# FREQUENTLY ASKED QUESTIONS

April 24, 2003

## Administrative Questions

### What will be on the next quiz?

I'm not sure yet. Prof. Roland will let you know in due time.

## Content Questions

### In today's practice problem, when considering self-inductance of a loop and there's a $B$ field coming out of the center of the loop, what does this oppose? What about the $B$ field on the outside of the loop?

In today's example, the $B$ field coming out of the board was the $B$ field due to the original current. It's not opposing; rather, it's opposed by the induced current, which causes a $B$ field opposing the $B$ field increasing out of the board (the induced current must therefore make a $B$ field going in, so it's CW). The $B$ fields on the outside of the loop don't matter; only $B$ fields *inside* loops matter for induction.

### What other shapes should we be able to find $L$ for?

Many different shapes, depending on the problem. If you know the rate of change of current and the induced EMF, you can find $L$ for any shape by $\varepsilon_{\text{ind}} = -L dI/dt$.

### What is the difference between $L$ and $M$?

Self-inductance $L$ gives you sensitivity of induced EMF to change in a loop's *own* current and involves a single circuit; mutual inductance $M$ gives you sensitivity of induced EMF to change in *another* loop's current, and involves more than one circuit.

### How do self-inductance and mutual inductance work together?

Well, any loop has a self-inductance and any two loops have a mutual inductance. They're just there; they don't really "work together".

**How do you know whether something will have self-inductance or not?**

*Every* loop has self-inductance (just like everything has capacitance). But single loops tend to have small self-inductance. Certain objects (for instance those with lots of loops) are *designed* to have a big (or a particular) $L$; such objects are called "inductors".

**What actually *is* an inductor?**

It's a circuit element made to have a particular $L$. It can actually be a little tiny coil with lots of loops.

**Can you explain Lenz' Law for self-inductance? How come $\varepsilon_{\text{ind}}$ is in the same direction?**

Induced EMF is *not* in the same direction as the applied EMF; it's in the opposite direction in order to oppose change in current and flux.

**What do self-inductance and mutual inductance really mean?**

The physical meaning is "sensitivity of EMF to change in current". A big self-inductance means a big induced EMF for a given change in current in the coil; a small $L$ means a small induced EMF for the same change in current. Mutual inductance has a similar meaning, except that it refers to induced EMF in one coil due to change in current in another.

**For mutual inductance, does there only have to be one current?**

Currents can (and will) be present in both coils. But the mutual inductance refers to the induced EMF in one coil due to the change in current of the other.

**Can we have another example problem for mutual inductance?**

There is another problem from April 17.

**We saw that a capacitor is like little plates and an inductor is like a little solenoid... what about the internal structure of a resistor?**

A resistor is just made of "stuff"... it's just plain material; resistance is provided by electrons bouncing off atoms. Anything has resistance, but I think resistors are carefully selected for particular resistivity properties, material purity, uniform composition and shape, etc. so that resistance is well-defined.

**In the practice problem, what was the difference between $n$ and $N$?**

$N$ is the absolute number of loops, and $n$ is $N/D$, or loops per unit length.

**In the practice problem, how did you get $N^2$ in the expression for $\Phi_B$?**

One $N$ comes from the $B$ field for one loop, which is proportional to $N/D$, and the other comes from the fact you have $N$ loops so you have a factor of $N$ in the total flux.

**In the practice problem, why is power heat over time? Does all the energy go to heat?**

Power is $dW/dt$, or work per time. Work done which does not turn into kinetic energy goes into heat (actually, kinetic energy of jiggling atoms). Yes, since the circuit doesn't fly off anywhere (none of the energy turns into K.E.), all energy goes to heat.

**In the last demo, how was the coil able to levitate? Why does AC matter?**

Unfortunately I missed class for this one... but I think I can understand from Prof. Roland's slides on the web.

The idea was to demonstrate both Faraday's and Lenz's Laws, and delay in response to change in current (phase shift). You start with a current loop over a metal sheet, and you put an AC current, which varies sinusoidally according to $I_0 \sin \omega t$, through the loop. This is the orange plot labeled "$I_{AC}$" on the slide. This changing current causes a change in magnetic flux, which by Faraday's Law induces a current in the metal sheet. By Faraday's Law, the induced current is proportional to the derivative of $I_{AC}$, which is $-\cos(\omega t)$. This is the bottom, green plot labeled "$I_{\text{ind}}$". *This also assumes that the current can be induced instantaneously*, i.e. there's no time delay between $I_{AC}$ and $I_{\text{ind}}$. You can also understand the shape of the bottom plot by thinking of Lenz' Law: while current in the coil is increasing, it's increasing flux. The current in the metal sheet tries to decrease that, so the induced current is in the opposite direction (negative). When the $I_{AC}$ siAnusoid turns over, and the current in the coil starts decreasing, the induced current tries to increase it, so it's in the same direction. And so on.

Now consider forces for this zero-delay case. When the currents are in the same direction (both positive or both negative), the force between the coil current and the induced current is attractive, but when the currents are in the opposite direction, force is repulsive. Half the time the force is attractive and half the timee it's repulsive. So there's no net force.

*But that's not what actually happens.* In reality, the induced current actually takes some time to happen, due to self-inductance effects: there is a delay. This causes the induced current to be shifted in later time, which can be described mathematically as a phase shift $\phi$ in the cosine. The shifted $I_{\text{ind}}$ is the green plot on the last levitating coil slide. If you compare signs of $I_{AC}$ and $I_{\text{ind}}$ in the orange and green plots, you see that most of the time they are in the opposite direction (one positive and the other negative), so most of the time the force is repulsive. So the coil levitates.

**Can you explain the RL circuit demo?**

When the first switch is opened, the current reaches its steady state value instantaneously, because there is no inductance (in reality, there is a bit of self-inductance in the loop itself, but it's small and we neglect it). Then, if you put an inductor in the circuit, the current takes longer to reach its steady state value, because there is a large induced back-EMF fighting the applied EMF. So it takes some time for the bulbs to come on completely. Then when the switch is opened: again, because of the inductor, the current takes some time to die away. It doesn't just switch off instantaneously, because the change (decrease this time) in current causes a change in flux through the inductor, which creates a back-EMF opposing the change, which keeps current flowing for a while. So light bulb III turns off only slowly.

One can also think of what happens in terms of energy. When current is flowing, the inductor stores energy (in the magnetic field created by the current through the coils). When the current turns off, this energy is "released" and goes into lighting the bulb.

This can all be described quantitatively by solving the differential equation for $I(t)$ you get from Kirchoff's Loop Rule, as is done in your text, section 30-4.

**How important is it to know about time-related stuff in this class?**

You definitely need to know about how induced EMF relates to time-dependent currents, and about LC and LR transients, and about AC circuits.

**Can you explain step-up transformers?**

A transformer is just a pair of coils sharing the same magnetic flux. A change in the current (or voltage) of one will cause a current (voltage) in the other. The relative induced EMFs depend on the ratio of the number of loops in each circuit, according to $V_s/V_p = N_s/N_p$. This means that you can *control* the ratio of voltages by devising coils with a particular ratio. So you can make a big voltage from a small one (the "step-up"), as for HVPS. You can also "step down". See also text pp. 744-745. Note that you must have a changing current (e.g. AC, sinusoidally changing current) for this to work, since for DC the current is steady: no change, no induction, no transformer action.

**What was the "goal" in creating the Marconi coils? How did the transmitting field relate to it, and how did it work?**

I missed this one too, but according to my notes from last year: this is a demo of transformer action. You put a changing voltage across a primary coil with few loops. This coil shares flux with a many-loop secondary coil, so the voltage is stepped up to a high voltage in the secondary, and causes a spark. This spark, when connected to an antenna, makes an electromagnetic wave (as we'll see in the microwave experiment... we're not quite there yet).

So how do you get the changing voltage with a DC power supply? Remember *change* in current/voltage is required for transformer action, since it relies on induction. The changing voltage is achieved in a clever mechanical way: when the switch is first closed and current runs through, the magnet inside the coils gets attracted to a spring. This opens the circuit, so current decreases again. The spring then sproings the magnet back, closing the switch again. The current increases again, attracting the magnet... and so on. So the current is continually changing, so that induction keeps happening, and the transformer action works.

**Can you explain AC circuits?**

Alternating current is just a current which goes back and forth between positive and negative in a sinusoidal way. We'll be getting to this soon.

**Is $N_p$ always on the inside and $N_s$ always on the outside?**

Not necessarily. "Primary" and "secondary" are just labels. Usually the "secondary" refers to the voltage you are trying to get from another voltage (i.e. secondary is the output, primary is the input).

**For the pset, do we need to derive formulas for $\varepsilon$ and $L$, $M$?**

No, you can use formulae you know.

**How do you derive the time constant for a solenoid?**

It's just $\tau = L/R$. It's derived in section 30-4 of your text by using Kirchoff's Rules around an LR circuit and solving the resulting DE.

**Can you explain the CyberTutor problem about the inductor as a circuit element?**

I'm not sure which one this is? The one many people have asked me about is the "Self-Inductance of a Solenoid", parts D and E. Note that part E is not particularly referring to part D, it's talking about applying a voltage to a coil with an arbitrary current.

There are two ways to think about this:

- Think of the self-inducting coil in terms of Lenz' Law. Which way is the induced current for a given $dI/dt$? Then imagine the inductor as an imaginary battery (EMF) providing the current. Which is the positive side of the imaginary battery?

- You can also think algebraically using the sign of the induced EMF in Faraday's Law (using the minus sign).

**For the AMP experiment, how do I distinguish between the two potentiometers of different resistance?**

You can use your multimeter on ohm setting to measure the resistance range for the pots.

**Can we have some hints for the pset?**

- Problem 1: You actually don't really need to know much about step-up transformers for this one. If you increase energy per unit charge per time, how can you make sure you have the same total energy?
- Problem 2: Actually I am not totally sure what is wanted for this one. Remember that true "self-inductance" depends only on geometry. But if what is wanted is "$L$" such that $\varepsilon = -LdI/dt$ for some part of the solenoid, then this $L$ will depend on flux in that part of the solenoid (and remember that flux decreases near the ends). However this isn't really true "self" inductance since it depends on the rest of the solenoid.
- Problem 3: How does the number of loops change for the fatter loop solenoid? How is $R$ different, using $R = \rho l/A$? You can assume resisitivity is the same for both. You can just use that $\tau = L/R$.
- Problem 4: This one is straightforward... if you are doing complicated calculations, you are on the wrong track.
- Problem 5: This one is mostly algebra. Assume the current is given by equation 30-9 in your text. The power is the sum of inductor power and power dissipated in the resistor... just plug $I(t)$ in and show that this sum is the same as the power provided by the battery. You can also use equation 30-10 to simplify.

## Tidbits

An atom goes the doctor. “I feel lousy”, she says, “I think I’ve lost one of my electrons”. “Are you sure?” the doctor asks. “Yes, I’m positive”, she replies.