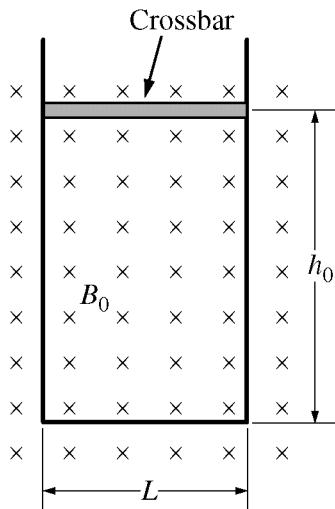


**2012 AP® PHYSICS C: ELECTRICITY AND MAGNETISM FREE-RESPONSE QUESTIONS**



E&M. 3.

A closed loop is made of a U-shaped metal wire of negligible resistance and a movable metal crossbar of resistance  $R$ . The crossbar has mass  $m$  and length  $L$ . It is initially located a distance  $h_0$  from the other end of the loop. The loop is placed vertically in a uniform horizontal magnetic field of magnitude  $B_0$  in the direction shown in the figure above. Express all algebraic answers to the questions below in terms of  $B_0$ ,  $L$ ,  $m$ ,  $h_0$ ,  $R$ , and fundamental constants, as appropriate.

- (a) Determine the magnitude of the magnetic flux through the loop when the crossbar is in the position shown.

The crossbar is released from rest and slides with negligible friction down the U-shaped wire without losing electrical contact.

- (b) On the figure below, indicate the direction of the current in the crossbar as it falls.



Justify your answer.

- (c) Calculate the magnitude of the current in the crossbar as it falls as a function of the crossbar's speed  $v$ .

- (d) Derive, but do NOT solve, the differential equation that could be used to determine the speed  $v$  of the crossbar as a function of time  $t$ .

- (e) Determine the terminal speed  $v_T$  of the crossbar.

- (f) If the resistance  $R$  of the crossbar is increased, does the terminal speed increase, decrease, or remain the same?

Increases     Decreases     Remains the same

Give a physical justification for your answer in terms of the forces on the crossbar.

**STOP**

**END OF EXAM**

**AP® PHYSICS C: ELECTRICITY AND MAGNETISM**  
**2012 SCORING GUIDELINES**

**Question 3 (continued)**

**Distribution  
of points**

(d) 4 points

For a correct net force equation showing opposite directions for the gravitational and magnetic forces,  $F_g$  and  $F_M$

1 point

$$\sum F = ma = F_g - F_M = mg - F_M$$

$$a = g - \frac{F_M}{m}$$

For using an appropriate equation to find  $F_M$

1 point

$$F_M = \int I |d\ell \times \mathbf{B}| = ILB_0$$

For substituting the current from part (c)

1 point

$$F_M = \left( \frac{B_0 L v}{R} \right) LB_0 = \frac{B_0^2 L^2 v}{R}$$

For expressing acceleration  $a$  as  $dv/dt$

1 point

$$\frac{dv}{dt} = g - \frac{B_0^2 L^2 v}{mR}$$

(e) 2 points

For setting the gravitational force equal to the magnetic force

1 point

$$a = 0; \text{ therefore } F_M = F_g$$

For correct substitution of expressions for the forces

1 point

$$mg = ILB_0 = B_0^2 L^2 v_T / R$$

$$v_T = \frac{mgR}{B_0^2 L^2}$$

Note: If the correct expression for  $v_T$  is stated without support, 2 points are awarded.