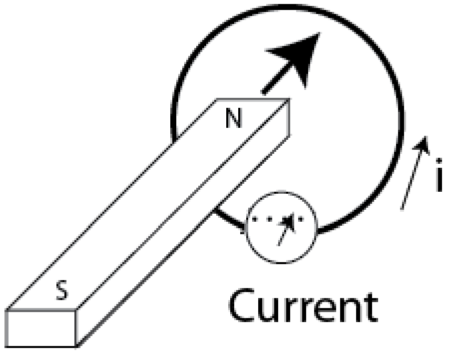
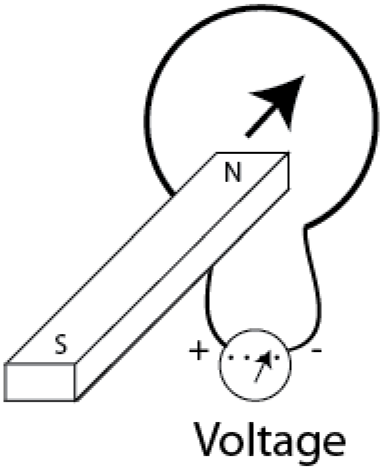
Since spring-break we have been discussing the interaction between electric currents. We have learned that a current creates a magnetic field and vice versa that a wire that carries a current and is placed in an external magnetic field feels a force exerted on it.

This week's lab is about a third effect. We will see that a changing magnetic field creates an electric field. If this electric field is near a conductor that is part of a complete circuit, a current will be generated in the conductor. We call this the induction current since the current is induced by a changing magnetic field. If the conductor is not part of a complete circuit then a electric potential will be measurable across its terminals. We call this the induced voltage or the induced emf.





DEMO1a: Do the experiment with the provided setup and show that when you move a permanent magnet in a coil connected to a meter, the meter gives a deflection when you move the magnet in the coil or pull it out of the coil.

Note that we say a changing magnetic field. So just a static magnetic field around a magnet that is moved around will not create an electric field, so no induction current will be observed in a wire loop or coil that is part of a complete circuit and that is placed in a constant magnetic field and no induction voltage is measured across the terminals of an open loop that is placed in a constant magnetic field. See also the drawings below.

DEMO1b: Show that just holding the permanent magnet in the coil does not give a deflection of the meter.

The effect that a changing magnetic field creates an electric field was first discovered by Faraday. It couples electric and magnetic fields to each other, i.e. changing magnetic fields cause electric fields. Although you will more specifics about this law in the lectures for today's lab-assignment we will use the following form of Faraday's law:

$$V = -\frac{d\Phi_B}{dt}$$

Or in words the induced voltage measured around a closed loop is equal to the derivative of the magnetic flux that goes through the loop. I hope that this equation is not intimidating to you. Magnetic flux, although maybe not discussed in class yet, is similarly to electric flux, but now we use the magnetic field vector:

$$\Phi_B = \iint \vec{B} \cdot d\vec{A}$$

The integral is taken over the area enclosed by the loop. If we consider that the magnetic field is everywhere the same within the loop, and everywhere perpendicular to the loop we can simplify this expression to:

$$\Phi_B = \left|\vec{B}\right| A$$

Where B is the magnitude of the magnetic field and A is the surface area of the loop. So by moving the permanent magnet closer to the loop, we change the magnetic flux through the loop and according to Faraday's law an induction voltage is created in the loop. The larger $d\Phi/dt$, i.e. the faster we move the magnet towards the loop, the larger the induced voltage.

Faraday's law is important for a lot of applications such as motors, generators, and transformers. This is a little hand-held generator that contains a coil. By cranking the handle, a permanent magnet is rotated near a coil and continuously produced a $d\Phi/dt$ in the coil, generating an induced emf across its terminals. If we complete the circuit and connect a lamp to the generator, the induced emf will cause a current through the lamp and let it glow.

DEMO2: Demonstrate this with the provided generator.

Note that Faraday's law has a negative sign it it. So the induced emf, or the induction current is opposite to the Flux change. So if we increase the magnetic flux through a closed coil, the induction current through the coil creates a magnetic field that is opposing this flux change, creating magnetic field opposite to that of the magnet that you are trying to push into the coil. Note that the induction current through the coil will turn the coil in a electromagnet. The north pole of that electromagnet is pointing towards the north pole of the bar magnet you are pushing into the coil, repelling the bar magnet. So you need to do work to move the magnet in the coil. Similarly if you pull the magnet out of the coil, the decreasing flux creates an induction current in the opposite direction, creating an electromagnet that has now a south pole pointing toward you. This south pole attracts the north pole of the bar magnet that you are trying to pull out of the coil, so again you have to do work. This is called Lenz law and is responsible for some interesting effects:

Demo3: now demonstrate the falling magnet through the copper tube, the pvc tube, and the brass tube. If you use the pvc tube, make sure you drop the magnet in a beaker with tissues, as those small rare-earth magnets are brittle an can easily break if you drop it on the floor from 2 meter height.

Demo4: Demonstrate the Gauss gun. Emphasize the difference between the continuous ring and the open ring.

By the end of the lab assignment ask them whether or not they think that the magnet in their experiment is slowed down by the coil. In order to help them answer that question, ask them whether their coil is part of a complete circuit, or an open circuit? Do you measure the induction voltage or do you measure the induction current with the setup.