WEEK 10: Go to class 19, 20

Homework assignments

CLASS 19:

ROWLAND'S EXPERIMENT:

We mentioned that current can produce a magnetic field, and this current can be produced by moving charge. Henry Augustus Rowland [1848-1901] had showed explicitly that a spinning charged disc would produce a circular current, which would in turn produce a magnetic field. What was so striking about this experiment (conducted in Berlin in the lab of Hermann von Helmholtz [1821-1894]) was that until that moment, in the late 1800s, it was not clear exactly what charge or current were. The most interesting part of Rowland's experiment is that it led to the discovery by Rowland's student, Edwin H. Hall [1855-1938], of the Hall effect.

Be sure to read the poetic exchange between James Clerk Maxwell [1831-1879] and his buddy, Peter Guthrie Tait [1831-1901] to get a sense of the important unanswered question in E&M in the years between these two experiments.

THE HALL EFFECT:

Hall read in his E and M textbook, written by Maxwell, that the Lorentz force, $\vec{F}_B = Q\vec{v} \times \vec{B}$, acted on the conductor and not on the charge itself. He wished to see whether this was true because he found it counter-intuitive. A great story: the graduate student seeking to disprove the great master. Another motivation for Hall's work, probably provided by Rowland, his mentor, was to find out whether the charges that flowed in a metal was positive or negative, or indeed whether they were particles at all or merely a flow such as water flow or that which used to be called caloric (the flow of heat), and this effect would actually be capable of determining the sign of the charge, unlike other electrical phenomena.

The Hall effect occurs when a current flows in a direction perpendicular to some magnetic field. The Lorentz force, $\vec{F}_B = Q\vec{v} \times \vec{B}$, produces a transverse electric field, which in turn produces a voltage which can be measured. This voltage is generally a very small, about 100 or 1,000th the size of the voltage drop in the direction of current flow due to the resistivity of the material. For this reason, researchers who work with the Hall effect (your instructor, for one) like to describe their work to looking for the proverbial needle in the haystack.

HALL VOLTAGE, HALL COEFFICIENT: $V_H = \frac{R_H IB}{t}$, where $R_H = 1/nq$.

The Hall effect is proportional to a quantity R_H called the Hall coefficient. It is characteristic of the material being studied. For many materials, R_H is inversely proportional to the density of charge carriers, q. It can also be either positive or negative, signifying -- for most materials -- whether charge conduction is mostly done by postively or negatively charged particles.

What is the Hall effect good for? First you can use it to measure an unknown magnetic field. Second you can use it to find the "gender" of the charge carriers in a material (i.e. positive or negative), which are usually negative in metal signifying electron flow, but also often positive. (This is like determining the sex of a gnat under a microscope.) In fact, since the Hall effect is inversely proportional to the density of charge carriers, measuring both Hall effect and resistivity allows one to measure two microscopic quantities, namely the mobility and the charge density. In this way, charge transport measurements, as Hall and resistivity measurement is called, can be considered a cheap subatomic microscope. Finally, you can use the Hall effect to look at other intrinsically interesting physical effects. Among these are the Quantum Hall effect, in which the Hall effect is quantized in two dimensional systems. Another interesting exotic physical phenomenon is the anomalous Hall effect, which occurs in magnetic materials. We can imagine that this arises from a material like iron producing its own internal magnetic field when placed in some external magnetic field, and thus producing a Hall voltage which may be hundreds of times larger than it would be for similar nonmagnetic metals.

CLASS 20:

ELECTROMOTIVE FORCE: $\mathcal{E}$

The book talks about Electromotive force and its various causes, but there is not a lot here worth spending a lot of time with. The main thing I want you to see is that the Electromotive force, or “Emf” (normally pronounced “E-M-F”), is a voltage, not a force. Maybe the best thing to do is to write Emf, but pronounce it "oomf". I call it oomf because it is what provides the oomf to cause the charges to move in a circuit. OK, so in summary, Emf = voltage. The author's main reason for making a big point of the Emf seems to me to prepare you for the fact that there can be a nonzero Emf around a circuit. This contradicts Kirchhoff's voltage rule only if you confuse Emfs with voltages (which is a better thing to confuse them with than say 'forces').

MOTIONAL EMF: $\mathcal{E} = Blv$

Let's return to the Hall effect. In the Hall effect a charge moving in a magnetic field is deflected, and this gives rise to a voltage perpendicular to both the charge's motion and the magnetic field. Interestingly, you can use the Hall effect to tell what kind of carrier you have, positive or negative. Let's consider the a bar of metal moving in a magnetic field, with the length of the bar, its direction of motion, and the magnetic field all at right angles to each other. Now there are both positive and negative charges inside that metal rod, and both are moving through space, technically producing currents (according to the definition of current). Because there are as many positive charges is negative charges however, the two currents cancel. But, both represent the current perpendicular to a magnetic field, and therefore both of them give rise to a electric fields along the length of the moving bar. We should be able to measure the voltage set up by a these moving charges. Interestingly enough, unlike with the Hall effect, these charges are pushed in opposite directions, and so it is impossible to tell what kind of charge carriers we have by measuring this voltage.
This is illustrated in the video on the lefthand side below.

Motional EMF
http://www.youtube.com/watch?v=P-YHSxoaFDg

Jumping ring:
http://www.youtube.com/watch?v=Pl7KyVIJ1iE&feature=channel

SECTION 7.2: ELECTROMAGNETIC INDUCTION

FARADAY'S LAW: $\mathcal{E} = -\frac{d\Phi}{dt} = -\dot{\Phi}$

Now if we take this moving bar ('Motional Emf', last section) and place it along two conducting rails which are connected by resistor to each other somewhere else, and if there's a magnetic field perpendicular to the plane of the rails, then this voltage will actually produce the current through the closed loop. We can define a *magnetic* flux, Φ_m, which will be just the magnetic field times the area of this closed loop. More generally, the flux is the surface integral

$$\Phi_m = \int \vec{B} \cdot d\vec{a} \, .$$

With this picture we can think of the motional Emf as being the result of a change in magnetic flux. In fact the relationship between the Emf and the rate at which the flux is changing is a very simple one: Faraday's law.

The video to the top right illustrates Faraday’s Law. The ring doesn’t want to have its flux changed, and that induces a circular electric current in the coil that produces a B-field opposite to the proposed change in magnetic field. That causes the ring to levitate (unless it is a slit ring that can’t produce that induced current).