. This makes them best suited for open spaces, such as fields, that have a lot of wind.



vertical-axis wind turbine

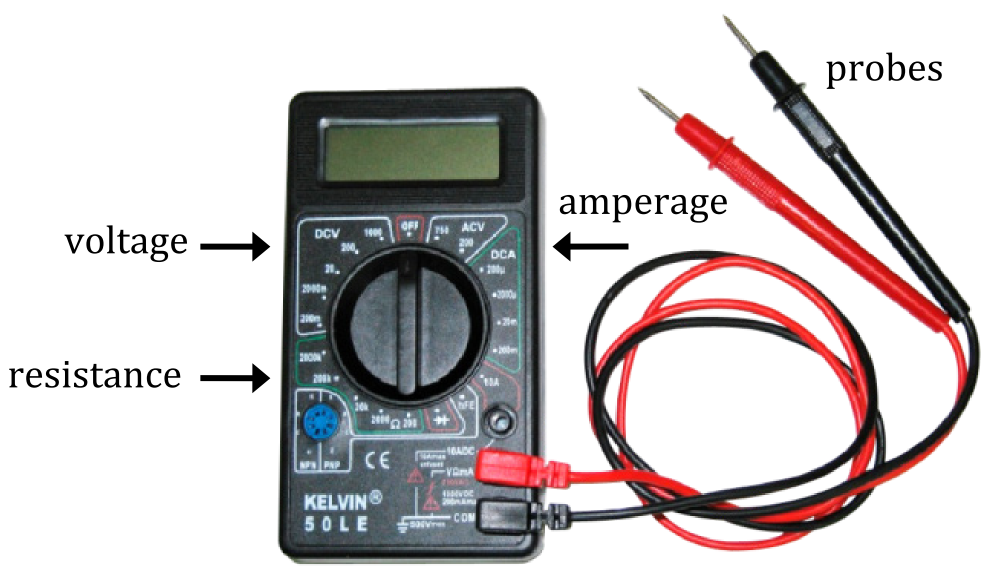
The other kind of turbine is called a vertical-axis wind turbine, and it often looks like a massive egg beater. In the vertical-axis wind turbine, the main drive shaft is perpendicular to the ground. The main components are located at the base, making any service and repair much easier. One advantage of the vertical-axis wind turbine is that it does not need to be pointed into the wind. It will function similarly regardless of wind direction. This makes it a better option for many urban areas where tall buildings make wind flow more unpredictable. However, this design is less efficient than horizontal-axis wind turbines because the blades rotate more slowly.

How to Use a Multimeter

- The multimeter will allow you to measure the amount of voltage produced by your wind turbine. It can also be used to measure amperage and resistance, but only voltage will be measured in your circuits.
- The dial on the multimeter turns the instrument on and is used to select what you want to measure.
- **DO NOT** use this instrument to test wall outlets or other electrical devices.
- To extend the life of the battery, the switch should be in the "OFF" position when the instrument is not in use and the dial should be turned slowly.

Symbols

- A multimeter dial is divided by the type of measurement being taken. The options are:
  - DCV = Direct Current **(Voltage)**
  - DCA = Direct Current **(Amperage)**
  - ACV = Alternating Current **(Voltage)**
  - Ω = **(Resistance)**



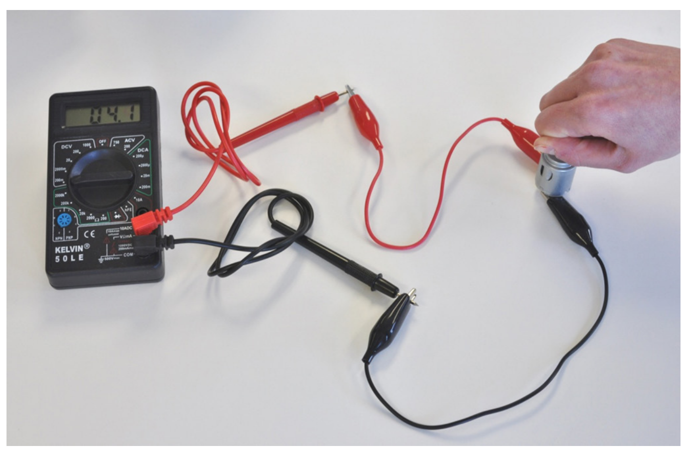
Units

- Values on the multimeter represent the available range of measurements from 1 millivolt or less to 1,000 volts.
- The range of settings determines the maximum quantity that can be measured. For example: DCV 200m measures up to 200 millivolts; DCV 2,000m measures up to 2,000 millivolts, etc. The lesson will tell students which value to select on the multimeter. Changing the setting on the multimeter changes the sensitivity of the measurement. Students sometimes think that if they change the setting, the voltage will increase or decrease in the circuit, which is not the case.
- The units for voltage follow the same standards as other metric system measurements (k = kilo, m = milli, μ = micro).

Measuring Voltage of a Motor

1. Plug in the multimeter test leads. The **red lead** (positive) goes into the VΩmA port and the **black lead** (negative) goes into the COM port.
2. Slowly turn the dial to DCV on the multimeter and select the voltage range required.
3. Place or attach the metal probes of the test leads to the corresponding electrodes of the device you are testing.

NOTE: If you get a negative reading from the multimeter, the electrical polarities (positive and negative sides of the multimeter) are reversed. Swap the position of the black and red probes contacting the electrodes on your device to correct.



The photo shows a multimeter measuring the voltage output of a motor as a person spins the axle. The motor is functioning as a generator in this context.

Safety: Short Circuits

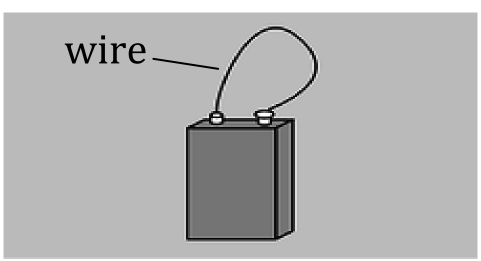
Review how to avoid short circuits and safety precautions with the class prior to using circuitry materials in each lesson.

<u>What is a short circuit?</u>

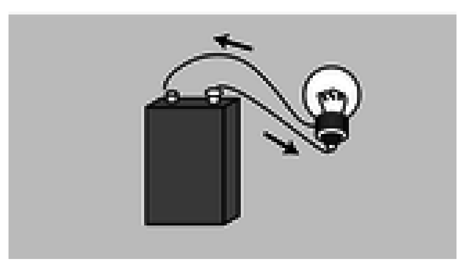
A short circuit occurs when the positive and negative terminals of a battery are connected together with a single wire, or when electricity flows through a circuit with no object (light bulb, motor etc.) attached that can do work. With low resistance in the circuit, a high current exists. The high current causes the battery to deliver a large amount of energy in a short time.

A large current through a circuit can cause a large buildup of heat and pressure. Potential fire or burns could result if circuits are not assembled properly. If any circuit components (battery and wires) become hot to touch, unclip the wires immediately from the battery and assess for short circuits or material damage. Allow undamaged components to cool before reassembling the circuit correctly.

<u>Goggles must be worn at all times when using electrical components.</u>



short circuit
(no object in the circuit
that can do work)



simple circuit with object
that can do work
(light bulb); no short circuit

Lesson 1: Magnetism and Energy

<u>Objective</u>: Students first use a model to explore the size of a magnetic field and then carry out an investigation to evaluate how the amount of potential energy stored in a system of repelling magnets can change depending on the position and configuration of the magnets.

<u>Materials</u>:

Consumable

A. Goggles – 1 per student
B. "Magnetic Fields Investigation" and "Repelling Magnets Investigation" – 1 per student (lab manual)
C. Craft sticks – 1 per team
D. Plastic cups (10 oz) – 1 per team
E. String – shared spool
F. Small paper clips – 1 per team
G. Dowels – 1 per team

Non-Consumable

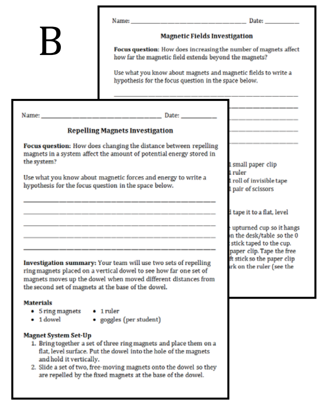
H. Ring magnets – 5 per team
I. Magnetic Interactions Visual – (not shown)
J. Energy Transfers in a System Visual – (not shown)

Teacher Tool Kit

K. Invisible tape – 1 per team
L. Scissors – 1 per team
M. Rulers – 1 per team

A

B



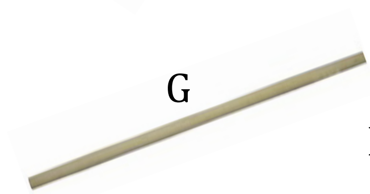
C

D

E

F

G



H

K

L

M

<u>Teacher Preparation</u>:

- Download visuals from the KnowAtom Interactive website.
- There are two investigations in this lesson, each with a short Socratic dialogue to introduce it. Use the pacing guide in the beginning of the unit for one example of how to pace the lesson.
- Arrange several pick-up stations for students to pick up the materials they will use at their desks during each part of the lesson. For example:
  Investigation 1:
  - <u>Pick-Up Station 1</u>: student lab manuals, string, ring magnets, craft sticks, and plastic cups (10 oz)
  - <u>Pick-Up Station 2</u>: small paper clips, rulers, and invisible tape
- **Investigation 2:**
  - <u>Pick-Up Station 1</u>: dowels, ring magnets, and rulers

<u>Student Reading Preparation</u>:

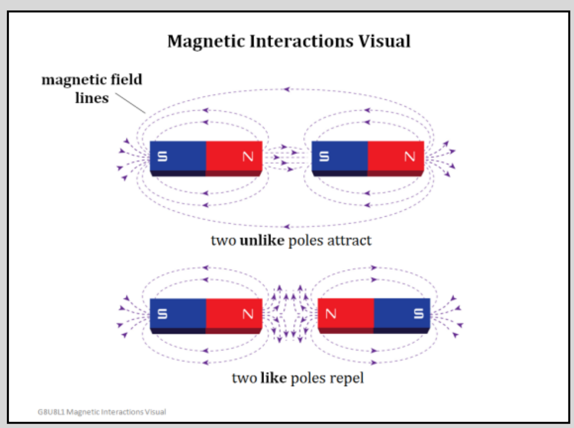
- Students read Section 1 of the student lab manual. In 8th grade, students are expected to come to class having already read the lab manual so they can actively participate in the Socratic dialogue before the lab portion of the lesson. At the beginning of the school year (September-October), the lab manual can be read in class.
- If class time is used to read the lab manual together, model how to read closely for understanding. For example:
  - Emphasize connections between examples in the reading and broader concepts. For example, ask why a certain example was used to support the reading's main point.
  - Use "why" and "how" questions to connect ideas in the reading to student experiences.

Socratic Dialogue 1:

- The Socratic dialogue serves as the bridge between the nonfiction reading and the hands-on portion of the lesson.
- The example Socratic dialogue below describes one possible progression of ideas to engage students in higher order thinking. Blocks are used to divide the dialogue according to key organizing concepts. They are not meant to indicate how much time a dialogue should take; length of time may vary depending on the subject matter and student understanding of the concepts. Note that in a Socratic dialogue, the teacher is not the only one asking questions and challenging ideas. Students should be actively engaged in proposing questions, challenging assumptions, and using evidence to support their arguments. *Not sure how to set up a Socratic dialogue? Check out www.knowatom.com/socratic for an in-depth look at how to hold a next generation Socratic dialogue in the classroom.*

Block 1-1: Introduction to Magnetic Interactions

1. Display *Magnetic Interactions Visual*. Begin a dialogue with students about how **magnets** are objects that produce a magnetic field. A **magnetic field** is the invisible area around a magnet that attracts or repels other magnets and magnetic materials such as iron.



- ☐ **Big Idea 1**: Coach students toward the idea that whenever a magnet or a magnetic material is within another magnet's magnetic field, the field exerts a force that either attracts or repels the magnet or magnetic material. For example:

- *Provide each student with two magnets so they can spend a couple of minutes observing how the two magnets interact with one another.*
- *Ask one student to describe how the two magnets interacted with each other. (Depending on how they held the magnets, the two magnets were either attracted to each other or repelled. To **attract** means to pull toward, and to **repel** means to push apart.)*
- *Ask another student how their observations support the claim that magnets can exert a force on other magnets without coming into contact with them. (A force is any push or pull that acts on an object, changing its speed, direction, or shape. The magnets didn't have to touch each other to push apart from one another or to pull together. Both the pushing and the pulling are forces that act on the magnets because they change their motion.)*
- *Ask the first student to explain why the magnets sometimes attract each other and sometimes repel each other. (All magnets have a north pole and a south pole. The north pole of one magnet always attracts the south pole of another. However, two north poles will always repel each other. Two south poles will also repel each other. The interactions of the two magnets depend on how each one is oriented relative to the other.)*
- *Ask another student how these principles of magnetism explain how refrigerator magnets work. (Given the principles of magnetism, the fridge must be made of magnetic materials for magnets to stick to it. This is because magnets only interact with other magnets or magnetic materials. The poles of the fridge magnet have to be opposite the poles of the fridge because the force between the two is attractive. This is how the magnets stick to the fridge.)*

- *Ask the first student to add to what the first student said, asking questions for clarification, adding additional details to support their answer, or respectfully contradicting it with evidence.*
- *Ask another student to hold the magnets as far apart as they can, and to apply what they know about magnetic fields to explain what happens. (Students should observe that the magnets don't exert any force on each other. This is because they are outside each other's magnetic fields. It is the magnetic field that exerts the force on other magnets or magnetic materials, so when a magnet is outside another magnet's magnetic field, there are no interactions.)*

Investigation 1:

SAFETY: Students should wear goggles during this activity.

1. Divide the class into teams of two. Students collect their lab manuals and turn to the "Magnetic Fields Investigation." Explain that each team will:

- Use the "**Magnetic Fields Investigation**" to explore the focus question of the investigation: How does increasing the number of magnets in a system affect how far the system's magnetic field extends beyond the magnets?
- Use what you know about magnets and magnetic fields to write a hypothesis for the focus question.

2. Students take five minutes to discuss the question with their partner and form a hypothesis. Differences in team hypothesis are expected and encouraged. Even though this lesson follows an investigation format, students generate a hypothesis in the same way they would in their lab notebook. Teams check in with the teacher to briefly go over their hypothesis when complete before moving on to the next part of the investigation.

3. Stand by the materials stations to explain how the materials will be used and the amount each team can collect. Students should go to the stations to pick up the materials they will use at their desks.

<u>Pick-Up Station 1</u>:

- string – 15 centimeters per team
- ring magnets – 5 per team
- craft sticks – 1 per team
- plastic cups – 1 per team

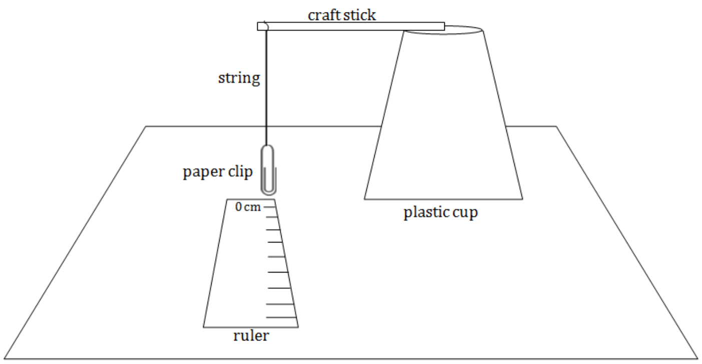
<u>Pick-Up Station 2</u>:

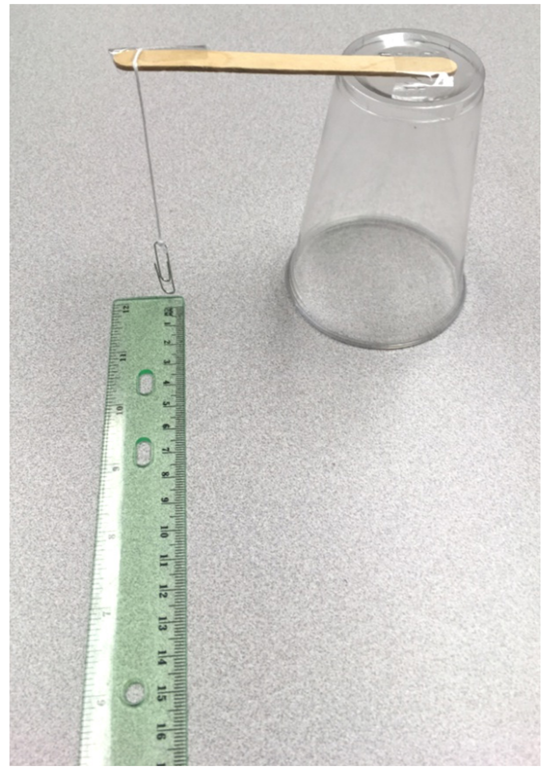
- small paper clips – 1 per team
- rulers – 1 per team
- invisible tape – 1 per team
- scissors – 1 per team

Explain that each team will use the materials list, model set-up, and test procedure outlined on the investigation sheet as a guide to work through the investigation:

- ☐ **Model Set-Up**
    1. Turn the plastic cup upside down and tape it to a flat, level surface.
    2. Tape a craft stick to the bottom of the upturned cup so it the majority of the craft stick hangs off the edge of the cup. Place a ruler on the desk/table so the 0 centimeter end is just under the craft stick taped to the cup.
    3. Tie the string to one end of the small paper clip. Tape the free end of the string to the end of the craft stick hanging off the cup so the paper clip hangs just above the 0 centimeter mark on the ruler (see the diagram on the next page).

Photo and diagram show the cup set up with the string and paper clip on a desk surface.





☐ **Test Procedure**

1. Bring one ring magnet near the paper clip so the paper clip attaches to it.
2. Hold the magnet with the attached paper clip upright against the desk/table surface. Slowly move the magnet away from the cup until the paper clip just starts to separate from the magnet. Place the 0 centimeter end of the ruler at this point.
3. Move the magnet away from the cup along the edge of the ruler until the force of the magnetic field acting on the paper clip weakens and the paper clip falls back toward the cup.
4. Record the maximum distance between the magnet and the paper clip before the paper clip falls back toward the cup. Record this measurement in Table 1.
5. Repeat Steps 1-4 for four more tests, using one additional magnet in each test

Photo shows one magnet being tested with the paper clip near the ruler.

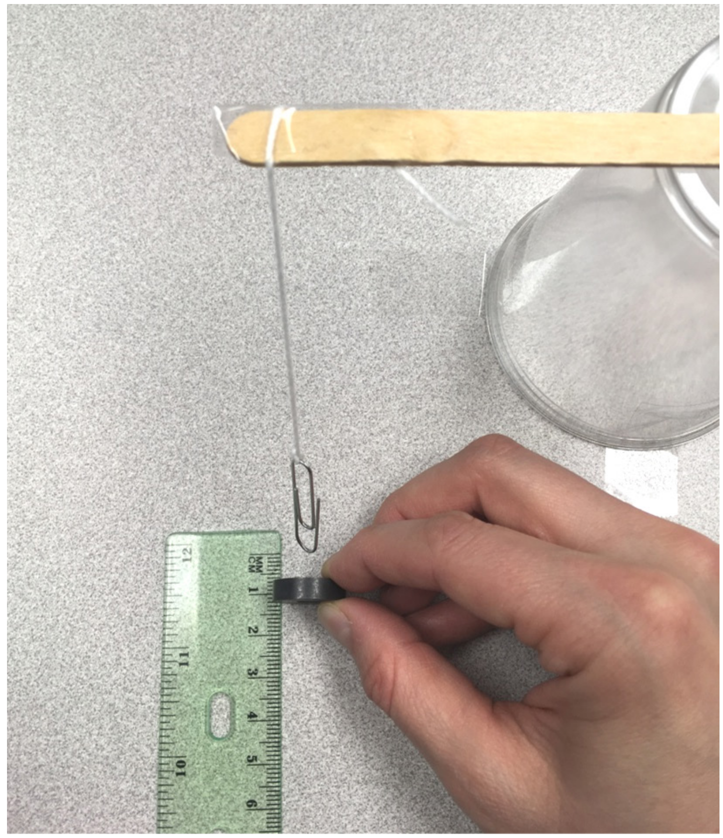
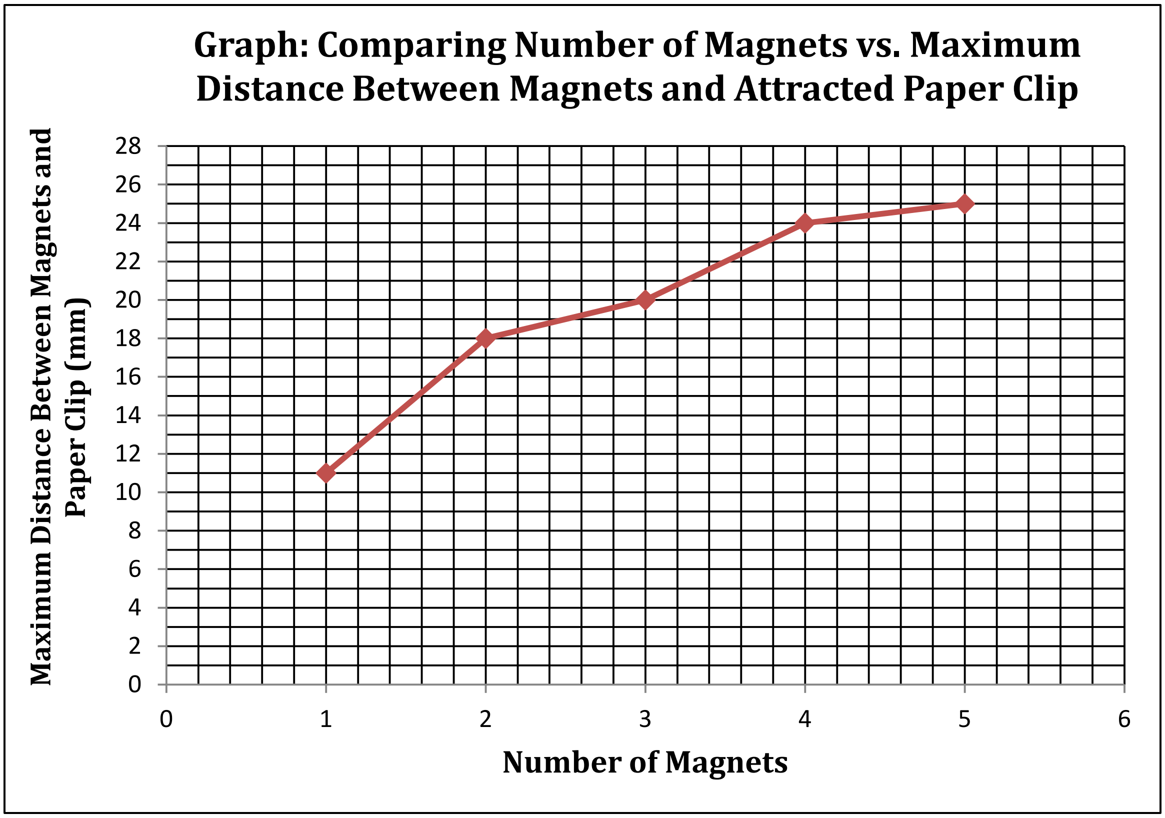


Table 1: Comparing How Number of Magnets Affects Maximum Distance Between Magnets and Attracted Paper Clip		
Tests	**Number of Magnets**	**Maximum Distance Between Magnet and Attracted Paper Clip (mm)**
1	**1**	11
2	**2**	18
3	**3**	20
4	**4**	24
5	**5**	25

NOTE: Team data may vary slightly from example data.



- ☐ **Analysis and Conclusion:** Explain how the data you collected in the investigation does or does not support your hypothesis about how the number of magnets in a system affects how far the system's magnetic field extends beyond the magnets. Use specific evidence from the investigation to support your argument.

4. Move throughout the class as teams work through the investigation to ask questions that gauge student thinking and to help facilitate if needed. Student conclusions should follow the same format they use in a formal lab write-up.

<u>Wrap-Up</u>:

1. Begin a dialogue with students to review how their results provide evidence that magnetic fields exist and can exert a force on other magnets or magnetic materials. For example:

- Ask one student to present their conclusion to the class, explaining how the data they collected either supported or rejected their hypothesis. [*Answers will vary depending on students' hypotheses and their individual results. Students should have observed that adding more magnets increased the distance that the system's magnetic field extended because the paper clip's motion changed at a greater distance from the magnets.*]
- One at a time, provide multiple teams with the chance to present their conclusions to the class, explaining whether their results and conclusion are similar to or different from the first team's conclusion. Talk through the differences, providing teams with the chance to question each other about their conclusions or process.

2. Transition to the next part of the lesson by focusing on how two magnetic materials within each other's magnetic fields form a system because they are interacting with one another. For example:

- Ask one student what forces they observed in the investigation. [*Students should connect the change in motion of the paperclip with a force since objects can only change their motion when a force is applied. In this case, the magnet's magnetic field exerted a force on the paperclip, causing it to change its motion.*]
- Ask another student to build on what the first student said, asking questions for clarification, providing additional details to support their answer, or respectfully contradicting it. Provide the first student with the chance to respond so that students are evaluating and analyzing each other's responses.
- Ask the first student why the magnets and paperclip formed a system. [*They formed a system because they interacted with and influenced one another.*]

Name: ______________________________ Date: __________

Magnetic Fields Investigation

Focus question: How does increasing the number of magnets in a system affect how far the system's magnetic field extends beyond the magnets?

Use what you know about magnets and magnetic fields to write a hypothesis for the focus question in the space below.

____

____

____

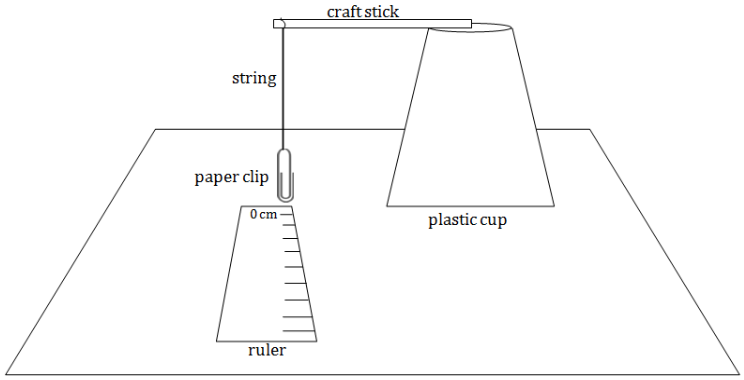
____

Materials

- 15 centimeters of string
- 5 ring magnets
- 1 craft stick
- 1 plastic cup
- 1 small paper clip
- 1 ruler
- 1 roll of invisible tape
- 1 pair of scissors

Model Set-Up

1. Turn the plastic cup upside down and tape it to a flat, level surface.
2. Tape a craft stick to the bottom of the upturned cup so it the majority of the craft stick hangs off the edge of the cup. Place a ruler on the desk/table so the 0 centimeter end is just under the craft stick taped to the cup.
3. Tie the string to one end of the small paper clip. Tape the free end of the string to the end of the craft stick hanging off the cup so the paper clip hangs just above the 0 centimeter mark on the ruler (see the diagram on the next page).



Test Procedure

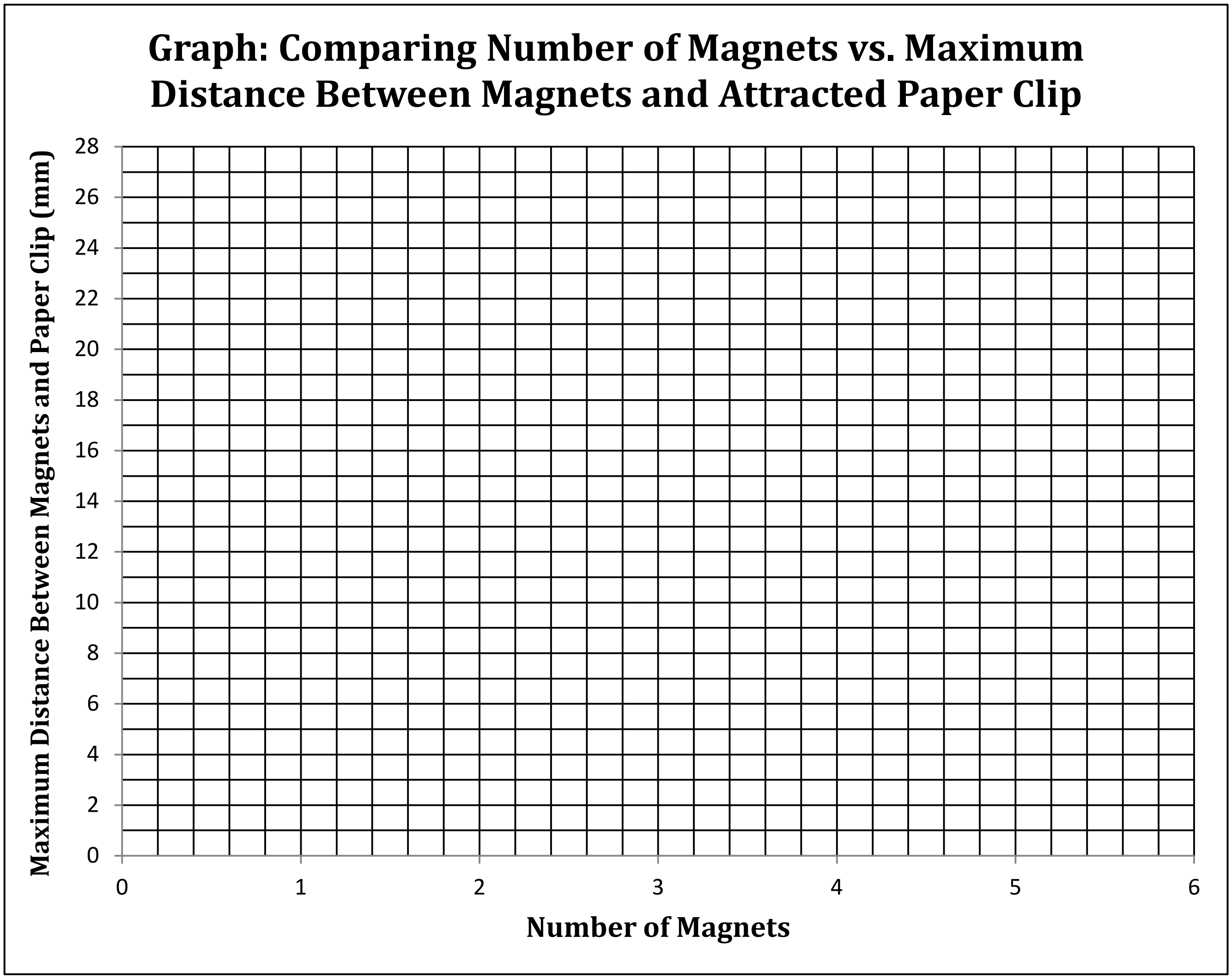
1. Bring one ring magnet near the paper clip so the paper clip attaches to it.
2. Hold the magnet with the attached paper clip upright against the desk/table surface. Slowly move the magnet away from the cup until the paper clip just starts to separate from the magnet. Place the 0 centimeter end of the ruler at this point.
3. Move the magnet away from the cup along the edge of the ruler until the force of the magnetic field acting on the paper clip weakens and the paper clip falls back toward the cup.
4. Record the maximum distance between the magnet and the paper clip before the paper clip falls back toward the cup. Record this measurement in Table 1.
5. Repeat Steps 1-4 for four more tests, using one additional magnet in each test

Data

Table 1: Comparing How Number of Magnets Affects Maximum Distance Between Magnets and Attracted Paper Clip

Tests	Number of Magnets	Maximum Distance Between Magnet and Attracted Paper Clip (mm)
1	1	
2	2	
3	3	
4	4	
5	5	

Graph your data from Table 1 in the blank line graph below.



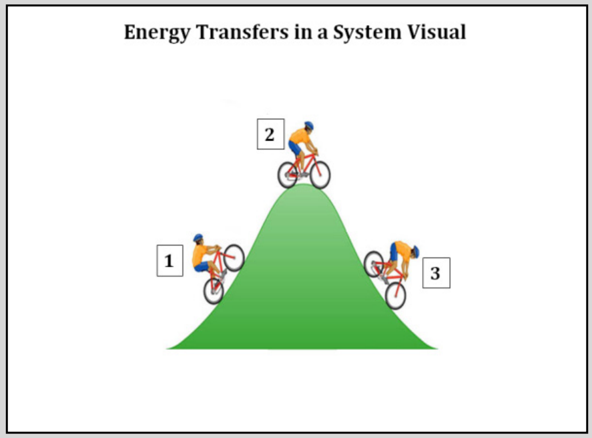
Analysis and Conclusion

Explain how the data you collected in the investigation does or does not support your hypothesis about how the number of magnets in a system affects how far the system's magnetic field extends beyond the magnets. Use specific evidence from the investigation to support your argument.

Socratic Dialogue 2:

Block 1-2: Relationship Between Forces and Energy

1. Display *Energy Transfers in a System Visual*. Continue the dialogue with students about magnetism, focusing on how a system of interacting objects can store different amounts of potential energy.



- **Big Idea 2:** Coach students toward the idea that whenever objects interact, they form a system that energy can be transferred into or out of. For example:
    - *Ask one student to describe the parts of the system shown in the visual. (Students should recognize that all of the parts that interact with or are influenced by one another are parts of the system. In this example, the person riding the bike, the bike, and the hill are parts of the system.)*
    - *Ask another student how the biker applies a force to the bike. (As the biker pushes down on the pedals, they are applying a force that transfers the mechanical energy of their legs to the pedals, which causes the bike to move because it now has mechanical energy.)*
    - *Ask the first student how the person's energy changes as they move up the hill. (As the person rides higher up the hill, the mechanical energy of them riding the bike changes to gravitational potential energy.)*
    - *Ask another student where that gravitational potential energy comes from. (Gravitational energy is potential energy stored as a result of an object's height above the ground. The higher up on the hill the biker is, the more gravitational energy they have.)*

- *Ask another student what happens to that gravitational energy once the biker starts moving down the other side of the hill. (That gravitational potential energy converts back to mechanical kinetic energy as the biker moves down the hill.)*
- *Ask the first student how they can use this energy system to describe the cause-and-effect relationship between the height of the biker on the hill and the amount of gravitational energy they have stored. (The biker's height on the hill affects how much potential energy they have stored. The higher up on the hill the biker is, the more gravitational potential energy they have stored.)*

- **Big Idea 3:** Transition to the experiment by connecting the energy system of the biker on the hill with an energy system made up of interacting magnets. For example:
  - *Ask one student why two magnets form a system. (They form a system because they interact with and influence one another. They either attract or repel each other depending on their orientation (whether like poles or opposite poles are facing each other).)*
  - *Ask another student how they can apply a force to the system of magnets. (Students should connect the idea of pushing or pulling with applying a force. Whenever they pull apart two attracting magnets or push together two repelling magnets, they are applying a force to the magnets.)*
  - *Ask the first student how they think this application of force, either pushing or pulling, would affect the energy of the system of interacting magnets. (Students should recognize that forces can transfer energy into the system. When they push together two repelling magnets or pull apart two attracting magnets, the mechanical energy of their motion is transferred to the system of magnets.)*

- *One at a time, provide multiple students with the chance to respond to this question. They don't need to get the "right" answer because they will be exploring the relationship between the amount of force applied to a system of magnets and the resulting amount of potential energy stored in the system. The key ideas they should be aware of are that energy can be transferred into a system by a force, and that the amount of energy a system can store depends on the amount of force applied to the system.*

Investigation 2:

SAFETY: Students must wear goggles during this activity.

1. Divide the class into teams of two. Students collect their lab manuals and turn to the "Repelling Magnets Investigation." Explain that each team will:

- ☐ Use the "**Repelling Magnets Investigation**" to explore the focus question of the investigation: How does changing the distance between repelling magnets in a system affect the amount of potential energy stored in the system?
- ☐ Use what you know about magnetic forces and energy to write a hypothesis for the focus question.

2. Students take five minutes to discuss the question with their partner and form a hypothesis. Differences in team hypothesis are expected and encouraged. Even though this lesson follows an investigation format, students come up with a hypothesis in the same way they would in their lab notebook. Teams check in with the teacher to briefly go over their hypothesis when complete before moving on to the next part of the investigation. The following examples represent the types of hypotheses teams could develop:

- *More potential energy is stored in a system of repelling magnets when a force is applied to move them closer together compared to farther apart.*
- *More potential energy is stored in a system of repelling magnets when a force is applied to move them farther apart compared to closer together.*
- *No potential energy is stored in a system of repelling magnets when a force is applied to move them closer together.*

3. When hypotheses are completed, stand by the materials stations to explain how the materials will be used and the amount each team can collect. Teams should go to the stations to pick up the materials they will use at their desks.

<u>Pick-Up Station 1</u>:

- ring magnets – 5 per team
- dowels – 1 per team
- rulers – 1 per team

Explain that each team will use the investigation sheet to:

- ☐ **Review the investigation summary:** Your team will use two sets of repelling ring magnets placed on a vertical dowel to see how far one set of magnets will move up the dowel when they are placed different distances from the second set of magnets at the base of the dowel and then released.
- ☐ **Set up the Magnet System:**
  1. Bring together three ring magnets and place them on a flat, level surface. Put the dowel into the hole of the magnets and hold it vertically.
  2. Slide a set of two, free-moving magnets onto the dowel so they are repelled by the fixed magnets at the base of the dowel.

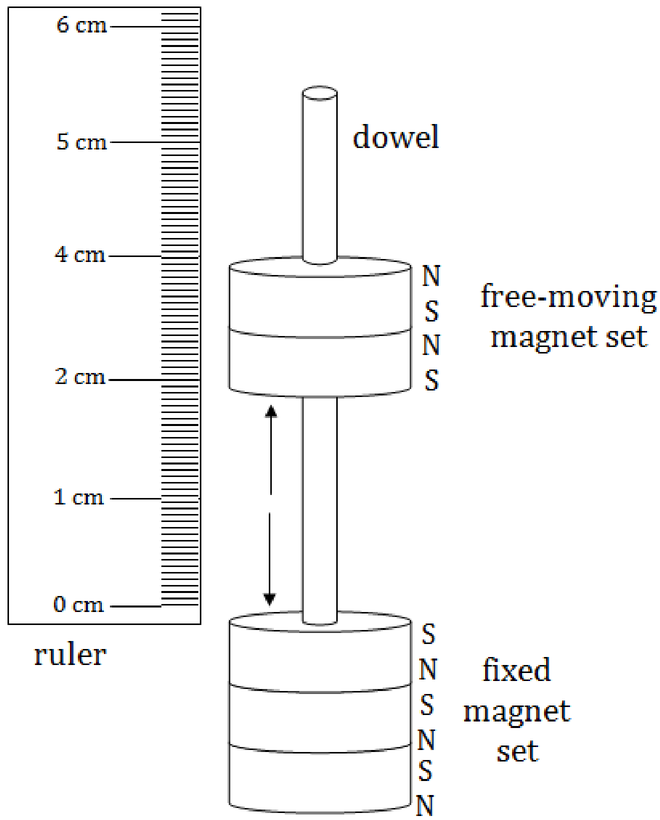


Diagram shows an example of the magnet system on the dowel.

☐ Carry Out the Test Procedure and Collect Data

1. Slide the free-moving magnets 2 centimeters from the fixed magnets on the dowel. Release the magnets and measure how high the base of the magnet set travels up the dowel.
2. Repeat Step 1 for two more trials.
3. Repeat Steps 1-2 for two more tests, first with the free-moving magnets 1 centimeter from the fixed magnets and then 0 centimeters away from the fixed magnets (in contact with the fixed magnets).

Table 1: Distance Repelled Magnets Travel Up a Dowel When Placed at Different Starting Positions from Fixed Magnets		
	Test 1: Base of Free-Moving Magnet Set Starting Position: 2 centimeters from Fixed Magnets	
	Maximum Distance Traveled (cm)	Total Distance Traveled (max. distance – starting position)
Trial 1	4	2
Trial 2	5.5	3.5
Trial 3	4.5	2.5
	Average Distance Traveled	2.7
	Test 2: Base of Free-Moving Magnet Set Starting Position: 1 centimeter from Fixed Magnets	
	Maximum Distance Traveled (cm)	Total Distance Traveled (max. distance – starting position)
Trial 1	10	9
Trial 2	9	8
Trial 3	9	8
	Average Distance Traveled	8.3
	Test 3: Base of Free-Moving Magnet Set Starting Position: 0 centimeters from Fixed Magnets	
	Maximum Distance Traveled (cm)	Total Distance Traveled (max. distance – starting position)
Trial 1	14	14
Trial 2	12	12
Trial 3	14	14
	Average Distance Traveled	13.3

NOTE: Example data represent one possible outcome. Variations in data may occur due to friction between the magnets and the dowel and how students release their magnets.

☐ **Analysis and Conclusion:**

1. Describe any patterns you noticed in the data you collected in Table 1.

2. Explain how the data you collected in the investigation do or do not support your hypothesis about how changing the distance between repelling magnets in a system affects the amount of potential energy stored in the system.

4. Move throughout the class as teams work through the investigation to ask questions that gauge student thinking and to help facilitate if needed. Student conclusions should follow the same format they use in a formal lab write-up. For example:

- *Our hypothesis that more potential energy is stored in a system of repelling magnets when a force is applied to move them closer together compared to farther apart is true. Our data show that as the distance between the repelling magnets in the system decreased, the free-moving magnets traveled farther up the dowel when they were released. When the free-moving magnet set was 0 centimeters from the fixed magnet set in the system, it traveled 5-10.6 centimeters farther up the dowel than when it started from 1-2 centimeters away from the fixed magnets. We can conclude that when two repelling magnets are pushed closer together, more potential energy is stored in the system. In our model, we saw how potential energy converted to kinetic energy when the magnets were released, causing them to move up the dowel. When more potential energy was stored in the system, there was more kinetic energy that was converted, causing the magnets to travel farther up the dowel.*

Wrap-Up:

1. Come together as a class to share team results from the investigation. For example:

- Ask a student from one team to present their conclusion to the class. Were the data consistent with all teams in the class? If not, what may have caused some teams to have different data? [*Answers will vary. Ask students to compare their results and* *analyze possibilities for any differences, such as a difference in carrying out the procedure.*]

- Ask a student from another team what, if any, challenges they experienced while conducting this investigation. [*Answers will vary. Challenges are a part of conducting investigations, and discussing them can help students think through their process, comparing their method with other student teams.*]
- Ask the first student why the free-moving magnet set moved more when the magnets were brought closer together. [*It took more force to move the magnets closer together, which resulted in more energy being transferred into the system of interacting magnets. This meant that there was more potential stored in the system, which converted to mechanical kinetic energy when the magnets were released.*]

2. Continue the dialogue with students to review how well they can apply their observations from the experiment to their magnet model from the investigation. For example:

- Ask one student how the experiment provided evidence for magnetic fields. [*The free-moving magnets never came into contact with the fixed magnets, except when pushed together with a lot of force. However, the free-moving magnets still interacted with the fixed magnets, hovering above them and moving different distances depending on the amount of potential energy stored in the system.*]
- One at a time, provide multiple students with the chance to respond to this question so that students are making connections between magnets and magnetic fields.

Name: ______________________________________ Date: ____________

Repelling Magnets Investigation

Focus question: How does changing the distance between repelling magnets in a system affect the amount of potential energy stored in the system?

Use what you know about magnetic forces and energy to write a hypothesis for the focus question in the space below.

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Investigation summary: Your team will use two sets of repelling ring magnets placed on a vertical dowel to see how far one set of magnets will move up the dowel when they are placed different distances from the second set of magnets at the base of the dowel and then released.

Materials

- 5 ring magnets
- 1 dowel
- 1 ruler
- goggles (per student)

Magnet System Set-Up

1. Bring together three ring magnets and place them on a flat, level surface. Put the dowel into the hole of the magnets and hold it vertically.
2. Slide a set of two, free-moving magnets onto the dowel so they are repelled by the fixed magnets at the base of the dowel.

Test Procedure

1. Slide the free-moving magnets 2 centimeters from the fixed magnets on the dowel. Release the magnets and measure how high the base of the magnet set travels up the dowel.
2. Repeat Step 1 for two more trials.
3. Repeat Steps 1-2 for two more tests, first with the free-moving magnets 1 centimeter from the fixed magnets and then 0 centimeters away from the fixed magnets (in contact with the fixed magnets).

Table 1: Distance Repelled Magnets Travel Up a Dowel When Placed at Different Starting Positions from Fixed Magnets		
	Test 1: Base of Free-Moving Magnet Set Starting Position: 2 centimeters from Fixed Magnets	
	Maximum Distance Traveled (cm)	Total Distance Traveled (max. distance – starting position)
Trial 1		
Trial 2		
Trial 3		
	Average Distance Traveled	
	Test 2: Base of Free-Moving Magnet Set Starting Position: 1 centimeter from Fixed Magnets	
	Maximum Distance Traveled (cm)	Total Distance Traveled (max. distance – starting position)
Trial 1		
Trial 2		
Trial 3		
	Average Distance Traveled	
	Test 3: Base of Free-Moving Magnet Set Starting Position: 0 centimeters from Fixed Magnets	
	Maximum Distance Traveled (cm)	Total Distance Traveled (max. distance – starting position)
Trial 1		
Trial 2		
Trial 3		
	Average Distance Traveled	

Analysis and Conclusion

1. Describe any patterns you noticed in the data you collected in Table 1.

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2. Explain how the data you collected in the investigation do or do not support your hypothesis about how changing the distance between repelling magnets in a system affects the amount of potential energy stored in the system.

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Lesson 2: Electric and Magnetic Interactions

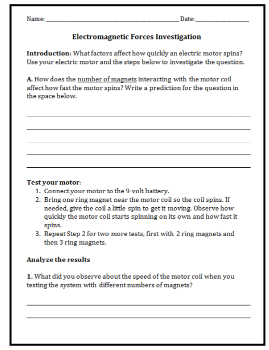
Objective: Students build simple electric motors using permanent magnets and electromagnets and then test the factors that affect how fast the motor spins.

Materials:

Consumable

A. Goggles – 1 per student
B. "Electromagnetic Forces Investigation" – 1 per student (student reader)
C. Batteries (9-volt) – 1 per team
D. Batteries (AA) – 1 per team
E. Magnet wire – shared spool
F. Safety pins – 2 per team
G. Thick foam pieces – 1 per team
H. Red alligator clip wires* – 1 per team
I. Black alligator clip wires* – 1 per student
J. Files – 1 per team

A


B


Name: ________________ Date: ________

Electromagnetic Forces Investigation

Introduction: What factors affect how quickly an electric motor spins? Use your electric motor and the steps below to investigate the question.

A. How does the number of magnets interacting with the motor coil affect how fast the motor spins? Write a prediction for the question in the space below.

Test your motor:
1. Connect your motor to the 9-volt battery.
2. Bring one ring magnet near the motor coil so the coil spins. If needed, give the coil a little spin to get it moving. Observe how quickly the motor coil starts spinning on its own and how fast it spins.
3. Repeat Step 2 for two more tests, first with 2 ring magnets and then 3 ring magnets.

Analyze the results

1. What did you observe about the speed of the motor coil when you testing the system with different numbers of magnets?

C


D


E


F


G


H


I


J


Non-Consumable

K. Ring magnets – 3 per team
L. Types of Magnets Visual – (not shown)
M. Electric Currents Visual – (not shown)
N. Electromagnets in Circuits Visual – (not shown)

K


*These materials are reused in Lesson 3.

Teacher Tool Kit
O. Rulers – 1 per team
P. Invisible tape – 1 per team
Q. Scissors – 1 per team
R. Markers – 1 per team

O 

P 

Q 

R 

Teacher Preparation:

- Download the visuals from the KnowAtom Interactive website.
- Photocopy the Student Electromagnetic Motor Instructions from the copy master on pages 81-83 for each team, or print the instructions directly from the KnowAtom Interactive site. These instructions were created as a visual guide to help students build their motors independently. The instructions are very similar to the teacher directions and have some of the same photos.
- Arrange several pick-up stations for teams to access the materials during the investigation. For example:
    - Pick-Up Station 1: magnet wire, rulers, markers, and scissors
    - Pick-Up Station 2: files and invisible tape
    - Pick-Up Station 3: safety pins and thick foam sections
    - Pick-Up Station 4: black and red alligator clip wires, 9-volt batteries, and one-third of the ring magnets
    - Pick-Up Station 5: remaining ring magnets and AA batteries

Student Reading Preparation:

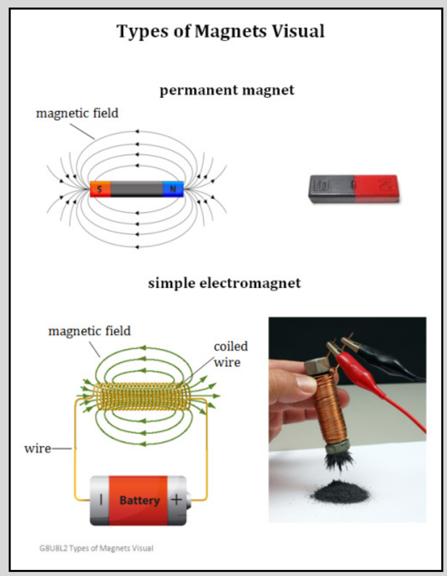
- Students read Section 2 of the student lab manual. In 8th grade, students are expected to come to class having already read the lab manual so they can actively participate in the Socratic dialogue before the lab portion of the lesson. At the beginning of the school year (September-October), the lab manual can be read in class.

- If class time is used to read the lab manual together, model how to read closely for understanding. For example:
  - Emphasize connections between examples in the reading and broader concepts. For example, ask why a certain example was used to support the reading's main point.
  - Use "why" and "how" questions to connect ideas in the reading to student experiences.

<u>Socratic Dialogue</u>:

<u>Block 2: Magnetism and Electricity</u>

1. Display *<u>Types of Magnets Visual</u>*. Connect the last lesson, which focused on basic magnetic interactions, with this lesson, which explores the relationship between magnetism and electricity.

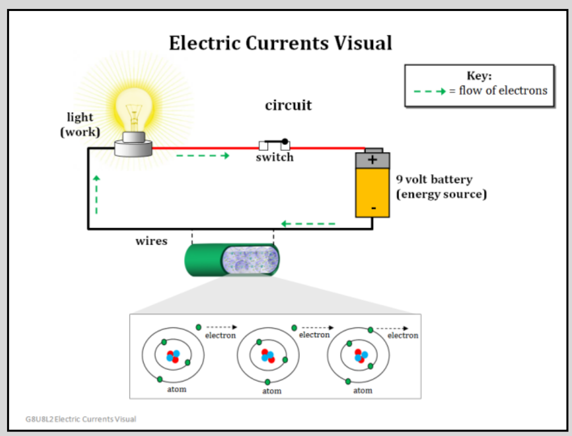


- **<u>Big Idea 4</u>:** Coach students toward the idea that there are different kinds of magnets, including **permanent magnets**, which stay magnetized without electricity, and **electromagnets**, which are tightly wound coils of wire that produce a magnetic field when electricity passes through the wire. For example:
  - *Ask one student how they would categorize the magnets they used in the last lesson, and why. (The magnets used in the last lesson were permanent magnets because they didn't need electricity to stay magnetized. They stayed magnetized on their own.)*
  - *Ask another student how electromagnets become magnetized. (They become magnetized when electricity*

*passes through the wire. **Electricity** is the flow of electrons through a conductor.)*

- *Ask the first student why electricity causes electromagnets to become magnetized. (Electric current produces a magnetic field. As electrons in a conductor move in the same direction as one another, their movement produces a magnetic field around the wire conductor.)*
- *Ask another student why a straight conductive wire doesn't become a useful electromagnet. (The magnetic field around a straight wire is not very strong. However, if the wire is wrapped in a coil, the fields produced in each turn of the coil add up to create a stronger magnetic field.)*
- *Ask the first student how electromagnets can be turned on and off. (Electromagnets are part of a **circuit**, which is the circular path that electrons travel in a negative to positive direction. When the circuit is closed, electricity flows and the electromagnet becomes magnetized.)*

2. Display *<u>Electric Currents Visual</u>*. Continue the dialogue with students, focusing on how the parts of a circuit work together to control the flow of electricity.



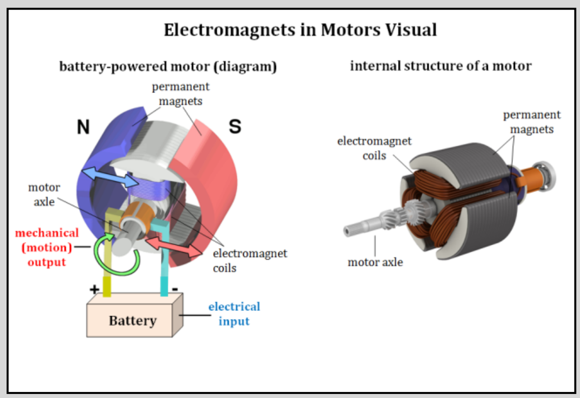
- ☐ **<u>Big Idea 5</u>:** Coach students toward the idea that all circuits have the same four basic parts. For example:
  - *Ask one student why all circuits need an energy source such as a battery. (The battery provides the force that pushes the electrons through the circuit.)*
  - *Ask another student what makes the electrons move in the same direction as one another. (All batteries have a positive side (+) and a negative side (-). Electrons travel from the negative end of the battery through the circuit to the*

positive end because the negatively charged electrons are attracted to the positive side of the battery.)

- *Ask the first student what part a circuit has to have so that electrons can travel. (The circuit must have wires, which are the conductive paths that electrons travel in the circuit.)*
- *Ask another student whether the circuit's wires need to be conductors or insulators. (The wires must be conductive because electricity has to be able to pass through. Wires are often made of some kind of metal, which is a good conductor.)*
- *Ask the first student why people design circuits. (Circuits need to include an object that can convert electrical energy to do work. This work, such as lighting a light bulb or spinning a motor, is why circuits are useful.)*
- *Ask another student how circuits convert energy from one form to another. (In circuits, electric currents transfer electrical energy to a device that can convert the energy to another form of energy. For example, in a circuit with a light bulb, the light bulb converts the electrical energy to light energy and heat. In a circuit with a motor, the motor converts the electrical energy to mechanical energy that spins the motor.)*
- *Ask the first student why it's important that a circuit always include something that can do work. (Without this part, the electricity will cause danger by overheating the circuit. This is called a "short circuit.")*
- *Ask another student why most circuits have switches. (The switch opens and closes the circuit. It is how people control when electricity flows and when it doesn't.)*
- *Ask the first student why work cannot be done in an open circuit. (An open circuit breaks the path that the electrons are traveling so they cannot reach the object to do work.)*

- *Use a light switch in the room to model this next question. Ask another student what happens when you flip the switch to "on." (This closes the circuit, which allows electrons to flow. When the electrons can flow, they can do work. This will cause the light in the room to turn on/ light up.)*
- *Ask the first student what happens when you flip the switch to "off." (This opens the circuit. It makes it so that electrons cannot flow so no work can get done.)*
- *Ask another student what would happen to the brightness of a light bulb in a circuit if they used a battery with a higher voltage. (A battery's voltage affects how much it can push and pull electrons through a circuit.* ***Voltage*** *is a measure of the difference in electric charge between two points. Using a battery with a high voltage will push and pull electrons with more force than a low voltage, so the light will be brighter.)*

3. Display <u>*Electromagnets in Motors Visual*</u>. Transition to the investigation with a dialogue about how electric motors use both permanent magnets and electromagnets.



- ☐ **<u>Big Idea 6</u>:** Coach students toward the idea that electric motors are technologies that people have designed using the principles of magnetism and the relationship between electricity and magnetism. For example:
  - *Ask one student if they have ever used something with an electric motor. (Electric motors are found in a wide range of household items, including electric screwdrivers, washing machines, automatic can openers, fans, electric toothbrushes, and many toys that move.)*

- *Ask another student why electric motors need two magnets. (Electric motors need both a permanent magnet and an electromagnet. If the electromagnet is positioned so that its north pole is near the north pole of the permanent magnet, the two magnets will repel each other, and be attracted to each other's south pole. These attracting and repelling forces cause the electromagnet to rotate, generating mechanical energy.)*
- *Ask another student to respond to the first student's answer, asking questions for clarification, providing supporting details, or respectfully contradicting it with evidence. Provide the first student with the chance to respond so that both students are evaluating and analyzing each other's responses.*
- *Ask the first student why electric motors don't just use two permanent magnets. (Electromagnets have the benefit of being able to be turned off and on. This is important in applications that don't run constantly.)*
- *Ask another student how energy is converted in a motor. (A* ***motor*** *is a machine that transfers an input of electrical energy into an output of mechanical energy. When it is part of a circuit, electrical energy moves through the circuit and magnetizes the electromagnet, causing it to rotate, generating mechanical energy.)*
- *One at a time, provide multiple students with the chance to respond to this question so that students are making connections between what they know about interacting magnets, circuits, and energy.*

Investigation:

SAFETY: Students should wear goggles during this investigation. Review short circuit safety information (page 29) with the class prior to starting the investigation.

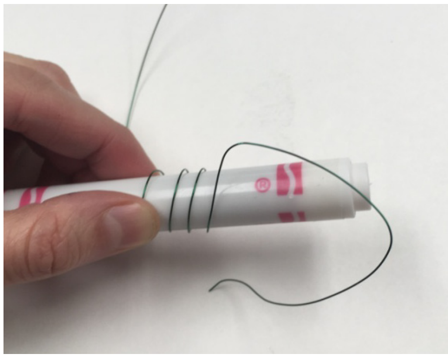
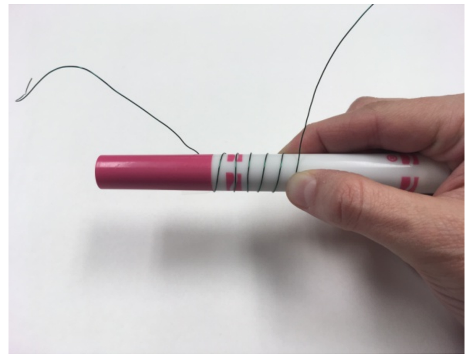
1. Divide the class into teams of two. In this investigation, teams first build a simple electromagnetic motor and then observe the factors that affect how fast the motor spins. Stand by the materials stations to explain how the materials will be used and the amount each student will receive. Students should go to the stations to collect the materials they will use at their desks.

Pick-Up Station 1:

- Student Electromagnet Motor Instructions – 1 per team (photocopied by teacher)
- magnet wire – 45 centimeters per team
- rulers – 1 per team
- markers – 1 per team
- scissors – 1 per team

Explain that each team will use the Student Electromagnet Motor Instructions to assemble an electromagnet motor:

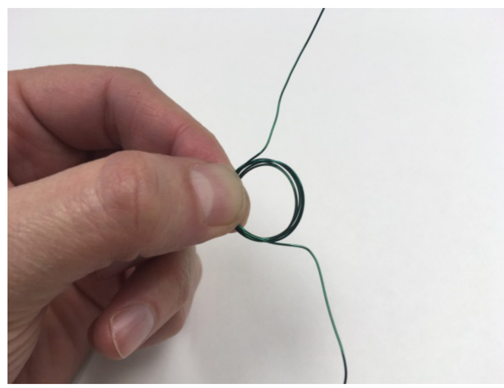
- ☐ Measure and cut one 45-centimeter length of magnet wire to create the **electromagnet coil:**
  1. Starting from the center of the magnet wire, wrap one side of the wire three complete times clockwise around the middle of a marker and then wrap the opposite side of the wire three complete times around the marker in the counterclockwise direction.

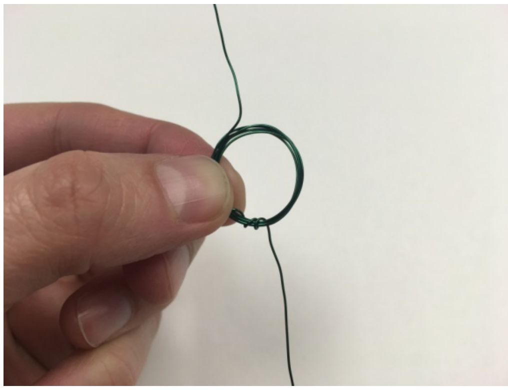
Photos show one end of the magnet wire after being wrapped around the marker clockwise (on the left) and then the opposite end of the wire after being wrapped counterclockwise (on the right).

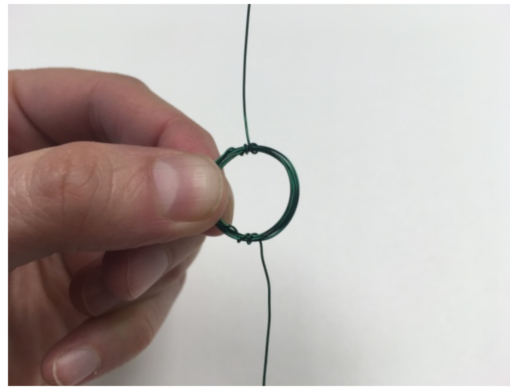
2. Push the coils together and carefully pull the coil off the marker, pinching the coils together to keep them together.

Photo shows the coil after it is pulled off the marker.



3. Wrap one of the tail ends of the magnet wire at least two times through and around the coil to keep the coil together and then wrap the other tail end of the magnet wire through and around the opposite side of the coil. Make sure the tail ends of the wire are equal distances from each other on opposite sides of the coil. The tail ends of the wire should be pointed away from the coil in opposite directions.





Photos show the tail ends of the coil wrapped through and around the coil to help keep its shape.

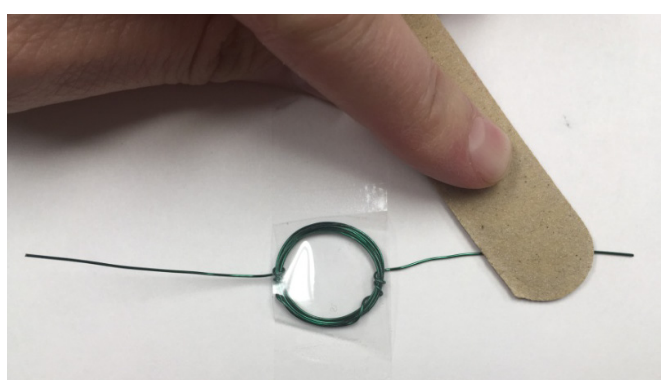
Pick-Up Station 2:

- files – 1 per team
- invisible tape – 1 per team

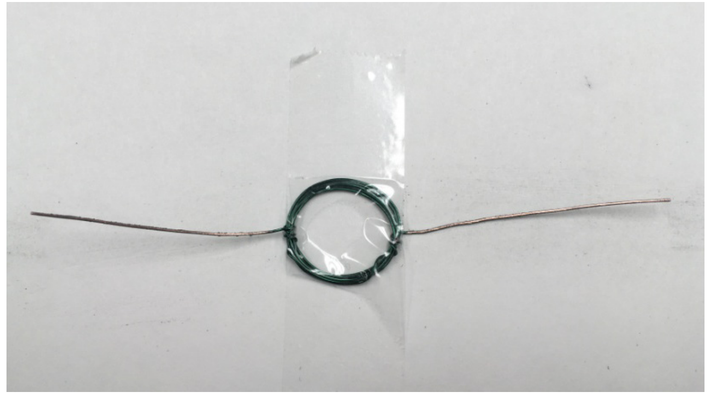
Each team will:

- ☐ Strip the insulated coating off the tail ends of the coil:
  1. Cut the tail ends of the coil so they are 4 cm long.
  2. Straighten the tail ends of the coil and then tape the coil flat to a desk or table
  3. Use a file or a scissor blade to strip the insulated coating from the **top half** of each wire. You will know the insulated coating is removed when you see the copper color of the wire. You do not need to remove the insulated coating off the bottom half of the wires.

Photos show the coil taped to a desk with the insulated coating in the process of being removed (top) and after the insulation is removed from both wire ends (bottom).



NOTE: Taping the coil to a desk will prevent students from accidently stripping the insulated coating off the bottom half of the wire.



2. Teams collect materials from the pick-up stations in order to create the electromagnetic coil. Circulate throughout the classroom to offer guidance as needed as students form the coil. Extra magnet wire is provided if some students' wire becomes knotted as they work with it or if they misinterpret the directions in some way. When the coils are complete, students should move on to create the motor stand and test their electromagnet coil.

<u>Pick-Up Station 3</u>:

- safety pins – 2 per team
- thick foam sections – 1 per team

Each team will:

- ☐ Use two safety pins and one section of thick foam to create the **stand** for the electromagnet motor:
  1. Lay the coil on the thick foam as a guide for the pins. The tail ends of the coil will go through the holes in the safety pins.
  2. To figure out the best position for the motor stand, open the safety pins and stick the sharp side of each pin into the foam near the middle of the tail ends of the coil, as shown in Photo A. Keep the pins as level with each other as possible.
  3. Put the tail ends of the coil through the holes in the pins so the coil hangs between the pins as shown in Photo B.

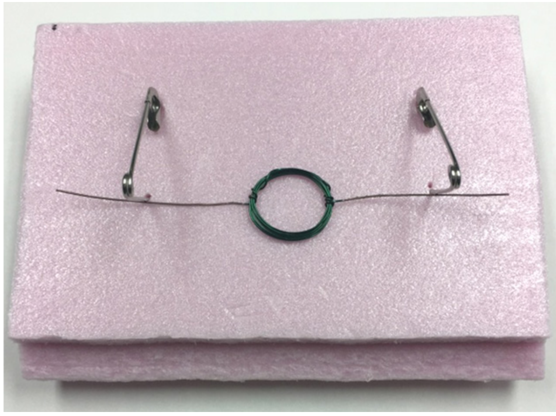


Photo A

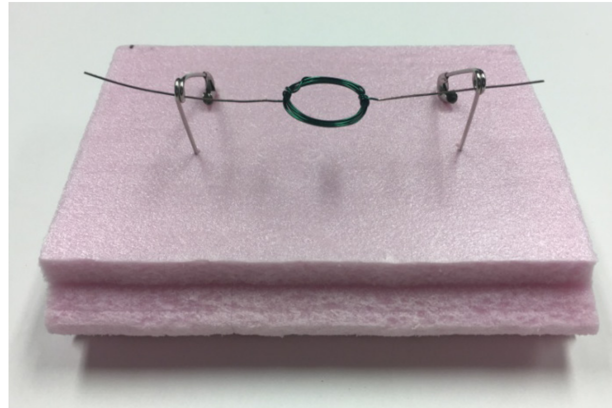


Photo B

NOTE: Students can reposition the pins in the foam as needed until the coil is in a level position.

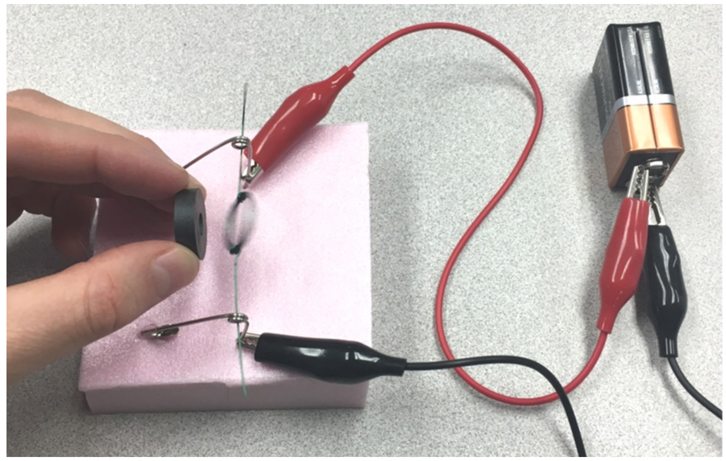
<u>Pick-Up Station 4</u>:

- batteries (9-volt) – 1 per team
- ring magnets – 1 per team
- black alligator clip wires – 1 per team
- red alligator clip wires – 1 per team

Each team will:

- ☐ **Test** the electromagnetic motor:
    1. Clip one alligator clip wire on each pin of the motor stand. Attach the free ends of the alligator clip wires to the positive and negative electrodes of the battery.
    2. Hold the magnet near the coil and spin the coil a little to get it started.
    3. The coil may get warm after a few minutes. Do not leave the motor running for longer than 1 minute at a time. Disconnect the wires from the battery to turn the motor off.

Photo shows the spinning electromagnetic motor attached to the battery.



3. Teams collect materials from the pick-up stations to create the motor stand and test their electromagnetic motors. Circulate throughout the classroom to offer guidance as needed.

NOTE: If students have trouble getting their motor to spin, they should inspect the coil to be sure it is balanced (the coils are tightly wound and the tail ends are wrapped around the coil at equal distances from each other on opposite sides of the coil). The coil can be readjusted as needed or a new coil can be made if the first coil is misshapen. The coil will not spin if students forget to strip the insulating coating from the top half of the coil tails or if the battery is dead. Here are a few other troubleshooting tips to keep in mind (students may figure these things out for themselves through trial and error):

- If one safety pin is higher than the other, the coil will not be level. If this happens, it will be harder for the coil to spin. Reposition the safety pins as needed to level the coil.
- The motor may spin on its own when the magnet is brought close to the coil. However, students may find that they need to give the coil a little spin to get it going.

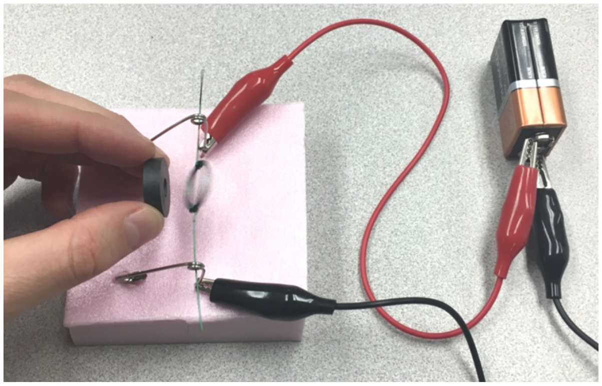
4. When motors are complete and functional, students move on to explore how the interactions between the magnetic and electric forces influence how fast the motor spins. Teams collect the following additional materials for this part of the lesson:

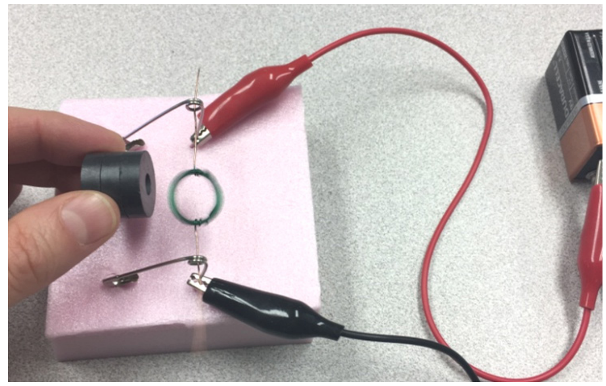
Pick-Up Station 5:

- "Electromagnetic Motor Investigation" – 1 per student (student lab manual)
- batteries (AA) – 1 per team
- ring magnets – 2 per team

Each team will:

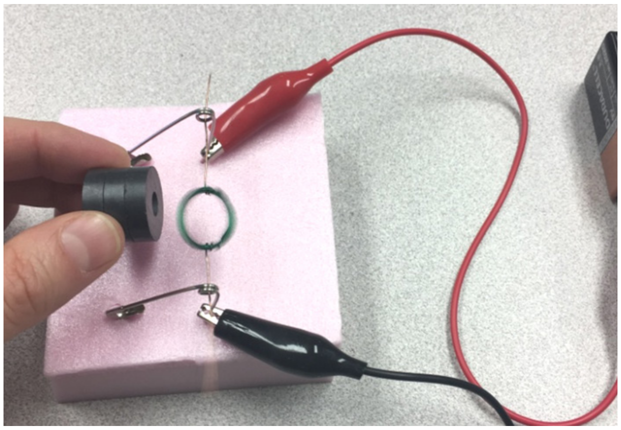
- ☐ Use the "**Electromagnetic Motor Investigation**" to explore the overarching question presented in the introduction: "What factors affect how quickly an electric motor spins?" Use your electric motor and the steps below to investigate the question.
- ☐ **A.** How does the number of magnets interacting with the motor coil affect how fast the motor spins? Write a prediction for the question in the space below.
- ☐ **Test your motor**:
  1. Connect your motor to the 9-volt battery.
  2. Bring one ring magnet near the motor coil so the coil spins. If needed, give the coil a little spin to get it moving. Observe how quickly the motor coil starts spinning on its own and how fast it spins.
  3. Repeat Step 2 for two more tests, first with 2 ring magnets and then 3 ring magnets.
- ☐ **Analyze the results:**
  1. What did you observe about the speed of the motor coil when you tested the system with different numbers of magnets?
  2. Explain how your observations support or do not support your prediction. Use evidence from the investigation to support your argument.

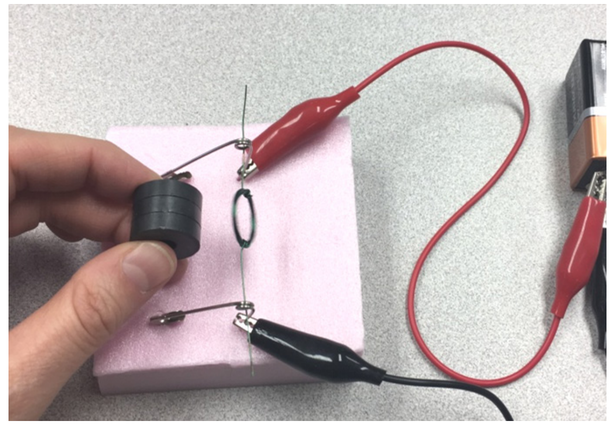




Photos show the motor coil being tested with different numbers of magnets.

- ☐ **B.** How does the orientation of the magnets interacting with the motor coil affect how fast the motor spins? Write a prediction for the question in the space below.
- ☐ **Test your motor**:
  1. Connect your motor to the 9-volt battery.
  2. Bring the end of a three-magnet set near the motor coil. If needed, give the coil a little spin to get it moving. Observe how quickly the motor coil starts spinning on its own and how fast it spins.
  3. Repeat Step 2, this time turning the magnet set so the sides of the magnets are near the motor coil.
- ☐ **Analyze the results:**
  1. What did you observe about the speed of the motor coil when you tested the system with the magnets in a different orientation?
  2. Explain how your observations support or do not support your prediction. Use evidence from the investigation to support your argument.





Photos show the motor coil being tested with magnets in different orientations.

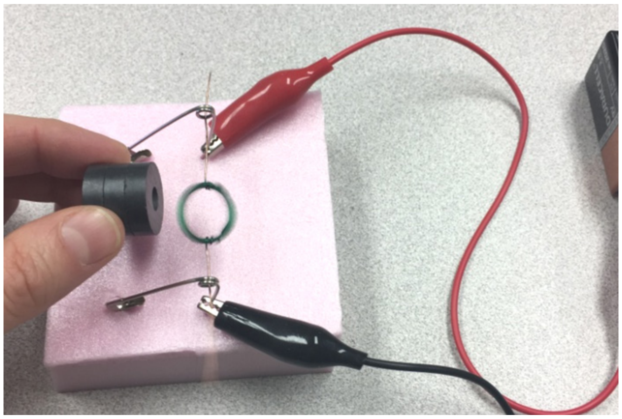
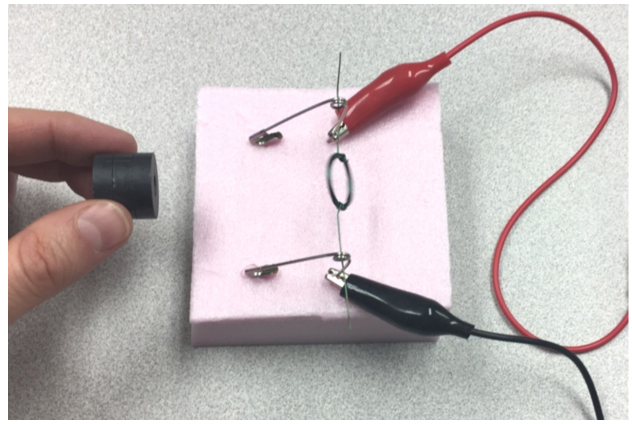
☐ **C.** How does the <u>distance between the magnet and the coil</u> affect how fast the motor spins? Write a prediction for the question in the space below.

☐ **Test your motor**:

1. Connect your motor to the 9-volt battery.
2. Bring the end of a three-magnet set near the motor coil. If needed, give the coil a little spin to get it moving. Observe how quickly the motor coil starts spinning on its own and how fast it spins.
3. Observe how the speed of the coil is affected as you slowly move the magnet set away from the coil, and then slowly move it back toward the coil.

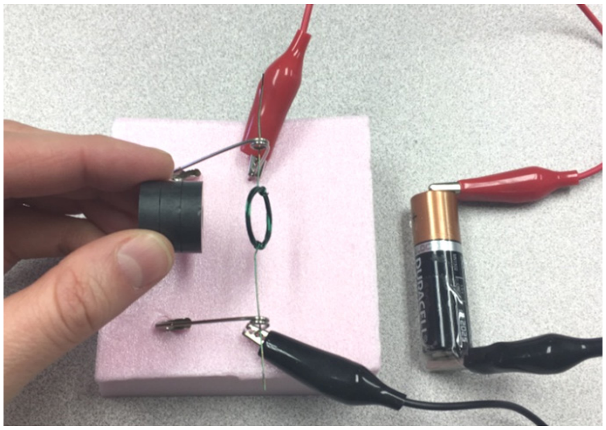
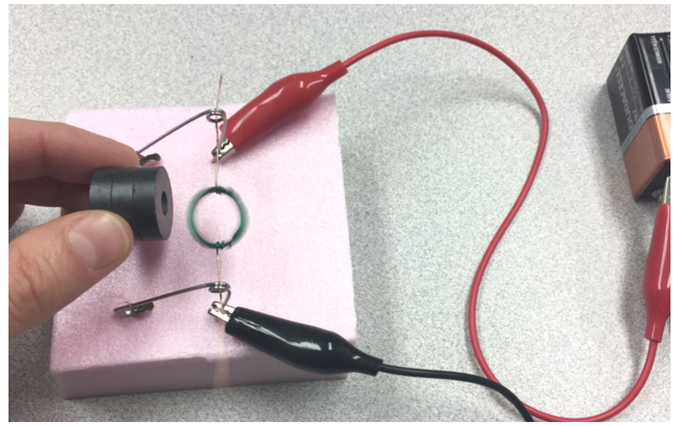
☐ **Analyze the results:**

1. What did you observe about the speed of the motor coil when the magnets interacted with the coil from different distances?
2. Explain how your observations support or do not support your prediction. Use evidence from the investigation to support your argument.

Photos show the motor coil being tested with magnets at varying distances from the motor coil.

- ☐ **D.** How does <u>increasing the voltage flowing through the motor</u> affect how fast the motor spins? Write a prediction for the question in the space below.
- ☐ **Test your motor**:
  1. Connect your motor to one AA battery (1.5 volts) by touching the black and red alligator clip wire ends to the positive and negative ends of the battery.
  2. Bring the end of a three-magnet set near the motor coil. If needed, give the coil a little spin to get it moving. Observe how quickly the motor coil starts spinning on its own, how consistently it spins, and how fast it spins.
  3. Repeat Steps 1-2 with a 9-volt battery.
- ☐ **Analyze the results:**
  1. What did you observe about the speed of the motor coil when batteries with different voltages were used to power the motor?
  2. Explain how your observations support or do not support your prediction. Use evidence from the investigation to support your argument.

Photos show the motor coil being tested with a 1.5 volt and a 9 volt battery.

5. As teams work independently to test their electromagnetic motors, move throughout the class to ask questions to gauge student thinking and to help facilitate if needed. When each team has finished recording their observations and analysis, bring the class together to share findings during the wrap-up portion of the lesson.

Wrap- Up:

1. Begin a dialogue with students to review student observations from their investigation. For example:

- Ask one student what they observed about the speed of the motor coil when they used different amounts of magnets, and whether these observations supported their prediction (Part A). [*Students should have observed that the speed of the coil increased when used three magnets compared to one magnet.*]
- Ask the class whether any teams had different results, and if so, what might explain the differences. Provide students from multiple teams with the opportunity to ask questions of one another as they work through any differences. Redirect if misconceptions arise.
- Ask another student what they observed about how the orientation of the magnets interacting with the motor coil

affected how fast the motor spun, and whether these observations supported their prediction (Part B). [*Students should have observed that when the poles of the three-magnet set were closest to the coil, the coil spun the fastest, and when they turned the magnet set so that the sides were closest to the magnet coil, it didn't spin as fast. This has to do with how magnets exert force on each other. The north and south poles of the magnet are what attract or repulse the poles of other magnets or magnetic materials.*]

- Ask the class whether any teams had different results, and if so, what might explain the differences. Provide students from multiple teams with the opportunity to ask questions of one another as they work through any differences. Redirect if misconceptions arise.
- Ask another student what they observed about how the distance between the magnet and the coil affected how fast the motor spun, and whether these observations supported their prediction (Part C). [*Students should have observed that the farther the magnet was from the coil, the slower the coil moved. This is because the strength of a magnetic field decreases with distance, and when the magnet was far away from the coil, the magnet's magnetic field was weaker.*]
- Ask the class whether any teams had different results, and if so, what might explain the differences. Provide students from multiple teams with the opportunity to ask questions of one another as they work through any differences. Redirect if misconceptions arise.
- Ask another student what they observed about how increasing the voltage flowing through the motor affected how fast the motor spun, and whether these observations supported their prediction (Part D). [*Students should have observed that when they increased the voltage of the battery, the motor spun faster. This has to do with the relationship between magnetism and*

electricity. A higher voltage produces more current, and a stronger current produces a stronger magnetic field.]

- Ask the class whether any teams had different results, and if so, what might explain the differences. Provide students from multiple teams with the opportunity to ask questions of one another as they work through any differences. Redirect if misconceptions arise.

2. Continue the dialogue with students, bringing together the different parts of the investigation. For example:

- Ask one student what all of the parts of the investigation provided evidence for. [*The investigation showed that there are different factors that affect how fast the motor coil spins, including the number of magnets used, the orientation of the interacting objects, and the distance between the interacting objects.*]
- Ask another student how this knowledge can be applied. [*Engineers use this knowledge when they build electric motors because they can affect the strength and speed of the motor by altering any one of these factors.*]

Name: ____ Date: ___________________

Electromagnetic Forces Investigation

Introduction: What factors affect how quickly an electric motor spins? Use your electric motor and the steps below to investigate the question.

A. How does the <u>number of magnets</u> interacting with the motor coil affect how fast the motor spins? Write a prediction for the question in the space below.

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Test your motor:

1. Connect your motor to the 9-volt battery.
2. Bring one ring magnet near the motor coil so the coil spins. If needed, give the coil a little spin to get it moving. Observe how quickly the motor coil starts spinning on its own and how fast it spins.
3. Repeat Step 2 for two more tests, first with 2 ring magnets and then 3 ring magnets.

Analyze the results

1. What did you observe about the speed of the motor coil when you tested the system with different numbers of magnets?

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2. Explain how your observations support or do not support your prediction. Use evidence from the investigation to support your argument.

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B. How does the <u>orientation of the magnets</u> interacting with the motor coil affect how fast the motor spins? Write a prediction for the question in the space below.

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Test your motor:

1. Connect your motor to the 9-volt battery.
2. Bring the end of a three-magnet set near the motor coil. If needed, give the coil a little spin to get it moving. Observe how quickly the motor coil starts spinning on its own and how fast it spins.
3. Repeat Step 2, this time turning the magnet set so the sides of the magnets are near the motor coil.

Analyze the results

1. What did you observe about the speed of the motor coil when you tested the system with the magnets in a different orientation?

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2. Explain how your observations support or do not support your prediction. Use evidence from the investigation to support your argument.

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C. How does the <u>distance between the magnet and the coil</u> affect how fast the motor spins? Write a prediction for the question in the space below.

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Test your motor:

1. Connect your motor to the 9-volt battery.
2. Bring the end of a three-magnet set near the motor coil. If needed, give the coil a little spin to get it moving. Observe how quickly the motor coil starts spinning on its own and how fast it spins.
3. Observe how the speed of the coil is affected as you slowly move the magnet set away from the coil, and then slowly move it back toward the coil.

Analyze the results

1. What did you observe about the speed of the motor coil when the magnets interacted with the coil from different distances?

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2. Explain how your observations support or do not support your prediction. Use evidence from the investigation to support your argument.

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D. How does <u>increasing the voltage flowing through the motor</u> affect how fast the motor spins? Write a prediction for the question in the space below.

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Test your motor:

1. Connect your motor to one AA battery (1.5 volts) by touching the black and red alligator clip wire ends to the positive and negative ends of the battery.
2. Bring the end of a three-magnet set near the motor coil. If needed, give the coil a little spin to get it moving. Observe how quickly the motor coil starts spinning on its own, how consistently it spins, and how fast it spins.
3. Repeat Steps 1-2 with a 9-volt battery.

Analyze the results

1. What did you observe about the speed of the motor coil when batteries with different voltages were used to power the motor?

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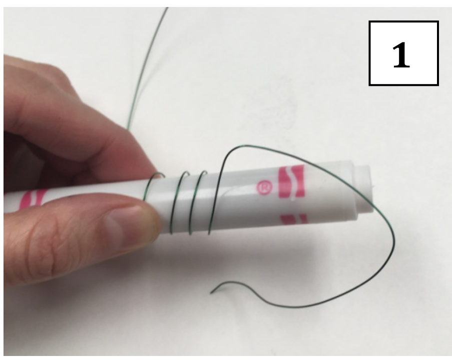
2. Explain how your observations support or do not support your prediction. Use evidence from the investigation to support your argument.

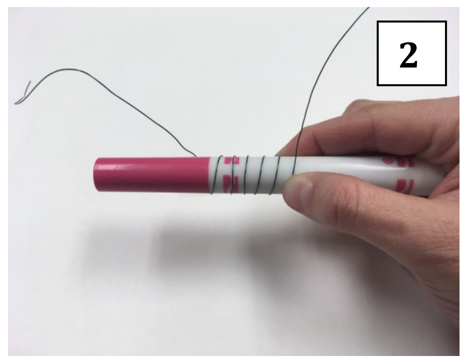
Student Electromagnet Motor Instructions

Use the materials and photos below to help you assemble your electromagnetic motor.

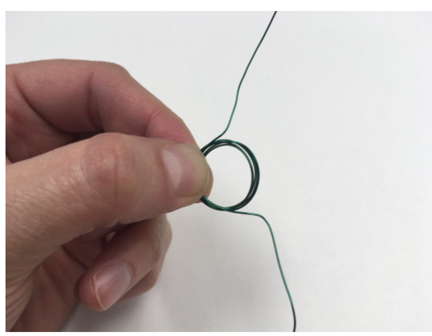
A. Create the electromagnetic coil with 45 centimeters of magnet wire and a marker:

1. Starting from the center of the magnet wire, wrap one side of the wire three complete times clockwise around the middle of a marker and then wrap the opposite side of the wire three complete times around the marker in the counterclockwise direction.



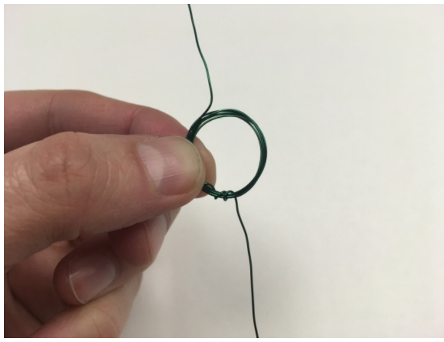
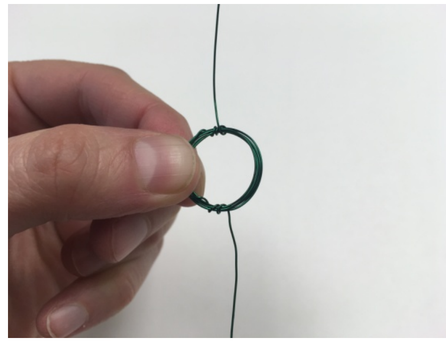


2. Push the coils together and carefully pull the coil off the marker, pinching the coils together to keep them together.

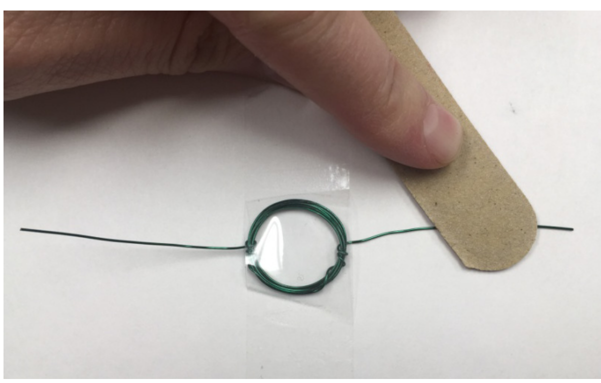
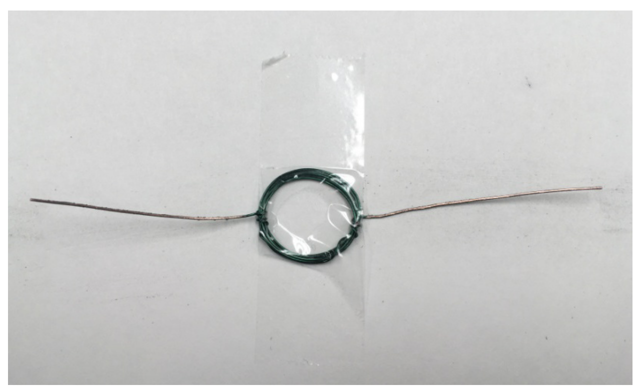


3. Wrap one of the tail ends of the magnet wire at least two times through and around the coil to keep the coil together and then wrap the other tail end of the magnet wire through and around the opposite side of the coil. Make sure the tail ends of the wire are equal distances from each other on opposite sides of the

coil. The tail ends of the wire should be pointed away from the coil in opposite directions.

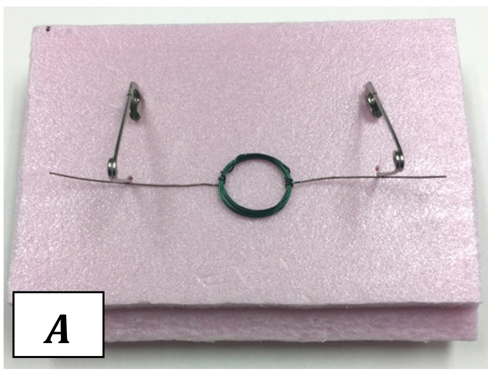
4. Strip the insulated coating off the tail ends of the coil using a file and invisible tape:
   - **A.** Cut the tail ends of the coil so they are 4 cm long.
   - **B.** Straighten the tail ends of the coil and then tape the coil to a desk or table
   - **C.** Use a file or a scissor blade to strip the insulated coating from the top half of each wire. You will know the insulated coating is removed when you see the copper color of the wire. You do not need to remove the insulated coating off the bottom half of the wires.

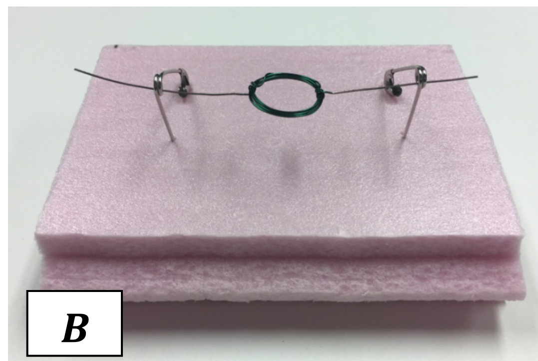
 

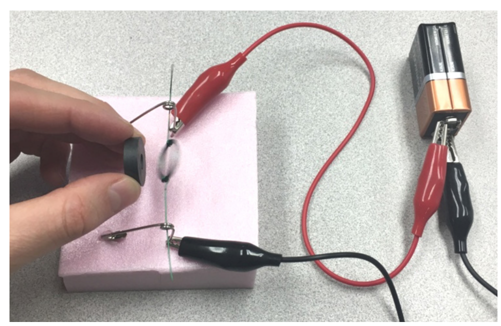
Photos show the coil taped to a desk with the insulated coating being removed (left) and after the insulation is removed from both wire ends (right).

B. Use two safety pins and one section of thick foam to create the **stand** for your electromagnet motor:

1. Lay the coil on the thick foam as a guide for the pins. The tail ends of the coil will go through the holes in the safety pins.
2. To figure out the best position for the motor stand, open the safety pins and stick the sharp side of each pin into the foam near the middle of the tail ends of the coil, as shown in Photo A. Keep the pins as level with each other as possible.
3. Put the tail ends of the coil through the holes in the pins so the coil hangs between the pins as shown in Photo B.







C. Test your electromagnetic motor using 1 battery, 1 magnet, 1 black alligator clip wire, and 1 red alligator clip wire.

1. Clip one alligator clip wire on each pin of the motor stand. Attach the free ends of the alligator clip wires to the positive and negative electrodes of the battery.
2. Hold the magnet near the coil and spin the coil a little to get it started. Spin it in each direction to see which direction works best. Adjust the distance of the magnet from the coil and spin the coil again if needed until the motor starts spinning.
3. The coil may get warm after a few minutes. Do not leave the motor running for longer than 1 minute at a time. Disconnect the wires from the battery to turn the motor off.

Lesson 3: Engineering Wind Turbines

Objective: Students design and build a vertical-axis wind turbine that generates a specific amount of electrical energy in low and high wind speeds.

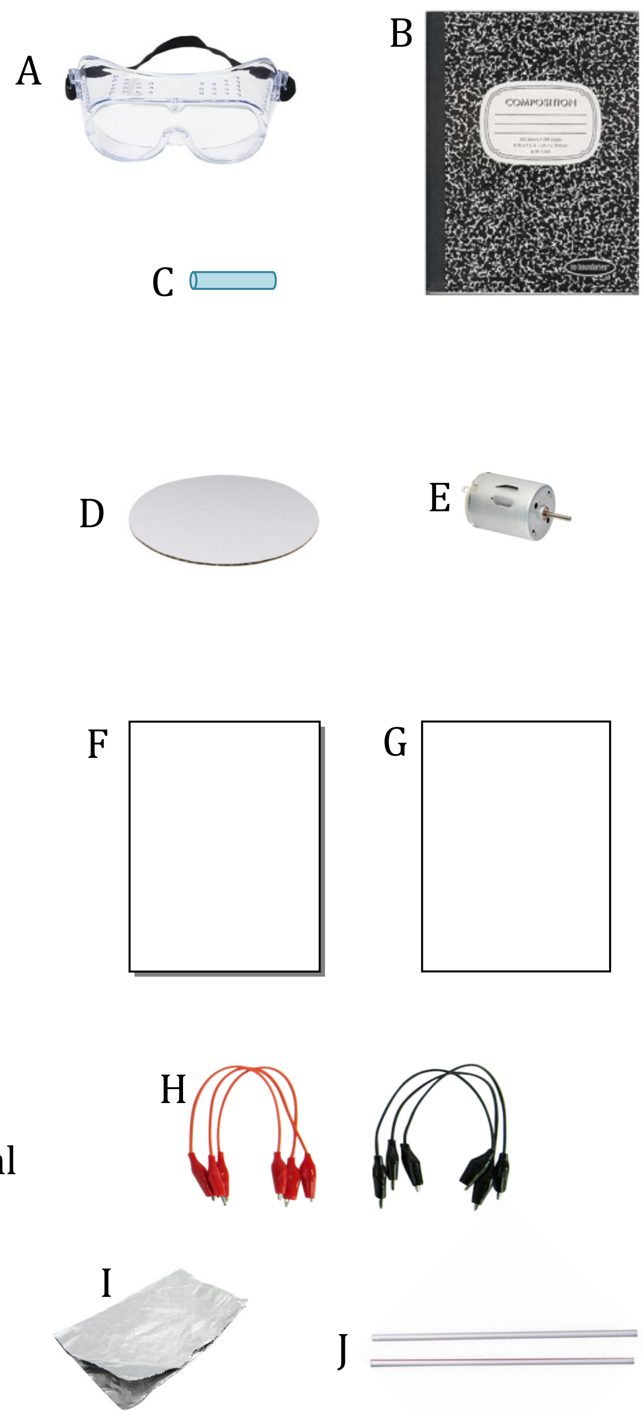
Materials:

Consumable

A. Goggles – 1 per student
B. Laboratory notebooks – 1 per student
C. Rubber connector tubes – 1 per team
D. Cardboard discs – 2 per team
E. Motors – 1 per team
F. Cardstock paper – 4 sheets per team
G. Copy paper – 4 sheets per team
H. Red/black alligator clip wires – 1 each per team*
I. Aluminum foil – 3 sheets per team
J. Straws – 5 per team

Non-Consumable

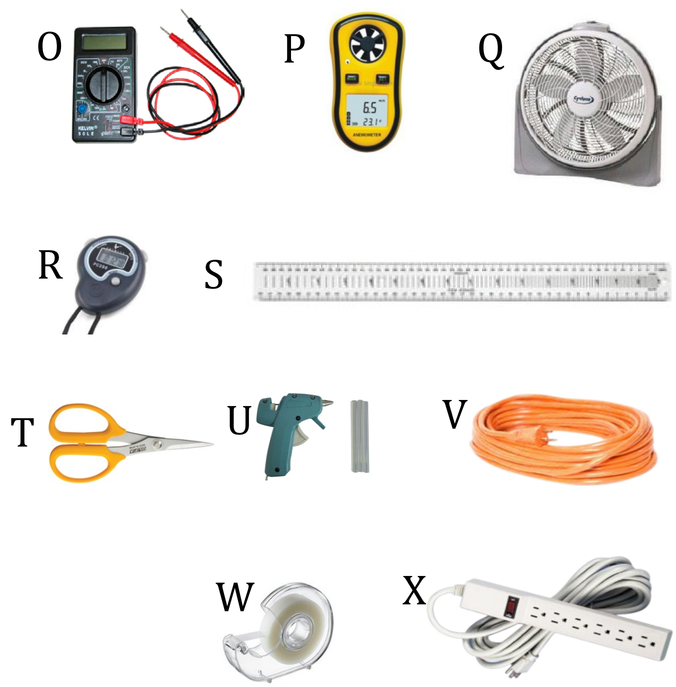
K. Engineering Scenario Visual – (not shown)
L. Motors and Generators Visual – (not shown)
M. Wind Energy Visual – (not shown)
N. Types of Turbines Visual – (not shown)



*These materials are reused from Lesson 2.

O. Multimeters – 1 per team
P. Anemometers – shared
Q. Fans – shared
R. Stopwatches – 1 per team

Teacher Tool Kit
S. Rulers – 1 per team
T. Scissors – 1 per student
U. Glue guns/glue
– shared
V. Extension cords
– teacher use\
W. Invisible tape – 1 per team
X. Power strips – teacher use



<u>Teacher Preparation</u>:

- Download the visuals from the KnowAtom Interactive website.
- To save time, prepare photocopies of the Blank Material Survey Chart, Facilitated Wind Turbine Base Set-Up Procedure, Facilitated Wind Turbine Test Procedure, and the Blank Data Table for each student using the copy masters on pages 106-107
- Set up one wind turbine base using the Facilitated Wind Turbine Base Set-Up Procedure. Teams will use the wind turbine base as a reference as they develop possible solutions and make their prototype diagrams. Teams will set up their own wind turbine bases in the lab.
- Arrange one or more <u>fan stations</u> using the extension cords and power strips for teams to take turns testing their prototype wind turbines. Place a stopwatch and anemometer at each fan station for teams to use for data collection.
- Arrange a <u>glue station</u> with hot glue guns and glue for teams to access during the building step of the lesson.

- Arrange several pick-up stations for students to collect materials during the lab. For example:
  - Pick-Up Station 1: straws, cardstock paper, copy paper, aluminum foil, and motors
  - Pick-Up Station 2: cardboard discs, rubber connector tubes, rulers, scissors, and invisible tape
  - Pick-Up Station 3: red/black alligator clip wires and multimeters

Student Reading Preparation:

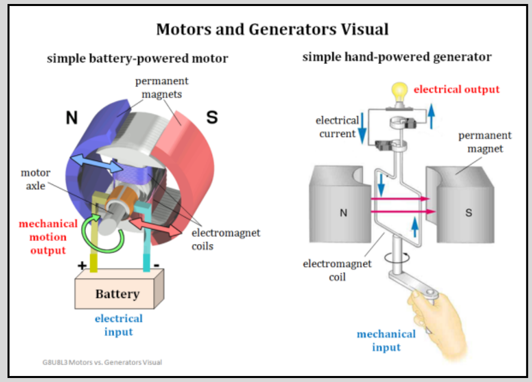
- Students read Section 3 of the student lab manual. In 8th grade, students are expected to come to class having already read the lab manual so they can actively participate in the Socratic dialogue before the lab portion of the lesson. At the beginning of the school year (September-October), the lab manual can be read in class.
- If class time is used to read the lab manual together, model how to read closely for understanding. For example:
  - Emphasize connections between examples in the reading and broader concepts. For example, ask why a certain example was used to support the reading's main point.
  - Use "why" and "how" questions to connect ideas in the reading to student experiences.

Socratic Dialogue:

Block 3: Engineering Wind Turbines

1. Display *Motors and Generators Visual*. Begin a dialogue with students about the similarities and differences between motors and generators.

- ☐ **<u>Big Idea 7</u>:** Coach students toward the idea that electric motors and generators are important in technologies that produce the electricity our society depends on. A **generator** is a machine that converts an input of mechanical energy into an output of electrical energy. For example:



  - *Ask one student to describe the inputs and outputs of energy in an electric motor. (In a motor, the energy input is electrical energy, which is carried by electric charge through a circuit. That electrical energy is converted to mechanical energy because the electric current produces a magnetic field, which magnetizes the electromagnet. This then causes the permanent magnet and the electromagnet to interact, exerting forces on each other that cause movement.)*
  - *Ask another student to describe the inputs and outputs of energy in a generator. (Generators have been called reverse motors because they have opposite inputs and outputs of energy. The input of energy is mechanical, while the output is electrical.)*
  - *Ask the first student how a generator is similar to a motor. (Both are machines that use the attractive and repelling forces between interacting magnets to convert energy from one form to another to do work.)*

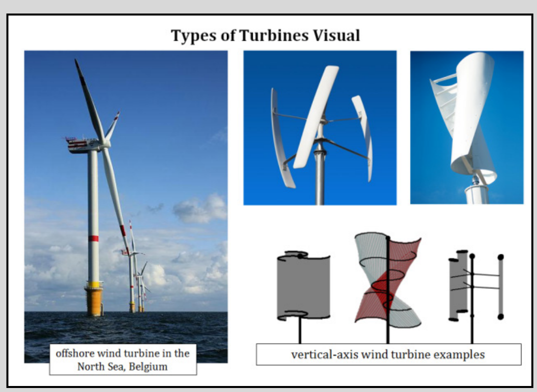
2. Display *<u>Wind Energy Visual</u>*. Continue the dialogue with students about generators, focusing on how **wind turbines** are devices that convert mechanical energy from the wind into electrical power.

- ☐ **<u>Big Idea 8</u>:** Coach students toward the idea that **wind** has energy because it is moving air molecules, and wind turbines are designed to capture this energy. For example:

- *Ask one student to explain why wind has mechanical energy. (Mechanical energy is the energy of an object or substance due to its motion. Wind has mechanical energy because it is moving air molecules.)*

- *Ask another student how the mechanical energy in wind is useful for people. (Wind turbines convert the wind's mechanical energy into electrical energy, which people use when they use electricity to power different appliances, lights, and technologies.)*
- *Ask the first student to describe how the mechanical energy of the wind is captured by a wind turbine. (As wind blows, it pushes on a wind turbine's blades. This pushing force transfers the mechanical energy in the wind to the blades, causing the blades to turn.)*
- *Ask another student how the turning blades can cause mechanical energy to convert into electrical energy. (The blades are connected to a drive shaft, which is a long bar of steel that can rotate. As the blades move, they rotate the drive shaft. That drive shaft is connected to a generator, which converts the mechanical energy into electrical energy.)*

3. Display <u>*Types of Turbines Visual*</u>. Have a dialogue with students about how there are two basic designs of wind turbines: vertical-axis turbines and horizontal-axis turbines.



- ☐ **<u>Big Idea 9</u>:** Coach students toward the idea that engineers are always looking for ways to design technologies that transform energy as efficiently as possible because they want to generate more work while using less energy. For example:

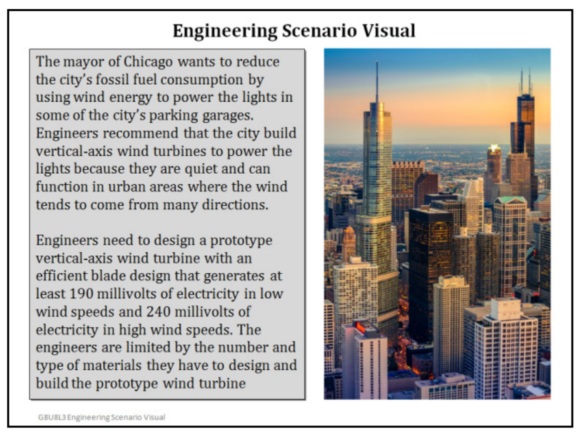
- *Ask one student why energy efficiency is important in wind turbines. (In any energy system where energy is being converted from one form to another, not all of the energy is converted to a form that can do work. Some is usually transformed into non-usable forms of energy. The less efficient a wind turbine is, the less electrical energy it generates because it means that a lot of the energy is being transformed into non-usable forms of energy.)*
- *Ask another student to respond to the previous student's response, asking questions for clarification, adding supporting details, or respectfully contradicting parts of it. Provide the first student with the chance to respond so that both students are evaluating and analyzing each other's responses.*

- **Big Idea 10:** Coach students toward the idea that engineers need to think about a variety of factors, including location and energy efficiency, when designing wind turbines. For example:
  - *Ask one student which kind of wind turbine they are most familiar with. (Answers may vary depending on your location, although horizontal-axis turbines are much more common because they are generally more efficient at converting the wind's mechanical energy into electricity. They look like massive airplane propellers on a pole.)*
  - *Ask another student why horizontal-axis turbines aren't always the best choice for a design. (They work most efficiently when the wind flows at a right angle to the blades. This means that the main rotating shaft and electrical generator must point into the wind. They are also very tall, with long blades. This makes them best suited for open spaces, such as fields, that have a lot of wind.)*

- *Ask the first student why vertical-axis turbines are more common in urban areas. (They don't need to be pointed directly into the wind and will function similarly regardless of wind direction. This makes them a better option for many urban areas where tall buildings make wind flow more unpredictable.)*

Engineering : Lab 11 – Wind Turbines

SAFETY: Students should wear goggles during this lab. Review multimeter safety and handling with the class. All students should be familiar with the safety guidelines outlined in the Multimeter User Guide in their lab manuals.



1. Display the *Engineering Scenario Visual*. Read and discuss the engineering scenario with the class. The visual can also be printed for each student from the KnowAtom Interactive if needed. "The mayor of Chicago wants to reduce the city's fossil fuel consumption by using wind energy to power the lights in some of the city's parking garages. Engineers recommend that the city build vertical-axis wind turbines to power the lights because they are quiet and can function in urban areas where the wind tends to come from many directions. Engineers need to design a prototype vertical-axis wind turbine with an efficient blade design that generates at least 190 millivolts of electricity in low wind speeds and 240 millivolts of electricity in high wind speeds. The engineers are limited by the number and type of materials they have to design and build the prototype wind turbine."

Problem
Divide students into teams of two. Students collect their lab notebooks to begin a new lab entry. Students summarize the problem presented in the engineering scenario in their lab notebooks, based on what they learned from the scenario. As part of their summary of the problem, students define the criteria (the needs or requirements the solution must meet) and constraints (ways the solution is limited) in their own words. It's important for students to be able to identify this information from the scenario so they know what their prototype needs to accomplish and the limitations they need to consider. You may need to point out that the available materials for the engineering challenge are a constraint. For example:

- **Problem**:
  - *The city of Chicago needs to reduce its fossil fuel consumption by using vertical-axis wind turbines to power the lights in the city's parking garages.*
- **Criteria**
  - *The prototype wind turbines need to generate at least 190 millivolts of electricity in low wind speeds and 240 millivolts of electricity in high wind speeds.*

  Constraints
  - *The type and quantity of materials available to build the prototype are limited.*

When teams are finished recording the problem, including its criteria and constraints, have students briefly share what they recorded with the class to clear up any misunderstandings related to the specific criteria and constraints they identified in the scenario. Students then move on to create a new title for the engineering lab that is relevant to the problem. In this example, relevant titles are "Wind Turbines" or "Vertical-Axis Wind Turbines," but other titles can be used as well.

NOTE: When students are finished summarizing the problem, display the *Engineering Process Visual* in place of the *Engineering Scenario Visual* to help guide them through the lab process. The *Who is an Engineer* poster can also be used as a guide.

Research

For research, students use information from their lab manuals and/or discussion to list up to three facts relevant to the problem. For example:

- *As the wind blows, it pushes on a wind turbine's blades, transferring mechanical energy to the blades, which causes the blades to turn.*
- *A wind turbine's blades are most efficient when the majority of the wind's mechanical energy is able to be converted into electrical energy*.
- *In a vertical-axis wind turbine, the main drive shaft is perpendicular to the ground. In a horizontal-axis wind turbine, the main drive shaft is parallel to the ground so the main rotating shaft and electrical generator point into the wind.*

Survey Available Materials

As a class, survey the available materials. Stand by the pick-up stations and explain that teams will have access to the following for building their prototypes:

- 5 straws
- 4 sheets of cardstock paper
- 4 sheets of copy paper
- 3 sheets of aluminum foil
- 1 motor

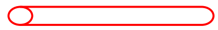
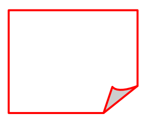
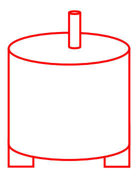
Teams will also have access to the following tools and testing materials for assembling and testing their prototypes. These items are not included in the materials survey chart:

Testing Materials and Tools:

- 2 cardboard discs
- 2 scissors
- 1 rubber connector tube
- 1 ruler
- 1 roll of invisible tape
- 1 fan (shared at fan stations)
- 1 anemometer (shared at fan stations)
- 1 stopwatch (shared at fan stations)
- 1 multimeter
- 1 black and 1 red alligator clip wire
- glue gun/glue (shared at glue stations)

Students collect prototype materials (or a sample of each prototype material) from the pick-up stations according to the materials listed on their materials survey chart. Tools and testing materials are not included in the survey chart. Photocopy and distribute blank survey charts to save time. The name and quantity of each material are pre-filled in the survey chart. Students record:

- sketch of each material
- description of what each material is made from
- 1-2 useful physical properties of each material given the context of the problem (e.g., shape, thickness, flexibility, relative weight, or any other relevant property you notice)

Materials Survey Chart				
Name	**Quantity**	**Sketch**	**Made From**	**Properties**
straws	5		plastic	long and flexible
cardstock	4		paper	thick and flexible
paper	4		paper	thin and flexible
aluminum foil	3		aluminum	thin and flexible
motor	1		magnets, metal, electromagnets	produces mechanical motion with electrical input; produces electrical current with mechanical input

NOTE: Tools and testing materials are not included in the materials survey chart.

<u>Checkpoint #1</u>: After Problem, Research, and Materials Survey
As teams are ready, they should check in with the teacher to review their problem, research, and materials survey. Do the lab notebooks of both team members match and meet expectations? Can both students within the team describe the criteria and constraints of the problem? Are the research questions relevant to the problem? Are the properties of the materials included in the survey chart? If not, ask for areas of clarification or correction before they advance further. Not all teams will arrive at the lab check-points at the same time, so teams independently receive the go-ahead to move on in their lab after they have made the necessary modifications. <u>Student lab notebook entries within the class will have the same problem, but variations from team to team in the remaining steps of the process are expected and encouraged</u>.

Possible solutions
Teams use what they know about the criteria and constraints of the problem, as well as their research, to list at least three possible solutions to the problem, given the available materials. Teams identify three different ways an engineer could design an efficient vertical-axis wind turbine that generates at least 190 millivolts of electricity in low wind speeds and 240 millivolts of electricity in high wind speeds. Briefly show the class one wind turbine base set up by the teacher to help them visualize how large their wind turbines need to be and how the spinning base will generate electricity. Teams will build their prototypes on top of the wind turbine base and attach their multimeters to the motor electrodes to collect voltage data as the base spins. Each team will receive a copy of the facilitated Wind Turbine Base Set-Up Procedure as a guide for setting up their wind turbine base after they develop their prototype diagrams.

Variation in teams' possible solutions is expected and encouraged. The following are three possible solutions with varying levels of detail that your students may come up with:

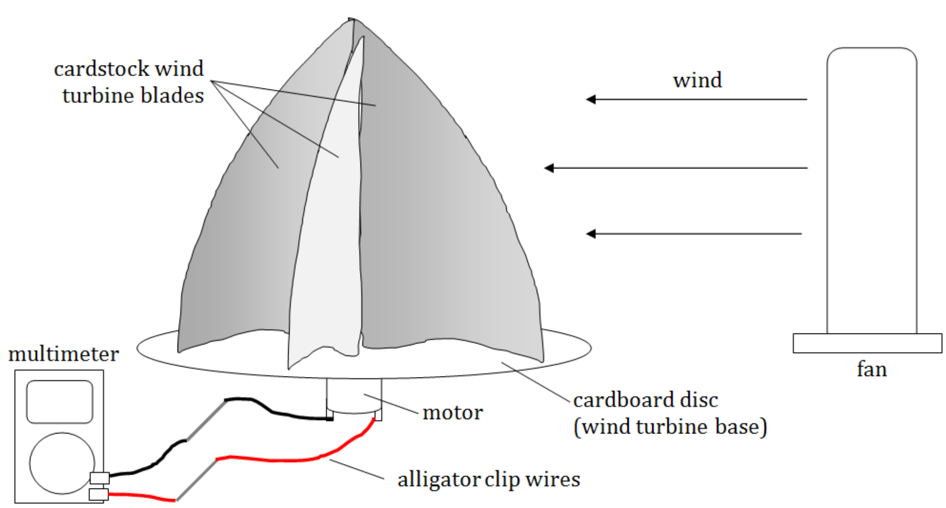
- Design a six-blade vertical-axis wind turbine to capture the most mechanical energy from the wind.
- Design a vertical-axis wind turbine with three tall narrow blades to minimize the mass of the turbine.
- Design a vertical-axis wind turbine with three blades made from lightweight materials.

<u>Checkpoint #2</u>: After Possible Solutions
As teams are ready, they should check in with the teacher to review the possible solutions for the problem. Do the lab notebooks of each team member match and meet expectations? Can students explain their reasoning for the possible solution they chose given the available materials? If not, ask for areas of clarification or correction before they advance further.

Diagram and build prototype

Students draw a scientific diagram of their prototype wind turbine. All diagrams should be titled and include labels of materials used. Students follow their prototype diagram when building.

Prototype Wind Turbine 1 Diagram



NOTE: Students can reserve an extra page in their lab notebooks for the prototype diagrams. Additional space will be needed as students modify or redraw the diagrams to incorporate improvements for each prototype. It may be helpful to remind teams that they do not have to use every available material, only the materials they think could be used to best solve the problem.

<u>Checkpoint #3</u>: After Diagram (Before Materials Are Collected to Build)
As teams are ready, they should check in with the teacher to review their prototype diagram before accessing materials to build. Are the diagrams complete? Diagrams should be titled and materials labeled. Can you understand the diagram? Could you follow it to build the prototype? If not, clarify expectations. Students make corrections or any modifications and return to the checkpoint for the go-ahead. After meeting this checkpoint, students collect the materials they need and then build their prototype based on their diagram.

Test
Teams test their prototypes when complete. The Wind Turbine Base Set-Up Procedure and Test Procedure in this engineering lab are facilitated. Photocopy and distribute the facilitated procedures for each student to add to their lab notebooks under "test." Briefly review the procedures, including safety precautions, with teams as needed.

Wind Turbine Base Set-Up Procedure (facilitated)

1. Punch a small hole in the center of the cardboard disc with a pencil.
2. Push the connector tubing onto the motor axle. Push the motor axle with connector up through the hole in the cardboard circle

and hot glue it in place. Make sure the cardboard disc is as level as possible. Let the glue dry.
3. Attach wind turbine prototype blades to the cardboard disc as desired.


Wind Turbine Test Procedure (facilitated)
1. Record the wind speed of the fan on its lowest and highest setting from 30 centimeters away from the fan blades.
2. Connect the red and black alligator clip wires to separate motor electrodes. Connect the free ends of the wires to the corresponding positive and negative probes of the multimeter.
3. Turn the multimeter to DCV 2000m (millivolts). Position the wind turbine 30 centimeters in front of the fan on its lowest setting and record the highest voltage generated over 10 seconds.
4. Repeat Step 3 with the fan on its highest setting.

<u>Checkpoint #4</u>: After Test Procedure
As teams are ready, they should check in with the teacher to review the prototype set-up and test procedure. Does each team understand the facilitated procedures? If not, clarify expectations. Students pick up blank data tables to tape inside their notebooks at this checkpoint.

NOTE: The cardboard discs can be reused multiple times by peeling off the wind turbine blades taped in place. If the motor axle becomes detached from the cardboard circle, students can re-glue them as needed.

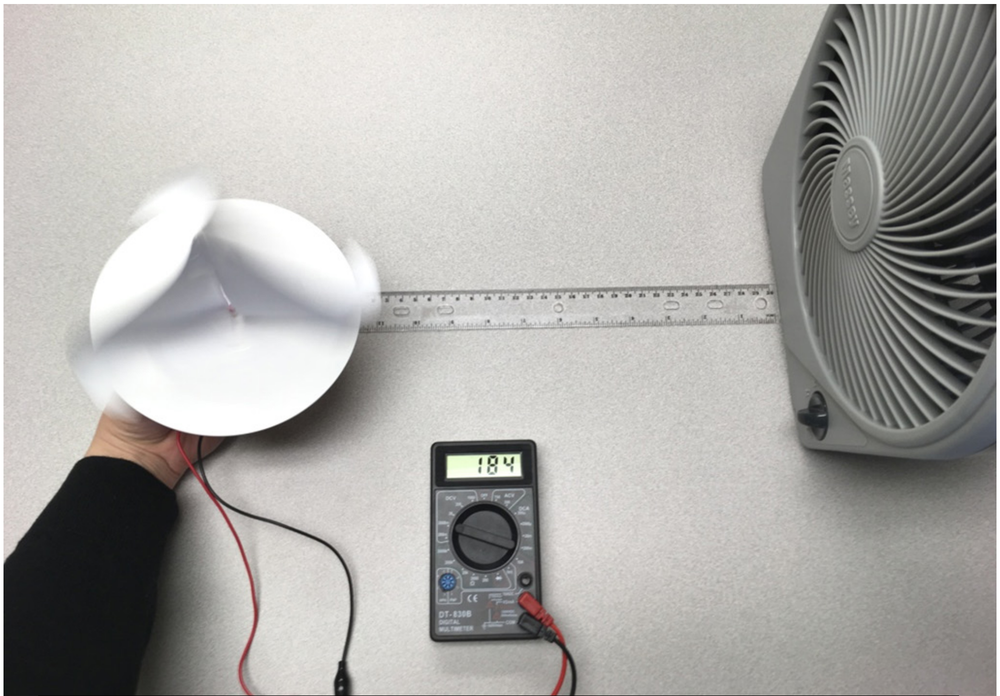


photo shows a prototype wind turbine being tested

Data

Teams record data for each prototype they design. Copy and distribute blank data tables to save time.

Table 1: Comparing Prototype Wind Turbine Electrical Output in Low and High Speed Winds				
	Low Wind Speed Test		**High Wind Speed Test**	
	wind speed (m/s)	voltage (mV)	wind speed (m/s)	voltage (mV)
Prototype 1	4.7	170	6.0	225
Prototype 2	4.7	185	6.0	235
Prototype 3	4.7	195	6.0	250

NOTE: Example data represent possible results. Individual team data will vary based on wind turbine design.

Refine or Replicate

Teams use the data and observations from their first prototype wind turbine to design Prototypes 2-3 with modifications and improvements to better meet the criteria of the problem, given the constraints. Teams can test and record results for up to three different prototypes. Teams can collaborate with other teams to share ideas if needed and revise their first prototype diagram to make the necessary changes. Teams use their new diagram as a guide for building their second prototype and repeat this process with their third prototype.

When the prototype testing is complete, students should be prepared to explain how well their prototype solution solved the problem, given the criteria and constraints. This should include how their modifications positively or negatively affected their prototype's ability to generate as much electricity as possible in both low- and high-speed winds. This should be supported with data (evidence) from their data table.

If students have trouble evaluating their data to determine whether or not they would refine or replicate any of their prototype solutions, students can use a decision matrix to help them analyze their data. A decision matrix can be useful for making a choice when many factors are involved. For example:

Wind Turbine Decision Matrix		
	Electrical Output (Voltage) in Low Wind Speed (mV)	Electrical Output (Voltage) in High Wind Speed (mV)
Prototype 1	170	225
Prototype 2	185	235
Prototype 3	195	250

The information should then be used to explain if students would refine or replicate any of their prototype solutions based on the data.

For example: “Our team successfully engineered a prototype vertical-axis wind turbine that generates at least 190 millivolts of electricity in low wind speeds and 240 millivolts of electricity in high wind speeds. Our first prototype had three blades made from cardstock paper. This prototype generated 170 millivolts of electricity in low wind speeds and 225 millivolts of electricity in high wind speeds. We noticed that our turbine had low electrical output because it was unbalanced and did not spin consistently. To fix this problem, we designed our second prototype with two turbine blades made from thin paper to reduce the mass of the turbine to make it easier to spin. We were careful to position the turbine blades at equal distances from each other to keep the turbine balanced. This prototype generated 185 millivolts of electricity in low wind speeds and 235 millivolts of electricity in high wind speeds. To increase the electrical output in our third prototype, we added one more turbine blade for a total of three blades. We used the same materials to make the additional blade to be sure the turbine remained balanced. This prototype generated 195 millivolts of electricity in low wind speeds and 250 millivolts of electricity in high wind speeds. Based on our test data and prototype designs, we would recommend that our third prototype be replicated for the city of Chicago to use for its parking garages because it met the criteria given the constraints of the problem.”

<u>Final Checkpoint</u>: After Data and Refine or Replicate
As teams are ready, they should check in with the teacher to review the data and refine or replicate steps of their lab. One team member reads the team's refine or replicate conclusion aloud to you while you review the other team member's lab notebook. Do they restate the problem and describe the prototype technology? Did they make a claim about whether the technology should be refined or replicated? Look for key data points that students gathered from their test data to support their recommendation to refine or replicate. Is it clear? Is it persuasive? Do the data support the claim?

<u>Wrap-Up</u>:

1. Have a dialogue with students to review their engineering prototype results. For example:

- Ask a student from one team to present their prototype and conclusion to the class, describing how well their prototype met the criteria of the problem within the constraints. If students encountered any challenges, they should describe those challenges and how they addressed them.
- Ask the same student what factors influenced how much electricity their prototype could generate. [*Answers will vary depending on each team's design and modifications. The ability of the blades to spin smoothly is an important part of this, and has to do with whether the blades are balanced on the rotor. Or students may have noticed that bigger blades generate more electricity but have more mass, and so they require more force to spin. This could make it challenging in low wind speeds. The shape of the blade also impacts how well the turbine can rotate.*]
- One at a time, ask multiple teams to describe their prototype and conclusion to the class, communicating about the challenges their designs posed and how they addressed those challenges.

Unit 8 Lesson 3: Lab Notebook Example

This complete lab notebook entry is intended to be used as an exemplar for teacher use only. It is not intended for student use.

Page

Wind Turbines, Date, Partner Name

Lab #11: Wind Turbines

Problem: The city of Chicago needs to reduce its fossil fuel consumption by using vertical-axis wind turbines to power the lights in some of the city's parking garages.

- Criteria: The prototype wind turbines need to generate at least 190 millivolts of electricity in low wind speeds and 240 millivolts of electricity in high wind speeds.
- Constraints: The type and quantity of materials available to build the prototype are limited.

Research: As the wind blows, it pushes on a wind turbine's blades, transferring mechanical energy to the blades, which causes the blades to turn. A wind turbine's blades are most efficient when the majority of the wind's mechanical energy is able to be converted into electrical energy. In a vertical-axis wind turbine, the main drive shaft is perpendicular to the ground. In a horizontal-axis wind turbine, the main drive shaft is parallel to the ground so the main rotating shaft and electrical generator point into the wind.

Survey Available Materials:

Materials Survey Chart				
Name	**Quantity**	**Sketch**	**Made From**	**Properties**
straws	5		plastic	long and flexible
cardstock	4		paper	thick and flexible
paper	4		paper	thin and flexible
aluminum foil	3		aluminum	thin and flexible
motor	1		magnets, metal, electromagnets	produces mechanical motion with electrical input; produces electrical current with mechanical input

<u>Unit 8 Lesson 3</u>: Lab Notebook Example

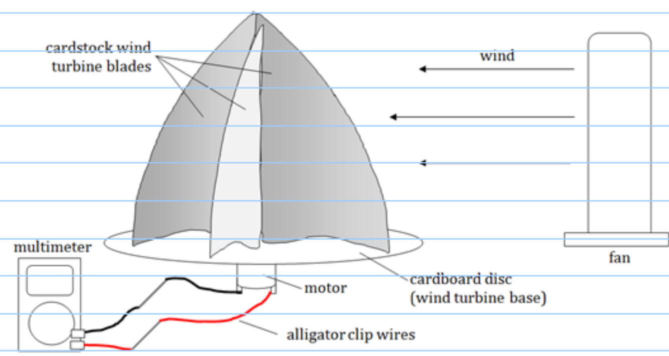
This complete lab notebook entry is intended to be used as an exemplar for teacher use only. It is not intended for student use.

<u>Possible Solutions</u> :

- Design a six-blade vertical-axis wind turbine to capture the most mechanical energy from the wind.
- Design a vertical-axis wind turbine with three tall narrow blades to minimize the mass of the turbine.
- Design a vertical-axis wind turbine with three blades from light-weight materials.

<u>Diagram and Build Prototype</u>:

Prototype Wind Turbine 1 Diagram



<u>Set-Up and Test Procedure</u>:

Wind Turbine Base Set-Up Procedure (facilitated)

1. Punch a small hole in the center of the cardboard disc with a pencil.
2. Push the connector tubing onto the motor axle. Push the motor axle with connector up through the hole in the cardboard circle and hot glue it in place. Make sure the cardboard disc is as level as possible. Let the glue dry.
3. Attach wind turbine prototype blades to the cardboard disc as desired.


Wind Turbine Test Procedure (facilitated)

1. Record the wind speed of the fan on its lowest and highest setting from 30 centimeters away from the fan blades.
2. Connect the red and black alligator clip wires to separate motor electrodes. Connect the free ends of the wires to the corresponding positive and negative probes of the multimeter.
3. Turn the multimeter to DCV 2000m (millivolts). Position the wind turbine 30 centimeters in front of the fan on its lowest setting and record the highest voltage generated over 10 seconds.
4. Repeat Step 3 with the fan on its highest setting.

Unit 8 Lesson 3: Lab Notebook Example

This complete lab notebook entry is intended to be used as an exemplar for teacher use only. It is not intended for student use.

Data:

Table 1: Comparing Prototype Wind Turbine Electrical Output in Low and High Speed Winds				
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Refine or Replicate: Our team successfully engineered a prototype vertical-axis wind turbine that generates at least 190 millivolts of electricity in low wind speeds and 240 millivolts of electricity in high wind speeds. Our first prototype had three blades made from cardstock paper. This prototype generated 170 millivolts of electricity in low wind speeds and 225 millivolts of electricity in high wind speeds. We noticed that our turbine had low electrical output because it was unbalanced and did not spin consistently. To fix this problem, we designed our second prototype with two turbine blades made from thin paper to reduce the mass of the turbine to make it easier to spin. We were careful to position the turbine blades equal distances from each other to keep the turbine balanced. This prototype generated 185 millivolts of electricity in low wind speeds and 235 millivolts of electricity in high wind speeds. To increase the electrical output in our third prototype, we added one more turbine blade for a total of three blades. We used the same materials to make the additional blade to be sure the turbine stayed balanced. This prototype generated 195 millivolts of electricity in low wind speeds and 250 millivolts of electricity in high wind speeds. Based on our test data and prototype designs, we would recommend that our third prototype be replicated for the city of Chicago to use for its parking garages because it met the criteria given the constraints of the problem.

<u>Unit 8 Lesson 3</u>: Blank Survey Chart

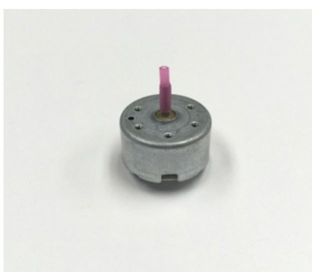
Materials Survey Chart				
Name	**Quantity**	**Sketch**	**Made From**	**Properties**
straws	5			
cardstock	4			
paper	4			
aluminum foil	3			
motor	1			

<u>Unit 8 Lesson 3</u>:

Facilitated Set-Up and Test Procedures

Wind Turbine Base Set-Up Procedure (facilitated)

1. Punch a small hole in the center of the cardboard disc with a pencil.
2. Push the connector tubing onto the motor axle. Push the motor axle with connector up through the hole in the cardboard circle and hot glue it in place. Make sure the cardboard disc is as level as possible. Let the glue dry.
3. Attach wind turbine prototype blades to the cardboard disc as desired.



Wind Turbine Test Procedure (facilitated)

1. Record the wind speed of the fan on its lowest and highest setting from 30 centimeters away from the fan blades.
2. Connect the red and black alligator clip wires to separate motor electrodes. Connect the free ends of the wires to the corresponding positive and negative probes of the multimeter.
3. Turn the multimeter to DCV 2000m (millivolts). Position the wind turbine 30 centimeters in front of the fan on its lowest setting and record the highest voltage generated over 10 seconds.
4. Repeat Step 3 with the fan on its highest setting.

Unit 8 Lesson 3:
Blank Data Table

Table 1: Comparing Prototype Wind Turbine Electrical Output in Low and High Speed Winds				
	Low Wind Speed Test		**High Wind Speed Test**	
	wind speed (m/s)	voltage (mV)	wind speed (m/s)	voltage (mV)
Prototype 1				
Prototype 2				
Prototype 3				

Name: ______________________________________ Date: ______________

Unit 8: Transforming Energy

Vocabulary Check

Part I: Circle the best answer for questions 1-5 below.

1. The area around a charged particle that attracts or repels other charged particles is called a(n) _________________________________.

A. electric insulator B. magnetic field

C. electric conductor D. electric field

2. A machine that converts an input of mechanical energy into an output of electrical energy is called a(n)_________________________.

A. motor B. generator

C. electromagnet D. permanent magnet

3. _______________________ is a measure of the rate that an electric charge passes through a point in an electric circuit over time.

A. Attraction B. Electric current

C. Repulsion D. Electric insulation

4. A(n) _______________________ is a tightly wound coil of wire that produces a magnetic field when electricity passes through the wire.

A. motor B. generator

C. electromagnet D. permanent magnet

5. A device that converts mechanical energy from the wind into electrical power is called a(n) _______________________.

A. motor B. generator

C. electromagnet D. wind turbine

Part II: Write the answers to questions 6-8 below.

6. Why are **generators** called reverse **motors**?

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____

____

____

7. How can **magnets** exert forces on other magnets without coming into contact with them?

____

____

____

____

8. Why do **electromagnets** form a **circuit**?

____

____

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____

Name: ______________________________ Date: ____________

Unit 8: Transforming Energy

Concept Check

Part I: Circle the best answer to each question.

1. Which of the following is evidence that Earth's outer core is magnetic?

A. A ball thrown up into the air will always fall back to the ground.
B. Electricity will always move through a circuit when it is closed.
C. A compass needle always aligns to Earth's magnetic poles.
D. all of the above

2. Amelia has a problem. She has created an electric motor that uses an electromagnet and a permanent magnet, but the motor is too weak. She needs a stronger electromagnet. What is one way that she can increase the strength of the electromagnet for her motor?

A. decrease the number of coils the electromagnet has
B. increase the voltage to increase the amount of current that flows through the wire
C. decrease the voltage to decrease the amount of current that flows through the wire
D. all of the above

3. Marquith has two magnets. He orients them so they are attracted to each other. What happens to the strength of the attraction between the two magnets when Marquith pulls the magnets far apart?

A. There is no way to know how the strength of attraction will change without testing it.
B. The strength of attraction increases when the magnets are pulled far apart.
C. The strength of attraction doesn't change when the magnets are pulled far apart.
D. The strength of attraction decreases when the magnets are pulled far apart.

Part II: Use the space below each question for your answer.

4. José has two permanent magnets. He moves one magnet across the top of a wood table by moving another magnet under the table. Why is he able to move the magnet on top of the table without touching it?

____

____

____

____

____

____

____

5. When you make an electromagnet, what causes it to be magnetic? Explain why this is so.

____

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6. Kathryn hears that companies in the aluminum industry pay people money for bringing in aluminum cans. She wants to earn some extra money, so she decides to collect aluminum cans. However, she has a problem. Her family has a large bin where they put all of their cans, including those made out of aluminum and those made out of iron.

Kathryn needs to design a simple technology that she can use to separate out the aluminum and iron cans. First, Kathryn does some research. She discovers that aluminum cans are not magnetic, while iron cans are. Kathryn is interested in how major recycling organizations separate out aluminum cans from iron cans. She reads that many places use a giant electromagnet to do this.

6a. How would an electromagnet work to separate out aluminum cans from iron cans?

6b. How can Kathryn use this information to help her design a can-separating technology?

Unit 8: Appendix 1
Answer Keys

Vocabulary Check

Part I

1. D. electric field [The area around a charged particle that attracts or repels other charged particles is called an electric field. A magnetic field is the area around a magnet that attracts or repels other magnets or magnetic materials. An electrical insulator is a material that electrons cannot pass through easily. An electrical conductor is a material that electrons can easily pass through.]
2. B. generator [A machine that converts an input of mechanical energy into an output of electrical energy is called a generator. A generator has been called a reverse motor because motors are machines that convert an input of electrical energy into an output of mechanical energy. A permanent magnet is an object that stays magnetized without electricity. An electromagnet is a tightly wound coil of wire that produces a magnetic field when electricity passes through the wire.]
3. B. Electric current [Electric current is a measure of the rate that an electric charge passes through a point in an electric circuit over time. Attraction is a force that pulls two objects together. Repulsion is a force that pushes two objects apart. Both magnetic and electric fields exert attractive and repulsive forces. Magnetic fields exert these forces on other magnets or magnetic materials, while electric fields exert these forces on charged particles.]
4. C. electromagnet [An electromagnet is a tightly wound coil of wire that produces a magnetic field when electricity passes through the wire. A permanent magnet is an object that stays magnetized without electricity. A motor is a machine that converts an input of energy into an output of mechanical energy. A generator is a machine that transfers mechanical energy into electrical energy.]
5. D. wind turbine [A device that converts mechanical energy from the wind into electrical power is called a wind turbine. Wind turbines are built with generators, which are machines that transfer mechanical energy into electrical energy. An electromagnet is a tightly wound coil of wire that produces a magnetic field when electricity passes through the wire. A motor is a machine that converts an input of electrical energy into an output of mechanical energy.]

Part II

6. [Generators are called reverse motors because motors convert an input of electrical energy into an output of mechanical energy, while generators convert an input of mechanical energy into an output of electrical energy.]
7. [Magnets exert forces on other magnets without coming into contact with them because magnets produce magnetic fields, and any time another magnet or magnetic material enters into another magnet's magnetic field, it is either attracted to or repulsed by the other magnet.]
8. [Electromagnets form circuits because electromagnets only become magnetized when electricity passes through the wire. Circuits are the circular paths that electrons travel in a negative to positive direction.]

Concept Check

Part I

1. C. A compass needle always aligns to Earth's magnetic poles. [The fact that a compass needle always aligns to Earth's magnetic poles is evidence that Earth's outer core is magnetic. This is because the compass needle is interacting with Earth's magnetic field, causing it to spin so that it aligns to the magnetic cores. All magnets produce a magnetic field that interacts with other magnets or magnetic materials, either attracting or repelling them.]
2. B. increase the voltage to increase the amount of current that flows through the wire [One way that Amelia can increase the strength of her electromagnet is to increase the voltage to increase the amount of current that flows through the wire. This is because more current will produce a stronger magnetic field, which will make the motor's electromagnet stronger. Decreasing the number of coils the electromagnet has will decrease the strength of the magnetic field, as will decreasing the voltage and therefore the current. Both of these actions will result in a weaker, not a stronger, electromagnet.]
3. D. The strength of attraction decreases when the magnets are pulled far apart. [If Marquith has two magnets oriented so they are attracted to each other, that strength of attraction will decrease when the magnets are pulled far apart. This is because the strength of any magnetic field decreases with distance.]

Part II

4. [The answer should explain that magnets have a magnetic field, which allows them to attract or repel other magnets without coming into physical contact with the object. The magnetic fields of the magnets on top of and below the table are interacting even though they aren't touching, which is how José is able to move one magnet without touching it.]
5. [Electromagnets become magnetic when electricity passes through a tightly coiled wire. This is because electrical current produces a magnetic field. All of the negatively charged electrons in a conductor are moving in one direction, and that movement produces a magnetic field around the wire.]
6. This question presents students with a scenario about Kathryn, who is trying to figure out a way to separate aluminum cans from iron cans. It assesses how well students can apply what they know about magnetic forces to come up with a simple technology that can solve a problem.

6a. [An electromagnet works to separate out aluminum cans from iron cans because electromagnets produce a magnetic field when electricity passes through the tightly wound coil of wire. This magnetic field would exert a force on the iron cans because iron is a magnetic material that is affected by magnetic fields. It wouldn't have any impact on the aluminum cans because aluminum isn't magnetic. As a result, the iron cans would be separated from the aluminum cans.]

6b. [Kathryn can use this information about how recycling centers use electromagnets to design a can-separating technology because she can design her own electromagnet, or she could use a permanent magnet that is strong enough to attract the iron cans. This would leave her with the aluminum cans separate from the iron cans.]

Lab Manual Answer Key

Section 1 Review

MC1. D. both A and B [It is true that Earth's magnetic core has a north pole and a south pole and that it produces a magnetic field because all magnets have these characteristics. All magnets have a north pole and a south pole, and all magnets have a magnetic field. Not all magnetic fields have the same strength or size; that depends on the materials that make up an individual magnet. For example, Earth's magnetic field extends far into space, but it isn't very strong.]

MC2. C. Magnets produce attractive or repelling forces that act on other magnets and magnetic materials without coming into contact with them. [A magnet interacts with other magnets and magnetic materials by exerting a force on them when those magnets or magnetic materials are within the magnetic field of the first magnet. This force can be attractive (pulling toward) or repelling (pushing away from) depending on the orientation of the magnets—like poles repel and opposite poles attract. It isn't true that a magnetic field is the physical outer part of a magnet that covers the magnetic poles. It also isn't true that magnets produce attractive or repelling forces when they come into contact with magnets or magnetic materials. Because magnets have magnetic fields, they don't need to come into contact with one another to exert forces on each other.]

CT1. [One magnet can exert a force on another magnet without the two magnets coming into contact with one another because all magnets have a magnetic field, which is the area around a magnet that attracts or repels other magnets and magnetic materials such as iron.]

CT2. [If Ayana has a magnet and she wants to test different materials to determine whether they are magnetic, she could bring each material close to her magnet to observe whether the material and her magnet interact with one another. Magnets only exert a force on other magnets or magnetic materials, so if the material isn't affected at all by her magnet, that material isn't magnetic. If the material is either pulled toward or pushed away from her magnet, it is magnetic.]

CT3. [You would have to apply a force to two repelling magnets if you wanted to push them together because you would have to overcome the force that is pushing them apart. Your force has to be greater than the force of repulsion between the two magnets to push them together.]

CT4. [Forces can transfer energy into or out of an object or system. For example, if you pull apart two attracting magnets, you apply a force that transfers energy into the system. If a moving object rubs against the ground, the force of friction will transfer energy out of the system by turning the mechanical energy into heat.]

Section 2 Review

MC3. B. more coils in the conductive wire [More coils in the conductive wire of an electromagnet would increase the strength of an electromagnet because the fields produced in each turn of the coil add up to create a stronger magnetic field. An electromagnet isn't made with a permanent magnet. Instead it is made up of tightly wound coils of conductive wire that electric current can pass through because electric current produces a magnetic field. Finally, a battery with a lower voltage would decrease the strength of the electromagnet because a higher voltage produces a stronger electric current, which produces a stronger magnetic field.]

MC4. C. a battery with a lower voltage [A battery with a lower voltage would decrease the strength of an electromagnet because voltage is a measure of the difference in electric charge between two points. A high voltage pushes and pulls electrons with more force than a low voltage, and this produces a stronger magnetic field. More coils in the conductive wire would make the electromagnet stronger.]

CT5. [Electric charges are similar to magnets because both create a field around them that can exert forces on other objects. Electric charges produce an electric field that acts on other charged particles, either attracting or repelling them, while magnets produce a magnetic field that acts on other magnets or magnetic materials, either attracting or repelling them. They are different because electric charge is caused by an imbalance of protons or electrons, while magnets are objects that have a north pole and a south pole.]

CT6. [Electromagnets combine electricity and magnetism because they produce a magnetic field when electricity passes through the wire.]

CT7. [An electric current produces a magnetic field because electrons flowing through a wire produce a magnetic field. Because electromagnets are tightly wound coils of wire that produce a magnetic field when electricity passes through the wire, it is likely that a stronger electric current will result in a stronger magnetic field.]

CT8. [Electric motors are designed with both an electromagnet and a permanent magnet. It is the interactions between the two magnets that cause energy to convert from electrical energy to mechanical energy to spin the motor. The attracting and repelling forces between the magnets cause the electromagnet to rotate, generating mechanical energy. Without a permanent magnet, the electromagnet wouldn't have anything to interact with or exert a force on, so the motor wouldn't spin.]

Section 3 Review

MC5. A. efficiency [Energy efficiency refers to the amount of energy a system requires to accomplish a task compared to other systems that accomplish the same task. An electric motor that transforms most of its energy into useful mechanical energy and wastes only a small amount as heat is very efficient.]

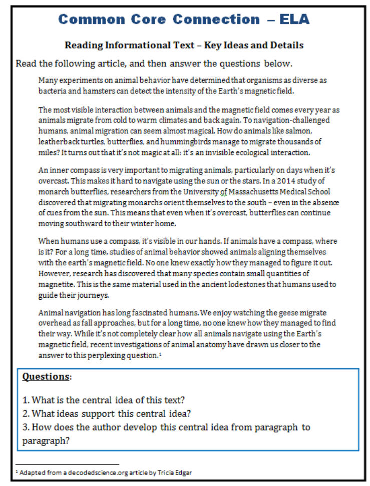
CT9. [As wind blows, it pushes on a wind turbine's blades. This pushing force transfers the mechanical energy in the wind to the blades, causing the blades to turn.]

CT10. [Wind turbines use generators because generators convert mechanical energy into electrical energy. Wind turbines convert the mechanical energy from the wind into electrical energy.]

CT11. [Generators are made with a permanent magnet and an electromagnet. These magnets exert attractive and repelling forces on each other, and it is these forces that cause the mechanical energy to convert to electrical energy.]

Unit 8: Appendix 2
Common Core Connections

KnowAtom units generally cover many Common Core ELA standards for reading informational texts and math standards in hands-on activities. The lab manual is designed to further connect science content to other disciplines with assignments that can be used as homework or in-class. This lab manual highlights one ELA standard:



Common Core Connection – ELA

Reading Informational Text – Key Ideas and Details

Read the following article, and then answer the questions below.

Many experiments on animal behavior have determined that organisms as diverse as bacteria and hamsters can detect the intensity of the Earth's magnetic field.

The most visible interaction between animals and the magnetic field comes every year as animals migrate from cold to warm climates and back again. To navigation-challenged humans, animal migration can seem almost magical. How do animals like salmon, leatherback turtles, butterflies, and hummingbirds manage to migrate thousands of miles? It turns out that it's not magic at all: it's an invisible ecological interaction.

An inner compass is very important to migrating animals, particularly on days when it's overcast. This makes it hard to navigate using the sun or the stars. In a 2014 study of monarch butterflies, researchers from the University of Massachusetts Medical School discovered that migrating monarchs orient themselves to the south – even in the absence of cues from the sun. This means that even when it's overcast, butterflies can continue moving southward to their winter home.

When humans use a compass, it's visible in our hands. If animals have a compass, where is it? For a long time, studies of animal behavior showed animals aligning themselves with the earth's magnetic field. No one knew exactly how they managed to figure it out. However, research has discovered that many species contain small quantities of magnetite. This is the same material used in the ancient lodestones that humans used to guide their journeys.

Animal navigation has long fascinated humans. We enjoy watching the geese migrate overhead as fall approaches, but for a long time, no one knew how they managed to find their way. While it's not completely clear how all animals navigate using the Earth's magnetic field, recent investigations of animal anatomy have drawn us closer to the answer to this perplexing question.[1]

Questions:

1. What is the central idea of this text?
2. What ideas support this central idea?
3. How does the author develop this central idea from paragraph to paragraph?

[1] Adapted from a decodedscience.org article by Tricia Edgar

ELA (page 9 of lab manual)
Reading Informational Text
Key Ideas and Details

- ELA-Literacy.RI.8.2: Determine a central idea of a text and analyze its development over the course of the text, including its relationship to supporting ideas; provide an objective summary of the text.

Students read an article that focuses on migrating animals that use Earth's magnetic field to guide them, and some of the ways that scientists have investigated this phenomenon. Students should understand that scientists have already answered some questions about how animals use Earth's magnetic field, but there are many questions that remain unanswered about how this actually happens.

Example Answer Key:
1. [*The central idea of this text is that many animals interact with Earth's magnetic field, and scientists have carried out different experiments to better understand how and why these interactions occur*.]
2. [*The central idea is supported by the examples of the phenomenon of animals migrating from cold to warm climates and back again, including details about the findings of one study of monarch butterflies.*]
3. [*In the first paragraph, the author introduces us to the idea that scientists have carried out experiments that confirm that different organisms interact with Earth's magnetic field. The author then supports this idea with the phenomena of animal migration in the second paragraph, followed by an example of a study that focused on one migrating animal that uses the magnetic field to navigate. The fourth paragraph links animal navigation with human navigation to introduce the question of how animals might be navigating. The article ends with a summary of the central point.*]

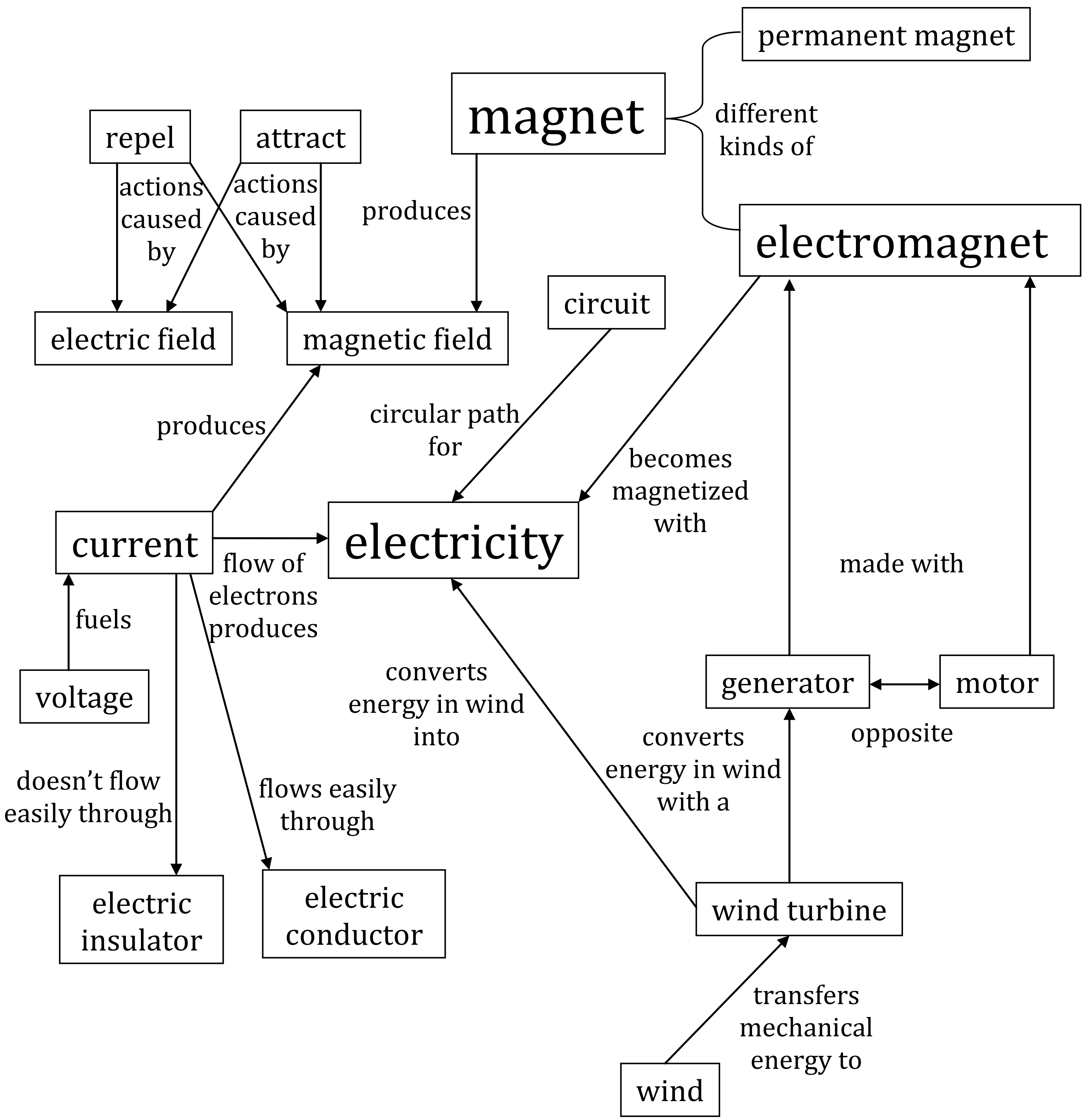
Students use the following Common Core standards in this unit.

ELA Standards	Applying ELA Connections to the Unit
Writing	
W.8.1. Write arguments to support claims with clear reasons and relevant evidence.	• In Lesson 1, students write a conclusion (argument) to summarize their findings in the magnetism investigation, analyzing whether or not the data (evidence) supported their hypothesis (claim). • In Lesson 3, students write a conclusion (argument) to summarize their results from the wind turbine engineering lab, analyzing whether or not their prototype met the criteria and constraints of the problem, using data (evidence) to support their argument.
W.8.2. Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content.	• In Lesson 3, students develop and write out the wind turbine engineering lab, including the problem, research, possible solutions, materials, testing procedure, diagram, and conclusion, using relevant data points in their conclusion to determine how their prototype solved the problem.
W.8.4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.	• In Lessons 3, students produce clear and coherent writing as they use their lab notebooks to work through the wind turbines engineering lab. The lab notebook must be clear, concise, and specific enough that someone else could replicate the prototype.
W.8.9. Draw evidence from literary or informational texts to support analysis, reflection, and research.	• In Lessons 1, 2, and 3, students use the nonfiction reading from their lab manuals to support their analysis, reflection, and research during the lesson.

Speaking and Listening	
SL.8.1. Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 8 topics, texts, and issues, building on others' ideas and expressing their own clearly.	• In Lessons 1, 2, and 3, students engage in Socratic dialogue before beginning the investigations and engineering challenge. Students apply what they have read in their lab manual's nonfiction reading, as well as any personal experiences or observations, to the dialogue.
SL.8.4. Present claims and findings, emphasizing salient points in a focused, coherent manner with pertinent descriptions, facts, details, and examples; use appropriate eye contact, adequate volume, and clear pronunciation.	• In Lessons 1, 2, and 3, students analyze what they have learned in the lesson in the wrap-up portion of class, coming together as a class to discuss important takeaways from the hands-on portion of the lesson. Student teams compare results, using their data and background knowledge to support their claims and evaluate other teams' claims.
Science and Technical Subjects	
RST.6-8.1. Cite specific textual evidence to support analysis of science and technical texts.	• In Lessons 1, 2, and 3, students use the information from their lab manuals to support their understanding of magnetism and electricity, applying what they know to design technologies that convert the wind's energy into electricity.
RST.6-8.2. Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.	• In Lessons 1, 2, and 3, students read their lab manuals, determining the main ideas and conclusions of the text. They use this reading to inform and support the Socratic dialogue portion of the lesson.

RST.6-8.3. Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.	• In Lessons 1 and 2, students follow a multistep procedure for building and then testing a system of interacting magnets to explore magnetic forces and energy and an electromagnetic motor to see what factors influence the speed at which it spins. • In Lesson 3, students follow a multistep procedure for testing their wind turbine prototypes.
RST.6-8.9. Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.	• In Lessons 1, 2, and 3, students use evidence from their investigations and engineering lab to support what they have read in their lab manual.
RST.6-8.10. By the end of grade 8, read and comprehend science/technical texts in the grades 6-8 text complexity band independently and proficiently.	• In Lessons 1, 2, and 3, students continue to develop their understanding of science/technical texts, using the unit vocabulary, context from the lab manual, and Socratic dialogue to support their comprehension of the nonfiction reading.

<u>Unit 8: Appendix 3</u>
Sample Concept Map



Unit 8: Appendix 4
Support for Differentiated Instruction

Core Expectation	Assessment Strategies	Possible Primary Evidence
MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.	Low Entry Point • Describe the relationship between force and motion. • Describe how an object's mass affects its motion. At Grade-Level Entry Point • Develop a plan that will investigate the relationship between an object's mass and its change in motion. • Conduct an experiment with independent and dependent variables to collect data on the relationship between mass and motion.	• engineering lab notebook entry completed by student • video of student explaining how the mass of their wind turbine blades affected their ability to spin
MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.	Low Entry Point • Describe how electric and magnetic forces can be either attractive or repulsive depending on the relative orientations of the interacting objects. • Explain how the distance between interacting objects affects the strength of magnetic forces. At Grade-Level Entry Point • Identify questions that can be asked to clarify the relationship between the strength of a magnetic field and the strength of an electric current. • Identify ways that questions can be answered to clarify the relationship between the strength of a magnetic field and the strength of an electric current.	• "Electromagnetic Forces Investigation" completed by student • video of student working in their team to predict which factors will increase or decrease the strength of their electromagnetic motor

Core Expectation	Assessment Strategies	Possible Primary Evidence
MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.	<u>Low Entry Point</u> • Explain how an investigation can provide evidence that magnetic objects can exert force on each other without coming into contact with each other. • Explain the relationship between a field and the force exerted on objects. <u>At Grade-Level Entry Point</u> • Plan and conduct an experiment with independent and dependent variables to collect data on magnetic fields.	• "Magnetic Fields Investigation" completed by student • "Repelling Magnets Investigation" completed by student
MS-PS3-2. Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.	<u>Low Entry Point</u> • Identify the components of a system made up of objects interacting at a distance. • Identify ways that energy can be transferred into the system of objects interacting at a distance. • Explain the force that connects the interacting objects (e.g., magnetic force). <u>At Grade-Level Entry Point</u> • Develop and use a model to show how the amount of energy transferred into the system can change depending on the force applied.	• "Repelling Magnets Investigation" completed by student • photos of student testing their magnetic system

Core Expectation	Assessment Strategies	Possible Primary Evidence
MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.	<u>Low Entry Point</u> • Identify a problem that needs to be solved. • Recognize that scientific knowledge can be used to solve problems. <u>At Grade-Level Entry Point</u> • Define the constraints of a particular design problem. • Define the criteria of a particular design problem. • Describe how the solution will solve the problem.	• engineering lab notebook entry completed by student • the engineering problem, along with its criteria and constraints, identified by student
MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.	<u>Low Entry Point</u> • Recognize that for any problem, there exist multiple solutions that could potentially solve the problem. • Recognize that some solutions will be more effective than others at solving the problem. <u>At Grade-Level Entry Point</u> • Use a systematic method for evaluating multiple solutions.	• engineering lab notebook entry completed by student • decision matrix filled out by student that evaluates how well each of their prototype solutions meets the criteria and constraints of the problem

Core Expectation	Assessment Strategies	Possible Primary Evidence
MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.	<u>Low Entry Point</u> • Test and collect data from multiple design solutions. <u>At Grade-Level Entry Point</u> • Identify relationships among the data collected to determine which characteristics worked well and which didn't.	• engineering lab notebook entry completed by student • photos of student testing their wind turbine prototype and then modifying it
MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.	<u>Low Entry Point</u> • Identify what worked well and what didn't work well during the testing of the design solution. <u>At Grade-Level Entry Point</u> • Use collected data to improve the design solution. • Identify limitations in the proposed solution.	• engineering lab notebook entry completed by student • photos of student designing and building their wind turbine prototype

Unit 8: Appendix 5

Materials Chart

	Lesson	Quantity	Notes	Used Again
Unit Kit Consumable				
Goggles	all	1 per student	safety	✓
Craft sticks	1	1 per team of 2	for suspending paper clips	
Plastic cups (10 oz)	1	1 per team of 2	for holding craft stick	
String	1	shared spool	for suspending paper clips	
Dowels	1	1 per team of 2	for holding ring magnets	
Small paper clips	1	1 per team of 2	for testing magnetic fields	
Batteries (9 volt)	2	1 per team of 2	for powering motors	
Magnet wire	2	shared spool	for making electromagnet coils	
Safety pins	2	2 per team of 2	for motor stand	
Thick foam pieces	2	1 per team of 2	for motor base	
Files	2	1 per team of 2	for filing magnet wire	
Batteries (AA)	2	1 per team of 2	for power EM motors	
Red alligator clip wires	2, 3	1 per team of 2	for motor circuit	
Black alligator clip wires	2, 3	1 per team of 2	for motor circuit	
Rubber connector tubes	3	1 per team of 2	for attaching motor to cardboard disc	
Cardboard disc	3	2 per team of 2	for wind turbine base	
Motors	3	1 per team of 2	for generating electricity	
Copy paper	3	4 per team of 2	for designing wind turbine blades	
Aluminum foil sheets	3	3 per team of 2	for designing wind turbine blades	
Straws	3	5 per team of 2	for designing wind turbines	
Non-Consumable				
Ring magnets	1, 2	5 per team of 2	for testing magnetic interactions	
Multimeters	3	1 per team of 2	for measuring voltage	
Stopwatches	3	1 per team of 2	for timing prototype tests	✓
Fans	3	shared	for testing wind turbines	✓
Anemometers	3	shared	for testing wind turbines	
Teacher Tool Kit				
Scissors	1, 2, 3	1 per student and 1 per team of 2	for cutting materials	✓
Rulers	1, 2, 3	1 per team of 2	for measuring materials	✓
Invisible tape	1, 2, 3	1 per team of 2	for taping materials	✓
Markers	2	1 per team of 2	for creating electromagnet coil	✓
Extension cords	3	teacher use	for powering fans and glue guns	✓
Power strips	3	teacher use	for fans and glue gun stations	✓

Glue guns/glue	3	shared	for gluing turbine bases	✓
Hand-outs				
Laboratory notebooks	3	1 per student	for “Lab 11”	
Lab manuals	1 and 2	1 per student	for “Magnetic Fields Investigation”, “Repelling Magnets Investigation” and “Electromagnetic Forces Investigation”	
Visuals	Download			
Lesson 1	Magnetic Interactions Visual, Energy Transfers in a System Visual			
Lesson 2	Types of Magnets Visual, Electric Currents Visual, Electromagnets in Circuits Visual			
Lesson 3	Engineering Scenario Visual, Motors and Generators Visual, Wind Energy Visual, and Types of Turbines Visual			

