Science-1A Lab: Week-6, Friday, February 19, 2021

The following videos mostly supplement the Lab notes of Wednesday February 17.

Ampère's Law (CC 33) 8 min 44 s
https://www.youtube.com/watch?v=5fqwJyt4Lus&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV&index=34

As usual, don't worry about the mathematical discussion. Just pay attention to how this relates to the 4th and 5th demonstrations in Wednesday's notes about how magnetic field circles are formed around a wire carrying a current, and how a solenoid enhances that effect.

You will not need to use the constant μ_0, just remember that such a constant exists and is involved in connecting magnetic fields and electric current.

As before, you will not need to remember right-hand rules.

Induction - An Introduction (CC 34) 9 min 49 s
https://www.youtube.com/watch?v=pQp6bmJPU_0&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV&index=35

This discussion is relevant to Wednesday's demonstrations 1, 2, and 6.

Magnetic flux is important, but not to this course.

Think of "EMF" as equivalent to a "generated voltage" which can come from a battery or electric generator.

Don't worry about Lenz's Law. Just remember that a changing magnetic field can cause a current flow that produces a magnetic field that opposes the original field change.

How Power Gets to Your Home (CC 35) 8 min 32 s
https://www.youtube.com/watch?v=9kgzA0Vd8S8&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV&index=36

On Wednesday, I did not talk about the simple motor/generator demonstration I usually show off in lab. But this discussion and its animations explain motors and generators very nicely.

A key part of this video discusses electrical transformers mentioned in Wednesday's demonstrations 10 and 11. As mentioned on Wednesday during demonstration 10, a future quiz question will involve the simple equation $\frac{V_s}{V_p}=\frac{N_s}{N_p}$ or equivalently $\frac{V_p}{N_p}=\frac{V_s}{N_s}$ starting at 6 min, 26 s into this video.

AC Circuits (CC 36) 10 min 6 s
https://www.youtube.com/watch?v=Jveer7vhjGo&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV&index=37

Remember, capacitors can hold charges and store energy in an electric field. Inductors, discussed here, are solenoids that store energy in a magnetic field.

You don't need to worry about the root-mean-squared method of averaging AC currents and voltages or the formula for the EMF of an inductor.

The impressive arcing seen in Wednesday's demonstration 10, is related to the discussion here about the voltage produced by changes in the current through an inductor as its magnetic field grows or shrinks.

Recall how the swinging pendulum alternately stored energy as gravitational potential energy and kinetic energy. Also, how a child can pump up the energy in a swing. A circuit made from a capacitor and inductor is similar – it can alternately store energy as electric energy in its capacitor or magnetic energy in its inductor. At a special frequency these work together and produce a resonant frequency. The knowledge gained from studying a pendulum applies directly to resonant electric circuits made of capacitors and inductors.

House Wiring
I have prepared a diagram to help explain house electrical wiring, circuit breakers, and some aspects of electrical safety. It is at
https://yosemitefoothills.com/Science-1A/Handouts/Week-06/HouseElectricalCircuits.png .

As explained in the last two videos, electrical power comes to our homes via the national electrical grid using high voltages to reduce energy loss. Transformers are then used to lower that voltage to 240 V composed of two opposite 120 V sides. This is shown at the upper left of the diagram. The 240 V is used for stoves, hot water heaters, clothes dryers, and other devices that consume large amounts of power. The 120 V sides are fed to two rows of circuit breakers in a "breaker box", usually located in a garage, service porch, or near the incoming power lines. Each 120 V breaker then feeds either a group of outlets in the house or a group of lights, but the National Electrical Code specifies that no breakers should feed both outlets and lights.

Normal circuit breakers
Circuit breakers in a house are automatic switches that open the circuit in the event of excess current being drawn, usually at 15 or 20 amperes. People can be killed by a current of more than 0.006 A, so normal circuit breakers protect against electrical fires, not electrocution.

Ground-fault interrupt (GFI) breakers
A more expensive and modern style of circuit breaker called a ground-fault interrupt (GFI) breaker will open if the outgoing current via one wire does not match the current returning via its paired wire. If that mismatch is greater than 6 mA (0.006 A), then it will open the circuit. Such breakers are required by the National Electrical Code in kitchens, bathrooms, garages, and outside outlets, but not in all circuits.

GFI breakers operate by having a solenoid wrapped around both wires. If those wires have equal and opposite currents, there will be no magnetic field since the net current inside the solenoid is zero, but if some current goes astray, like through a person to ground, the current will be unbalanced. The breaker will open if the unbalance is greater than 6 mA.

Protection provided by a 3rd wire
The section of the drawing that shows a person being shocked illustrates how an accidental connection between a power wire and a metal frame can cause electricity to flow through a person touching that metal frame. The current flows down to the ground through their feet and back to the main power connections which are also connected to the ground.

When I was in High School, I showed a friend visiting my house how a light bulb could be lit by connecting just one side of the bulb to an outlet and the other side to a steel rod pounded into the ground outside a window. He was so surprised that 40 years later when I met him again that demonstration was the main thing he remembered about me.

Old houses were wired with only two wires going to outlets, but about 70 years ago, the National Electrical Code was changed to require a 3rd wire. The sole purpose of that wire was to connect the metal frames of electrical devices directly to ground. In the event of an accidental short to the metal frame from the "hot" wires, that 3rd wire would divert power to ground, away from anyone touching the metal. The lower right part of the diagram showing a happy stick figure illustrates how that 3-wire arrangement protects a person.

Arc-fault breakers
There is still a danger that the 3rd wire and GFI breakers do not protect against. If for example, a rat in the attic chews through the insulation around some wiring, sparks can develop that might start a fire without tripping a normal breaker. Such arcing is characterized by rapid variations in current that can be detected by suitable electronic circuits and used to shut off a breaker. Such breakers are called arc-fault breakers.

Extra Physics Midterm questions

The following pages have possible additional questions (with solutions) that you might see on the Physics Midterm. The last 3 questions deal with house wiring and circuit breakers discussed above. These are at
https://yosemitefoothills.com/Science-1A/QuizAndTestPractice/PossibleAdditionalQuestionsForPhysicsTest.pdf
https://yosemitefoothills.com/Science-1A/QuizAndTestPractice/PossibleAdditionalQuestionsForPhysicsTest-Solutions.pdf

Maxwell's Equations (CC 37) 10 min 48 s

https://www.youtube.com/watch?v=K40lNL3KsJ4&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV&index=38

You will not need to use Maxwell's Equations, but they govern all of electricity, magnetism, and light. They are an amazing synthesis of phenomena that were once thought to be separate topics.

There is a lot of rapid-fire discussion here which you do not need to fully understand, but I would like you to listen to it (maybe even a 2nd time) and get a feel for what a remarkable discovery Maxwell made. T-shirts with Maxwell's equations on them are a favorite with physics students.

I discuss Maxwell's Equations on page 4 of the handout at
https://yosemitefoothills.com/Science-1A/Handouts/Week-06/ElectricAndMagneticEffects.pdf
The 4 equations in the black box are Maxwell's Equations using a form of mathematics called vector calculus. You don't need to understand vector calculus. Just look at these equations and understand the following:

1. The first equation, at the top left, shows how a electric field comes from charges (ρ). We saw that when discussing how static electricity is generated by separating charges. The second equation is about how a magnetic field $\vec{B}$ changing with time t, $\left(\frac{\partial \vec{B}}{\partial t}\right)$, causes electric effects. We saw that in demonstration 2, 3, and 6 of the Wednesday lab demonstrations.

2. The first of the second pair of equations show how magnetic field lines are just loops with north and south poles that can never be separated – there are no magnetic "charges". The last equation shows how magnetic fields are caused by electric currents $(\vec{J})$ and also by an electric field changing with time, $\left(\frac{\partial \vec{E}}{\partial t}\right)$. I could not directly demonstrate that effect since it is normally extremely weak. Still, without that changing electric field term, electromagnetic radiation like light and radio would not exist.

The last half of this note shows how Maxwell was able to connect the electric parameter ϵ_0 and the magnetic parameter μ_0 to the speed of light. Until Maxwell, it was thought that the physics of light had nothing to do with electricity and magnetism. This discovery provided astonishing evidence of the grand unity of Nature's laws.

The broad expanse of electromagnetic waves from radio waves through visible light to gamma rays is shown at
https://yosemitefoothills.com/Science-1A/Handouts/Week-07/Electromagnetic-spectrum.png .

To earn credit for this lab, report that you have done the following:

1. Report that you read this note.
2. Watched the 5 videos.
3. Looked at the note about Maxwell's Equations.
4. Studied the "Typical House Electrical Circuits" drawing while reading that paragraphs that discussed it.
5. Know where the breaker box is in your house in case you ever need to shut off power. It should have an index that explains which circuits each breaker controls.
6. Admired the colored diagram of the electromagnetic spectrum of which only a tiny section is visible light.