AP® Physics C: Electricity and Magnetism
2001 Sample Student Responses

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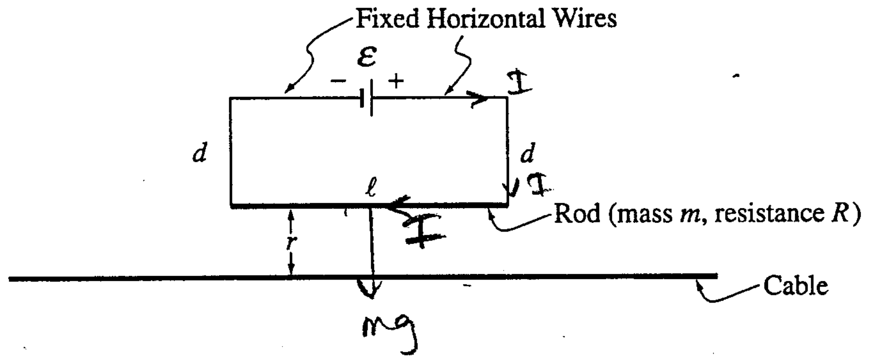


E&M 3.

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?

I $\boxed{\text{left}}$ in rod

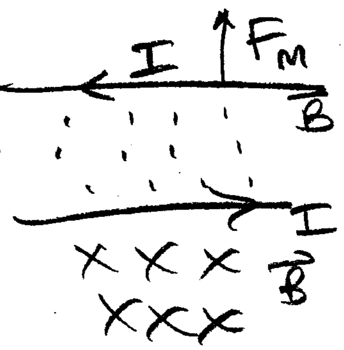
$\mathcal{E} = IR$ Ohm's law

$I_{rod} = \boxed{\dfrac{\mathcal{E}}{R}}$

conventional current flows $\oplus \rightarrow \ominus$

(b) In which direction must there be a current in the cable to exert an upward force on the rod? Justify your answer.

(right-hand rule)



$\vec{F}_M = I\vec{\ell} \times \vec{B}$

$= I\ell B \sin 90° = I\ell B$

I cable $\boxed{\text{right}}$

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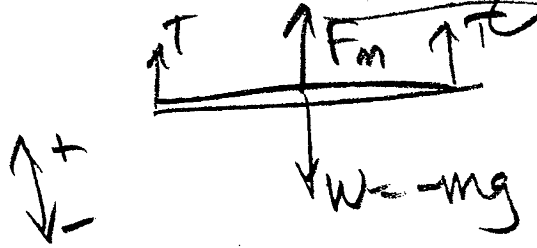
(c) With the proper current in the cable, the rod can be lifted up such that there is no tension in the connecting wires. Determine the minimum current I_c in the cable that satisfies this situation.



$$\sum F_y = 0$$

$$\cancel{2T}^{\,0} + F_m - W = 0$$

$$F_m = W = mg$$

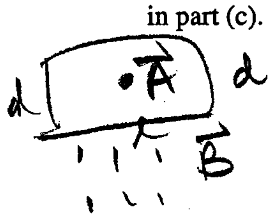
$$I_{rod}\, l\, B = mg$$

$$I_{rod}\, l\, \frac{\mu_0 I_c}{2\pi r} = mg \qquad B_{wire} = \frac{\mu_0 I}{2\pi r}$$

$$I_c = \frac{mg\, 2\pi r}{\mu_0\, l\, I_{rod}} = \boxed{\frac{mg\, 2\pi r R}{\mu_0\, l\, \mathcal{E}}}$$

$$I_{rod} = \frac{\mathcal{E}}{R}$$

(d) Determine the magnitude of the magnetic flux through the circuit due to the minimum current I_c determined in part (c).



$$\Phi_B = \int \vec{B}\cdot d\vec{A} = \int B\, dA \cos 0^\circ = \int B\, dA$$

$$\Phi_B = \int \frac{\mu_0 I_c}{2\pi r}(l\, dr)$$

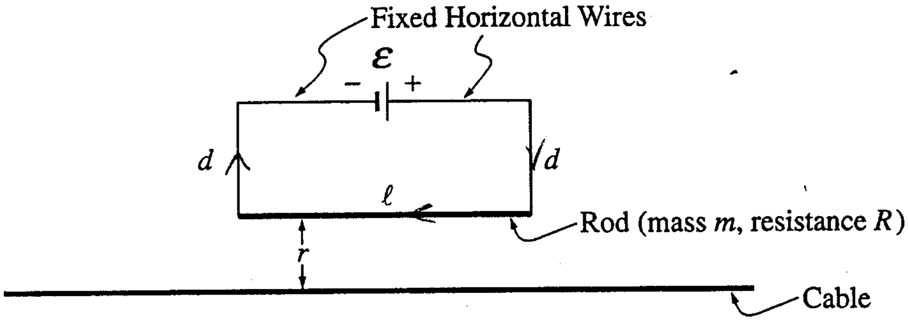
$$A = dl$$
$$dA = l\, dr$$

$$\Phi_B = \frac{\mu_0 I_c l}{2\pi}\int_r^{r+d} \frac{dr}{r} \qquad \ln(r+d) - \ln(r)$$

$$\Phi_B = \boxed{\frac{\mu_0 I_c l}{2\pi} \ln\left(\frac{r+d}{r}\right)}$$

$$= \frac{\cancel{\mu_0 l}}{\cancel{2\pi}}\left(\frac{mg\,\cancel{2\pi} r R}{\cancel{\mu_0 l}\,\mathcal{E}}\right) \ln\left(\frac{r+d}{r}\right)$$

$$= \boxed{\frac{mgrR}{\mathcal{E}} \ln\left(\frac{r+d}{r}\right)}$$



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(a) What is the magnitude and direction of the current I in the rod?

$I = \frac{\mathcal{E}}{R}$ toward left

(b) In which direction must there be a current in the cable to exert an upward force on the rod? Justify your answer.

toward right.

because the magnetic field above the cable then will be $\odot$ (out of page) and the force exerted on the rod (with current to the left) will be upward.

$(F = l\vec{i} \times \vec{B})$

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(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.

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_c$$

$$\vec{B} \cdot 2\pi \cdot r = \mu_0 I_c$$

$$\vec{B} = \frac{\mu_0 I_c}{2\pi r}$$

$$B \cdot i \cdot l = mg$$

$$\frac{\mu_0 I_c}{2\pi r} \cdot \frac{\mathcal{E}}{R} \cdot l = mg$$

$$I_c = \frac{2\pi r\, mgR}{\mu_0 \mathcal{E} l}$$

(d) Determine the magnitude of the magnetic flux through the circuit due to the minimum current I_c determined in part (c).

$$\phi = \int_r^{r+d} \vec{B} \cdot l \cdot dr = l \int_r^{r+d} \frac{\mu_0 I_c}{2\pi r}\, dr$$

$$= \frac{\mu_0 I_c l}{2\pi} \int_r^{r+d} \frac{1}{r}\, dr$$

$$= \frac{\cancel{\mu_0} \cancel{l}}{\cancel{2\pi}} \cdot \frac{\cancel{2\pi} r\, mgR}{\cancel{\mu_0} \mathcal{E} \cancel{l}} \ln r \Big|_r^{r+d}$$

$$= \frac{mgRr}{\mathcal{E}} \ln \frac{r+d}{r}$$

The flux is $\odot$ (out of page).