Physics 23 Final - 3 hours

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Monday, March 20

Write your answers in a blue book. Calculators and two pages of notes allowed. No textbooks allowed. Please make your work neat, clear, and easy to follow. It is hard to grade sloppy work accurately. Generally, make a clear diagram, and label quantities. Make it clear what you think is known, and what is unknown and to be solved for. Except for extremely simple problems, derive symbolic answers, and then plug in numbers (if necessary) after a symbolic answer is available. Use Gaussian centimeters-grams-seconds units for the electrostatic problems. **Put a box around your final answer... otherwise we may be confused about which answer you really mean, and you could lose credit.**

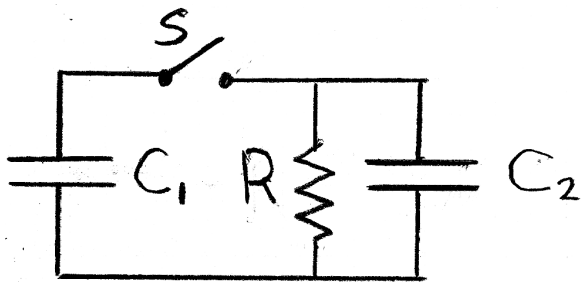

Figure 1: For use in Problem 1.

1. A circuit is shown in Fig. 1. The $C_1 = 40\,\mu\text{F}$, $R = 2\,\text{M}\Omega$, $C_2 = 10\,\mu\text{F}$. Initially, there is $Q_{10} = 500\,\mu\text{C}$ on capacitor C_1, and no charge on capacitor C_2. At time $t = 0$ the switch S is closed. Evaluate numerically:

   (a) For time $t < 0$, what is the voltage across C_1?

   (b) Just after $t = 0$, what is the voltage across C_2?

   (c) Just after $t = 0$, what is the current through R?

   (d) What is the current through R for all times $t \geq 0$?

2. Joe, who is at rest, sees Jane run from west to east with speed $v = 0.7c$, where c is the speed of light. First, Jane throws a ball toward the east with speed $v = 0.9c$ with respect to herself; second, Jane throws a ball toward the west with speed $v = 0.9c$ with respect to herself. What are the velocities of the first and second balls according to Joe? Evaluate numerically.

3. In the first reference frame, a particle with positive charge of $q = 0.2\,\text{esu}$ moves along the x axis with a constant speed of $0.8c$, where c is the speed of light. There is no magnetic field in this frame, but there is an electric field in the y direction of $5\,\text{statvolts/cm}$. A second reference frame moves with a velocity of $0.5c$ along the x-axis.

(a) What is the direction and magnitude of force felt by the charge in first frame due to the electric field? Evaluate numerically.

(b) What is the direction and magnitude of the force felt by the charge in the second reference frame due to the electric field in that frame? Evaluate numerically.

(c) What is the direction and magnitude of the force felt by the charge in *its rest frame* due to to the electric field in its rest frame? Evaluate numerically.

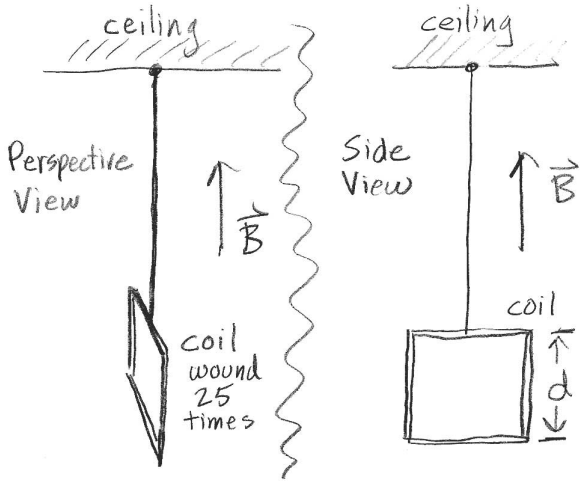

Figure 2: For use in Problem 4.

4. There is a uniform magnetic field of 100 Gauss vertically upward, and a special pendulum hangs in the field. The end or 'bob' of the pendulum has a square coil of wire on it, $d = 5\,\text{cm}$ on each side, and wound with $N = 1000$ windings; the bob weighs 100 gm. The plane of the square coil is vertical when the pendulum is at rest, as shown in Fig. 2. The length of the pendulum is $\ell = 10\,\text{cm}$. There is one $2500\,\Omega$ resistor in the coil. Take the acceleration of gravity $g = 10^3\,\text{cm/s}^2$; recall that the oscillation frequency of a pendulum is $f = (1/2\pi)\sqrt{g/\ell}$; treat the pendulum as a simple harmonic oscillator.

   You pull the pendulum from its rest position to an initial angle of $\theta_0 = 45°$, and then at $t = 0$ you release it. The pendulum bob is between your eye and the rest position.

   (a) Make a clear diagram that indicates the direction that you see the induced current flow in the coil after release of the bob.

   (b) Find an expression for the current in the coil as a function of time.

   (c) Numerically evaluate the current in the coil:

      i. An instant after you release it.

      ii. When its angle with respect to the vertical has decreased to $\theta = \theta_0/2$. Note $\cos(\pi/8) = 0.924$.

      iii. When the pendulum reaches the rest position.

5. A toriodal coil of height h and N windings is is wrapped between radii a and b from a center axis. A second wire runs along the center axis from $-\infty$ to $+\infty$.

   (a) A current $I_1(t)$ flows in the toroid. Find the voltage induced between the ends of the axial wire, in terms of $I_1(t)$ and/or its derivatives, h, N, a, b, and fundamental constants. Hint: reciprocity.

   (b) Repeat the last part, for the voltage induced in the toroidal coil itself, and evaluate the ratio of this voltage with respect to that found in the last part.