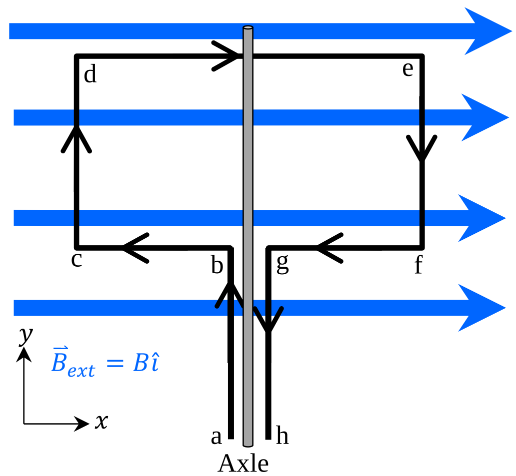
Motors

Apparatus (groups of 2 for this lab): Scissors, template, tape, 2 large paper clips per group, 5 m motor wire per group (28-30 gauge has worked, higher gauge means easier to rotate but also easier to break when sanding), two 8" segments of bare wire per group (probably 28 gauge so it to flexes with commutators), sandpaper, dissection needles, DMMs, Power Supplies, 1-Ohm power resistors, magnifiers

A current-carrying loop of wire is shown at right. Assume a battery is connected to points **a** and **h** so current flows clockwise around the loop as shown. Using the right hand rule determine the **direction** of the force experienced by each segment of wire in the loop pictured below.



$\hat{F}_{ab}$		$\hat{F}_{ef}$	
$\hat{F}_{bc}$		$\hat{F}_{fg}$	
$\hat{F}_{cd}$		$\hat{F}_{gh}$	
$\hat{F}_{de}$			

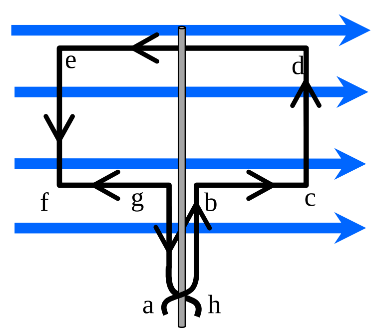
Rank the sizes of the forces clearly indicating any ties. Assume segments ab, cd, ef, & gh are equal length.

What is <u>net</u> force on the loop? Briefly explain your reasoning.

Which forces will be the dominant contributors to net torque on the loop? Briefly explain your reasoning.

What direction is standard for describing the torque direction on the loop at the instant shown.

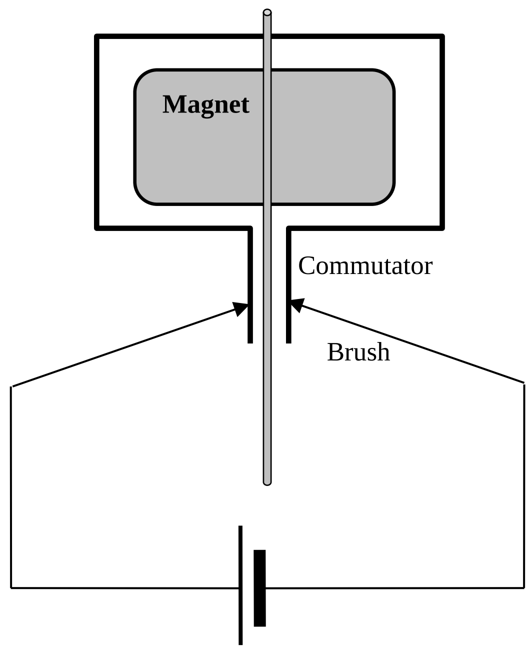
Assume rotates 180° about the vertical axle. Assume wire segments ab & gh twist around the axle slightly resulting in current flowing around the loop *in the opposite direction*. What happens to torque on the loop? Briefly explain why brushes and commutators required to keep the motor spinning (see next page for more information on this).



In order to make a motor useful one typically wants to reverse the direction of the current flow every time the loop rotates 180º. To do this one cannot have the wires being permanently connected at **a** and **h**. Wires or pieces of metal are used to lightly brush against the wire segments **ab** and **gh**. These wire segments are called, ingeniously, **brushes**. The wire segments **ab** and **gh** are called **commutators**. The net effect of using brushes and commutators is to keep torque on the loop acting in the same direction even when the loop flips 180°.

Visit the following website to get a feel for how the motor works. The animation is useful.
http://www.walter-fendt.de/ph14e/electricmotor.htm

On the following page is a top view of what your constructed motor will look like. Note that upon a half-revolution the commutators will be connecting to opposite brushes. This causes the current to still continue clockwise through the loop and thus causes the loop to experience a torque which keeps the loop rotating.



Construct the motor using the template on thick paper. Tips on construction:

- Be extremely cautious about properly sanding wires for making electrical contact. Once you put the motor together it is difficult to re-sand a wire without mutilating your commutators.
- Be careful cutting out the box. Small errors propagate and cause shoddy construction. Shoddy construction creates unnecessary friction which makes the motor unable to run.
- Every loop counts so don't get sloppy. **Be sure you always wrap the loops in one direction.**
- When you get ready to run the motor be careful to TURN OFF THE POWER SUPPLY IF THE MOTOR ISN'T RUNNING. If the motor doesn't turn and the power is on you might ignite it.

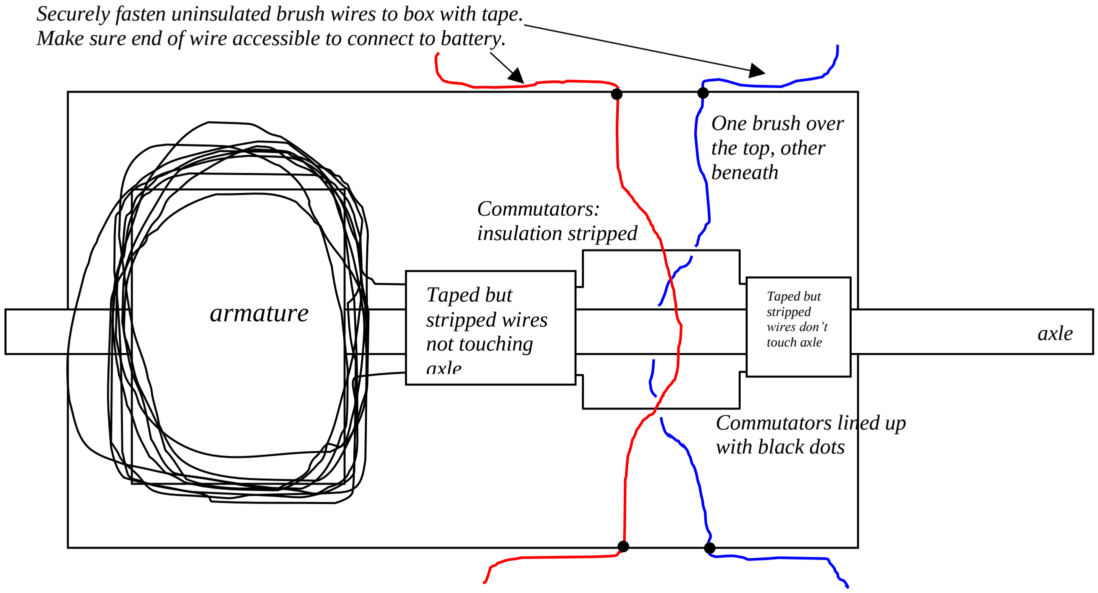
Stage 1

1) Cut out both the box portion and armature portion of the motor template on solid lines.
2) Fold both parts on dotted lines.
3) Punch holes in black dots.
4) Tape the box portion into a shoe-box shape and tape it securely (see instructor's motor).
5) Fold the armature over on itself (see instructor's motor).
6) Pierce a straightened paper clip thru the black dots on the armature. This paper clip will be the axle of your motor so try to make it as straight as possible.
7) A tiny piece of tape can be used to keep the armature from sliding around on the axle.

Stage 2

1) Take the 5 m portion of enameled motor wire and sand about 3" on each end.
2) Check if the ends are adequately sanded with a DMM. Use the diode setting and listen for the beep. A solid beeping tone indicates all the insulation has been properly stripped. Check both sides of both ends for solid tone. Repeat the sanding until this is the case.
3) Wrap the 5 m wire around the armature over and over in the same direction until all 5m has been used up. The small portions of stripped wire should remain along the axle.

4) At this point your armature should look approximately like the picture on the next page. The stripped portions of the 5m wire are going to become your commutators. Try to bend them into the shape shown in the picture. Try to make the commutators symmetrical.



Stage 3

1) Now run one of the "brushes" (the non-insulated wire) over the axle and commutators and thru the black dots. Run the second "brush" under both the axle and the commutators.
2) Align the brushes so they make contact with the commutators when the commutators and armature are vertically oriented.
3) Your commutators and brushes must make good electrical contact when the wire is vertically oriented regardless of which commutator is touching the top or bottom brush.
4) Check the electrical connection using the diode mode of your DMM. See stage 2 step 2 for instructions. Be sure to rotate the armature 360 degrees. You should hear a beep every time the armature is vertically oriented.

Stage 4 (READ ALL INSTRUCTIONS FIRST OR YOUR MOTOR MAY BURST INTO FLAME!)

1) Connect one lead of a power supply to a small resistor (say 1 Ohm).
2) If the power supply has a current limiter, set it to maximum. Set the voltage to 5 V. Verify your power supply is giving you 5 V with the DMM.
3) Connect the resistor to one of the brushes.
4) Connect the other lead of the power supply to the other brush.
5) "Kick start" the motor by flicking it lightly with your finger. You will probably see a few sparks. If the motor stops you should IMMEDIATELY turn off the voltage or you will burn out your motor and cry.
6) If you have trouble try increasing the voltage to get the motor started.
7) Optimize your motor by tweaking the commutators and brushes to reduce the minimum operating voltage. To improve the motor you want the brushes in contact with the armatures for as much time as possible without causing too much friction.
8) Check for and reduce friction on the axle.

If you get you motor to twitch but not turn over you get 7 points out of 10.
1 extra point for the first page of the lab handout correctly completed.
1 extra point for running the motor on a power supply and completing the data table below.

- TIP: record a video of the power supply as you lift the paper clips to get data!
- TIP: Use the most sensitive balance in the room to get at least 2 sig figs for mass of the paper clip.

1 extra point for completing the conclusion questions (on next page).

- Include some words which explain what question was asked (don't just do the math).

Optional: 1 extra point for completing computation of duty cycle and RPMs (discussed after conclusion questions).
Scores over 100% on this lab are possible.

CONCLUSION QUESTIONS ON THE NEXT PAGE.

	Use appropriate sig figs & include units
Power supply voltage used to lift paper clip	
Average current at that voltage	
Power **input** to motor ($P_{in}=I_{avg}\Delta V$)	
Mass of paper clips lifted	
Distance paper clips lifted	
Energy expended lifting the paper clips	
Time to lift the clips	
Power **Output** of Motor ($P_{out}=E/t$)	
Efficiency ($\eta=P_{out}/P_{in}$)	

Conclusions:

1) For typical student motors with no resistors in series, the power supply usually shows an applied voltage of 5.0 V with average current of 0.50 A (actual numbers vary wildly). That said, a quick calculation might make you think your coil resistance should be *about* 10 Ω…right? Let's learn more…

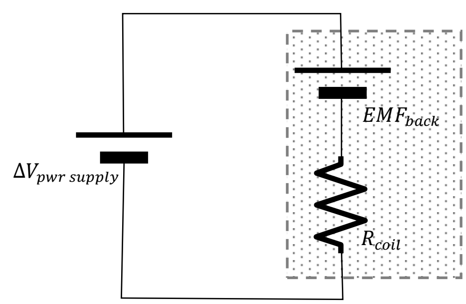
a) Determine the *actual* resistance of your coil using $R_{coil} = \frac{\rho L}{A}$. Look up the resistivity of copper online (citing your source). Look up the diameter of your particular choice of wire (cite your source). Assume you used 5.00 meters of wire to make the coil.

b) The resistance found in the previous part is the true resistance in your coil. Assume current is actually flowing in the motor only 20% of the time (duty cycle of 20%). What is the *expected* average current for a 5.0 V potential difference was applied to your coil's resistance? Hint: use Ohm's law and multiply by the duty cycle to get the average *expected* current.

c) In practice, the coil spinning in the presence of an external magnetic field creates *back EMF*. If we ignore the internal resistance of the power supply, we might model this scenario using the circuit shown at right. Notice the back EMF of the motor effectively cancels out part of the applied voltage from the power supply. In equation form we could write

$$\Delta V_{pwr\ supply} - EMF_{back} = i_{avg\ in\ actual\ experiement} R_{coil}$$

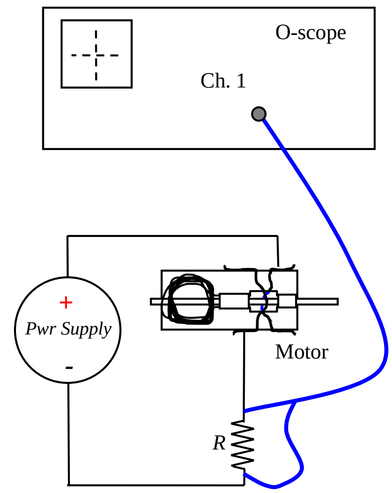
Use this equation to estimate the size of the back EMF for the your motor. Note: if you get a negative number for back EMF, talk to your instructor.



More on Back EMF and motor limitations: A coil moving in the presence of a magnetic field can experience an *induced EMF*. In this case, the motor coil has an induced EMF that is called a *back EMF*. This back EMF acts somewhat like a battery that OPPOSES current flow in the motor. So in your motor the power supply tries to spin the coil one direction while the back EMF tries to oppose that spinning motion. This is why it is important to unplug the motor if it stops spinning – when the coil is motionless no back EMF is produced and much more current flows (which burns out the motor). The back EMF effectively reduces the voltage applied to the circuit. Read the section in your book on back EMF.

There will also be drag on the motor as it spins. It turns out that both the drag and the back EMF increase with rotation rate. Friction between moving parts will also tend to inhibit the motion of the motors. As the current flows the wires get hot and reduce the current from an initial maximum. All these factors (some more than others) will contribute to setting an upper limit on the speed of the motor. Furthermore, one cannot simply apply more and more voltage to speed it up or the wires will melt!

The duty cycle and RPM measurements are <u>optional</u> for 1 extra point (scores over 100% possible). First finish all other parts.



To measure duty cycle, run the motor with a 1-ohm power resistor in series off the power supply. Use an oscilloscope to measure the voltage across the 1-ohm power resistor just like you would with a DMM. See the figure at right for what the circuit might look like. Finally get your motor running.

Once the motor is running, the scope will display voltage versus time data for the power resistor. The signal will be pretty messy looking. Try adjusting the horizontal divisions knob on the far right side of the scope until you see what looks like 4 to 8 messy blobs on your screen. Hit the RUN STOP button to capture a cycle.

Look closely at the messy patterns. Hopefully you see a messy blob, then a second messy blob with different shape. Hopefully you notice a third messy blob which looks nearly identical to the first. The fourth messy blob should look like the second blob. The idea is the odd blobs correspond to your commutators in one orientation while the even blobs correspond to the commutators rotated 180 degrees.

If the voltage is *zero* across the resistor (in series with your motor) we know the motor is *not* receiving power.
If the voltage is *non-zero*, the motor *is* getting power.
Duty cycle is the percentage of time the motor receives power.

To measure RPMs, determine the *period* of your motor's waveform.
This is the time for one full revolution.
Remember: the time for a revolution should correspond to the time between the start of the first messy blob to the start of the *third* messy blob!!!
Do a conversion to get RPM.

Duty Cycle (% of time current runs in motor)	
Period	
RPM	

Ideally you could figure out a way to include a printout of the waveform from the scope as well.