Last Name: ____________________ First Name: ____________________

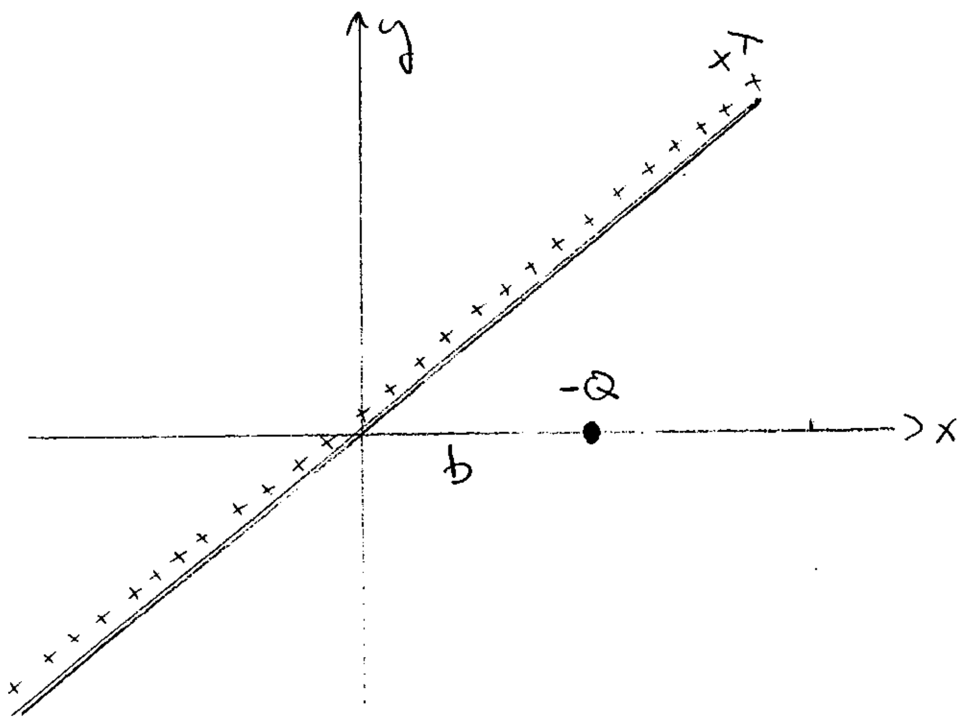
Physics 102 Spring 2004: Final Exam, May 1, 2004
Free Response and Instructions

- Print your LAST and FIRST name on the front of your blue book, on this question sheet, the multiple-choice question sheet and the multiple-choice answer sheet.
- TIME ALLOWED 3 HOURS
- The test consists of three free-response questions and 20 multiple-choice questions.
- The test is graded on a scale of 150 points; the free-response questions account for 90 points, and the multiple-choice questions account for 60 points (3 points each).
- Answer the three free-response questions in your blue book. Answer the multiple-choice questions by marking a dark X in the appropriate column and row in the table on the multiple-choice answer sheet.
- Consult no books or notes of any kind. You may use a hand-held calculator in non-graphing, non-programmed mode.
- Do NOT take test materials outside of the class at any time. Return this question sheet along with your blue book and multiple-choice question sheet.
- Write and sign the Pledge on the front of your blue book.

Show your work for the free-response problems, including neat and clearly labelled figures, in your blue book. Answers without explanation (even correct answers) may not be given credit.

I. (30 points) A very long, thin wire carries a positive uniform linear charge density $+\lambda$. The wire lies in the $x-y$ plane, making an angle of 45^o to the x–axis. In addition to the wire, a single negative point charge $-Q$ lies on the $x-axis$ at $x = b$. Express your answers in terms of λ, Q, b, q and possibly other constants.

(a) Determine the electric field vector $\vec{E}$ for an arbitrary point on the x–axis. Be sure to consider both positive and negative values of x.
(b) Determine the electric flux Φ_E through a sphere of radius $2b$, centered at the origin.
(c) How much work must be done by an external agent to move a positive test charge $+q$ from $x = 2b$ to $x = 4b$?

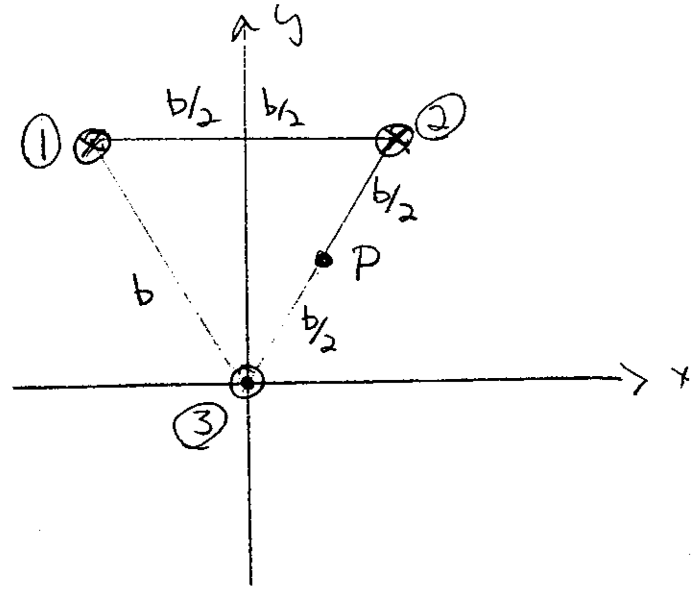


II. (30 points) Three very long wires are arranged to form an equilateral triangle of side b, as shown below. The wires carry current I perpendicular to the plane of the page. The two wires at the top of the triangle carry current into the page, while the wire at the bottom carries current out of the page. Express your answer in terms of B, I, b, and possibly other constants. Take the lower wire to be the origin of your coordinate system.

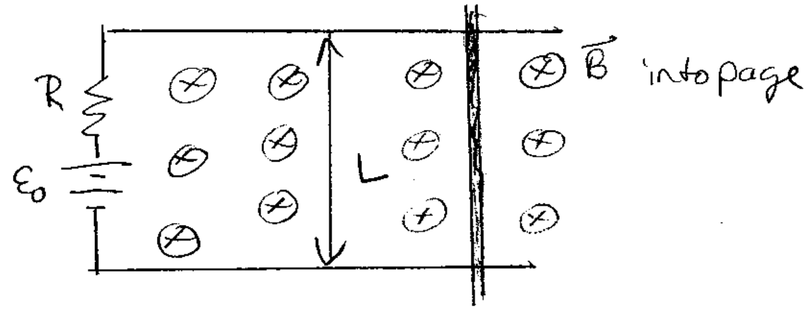
(a) Determine the magnetic field $\vec{B}$ at the location of the top left wire (numbered 1 in the drawing) due to the current in the other two wires.

(b) Determine the force per unit length on wire 1 due to the other two wires.

(c) Determine the magnetic field vector $\vec{B}$ at the point P indicated in the sketch, which is the midpoint of the right hand side of the triangle, due to the current in all three wires.

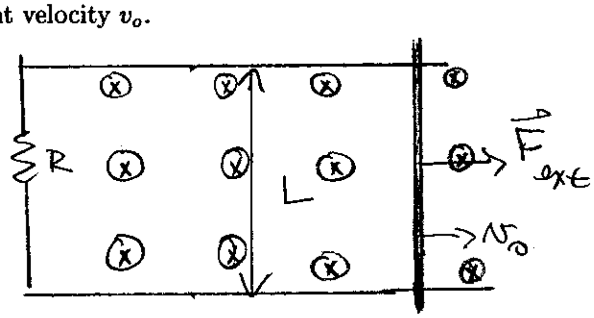


III. (30 points) A steel bar lies on a pair of parallel conducting rails which are a distance L apart. The bar is free to move along the rails, and for the purposes of this problem we can ignore friction. We can also ignore any resistance in the rails and the bar. A battery with emf $\mathcal{E}_0$ and a resistor R are connected across the ends of the bars as shown below. The entire apparatus sits in a uniform magnetic field $\vec{B}$ directed into the page. Express your answers in terms of $\mathcal{E}_o$, B, R, L, and possibly other constants.



(a) Determine the force on the vertical bar due to the current. Be sure to indicate both the direction and magnitude of the force.
(b) Due to this force, the bar starts moving. When the bar is moving with velocity v, determine the induced emf $\mathcal{E}_{ind}$. Be sure to indicate both direction and magnitude of the induced emf.
(c) Show that the bar reaches a terminal velocity and determine the value of the terminal velocity in terms of quantities specified above and possibly other constants.

Now suppose the battery is removed, while the resistor R remains in place. An external agent pulls the bar to the right at constant velocity v_o.



(d)Determine the induced emf $\mathcal{E}_{ind}$ and the current in the bar for this situation.
(e) Determine the rate at which energy is dissipated as heat in the resistor R when the bar is being pulled to the right at constant velocity v_o.
(f) What constant force must be applied by an external agent to keep the bar moving at the constant velocity v_o?
(g) Determine the rate at which this external agent does work, and compare to your answer in (e).

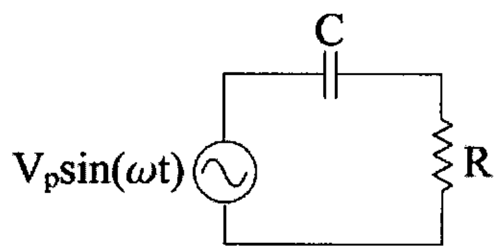
Last Name: First Name: .

Physics 102 Spring 2004: Final—Multiple-Choice Questions

1. Two identical, small, conducting spheres are separated by a distance of 1 m. The spheres originally have equal but opposite charges, and the force between them is F_0. Half of the charge on one sphere is then moved to the other sphere. The force between the spheres is now

   A) $F_0/4$.
   B) $F_0/2$.
   C) $3F_0/4$.
   D) $3F_0$.
   E) $3F_0/2$.

2. As the frequency ω in this simple ac circuit increases, keeping V_p constant, the rms current through the resistor



   A) increases.
   B) does not change.
   C) may increase or decrease depending on the magnitude of the original frequency.
   D) decreases.

3. A closed spherical surface of radius a is in a uniform electric field (**E**). The sphere is far from any charge. What is the electric flux Φ_E through the surface?

   A) $\Phi_E = 4\pi a^2 E$
   B) $\Phi_E = \pi a^2 E$
   C) $\Phi_E = 4\pi a^3 E$
   D) $\Phi_E = 0$
   E) Φ_E cannot be determined without additional knowledge

For questions 4 and 5: A hollow conducting ball has a single positive charge $+q$ fixed at its center. The ball has no net charge.

4. The charge on the inner surface of the ball is

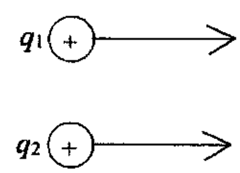
   A) $+2q$
   B) $+q$
   C) $-q$
   D) $-2q$
   E) 0

5. The charge on the outer surface of the ball is

   A) $+2q$
   B) $+q$
   C) $-q$
   D) $-2q$
   E) 0

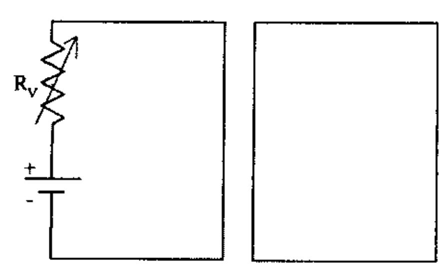
6. Two positive charges q_1 and q_2 are moving to the right (as shown in the figure below). What is the direction of the magnetic force on charge q_1 due to the magnetic field produced by q_2?

   A) Into the page
   B) Up the page
   C) Down the page
   D) Out of the page
   E) There is no direction since the force is zero.



7. Two loops lie in the plane of the paper, as shown. The resistance R_V in the left-hand circuit of figure below is being increased at a steady rate. What is the direction of the induced current in the right-hand circuit.

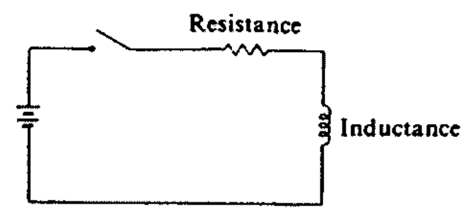
   A) into the page
   B) counter-clockwise
   C) zero (there is no current in the right-hand circuit)
   D) out of the page
   E) clockwise

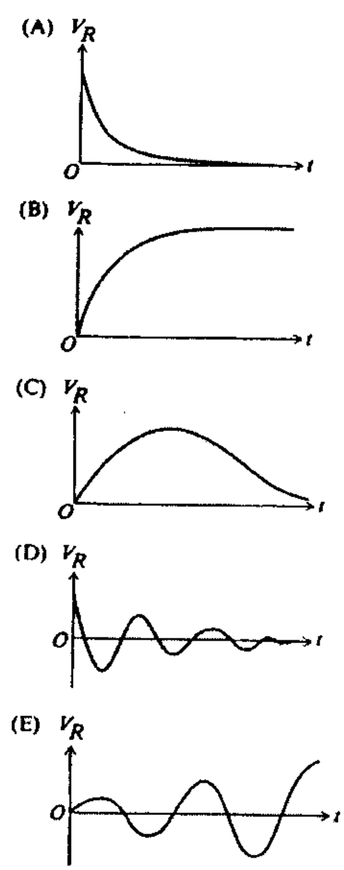


8. The frequency of an LC oscillator is f_0. The plates of the parallel-plate capacitor are then pulled apart to twice the original separation. What is the new frequency of oscillation?

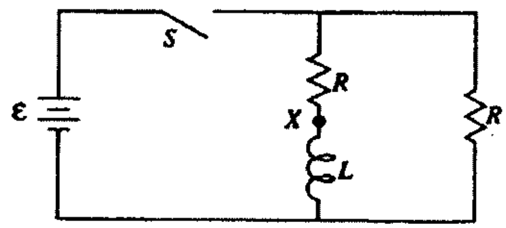
A) $2 f_0$
B) $\sqrt{2} f_0$
C) $f_0 / \sqrt{2}$
D) $f_0 / 2$

9. At time t = 0 s, the switch is closed in the circuit shown below. Which of the following graphs best describes the potential difference V_R across the resistance as a function of time t?





For questions 10 thru 12, refer to the circuit below (Note: Switch S has been open a long time).



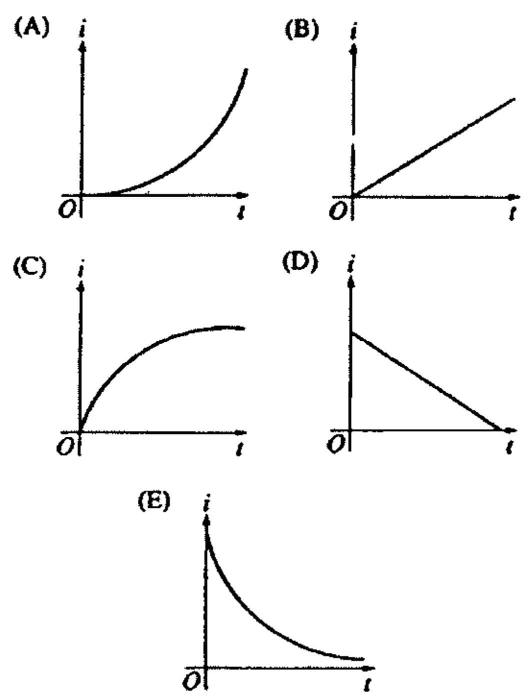
10. What is the instantaneous current at point X immediately after the switch is closed?

A) 0
B) ε/R
C) $\varepsilon/2R$
D) ε/RL
E) $\varepsilon L/2R$

11. When the switch has been closed for a long time, what is the energy stored in the inductor?

A) $\frac{L\varepsilon}{2R}$ B) $\frac{L\varepsilon^2}{2R^2}$ C) $\frac{L\varepsilon^2}{4R^2}$ D) $\frac{LR^2}{2\varepsilon^2}$ E) $\frac{\varepsilon^2 R^2}{4L}$

12. After the switch has been closed for a long time, it is opened at time $t = 0$. Which of the following graphs best represents the subsequent current I at point X as a function of time t?



13. The potential of an isolated conducting sphere of radius R is given as a function of charge q on the sphere by the equation $V = kq/R$. If the sphere is initially uncharged, the work W required to gradually increase the total charge on the sphere from zero to Q is given by which of the following expressions?

A) $W = \int_0^Q (kq/R)dq$.

B) $W = kQ^2/R$.

C) $W = kQ/R$.

D) $W = \int_0^Q (kq^2/R)dq$

E) $W = \int_0^Q (kq/R^2)dq$

14. Which of the following equations implies that it is impossible to isolate a magnetic pole?

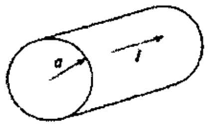
A) $\oint \vec{E} \bullet d\vec{A} = \frac{q}{\varepsilon_0}$.

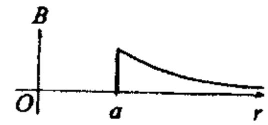
B) $\oint \vec{E} \bullet d\vec{l} = -\frac{d\Phi_B}{dt}$.

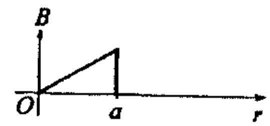
C) $\oint \vec{B} \bullet d\vec{A} = 0$.

D) $\oint \vec{B} \bullet d\vec{l} = \mu_0 I + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$.

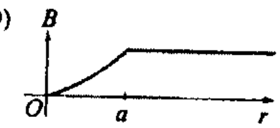
15. A current I, uniformly distributed over the cross section of a long cylindrical conductor of radius a, is directed as shown below. Which of the following graphs represents the magnitude B, of the magnetic field as a function of the distance r from the axis of the cylinder?

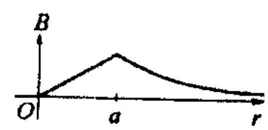


(A)


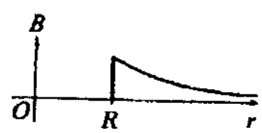
(B)


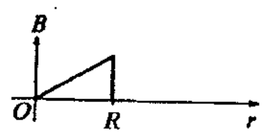
(C)

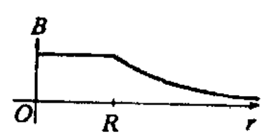

(D)


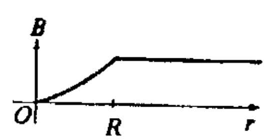
(E)


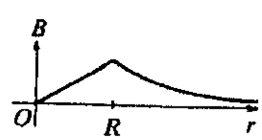
16. A parallel-plate capacitor in air has circular plates of radius R. While the capacitor is charging, a magnetic field is present between the plates of the capacitor. Which of the following graphs best represents the magnitude of the magnetic field, B, as a function of the distance r from the axis of the capacitor?

(A)


(B)


(C)


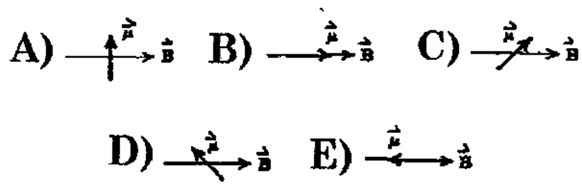
(D)


(E)


17. A battery is used to charge a parallel-plate capacitor, after which it is disconnected leaving the capacitor charged and isolated. The plates are then pulled apart to twice their original separation. This process will double the

A) capacitance
B) charge on each plate.
C) electric field between the plates.
D) stored energy.
E) surface charge density on each plate.

Refer to the figure below for questions 18 and 19. The diagrams show five possible orientations of a magnetic dipole $\vec{\mu}$ in a uniform magnetic field $\vec{B}$.



18. For which of these orientations does the magnetic torque on the dipole have its greatest magnitude?

19. For which of these is the potential energy greatest?

20. If the current through an inductor is doubled, the magnetic energy density of the magnetic field

A) remains the same
B) is doubled.
C) is halved.
D) is quadrupled
E) is quartered.

Last Name: ______________________ First Name: ______________________

Physics 102 Spring 2004: Final Exam—Multiple-Choice Answers
9:00 AM - 12:00 PM, 1 May, 2004

For each question, mark a single X in the box corresponding to the correct answer.

	A	B	C	D	E
1					
2					
3					
4					
5					
6					
7					
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9					
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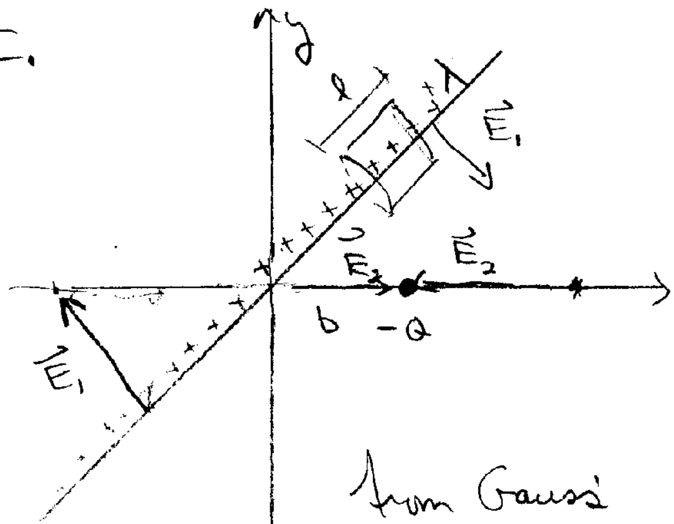
Phys 102

Final Exam – Spring 2004

I.



(a) $\vec{E}(x)$ on x-axis

first consider $x > b$

The field due to the line of charge will be $\perp$ to the line.

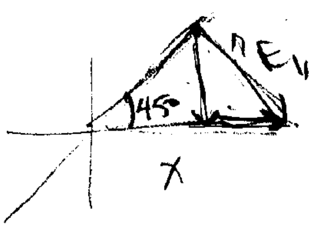
from Gauss' law:

$$\oint \vec{E}_1 \cdot d\vec{A} = \frac{q_{enc}}{\varepsilon_0}$$

$$2\pi r l E_1 = \frac{\lambda l}{\varepsilon_0}$$

$$|E_1| = \frac{\lambda}{2\pi\varepsilon_0 r}$$

where r is the distance from the line.



$$\vec{E}_1 = \frac{\lambda}{2\pi\varepsilon_0 r}\left[\sin 45^\circ \hat{\imath} - \cos 45^\circ \hat{\jmath}\right]$$

$x^2 = 2r^2$ or $r = \frac{x}{\sqrt{2}}$ $\quad \sin 45^\circ = \cos 45^\circ = \frac{1}{\sqrt{2}}$

$$\vec{E}_1 = \frac{\lambda\sqrt{2}}{2\pi\varepsilon_0 x}\left[\frac{1}{\sqrt{2}}\hat{\imath} - \frac{1}{\sqrt{2}}\hat{\jmath}\right]$$

(due to line of charge)

$$\boxed{\vec{E}_1 = \frac{\lambda}{2\pi\varepsilon_0 x}\left(\hat{\imath} - \hat{\jmath}\right)}$$

$\vec{E}_2$ (due to $-Q$) $= \dfrac{-Q}{4\pi\varepsilon_0 (x-b)^2}\hat{\imath}$

$$\vec{E}_{TOT} = \left(\frac{\lambda}{2\pi\varepsilon_0 x} - \frac{Q}{4\pi\varepsilon_0 (x-b)^2}\right)\hat{\imath} - \frac{\lambda}{2\pi\varepsilon_0 x}\hat{\jmath}$$ for $x > b$

$(x > b)$

for $0 < x < b$, $\vec{E}_2$ changes sign.

$$\vec{E}_{TOT} = \left(\frac{\lambda}{2\pi\varepsilon_0 x} + \frac{Q}{4\pi\varepsilon_0 (x-b)^2}\right)\hat{\imath} - \frac{\lambda}{2\pi\varepsilon_0 x}\hat{\jmath}$$ $0 < x < b$

for $x < 0$, both components of $\vec{E}_1$ change sign, but the x in the denominator also changes sign, so the expression is the same!

$$\vec{E}_{TOT} = \left(\frac{\lambda}{2\pi\varepsilon_0 x} + \frac{Q}{4\pi\varepsilon_0 (x-b)^2}\right)\hat{\imath} - \frac{\lambda}{2\pi\varepsilon_0 x}\hat{\jmath}$$ $x < 0$

(b) Determine ϕ_E through a sphere of $R = 2b$, centered at the origin. Gauss' Law gives:

$$\phi_E = \frac{q_{encl}}{\varepsilon_0}$$

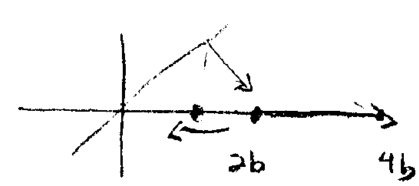
for $R = 2b$, $-Q$ is enclosed and $\lambda(2R) = +4b\lambda$ from the line is enclosed.

$$\phi_E = \frac{4b\lambda - Q}{\varepsilon_0}$$

(c) Work to move $+q$ from $x = 2b$ to $x = 4b$.

$W = q\Delta V$ $\quad \Delta V = -\int \vec{E} \cdot d\vec{l}$

$$= -\int_{2b}^{4b} E_x \, dx$$



$d\vec{l} = d\vec{x}$.

We only need to consider the x-component of the field!

$$E_x(x>b) = \frac{\lambda}{2\pi\varepsilon_0 x} - \frac{Q}{4\pi\varepsilon_0 (x-b)^2}$$

$$\Delta V = -\int \vec{E} \cdot d\vec{l} = -\int E_x \, dx$$

$$\Delta V = \frac{-\lambda}{2\pi\varepsilon_0} \int_{2b}^{4b} \frac{dx}{x} + \frac{Q}{4\pi\varepsilon_0} \int_{2b}^{4b} \frac{dx}{(x-b)^2}$$

$$= \frac{-\lambda}{2\pi\varepsilon_0} \ln\left(\frac{4b}{2b}\right) + \frac{Q}{4\pi\varepsilon_0} \left. \frac{(x-b)^{-1}}{-1} \right|_{2b}^{4b}$$

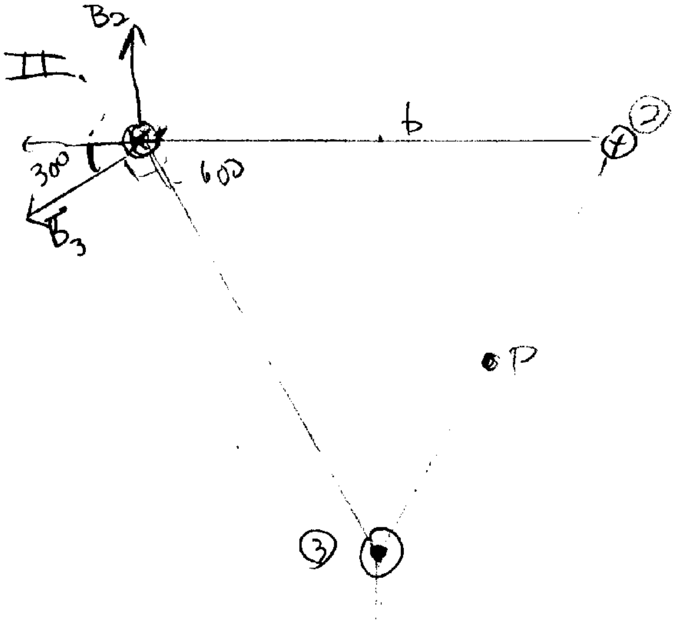
$$\Delta V = \frac{-\lambda}{2\pi\varepsilon_0} \ln 2 - \frac{Q}{4\pi\varepsilon_0} \left(\frac{1}{3b} - \frac{1}{b} \right)$$

$$= \frac{-\lambda}{2\pi\varepsilon_0} \ln 2 + \frac{Q}{4\pi\varepsilon_0} \left(\frac{2}{3b} \right)$$

$$\boxed{\Delta W = q\,\Delta V = \frac{qQ}{6\pi\varepsilon_0 b} - \frac{q\lambda \ln 2}{2\pi\varepsilon_0}}$$

This is the work done by an external force to move q from $x = 2b$ to $x = 4b$.

II.



(a) Find $\vec{B}$ at ① due to the other two wires

from Ampere's Law $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$

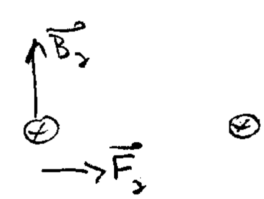
$2\pi r B = \mu_0 I$ $\quad |\vec{B}| = \dfrac{\mu_0 I}{2\pi r}$, direction is concentric loops

$\vec{B}_2 = \dfrac{\mu_0 I}{2\pi b}\hat{j}$ $\quad |B_3| = \dfrac{\mu_0 I}{2\pi b}$

$\vec{B}_3 = \dfrac{\mu_0 I}{2\pi b}\left[-\cos 30^\circ \hat{i} - \sin 30^\circ \hat{j}\right] = \dfrac{\mu_0 I}{2\pi b}\left(-\dfrac{\sqrt{3}}{2}\hat{i} - \dfrac{1}{2}\hat{j}\right)$

$$\boxed{\vec{B} \text{ at } 1 = \dfrac{\mu_0 I}{2\pi b}\left[-\dfrac{\sqrt{3}}{2}\hat{i} + \dfrac{1}{2}\hat{j}\right]}$$

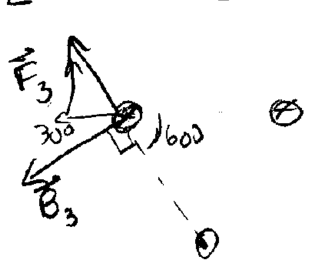
(b) $\dfrac{F}{L}$ on ① due to $\vec{B}$



$\vec{F} = I\vec{L} \times \vec{B}$

$\vec{F}_2 = I L B_2 \hat{i}$ $\quad \dfrac{|\vec{F}_2|}{L} = \dfrac{\mu_0 I^2}{2\pi b}\hat{i}$

(due to 2)



$\vec{F}_3 = I\vec{L} \times \vec{B}_3$

$\dfrac{|F_3|}{L} = I|B_3| = \dfrac{\mu_0 I^2}{2\pi b}$

Taking the components:

$$\frac{\vec{F}_3}{L} = \frac{\mu_0 I^2}{2\pi b}\left[-\cos 60^\circ\,\hat{\imath} + \sin 60^\circ\,\hat{\jmath}\right]$$

$$\frac{\vec{F}_3}{L} = \frac{\mu_0 I^2}{2\pi b}\left[-\frac{1}{2}\,\hat{\imath} + \frac{\sqrt{3}}{2}\,\hat{\jmath}\right]$$

$$\text{Total } \frac{\vec{F}}{L} = \frac{\mu_0 I^2}{2\pi b}\left[\frac{1}{2}\hat{\imath} + \frac{\sqrt{3}}{2}\hat{\jmath}\right]$$

Alternate solution: just take $\vec{B}$ from (a)

$$\vec{B} = \frac{\mu_0 I}{2\pi b}\left[-\frac{\sqrt{3}}{2}\hat{\imath} + \frac{1}{2}\hat{\jmath}\right] \qquad I\vec{L} = IL(-\hat{k}) \quad (I \text{ is in } -\hat{k} \text{ direction})$$

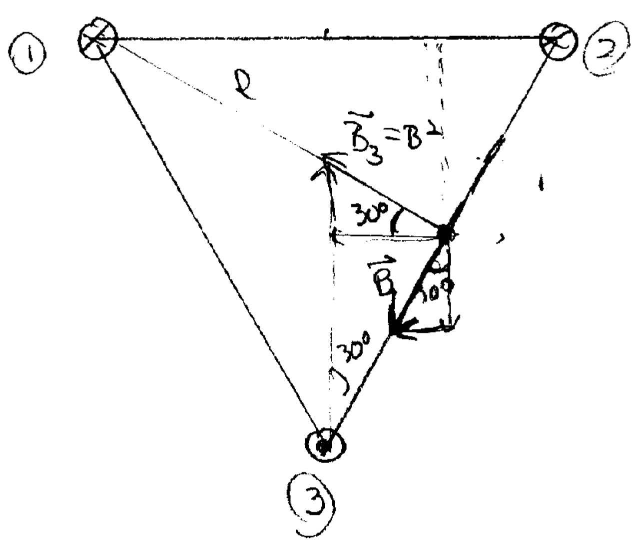
$$F = I\vec{L}\times\vec{B}$$

$$(-\hat{k})\times(-\hat{\imath}) = \hat{k}\times\hat{\imath} = +\hat{\jmath}$$

$$(-\hat{k})\times\hat{\jmath} = -(\hat{k}\times\hat{\jmath}) = +\hat{\imath}$$

$$\frac{\vec{F}}{L} = \frac{\mu_0 I^2}{2\pi b}\left(\frac{1}{2}\hat{\imath} + \frac{\sqrt{3}}{2}\hat{\jmath}\right) \text{ as above!}$$

(c) $\vec{B}$ at midpoint of right side



$$|\vec{B}_3| = |\vec{B}_2| = \frac{\mu_0 I}{2\pi(b/2)} = \frac{\mu_0 I}{\pi b}$$

$$\vec{B}_2 + \vec{B}_3 = \frac{2\mu_0 I}{\pi b}\left(-\cos 30^\circ\,\hat{\imath} + \sin 30^\circ\,\hat{\jmath}\right)$$

$$= \frac{2\mu_0 I}{\pi b}\left[-\frac{\sqrt{3}}{2}\hat{\imath} + \frac{1}{2}\hat{\jmath}\right]$$

$$\vec{B}_2 + \vec{B}_3 = \frac{\mu_0 I}{\pi b}\left(-\sqrt{3}\,\hat{\imath} + \hat{\jmath}\right)$$

$|\vec{B}_1|$ at P $= \dfrac{\mu_0 I}{2\pi l}$ where $l^2 + \dfrac{b^2}{4} = b^2$

$l^2 = \dfrac{3b^2}{4}$ $\quad l = \dfrac{\sqrt{3}\,b}{2}$

$$|B_1| = \frac{\mu_0 I}{2\pi\left(\frac{\sqrt{3}\,b}{2}\right)} = \frac{\mu_0 I}{\sqrt{3}\,\pi b}$$

$$\vec{B}_1 = \frac{\mu_0 I}{\sqrt{3}\,\pi b}\left[-\sin 30^\circ\,\hat{\imath} - \cos 30^\circ\,\hat{\jmath}\right]$$

$$= \frac{\mu_0 I}{\sqrt{3}\,\pi b}\left[-\frac{1}{2}\hat{\imath} - \frac{\sqrt{3}}{2}\hat{\jmath}\right]$$

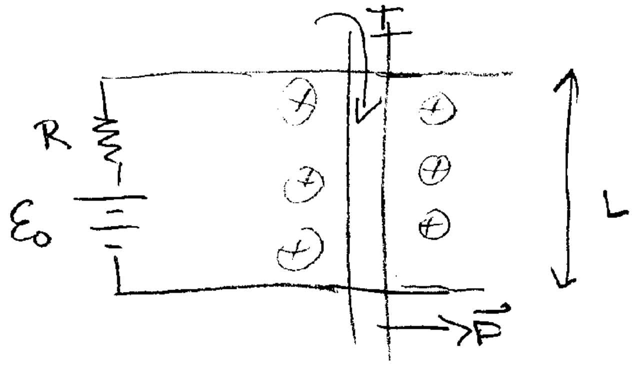
$$-\sqrt{3} - \frac{\sqrt{3}}{6} = -\left(\frac{7\sqrt{3}}{6}\right)$$

Combine:

$$\vec{B}_{TOT} \text{ at } P = \frac{\mu_0 I}{\pi b}\left[\left(-\sqrt{3} - \frac{1}{2\sqrt{3}}\right)\hat{\imath} + \left(1 - \frac{1}{2}\right)\hat{\jmath}\right]$$

$$\boxed{\vec{B}_{TOT} \text{ at } P = \frac{\mu_0 I}{\pi b}\left[-\frac{7\sqrt{3}}{6}\hat{\imath} + \frac{1}{2}\hat{\jmath}\right]}$$

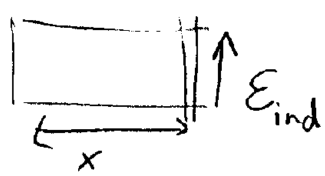
III.



(a) $I = \dfrac{\mathcal{E}_0}{R}$ $\qquad \vec{F} = I\vec{L}\times\vec{B}$

$$\boxed{\vec{F} = \frac{\mathcal{E}_0 LB}{R}\ \hat{\imath}\ \text{(to the right)}}$$

(b) When the bar move with velocity v,



$\phi_B = LxB \qquad \dfrac{d\phi_B}{dt} = LB\dfrac{dx}{dt} = LBv$

From Faraday's law,

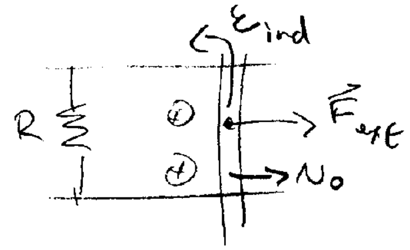
$$\mathcal{E}_{ind} = -\frac{d\phi_B}{dt} = \boxed{-LBv = \mathcal{E}_{ind}}$$ ccw direction

The direction is so as to oppose the change in flux - it opposes $\mathcal{E}_0$ & would drive a current ccw.

(c) As long as the $\vec{F}$ from (a) is non-zero, the bar accelerates to the right. As v increases, $\mathcal{E}_{ind}$ increases & at some point $\mathcal{E}_{ind} = \mathcal{E}_0$ & $I \to 0$. At that point $\vec{F} \to 0$ and the bar does not accelerate any more $\Rightarrow v_t$ occurs when $|\mathcal{E}_{ind}| = |\mathcal{E}_0|$

$$LBv_t = \mathcal{E}_0$$

$$\boxed{v_t = \frac{\mathcal{E}_0}{BL}}$$



$\mathcal{E}_0$ removed,

external force pulls bar to the right at constant speed v_0

(d) $\mathcal{E}_{ind} = -\frac{d\phi_B}{dt} = -BL\frac{dx}{dt}$

$\mathcal{E}_{ind} = -BLv_0$ — CCW

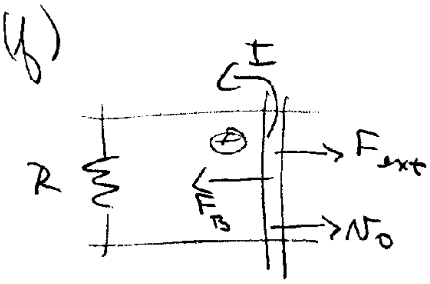
$I = \frac{\mathcal{E}_{ind}}{R} = \frac{BLv_0}{R} = I$

CCW

(e) $P = I^2R$

$P = \frac{B^2L^2v_0^2}{R}$ (in R)

(f)



for v_0 constant, $|\vec{F}_{ext}| = |\vec{F}_B|$

$\vec{F}_B = I\vec{L}\times\vec{B} = ILB(-\hat{i})$

$|F_B| = \frac{BLv_0}{R} \cdot LB = |F_{ext}|$

$|F_{ext}| = \frac{B^2L^2v_0}{R}$

This force must be applied to keep the bar moving.

(g) $P = \frac{dw}{dt} = \frac{d}{dt}\int \vec{F}\cdot d\vec{x} = \vec{F}\cdot\vec{v}$

$P = \frac{B^2L^2v_0^2}{R}$ ⟹ Same as in (e)!

The work done by an external agent in pulling the bar appears as I^2R heating of the resistor!

I. Grading criteria

30 pts total

(a) 10 pts

Gauss law for line +2

E for line +2

E for Q +2

Correct answer $x > b$ +2

Correct answer $x < b$ +2

(b) 10 pts

Gauss law +2

(c) 10 pts

Work = $q \Delta V$ +2

$\Delta V = -\int \vec{E} \cdot d\vec{l}$ +2

X - components only +2

correct contribution from line +2

correct contribution from $-Q$ +2

II. 30 pts

(a) 10 pts

Ampere's law +2

Correct contribution from ② +3

Correct contribution from ③ +3

Correct final answer +2

(b) 10 pts

Correct force eqn +2

Correct contribution from ② +3

Correct contribution from ③ +3

Correct final answer +2

(c) 10 pts

Correct contribution from ② & ③ +4

Correct contribution from ① +4

Correct sum +2

III. Grading criteria
30 pts total

(a) 3 pts

Current +1
Force +2

(b) 4 pts

Faraday's law +1
Correct $\mathcal{E}_{ind}$ 3
−1 if no direction specified or if wrong direction

(c) 5 pts
Argument as to why N_t is needed +2
Correct value +3

(d) 4 pts

Faraday's law +1
Correct $\mathcal{E}_{ind}$ +3

(e) 4 pts
I^2R +2
Correct ans +2

(f) 4 pts
Force eqn +2
Correct answer +2

(g) 6 pts
Work = $F \cdot dl$ $\frac{dw}{dt} = F \cdot v$ +2

Correct ans +2

Comparison to (e) +2