

# Physics 24 Practice Final - 3 hours

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Friday, March 20

Write your answers in a blue book. Calculators and two pages of notes allowed. No textbooks or other material 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.**

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1. Pam is running with speed  $v = (\sqrt{3}/2)c$ , where  $c$  is the speed of light, down a hill. The slope of the hill is  $30^\circ$  with respect to the horizontal. Pam kicks a soccer ball with speed  $u = (1/2)c$  with respect to herself; in her frame, the ball proceeds at an angle of  $45^\circ$  above the slope of the hill. What angle does the ball make with respect to the slope of the hill, according to an observer sitting on the hill?
2. A charge of strength  $Q = 10$  esu sits at the origin of an  $x$ - $y$  coordinate system.
  - (a) Initially, the charge is at rest. Find (numerically) the electric and magnetic fields at the point  $(x, y) = (10, 0)$ , given in centimeters.
  - (b) Repeat for  $(x, y) = (0, 10)$ , given in centimeters.
  - (c) Now imagine that the charge is still at the origin, but moves with a velocity in the  $x$  direction of  $(\sqrt{3}/2)c$ . Find (numerically) the electric and magnetic fields at the point  $(x, y) = (10, 0)$ , given in centimeters.
  - (d) Repeat for  $(x, y) = (0, 10)$ .
3. A charge of strength  $Q = 5$  esu is at  $(x, y, z) = (0, 0, 5)$  in centimeters, and moves with velocity  $v = 0.01c$  in the  $x$ -direction. Below it in the plane  $z = 0$  is a wire bent into a circle with radius  $b = 5$  cm, having a current  $I = 3$  esu/sec going around in the clockwise direction, as viewed from above (positive  $z$ ). You may assume that the strength of the magnetic field on the axis of a circular wire is:

$$B = \frac{2\pi b^2 I}{c(b^2 + z^2)^{3/2}}$$

- (a) What is the direction and magnitude of the force on the charge?
  - (b) What is the value of the vector potential at the position of the charge?
4. A metal crossbar of mass  $m$  slides without friction down long parallel conducting rails which are a distance  $b$  apart, as shown in Fig. 1. The bar feels the force of the earth's gravity. A resistor  $R$  is connected across the rails at one end; all other resistances are negligible compared to  $R$ . There is a uniform  $\mathbf{B}$  field perpendicular to the figure. The cross bar falls, and eventually comes asymptotically to a terminal velocity. Consider the balancing of magnetic and gravitational forces to arrive at an expression for the terminal velocity in terms of the other quantities.

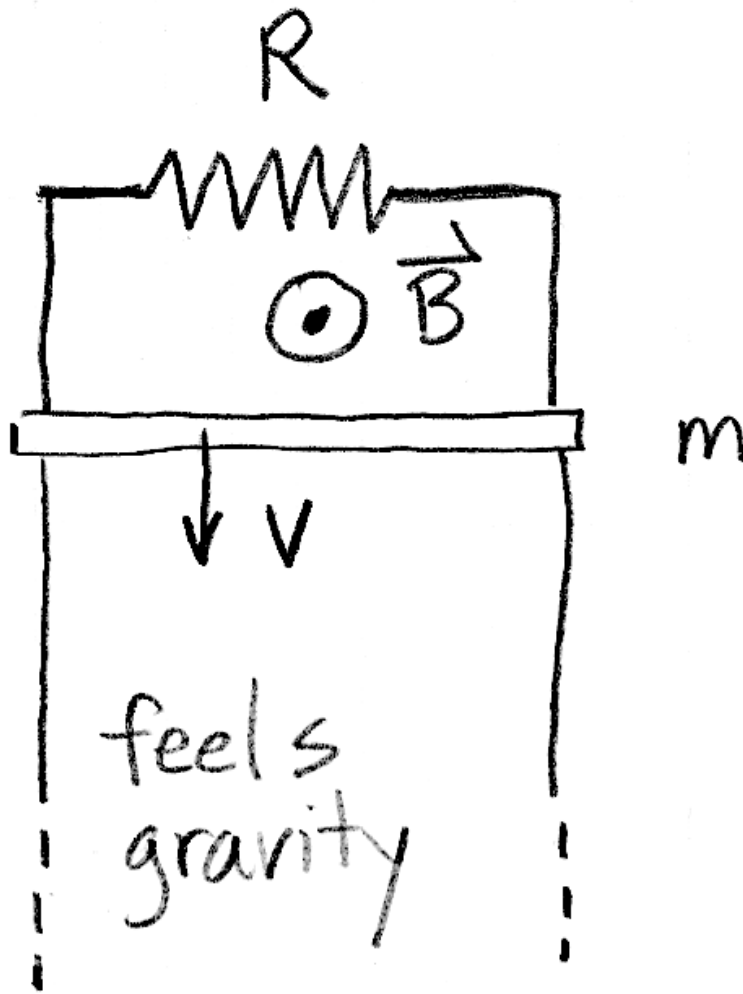


Figure 1: For use in Problem 4.

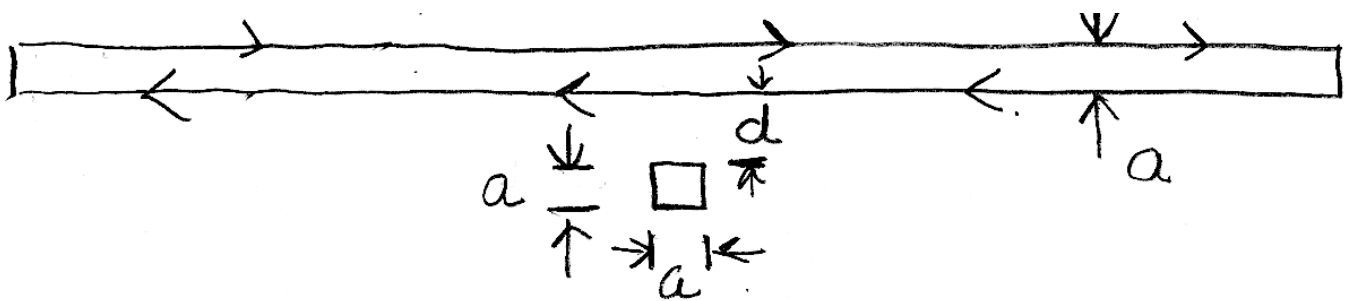


Figure 2: For use in Problem 5.

5. A very long, narrow, rectangular loop is formed by wires a distance  $a$  apart from one another, and joined at their ends, so that the length of the loop is much, much greater than  $a$ , as shown in the top of Fig. 2. A square loop, with each side also equal to  $a$ , is placed so that one of its sides is a distance  $d$  from the closer wire in the long narrow loop. The distance  $d$  is also much smaller than the length of the long loop. Find the mutual inductance of these loops.
6. In the circuit shown in Fig. 3, the switch  $S$  is closed at  $t = 0$ . The voltage  $\varepsilon = 10\text{ V}$ , the resistance

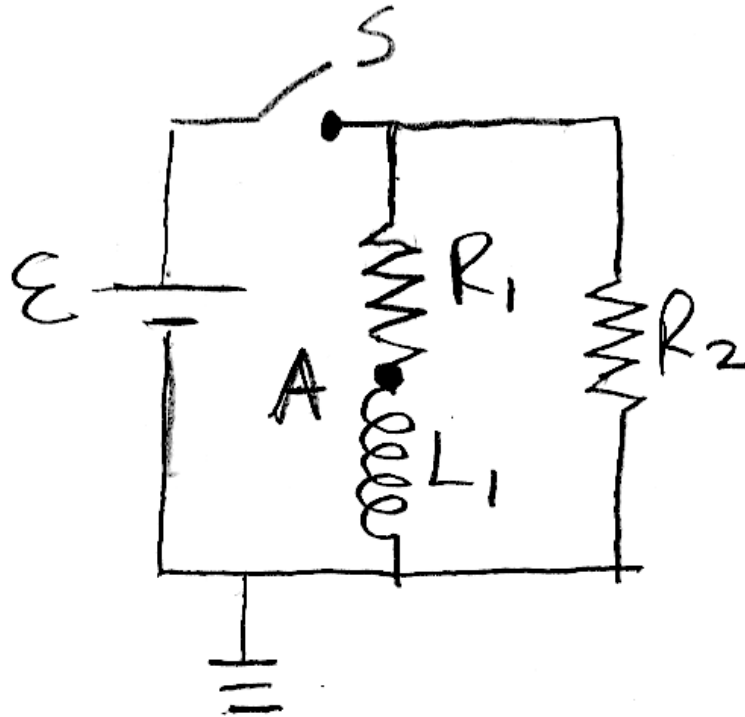


Figure 3: For use in Problem 6.

$R_1 = 100\ \Omega$ , the inductor  $L_1 = 100$  millihenry, and the resistance  $R_2 = 10\ \Omega$ .

- (a) Find the time constant  $\tau$  in the exponential  $e^{-t/\tau}$  used in the expression that describes the current that flows through the inductor  $L_1$  after the switch is closed. Find  $\tau$  both symbolically and numerically.
  - (b) Find the voltage of point A as a function of time, for times  $-\infty < t < \infty$ , both numerically and symbolically.
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