Teacher Content Brief

Electric Motors

Introduction

Motors convert electric energy into mechanical energy. This mechanical energy turns the propellers on your Sea Perch. But what makes a motor spin? To understand how motors function it is important to understand how magnetic fields and electric fields are related.

Standards

Benchmarks 2061 Project (see References section to link to the online standards):

- At the end of 8th grade, students should know that
  - Electric currents and magnets can exert a force on each other.

- At the end of 12th grade, students should know that
  - magnetic forces are very closely related to electric forces and are thought of as different aspects of a single electromagnetic force. Moving electrically charged objects produces magnetic forces and moving magnets produces electric forces.
  - the interplay of electric and magnetic forces is the basis for many modern technologies, including electric motors, generators, and devices that produce or receive electromagnetic waves.
  - electric currents in the earth's interior give the earth an extensive magnetic field, which we detect from the orientation of compass needles.

Background Information

Magnetic Fields

Magnets are named for a region in Asia Minor known as Magnesia where people noticed that some rocks were attracted to one another. One of the earlier uses of magnets was in China in the early 11th century in compasses – the needle was made from magnesia, which acted as a magnet that automatically oriented itself towards the North Pole. This happens because the Earth has a magnetic field created by the materials in the outer core. This magnetic field not only helps us navigate using a compass but it also protects the Earth from radiation emitted by the Sun.

Magnets are surrounded by magnetic fields and attract certain metals (iron, nickel, and cobalt). This magnetic effect comes from a special alignment of the atomic structure of the material. All magnets have two poles, a north pole and a south pole. It is impossible to have a singular magnetic pole; they always come in pairs. Magnets follow the rule that opposites attract and like poles repel. This means north poles attract south poles and repel north poles. Conversely south poles attract north poles and repel south poles.

Magnets are used in our daily lives, from holding papers on the refrigerator door to carrying important information encoded on the magnetic strips on the back of credit cards.

Electric Fields

Electric fields are created by charged particles such as protons and electrons. These charged particles can push and pull on each other with the electrostatic force. They follow the same rule as magnets. Opposite charges attract and like charges repel each other. When these charges move along a wire, an electrical current is produced. This current is what runs electrical appliances and electrical motors.

Electromagnetics

Hans Christian Oersted discovered the relationship between mechanical force, magnetism, and electricity through a series of experiments in the early 1800's. He noticed that when a current flowed through a wire, it deflected a nearby compass. He understood that this meant the current flowing in the wire induced a magnetic field that turned the compass. Later it was discovered that when a wire conducting current is placed in a magnetic field, a force is induced on the conductor. This force is the basis for the electric motor.

The force is given by the equation:

$$F = iL \times B$$

where *F* is force, *B* is the magnetic field strength, *L* is the length of the conductor, and *i* is the current. This equation uses vector multiplication, which depending on the age of your students may be introduced during the vector module. There are two types of vector multiplication. The dot product is used when two vectors are multiplied and produce a scalar. In the instance described above, a cross product is used because when the current vector is multiplied by the magnetic field vector, a new vector is produced that represents the size and direction of the force on the conductor.

THOUGHT EXERCISE:

- Ask your students to make a connection between motors and generators. When are they used? How are motors and generators related? If a motor uses a current in a magnetic field spin something, how does the spinning of a generator make a current?
- (A generator takes a manual force (a person turning a crankshaft) and moves a conductor through a magnetic field to produce an electric current.)

Inside a Motor

The force on a conductor in a magnetic field can be turned into a torque by running current through a loop of wire in a magnetic field (as seen in Figure 2).

$$\tau = r \times F.$$

A torque, τ, is a rotational force that is described by another cross product. In this equation, F is the force applied and r is the distance from the pivot point where the force is applied. If r and F are perpendicular to each other, the torque is maximized. If they are parallel to each other, the torque is zero. You can apply this concept to what happens when you open a door. If you push on the door perpendicular to its surface, it will rotate around the hinges. If you push on the door parallel to its surface the door will not move.

When a motor is connected to an energy supply it creates a current that runs around the loop. This means the current is in one direction on one side of the loop and in the other direction on the other side. This creates a pair of force vectors (*F* in figure 2) in different directions. This causes a torque around the center axis of the loop (shown as a dotted line).

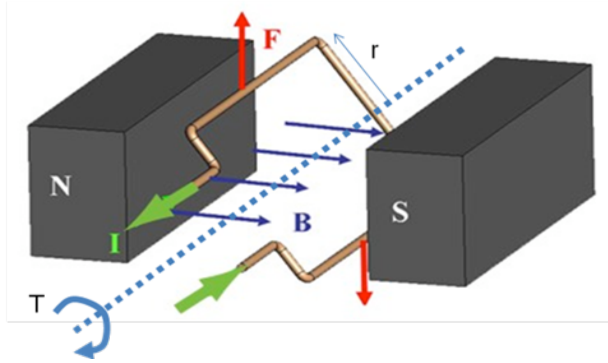

Figure 2: Schematic diagram of a coil of wire conduction current in a magnetic field.
Adapted from: http://hades.mech.northwestern.edu/wiki/index.php?title=Brushed_DC_Motor_Theory

Without any changes, the coil of wire will move, but it won't spin. It will stop once the torque has changed from the maximum value to zero. As shown in Figure 3, the forces on the coil will just cause the coil to align with the magnets and then it will stop.

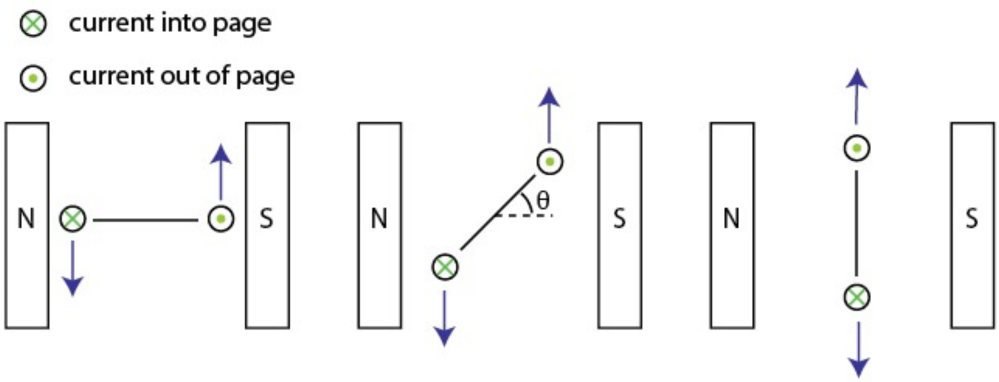

Figure 3: Schematic diagram showing the difficulty with a coil in a magnetic field.
Adapted from: http://hades.mech.northwestern.edu/wiki/index.php?title=Brushed_DC_Motor_Theory

THOUGHT EXERCISE:
What can we do to make the coil spin continually? Have your students try to determine different ways to make the motor spin once they know how the force is generated from the current in the magnetic field.

There are a few different ways to make the coil spin, but the most common is to add physical components to make the current change direction, which will change the direction of the force (See Figure 4 for schematic of simplified motor components).

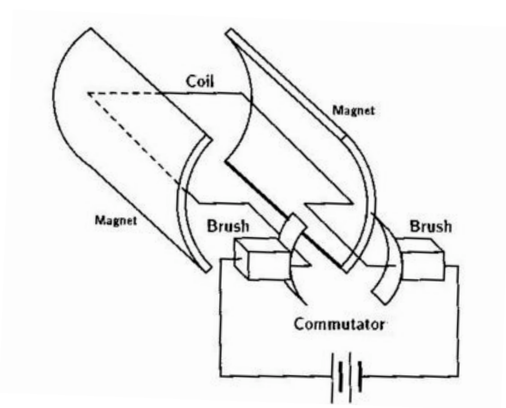

Figure 4: Internal parts of a motor. Adapted from: http://hades.mech.northwestern.edu/wiki/index.php?title=Brushed_DC_Motor_Theory

In order to switch the direction of the current, the electrical connection is switched using brushes and a commutator. A commutator is a rotary electrical switch in an electric motor that periodically reverses the current direction between the rotor and the external circuit. The commutator is attached to the coil so it spins when the coil spins. The brushes are

attached to the power source and do not move. As the commutator spins, the brushes automatically change the connection direction, thus switching the current direction.

This is the type of motor that will move your Sea Perch through the water. The three motors will spin propellers so that you can navigate the Sea Perch. As you learn more about electric circuits you will experiment with ways to make the motor switch directions. You will also want to be able to change the speed of your motor.

Additional Resources

- **If you would like to learn more about electric motors, please visit the following URL:** ***http://en.wikipedia.org/wiki/Dc_motor***
- **For some additional information, try the following sites to engage in some interactive simulations** **http://phet.colorado.edu/en/simulation/faradays-law** **and** **http://phet.colorado.edu/en/simulation/magnet-and-compass**

GLOSSARY

Magnet: A material that produces a magnetic field. It pulls on other magnetic materials.

Magnetic Field: A field of force produced by a magnetic object that can be detected by the force it exerts on other magnetic materials and moving electric charges.

Permanent Magnet: Magnetic material that creates its own persistent magnetic field.

Magnetic Moment: A measurement of an object's tendency to align with a magnetic field.

Electric Field: A field of force that surrounds charged particles. It pulls on other charged particles.

Electrons: Negatively charged particles that orbit the nucleus of an atom.

Protons: Positively charge particles found in the nucleus of an atom.

Electrical Current: A flow of electrons. The rate of electrons per unit time.

Dot Product: Known as the scalar product, takes two vectors and multiplies them and produces a scalar.

Cross Product: Known as the vector product, takes two vectors and multiplies them producing a new vector quantity.

Torque: A rotational force calculated by the size of a force multiplied by the distance from the turning point.

Motor: A machine that converts electrical energy into mechanical energy.

Commutator: An electrical switch inside the motor that changes the direction of the current.