ELECTRIC MOTOR
65305-05

STUDENT'S WORKBOOK
By Lawrence F. Lowery

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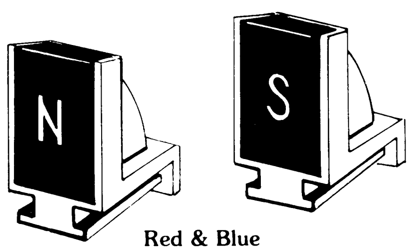
INTRODUCTION

Electric Motors are used to drive tools and machines of all sizes. They move huge pots of molten steel in steel mills; they run mixers in the kitchen and drills in the garage. You may have used model cars or trains powered by electric motors. Electricity for these motors may come from batteries, from house current, or from some special supply. The electric motor in your Discovery Kit is powered by a small battery.

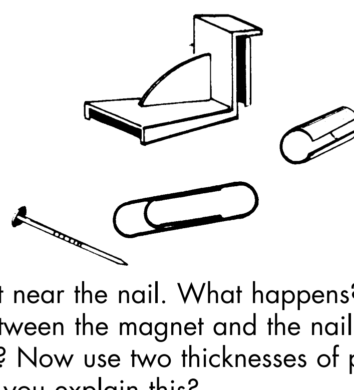
Exploration 1: How a Magnet Works

Your Discovery Kit contains a magnet in a red plastic holder and a magnet in a blue plastic holder. Each of these magnets is called a permanent magnet because it keeps its magnetism all the time. When magnets are used as part of an electric motor, they are called field magnets.



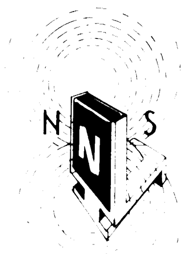
Red & Blue
Field Magnets

Hold one of the magnets near some of the metal objects from your kit. Does it pick them up?



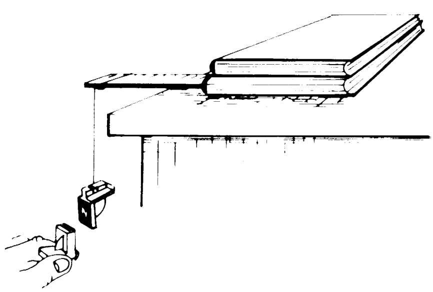
Slowly move the magnet near the nail. What happens? Hold a small piece of paper between the magnet and the nail. Will the magnet pick up the nail? Now use two thicknesses of paper. Is there a difference? Can you explain this?
Can you pick up the nail with the plastic-covered side or edge of the magnet? Try the top and the bottom.

Magnetism surrounds magnets in a field. The magnetic field gets much weaker very quickly as you move an object away from the magnet. You cannot see, hear, smell, or feel a magnetic field, but it works on nails and paper clips and other objects made from iron. You will learn more about magnetic fields in the next Exploration.



Exploration 2: Polarity and Magnetism

Tie or tape some thread or fine string to one of the magnets and hang it from the edge of your desk. It should balance as shown in the sketch. When the magnet stops moving, slowly bring the bare face of the other magnet near the bare face of the hanging magnet. What happens? How far apart are they when the hanging magnet begins to move? Measure the distance between the magnets when the hanging magnet just begins to move.

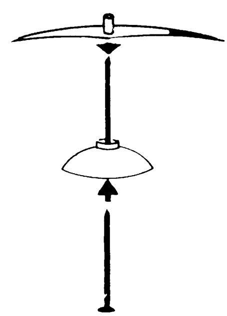


Stop the motion of the hanging magnet. This time bring the other magnet toward the plastic edge of the hanging magnet. What happens? Try it again, but very slowly this time. Measure the distance at which the hanging magnet begins to move.

The distance between the magnets when the hanging magnet barely begins to move illustrates the edge of the magnetic fields around the two magnets. Was there a difference when you brought the magnet towards the bare face of the hanging magnet and then towards the plastic edge? Is the magnetic field the same in each case?

When these magnets were constructed, they were put in the plastic holders so that the bare face of the red magnet (N) would attract the bare face of the blue magnet (S). This was done so that different poles were exposed. These poles are called north and south. The red and blue magnets each have a north and south pole. The bare face of the red magnet (with the letter N) is called the north or N pole; the other side of the magnet, covered by the plastic, is the S pole. The bare face of the blue magnet (with the letter S) is the S pole; the other side, covered by the plastic, is the N pole. What happens when the same poles of the red and blue magnets come together?
Slide one of the magnets out of its plastic holder. Move the side of the magnet without a letter towards the magnet still in its holder. What happens? You have brought two like poles (N-N or S-S) together. Was there a difference when you brought the N-S or S-N poles, which are unlike poles, together? What happened?
If you have other magnets, test them with the hanging magnet. Measure the distance at which attracting or repelling forces make the hanging magnet move. What conclusions do you draw from your observations?

Exploration 3: Finding Polarity Using a Compass



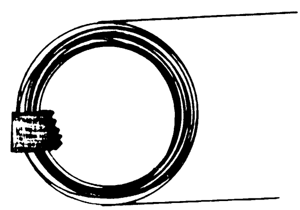
Take the blue plastic disk, the nail, and the compass needle from your Discovery Kit.
Insert the nail through the underside of the disk. Push it all the way through the hole so that the disk can be placed flat on a desk top. Place the needle on top of the nail. Which way does the red end of the compass point? Do you know how a compass works? The red end of this compass points south, and the other end points north. The earth is like a giant magnet and has a north magnetic pole and a south magnetic pole.
When your hanging magnet is very still, observe in which direction the bare face of the magnet points. Compare that direction with the needle of your compass. Did you expect this? Slowly bring the N pole of the red magnet toward the south end of the compass needle. What happens? Now bring the N pole of the red magnet to the north end of the compass needle. What happens? Try this using the blue magnet. Can you explain what you saw? Which end of the compass needle must be the N pole end? Which is the S pole end? Why do you think this is so?

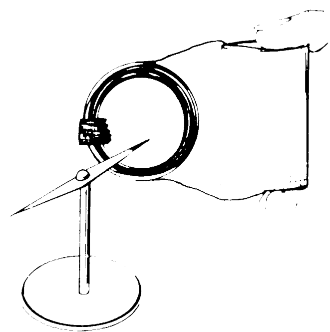
Additional Exploration
Using your hanging magnet, how could you tell which is the N pole end of an unmarked magnet?

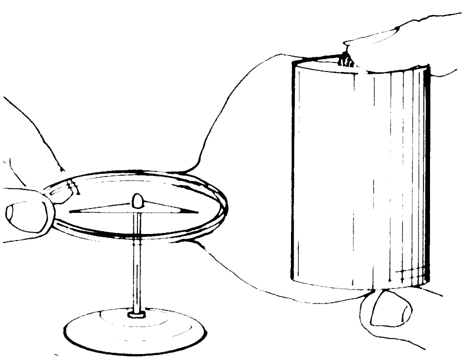
Exploration 4: Making an Electromagnet

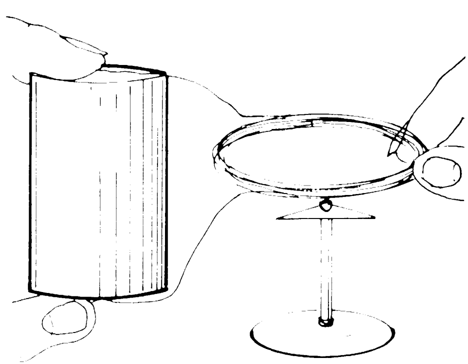
Some materials are naturally magnetic. The Chinese used a stone called lodestone to make compasses before Marco Polo's time. Today we can create magnets and magnetic fields by using electricity.

Step 1: Take the coil of wire from your kit. Hold the coil so that it doesn't come apart and remove the piece of tape that is holding the wire together. Unwind about 4 inches of wire from each end of the coil; then take another piece of tape and wrap it around the coil to hold the wire together as shown in the sketch. Scrape or sand the ends of the wire until they are bright and copper colored. Hold the ends of the wire to the ends of the battery. What happens? Turn the coil. What happens to the compass needle? Move the coil away from the compass and turn the battery upside down. Move the coil over the compass again. How does the compass behave? Rotate the coil slowly over the compass needle. Where does the needle point?





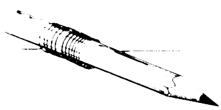


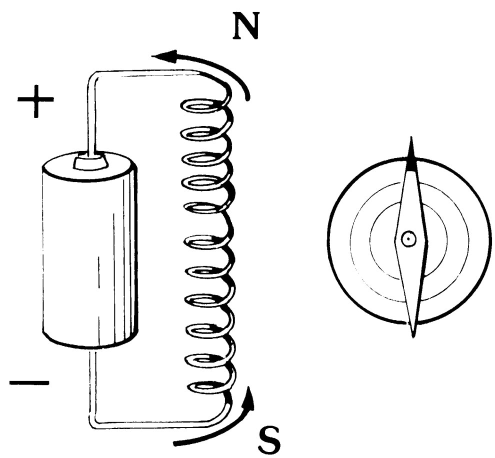


Step 2: Disconnect the coil from the battery. Put some thumb tacks or paper clips on the top of your desk. Connect the coil to the battery, and move the coil close to the thumb tacks or paper clips. What happens? Did you expect this?

Did you notice any difference in the way the compass acted when you brought your magnet near and when you brought the coil of wire near the compass? Use one of your magnets to see if the compass is affected by the magnet as it is by the coil of wire. What happened? Does the magnet affect the compass? Does it also pick up the iron objects? Did the coil do these things?

Step 3: Cut 18 inches off the end of the coil of wire. Scrape or sand both ends until they are bright. Carefully and evenly wind the wire at least 12 times around a pencil. Leave about 3 inches free at each end. Slip the pencil out of the coil of wire, and lay the coil in a north-south position. Connect the coil tot he battery. Keep the coil in a north-south position and move the compass near one end of the coil. What happens to the compass needle? Reverse the way the coil is hooked up to the battery. What happens? Did you expect this?





Does the coil make a magnetic field when it is connected to the battery? Disconnect the battery and move the compass near the coil. What happens? Put the compass along one side of the coil. Connect the battery. What does the needle of the compass do? Change the connections to the battery so that the current flows the other direction. Does the compass needle point the same direction? Does a current-carrying coil have magnetic poles? How could you find out?

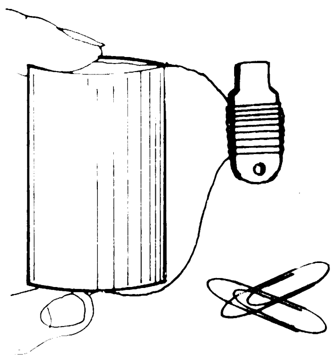
A magnet produces a magnetic field which affects the compass needle and it will pick up iron objects. A current-carrying coil also produces a magnetic field which affects the compass needle, but it will not pick up iron objects.

Save the 18-inch piece of wire to use in Exploration 5.

Exploration 5: Increasing the Strength of an Electromagnet

Straighten the wire you used in Exploration 4. Carefully wrap it around the motor shaft support in an even, parallel coil as shown in the sketch. Connect the coil to the battery and bring the end of the shaft support near some paper clips. What happens?

Disconnect the battery from the coil. Now try to pick up the paper clips. What happens? Why do you think this is so?



Re-connect the battery and hold your compass near one end and then the other end of the shaft support in the coil. What happens? Now reverse the battery and try this again. Is there a difference?

Bring the end of the shaft support near the paper clips again. With the wires still connected to the battery, slide the shaft support from the coil. What happens to the coil and the paper clips?

A coil of wire affects a compass needle when it is carrying a current in the same way that your magnet does. However, it is different than the magnet because the coil alone will not pick up iron objects. By wrapping the coil around the iron core of the motor shaft support, you made an electromagnet. The electromagnet picked up the paper clips when the electric current from the battery flowed through the coil. An electromagnet is a temporary magnet; the magnetism is there only when the electric current is on. Electromagnets are very useful. Huge ones are used to pick up complete automobiles in junk yards. By turning off the current, electromagnets release the objects they hold.

Additional Explorations

Does the amount of wire in the coil affect the magnetic field? Which would produce a stronger magnetic field: a coil of thin wire or a coil of thick wire of the same length? How would you find out? Would increasing the number of batteries have any effect on the magnetic field?

Exploration 6: Assembling an Electric Motor

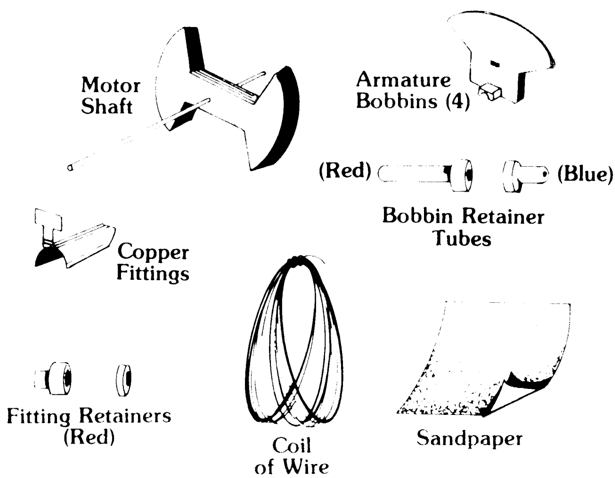
Electric motors couldn't work without magnetism. The electric motor in this kit contains two permanent magnets and two electromagnets. You have already observed three important principles that will help you understand how your electric motor works. These principles are:

1. A current-carrying coil acts as a strong magnet when it has a core; it is called an electromagnet.

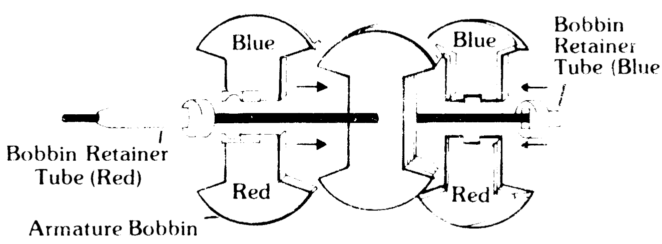
2. Unlike poles attract each other and like poles repel each other.
3. The poles of an electromagnet change when the direction of the current changes.
There are two main parts to your motor: the armature and the base. It is best to put these together separately, and then assemble the motor when they are complete.

Part I: The Armature

Armature is the name given to that part of the motor which turns when the motor is running. It is made up of electromagnets that are similar to the one you made earlier. To assemble the armature, find the following parts from your Discovery Kit:

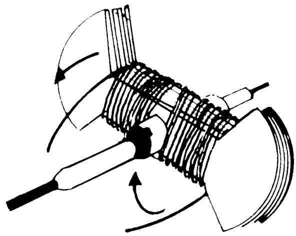


1. Take the motor shaft and place the plastic armature bobbins against the motor shaft as shown below. Both blue bobbins go on top and both red bobbins go on the bottom. Push the bobbin retainer tubes on the motor shaft to lock the bobbins in place; the red bobbin retainer tube goes on the long end of the shaft and the blue bobbin retainer tube goes on the short end.

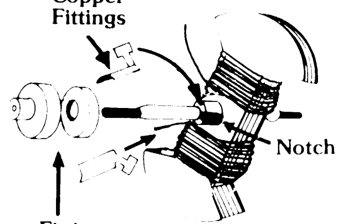


2. Slowly unwind the large coil of wire and then fold it in half, being careful not to kink it.

3. Hold the center of the piece of wire at the center of the motor shaft between the red and blue armature bobbins. Holding it firmly in place, wind the wire smoothly and tightly around the red side of the motor shaft in a clockwise direction as shown - making an even, parallel coil. This is your first row of wire. You will have enough wire to make at least four rows, back and forth, one on top of the other. The last row of wire should end near the motor shaft.



4. Now wind the blue side of the armature bobbin in the opposite direction (counterclockwise), making four rows of wire as you did on the red side, ending near the motor shaft. There will be some wire left over. Cut off a 5-6 inch piece of wire from both ends. You will need these two pieces of wire later.

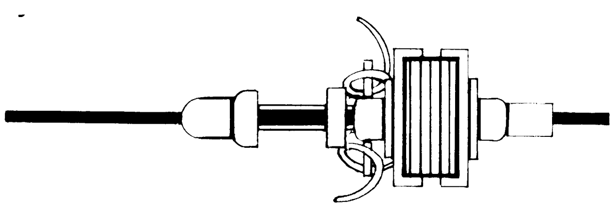


5. Place the copper fittings in the notches on opposite sides of the red bobbin retainer tube as shown. If the notches aren't on either side as shown in the sketch, rotate the bobbin retainer tube until the notches are in the correct position.

6. Lock the copper fittings in place with the fitting retainers (red). First slide the red ring over the copper fittings, then the end cap. It is important that the copper fittings are evenly spaced on wither side of the bobbin retainer tube. If the fittings are touching one another, the electric motor will not work.

7. Use sandpaper to rub the enamel off the last inch of each end of the wire near the motor shaft.

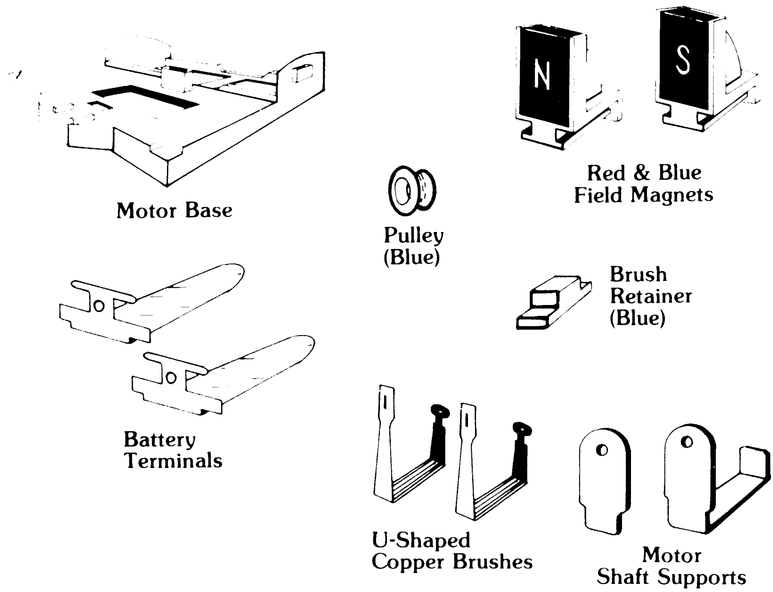
8. Wind the ends of the wire around the tabs on the copper fitting. Make sure the wire is tight. (See sketch.) Trim any excess wire.



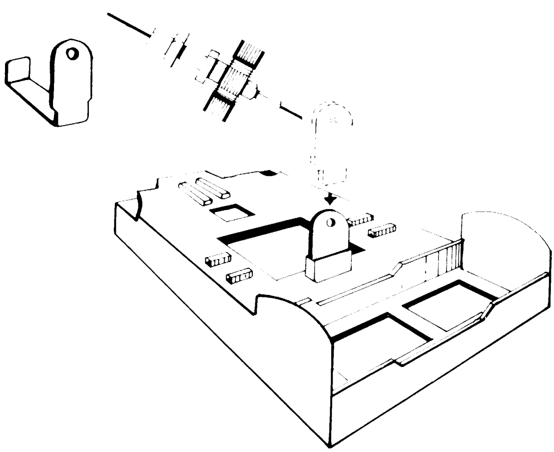
You have now completed the armature part of the electric motor.

Part II: The Motor Base

Lay out the remaining pieces as shown.

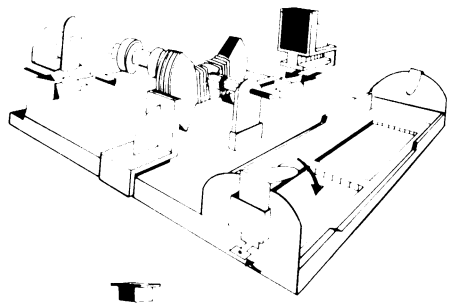


1. Push the straight motor shaft support into the slit in the motor base nearest the battery bed.
2. Fit the shorter end (blue) of the armature shaft into the hole of the motor shaft support.

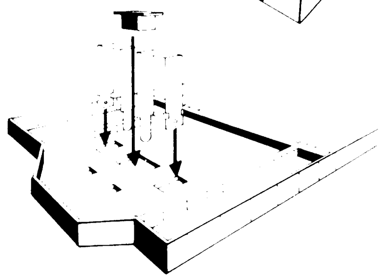


3. Put the longer end (red) of the armature shaft through the hole in the U-shaped motor shaft support.
4. Now slide the shaft support into the rails on the motor base. Leave enough room so the armature will turn freely.

5. Slide the two field magnet into the rails on both sides of the armature.
6. Push one of the metal battery terminals up through the slot on the battery bed. Bend the terminal down over the battery bed. Now do the same for the other terminal.

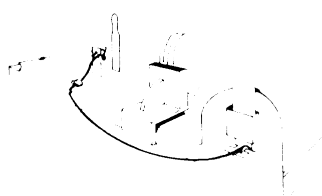


7. Turn the motor base over and fit the two U-shaped copper brushes through the three openings as shown in the sketch. The longer end of each brush should be in the center hole. When in place, the copper brushes should rest on either side of the copper fittings on the armature shaft.



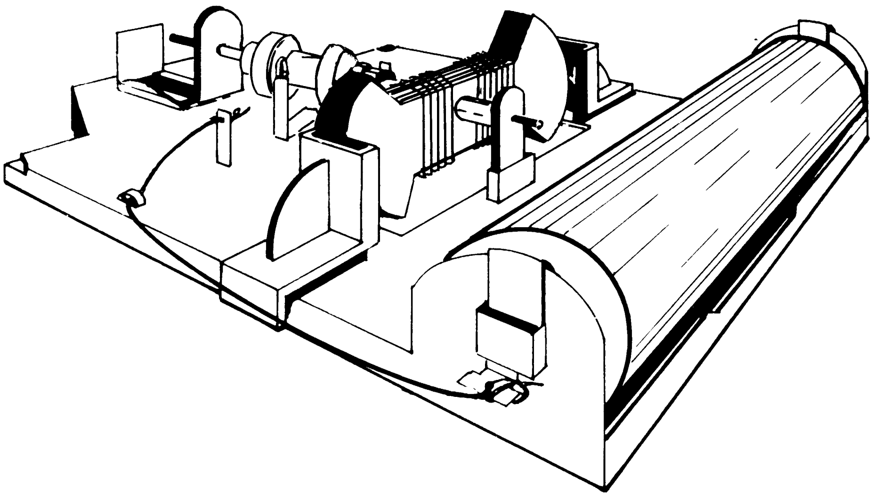
8. Lock the brushes in place by pressing the brush retainer (blue) into the opening.

9. Take the two 5-6 inch pieces of copper wire you saved in Part I, Step 4. Sand each end of each piece until it is bright and copper colored.
10. Take one end of each wire and pass it through the small holes on the motor base.
11. Attach the one end of each wire to the shorter end of each copper brush. Push the wire through the hole and wrap it around once to make it secure.
12. Attach the other end of each wire to a battery terminal.



13. Check to make sure that the longer end of each copper brush lightly touched the copper fittings (commutators). Slowly rotate the armature shaft with your finger and watch the copper brushes to make sure they are in direct contact with the copper fittings for the full rotation of the armature. If the brushes are not pressing firmly against the armature for the full rotation, use the tip of a pencil close to the base of each brush to carefully bend the brush into position.

14. Slide the pulley onto the long end of the motor shaft.
15. Insert the battery onto the battery bed. Make sure that each battery terminal touches one end of the battery. Your electric motor is now complete.



Start the motor by giving the shaft a turn. If it doesn't start, turn it in the other direction. If you have trouble starting the motor, re-check the assembly directions to see if you made a mistake. If you can't find anything wrong, ask your teacher for help.

Exploration 7: Testing the Electric Motor

Start your motor. In what direction does the shaft turn? Remove the battery and replace it so that it faces the other direction. Start the motor again. What happens? How can you tell which way the current is flowing?

Remove the battery from the battery bed. Remove the compass needle from the compass and insert the point of the nail up through the small hole in the battery bed. Place the compass needle back on the compass.

Which way does the needle point? (Remember that opposite poles attract and that the red end of the compass needle is the South pole).

Record the polarity of the red and the blue field magnets on a record sheet like the once shown on the next page.

RECORD SHEET			
Battery Head Facing Red Magnet		Battery Head Facing Blue Magnet	
	Polarity		Polarity
Red Magnet	__________	Red Magnet	___________
Blue Magnet	__________	Blue Magnet	___________
Red Bobbin Up	__________	Red Bobbin Up	___________
Blue Bobbin Down	__________	Blue Bobbin Down	___________
Red Bobbin Down	__________	Red Bobbin Down	___________
Blue Bobbin Up	__________	Blue Bobbin Up	___________

Put the battery in the battery bed so the button (positive pole) faces the blue field magnet. Start the motor to make sure it is still operating as before. Stop the motor with your finger and place the armature in a vertical position. Use your compass to determine the polarity of the armature magnets. You will have to bring your compass needle quite close to the end of the armature crossbar. The polarity of the end of the armature facing up can be determined with the motor base sitting on the table. The polarity of the lower end of the armature can be determined by lifting the motor off the table and bringing the compass needle underneath the motor base. Record the polarities on your record sheet. Do the same with the other end of the armature in the Up position.

Test each of the conditions shown on the record sheet. Compare the polarities of the armature poles and the polarities of the field magnets. Put the armature in the vertical position. Note from your record sheet what the polarities of the armature and field magnets are in this position. Turn the armature shafts slightly in both directions until the motor starts to turn by itself. Which field magnet was the Up end of the armature attracted to when the motor started to turn by itself? Does reversing the battery affect the polarity and direction of rotation? Can you make up a rule about the differences in magnetism between the magnets and the armature?

Are the magnets as close to the armature as they can be? While the motor is running, squeeze the two field magnets towards the armature until they almost touch it. What happens?

Note: Do not leave the battery in the holder when you are not running the motor. If you do, the battery will wear out very quickly. Why do you think this happens?

Additional Explorations

1. What kinds of work can your motor do? What kinds of work can it make other kinds of machines do?

2. Find some electrical machines at home (mixers, fans, etc.) and try to find out where the motors are in them. Without taking them apart, try to trace their circuits.

Dr. Lawrence F. Lowery is a professor of science education at the University of California, Berkeley. He has had extensive elementary and junior high school teaching experience, has written numerous films and books on science and has written many articles for teachers on science instruction.

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