FREQUENTLY ASKED QUESTIONS

April 15, 2003

Administrative Questions

What are most important concepts for the quiz?

I'll give you a "WUN2K" on Thursday.

Content Questions

What are the two right hand rules?

One RHR (I call this one the "first RHR") tells you how to relate force, velocity and magnetic field for a charged particle moving in a magnetic field. The other (the "second RHR") tells you how to relate magnetic field and current.

How do you know which RHR to use?

Ask yourself what you are trying to find, and what you know. If you're trying to find force due to current (moving charge) in a magnetic field, use the first RHR. If you're trying to find field due to a current (or current direction for a field), use the second RHR.

What is the "Corkscrew Rule"?

This is the same as the second RHR..

In today's first practice problem with the changing magnetic field, how did you use the RHR to get the direction of current? Which RHR was that?

We used Lenz's Rule, which tells us that whatever direction the current is in, it must be such that it makes a $\vec{B}$ field which *opposes* the change. The $\vec{B}$ field was *decreasing* into the board. So the induced current must *increase* it into the board. So the induced current must produce an induced $\vec{B}$ field into the board, too. So we used the second RHR to relate the current and the induced B field it produces: thumb in direction of induced $\vec{B}$ field, fingers curl around CW.

What is flux exactly?

Magnetic flux through an area is defined as $\Phi_B = \vec{B} \cdot \vec{A}$, where $\vec{A}$ is defined as the vector with magnitude equal to the area, and direction $\perp$ to the area (similarly for electric flux). Flux depends on the magnitude of the $\vec{B}$ field, the area, and the angle between them. It can also be visualized as a quantity proportional to the number of magnetic field lines poking through a surface.

How do you find $d\Phi/dt$ if B is changing but you don't have a graph/slope?

Well, you do need to know *how* the B field is changing. Typically you will be told something about this. For instance, in your pset problem 2, you're told that B field is reduced to zero "at a constant rate", i.e. with constant negative slope.

Is Lenz's Law an actual equation?

No, it's a statement that tells you about the *sign* of the induced EMF or current.

How does the direction of ε_{ind} affect induced flux?

The direction of induced EMF and current affect the direction of induced magnetic field: use the second RHR to find the relation between field and current.

Why would you find ε_{ind} as opposed to I_{ind}?

Sometimes EMF is what is wanted. For instance, a signal transmitted by radio can be described in terms of voltage vs time. In this case, it's EMF directly you're interested in. Your problems could ask for either induced EMF or induced current.

How do we figure out the direction of $I\vec{l}$?

$d\vec{l}$ is defined to be in the direction of the current. You can find the direction of an induced current using Lenz's Rule.

How do we figure out the direction of induced flux?

Use Lenz's Rule. The induced flux has to be such that it opposes the change in external flux.

In pset problem 2, how do you get EMF if $\vec{B}$ is constant?

$\vec{B}$ may be uniform in space, but it's not constant in time. It's reduced to zero at a constant rate. Since the rate of change is constant, the EMF will then be constant as a function of time.

How do you solve differential equations?

Well, I think this really a subject for your math courses... mostly it just takes practice. Most problems you will see in this class will allow a straightforward approach: say you have an equation for dv/dt. Separate the terms with "v" on one side, and "t" on the other side. Then integrate both sides from the start to where you want to find $v(t)$. Please see the handouts, and the textbook, for examples.

In today's second practice problem, why was there a $-$ sign in $F = -IlB$?

The force was in the $-x$ direction (it's a retarding force).

In today's second practice problem, part a, why did the rod travel with constant speed?

There was no loop, so no induced current (ignoring any small eddy currents in the rod). So there was no force, so no acceleration. Since the rod has an initial speed, if there's no acceleration then it travels at that speed forever. (Note that in a real conducting rod, there will be eddy currents –

little loops of induced surface currents – which will cause forces opposing the motion, but we're ignoring that).

In today's second practice problem, part b, how did you find the force?

The force was *due to the induced current in the external magnetic field.* First we found the induced current. The force is then $Id\vec{l} \times \vec{B}$ (this is just Biot-Savart on a wire of length l). The direction of the force is given by the first RHR (here you are finding a force, so you use the first RHR).

You might ask (and I think somebody did in R01): what about the force on the induced current due to the induced magnetic field? Well, the induced current is the *source* of the induced magnetic field. You can ignore the induced magnetic field's effect on its own source... the force is due to the *external* magnetic field acting on the induced current.

Can you explain the CyberTutor problem with the solenoid?

If this is the one where you find the field in the solenoid using a carefully chosen Ampèrian loop, I think section 28-5 in your textbook will help.

Can you explain mutual inductance?

We didn't quite get to this in class today; I'll talk about it some more on Thursday. I think the easiest way to think of it is in terms of two coils nearby each other. If you change the current I_1 in one, it will change the flux through coil 2, $\Phi_{2,1}$ (the flux through coil 2 due to current in coil 1) . This changing flux will induce a current I_2 in coil 2. The flux $\Phi_{2,1}$ is proportional to I_1. The EMF in coil 2 is therefore proportional to the rate of change of I_1. The constant of proportionality is given the name "mutual inductance", so we write $\varepsilon_2 = -M_{21} dI_1/dt$; you can show that $M_{21} = N_2 \Phi_{2,1}/I_1$. Physically, this constant of proportionality M_{21} tells you "sensitivity to change in current": it tells you how big an EMF you will get in coil 2 for a given change in current in coil 1. The bigger M, the easier it is to induce a current. Note that mutual inductance depends on geometry of a configuration. (There's a current in the definition of M, but that will cancel out when you work out the flux and divide by current. It's sort of similar to the way that the definition of capacitance involves charge and voltage, but then capacitance ends up being a property of the object only, not what particular charge and voltage it has.)

Can you explain the relevance of yesterday's demos?

The first demo yesterday was supposed to demonstrate mutual inductance. Suppose you have 2 coils near each other. The current in one creates a magnetic field. This magnetic field goes through the second coil. Now suppose the current in loop 1 changes: this will create a changing magnetic field through loop 2. A changing magnetic field through loop 2 creates an induced current in loop 2, So a changing current in 1 produces a current in 2.

The first demo had a radio connected to loop 1; the radio signal corresponds to a changing current in loop 1. This changing current induced a current in loop 2, which was connected to a speaker. A signal was transmitted even though the loops were not physically connected! (We'll talk more about this later in the context of electromagnetic waves). Part of this demo was also to show that the induced current in coil 2 depended on the geometry of the situation. When the coils were moved apart, or rotated with respect to one another, the flux through loop 2 changed, and so the induced current changed (for instance, when the coils were perpendicular, there was no flux through loop 2, so no signal). The "mutual inductance" gives the constant of proportionality between the induced EMF in loop 2 and the change in current in loop 1; it's a geometric property of the loop configuration (and is changed by moving or rotating the loops with respect to each other). The bigger the mutual inductance, the more sensitive the system is to changes in current.

The second set of demos had to do with eddy currents. The pendulum demo is my favorite one. If you have a pendulum made of metal, current can flow everywhere in the metal, so you can have current loops anywhere on the surface. When it enters a magnetic field, the flux through any loop on the surface is changing. So you get induced currents ("eddy currents") in the metal, happening all over the surface. According to Lenz's Rule, these induced currents create B fields opposing the change in flux, which create forces that oppose the motion (whichever way the motion happens to be). So the pendulum slows down as it goes through. The more of the pendulum's area in the magnetic field, the more flux inside the loop, and the bigger the change in flux as it swings, so the more dramatic the effect. Then, if slits are cut in the pendulum: this impedes the flow of current, so it decreases the effect.

The levitating magnet was also designed to show Lenz's Law and eddy currents in action. The rotating disk is made of metal, so currents can flow everywhere. The little piece of disk the magnet is sitting on is pierced by magnetic field lines. As the disk rotates, consider a little piece of disk that sweeps under the magnet. The flux through it will change as it sweeps by the magnet. So a current is induced in the piece of disk. The direction of this current creates a field which opposes the magnet's field, by Lenz's Rule. So it acts as a repelling magnet, and the magnet levitates.

In the levitating magnet demo, what was beneath the magnet? How does the disk turning change flux?

See above... it's an conducting aluminum disk beneath the magnet. (I think there's a separating layer of plastic, probably just to stop the magnet flying off sideways). The disk turning changes flux through any little piece of the disk under the magnet (imagine a little piece sweeping around.)

Can you explain the demo with the jumping ring?

I missed this one, but my guess: a ring jumps off a magnet when a field is turned on. As the B field turns on, the flux through the ring increases. A current is induced in the ring so as to produce a field opposing the increase in current. This field is in the opposite direction to the external field, so it repels: the ring jumps away.

Can you give us some hints for the pset?

- Problem 1: This is a classic Lenz's Rule problem. Remember that loops hate change.
- Problem 2: The triangle practice problem should help.

- Problem 3: This one is actually quite hard. Here's a strategy: first, use the Faraday/Lenz howto to find the induced EMF and current, and direction of it. Then, find the force due to this current in the external magnetic field. Then, apply $\Sigma F = ma$, where the sum of the forces includes both gravity and the magnetic force. What you will get is a DE for velocity, that you can solve for $v(t)$. You should get something similar to the case of motion with friction or drag (i.e. velocity that approaches a terminal velocity, see 8.01 material).

  Actually, strictly it's *neither* constant velocity nor constant acceleration. But if you work out the time constant (i.e. time for it to reach terminal velocity) you will find that this time is very short. So during most of its drop it will be at very nearly constant velocity. You can use this to calculate the time it takes to leave the field.

- Problem 4: This one is also quite hard, but similar to problem 3. The practice problem from class should help, (the practice problem is simpler). For part a, consider the force on the rod. Is it constant? Then what is the motion of the rod? For part b, the setup and math are almost identical to problem 3: here the total current is now a sum of current from the battery and induced current. You should get a DE for $v(t)$ to solve.

- Problem 5: This one is labelled with a "III" but I think actually it's straightforward. It's very similar to example 30-1 of your text, except that the inner coil is at an angle. Hint: is it $\sin\theta$ or $\cos\theta$? To figure that out, think about what the flux (and mutual inductance) should be if the coils are parallel and perpendicular.