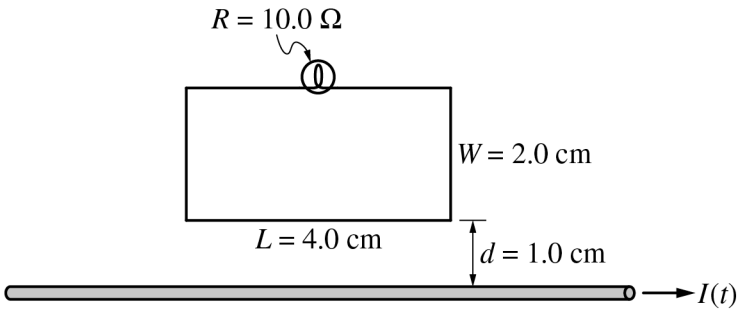
Begin your response to **QUESTION 3** on this page.



3. A lightbulb of resistance $R = 10.0\ \Omega$ is connected to a rectangular loop of wire of negligible resistance near a very long current-carrying wire. The rectangular loop has a length $L = 4.0\ \text{cm}$ and a width $W = 2.0\ \text{cm}$ and is positioned so one of the longer sides of the loop is a distance $d = 1.0\ \text{cm}$ above and parallel to the long wire, as shown. The current in the long wire is initially flowing to the right and is given by $I(t) = C - Dt$, where $C = 10.0\ \text{A}$ and $D = 2.0\ \text{A/s}$. At time $t = 5.0\ \text{s}$, the current in the long wire is instantaneously zero as the current changes direction.

(a) What is the direction, if any, of the magnetic field produced by the induced current in the rectangular loop as the current in the long wire changes direction?

___ Into the page ___ Out of the page ___ No direction, because the field is zero

Justify your answer.

(b) Calculate the magnetic flux through the loop due to only the long wire at time $t = 3.0\ \text{s}$.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.

(c) Calculate the current through the lightbulb at time $t = 3.0\,\text{s}$.

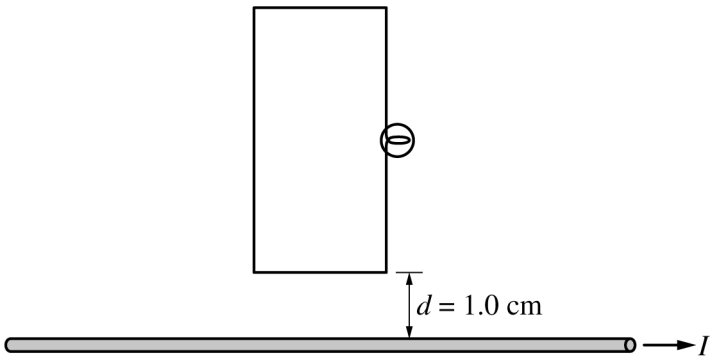
(d) A group of students attempts to experimentally verify whether the current through the lightbulb is consistent with the current calculation from part (c). The current in the rectangular loop is measured to be greater than the current calculated in part (c). Which of the following could explain this discrepancy? Select one answer.

___ The students did not account for Earth's magnetic field.
___ The rectangular loop is tilted and is not in the same plane as the wire.
___ The resistance of the lightbulb is greater than the recorded value.
___ The long side of the rectangular loop is shorter than the recorded value.
___ The current in the long wire changes at a faster rate than expected.

Briefly justify your answer.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.



(e) Later, the same rectangular loop with lightbulb is rotated such that a short side of the loop is 1.0 cm above and parallel to the long current-carrying wire, as shown. The current in the wire is again initially flowing from left to right and given by $I(t) = C - Dt$, where $C = 10.0\,\text{A}$ and $D = 2.0\,\text{A/s}$. The current through the lightbulb in the loop's new orientation at time $t = 3.0\,\text{s}$ is I_2. Which of the following correctly relates the current I_2 to I_1, the current through the lightbulb in part (c)?

___$I_2 < I_1$ ___$I_2 = I_1$ ___ $I_2 > I_1$

Justify your answer.

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Question 3: Free-Response Question — 15 points

(a)

For selecting "Out of the page" and an attempt at a relevant justification — **1 point**

For a justification that correctly relates how the changing current in the long wire changes the flux through the loop with respect to time — **1 point**

For indicating the induced current will oppose the change in magnetic flux — **1 point**

Example Response

Because the current in the straight wire is decreasing, the magnetic field, which is originally pointing out of the page, is decreasing. Hence, the induced current produces a field that is directed out of the page to compensate for the decreasing flux.

Total for part (a) 3 points

(b)

For using an appropriate integral equation, with a substitution of an expression for magnetic field, to calculate magnetic flux — **1 point**

Example Response

$$\Phi_B = \int \vec{B} \cdot d\vec{A}$$

For writing a correct equation for the magnetic field as a function of distance from the wire — **1 point**

Example Response

$$B = \frac{\mu_0 I}{2\pi r}$$

For substituting the value of $t = 3$ s to find the electric current — **1 point**

Example Response

$$I(t) = C - Dt$$
$$I(3\text{ s}) = 10\text{ A} - (2\text{ A/s})(3\text{ s})$$
$$I(3\text{ s}) = 4\text{ A}$$

For integrating B with correct limits and a correct substitution for dA, to determine the total flux through the loop — **1 point**

Example Response

$$\Phi_B = \int_d^{d+W} \frac{\mu_0 I L}{2\pi r} dr$$
$$\Phi_B = \frac{\mu_0 I L}{2\pi} \ln[r]_d^{d+W}$$
$$\Phi_B = \frac{\mu_0 I L}{2\pi} \ln\left[\frac{d+W}{d}\right]$$
$$\Phi_B = \frac{(4\pi \times 10^{-7}\ \text{T•m/A})(4\text{ A})(0.04\text{ m})}{2\pi} \ln\left[\frac{0.03\text{ m}}{0.01\text{ m}}\right] = 3.52 \times 10^{-8}\ \text{T•m}^2$$

Total for part (b) 4 points

(e)	For selecting "$I_2 < I_1$" with an attempt at a relevant justification	**1 point**
	For indicating the total flux in the loop is less in the new orientation	**1 point**
	For correctly relating the rate of change of the flux to the total flux inside the loop	**1 point**
	Example Response *With the new orientation, some parts of the rectangle are further away from the straight wire, which means that the magnetic flux through the rectangle will be less. The rate of change of the flux has the same dependence on distance and will also decrease, resulting in a smaller current.*	
	Total for part (e)	**3 points**
	Total for question 3	**15 points**