University of Alabama
Department of Physics and Astronomy

PH 102-2 / LeClair — Spring 2008

Exam II

Instructions:

- Answer 6 of the 8 problems below. All problems have equal weight.
- Indicate which problems you have attempted by filling in the adjacent box.
- Show your work for full credit. Significant partial credit will be given.
- You are allowed 2 sides of a standard 8.5x11 in piece of paper with notes/formulas and a calculator.

□ **1.** In a motorboat, the compass is mounted at a distance of 0.80 m from a cable carrying a current of 20 A from an electric generator to a battery.

(a) What magnetic field does this current produce at the location of the compass? Assume the cable is a long, straight wire.

(b) The horizontal (north) component of the Earth's magnetic field is 1.8×10^{-5} T. Since the compass points in the direction of the *net* horizontal magnetic field, the current will cause a deviation of the compass needle. Assume that the magnetic field of the current is horizontal and at a right angle to the horizontal component of the earth's magnetic field. Under these circumstances, by how many degrees will the compass deviate from true north?

□ **2.** A 50 kV direct-current power line consists of two conductors precisely 2.0 m apart. The current travels down one conductor, to a load, and back up the other conductor.

(a) When this line is transmitting 10 MW, how strong is the magnetic field midway between the conductors?

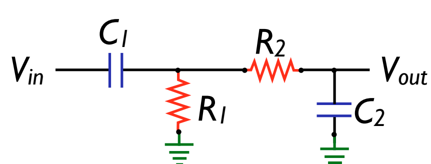
(b) What is the force per unit length between the two wires? Is it attractive or repulsive?

□ **3.** The rate of flow of a conducting liquid can be measured with an electromagnetic flowmeter that detects the voltage induced by the motion of the liquid in a magnetic field. Suppose that a plastic pipe of diameter 0.10 m carries beer with a speed of 1.5 m/s. The pipe is in a transverse magnetic field (*i.e.,* perpendicular to the pipe axis) of about 1.5×10^{-2} T.

(a) Presume the beer is an ideal conductor. What voltage will be induced between the opposite sides of the column of liquid?
(b) Does it matter whether the conductivity of the beer is due to mobile positive or negative charges?

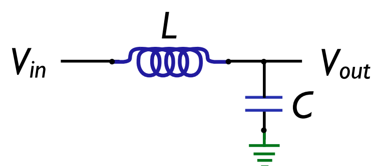
□ **4.** The circuit below shows what is known as a *bandpass filter,* it may be thought of as two simple filters in series.

(a) Sketch the output of this circuit versus frequency, assuming the input contains all frequencies with equal amplitudes.
(b) Let $R_1 = 200\,\Omega$, $R_2 = 100\,\Omega$, $C_1 = 0.5\,\mu$F, and $C_2 = 0.01\,\mu$F. Determine the upper and lower cutoff frequencies for this filter **in Hz**, and point them out on your sketch.
(c) Could this circuit be replaced by one with a single resistor and capacitor? Explain your reasoning briefly.



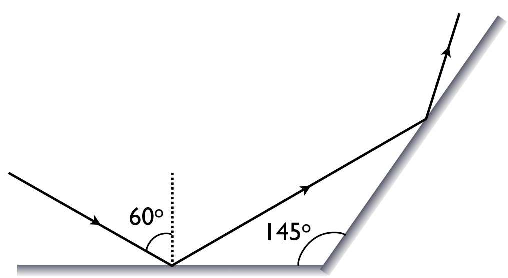
□ **5.** The circuit below is a simple filter based on an inductor and a capacitor.

(a) What sort of filter is this? Briefly explain your rationale.
(b) Sketch the output of this circuit versus frequency, assuming the input contains all frequencies with equal amplitudes.
(c) The cutoff frequency of a filter is the frequency at which the reactance of each component is equal - in this case, the frequency at which the inductive reactance is equal to the capacitive reactance. What is the cutoff frequency f in terms of L and C?



□ **6.** A scuba diver is underwater; from there, the sun appears to be at 30° from the vertical. At what actual angle is the sun located (with respect to directly overhead)? The index of refraction of water may be taken as $n_{\text{water}} = 1.33$, while that of the air may be taken as $n_{\text{air}} = 1.00$.

□ **7.** Two flat mirrors are arranged at an angle of 145° with respect to each other (see below). A ray of light strikes one of the mirrors at an angle of incidence of 60°, it is reflected, and then strikes the other mirror. What is the angle of reflection at the second mirror, relative to a line perpendicular to the second mirror?



□ **8.** A point source of light is placed at a fixed distance l from a screen. A thin convex lens of focal length f is placed somewhere between the source and screen, a distance q from the screen and p from the source. The lens is moved back and forth between the source and screen, but both screen and source remain fixed, thus $p + q = l$ at all times.

What is the minimum value of l such that a focused image will be formed at two different positions of the lens? Recall our recent laboratory experiment.

BONUS: *worth 1/3 of a normal question*
During an in-class demonstration, we dropped a magnet and a non-magnet of equal weight and size through a copper tube. The non-magnet fell through the tube at the expected rate, but the non-magnet took many times longer to fall out, due to eddy current braking. Is it possible to have a magnet strong enough (or a tube conductive enough, etc) that it would actually stop inside the tube? Explain.

Cheat Sheet

Constants:

$$k_e = 8.98755 \times 10^9\,\mathrm{N \cdot m^2 \cdot C^{-2}}$$
$$\epsilon_0 = 8.85 \times 10^{12}\,\mathrm{C^2/N \cdot m^2}$$
$$e = 1.60218 \times 10^{-19}\,\mathrm{C}$$
$$\mu_0 \equiv 4\pi \times 10^{-7}\,\mathrm{T \cdot m/A}$$
$$c = 2.99792 \times 10^8\,\mathrm{m/s}$$
$$m_{e^-} = 9.10938 \times 10^{-31}\,\mathrm{kg}$$
$$m_{p^+} = 1.67262 \times 10^{-27}\,\mathrm{kg}$$

Quadratic formula & vectors:

$$0 = ax^2 + bx^2 + c \Longrightarrow x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$
$$|\vec{\mathbf{F}}| = \sqrt{F_x^2 + F_y^2} \quad \text{magnitude}$$
$$\theta = \tan^{-1}\left[\frac{F_y}{F_x}\right] \quad \text{direction}$$

Ohm:

$$\Delta V = IR$$
$$\mathscr{P} = E \cdot \Delta t = I\Delta V = I^2 R = \frac{[\Delta V]^2}{R} \quad \text{power}$$

Induction:

$$\Phi_B = B_\perp A = BA\cos\theta_{BA}$$
$$\Delta V = -N\frac{\Delta\Phi_B}{\Delta t}$$
$$L = N\frac{\Delta\Phi_B}{\Delta I} = \frac{N\Phi_B}{I}$$
$$\Delta V = |\vec{\mathbf{v}}||\vec{\mathbf{B}}|l = |\vec{\mathbf{E}}|l \quad \text{motional voltage}$$

Optics:

$$\mathscr{E} = hf = \frac{hc}{\lambda}$$
$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in a medium}} = \frac{c}{v}$$
$$\frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{c/n_1}{c/n_2} = \frac{n_2}{n_1} \quad \text{refraction}$$
$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \quad \text{Snell's refraction}$$
$$\lambda f = c$$
$$M = \frac{h'}{h} = -\frac{q}{p}$$
$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} = \frac{2}{R} \quad \text{mirror \& lens}$$
$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R} \quad \text{spherical refracting}$$
$$q = -\frac{n_2}{n_1}p \quad \text{flat refracting}$$
$$\frac{1}{f} = \left(\frac{n_2 - n_1}{n_1}\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \quad \text{lensmaker's}$$

Magnetic fields & forces:

$$|\vec{\mathbf{F}}_B| = q|\vec{\mathbf{v}}||\vec{\mathbf{B}}|\sin\theta_{vB} \quad \text{charge } q$$
$$|\vec{\mathbf{F}}_B| = BIl\sin\theta \quad \text{wire}$$
$$|\vec{\boldsymbol{\tau}}| = BIAN\sin\theta \quad \text{torque current loop}$$
$$\vec{\mathbf{B}} = \frac{\mu_0 I}{2\pi r}\,\hat{\theta} \quad \text{wire}$$
$$\vec{\mathbf{B}} = \mu_0\frac{N}{L}I\,\hat{\mathbf{z}} \equiv \mu_0 nI\,\hat{\mathbf{z}} \quad \text{solenoid}$$
$$\frac{|\vec{\mathbf{F}}_{12}|}{l} = \frac{\mu_0 I_1 I_2}{2\pi d} \quad \text{2 wires, force per length}$$

ac Circuits

$$\tau = L/R \quad \text{RL circuit}$$
$$\tau = RC \quad \text{RC circuit}$$
$$\omega_{\text{cutoff}} = \frac{1}{\tau} = 2\pi f_{\text{cutoff}}$$
$$X_C = \frac{1}{2\pi fC} \quad \text{“resistance” of a capacitor for ac}$$
$$X_L = 2\pi fL \quad \text{“resistance” of an inductor for a}$$

Units

$$1\,\mathrm{T \cdot m/A} = 1\,\mathrm{N/A^2}$$
$$1\,\mathrm{T \cdot m^2} = 1\,\mathrm{V \cdot s}$$
$$1\,\mathrm{T} = 1\,\mathrm{kg/A \cdot s^2}$$
$$1\,\mathrm{eV} = 1.6 \times 10^{-19}\,\mathrm{J}$$
$$1\,\mathrm{J} = 1\,\mathrm{N \cdot m} = 1\,\mathrm{kg \cdot m^2/s^2}$$
$$1\,\mathrm{N} = 1\,\mathrm{kg \cdot m/s^2}$$
$$1\,\mathrm{W} = 1\,\mathrm{J/s} = 1\,\mathrm{kg \cdot m^2/s^3}$$
$$1\,\mathrm{F} = 1\,\mathrm{C/V}$$
$$1\,\mathrm{C} = 1\,\mathrm{A/s}$$
$$1\,\mathrm{N/C} = 1\,\mathrm{V/m}$$

EM Waves:

$$c = \lambda f = \frac{|\vec{\mathbf{E}}|}{|\vec{\mathbf{B}}|}$$
$$\mathcal{I} = \left[\frac{\text{photons}}{\text{time}}\right]\left[\frac{\text{energy}}{\text{photon}}\right]\left[\frac{1}{\text{Area}}\right]$$
$$\mathcal{I} = \frac{\text{energy}}{\text{time} \cdot \text{area}} = \frac{E_{\max}B_{\max}}{2\mu_0} = \frac{\text{power } (\mathscr{P})}{\text{area}} = \frac{E_{\max}^2}{2\mu_0 c}$$

Right-hand rule #1

1. Point the fingers of your right hand along the direction of the velocity.
2. Point your thumb in the direction of the magnetic field $\vec{\mathbf{B}}$.
3. The magnetic force on a positive charge points out from the back of your hand.

Right-hand rule #2:

Point your thumb on your right hand along the wire in the direction of the current. Your fingers naturally curl around the direction of the magnetic field caused by the current, which circulates around the wire.