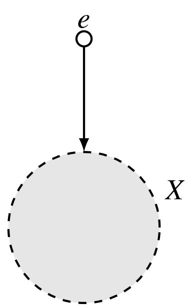
Student #: ____________________________ Student Name: ___________________________________

AP PHYSICS C: MAGNETISM

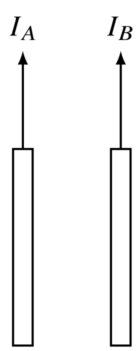
Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and place the letter of your choice in the corresponding box on the student answer sheet.

1. An electron is moving downward toward the bottom of the page when it passes through a region of magnetic field, as shown in the figure by the shaded area. The electron travels along a path that takes it through the spot marked X. The gravitational force on the electron is very small. What is the direction of the magnetic field?



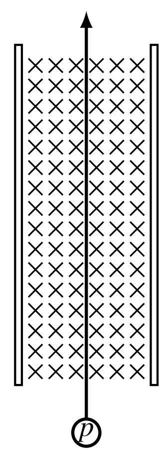
(A) Toward the bottom of the page
(B) Toward the top of the page
(C) Out of the page
(D) Into the page

2. Two long parallel wires carry currents (I_A and I_B), as shown in the figure. Current I_A in the left wire is twice that of current I_B in the right wire. The magnetic force on the right wire is F. What is the magnetic force on the left wire in terms of F?

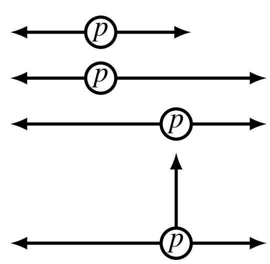


(A) F in the same direction
(B) F in the opposite direction
(C) $F/2$ in the same direction
(D) $F/2$ in the opposite direction

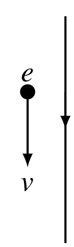
3. A magnetic field, directed into the page, is placed between two charged capacitor plates, as shown in the figure. The magnetic and electric fields are adjusted so a proton moving at a velocity of v will pass straight through the fields. The speed of the proton is doubled to $2v$. Which of the following force diagrams most accurately depicts the forces acting on the proton when traveling at $2v$?



(A)
(B)
(C)
(D)



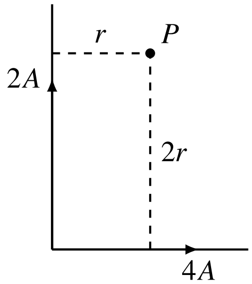
4. Which of the following is true concerning the force on the current-carrying wire due to the electron?



(A) The force is directed toward the right.
(B) The force is directed toward the left.
(C) The force is directed into the page.
(D) There is no force on the current-carrying wire due to the electron.

Questions 5–6

Two wires carry currents $2A$ and $4A$ in the directions shown. Point P is a distance r from the wire carrying $2A$, and a distance $2r$ from the wire carrying $4A$.



5. Which of the following statements is true?

   (A) The magnetic field produced at point P by the wire carrying $2A$ is greater than the magnetic field produced at point P by the wire carrying $4A$, but opposite in direction.
   (B) The magnetic field produced at point P by the wire carrying $2A$ is less than the magnetic field produced at point P by the wire carrying $4A$, and in the same direction.
   (C) The magnetic field produced at point P by the wire carrying $2A$ is equal to the magnetic field produced at point P by the wire carrying $4A$, but opposite in direction.
   (D) The magnetic field produced at point P by the wire carrying $2A$ is equal to the magnetic field produced at point P by the wire carrying $4A$, and in the same direction.
   (E) The magnetic field produced at point P by the wire carrying $2A$ is greater than the magnetic field produced at point P by the wire carrying $4A$, and in the same direction.

6. The magnitude of the resultant magnetic field at point P due to the current in the two wires is

   (A) zero
   (B) $\dfrac{\mu_0(2A)}{2\pi r}$
   (C) $\dfrac{\mu_0(2A)}{\pi r}$
   (D) $\dfrac{\mu_0(4A)}{2\pi r}$
   (E) $\dfrac{\mu_0(6A)}{4\pi r}$

Questions 7–8

Two wires are parallel to each other, one carrying twice the current as the other. The two currents flow in the same direction.

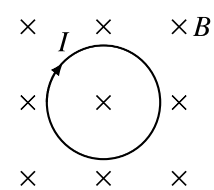
7. Which of the following is true of the forces the wires exert on each other?

   (A) The wire with the larger current exerts a greater force on the other wire.
   (B) The wire with the smaller current exerts a greater force on the other wire.
   (C) The wires exert equal and opposite forces on each other.
   (D) The wires exert equal forces on each other, but in the same direction.
   (E) The net force between the wires is zero.

8. The direction of the force between the wires is

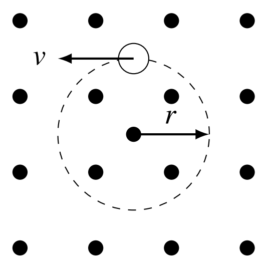
   (A) repulsive
   (B) attractive
   (C) zero
   (D) into the page
   (E) out of the page

9. A loop of wire in the plane of the page carries a clockwise current I and is placed in a magnetic field that is directed into the page as shown. Which of the following will happen as a result of the wire loop being in the magnetic field?



   (A) The wire loop will rotate clockwise.
   (B) The wire loop will rotate counterclockwise.
   (C) The wire loop will flip on a horizontal axis through its center.
   (D) The wire loop will expand in size.
   (E) The wire loop will contract in size.

Questions 10–11 A negatively charged particle of mass m and charge q in a uniform magnetic field B travels in a circular path of radius r.



10. In terms of the other given quantities, the charge-to-mass ratio q/m of the particle is

    (A) $\dfrac{Bv}{r}$
    (B) $\dfrac{r}{Bv}$
    (C) $\dfrac{rv}{B}$
    (D) rvB
    (E) $\dfrac{v}{rB}$

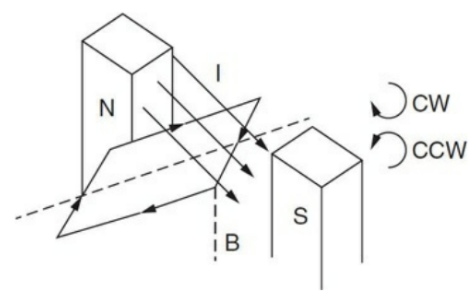
11. The work done by the magnetic field after two full revolutions of the charge is

    (A) zero
    (B) $-qvB/rm$
    (C) qvm/Br
    (D) $-mBr/qv$
    (E) $-mqvBr$

12. A current is passed through an analog ammeter and the needle moves to indicate the current flowing through the circuit. Which of the following best explains how an analog ammeter works?

    (A) Current is passed through the needle placed in a magnetic field, and the needle is attracted to the high side of the scale.
    (B) The needle is a magnet, and is attracted to a magnet on the high side of the scale.
    (C) The needle gathers an electrostatic charge from the current, and is attracted to an electrostatic charge on the high side of the scale.
    (D) Current is passed through a spring coil of wire placed in a magnetic field, and the coil rotates, moving the needle proportionally to the current in the coil.
    (E) Current flows through the needle, making it heavier, and it falls to the high side of the scale.

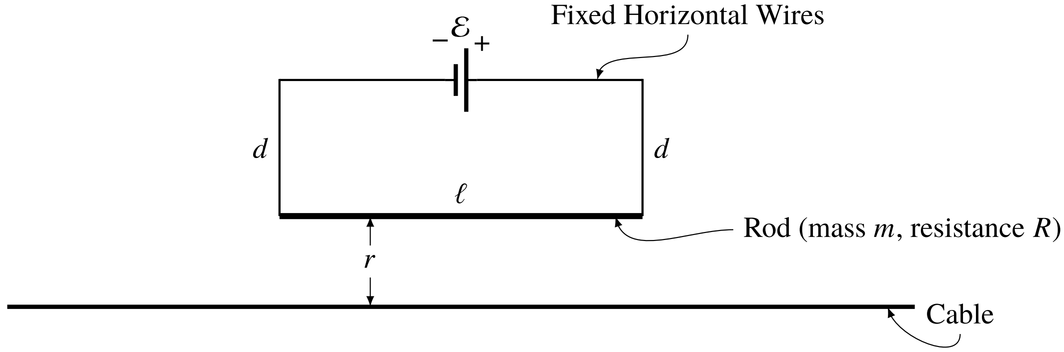
13. An electric motor consists of a current-carrying loop of wire mounted to an axle and turned at a slight angle in a magnetic field as shown. The wire loop will



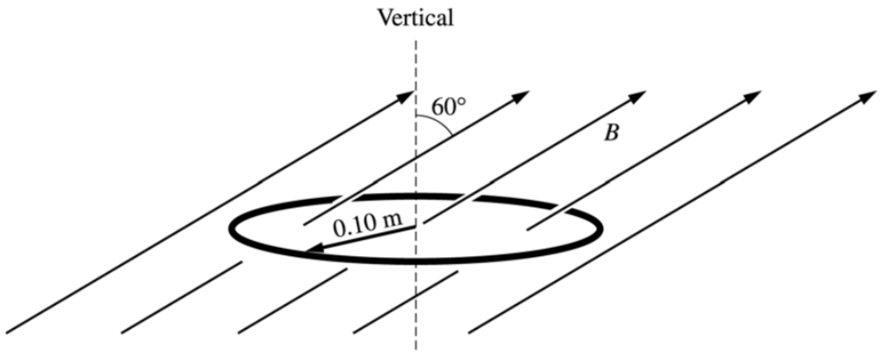
    (A) experience a torque and turn clockwise
    (B) experience a torque and turn counterclockwise
    (C) accelerate upward out of the magnetic field
    (D) accelerate downward out of the magnetic field
    (E) not experience a force or torque

AP PHYSICS C: MAGNETISM
SECTION II
8 Questions

Directions: Answer all questions. The parts within a question may not have equal weight. All final numerical answers should include appropriate units. Credit depends on the quality of your solutions and explanations, so you should show your work. Credit also depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should clearly indicate which part of a question your work is for.



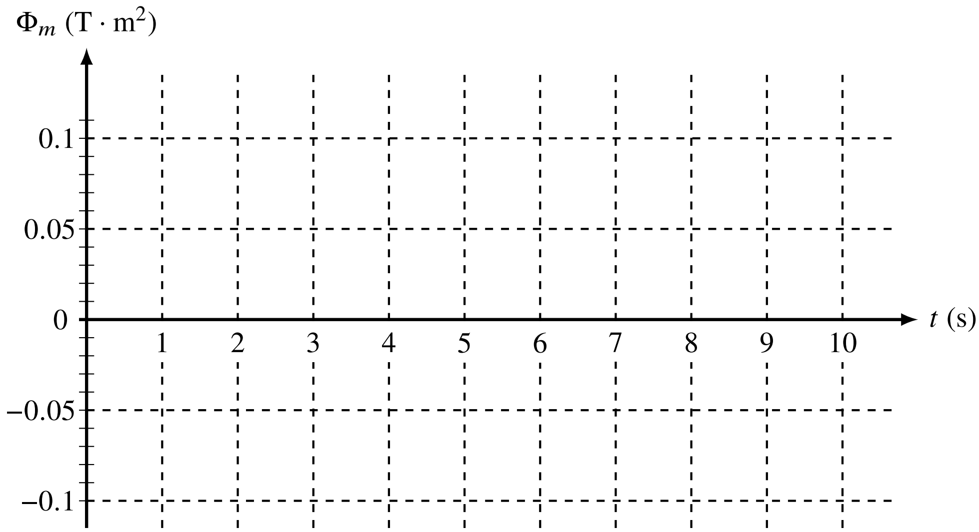
1. The circuit shown above consists of a battery of emf $\mathcal{E}$ in series with a rod of length ℓ, mass m, and resistance R. The rod is suspended by vertical connecting wires of length d, and the horizontal wires that connect to the battery are fixed. All these wires have negligible mass and resistance. The rod is a distance r above a conducting cable. The cable is very long and is located directly below and parallel to the rod. Earth's gravitational pull is toward the bottom of the page. Express all algebraic answers in terms of the given quantities and fundamental constants.
   (a) What is the magnitude and direction of the current I in the rod?
   (b) In which direction must there be a current in the cable to exert an upward force on the rod? Justify your answer.
   (c) With the proper current in the cable, the rod can be lifted up such that there is no tension in the connecting wires. Determine the minimum current I_c in the cable that satisfies this situation.
   (d) Determine the magnitude of the magnetic flux through the circuit due to the minimum current I_c determined in part (c).



2. A circular wire loop with radius 0.10 m and resistance 50 Ω is suspended horizontally in a magnetic field of magnitude B directed upward at an angle of 60° with the vertical, as shown above. The magnitude of the field in teslas is given as a function of time t in seconds by the equation $B = 4(1 - 0.2t)$.

(a) Determine the magnetic flux Φ_m through the loop as a function of time.

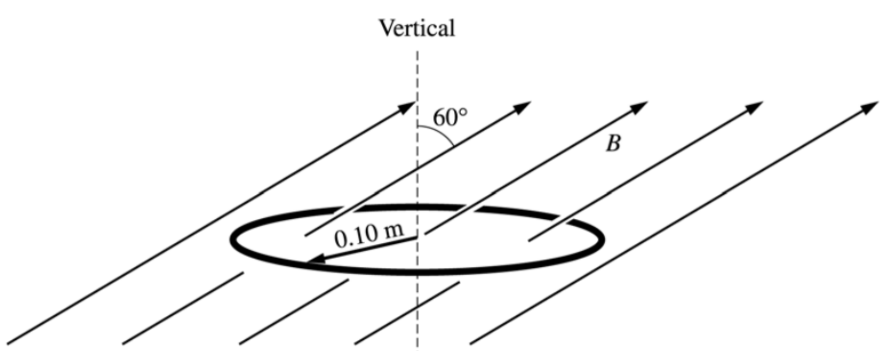
(b) Graph the magnetic flux Φ_m as a function of time on the axes below.

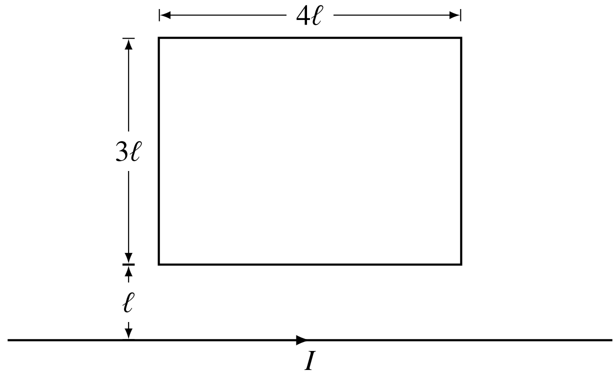


(c) Determine the magnitude of the induced emf in the loop.

(d) i. Determine the magnitude of the induced current in the loop.

ii. Show the direction of the induced current on the following diagram.





3. A rectangular loop of dimensions 3ℓ and 4ℓ lies in the plane of the page as shown above. A long straight wire also in the plane of the page carries a current I.

   (a) Calculate the magnetic flux through the rectangular loop in terms of I, ℓ, and fundamental constants.

   Starting at time $t = 0$, the current in the long straight wire is given as a function of time t by $I(t) = I_0 e^{-kt}$, where I_0 and k are constants.

   (b) The current induced in the loop is in which direction? Justify your answer.

   _______ Clockwise   _______ Counterclockwise

   The loop has a resistance R. Calculate each of the following in terms of R, I_0, k, ℓ, and fundamental constants.

   (c) The current in the loop as a function of time t

   (d) The total energy dissipated in the loop from $t = 0$ to $t = \infty$

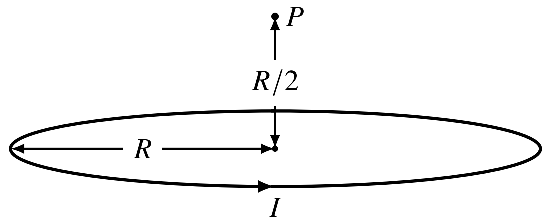


Figure 1

4. The circular loop of wire in Figure 1 above has a radius of R and carries a current I. Point P is a distance of R_2 above the center of the loop. Express algebraic answers to parts (a) and (b) in terms of R, I, and fundamental constants.

   (a) i. State the direction of the magnetic field B_1 at point P due to the current in the loop.

   ii. Calculate the magnitude of the magnetic field B_1 at point P.

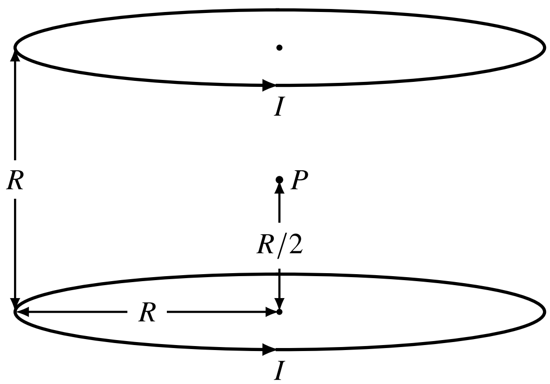


Figure 2

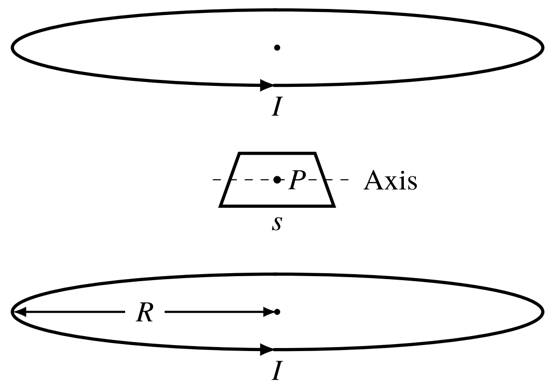


Figure 3

A second identical loop also carrying a current I is added at a distance of R above the first loop, as shown in Figure 2 above.

(b) Determine the magnitude of the net magnetic field B net at point P.

A small square loop of wire in which each side has a length s is now placed at point P with its plane parallel to the plane of each loop, as shown in Figure 3 above. For parts (c) and (d), assume that the magnetic field between the two circular loops is uniform in the region of the square loop and has magnitude B_{net}.

(c) In terms of B_{net} and s, determine the magnetic flux through the square loop.

(d) The square loop is now rotated about an axis in its plane at an angular speed ω. In terms of B_{net} , s, and ω, calculate the induced emf in the loop as a function of time t, assuming that the loop is horizontal at $t = 0$.

5. A section of a long conducting cylinder with inner radius a and outer radius b carries a current I_0 that has a uniform current density, as shown in the figure above.

   (a) Using Ampère's law, derive an expression for the magnitude of the magnetic field in the following regions as a function of the distance r from the central axis.

   i. $r < a$

   ii. $a < r < b$

   iii. $r = 2b$

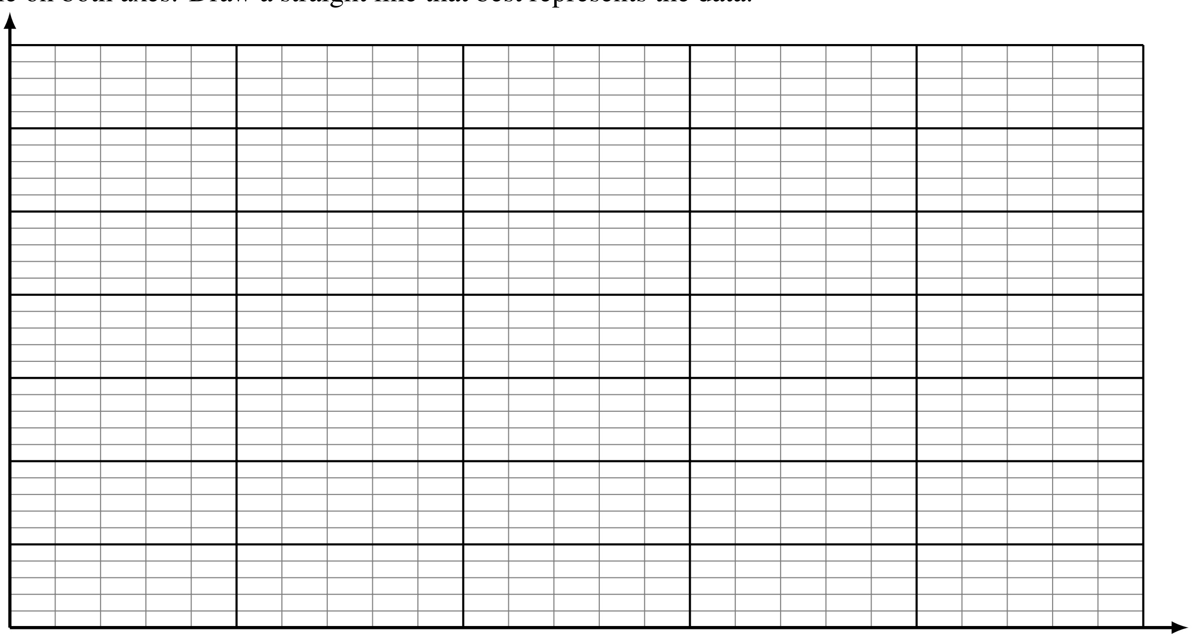
   (b) On the cross-sectional view in the diagram above, indicate the direction of the field at point P, which is at a distance $r = 2b$ from the axis of the cylinder.

   (c) An electron is at rest at point P. Describe any electromagnetic forces acting on the electron. Justify your answer.

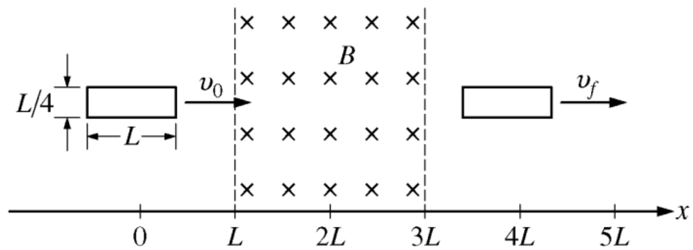
Now consider a long, solid conducting cylinder of radius b carrying a current I_0. The magnitude of the magnetic field inside this cylinder as a function of r is given by $B = \mu_0 I_0 r / 2\pi b^2$. An experiment is conducted using a particular solid cylinder of radius 0.010 m carrying a current of 25 A. The magnetic field inside the cylinder is measured as a function of r, and the data is tabulated below.

Distance r (m)	0.002	0.004	0.006	0.008	0.010
Magnetic Field B (T)	1.2×10^{-4}	2.7×10^{-4}	3.6×10^{-4}	4.7×10^{-4}	6.4×10^{-4}

   (d) i. On the graph below, plot the data points for the magnetic field B as a function of the distance r, and label the scale on both axes. Draw a straight line that best represents the data.



   ii. Use the slope of your line to estimate a value of the permeability μ_0.



6. The rectangular loop of wire shown on the left in the figure above has mass M, length L, width $L/4$, and resistance R. It is initially moving to the right at constant speed v_0 , with no net force acting on it. At time $t = 0$ the loop enters a region of length $2L$ that contains a uniform magnetic field of magnitude B directed into the page. The loop emerges from the field at time t_f with final speed v_f . Express all algebraic answers to the following in terms of M, L, R, B, v_0, and fundamental constants, as appropriate.

   (a) Let x represent the position of the right end of the loop. Place a check mark in the appropriate box in each column in the table below to indicate whether the speed of the loop increases, decreases, or stays the same as the loop moves to the right.

   (b) Derive an expression for the magnitude of the current induced in the loop as its right edge enters the field.

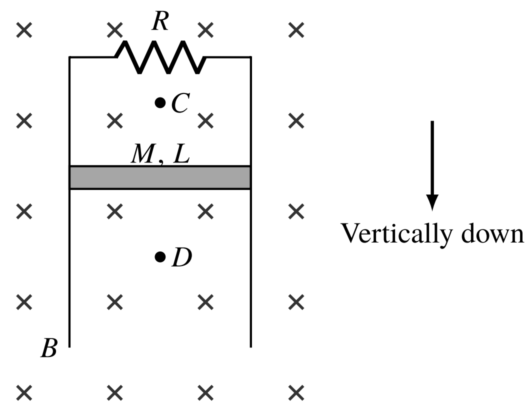
   (c) What is the direction of the induced current determined in part (b) ? Justify your answer.

   _______ Clockwise _______ Counterclockwise

   (d) Write, but do not solve, a differential equation for the speed v as a function of time as the loop enters the field.

   (e) What is the direction of the acceleration of the loop just before its left edge leaves the field? Justify your answer.

   _______ Left _______ Right _______ Up _______ Down



7. A conducting bar of mass M, length L, and negligible resistance is connected to two long vertical conducting rails of negligible resistance. The two rails are connected by a resistor of resistance R at the top. The entire apparatus is located in a magnetic field of magnitude B directed into the page, as shown in the figure above. The bar is released from rest and slides without friction down the rails.

   (a) What is the direction of the current in the resistor?

   _______ Left _______ Right

   (b) i. Is the magnitude of the net magnetic field above the bar at point C greater than, less than, or equal to the magnitude of the net magnetic field before the bar is released? Justify your answer.

   _______Greater than _______Less than _______Equal to

   ii. While the bar is above point D, is the magnitude of the net magnetic field at point D greater than, less than, or equal to the magnitude of the net magnetic field before the bar is released? Justify your answer.

   _______Greater than _______Less than _______Equal to

   Express your answers to parts (c) and (d) in terms of M, L, R, B, and physical constants, as appropriate.

   (c) Write, but do NOT solve, a differential equation that could be used to determine the velocity of the falling bar as a function of time t.

   (d) Determine an expression for the terminal velocity v_T of the bar.

   Express your answers to parts (e) and (f) in terms of v_T, M, L, R, B, and physical constants, as appropriate.

   (e) Derive an expression for the power dissipated in the resistor when the bar is falling at terminal velocity.

   (f) Using your differential equation from part (c), derive an expression for the speed of the falling bar v_t as a function of time t.