

Creating an Electric Motor

Developed by James Mulanax, Monroe High School, *Monroe, Oregon*
Grades 3-12

This is lesson 2 of 7 of the educator's Unit: [A Study of Alternative Fuels](#)

Lesson 2: Creating an Electric Motor	
Lesson Overview	• Grade Level: Elementary – High School • Time Required: 3-4 hours • Expendable Cost/Group of 25: \$344.47 • Group Size: 1 • Activity Dependency: Creating an Electromagnet/Field Lab • Associated Informal Learning Activity: Manipulation of Refrigerator Magnets/Previous Electro Magnets. • Subject Areas: Physical Science, Physics
Lesson Summary	Students will discover some properties of electromagnets. They will create their own electric motor and measuring its torque by picking up a weight over a given distance and time. With this motor, they will learn how an electric motor works and to troubleshoot for optimum operation.
Engineering Connection	Electric motors are a basic part of everyday life. Engineers design electric motors to perform various jobs. Electric motors make our lives easier, and we may not even realize how much we interact with them. Common devices include, toothbrushes, electric razors, kitchen appliances, automotive components such as starters, wiper motors, seat adjustment motors and heater/AC fans. Other items include electric bicycles, motorcycles, skateboards, sewing machines, various woodworking tools, clocks and computers.
Learning Objectives	After this activity, student learners should be able to: • Relate that electric current creates a magnetic field. • Describe how electromagnets are made. • Investigate ways to change the strength of an electric motor. • List several items that engineers have designed using electric motors.
Educational Standards	NGSS Performance Expectation <u>3-5 Engineering Design</u> 3-5-ETS1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or costs. 3-5-ETS1-2: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints on materials, time, or cost.

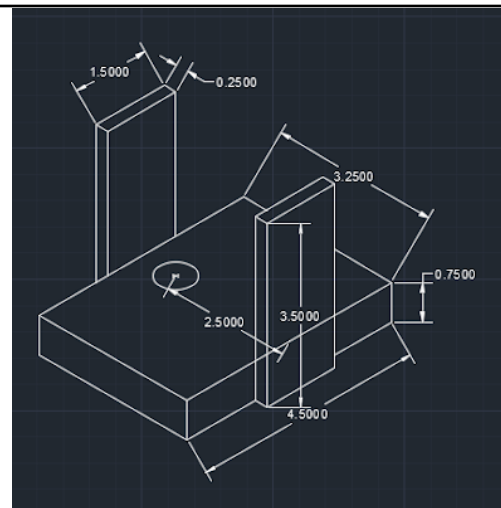
	3-5-ETSI-3: Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved. <u>M.S. Engineering Design</u> MS-ETSI-1: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. MS-ETSI-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. MS-ETSI-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. MS-ETSI-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>H.S. Engineering Design</u> HS-ETSI-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. HS-ETSI-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. HS-ETSI-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.
Materials List	Electric Motor: • 4 – Common bright nail 16D (3-1/2" long) • 3- 26 foot sections of 22 AWG magnet wire • 1- 6 Volt 10 Amp battery charger • 2 - Paper clips per motor • Multi-meter (to measure conductivity and Voltage) • 2 – test leads w/alligator clips • 1 – 3/4" by 4-1/2" by 3-1/4" block of wood or plywood (base) • 2 – 1/8"- 1/4" by 1-1/2" x 3-1/2" inch wood (armature supports/thin door skin or like material) • Band saw or handsaw for entire class to use • 1 – 3/8" x 3-1/8" dowel per motor • Thin aluminum (28-32 gauge) available in hardware store as "flashing" in roll form

	• Tin snips entire class can share • Roll of electricians' tape entire class can share • 1 – hammer entire class can share • ¾" spade bit • Hand drill or drill press (entire class can share) • 2 – Bright finishing nails (1-1/2" long) per motor • 2 – No. 8 x 9/16" Phillips low profile head screws per motor • WD-40 (1 spray can per class) • 1 – bottle of woodworking glue for entire class • 1 – yard stick for the class • 4 feet of light-weight string for the class • 1 roll of masking tape for the class • 1-3/4inch "C" clamp to secure motor base to cabinet edge
Required Knowledge	Some common knowledge of magnetic forces and poles is helpful but not entirely necessary. Consider allowing students to play with a group of refrigerator magnets and their electromagnets from the previous lab for a few minutes prior to lesson followed up with necessary questions regarding attraction, repulsion, strength and poles.
Introduction/ Motivation	If desired, allow students to play with groups of simple refrigerator magnets and their electromagnets from the previous lesson for a few minutes to engage memory recall if necessary or to introduce the concept of magnetic fields and poles. • Determine what the students already know about magnetic fields, poles and electromagnets. • Breakdown the word "electric motor" into its constituent parts for its basic definition. • Explain the importance of this project that a magnetic field can be created using electricity. • A wire with electrical current running through it creates an electrical field. • Altering the poles of the electromagnet can create rotation about an axis like an everyday motor. • Turning the armature off and on relates to the change of poles to create the needed attraction and repulsion to initiate rotation of a basic motor. • Share that today the students are going advance the construction of their previous electromagnets to make a hand-built electric motor. When the motor is operating, they will then measure its torque (twisting effort)
Lesson Sequence	Electric Motor Procedure (Teacher's Edition) 1) Electric Motor Construction and Lab Worksheet <u>Before the activity</u>

1. Gather the following materials and make copies of the [Building an Electric Motor worksheet](#).
2. Set up enough electric motor stations to accommodate teams of two students each or one if desired.

Instructions for Electric Motor:

- a) 2-Field Magnets: Obtain 26 feet of 22 AWG magnet wire and the wire around one nail. At the beginning of the nail wrap, leave a six-inch-long wire tail. Wrap the nail tightly with no gaps from one end to the other and back as many times as necessary to use all the wire except for approximately six inches for the final tail of the wire. Use masking tape to secure the wire wrap to the nail. Leave approximately $\frac{1}{2}$ " of the pointed end of the nail unwrapped. Construct a second field magnet using the same directions.



- b) Sand both wire tails of each field magnet with sandpaper to expose 1-2" of bare copper wire.
- c) Connect one wire tail to one end of the 6-Volt battery charger using a test lead. Connect the remaining wire tail to the other end of the battery with another test lead.



- d) Place a paper clip near the head of the nail and take notice that there is an attraction between the electromagnet and the paperclip. The purpose of this is to verify that the electromagnet is functioning. *(If the unit is not working, make sure you have plugged in the battery charger, check to see that your alligator clips are secure and/or make sure the wires are sanded properly. If still not working, perform a continuity test from one wire end to the other. If there is no continuity, the wire may be broken somewhere—start over).* Check the polarity of each field magnet with a small trail compass.

- e) Armature: Obtain a premade armature dowel from the teacher. Insert two finishing nails into the end of the





dowel (one nail per end). Attach two box nails to the dowel as illustrated. Tape the ends of the nails together to secure. Make sure the box nails do not easily slip from side to side. Balance the armature by sliding the armature gently towards the heavy side.

- f) Obtain 26 feet of 22 AWG magnet wire. Find the middle of the wire length by folding the two ends together and pinching the wire together. Place the center of the wire crosswise over the box nails. Wrap one end of the wire in one direction around the box nails tightly with no gaps from one end to the other and back as many times as necessary to use all the wire except for approximately 2 inches for the final tail of the wire. Repeat with the remaining end of the wire. Make sure this wire wraps in the opposite direction as the first wire end. Again, wrap the wire around the box nails tightly with no gaps from one end to the other and back as many times as necessary to use all the wire except for approximately 2 inches for the final tail of the wire.
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- g) Sand both wire tails with sandpaper to expose 1" of bare copper wire.
 - h) Connect one wire tail to one end of the 6-Volt battery charger using a test lead. Connect the remaining wire tail to the other end of the battery charger with another test lead.
 - i) Place a paper clip near the ends of the nails and take notice that there is an attraction between the electromagnet and the paperclip. The purpose of this is to verify that the electromagnet is functioning. If the unit is not working, make sure you have plugged in the battery charger, check to see that your alligator clips are secure and/or make sure the wires are sanded properly. If still not working, perform a continuity test from one wire end to the other. If there is no continuity, the wire may be broken somewhere—start over. (Recheck for proper operation).
 - j) If the armature electromagnet is functioning, place a small compass at the ends of the nails. The compass readings should be opposite to either end. If not, one end of the armature is wrapped backwards—unwind and rewind in the opposite direction. Recheck for proper operation.
 - k) Base: The base is constructed as per illustration. Be sure to cut the slots to support the armature so that the armature spins freely but not so loose to allow for sloppy operation. Use wood glue to secure the armature uprights in place.



- l) Shells: Cut two small pieces of thin aluminum and form around a piece of scrap doweling. The end result should look like the illustration. Key to good performance is a gap that is both even and symmetrical. Using a spare nail works great to form the shell around the wooden dowel.



- m) Attach the aluminum “shells” to the armature dowel with the bare wire tails under them... one wire per shell. The alignment of these shells with representation to the winding is important. The gap should be centered to the nails. Secure tightly with electrical tape. If too much is added, trim some of the tape off to expose the aluminum shells



- n) Test the armature using a battery with test leads touching the aluminum shells. One lead per shell. Use a paper clip to verify that there is magnetism. Place the finished armature assembly into the base

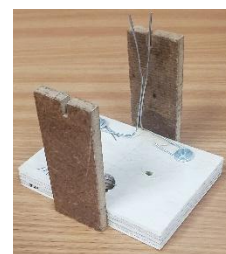


and make sure the unit spins freely.

- o) Brushes: Unfold two paper clips as shown and attach to base with screws and one flat washer per screw. Make sure the brushes are not next to the hole in the base as shown.



- p) shells of the armature are **not** placed over the hole in the base. Be sure to attach one sanded wire tail under the paper clip—one wire tail from one field electromagnet to one paper clip, and one wire tail from the other field electromagnet to the other paper clip. Twist the remaining field magnet wire tails together.

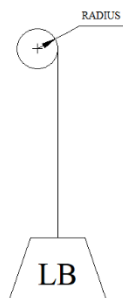


- q) Attach the battery charger via test leads to the screws—positive to one paper clip and negative to the remaining paper clip. Check that the heads of the field magnets have opposite polarity. If they are identical. Switch the tail ends around on one field magnet only and recheck for opposite polarity.
- r) Place the armature assembly into the base and move the paper clips so that they gently touch the shells. If the paper clips will not remain touching the shells after moving, remove the armature assembly and push the paper clip further ahead. Replace the armature and check the brush pressure. This make take a while to get the right pressure. Too much pressure creates a slow or nonfunctioning motor. Too little pressure creates a weak contact, and the motor may not work. You can test the brushes individually by pulling one brush away and testing the spin of the armature by spinning it with your finger. Swap side and test the other brush pressure. Ensuring equal and gentle brush pressure can help a lot towards constructing an efficient motor.
- s) Apply a small amount of WD-40 on the bush/shell assembly to help with conductivity.
- t) With a partner, attach the battery charger and give the motor a spin. Detach the battery charger immediately if the motor does not spin right away. Try the procedure again except spin the motor in the opposite direction. Label one screw “+” and the other “-” so the battery polarity is always attached the same way. If the motor spins, **CONGRATULATIONS!** Label the armature upright with an arrow to indicate the direction of rotation. If the motor is not working or is incredibly slow, check the previous steps for troubleshooting. You can also perform tests such as switching out a known working armature assembly to isolate what is or is not working on your unit.
- u) Horsepower: To measure the horsepower of your electric motor, you will need a string, paper clip, scale, and timer. I suggest practicing this until a reasonable result is obtained. The string will be tied to the armature with a paper clip tied to the other end of the string. The string will wrap around the armature and be pulled up through the hole in the base. Jot down the height of the paper clip above the floor. The yardstick should be taped to the cabinet so as to monitor distance the paper clip travels. With multiple people, you will assign duties to perform the following efficiently: 1) record start and end distance. 2) time the test. 3) call start/stop. 3) attach



and detach the battery charger. 4) gently spin the motor in the correct direction. It is likely that multiple attempts will be needed. Allowing the battery to remain attached while the motor does not spin can result in burnt wire(s) or rendering the motor damaged. Using the formula below, you can measure the amount of horsepower your motor develops.

$$\text{horsepower} = \frac{(\text{ } \text{oz.}) (\text{ } \text{in.})}{105,600 \text{ oz. in.}} \times \frac{1}{(\text{ } \text{sec.})}$$



Activity Extensions

Another way to vary the current in the electromagnet is by using a wire of different gauge (diameter) or by using a different wire material such as aluminum instead of copper. Keep in mind that for accurate comparisons, the same battery charger settings, and exact wire lengths should be the same.

Vocabulary / Definitions

Battery: A cell that carries an electrical charge that can power an electric current.

Electrical Current: The flow of electrons.

Electromagnet: A magnet made with insulated wire wrapped around an iron core that produces magnetism when electrical current flows through the wire.

Electromagnetism: Magnetism created by an electric current.

Engineer: A person who applies the understanding of science and mathematics to create, design, manufacture and operate structures such as machines, products, processes and systems.

Magnet: An object that generates a magnetic field.

Electric Motor: An electrical device that converts electrical energy into mechanical energy.

Permanent Magnet: A magnet that generates a magnetic field on its own without the help of electrical current

Assessment	Pre-Activity Assessment • Prediction: After students have used their refrigerator magnets and experienced magnetism, attraction and repulsion of the two poles, ask them to predict what will happen when a wire is wrapped around a nail and the wire tails are attached to a battery. Record their predictions where everyone can see them. • Brainstorming: In small groups, have students engage in open discussion about what an electromagnet is. Remind them that no idea or suggestion is “silly”. All ideas should be should be respectfully heard. Activity-Embedded Assessment • Worksheet: After student teams have completed their worksheets, have them compare drawings and answers with other teams. After teams finish their assessments, review their answers to gauge their mastery of the subject. • Hypothesize: As students are making their electric motors, ask each group what they think would happen if the change the voltage of the battery and what would happen if more wraps of wire were added to the nail or armature? (Answer... either way, the electromagnet would become stronger). Post-Activity Assessment • Engineering Discussion Questions: Solicit, integrate and summarize student responses. • What are ways an engineer might modify an electromagnet to change the strength of its magnetic field? (Answers... changing the number of wraps or the voltage/current of electricity, or an engineer might use a core that is more easily magnetized). • How might engineers use electric motors to move objects? • What are some ways engineers might be able to use electric motors? • How are electric motors used in everyday applications? (Possible answers... common devices include speakers, toothbrushes, electric razors, kitchen appliances, automotive components such as starters, wiper motors, seat adjustment motors and heater/AC fans. Other items include electric bicycles, motorcycles, skateboards, sewing machines, various woodworking tools, clocks and computers). • Make a graph that shows how much torque each working electric motor produced.
Safety & Tips	Safety Issues The electromagnet can get quite warm, particularly at the terminals, so have students disconnect their battery charger at frequent intervals. Also, if the

electromagnets do get warm, have the students use kitchen gloves for handling the electromagnets.

Troubleshooting Tips

- A high density wraps of the nails is important to produce a good magnetic field. If the wrapped nails do not act as a magnet, check the wraps to ensure the wires not crisscrossed, they are tightly wound, or that the wire is broken somewhere. (A broken wire can be checked with a multi-meter).
- Iron nails work better than bolts as the bolt threads can interfere with tightly wound wire wraps.
- Wear rubber gloves if electromagnets get warm.