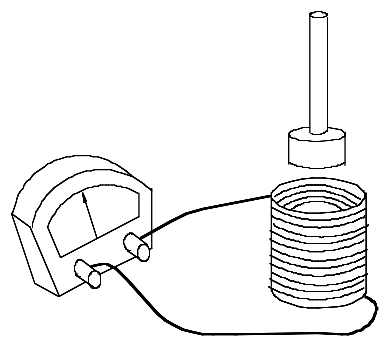
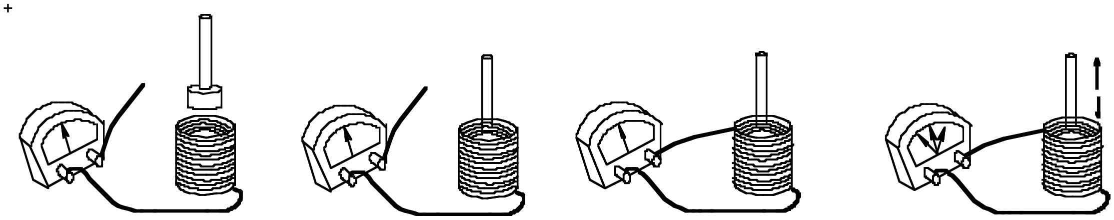
A discussion of the basics of Electromagnetic Induction

After Oersted discovered how an electric current could produce magnetism in 1819, it remained for 10 years before the reverse was discovered. Attempts to use fixed magnets in coils of wire failed to recognize that the magnetic field must change to produce a current. Joseph Henry, Michael Faraday and Emil Lenz discovered, at nearly the same time, the essential facts of Electromagnetic Induction. Since Faraday was the first to publish, it is now known as Faraday's Law.

Demonstration to show the essentials of Electromagnetic Induction.



On the left is shown the basic apparatus for the following of several steps to show EM Induction. A sensitive galvanometer, a strong magnet attached to a dowel, and a solenoid (coil of wire).
1. With the galvanometer disconnected, carefully place the magnet inside of the solenoid, perhaps resting it on a small block to hold it still. Attach the galvanometer and discuss how there is no deflection. This illustrates early failures to create the reverse of how electric currents produced magnetism.



1 2 3 4

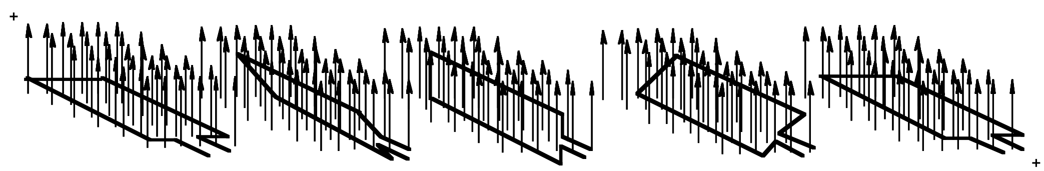
Steps 1 and 2 above show placing the magnet inside the solenoid with the galvanometer disconnected. With the magnet held still and the galvanometer connected in step 3, there is no current. In step 4, when the magnet is moved up and down, carefully observe how the galvanometer needle deflects showing when the current flows and in what direction.

Students may wonder why it took 10 years to discover this easily demonstrated effect. Point out that sensitive galvanometers like the one you are using had not yet been invented and the very strong magnet you were using had also not yet been discovered. The original experimenters were most likely using electromagnets with large coils around iron cores for magnets. They probably noticed sparks when the coil was disconnected. A visible spark involves voltages much higher than is required to cause galvanometer deflection.

The essential electromagnetic induction statement in words is:
When a magnetic flux changes in space, an electric field will surround this flux change that is proportional to the time rate of change of the magnetic flux.
If this were the first time your students have used "flux" (electric, magnetic, gravitational, etc.) it would be well to help them to understand the flux concept.

Flux

If some type of vector field exists in space and passes through a definite area, the amount of the field passing through the area is the flux through the area. A specific example may help. The illustration below shows a flat loop of wire rotating through an upward directed magnetic field. (This example will help when discussing the basics of generators.)



1 2 3 4 5

In illustration 1, the magnetic field passes through the entire area. Therefore, the magnetic flux through the loop would be proportional to the magnetic field intensity, **B**. times the area of the loop. As the loop turns, less magnetic field threads through the area until at position 3, no flux threads through the area. In illustrations 4 and 5, the flux through the loop returns to maximum. If Faraday's law were used to describe the voltage induced across the ends of the loop, no voltage would be induced in illustration 1 or 5. (At this instant there is no change in flux but in illustration 3, the voltage would be maximum, maximum change in flux.) Also notice in this half revolution the voltage will build from zero to maximum and back down to zero. In another half revolution the voltage will build and drop but the sign of the current direction will reverse in the loop.

Faraday-Lenz Law

The mathematical statement of Faraday & Lenz's law: $V = - \Delta\phi / \Delta t$

V is the potential difference (or voltage) induced around the loop, ϕ is the magnetic flux and the minus sign is Lenz's law. This will be discussed briefly below.

Lenz appreciated that if a changing magnetic flux could induce a current in a coil of wire, energy conservation demanded that work must have been done to create this current. This means that the magnetic field created must oppose the field change that created it.

Imagine thrusting a magnet down into a coil of wire. The current flowing in the coil must produce a magnetic field that opposes the magnet entering the coil and the resulting force would require that work would have to be done in forcing the magnet into the coil. Another way of saying this is, if the direction of the current in the coil produces a north pole at the top of the coil, the magnet being trust into the coils must have its north pole facing down and opposing the direction of the top pole created in the coil. These same facing magnetic poles would oppose each other, requiring work to be done.

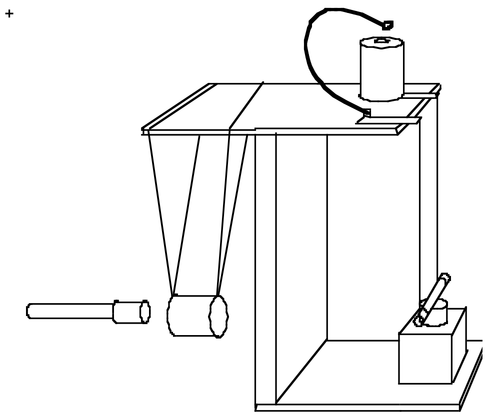
The importance and applications of electromagnetic induction

The importance of electromagnetic induction cannot be overstated. Generators and alternators using EM Induction create essentially all the electric power generated in the world today. Transformers, sound recording devices, microphones, some computer memories and many other electric devices, too numerous to name here, use EM Induction. Maxwell used the fact that EM Induction created an electric field as his first step in developing the electromagnetic wave theory.

Several simple demonstrations of electromagnetic induction

Thrusting a magnet into a coil of wire as discussed on the previous pages is an excellent demonstration to start the discussion. Having the magnet held still as discussed is a great way to discuss the history and to stress that the change in magnetic flux is essential.

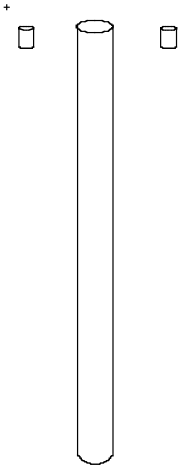
The Lorentz force law and Lenz's law demonstrator



On the left is illustrated a simple device that can both demonstrate the Lorentz force and EM induction. On the right of the apparatus is a copper bar that can be connected to the battery on top. Under this suspended bar is a strong magnet held in a wooden block. When the top of the battery is tapped making connection, the bar will either swing out or in. When the battery is inverted the current will flow in the opposite direction causing the bar to swing the other way illustrating the essentials of the Lorentz force law.

On the left of the illustration above is a section of copper pipe suspended by strings. The strong small magnet attached to a dowel can be moved in and out of the section of copper pipe. The direction of the motion of the swinging copper pipe will illustrate how the current in the pipe always opposes the change in magnetic flux.

Dropping a strong magnet through a long copper pipe
Another popular and spectacular demonstration is shown on the far right. It involves a long section of copper plumbing pipe (available at Home-Depot or any pipe store) and a strong small magnet. If a small soft steel cylinder of the same size as the magnet can be found that looks like the magnet, the demonstration can be made more spectacular. Dropping the soft steel cylinder through the pipe will fall at the expected rate. Dropping the magnet through the pipe will fall much slower. Use creativity here.



The jumping ring demonstration
Another excellent demonstration of EM induction is the jumping ring demo. Search the web for this demo but the best is James's excellent video: https://www.youtube.com/watch?v=GOsTOcyhcFM
Should you want to build your own, watch subsequent videos that can describe the construction of this device.

Buying the apparatus can be expensive and building you own is involved. But having the apparatus in your classroom can give you the opportunity to discuss the physics of EM induction in detail and with spectacular verification. Also, this helps to understand how a transformer works.

The motor and light bulb in series demonstration

This demonstration has been presented at previous workshops and Bill has several to distribute. An attached document describes the demonstration. To obtain the apparatus, send your name and mailing address to: Bill Layton<Layton@physics.ucla.edu>