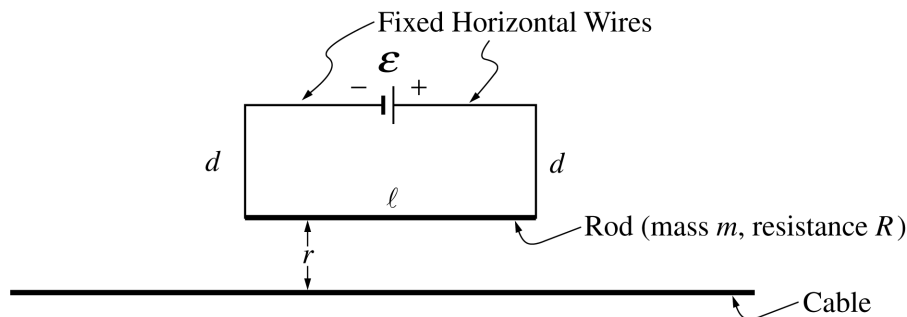


**2001 AP<sup>®</sup> PHYSICS C: ELECTRICITY AND MAGNETISM  
FREE-RESPONSE QUESTIONS**



E&M 3.

The circuit shown above consists of a battery of emf  $\mathcal{E}$  in series with a rod of length  $\ell$ , 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.

- What is the magnitude and direction of the current  $I$  in the rod?
- In which direction must there be a current in the cable to exert an upward force on the rod? Justify your answer.
- 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.
- Determine the magnitude of the magnetic flux through the circuit due to the minimum current  $I_c$  determined in part (c).

**END OF SECTION II, ELECTRICITY AND MAGNETISM**

**AP<sup>®</sup> PHYSICS C: ELECTRICITY AND MAGNETISM  
2001 SCORING GUIDELINES**

**Question 3**

**15 points total**

**3. (a) 2 points**

**Distribution  
of Points**

Using Ohm's law:

$$V = IR$$

For correct equation for  $I$

**1 point**

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

For correctly indicating the current direction on the diagram or in the answer space, such as by stating that it is clockwise, or to the left, or by showing an arrow pointing left

**1 point**

**3. (b) 4 points**

For indicating on the diagram or in the answer space a direction opposite to the answer in part (a). If part (a) does not contain a direction, then for an indication that the direction is to the right or by showing an arrow pointing right.

**1 point**

For a complete justification

**3 points**

**Full credit** awarded for an answer that indicated the right-hand rule to obtain the magnetic field directed out of the page at the rod, and then used the cross product to obtain that the force on the rod is up

**2 points** partial credit awarded for an answer that just stated the rule that antiparallel currents repel or that just stated  $I \ell \times \mathbf{B}$  and the right-hand rule

**1 point** partial credit awarded for an answer that just stated the right-hand rule or  $I \ell \times \mathbf{B}$  or some fragment with some correct element

**3. (c) 4 points**

For indicating that the gravitational force will be equal to  $I \ell \times \mathbf{B}$

**1 point**

$$F = I \ell \times \mathbf{B} = mg$$

For giving the correct equation for the magnetic field

**1 point**

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

For correctly substituting in the first equation above the values for  $B$  and for  $I$  from part (a)

**1 point**

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

For the correct answer

**1 point**

$$I_c = \frac{2\pi mgrR}{\mu_0 \ell \mathcal{E}}$$