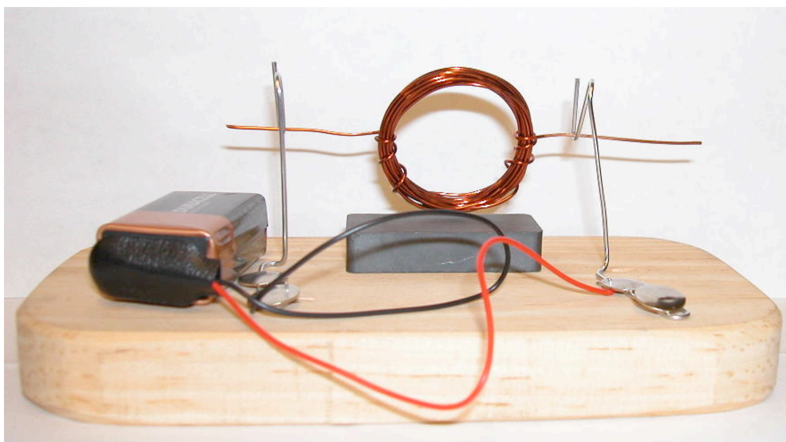
The Simple DC Motor:
A Teacher's Guide



Kristy Beauvais
Research Experience for Teachers
Center for Materails Science and Engineering
Massachusetts Institute of Technology
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Motor Design: Steven Leeb, MIT

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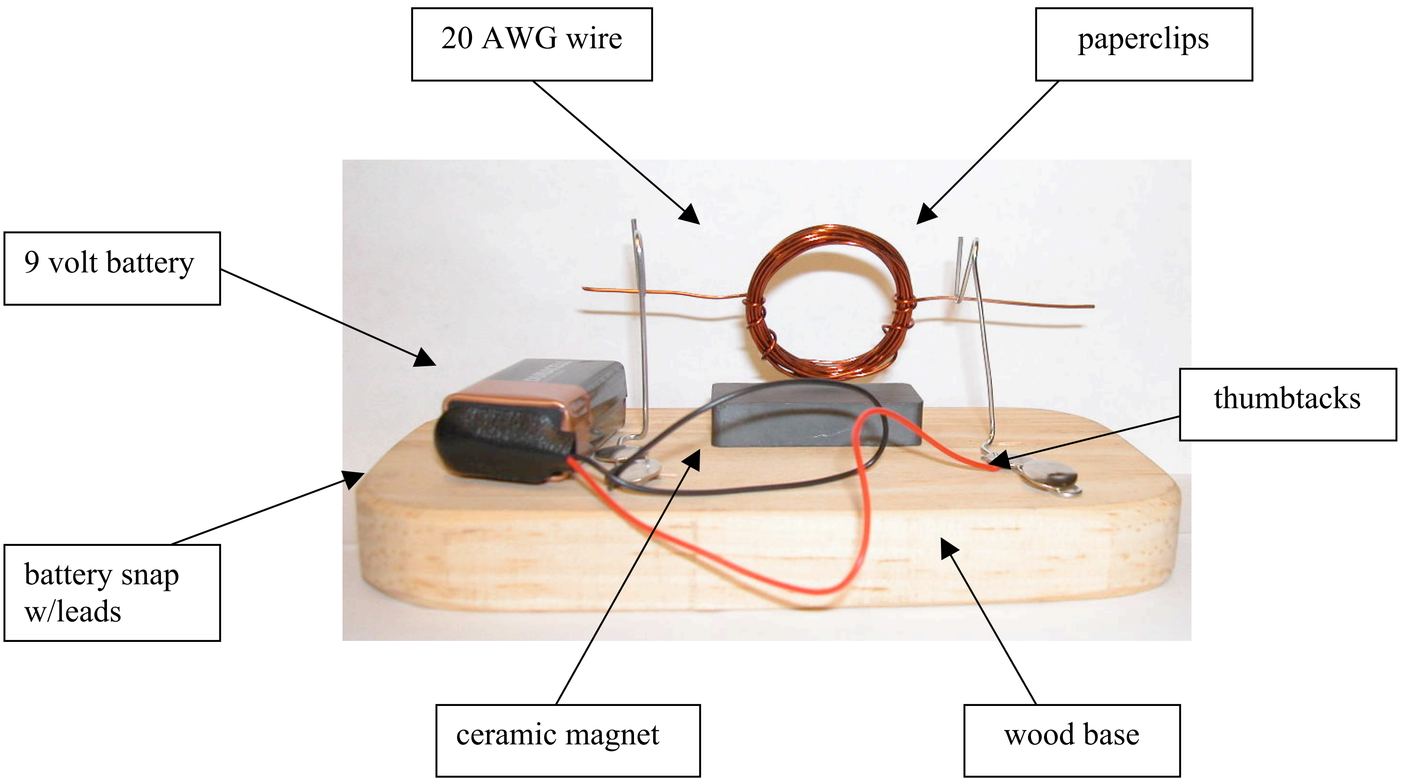
The Anatomy of the Motor:
What are its components?



The Physiology of the Motor:
How does it work?

Motors convert electrical energy (from a battery or voltage source) into mechanical energy (used to cause rotation).

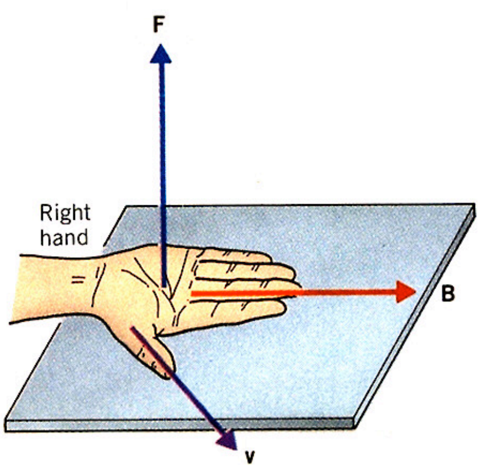
When a wire that carries current is placed in a region of space that has a magnetic field, the wire experiences a force.

- The *size* of the force, which determines how fast the motor spins, depends on :
  - the amount of current in the wire
  - the length of the wire
  - the strength of the magnetic field

Force = (current) x (wire length) x (magnetic field)

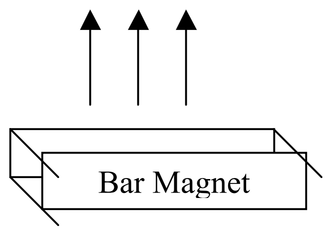
- The *direction* of the force, which determines which direction the motor spins, depends on:
  - the direction of the current in the wire
  - the direction of the magnetic field

  The Right Hand Rule is used to determine the direction of the force when the direction of the current and the direction of the magnetic field are known.



Thumb	=	direction of current
Fingers	=	dir. of magnetic field
Palm	=	direction of force

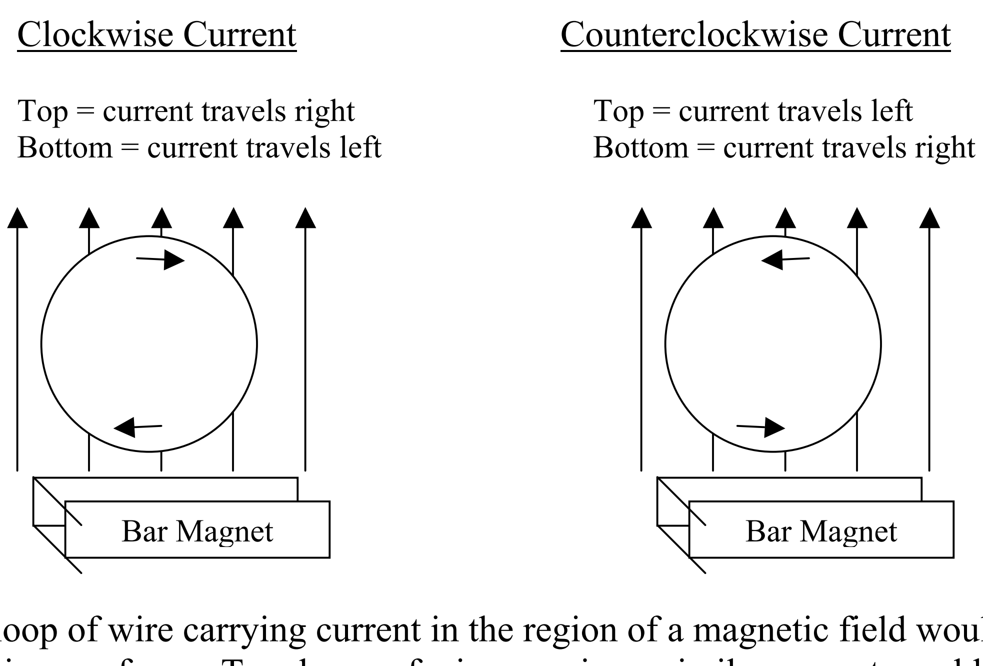
The ceramic bar magnet provides the magnetic field in this simple DC motor. With the magnet in position, the magnetic field is directed vertically (out of or into the magnet depending on which side of the magnet is exposed).



When the rotor sits in the paperclip supports so that the plane of the loop is oriented vertically, the **top and bottom sections of the loop act as current carrying wires in the region of a magnetic field.**

Q: Why only the top and bottom sections? Doesn't the rest of the loop matter?

A: Only the sections of wire oriented *perpendicularly* to the magnetic field experience forces. Since the magnetic field is oriented vertically here, only the sections of wire where the current runs horizontally matter (experience forces). The current only runs horizontally in the top and bottom sections of the loop.

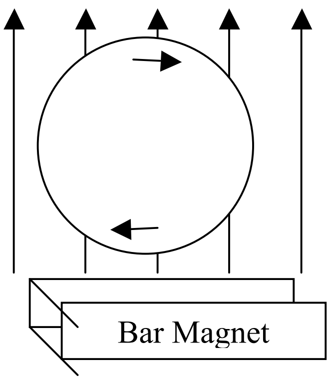


One loop of wire carrying current in the region of a magnetic field would experience a force. Two loops of wire carrying a similar current would experience twice the force. **If the rotor contains 12-15 loops of wire, it experiences 12-15 times the force of one loop.**

What about the direction of the force? As mentioned above, the direction of the force on a current carrying wire in a magnetic field, and thus the **direction that the**

motor turns, can be determined by the Right Hand Rule. Let's apply the Right Hand Rule to the simple DC motor.

Example: Consider the case where the bar magnet is oriented so that the magnetic field is pointing *away* from the magnet and the current runs *clockwise* in the rotor.



Top of Loop

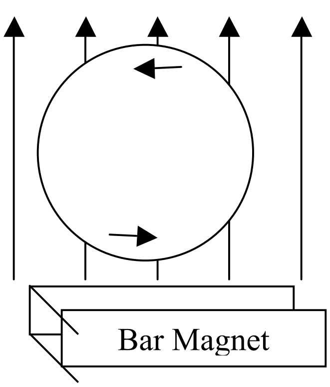
Thumb:	direction of current	= right
Fingers:	dir. of magnetic field	= up
Palm:	direction of force	= *out of plane of paper*

Bottom of Loop

Thumb:	direction of current	= left
Fingers:	dir. of magnetic field	= up
Palm:	direction of force	= *into plane of paper*

Since the top of each loop experiences a force directed *out* of the plane of the paper and the bottom of each loop experiences a force directed *into* the plane of the paper, the rotor experiences a "torque" or tendency to rotate. The greater the number of loops, the greater the experienced torque. Thus, the rotor begins to turn.

But…consider the rotor after the loop has completed a half of a turn. What *was* the bottom section (carrying leftward current) quickly becomes the top section; what *was* the top section (carrying rightward current) is now on the bottom. The current that used to be directed clockwise is all of a sudden directed counterclockwise.



A simple application of the Right Hand Rule would indicate correctly that while a clockwise current caused the motor to turn one way, a counterclockwise current causes it to turn the other way. More specifically, the top of the rotor used to experience a force directed *out* of the plane of the paper. Now, since the current has changed direction, the top of the rotor experiences a force directed *into* the plane of the paper. Here is the problem…

If left to its own accord, the rotor would never make a single complete rotation. The rotor would oscillate back and forth, first turning 180 degrees one way, then 180 degrees the other way, and so on, never completing more than a half of a turn. This would not make a very effective motor. Imagine the platform of a CD player that runs off of such a motor; the CD wouldn't even make it around once.

A simple technique that momentarily turns off the flow of current is used to eliminate this problem and thus allow for a rotor that turns continuously. Recall that on one of the straight sections of the rotor, only the *top* section is stripped. This is a key point since the circuit is only complete (and thus current only flows) when the paperclip supports are in contact with the stripped section.

- The rotor is given a nudge so that the stripped section comes into contact with the paperclip support.
- The circuit is complete, current flows, and the rotor experiences a torque in the direction determined by the Right Hand Rule.
- The rotor completes one half of a turn and the circuit is broken as the paperclip support comes into contact with a non-stripped section of wire.
- No current flows, thus no opposing forces are experienced and the rotor does not get pushed into a cycle of alternating half turns.
- Instead, the inertia from the initial half turn carries the rotor the rest of the way around until it has completed a single turn.
- At this point, the stripped section of the rotor again comes into contact with the paperclip support, completing the circuit and beginning the cycle again.
- The rotor spins continuously providing a working motor.

The *direction* that the motor spins can be controlled by varying the direction that the current runs through the rotor (by switching the battery leads) and varying the direction of the magnetic field (by flipping the magnet from one side to the other).

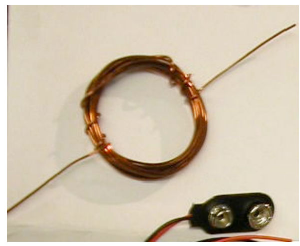
The *speed* at which the motor spins depends on the size of the force experienced by the wires that make up the rotor. Recall that the force experienced by each individual loop is determined by the amount of current in the wire, the length of the wire, and the size of the magnetic field. Thus, it is possible to increase the size of the force and thus the speed at which the motor turns by:

- Increasing the number of current carrying wires (number of loops in the rotor)
- Increasing the current in the rotor by using a bigger battery
- Increasing the current in the rotor by using wire with less resistance
- Increasing the size of the magnetic field by using additional and/or stronger ceramic magnets

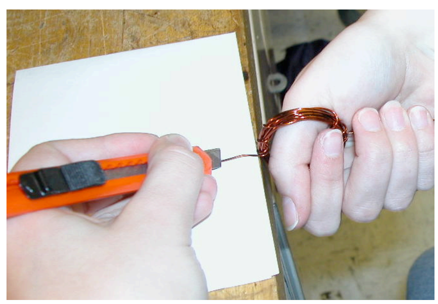
The Blueprint:

How to build a simple DC motor

1. Wind 20 AWG magnet wire around a small cylindrical object (i.e. film canister, D-cell battery) making 12-15 loops. This pack of coils is called the rotor. Leave about 2 inches of straight wire on each side of the rotor.

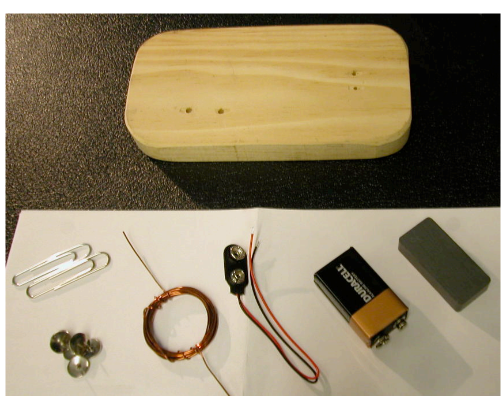


2. Hold the loop vertically by placing your thumb through the center of the rotor Place one of the straight sections of wire on a flat surface. Using a razor blade, strip ONLY the TOP surface of the wire. Be sure not to strip the sides or the bottom, just the top. Strip the wire from the coil all the way to the end of the straight section



3. Strip the other straight section of wire completely – top, bottom and sides.

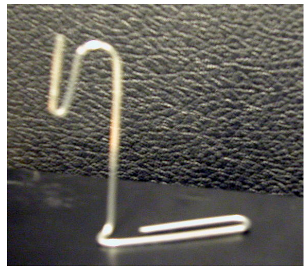
4. Prepare to assemble the motor.



Not Shown: electrical tape (optional)

5. Place the ceramic magnet in the middle of the wooden base.

6. Bend two large paperclips as shown below.



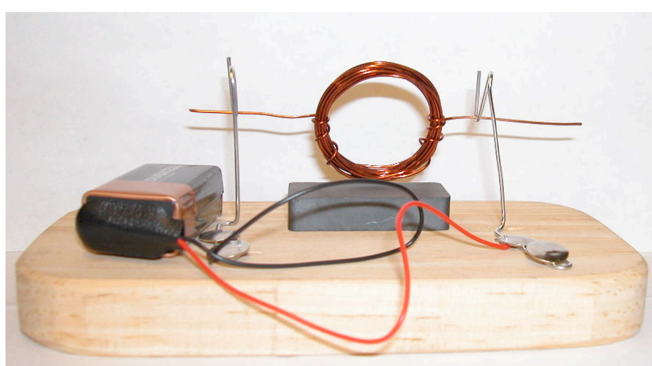
7. Using thumbtacks, secure the paperclips to the wooden base. Secure one paperclip at each end of the magnet.

8. Place the rotor in the paperclip supports. When the loop of wire is oriented vertically, the plane of the loop should be directly over the magnet. Adjust the magnet and/or supports accordingly.

9. Attach the battery snap to the battery. If desired, secure battery to base using electrical tape.

10. Touch (or secure with electrical tape) the black lead from the battery snap to the thumbtack that is securing one of the paperclips.

11. To complete the circuit, touch (or secure with electrical tape) the red lead from the battery snap to the thumbtack securing the other paperclip.



12. Give the rotor a little nudge:
    a. If the rotor spins… Ta-dah! A working motor!
    b. If the rotor does not spin…try giving the rotor a nudge in the other direction.
    c. If the rotor still does not spin…refer to the Troubleshooting Tips page.

13. Be sure to disconnect either or both leads to turn off the motor.

Troubleshooting:
What if it doesn't work?

- Has the rotor been stripped correctly? Hold the plane of the loop so that it is oriented vertically. One of the straight sections of the rotor should be stripped completely (from rotor to end); the other straight section should be stripped on the *top* only.

- Is the circuit complete? Check each connection: red lead to thumbtack, thumbtack to paperclip, paperclip to *stripped* section of rotor, other *stripped* section of rotor to other paperclip, paperclip to thumbtack, thumbtack to black lead. Any break in the circuit will prevent current from flowing and thereby prevent motor from working.

- Is the rotor level and directly above the magnet? Adjust the rotor, paperclip supports and magnet until both straight sections of the rotor are perfectly horizontal, both paperclip supports are at the same height, and the magnet is directly underneath the rotor when the rotor is oriented so that the plane of the loop is vertical.

- Is the rotor close to the magnet? The magnetic field is strongest nearest to the magnet. When the plane of the rotor is oriented vertically, the bottom of the rotor should be as close to the magnet (without touching) as possible.

- Is the battery providing power? Use a voltmeter or multimeter to check the voltage of the battery or simply replace with a fresh 9 volt battery.

Pre/Post Assessment:
What do I know about motors?

Part I. Fill in the blanks.

1. Motors are devices that convert _________ energy into _________ energy.

2. The basic principle behind the simple DC motor is that wires that carry _________ experience _________ when placed in regions of space that have _________.

3. Only sections of wire that carry current in a direction _________ to a magnetic field experience forces.

4. The speed at which the rotor of a motor spins depends on three important factors: _________, _________, and _________.

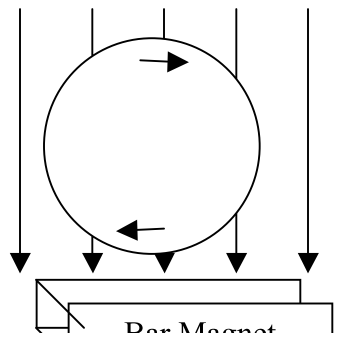
5. The direction that the rotor of a motor spins depends on the _________ rule.

Part II. Multiple Choice.

1. Which of the following changes to a motor might *decrease* the speed at which it spins?
   a. Using two magnets instead of one
   b. Using two batteries instead of one
   c. Using a rotor with only six loops instead of twelve

2. When using your hand to determine the direction that the motor spins, your thumb always points in the direction of
   a. The current
   b. The magnetic field
   c. The force experienced by the wire

3. Consider the motor shown below. The magnetic field is oriented vertically so that it is directed into the magnet. The current runs through the loop in a clockwise manner. What will the direction of the force on the *bottom* section of the rotor be?



   a. Into the plane of the paper
   b. Out of the plane of the paper
   c. No force will be experienced by the bottom section

4. Consider the motor in the previous question. What will happen to the direction that the motor spins if the bar magnet is flipped so that the direction of the magnetic field is reversed AND the battery leads are switched so that the direction of the current is reversed?
   a. The motor will continue to spin in its initial direction.
   b. The motor will reverse the direction that it spins

5. Two students build a DC motor during class one day. When stripping the rotor, the students don't follow the directions exactly… instead they strip both straight sections completely – top, bottom, and sides. What will happen when they try to run their motor?
   a. The rotor will spin, but more slowly than it would have if they had stripped correctly
   b. The rotor will remain stationary, not moving at all
   c. The rotor will oscillate back and forth but never make a complete turn

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Part III. Extension Questions.

1. Give three examples of motors that you see working inside the classroom.

2. Give three examples of motors that you see working outside of the classroom.

3. Engineers often find that while increasing the value of a variable may be beneficial to a desired outcome, a critical point is often reached where increasing the value of that variable any further actually works against them. With the simple DC motor, the number of loops in the rotor acts as such a variable.
   a. Explain why increasing the number of loops is initially beneficial.
   b. Explain why there is a limit to increasing the number of loops. In other words, why is it that at some point, increasing the number of loops does not increase the speed at which the motor spins?

4. A fellow student suggests making a square rotor instead of a circular one. She proposes that using a similarly sized square rotor will actually allow the motor to spin faster. Do you agree with her? Why or why not?

5. The directions for building the motor require one straight section of rotor to be stripped completely and the other straight section to be stripped on the *top section* only. A fellow student theorizes that in fact, both straight sections need to be stripped on the top only.
   a. Is the student correct? Would the motor work if stripped as he suggests?
   b. If not, why not?
   c. If so, why do you suppose the directions require one side to be stripped completely?

Supply List:

Where can I get the materials?

Item	Suggested supplier	Cost
Wood Base (5 x 7 in)	• School woodshop • Home Depot (2' x 4' cut into pieces) • Craft store (pre-cut project board)	$0.50-$3.00
Rectangular Ceramic Magnet	• American Science & Surplus (847) 647-0011 www.sciplus.com product # 10584	$1.25 ($2.50/pkg 2)
Magnet Wire (20 AWG)	• Marlin P. Jones & Associates, Inc. (561) 848-8236 www.mpja.com product # 7255 WI	$0.25 ($6.95/100 ft)
9-Volt battery	• Local electronics/hardware store (ex: Radio Shack, Home Depot)	$1.50-2.00
battery snap (w/leads)	• Local electronics store/hardware store (ex: Radio Shack, Home Depot)	$0.25-$0.50
large paper clips (2)	• School stock room • Office supply store (ex: Staples)	$0.01 ($5 / box 1000)
thumbtacks (4-6)	• School stock room • Office supply store (ex: Staples)	$0.01 ($0.25/ box 100)