#1 Two (2) Shaft Supports - 51-1355

#2 Two (2) copper wire coils, 40 inches long - 60-0135

#3 Two (2) Battery Clips - 26-1040

You supply one new AA or rechargeable Ni-MH battery.

#4 Two (2) Fasteners - 29-1038

#5 Two (2) Armature halves - 51-1350

#6 Insulating Tubing - 26-9214

#7 Motor Shaft - 31-0135

#8 Mounting Bracket - 51-1358

#9 Two (2) Wire brushs-

#10 Two (2) Commutators - 57-1005. Slide halves together as shown.

#11 Plastic Base - 57-0135

#12 Field pole - 51-1352

Tools Needed:
- Sandpaper
- Sharp knife, scissors, razor blade or wire cutters for cutting and scraping.
- Small screwdriver (slotted)
- Pair of needle nose pliers
- Ruler (below).

You need one (1) new AA battery, not included.

| Cut tubing in 1/4" and 7/16" pieces | Scrape wire 1" | (Armature ends, field coil end are 2"

<table>
<thead>
<tr>
<th>Inch Scale</th>
<th>1/4&quot;</th>
<th>7/16&quot; - cut 2</th>
<th>1&quot;</th>
<th>2&quot;</th>
<th>Cut wire in 1&quot;, 2&quot; and 6&quot; pieces</th>
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<tbody>
<tr>
<td>6&quot; (Leads to battery and field coil are 6&quot;)</td>
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You need one (1) new AA battery, not included.
Motor Assembly:

Important! The wire supplied has an insulating coating on it. Using sandpaper, clean the coating of insulation to a length of 1" off all wire ends.

A. Field Coil

1. Unroll one of the wire coils (2). Place the coil on one of your fingers and pull one end to unwind.

2. Cut off a 6" piece from one end (use the inch scale, Page 1.) Using sandpaper, scrape off 1" of the coating from each end. Place this piece to the side. (It will be used in Section E.)

3. Hold field pole (#12) and mounting bracket (#8) together. Using the coil of wire from Part 2, leave 2" of wire free. Begin winding the coil tightly around the two parts as shown in Diagram 1. Continue wrapping the coil until there are 6" left. Using sandpaper, scrape off 1" of the coating from each end.

4. Scrape 1" insulation off each wire end and set field coil aside.

B. Armature

1. Unroll the second coil wire coil. Using sandpaper, scrape off 2" of the coating from each end.

2. Put the two halves of the armature (#5) together with the motor shaft (#7) between them.

3. Leaving 2" of wire free, wrap the wire coil 8 times around one side and then cross over the other side and wrap the coil 8 times around that side. Repeat until there are 2" of wire left. See Diagram 2. Have the windings always go in the same direction and to have about the same amount of windings on each side.

C. Commutator (Diagram 3)

1. Cut a 7/16" piece of tubing (#6). Slide the cut piece onto the end of the armature shaft with protruding wires. Tubing must be pushed directly against the armature halves.

2. Place the halves of the commutator (#10) together as shown in the parts list on page 1.

3. On the same side as the tubing, slide commutator onto the armature shaft. Use the large center hole.

4. Run the wire from one side of the armature through one of the small holes of the commutator. Repeat with the wire from the other side of the armature. Both commutator halves must be at right angles to the armature. The holes should be vertical when armature is horizontal. Motor won't run well if this is not done.

5. Cut a 1/4" piece of tubing. Slide it onto motor shaft so that the commutator is held between pieces of tubing. Trim the wire extending after the commutator.

6. Cut a second piece of tubing 7/16" long and slide onto the opposite end.

D. Assembling Motor (Diagram 6)

1. Fasten the field coil assembly to the plastic base (#11) by pressing mounting bracket onto Hole #1 in Diagram 5. Wire ends should be pointing toward the middle of the base.

2. Place one shaft support (#1) into the rectangular hole closest to the field coil (Hole #7). The support should be perpendicular to the base. See Diagram 7.

3. Place the second shaft support (#1) into the rectangular hole farthest from the field coil (Hole #2, Diagram 6). The shaft support should be perpendicular to the base.

4. Loop the end of the 2" wire from the field pole (Step 3, Section A - Field Coil) around one of the paper fasteners and twist. Slide the fastener through Hole #3. (Do not open fastener yet.) See Diagram 9.

5. Loop the end of the 6" long single wire cut from the coil (Section A, Step 2 - Field Coil) through the other paper fastener and twist. Slide fastener through Hole #4. (Do not open fastener yet.) See Diagram 4, 5, 8.

6. Bend looped end of brush (#9) 90°. (See Diagram 4.) Flip the base over. Slide one brush through Hole #5. Then slide the loop at the end of the brush over the fastener in Hole #3. Spread the fastener open. Slide the second brush through Hole #7. Then slide the loop over the paper fastener in Hole #4. Spread the fastener open. See Diagram 4 and 5 for hole locations.

7. Using a light oil, lubricate the armature shaft joints. Then lay the armature on the two shaft supports and pop into place. (The commutator should be touching the brushes.) Diagram 10.

E. Connect Motor To Battery

1. Lace the end of the remaining wire from the field coil into the small hole in one of the battery clips (#3). Snap the battery clip into Hole #8.

2. Lace the remaining 6" wire into the small hole in second battery clip (#3). Snap battery clip into Hole #9. (Terminals on clips point away from each other.)

3. Place new battery in clips.

4. Spin the shaft by hand to get the motor started. See Diagrams 9 and 10.

Hint: Use a needle nose pliers to bend field coil uprights so armature turns freely but is not too far from uprights. (See diagram 8)
Experiments:
1. Put the battery in the other way. What does the motor do? Will it spin the same or opposite way? Answer this before you do the experiment.
2. What happens to the direction of shaft rotation if you turn the commutator 180°? Answer before the experiment.
3. Put the commutator in the same plane as the armature and try to run the motor. How important is the plane of the commutator relative to the plane of the armature?
4. Handle the shaft with your fingers as it rotates at low speeds. Note how the twisting force (torque) is not constant as the shaft rotates through one revolution. Plot out the graph of torque vs. angular position. Define 0° starting point for the armature, then feel the torque as the shaft rotates through 360°. Explain your graph.
5. Short out the commutator with fine wire. Attach two wires from each brush to an armature wire. What is the resting, stable position of the armature when power is connected? (Use short, quick connections.)
6. The field pole extends up and around the armature but has no wire around it. Do you need this? Could you wind wire around the middle of the mounting bracket instead? Unwind the field coil and remove it. Now wind the coil of wire back again and connect up the motor. Does removal of the field pole reduce the efficiency of the motor? Explain.
7. Connect 6-9 volt batteries to the motor. What happens?
   • How would you redesign the motor to run on 15 volts? Note the blackening around the brushes and commutator. Why does this happen?
   • Leave the motor going with 9 volts attached and run it to destruction. What part fails first? What part do you think would have failed next? Fix it if you can and run it again until it fails. This is called destructive testing. What does it teach you?
8. Try connecting an AC voltage source such as a 6-12 volt AC wall transformer in place of the battery. (Do not use the 110 volt line outlet directly as this is dangerous and will instantly destroy your motor!) Does the motor run? Why?
   Hint: This kind of motor is known as a universal motor. Explain.

Warranty and Parts:
We replace all defective or missing parts free of charge. Our products are warranted to be free from defect for 90 days. While we will gladly send missing parts promptly, we do not sell replacement parts singly.

Tools Needed:
Toy Motor in cost-saving bulk packs
10-137 - Enough parts for 30 students (15 instructions)
10-138 - Enough parts for 48 students (24 instructions)
Please contact us for current pricing.
Theory:
Every magnet has 2 poles - *north*, or *positive*, and *south* or *negative*. "Like" poles repel each other; "unlike" poles attract. One north pole repels another north and attracts a south.

The attracting and repelling of the magnets causes the motor to run. The field poles become an electromagnet when an electric current flows through the wire coil around them. The armature becomes an electromagnet when an electric current passes through its wire coil. The armature, however, produces a reversing magnetic field while the magnetic field produced by the field poles remains stationary.

The North pole of the field pole attracts the South pole of the armature, which turns in response to this magnetic attraction. But in order to keep the armature turning, you must break the current and change the polarity of the armature magnet. Otherwise the armature would remain permanently fixed in one position for as long as electric current was flowing and nothing would move.

Breaking the electric current through the armature and reversing its direction is done by a switch consisting of brushes and commutators. The commutators attach directly to the motor due to their location on the shaft and are connected to the armature by the wires threaded through them. The brushes rest lightly against the wires connecting the commutators to the armature. The brushes complete the electric circuit and enable the electric current to flow into the armature wires.

If the electricity always flowed in the same direction, the field magnet would pull the armature in the same position. It would freeze in this position and there would be no motion. However, just at the height of the attraction of field magnet for armature magnet, when the armature magnet has turned halfway around, the brush strikes the armature wires on the motor shaft to reverse the current's direction. Instead of flowing from the left wing of the armature through to the right, it now flows in the other direction, reversing North and South poles.

The arrangement of wires from armature through commutators is what causes this reversal. Remember that you twisted the wires 90° to position them at right angles to the armature. Due to this orientation, the armature magnet reverses itself as the armature turns halfway, and the armature completes its revolution as what is now a North pole is repelled by the North pole of the field magnet. The South pole of the armature will be continually turning in a series of half turns to seek the stationary North field pole.

The reason the armature revolves in a complete circle of 360° rather than flipping back and forth in half circles is because the momentum of the motor will carry the attraction of North and South a little past the point of peak attraction; as polarity changes, the armature completes its revolution in an attempt to "catch up" with the change in location of the poles.

What to do if your motor doesn't work:

1. Watch for tiny sparks between the brushes and commutator. Sparks indicate a complete circuit.
2. When spinning by hand to initially start the motor, you may feel resistance from the armature. If so, reverse the direction you are trying to spin the armature (or reverse the battery to spin the motor in that direction).
3. Check all electrical connections. Are they scraped free of insulation? (Places to check: both wires from the armature threaded through the commutators - one to the battery, one to the brushes; both ends of wire leading from the battery to the brushes.)
4. Use a multimeter to check for continuity. When the armature wires that run through the commutator are in contact with the brushes, the circuit will be complete.
5. Can the shaft spin freely by hand? If not, you may have to trim your tubing. (If the field pole interferes with armature rotation, gently bend it out of the way.)
6. Make sure holes in both commutators are at right angles to the armature.
7. Is your battery fresh? Try using more voltage up to and including a 9v battery.
8. Do both brushes contact the commutator lightly? Adjust by trial and error. If the brushes are too close together, they will not allow the commutator to spin freely.
9. Use an occasional drop of oil at both ends of the motor shaft where it meets the shaft supports.
10. The "bright" surfaces of the bronze wires may oxidize eventually. This may lead to poor contact between brushes and commutators. To prevent this, coat the "bright" surfaces with solder by "tinning" the surfaces using an electric solder iron.
11. To keep the armature and commutators at right angles to each other, you can apply some "super glue" to make a permanent bond at the contact points.
12. You may have to bend the field poles to get them close to the armature assembly. They should be as close as possible without touching.
13. Make sure the windings on the armature are even on either side, and go in the same direction.