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Revving it Up! Helping Students Investigate the Forces that Power a Motor

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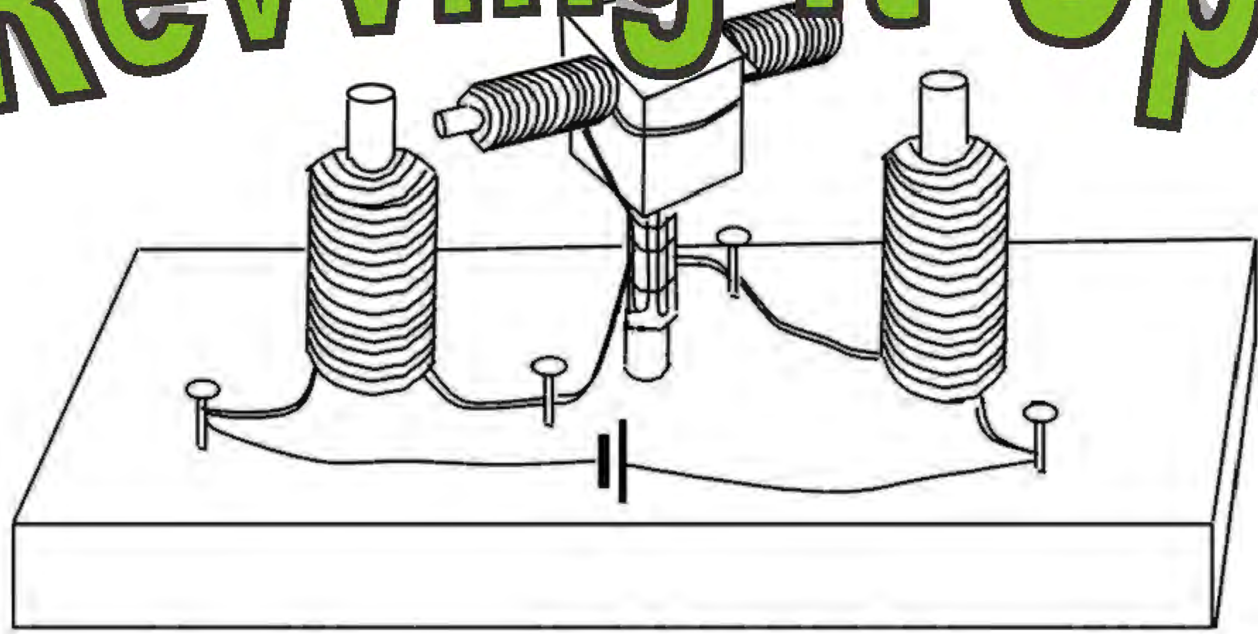


Helping Students Investigate the Forces that Power a Motor

by **Roy D. Unruh and Larry Escalada**

ABSTRACT: The Electric Motors learning cycle demonstrates how magnetic fields and electric currents interact to produce a force on a moving charge. In the exploratory activity students manipulate a magnetic field to produce motion in a cone and construct an electric motor by winding an armature and field coils. In the concept development activity, students construct a simple motor with a single coil and ceramic magnets. They feel the force on a current carrying coil in a magnetic field that leads to the right-hand rule. They also analyze the operation of a motor used to power a toy car. The application activity compares the mechanical power transferred in lifting weights with an electric motor to the power consumed by the electric motor. *This article promotes National Science Education Content Standards A and B, and Iowa Teaching Standards 2, 3, 4, and 5.*

Introduction

Consider the relationship between a magnetic field, a current in a conductor and the force on that conductor. How do you teach these concepts in a way that students truly wrestle with making sense of these phenomena to the extent that they can apply it to understanding how an electric motor works? One highly effective approach is to use a three-phase learning cycle teaching strategy demonstrated in the PRISMS PLUS curriculum materials. The Iowa Professional Development Model Content Network* has summarized the research regarding the effectiveness of the PRISMS Project.

The activities appearing below are an enhanced version of the original *Physics Resources and Instructional Strategies for Motivating Students* (PRISMS) curriculum materials (Cooney &, Unruh, 1982). The exploratory phase is designed to engage students in a high-interest activity in which they make predictions and observations,

*Visit IPDMCN at http://www.state.iowa.us/educate/ecese/tqt/tc/profev/main.html and seek patterns and relationships. The exploration activity encourages students to develop accepted scientific relationships based on their own observations and data. The concept development phase uses guided inquiry where the teacher coaches students to collect their own data and interpret it in a manner that results in students “discovering” the desired targeted scientific concept within the context of their observations. Following this activity, students may read the logic and theory that helps them make the connections between concepts and phenomena they observed in the Concept Enhancer found in the student edition of the materials. The Conceptual Practice provides written exercises for students to use and practice their newly acquired knowledge and skills to analyze additional situations. The final phase of the learning cycle is the application activity where the students apply their understanding of the concept to other related phenomena often within a real-life context.

Exploration Activity – Let's do the Rotation

Provide the students with a wire, battery, and compass and ask them to try to find ways to make the compass needle move. Warn them to only make momentary contact between the wire and the battery because the wires will get hot and the battery will discharge if contact is continuous. Once students have discovered that the creation of an electric current causes the compass needle to deflect, ask them how they might cause the compass needle to rotate for several rotations. Point out that getting a mechanical device, such as a compass, to rotate is one step toward harnessing the energy from an electric current and producing rotational kinetic energy. This rotational motion was utilized in the form of large electric motors to help power the industrial age.

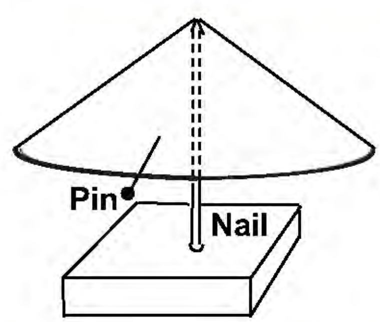
Ask students what pattern, if any, they determined between the direction of the current in the wire and the direction of the deflection of the compass. Don't be concerned about “correct” answers at this point. The purpose of the question is to stimulate them to look for patterns. Interpreting patterns is an important component of students doing science. Students who listen to teacher explanations are not doing science.

A Cone Motor

Have the students construct a paper cone from a circle with a diameter of at least 10 cm by cutting along a radius and overlapping ends of the circle, as shown in Figure 1. After the cone has been constructed, check that it balances easily on a nail. A block of wood may support the nail. Some tape or small pieces of paper may be added to bring the cone into a well-balanced condition.

Now add two metal pins to the cone on opposite sides of the cone with the heads protruding below the cone. Stroke the head of one pin with a pole end of a magnet, giving the head of the pin the same North (N) or South (S) polarity as the magnet. Stroke the other pin with the other pole of the magnet. With a compass check the polarity of each pinhead and mark it on the cone near the pin.

FIGURE 1



Students construct a cone motor.

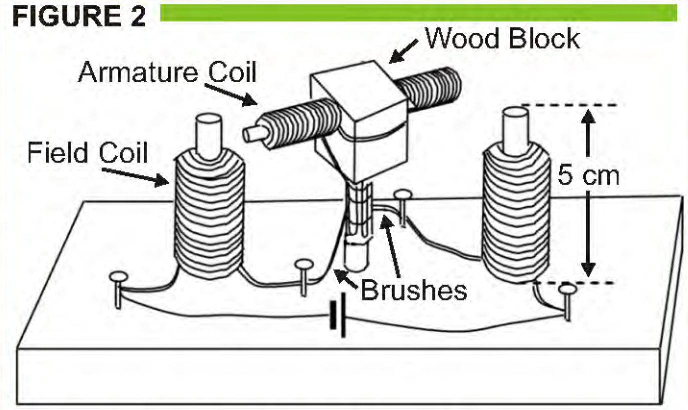
Have students select a magnet that can be used as a propelling force to cause the cone to rotate. With a compass they determine the polarity (N or S) of the magnet that they are using. By keeping the magnet in one general place and manipulating it with their hand, direct them to see whether they can make the cone rotate. Let them try as many techniques as they can develop. Have students describe the technique they used that was most successful in rotating the cone.

A Simple Motor

Have students construct an electric motor with some of the more conventional parts of electric motors. Use Figure 2 as a guide for the construction of the motor. Drill holes in a board for the nails/rivets for the field coils. The holes should be 1.0 cm farther apart than the length of the armature. Neatly wrap approximately 8 m of No. 20 - 24 enameled magnet wire for each field coil. Wrap both of them in the same direction. Sand or steel wool the ends of the wire and fasten one end to a post that will get connected to a battery. Wrap the other end around a nail and position it against the commutator of the armature.

Select a wood block approximately 1x1x2 inches and drill a hole in the upper part of the larger face midway between the two edges of the block. Insert a nail/rivet through this hole so that equal lengths protrude through the block. The nail/rivet should not exceed 10 cm. Wrap approximately 5 m of enameled wire in the same direction on each segment of the armature. Drill a hole exactly along the vertical axis of the block to accept a glass tube 6 mm in diameter and approximately 45 mm in length. Fire the end of the glass tube to close the tube so that it rotates freely on the vertical nail. Place the armature on a nail/rivet with a length to allow the armature to rotate past the top of the field coil as seen in Figure 2.

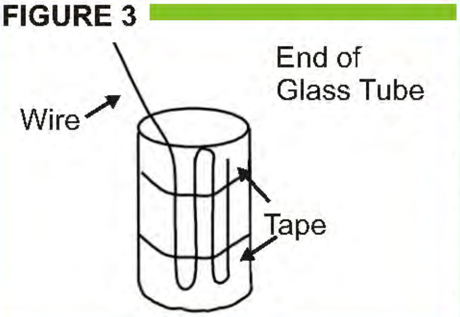
FIGURE 2



Basic design for building a simple motor.

The brushes will need to make contact with the commutator to switch the direction of the current in the armature coil every half rotation. To do this sandpaper or steel wool the ends of the armature coil and bend the ends back and forth as shown in Figure 3. The two wires must be directly opposite each other on the bottom part of the glass tube. Tape them in place with a space between the tape strips for the brushes to make contact with the wires.

FIGURE 3



Place the armature on the supporting nail/rivet and adjust the brushes to make contact with the commutator. Connect one or more batteries to the terminals. Give the armature an initial spin to help it get started. If it does not respond adjust the position of the brushes to make contact with the commutator at the best location for continued motion.

Ask students how they would explain the operation of this motor. Ask “What variables do you think might affect the rotation rate of this motor?” If you have sufficient time, you could encourage the students to conduct further investigations in an attempt to determine further patterns.

Concept Development – What Makes It Go?

A single coil motor with a small ceramic magnet, shown in Figure 4, is used to demonstrate the direction a force is produced as a current passes through a magnetic field. Paper clips are bent and inserted into small wooden blocks to give both stability and flexibility in the set-up.

Coil a length of insulated wire around two fingers, creating from four to seven loops and leaving five to seven cm of wire to wrap around the loop at each end and bending the wire ends out to form an axle. The ends should be wrapped around the coil so that the axle passes through the center of mass of the coil and is in rotational balance. Remove (sandpaper) the enamel insulation on the straightened part of one end. On the other end remove the insulation on only the bottom half of the coil when it is in a vertical position. If you are using insulated wire, strip the insulation from the ends of the wire and then apply fingernail polish on the upper side of one axle when the coil is in a vertical plane.

Place a ceramic magnet underneath the coil with a magnetic pole facing up. With a compass determine which pole is facing up. Connect leads from the paperclips to a battery. The coil may need an initial push to help it get started with its rotation.

FIGURE 4

A single coil motor is used to demonstrate the direction of a force.

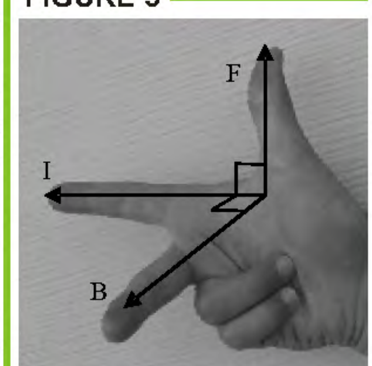
Ask students how they would explain the operation of this motor. Remove the magnets and hold the coil vertically. While electrical contact is made from the coil to the battery in a complete circuit, check the magnetic field inside and around the coil/armature. Adjust the coil so that the insulated part on the one end of the wire is facing up. Replace the magnets underneath the coil as shown in Figure 4. Close the circuit and observe the direction of rotation. If the rotation is too fast to observe the direction of rotation have students hold their thumb and index finger on either side of the bottom or top of the coil. Then briefly close the circuit and note the direction of the attempted rotation against their thumb or finger. Guide your students to recognize a relationship between the current in a wire, the magnetic field, and the force on the current carrying wire. The following questions encourage students to make the desired links:

- What is the direction of the magnetic field above the magnet?
- Which direction is the current in the loop just above the magnet?
- Which direction is the force on the lower part of the loop?

This can be summarized as the motor effect and is called the *right-hand rule.* With your right hand extend your index finger, middle finger and thumb so they are each at right angles to each other as shown in Figure 5. The index finger represents current (I), the middle finger the magnetic field (B), and the thumb represents the thrust or force (F) on the current carrying conductor. If you prefer to designate the direction of electron flow as the current, then the rule becomes a *left-hand rule*.

Ask students to apply the right-hand rule to both the top and bottom of the coil in the presence of the vertical magnetic field above the magnet. How do the proper direction of the force on the coil and the resulting direction of coil rotation compare to that predicted by the right hand rule?

FIGURE 5



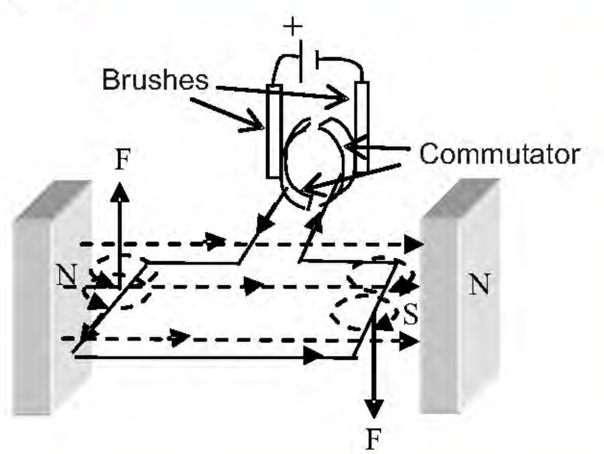
The right hand rule.

Some electric model cars have motors with two permanent magnets and an armature or motors with electromagnets and an armature. Have the students check the direction of the current through the commutator and armature and explain the forces that cause the motor to rotate.

Concept Enhancer

The concept enhancer is designed to assist or confirm the logic from the exploratory and concept development activities in developing major concepts. The relationship between a magnetic field, a current in a conductor, and the force on that conductor is often explained as the right-hand rule, which is an empirical relationship. A fundamental way of looking at these interactions is to look at the interaction of the magnetic field caused by the electric current and the magnetic field of the permanent magnets as shown in Figure 6. By having students analyze the magnetic fields above and below each branch of the circuit, they will wrestle with the major concepts addressed above and come to understand that there is a net force up on the left branch and a net force down on the right branch of the circuit producing a torque to cause the armature to rotate in a clockwise direction. The commutator allows the current to be reversed every half rotation and the armature to continue to rotate in a clockwise direction.

FIGURE 6



Model to visualize the interaction of a magnetic field.

Conceptual Practice

In this section physical arrangements of magnets and conducting wires are shown or described and students are asked to analyze the forces on the conducting wires. In one case, aluminum rods are placed parallel to each other over a field of ceramic magnets and connected to a battery. Another small aluminum rod is placed perpendicular to the other two rods. Will there be a force on this smaller aluminum rod? If it could roll, which direction do you predict it would roll? Explain your prediction.

Application – Racer on the Move

In this activity students compare the mechanical power that electric motors provide with the electrical power used by the electric motors. Mechanical power can be varied by the amount of weight lifted to a given height. If students use a model car with an electric motor, fasten the car in an elevated position so that it can lift a weight by rolling up string on a drive wheel. Mechanical power (P) can be calculated from the definition, $P = W/t$, where W is the mechanical energy expended and t the time required for lifting the weight to a given height. Electrical power can be calculated from the relationship, $P = VI$, where V is the electrical potential difference provided by an energy source and I is the current through the motor.

Ask students to organize an experiment to collect the appropriate data. Have them show all their data in an organized data table in such a manner that it will tell the story of how they conducted their experiment. Plot a graph of mechanical power applied to the weight vs. electrical power used by the motor. Determine the efficiency of the energy transfer.

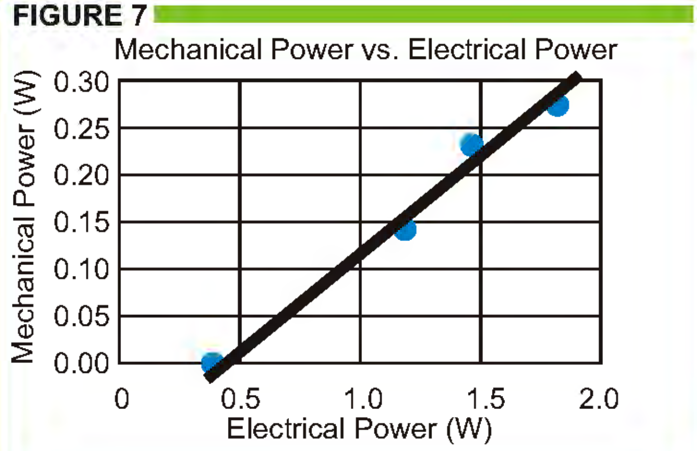
If you have a battery-powered vehicle that can travel up a ramp, measurements can be taken to calculate the increase in gravitational potential energy in a measured time. The current through the motor and voltage across the motor need to be measured to calculate the input electrical power by the motor. The experiment could be conducted for different slopes of the ramp.

Sample Data/Calculations

The graph from a set of data using the Mars Crawler from Seibun (http://www.SeibunUSA.com) is shown in Figure 7. The graph shows a linear relationship between the mechanical power and the electrical power to lift the weights. The graph does not go through the origin showing a threshold energy required to begin to lift the weight.

Efficiency = $\Delta Power_m / \Delta Power_e$
Eff. = (0.225 - 0.025)W/(1.5 - .5)W
Eff. = 0.20 = 20%

FIGURE 7



Summary

In this series of activities, students are provided with experiences in which they make observations and gather data that are helpful for them to develop a concept connecting magnetic fields, current carrying conductors, and forces on these current carrying conductors. Students are taught to develop understandings and concepts based on observations and data. And these important experiences are available for students to recall and use in understanding and remembering important abstract ideas involved in magnetic fields.

Understanding science is to comprehend it as a process that formulates hypotheses and conclusions based on evidence. The activities and crucial teacher role described above guides students to correct understandings of motors and the underlying scientific principles at work. The concrete experiences and teacher questions together provide the needed assistance to help students understand several abstract relationships, and apply these concepts to concrete physical phenomena.

References

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