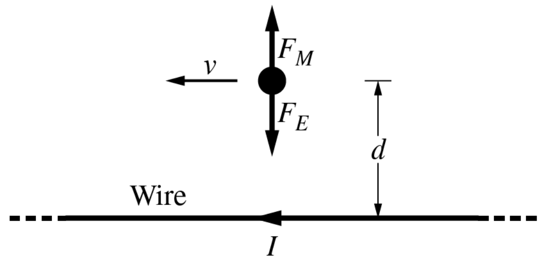
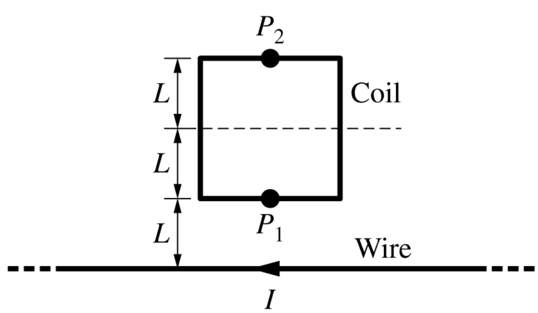
Begin your response to **QUESTION 4** on this page.



4. (10 points, suggested time 20 minutes)

At the instant shown above, a negatively charged object is moving to the left with constant velocity v near a long, straight wire that has a current I directed to the left. The region contains a uniform electric field of magnitude E, and the charged object is at a distance d from the wire. The figure shows the electric and magnetic forces, F_E and F_M, respectively, exerted on the charged object.

(a) Derive an expression for v in terms of E, d, I, and physical constants, as appropriate.



(b) The charged object is removed, and a square coil with side length $2L$ is placed near the long, straight wire, as shown above. The bottom of the coil is a distance L from the wire. The magnitude of the magnetic field due to the current in the wire is $3B_0$ at point P_1 and B_0 at point P_2.

i. Write an "X" at a location on the figure where the magnitude of the magnetic field is $2B_0$. Briefly justify your reasoning.

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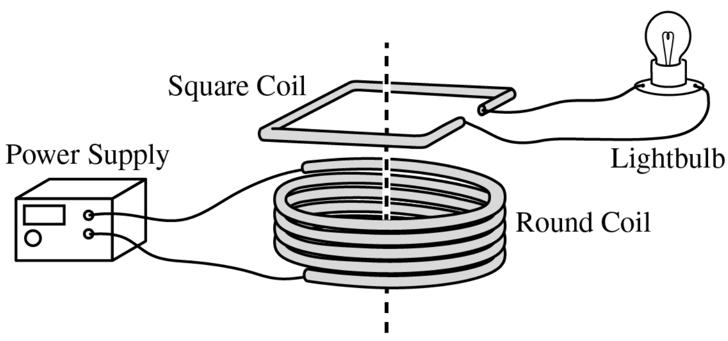
Continue your response to **QUESTION 4** on this page.

ii. Over a time interval of 2.0 s, the current in the wire is decreased. The initial magnetic flux through the coil is $5.0 \times 10^{-5}\ \text{T}{\cdot}\text{m}^2$ and the final magnetic flux through the coil is $1.0 \times 10^{-5}\ \text{T}{\cdot}\text{m}^2$. The coil has a total resistance of $10\ \Omega$. Calculate the magnitude of the average current in the coil during the 2.0 s time interval.



The wire is removed and the square coil is positioned so that the coil is directly above and concentric with a round coil of wire connected to a power supply. A part of the square coil is removed and a lightbulb is connected to the coil, as shown above.

(c) During a short time interval, the current in the power supply is constantly increasing. Use physics principles to explain why the lightbulb is lit during the entire time interval.

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Question 4: Short Answer — 10 points

(a)	For an appropriate use of Newton's laws to set the magnetic force equal to the electric force	**1 point**
	For using correct expressions for the magnetic and electric forces	**1 point**
	For substituting an expression for the magnetic field to yield a correct expression that includes v and the given quantities	**1 point**

Example Response

$$\Sigma \vec{F} = m\vec{a}$$

$$F_M - F_E = 0$$

$$F_M = F_E$$

$$qvB = qE$$

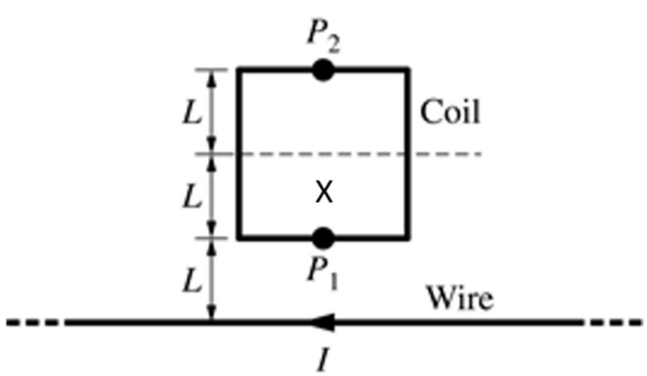
$$v\left(\frac{\mu_0 I}{2\pi d}\right) = E$$

$$v = \frac{2\pi d E}{\mu_0 I}$$

Total for part (a) — 3 points

(b)(i)	For an "X" between point P_1 and the dashed line	**1 point**

Example Response



For indicating that the magnetic field strength is inversely proportional to the distance from the wire	**1 point**

Example Response

Magnetic field is inversely proportional to the distance from a long, straight current carrying wire: $B = \frac{\mu_0 I}{2\pi r}$ *. Doubling the distance from the wire from* L *to* $2L$ *would reduce the magnetic field from* $3B_0$ *to* $1.5B_0$*. Therefore, the magnetic field would be equal to* $2B_0$ *somewhere between* L *and* $2L$ *.*

(b)(ii)	For using the change in flux, with correct substitutions, to determine the emf	**1 point**
	For correctly applying Ohm's law with correct substitutions	**1 point**

Scoring Note: It is not necessary to independently calculate a numerical value for the emf.

Example Response

$$|\mathcal{E}| = \left|-\frac{\Delta\Phi_B}{\Delta t}\right| = \frac{\left(5.0\times10^{-5} - 1.0\times10^{-5}\right)\ \text{T}\bullet\text{m}^2}{2.0\ \text{s}} = 2.0\times10^{-5}\ \text{V}$$

$$I = \frac{|\mathcal{E}|}{R} = \frac{2.0\times10^{-5}\ \text{V}}{10\ \Omega} = 2.0\times10^{-6}\ \text{A}$$

Total for part (b) 4 points

(c)	For indicating that the current in the round coil produces a magnetic field	**1 point**
	For indicating that the magnetic field from the round coil produces a flux through the square coil	**1 point**
	For indicating that the changing flux produces an emf or current in the square coil circuit	**1 point**

Scoring Note: A response that indicates that the magnetic flux only changes during a portion of the entire time interval does not earn this point.

Example Response

The current in the round coil produces a magnetic field. The magnetic field from the round coil passes through the square coil, producing a flux. As the current in the power supply increases, so does the current in the round coil, and, therefore, the magnetic field created by the current increases. Since the magnetic field changes, the flux through the square coil changes. The constantly changing magnetic flux through the square coil produces an emf and, therefore, current in the square coil to light the lightbulb.

Total for part (c) 3 points

Total for question 4 10 points