Pre-lecture Notes Section 11:

Electromagnetic Induction

I. Introduction to Electromagnetic Induction

In this section we are finally ready to answer the following question:

What if the electric or magnetic field generated by a set of charges (or moving charges) changes with time?

The study of such phenomena is called electrodynamics, and we will find that if a field is changing with time, another field emerges, and is said to be "induced". Thus the name of this section is "Electromagnetic Induction".

II. Faraday's Three Experiments and the Law of Induction

In the early 1800's, Michael Faraday carried out a series of experiments involving electric and magnetic fields and forces. He found three general results:

Result 1: When a loop of wire is pulled from a region with no magnetic field into a region with a magnetic field, a current flows in the loop.

Result 2: When a magnet (which of course creates a magnetic field) is pulled across a stationary loop of wire, current flows in the loop.

Result 3: When two loops of wire are placed at rest next to each other (one hooked up to a battery and one not), and the current in the one hooked up to the battery is changed, a current flows in the other loop.

Faraday proposed a general rule to account for all three experiments. This rule is called **Faraday's Law of Induction** and can be stated as follows:

Any time the magnetic flux through a closed loop of wire changes, there will be an emf induced in the loop. The magnitude of the induced emf is equal to the rate of change of the magnetic flux through the loop.

Mathematically, Faraday's law of induction can be stated as

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

where $\Phi_B \equiv \int \vec{B} \cdot \vec{A}$, and is the magnetic flux through the loop of wire. The negative sign in the law of induction is related to the ***direction*** of the induced emf which relates to the direction of current flow, but does not affect its magnitude. The direction of the induced emf can be tricky to find using Faraday's law directly, but we will soon learn a "trick" which allows one to find the direction of the induced current.

There are many physical examples of a changing magnetic flux through a loop. In each example, an emf is induced and therefore a current is generated in the loop. Any device which generates a current in a loop as the result of a changing magnetic flux through the loop is termed a **generator**. Some examples of generators are the following:

1. Simple alternators: The magnetic field stays constant but the loop is rotated in the magnetic field, causing a change in flux and thus producing an induced emf. This type of generator produces an emf (and thus a current) which alternates sinusoidally. See example 29.3 in text.

2. DC alternators: Similar to a simple alternator, but a "trick" is used (a so-called "split ring" commutator) to keep the current flowing in the same direction instead of alternating. See example 29.4 in text.

3. Slidewire generators: A movable section of wire is moved across a pair of rails while being exposed to a magnetic field. The area of the loop therefore changes, meaning that there is a changing flux through the loop, and therefore an induced emf. See example 29.5 in text.

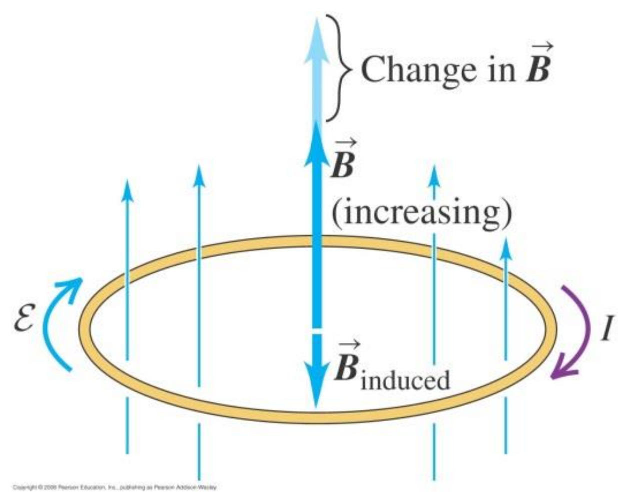
III. Lenz's Law and the Direction of the Induced Current

In 1834, Heinrich Lenz described a "rule" that could be used to determine the direction of the induced emf in a loop of wire, and thus the orientation of the current flow in the loop.

Lenz's law can be stated very simply:

A loop of wire through which the magnetic flux is changing will always generate its own magnetic flux to OPPOSE the change.

As an example, see the picture to the right. Since the applied magnetic field directed upwards is increasing, the upwards magnetic flux through the loop is increasing. The loop will therefore generate its own magnetic field to oppose this change, meaning that it must generate an induced magnetic field directed downward. To do this, the loop must generate a current flowing clockwise as viewed from above (make sure you can use the RHR to verify this!).



The same principle applies in the four diagrams below. Note that the loop produces its own magnetic field to oppose the ***CHANGE*** in magnetic flux. Therefore it is not the amount or direction of applied magnetic field that matters, but it is the ***CHANGE*** in magnetic flux which is the determining factor.