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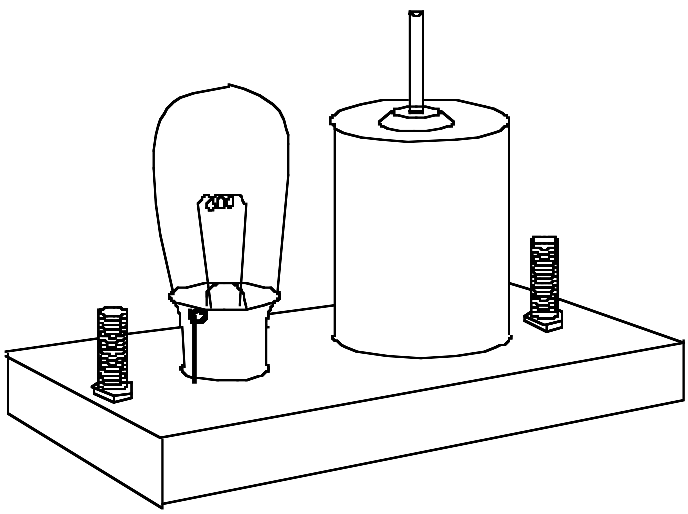
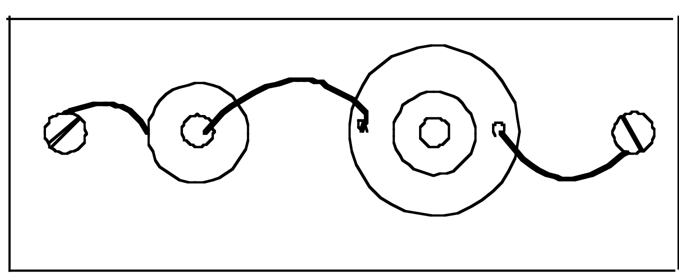
Small motor in series with light-bulb demonstration

This demonstration illustrates how an electric motor draws more current at lower rpm and also produces more torque at lower rpm. The demonstration can be useful in helping students understand how a motor also acts as a generator producing maximum back emf at maxim rotational speed.[1,2,3] This in turn can help them to understand Lenz's law.

The apparatus can be conveniently attached to a small board with properly drilled holes. The bulb and motor are wired in series and attached to the binding posts at either end of the board. See illustration below:



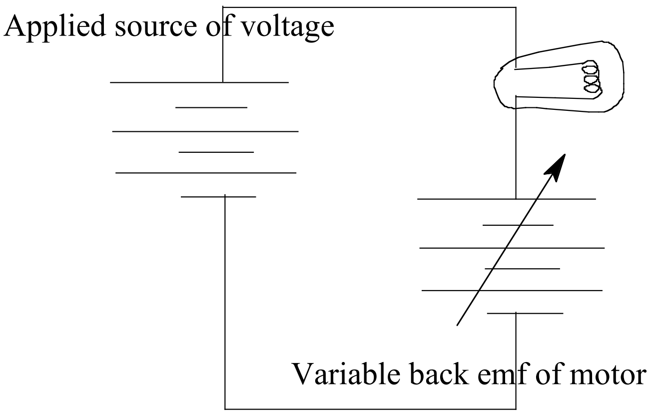
Bottom view of series wiring



As shown in the bottom view, the bulb and motor are wired in series and are attached to the binding posts on either end. The demonstration begins with a source of potential difference attached to the binding posts and set to about the maximum rating of the bulb and motor separately. (Ideally this will be the same for each.) When the voltage is applied, the motor will spin rapidly and the bulb will not light. Ask the students what will happen if the shaft of the motor is grasped slowing it down. Most will correctly answer that the bulb will light as the motor rotates more slowly. However, when asked to explain why, many will incorrectly suggest that since less power is going to the motor, more must go to the bulb. Even when it is stressed that the same current must pass through the motor and the bulb, they may still hold on to this misconception.

Your explanation should help the students to understand that the motor is actually using little power when it is spinning at maxim rotational speed and only when you grab the shaft does it begin to do work. Stress that the motor is also a generator and when spinning at a smaller rpm, it develops a smaller back emf. (An application of Lenz's law.) Since the motor in series with the bulb now has a smaller back emf, it allows more current to flow through both the series bulb and motor. finally supplying enough power to the bulb to light it. The total potential difference across the motor and bulb remains approximately constant (depending upon the power supply) and since the potential difference across the bulb is larger as the motor slows, the bulb now receives enough power to light. However, both motor and bulb are passing more current as the motor rotates at a slower rpm against the frictional force of your thumb and finger.

The following diagram and discussion may help to make the demonstration clear:



The applied source of voltage remains essentially constant. However, the back emf of the spinning motor will change depending on the speed of the motor. When the armature is completely stopped, it acts as a wire with essentially the entire applied voltage across the bulb. The bulb will glow brightly. As the motor spins faster and faster, the armature is moving at a greater rate through the magnetic field of the motor's field magnets, producing a greater back emf. At maximum rotational speed, the back emf of the motor nearly equals the applied voltage and will leave only a small potential difference across the bulb. The lower voltage across the bulb and decreased current through it will not provide enough power to make the bulb to glow.

A nice consequence of this demonstration will lead to a discussion of how an electric motor develops maximum torque at zero rpm. This makes it possible for electric cars to do without clutches and transmissions. The internal combustion engine requires a minimum rpm to set the car in motion; hence the transmission and clutch insure this minimum rpm is reached before the power is connected to the wheels. Also, since electric motors are also generators, this makes regenerative breaking possible. Rather than wasting the kinetic energy of the car on friction brakes, the kinetic energy of the moving car can be used to charge the batteries while breaking.

1 The first time I saw this demonstration was in the old high school text *Modern Physics* by Dull, however this book seems to be lost. A more "recent" version contains a detailed discussion in chapter 24 Electromagnetic Induction, page 509-10; section 15
2. *Modern Physics* by Williams, et al. Holt, Rinehart and Winston, Inc. 1968
3. *Demonstration Experiments in Physics* by Sutton McGraw-Hill Book Company, Inc. 1938 page 347; E-230 Counter Electromotive Force in a Motor.