CHAPTER 20

MAGNETIC FORCE

OVERVIEW

How does a charge q:	**Create a Field**	**React to a Field**
Electric		
Magnetic		

OVERVIEW

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Magnetic		

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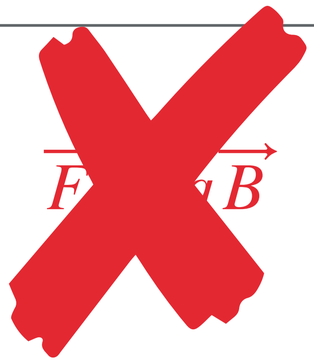
Magnetic	$\vec{B} = \frac{\mu_0}{4\pi}\frac{q\vec{v}\times\hat{r}}{r^2}$	

MAGNETIC FORCE ON A POINT CHARGE

$$\overrightarrow{F}_{\text{magnetic}} = q\overrightarrow{v} \times \overrightarrow{B}$$

MAGNETIC FORCE ON A POINT CHARGE

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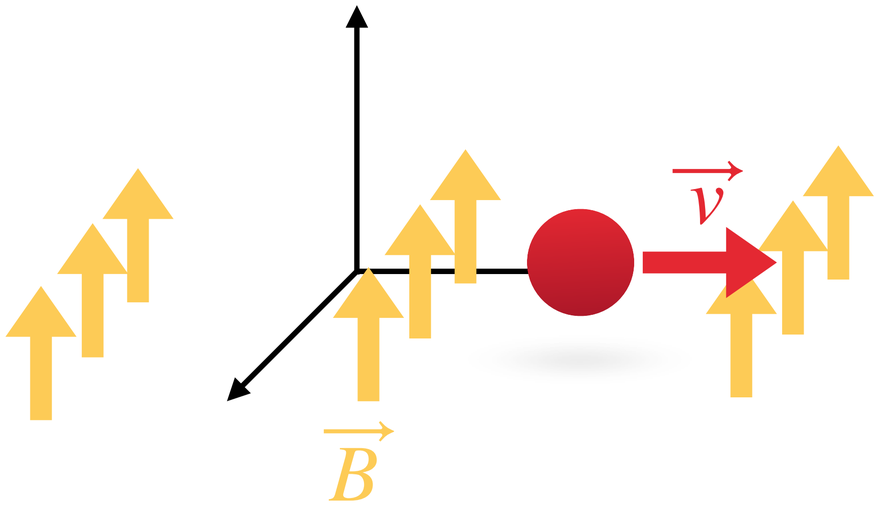
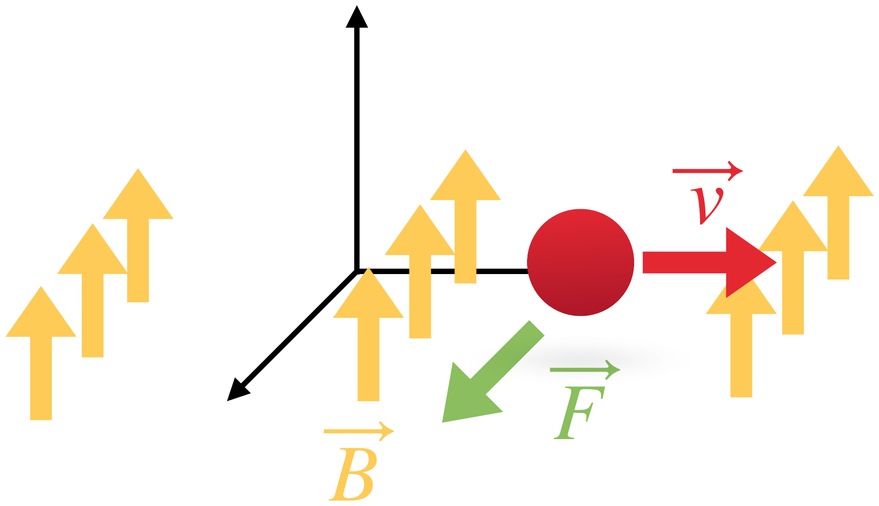
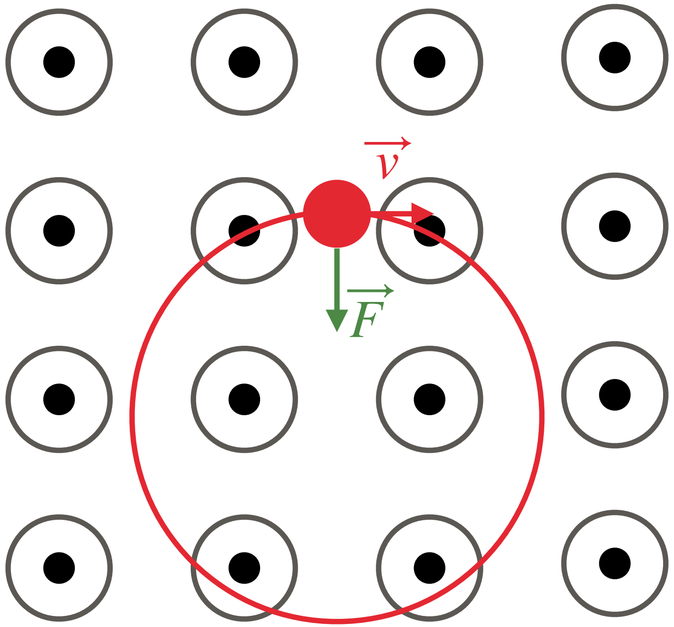
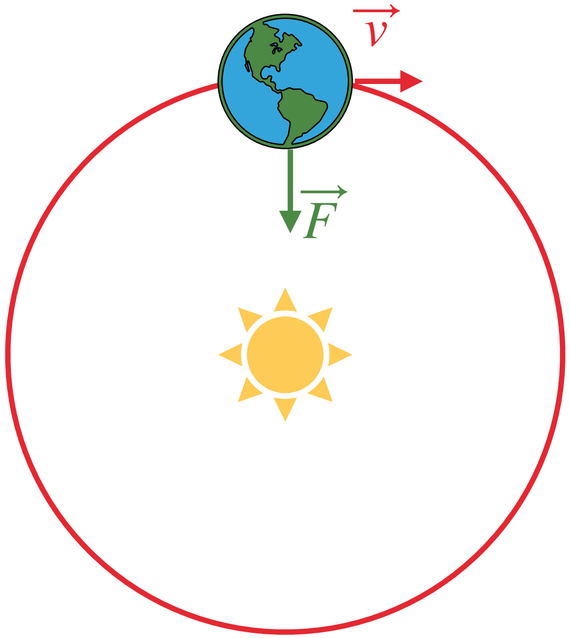
1. Only moving charges feel magnetic force
2. Direction of force is perpendicular to both velocity and field


$\vec{v}$
$\vec{B}$


$\vec{v}$
$\vec{F}$
$\vec{B}$


$\vec{v}$
$\vec{F}$


$\vec{v}$
$\vec{F}$

THE ENERGY PRINCIPLE

Recall:

Work done by the **electric** field

$$W = \vec{F} \cdot \Delta\vec{r} = q\vec{E} \cdot \Delta\vec{r} = -q\Delta V$$

THE ENERGY PRINCIPLE

Recall:

Work done by the **electric** field

$$W = \vec{F} \cdot \Delta\vec{r} = q\vec{E} \cdot \Delta\vec{r} = -q\Delta V$$

Electric field can increase/decrease a charge's speed

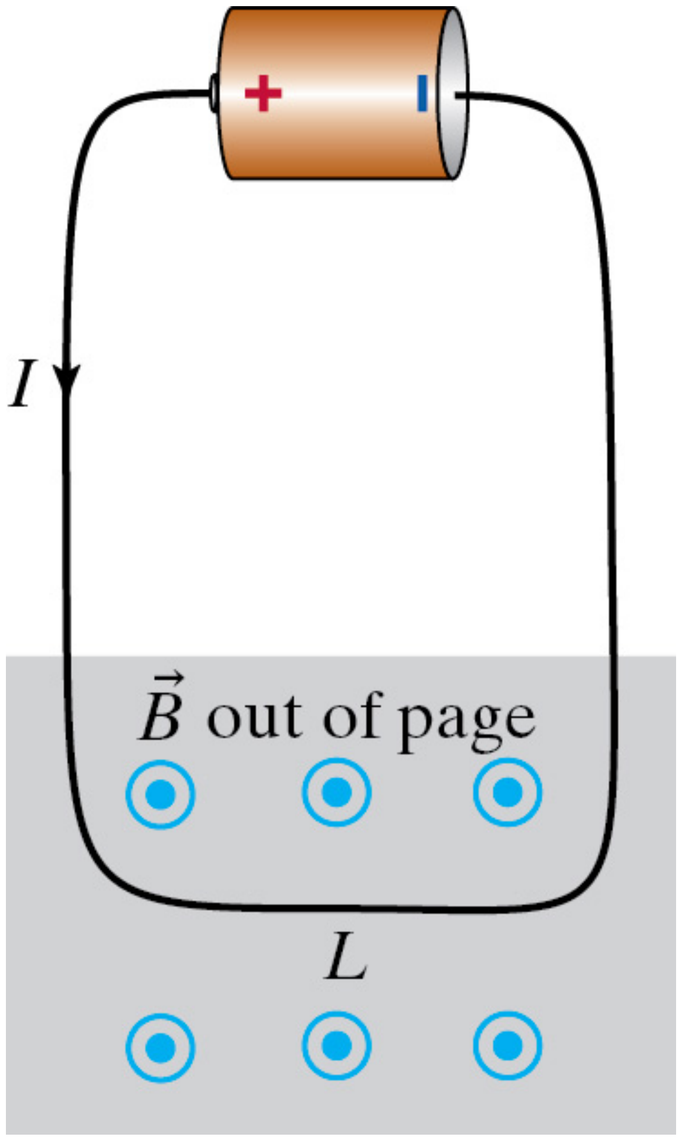
MAGNETIC FORCE AND THE ENERGY PRINCIPLE

MAGNETIC FORCE DOES NO WORK

- Magnetic field alone cannot change a particle's energy
- *Direction* of velocity will change, *magnitude* will **not**
- Magnetic forces deflect moving charged particles

ANNOUNCEMENTS

- Ch 19 Homework due tonight
  - Quiz Wednesday
- Exam II (chapters 16-19) **Thursday**
  - Review session Wednesday night (HT 318, 7pm)
- Lab makeup
- New mask policy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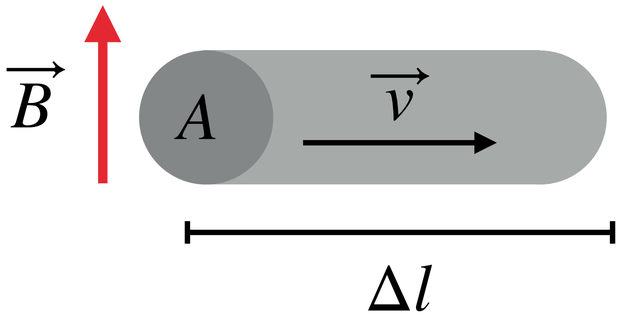
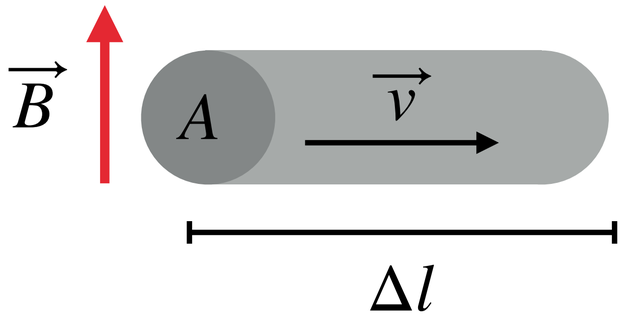
MAGNETIC FORCE ON A SHORT CURRENT-CARRYING WIRE

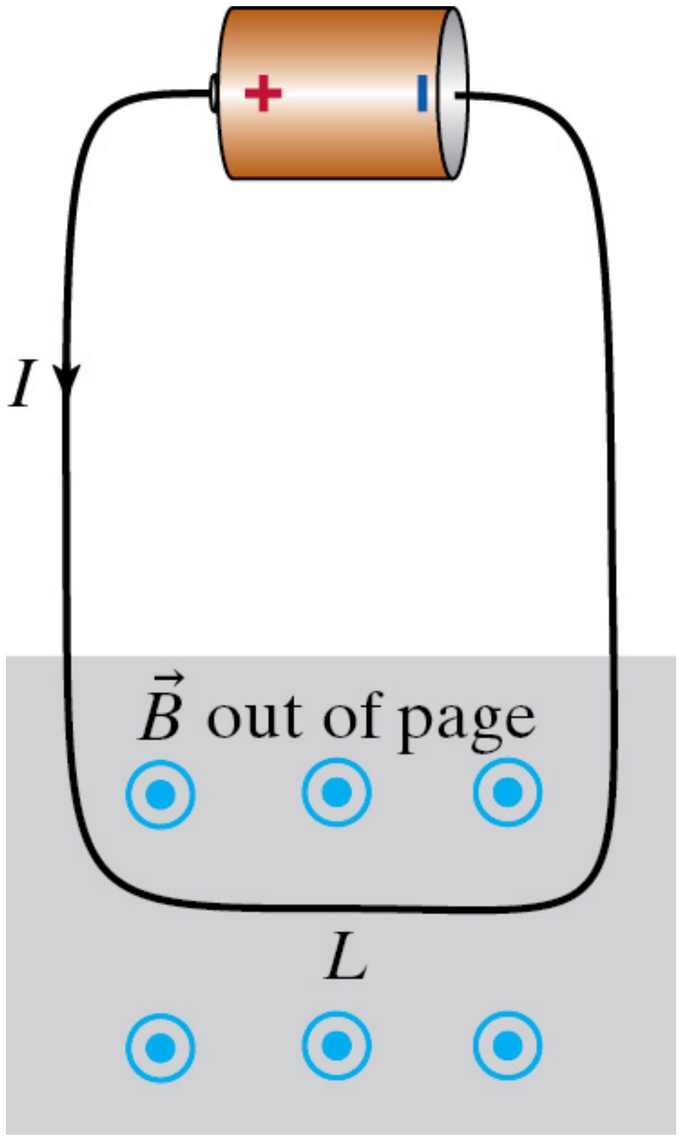


MAGNETIC FORCE ON A SHORT CURRENT-CARRYING WIRE

$$\Delta \vec{F} = I \Delta \vec{l} \times \vec{B}$$

$\Delta \vec{l}$ points in the direction of conventional current I

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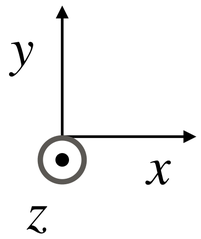
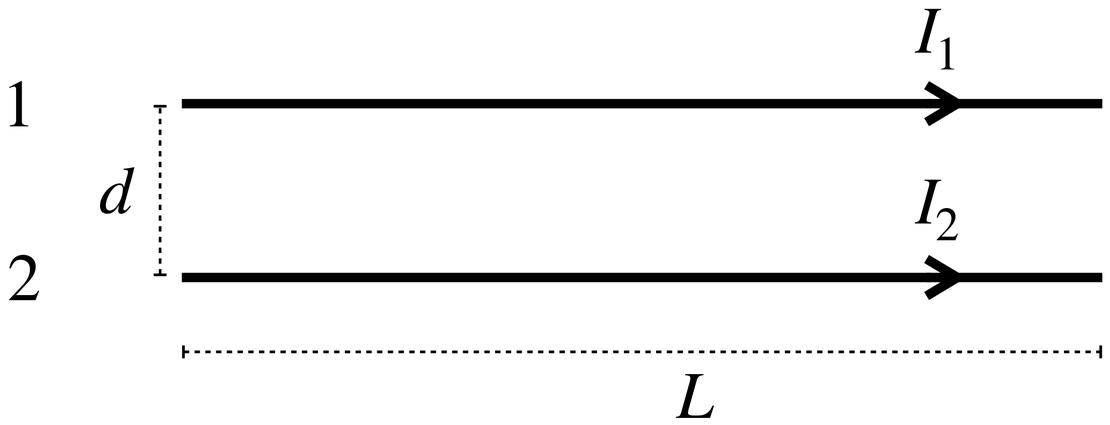
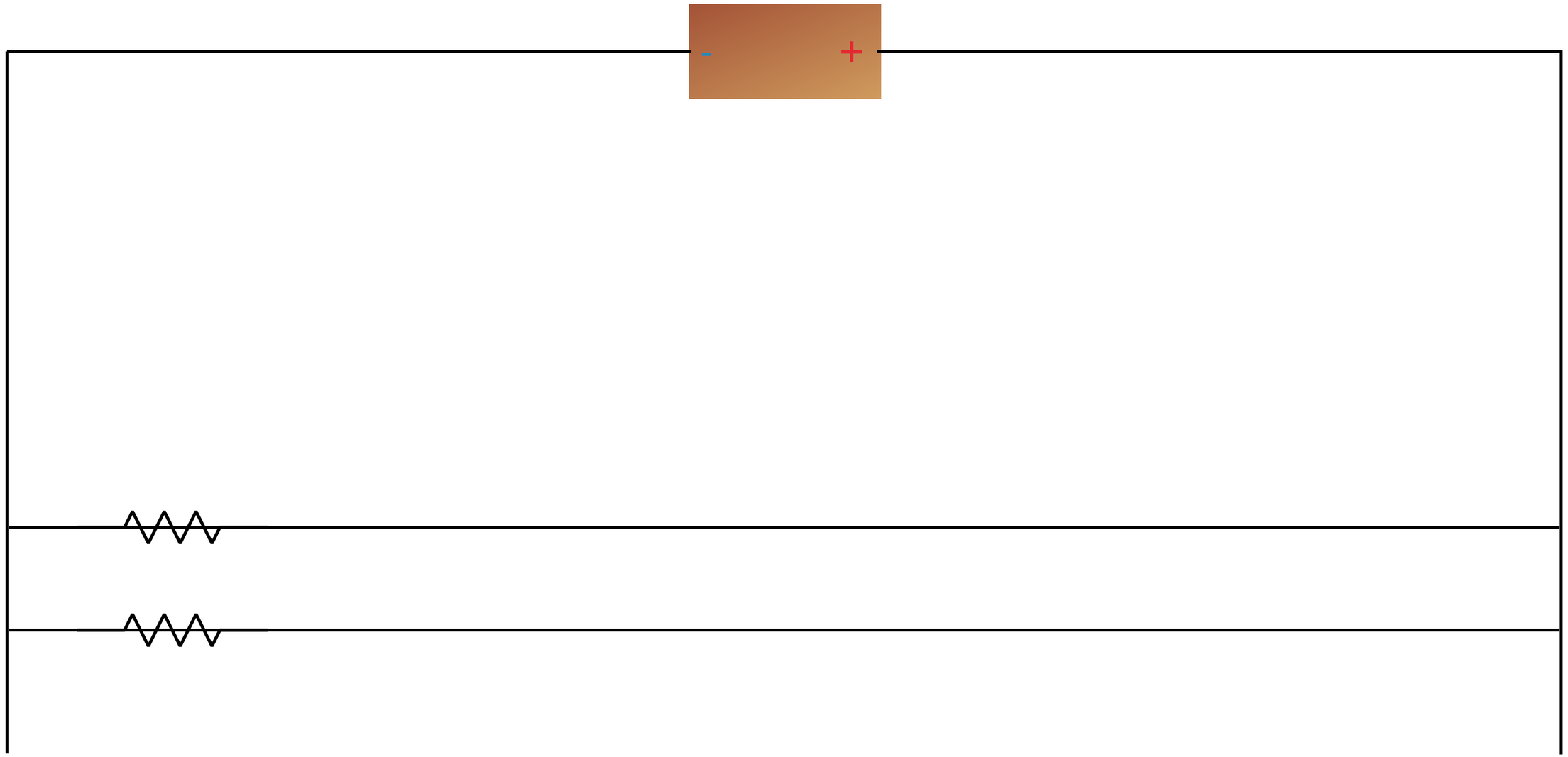
CURRENT FLOWING THROUGH PARALLEL WIRES

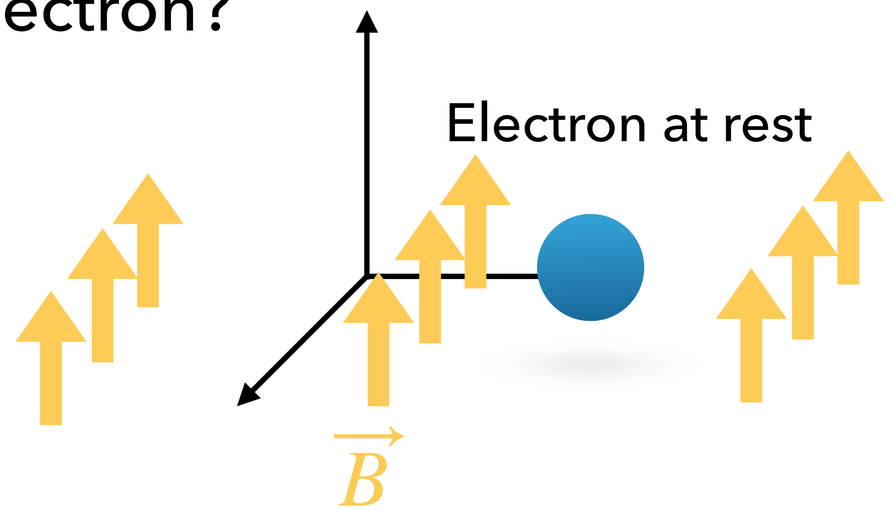




EXAMPLE



What is the force on the electron?



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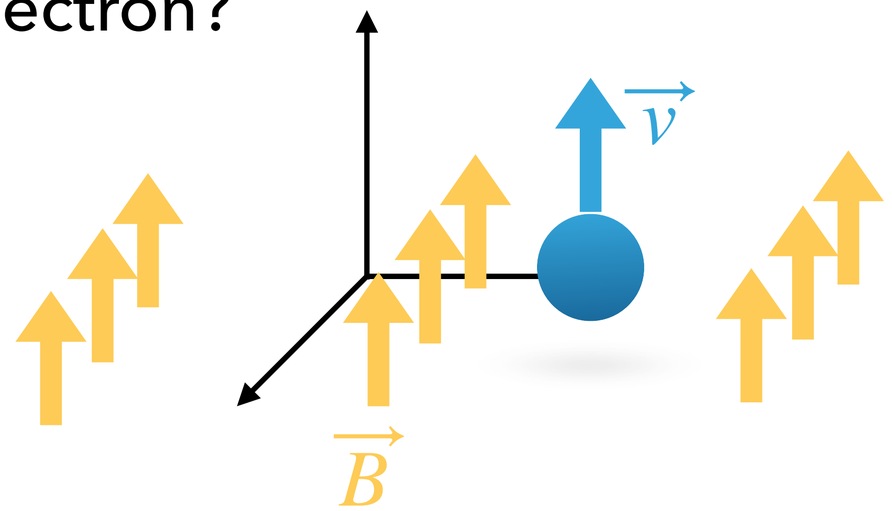

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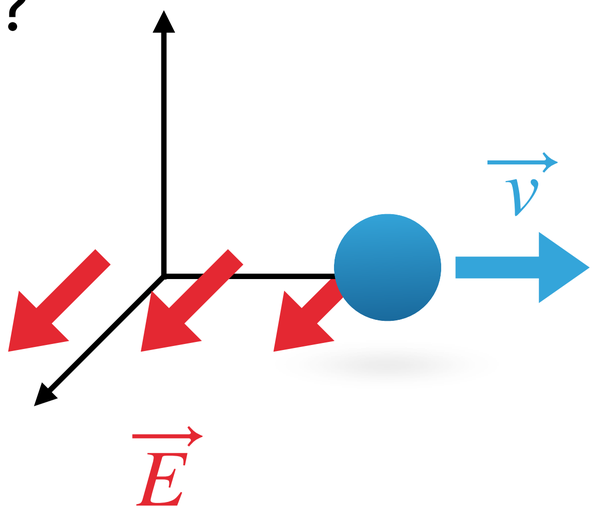
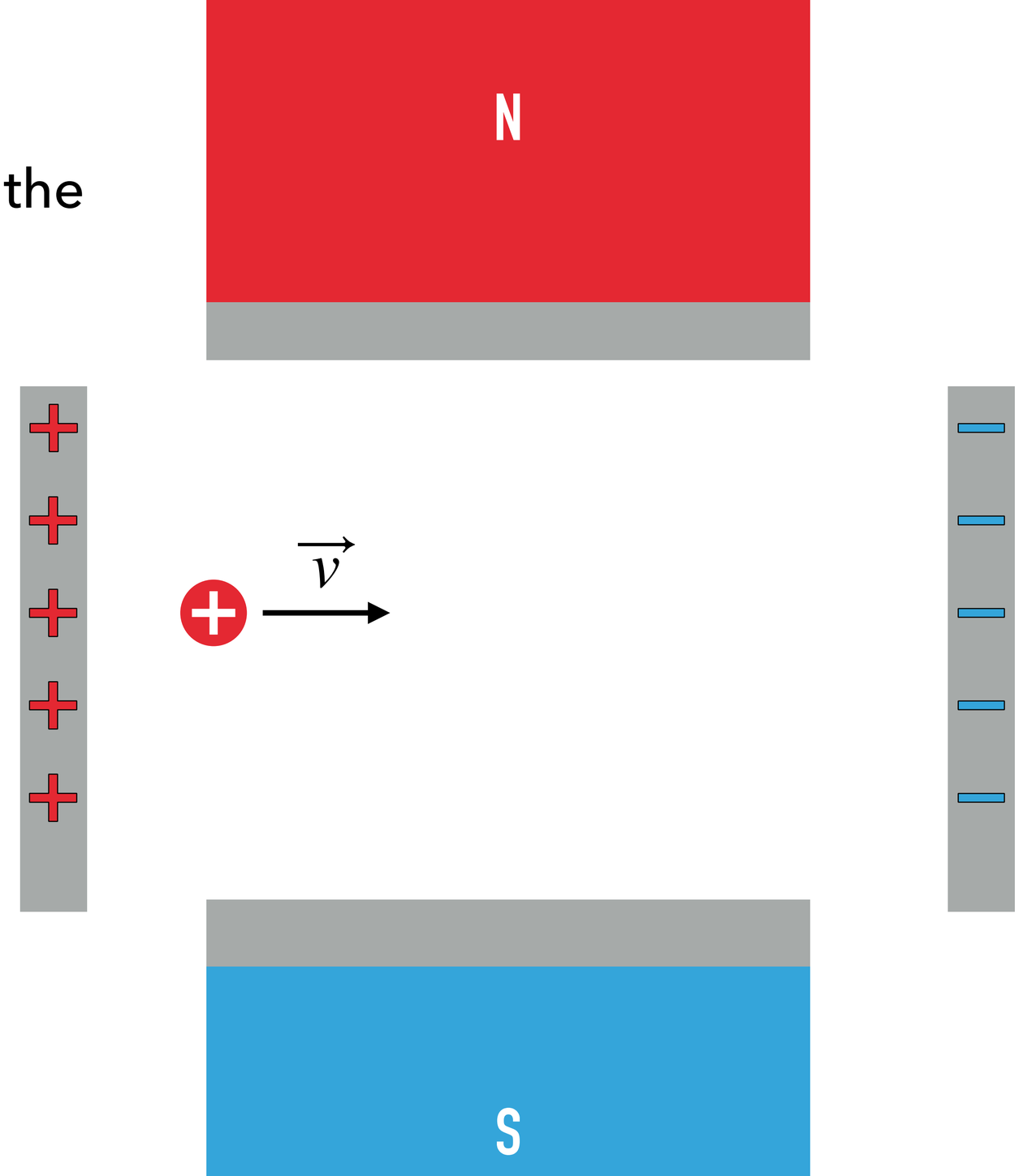


What is the force on the proton?



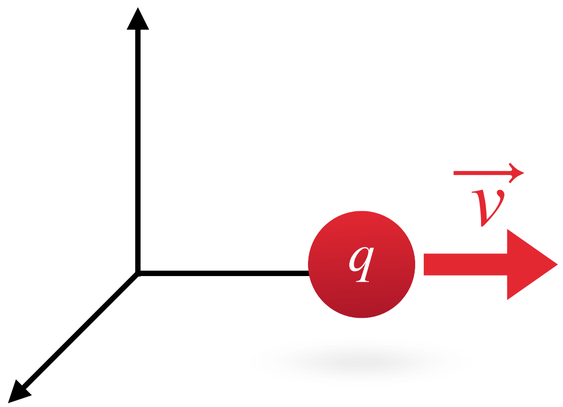
GENERAL FORCE ON A CHARGED PARTICLE

- In general, both electric AND magnetic fields may be present

$$\vec{F} = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

SPECIAL CASE: $\overrightarrow{F}_{\text{net}} = 0$

Find a combination of electric and magnetic fields that results in straight-line motion



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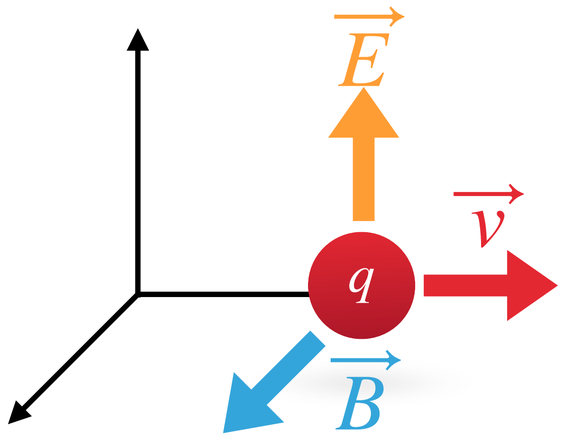
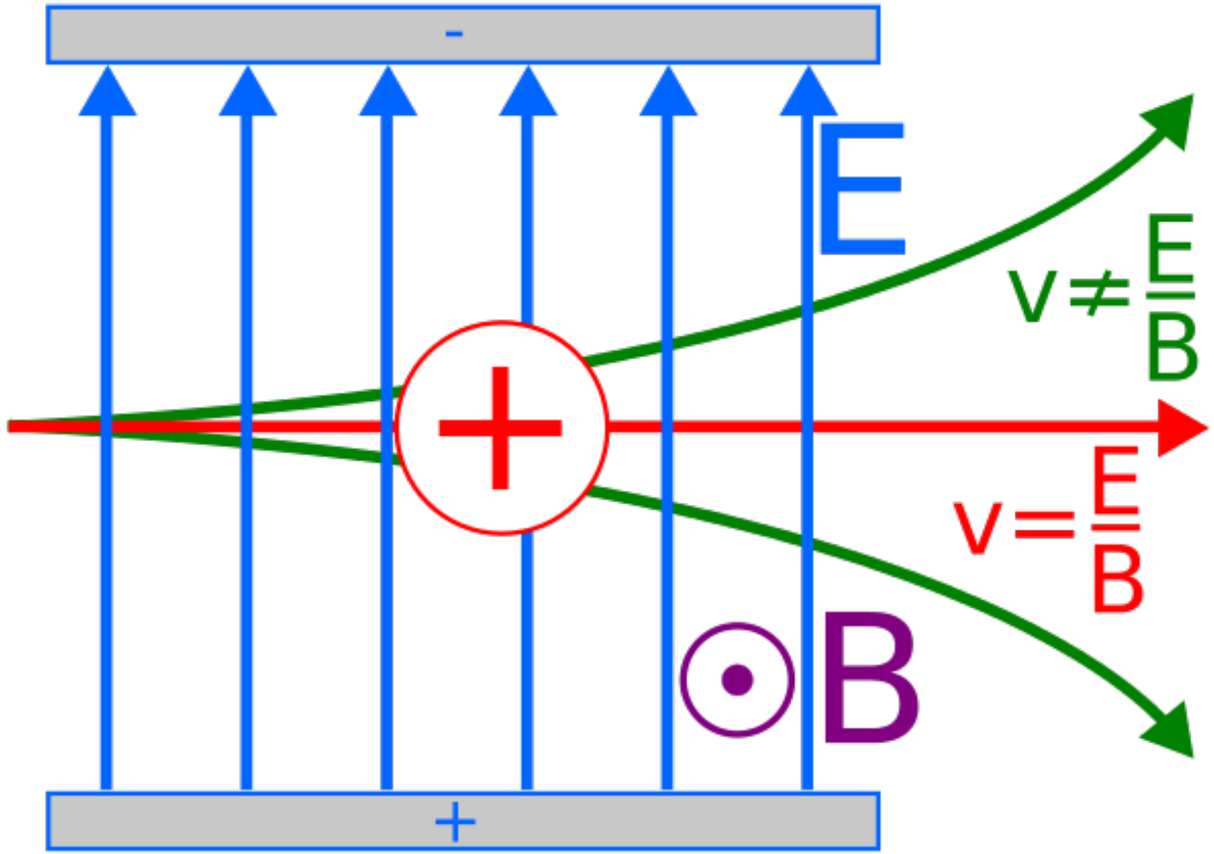
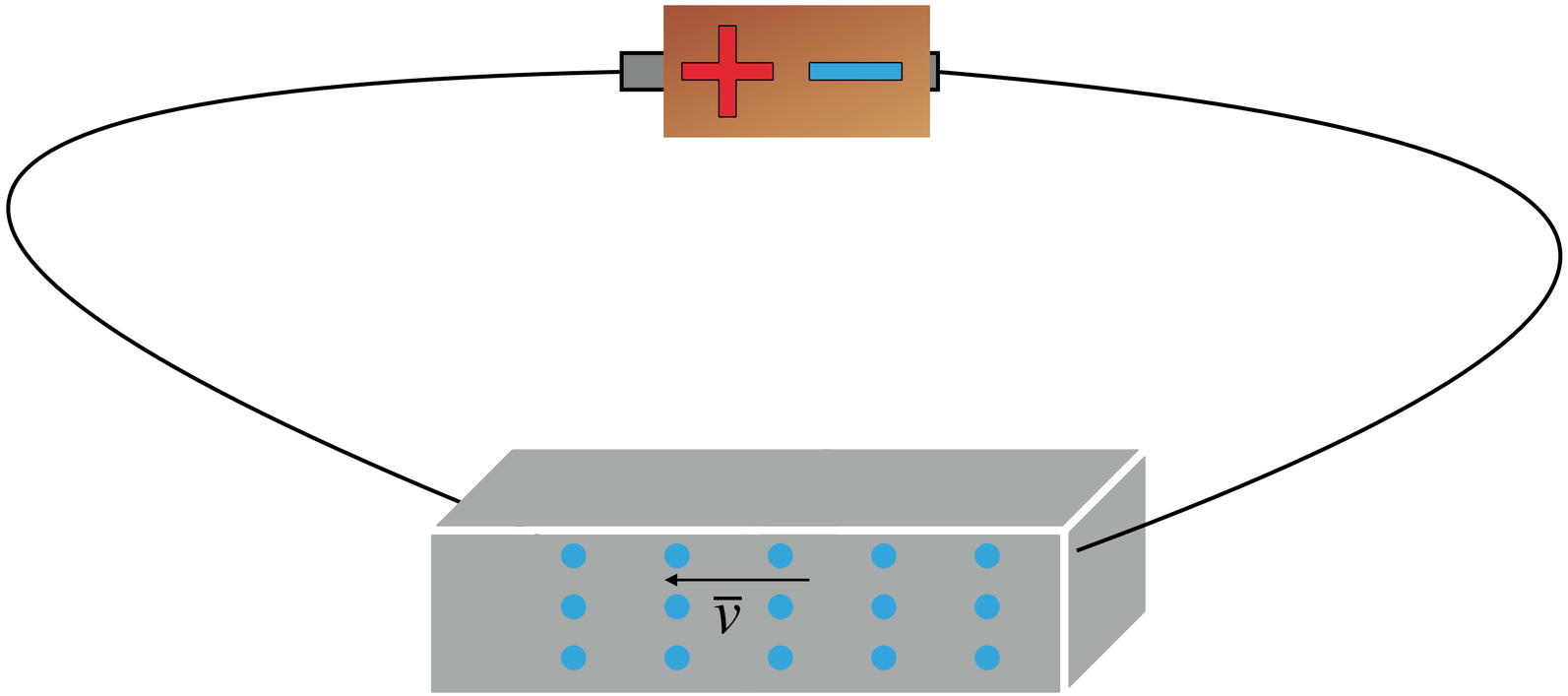
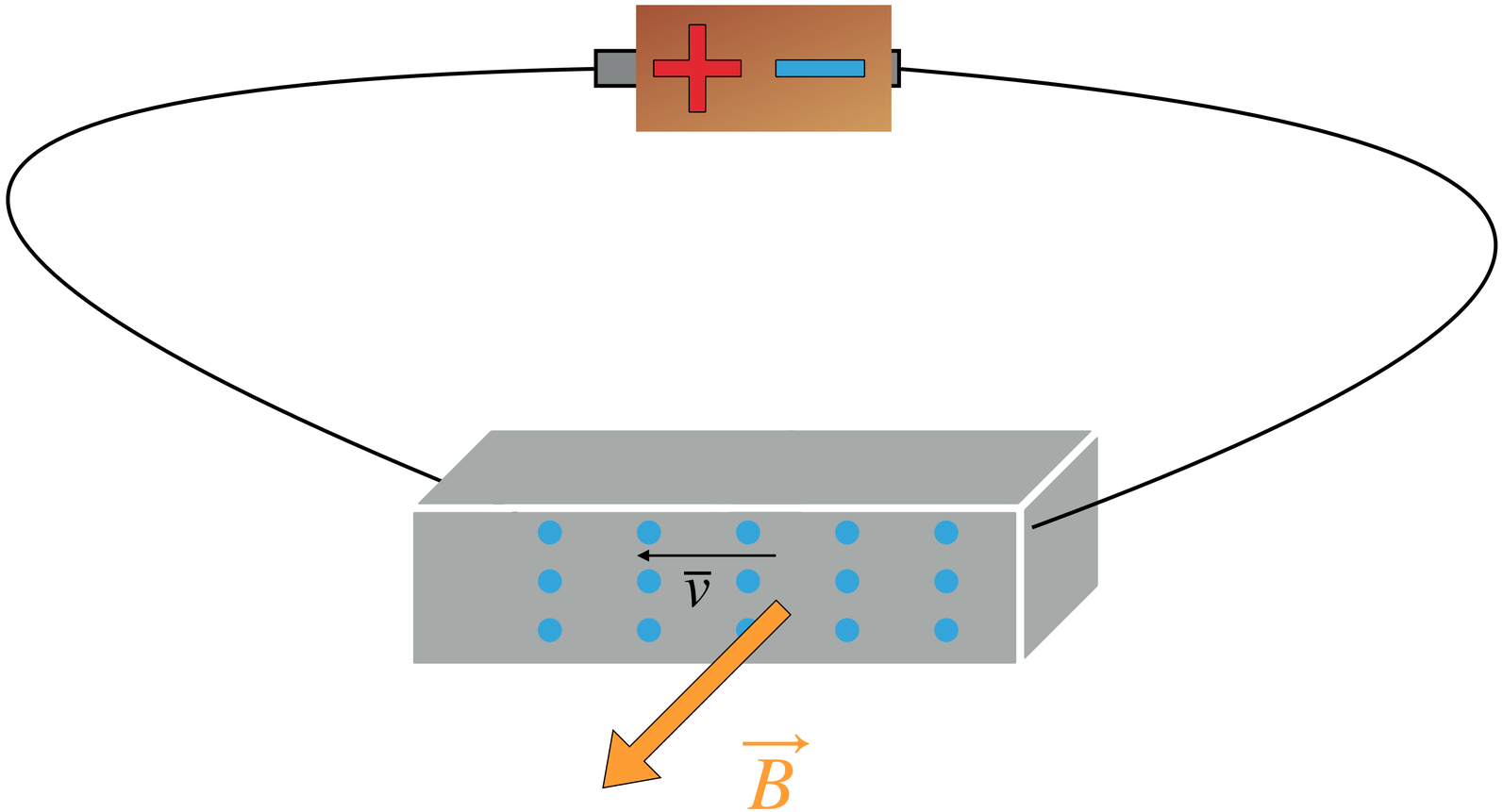
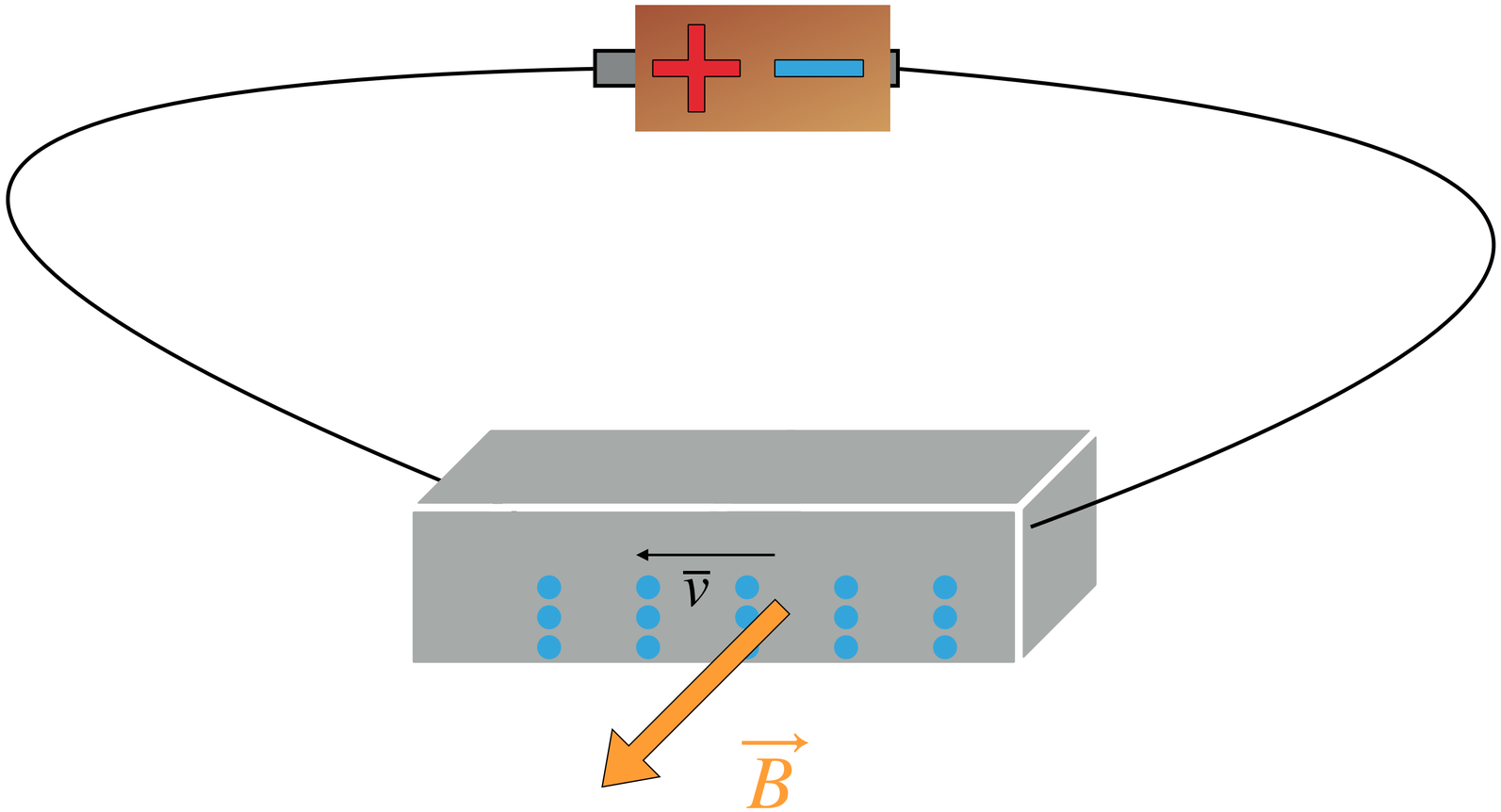


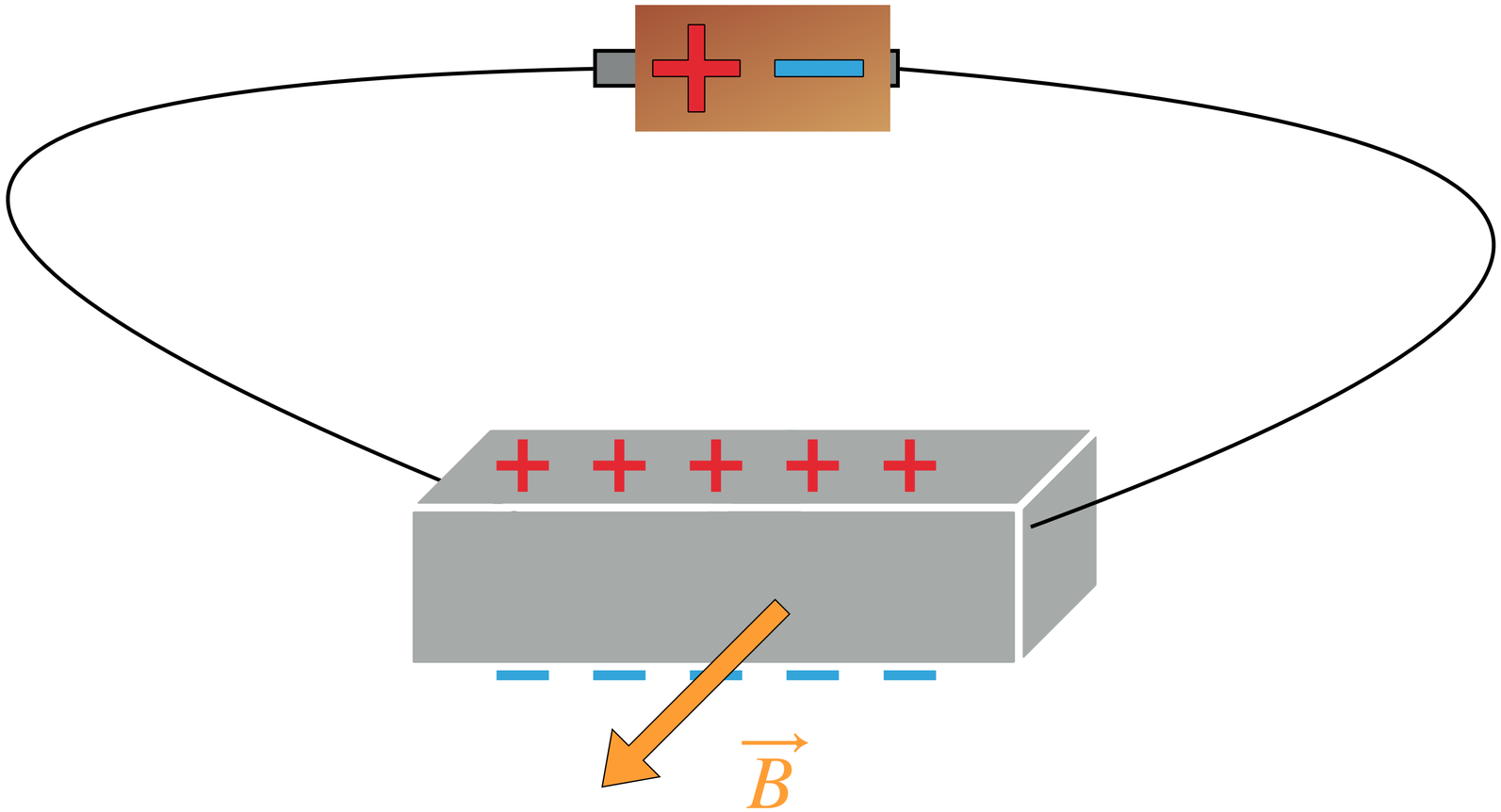
VELOCITY SELECTOR



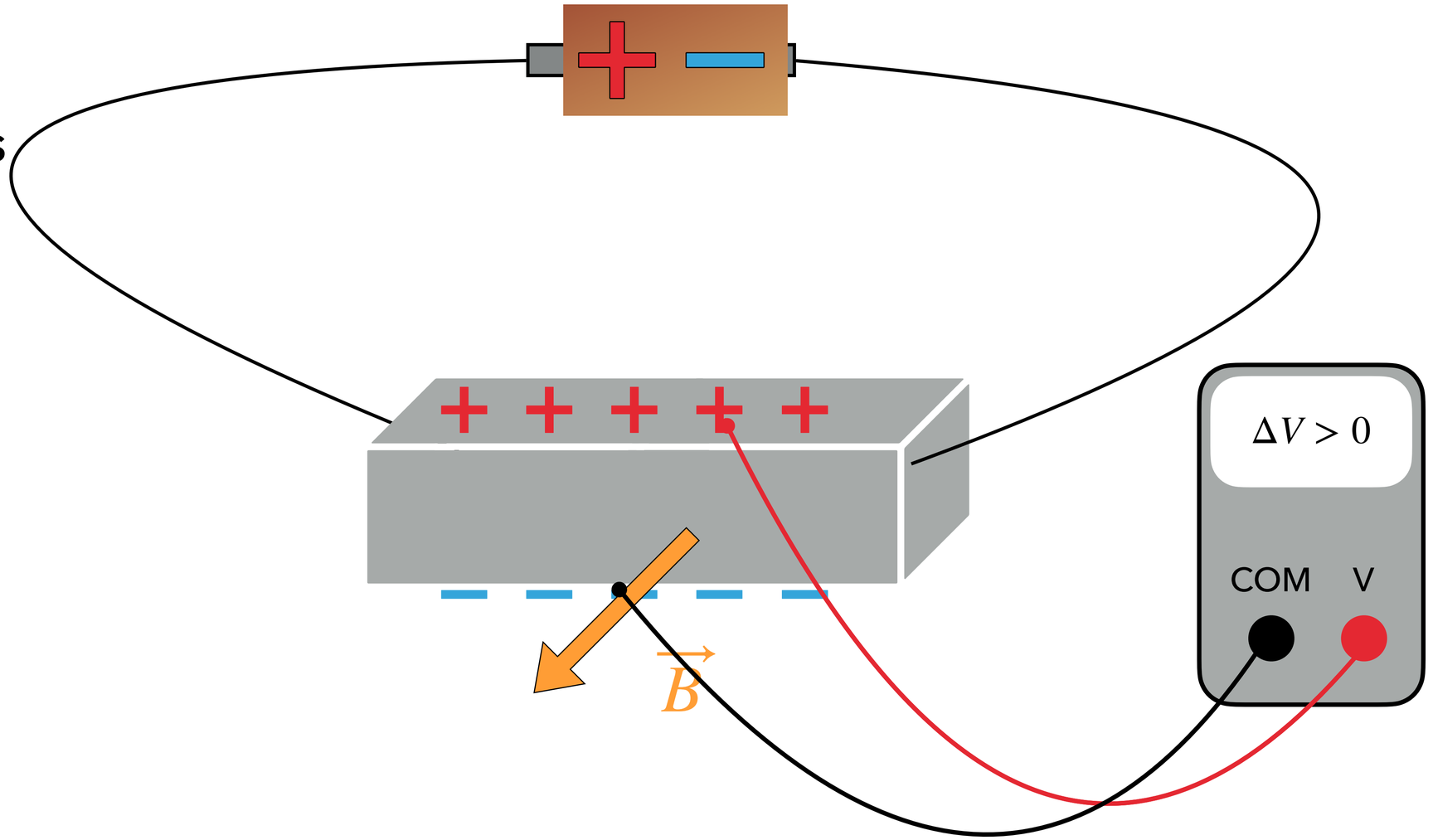

$\overline{v}$


$\overline{v}$
$\overrightarrow{B}$

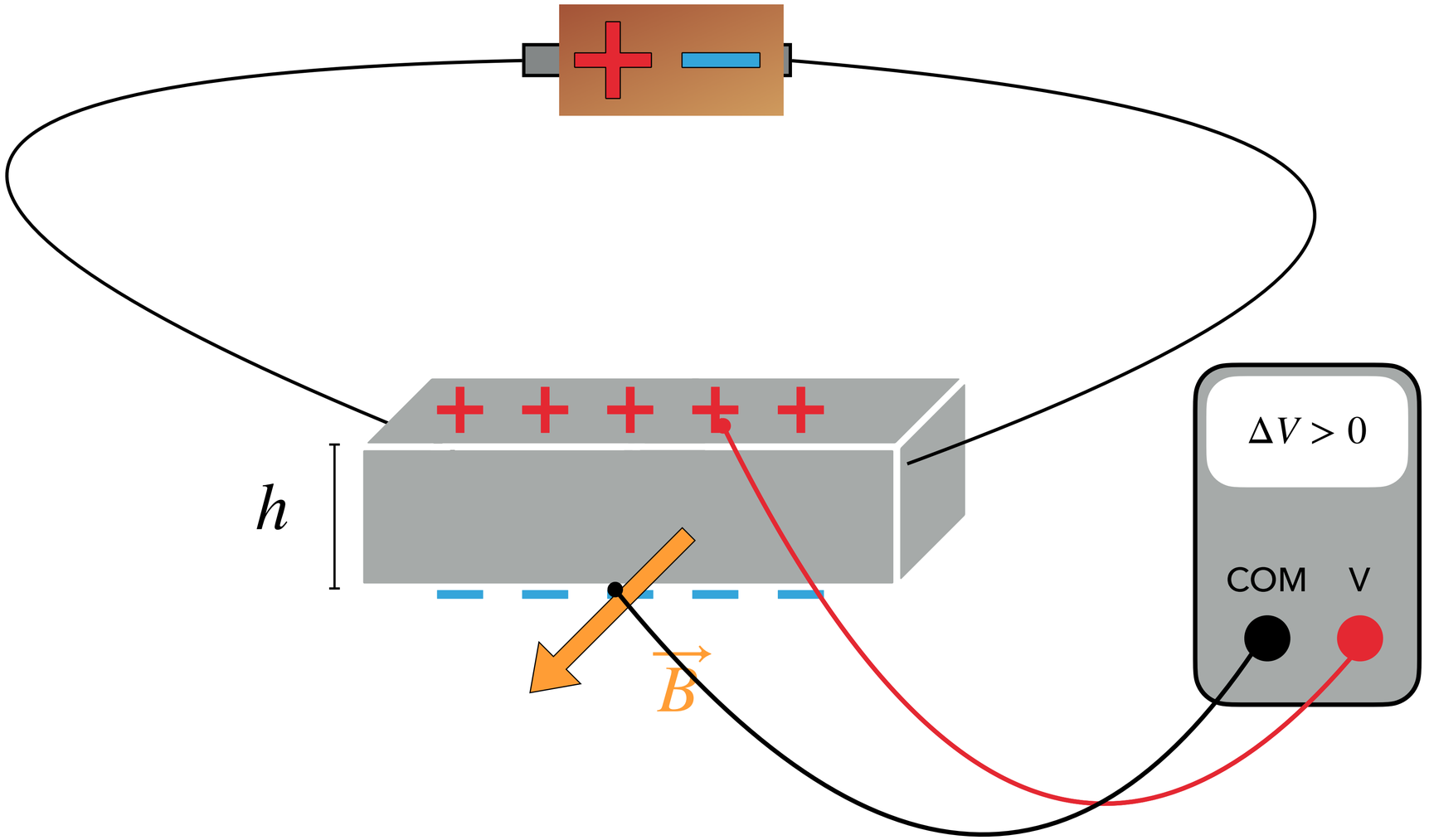

$\overline{v}$
$\overrightarrow{B}$


$\vec{B}$

- If charge carriers are *negative*, voltmeter reads positive voltage



- What will the voltmeter read?



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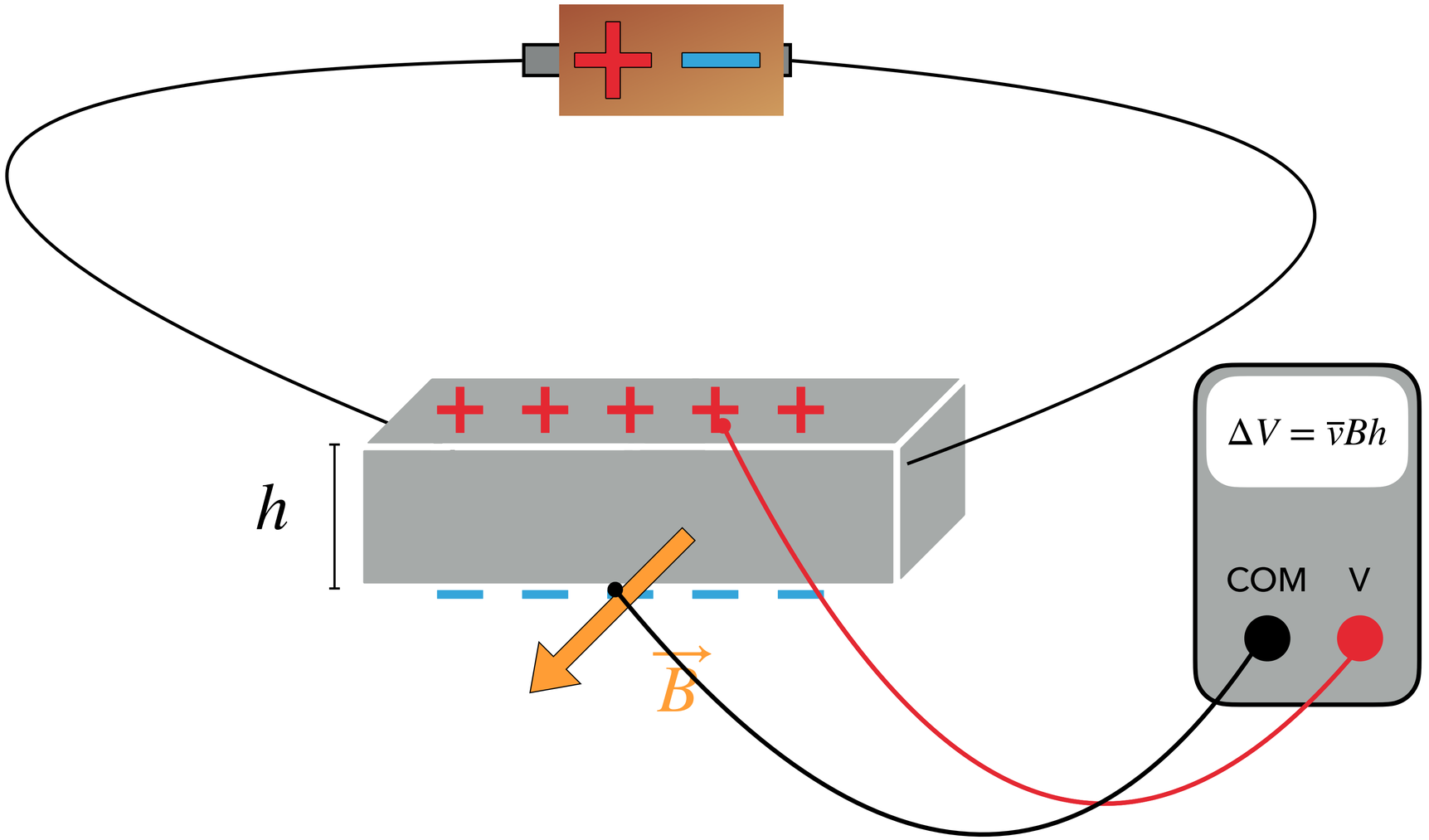
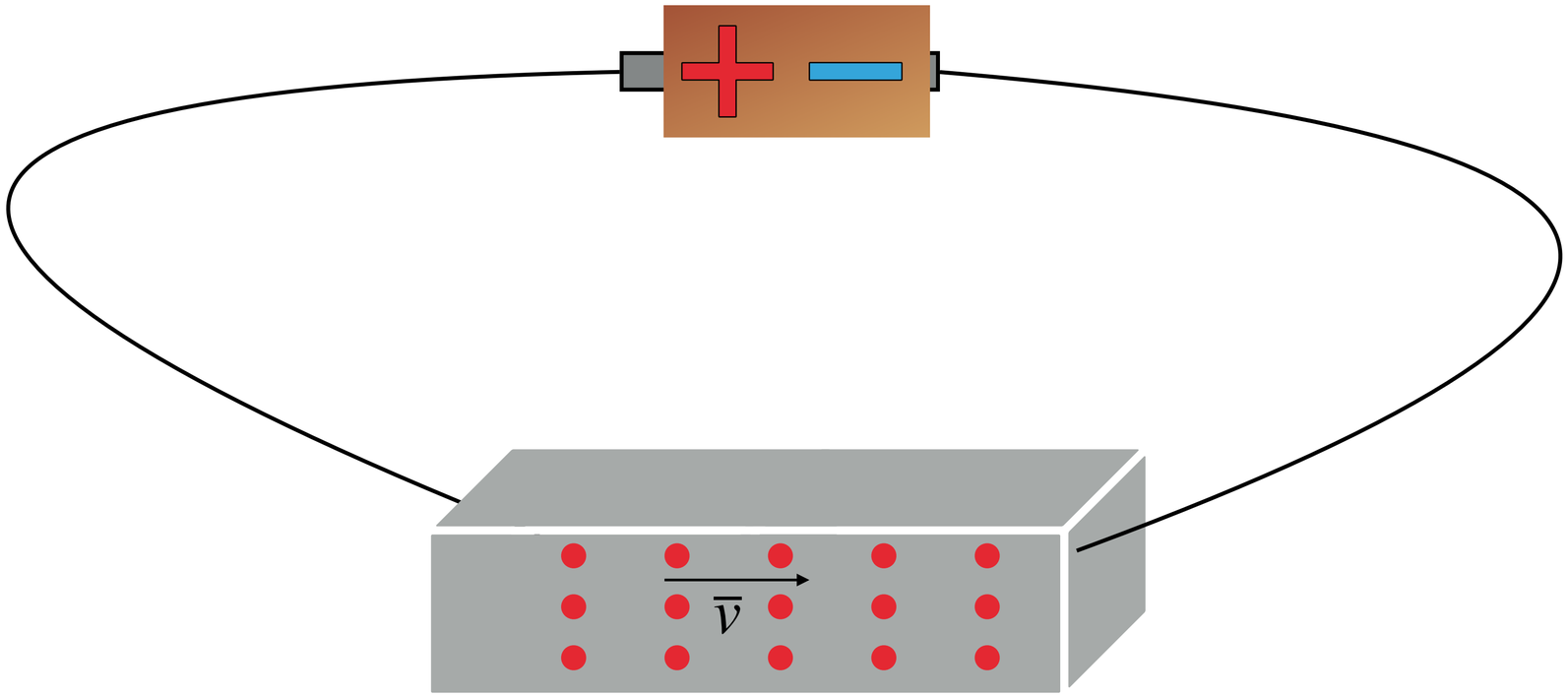
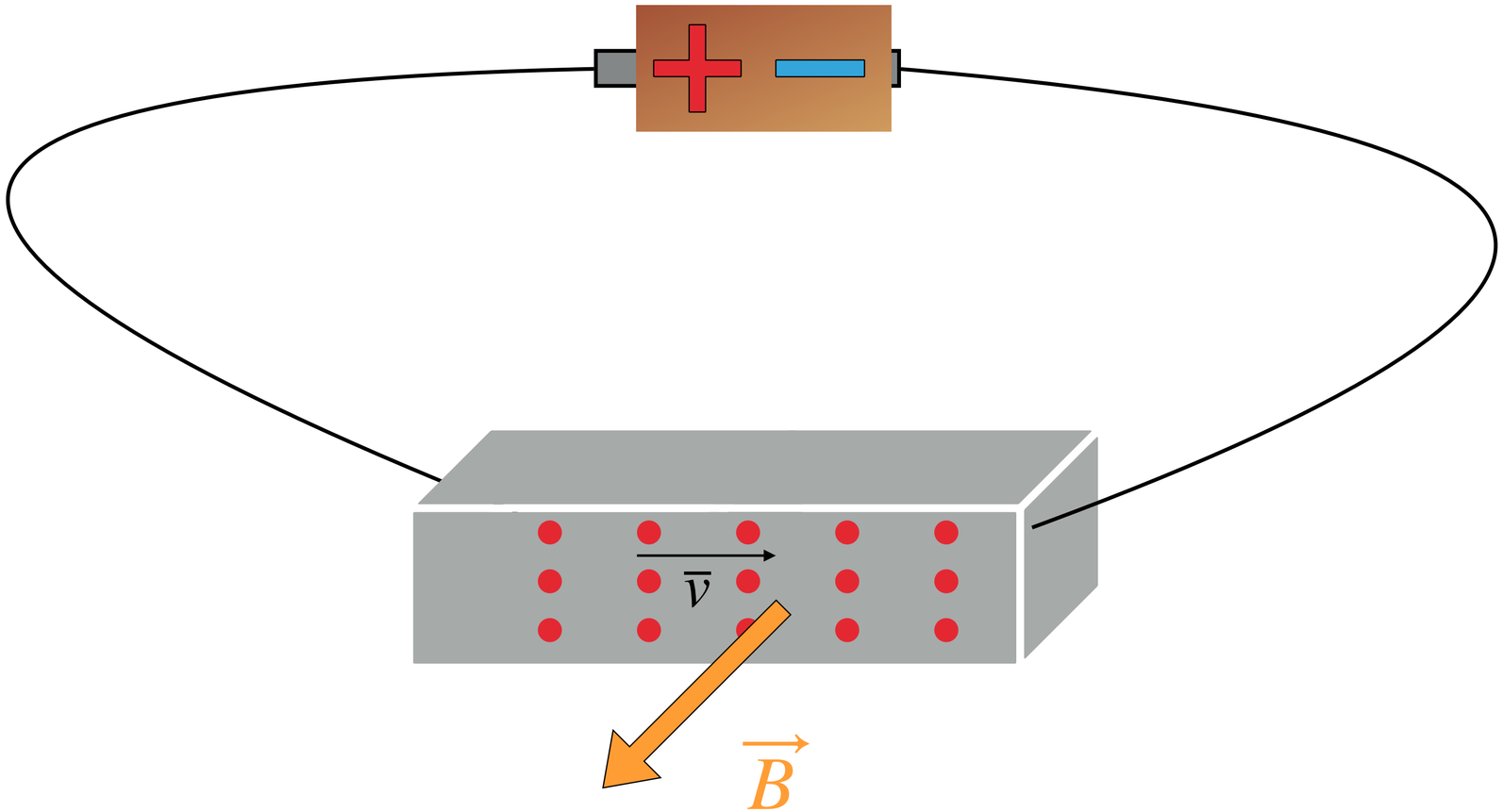
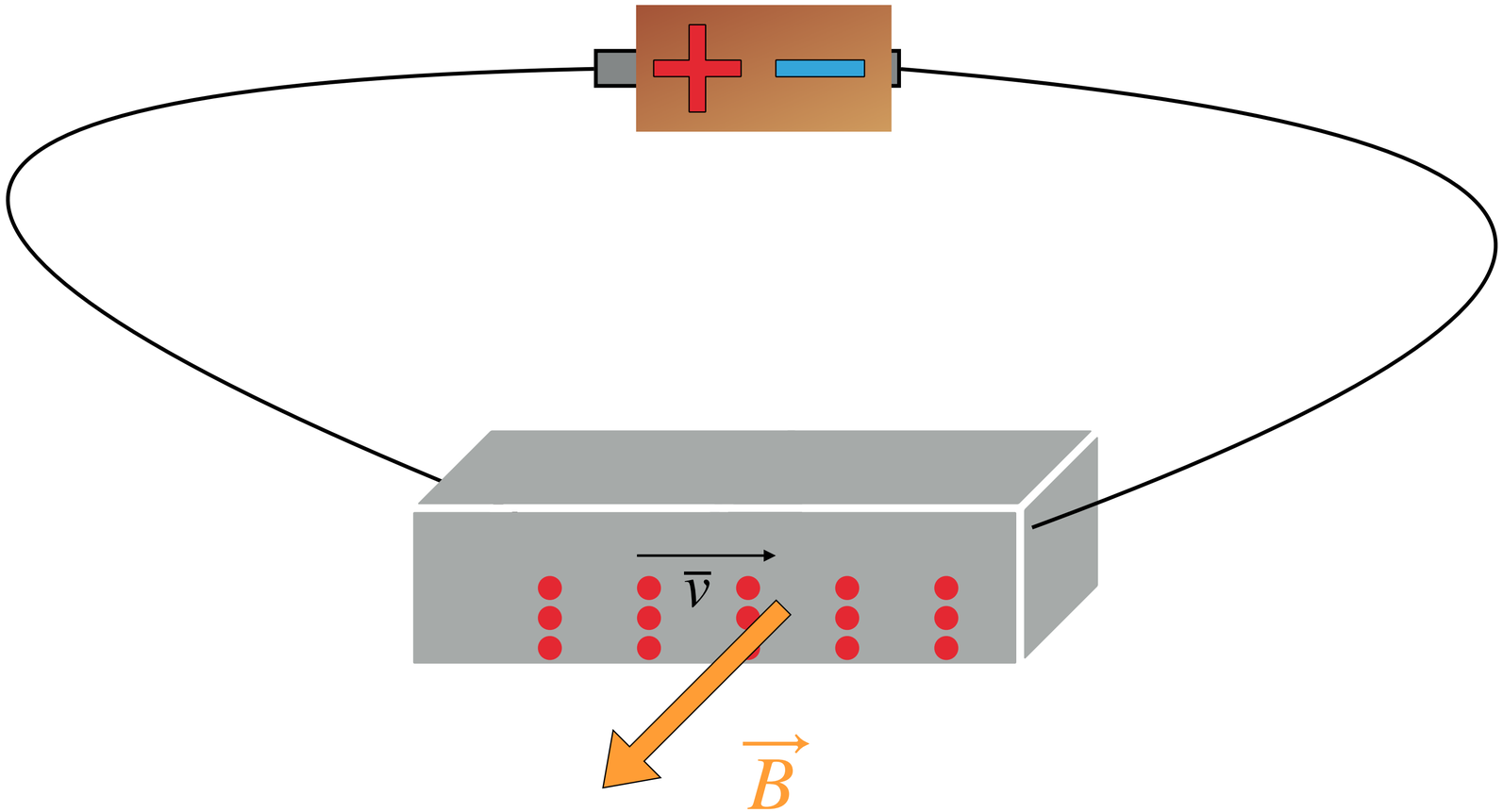
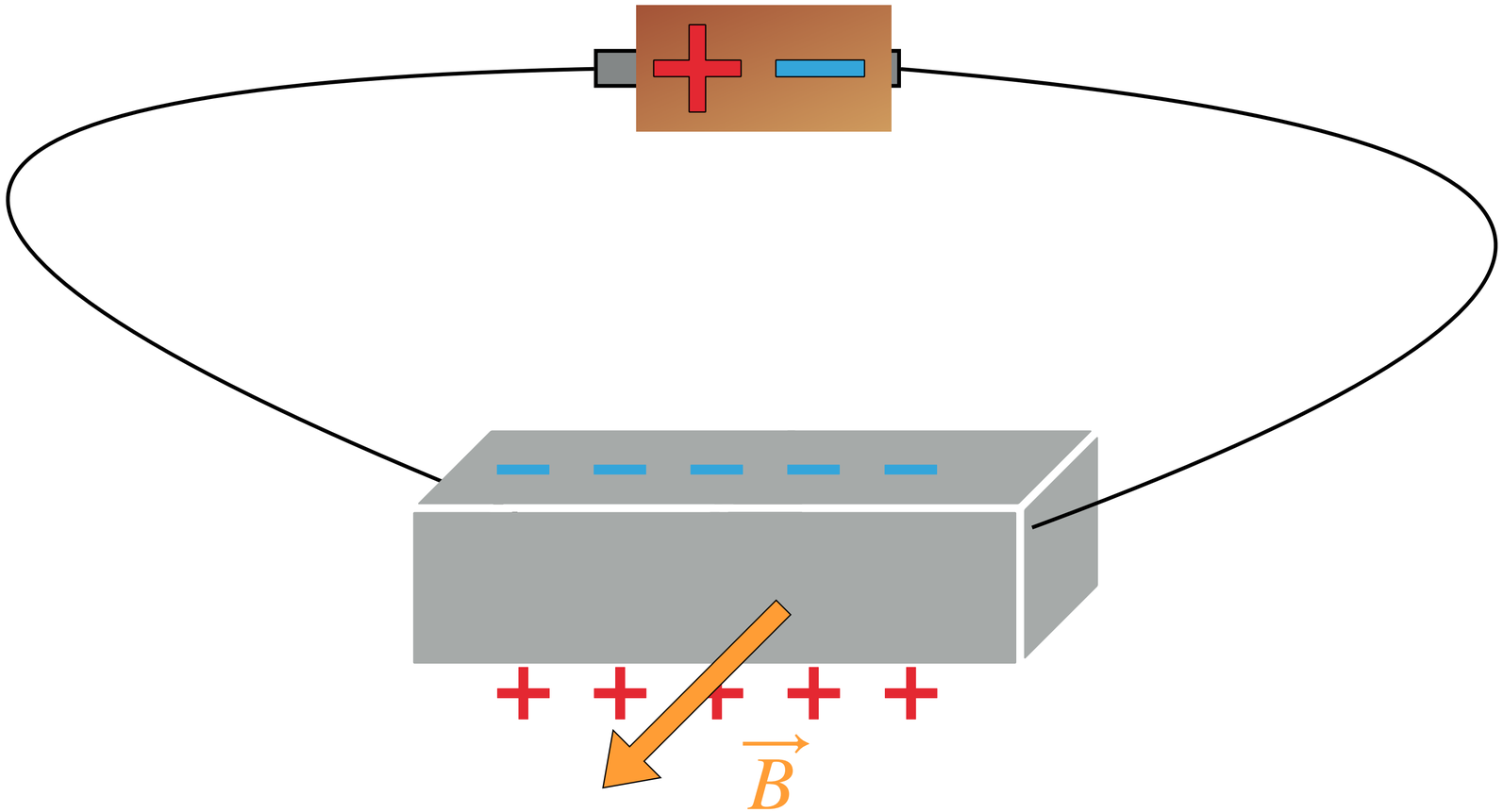


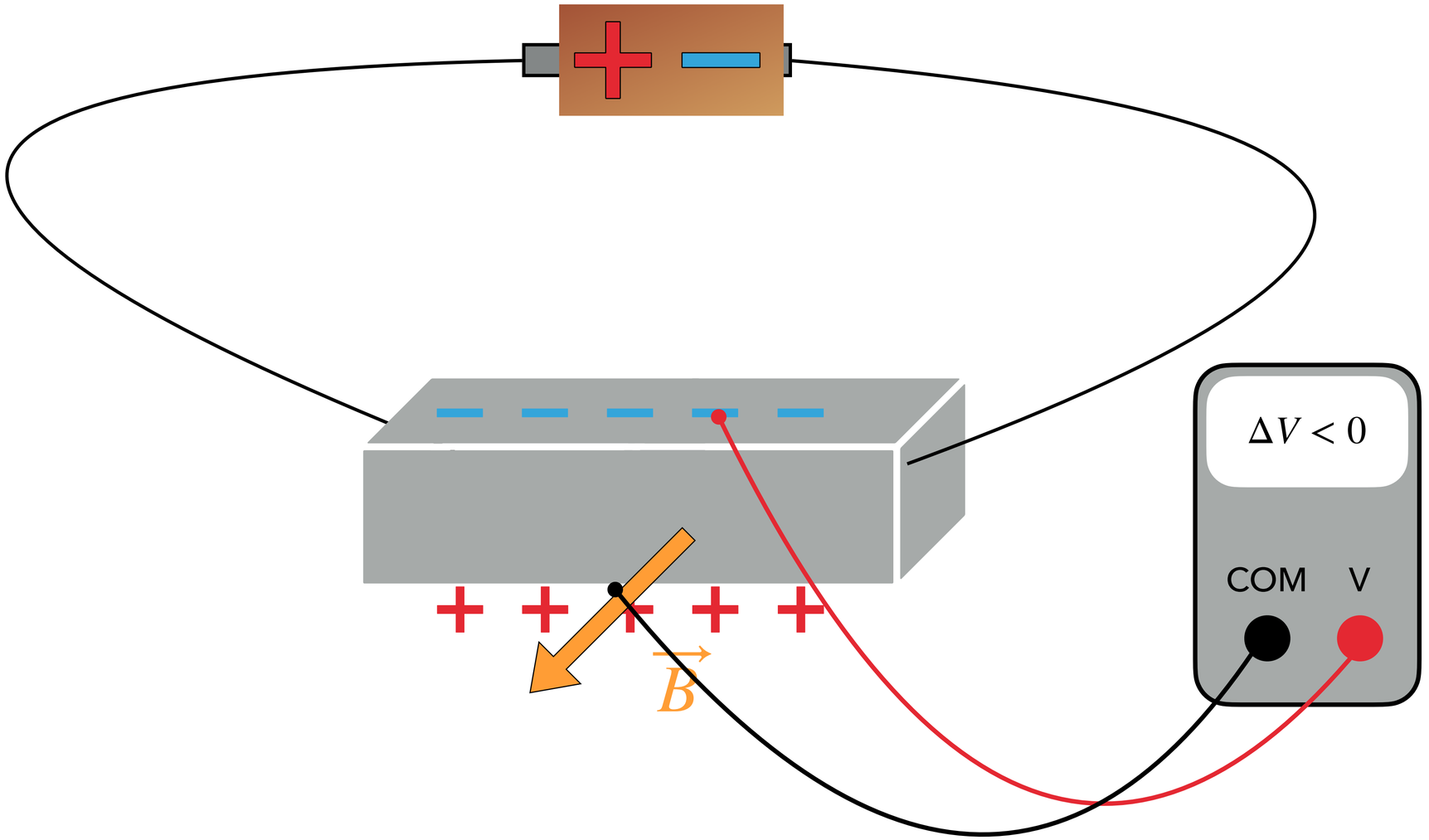
- What if charge carriers were positive?




$\overline{v}$
$\overrightarrow{B}$


$\overline{v}$
$\overrightarrow{B}$

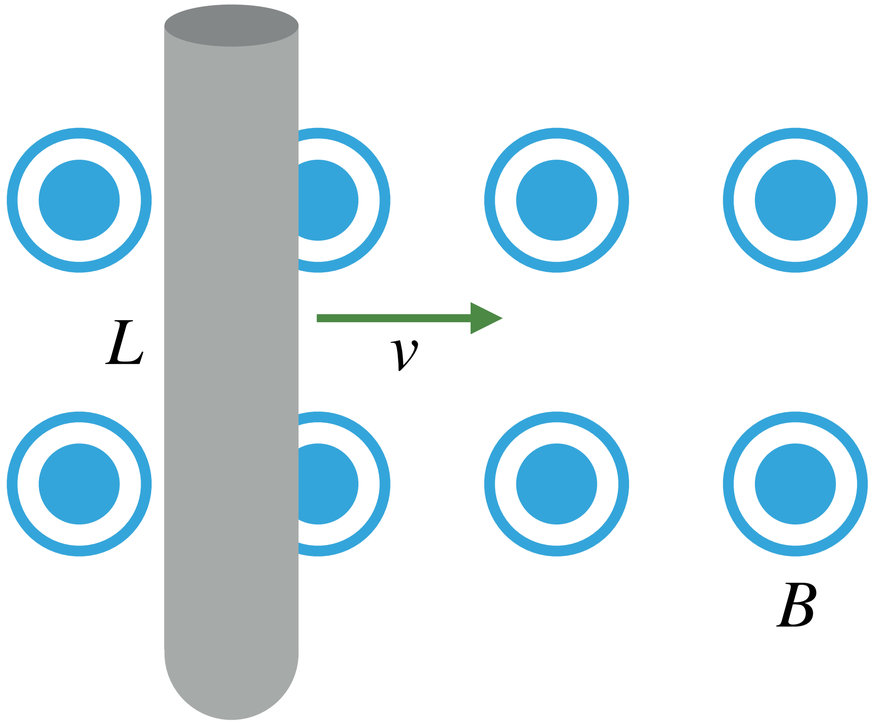

$\vec{B}$


$\Delta V < 0$
COM
V
$\vec{B}$

THE HALL EFFECT

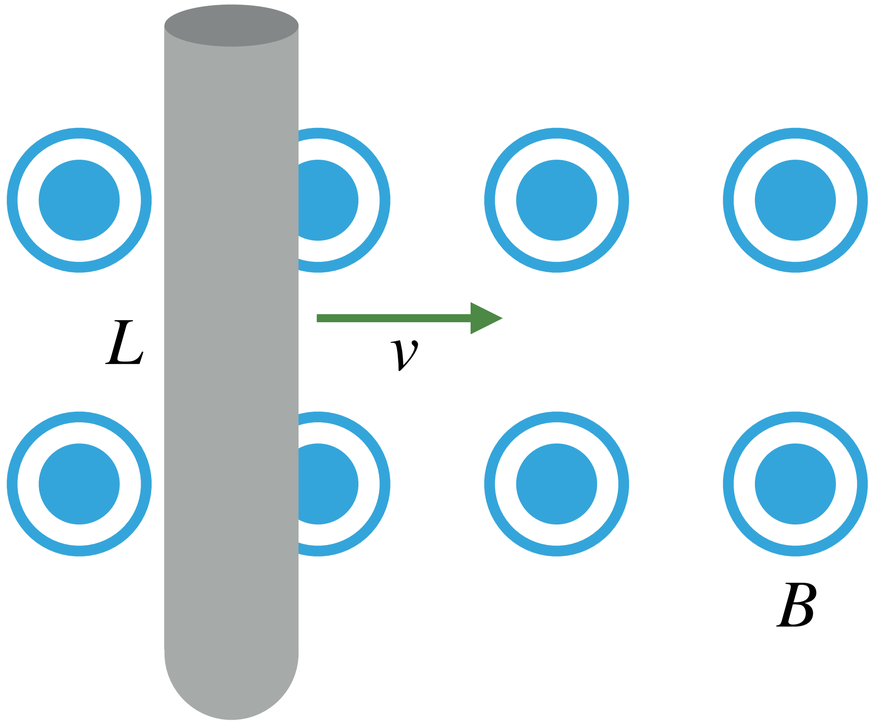
- Magnetic field polarizes moving charges within a circuit
  - Creates measurable voltage difference across top-bottom of wire
  - Used in determining sign of moving charges in circuit

CONSIDER



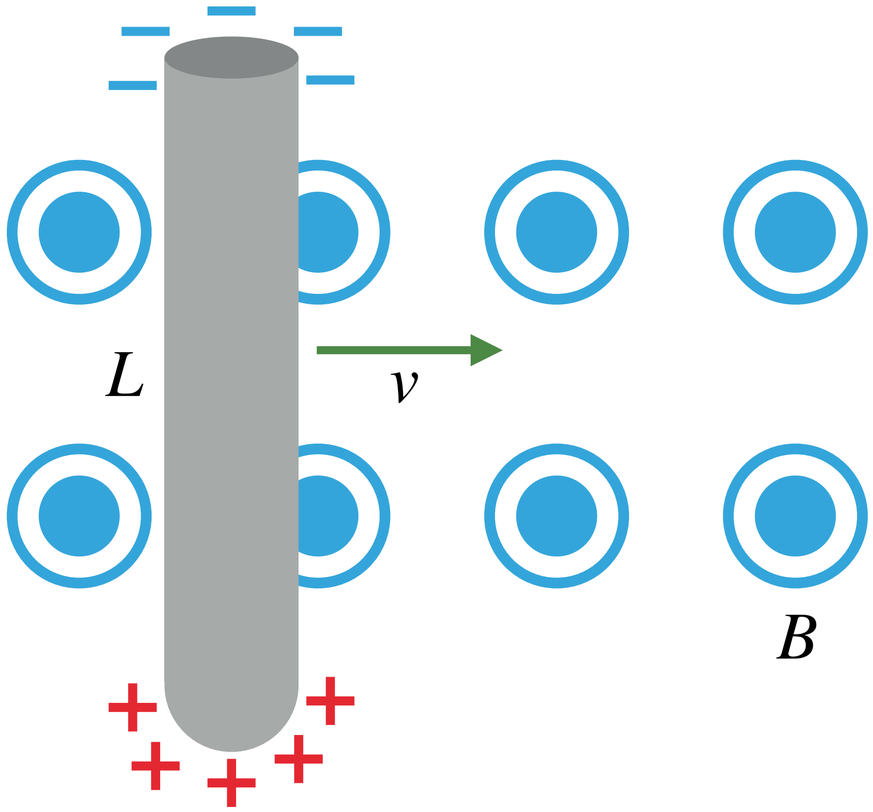
CONSIDER

- What happens?



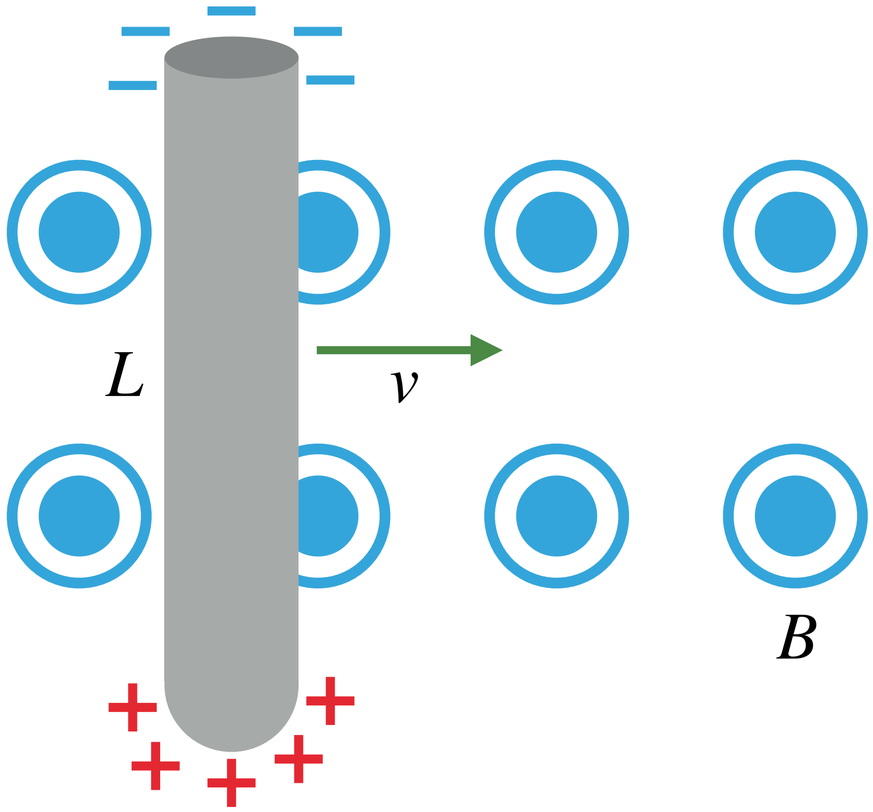
CONSIDER

- Electrons in bar are moving
- Experience force $\overrightarrow{F} = q\overrightarrow{v} \times \overrightarrow{B}$



CONSIDER

- When (if ever?) does charge separation stop?



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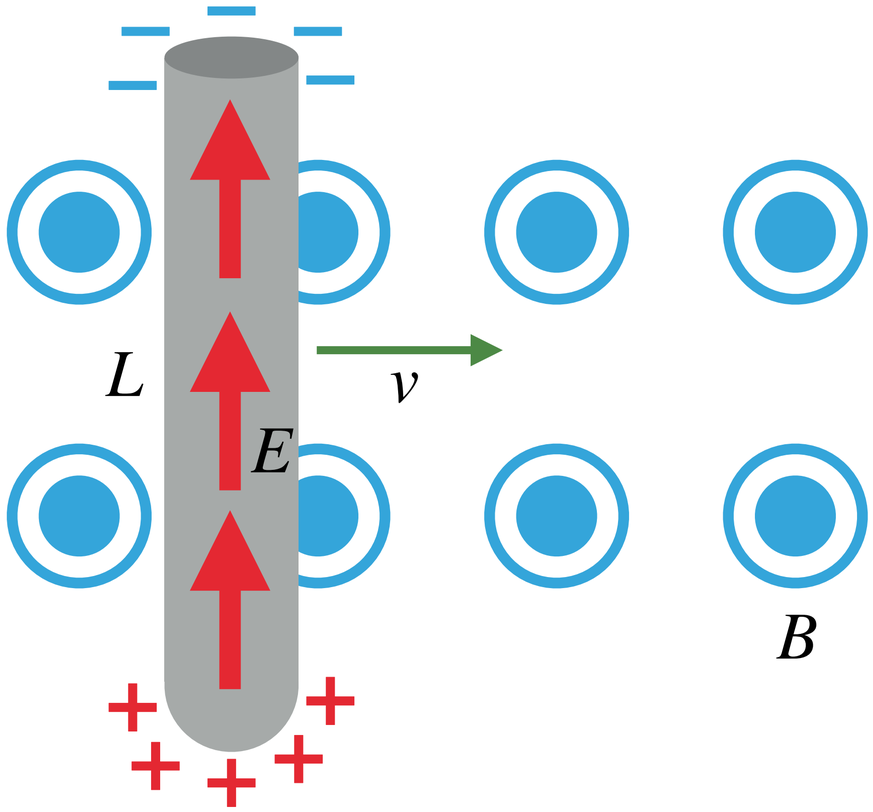

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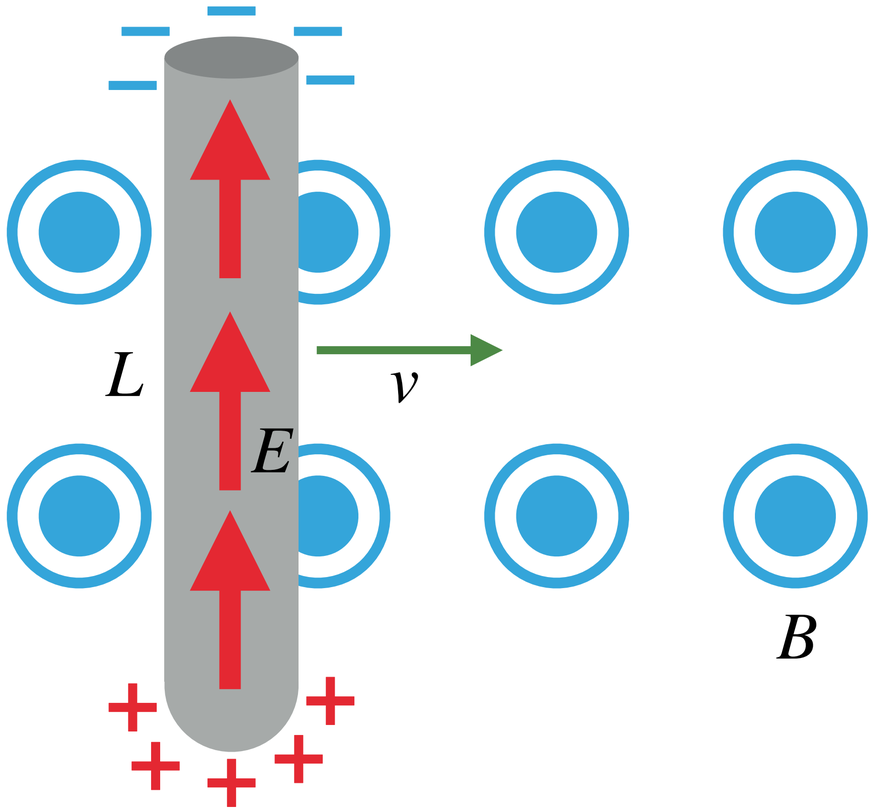

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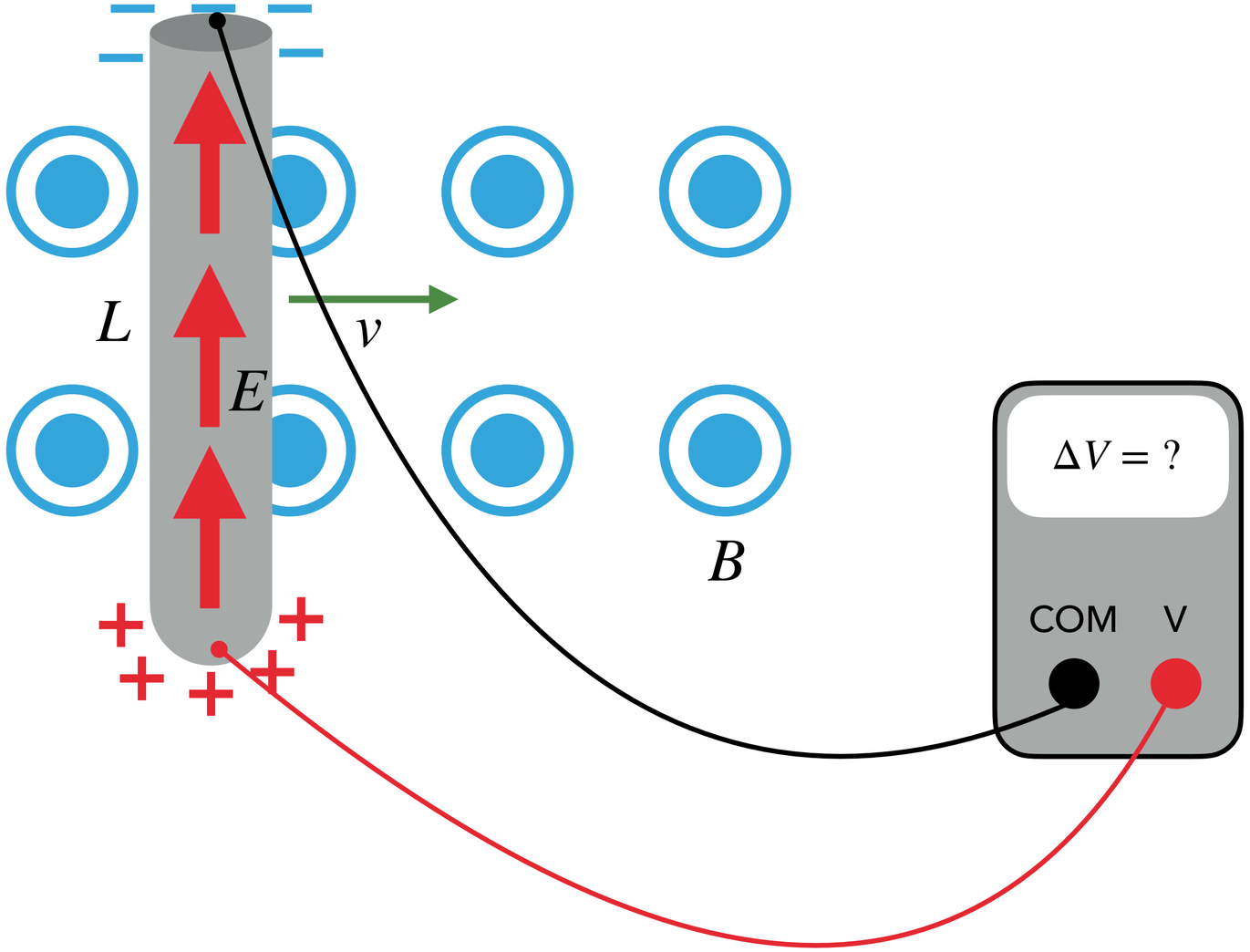
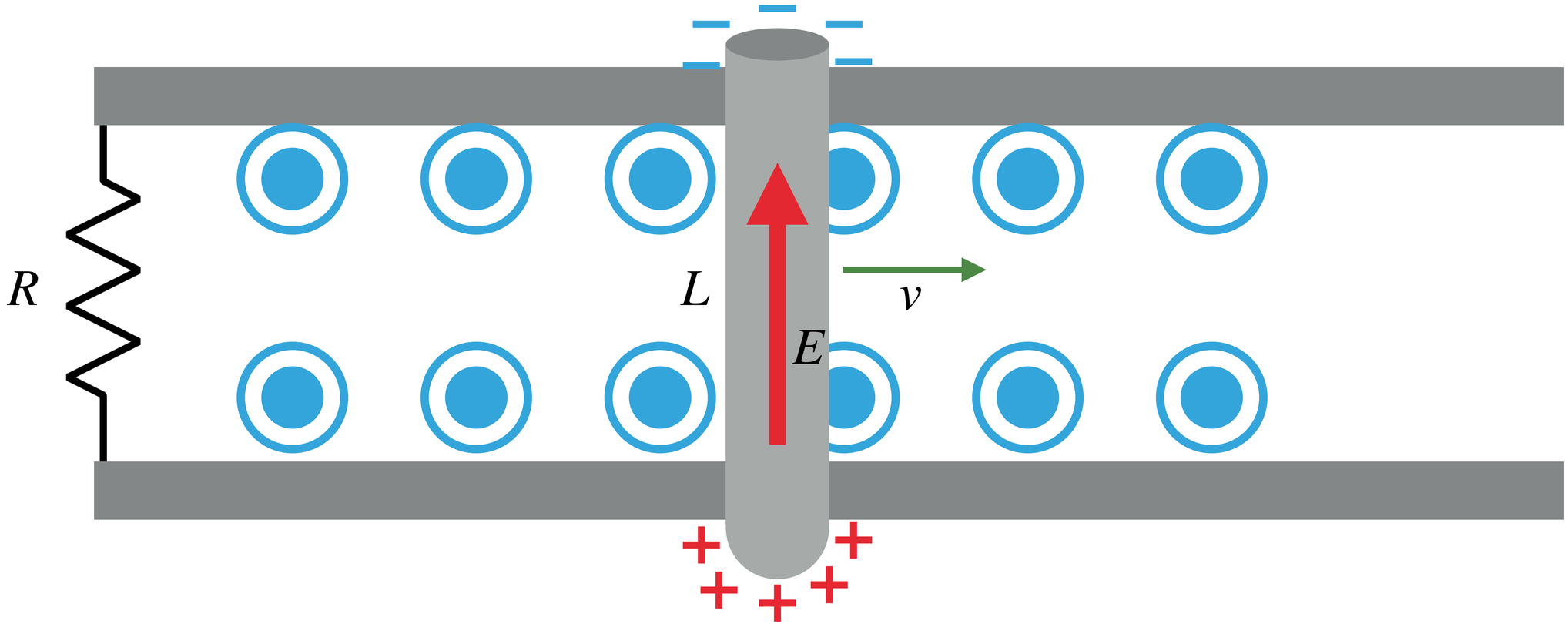
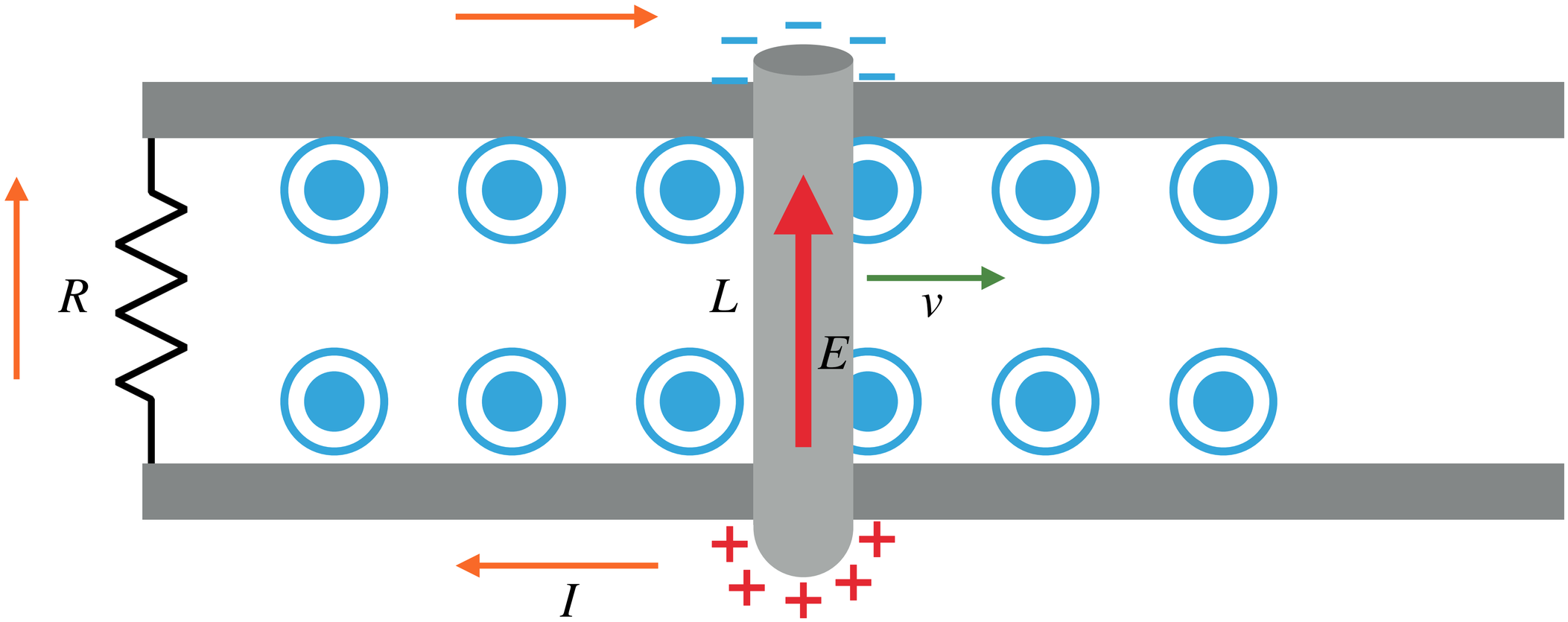


CONSIDER

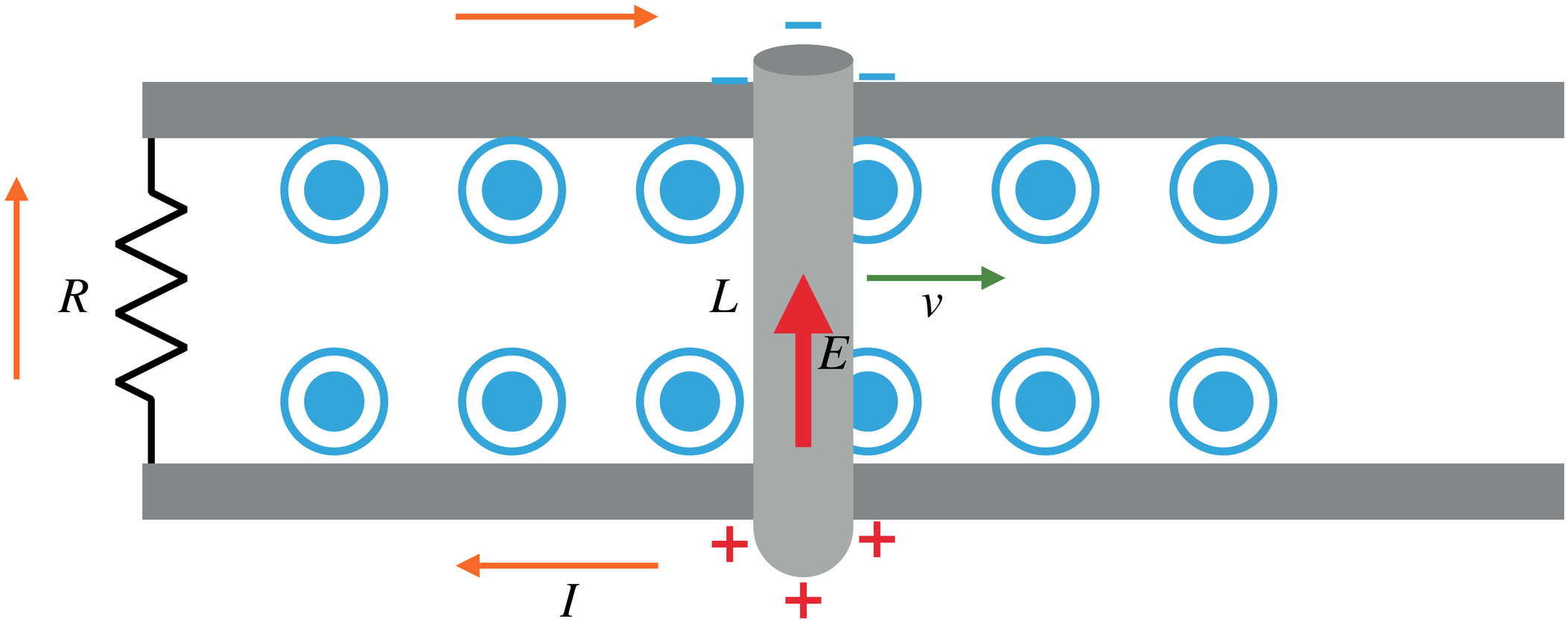


CONSIDER



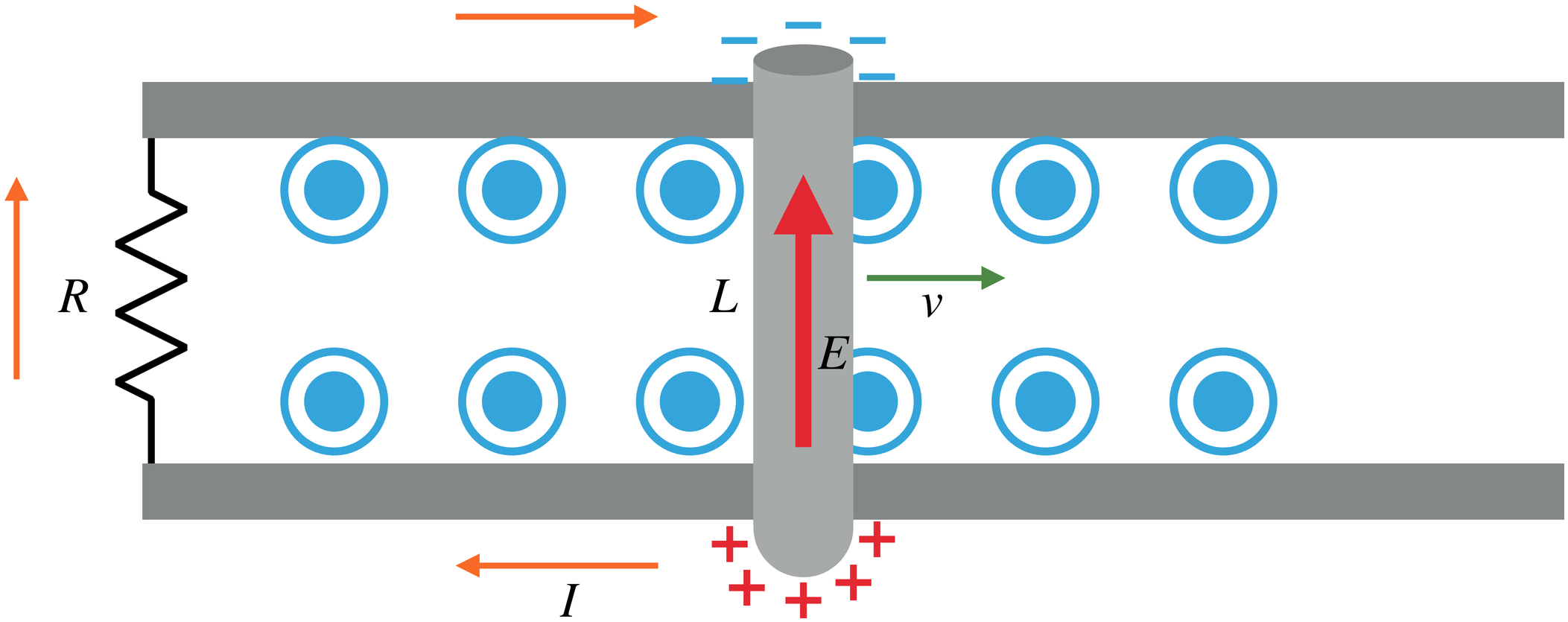
Electric field drives a current through the circuit

CONSIDER



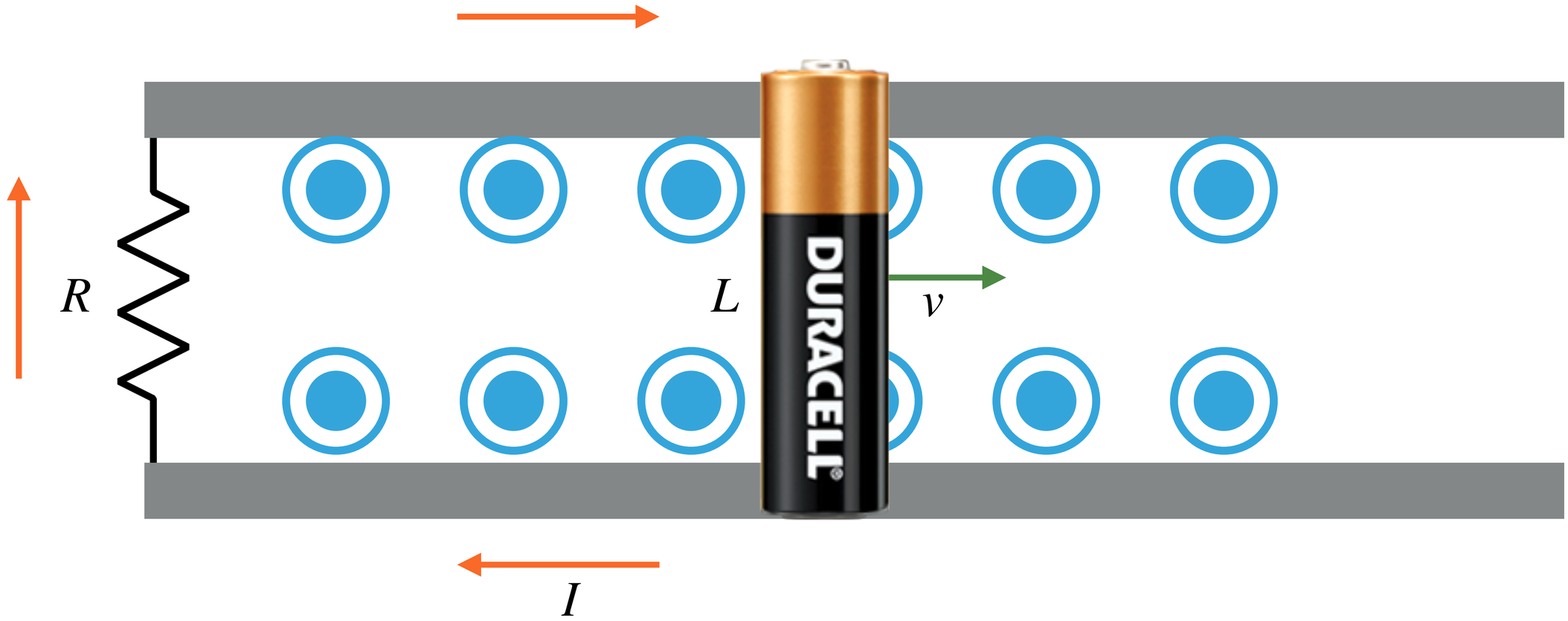
As current flows, charges leave metal bar, reducing electric field

CONSIDER



Decrease in electric field unbalances $qE - qvB$, and vacating charges get replaced

CONSIDER

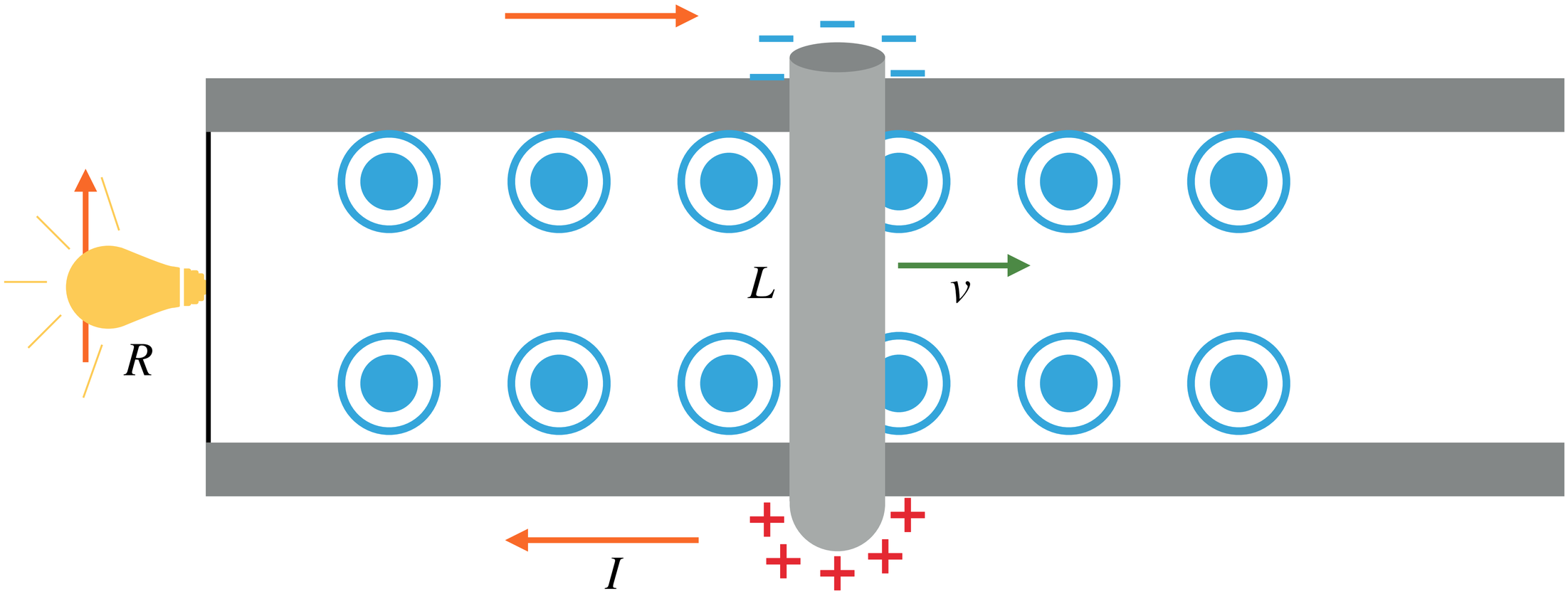


Moving metal bar acts just like a battery!

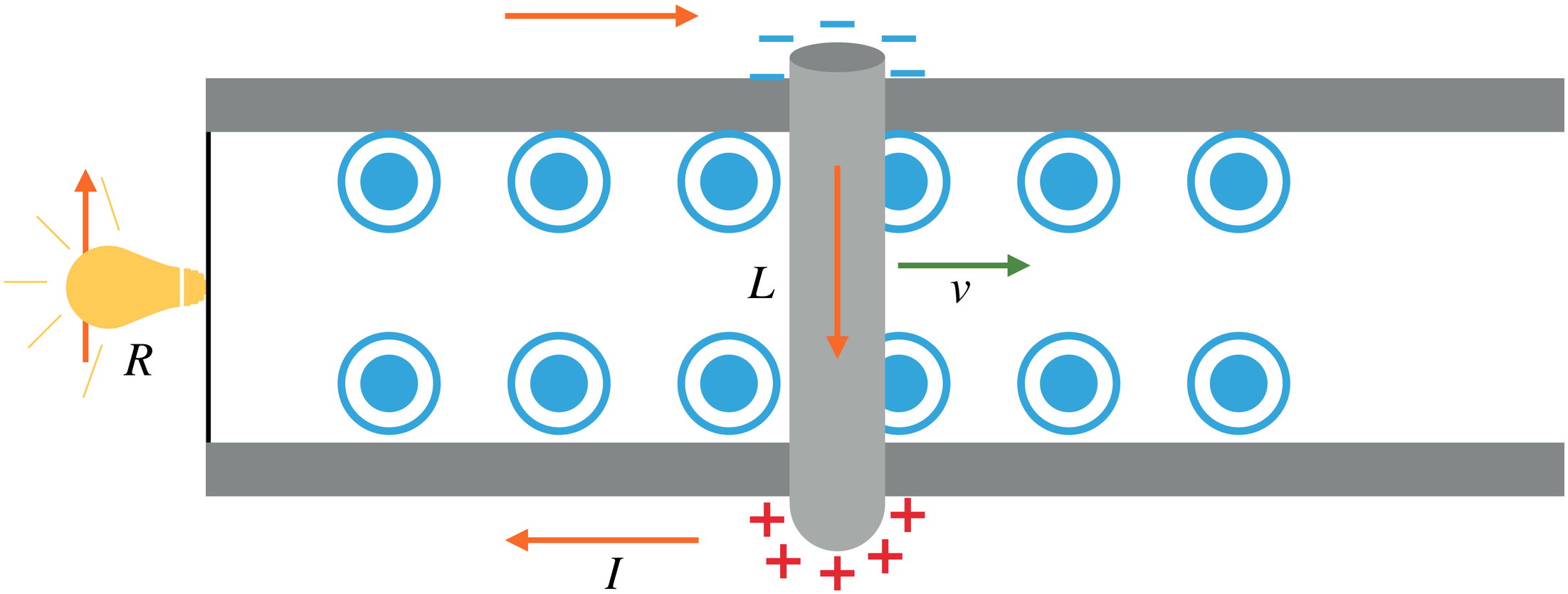
MOTIONAL EMF

- Moving metal bar maintains charge separation with constant $\Delta V = BLv$
- Functions as a battery with emf $\varepsilon = BLv$
- This phenomenon is called **motional emf**
  - Main point: Moving a wire through a magnetic field drives a current

FREE ENERGY?

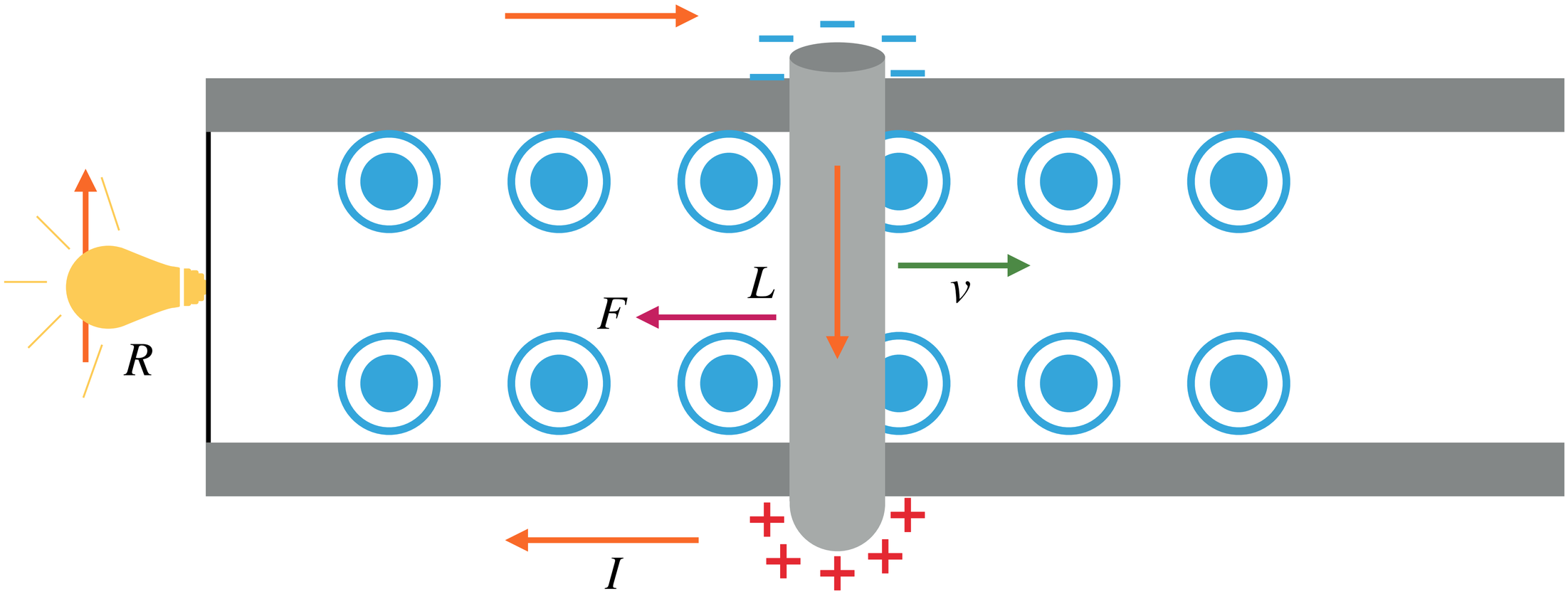


FREE ENERGY?



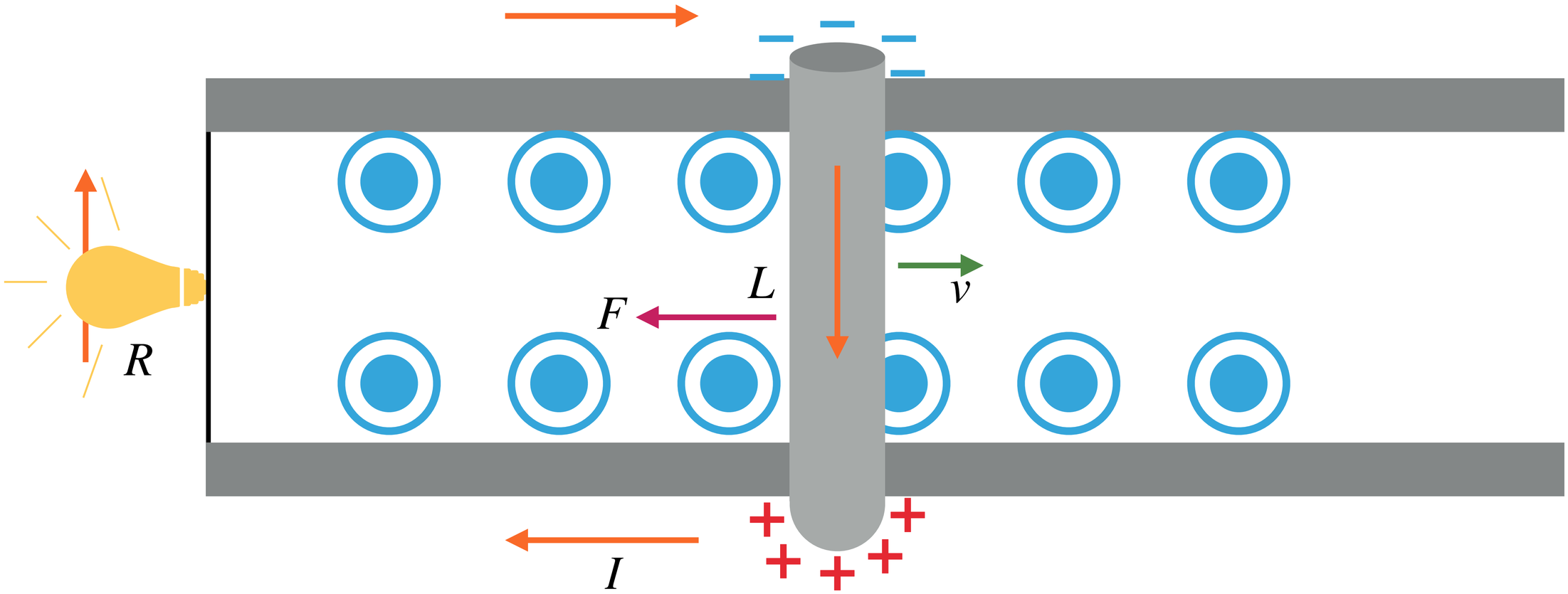
Motional emf drives current through bar

FREE ENERGY?



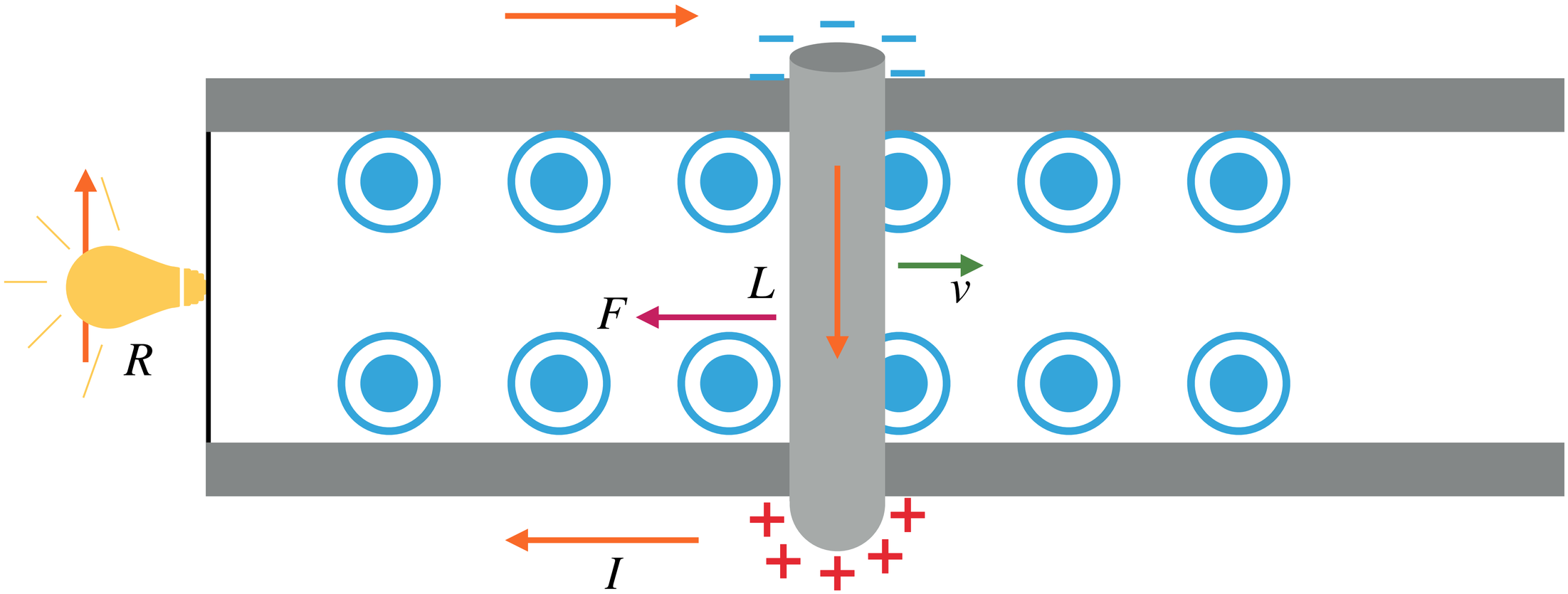
Magnetic field exerts force on current carrying wire

FREE ENERGY?



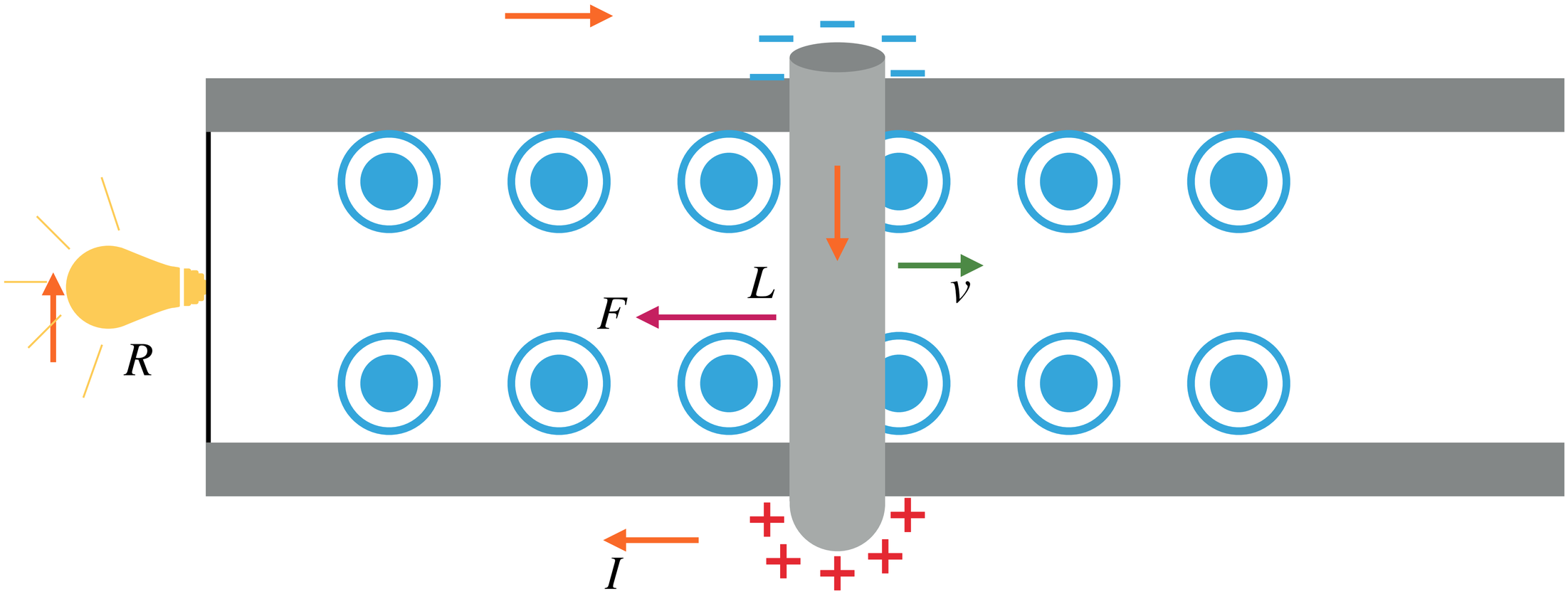
Force reduces velocity

FREE ENERGY?



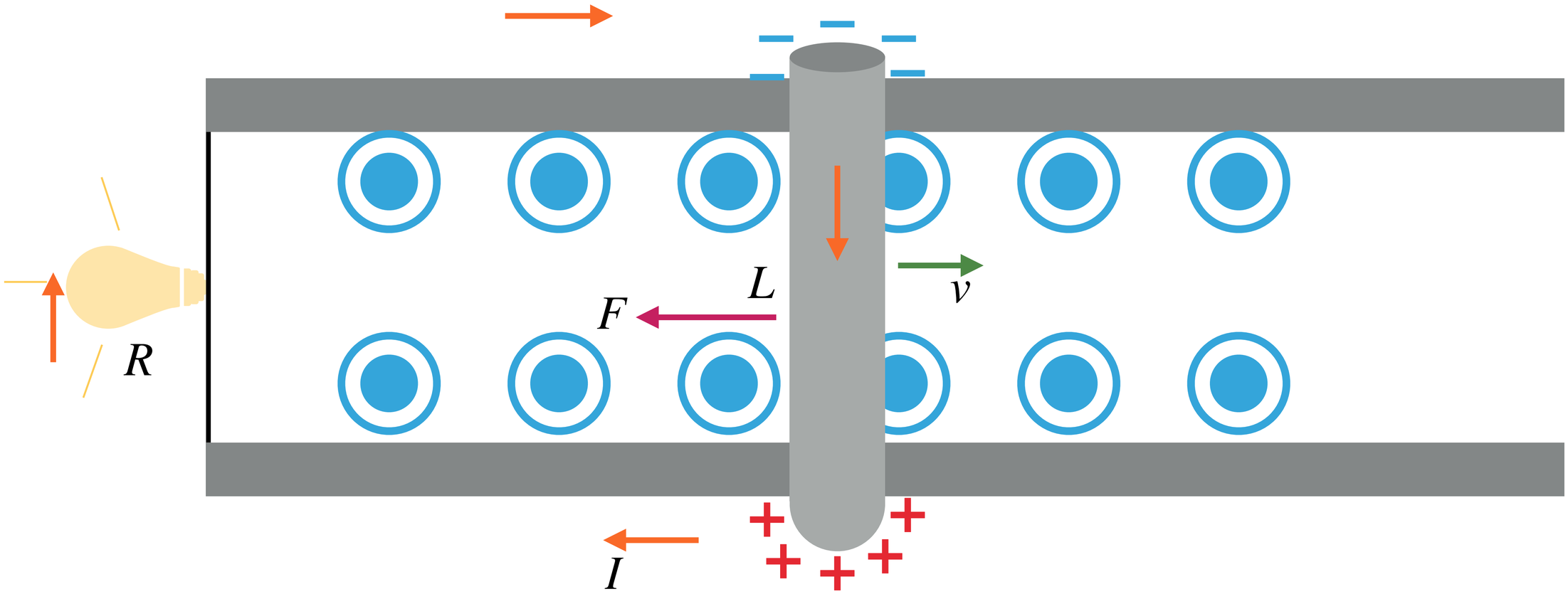
Which reduces emf ($\varepsilon = BLv$)

FREE ENERGY?



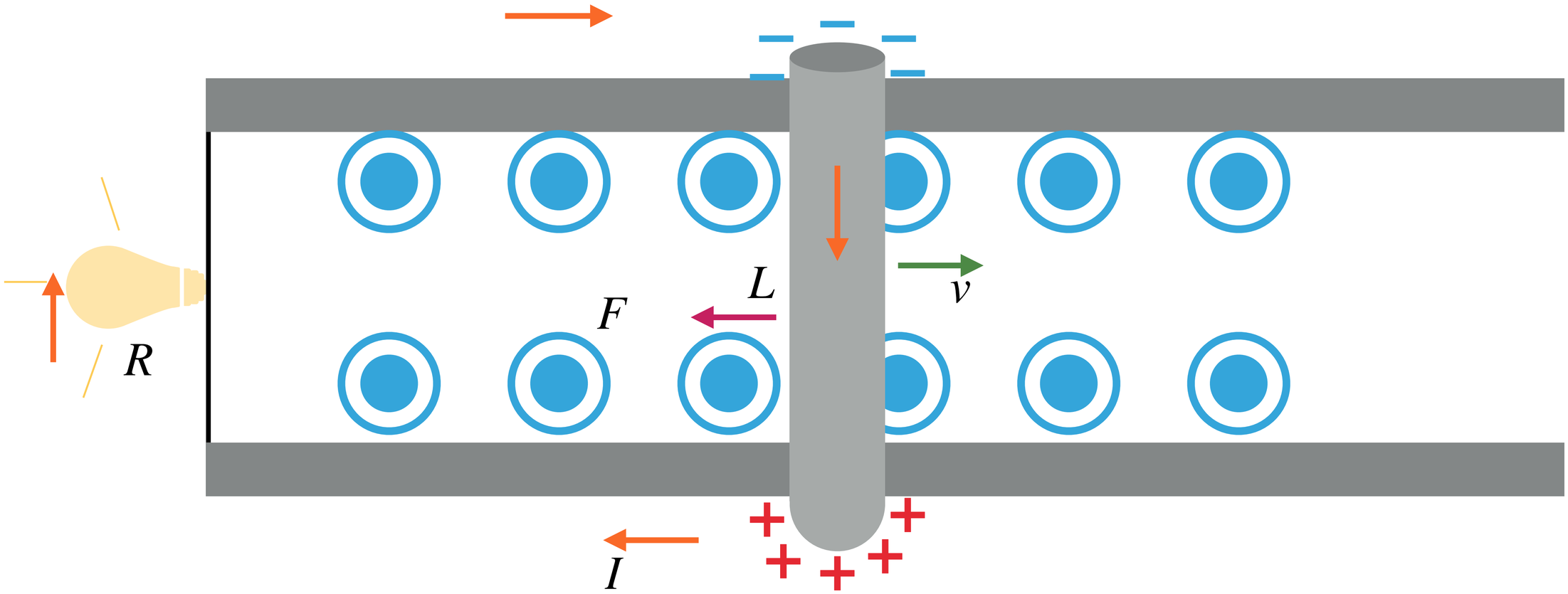
Reduced emf results in reduced current

FREE ENERGY?



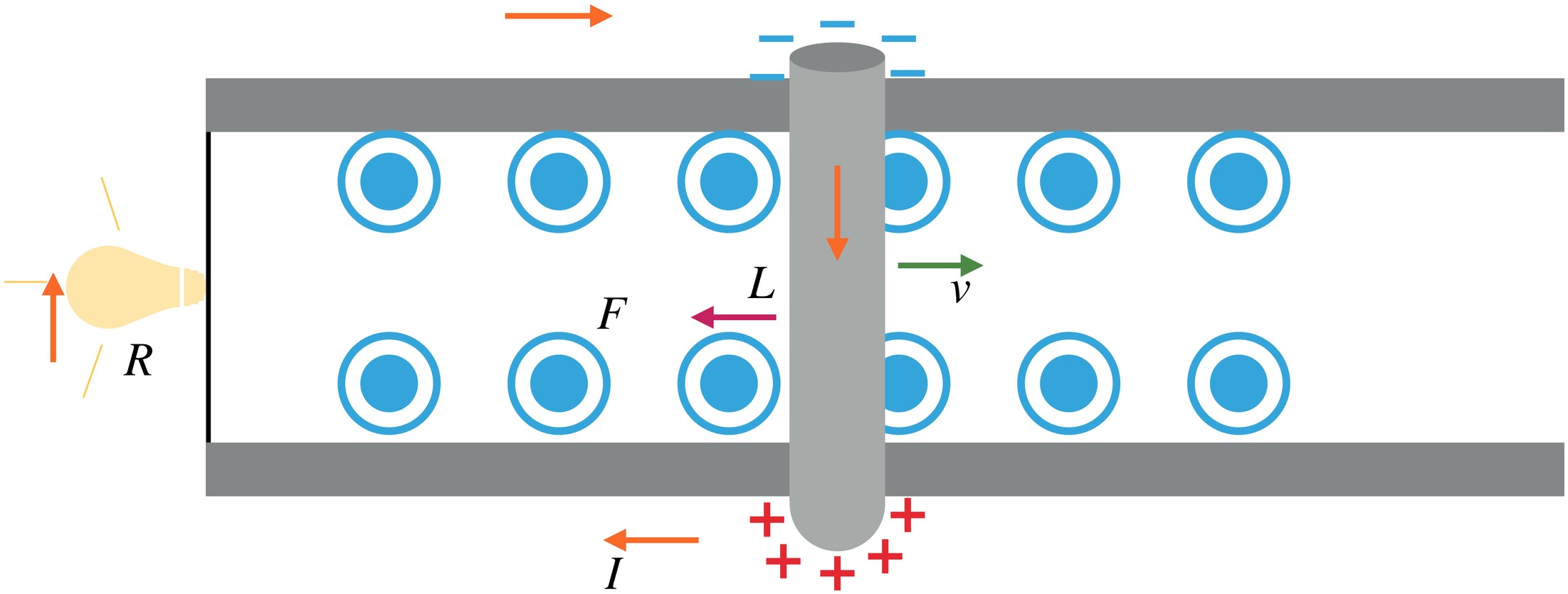
Reduced emf results in reduced current (which means less power is available for the bulb)

FREE ENERGY?



Reduced current results in reduced force (ILB)

FREE ENERGY?

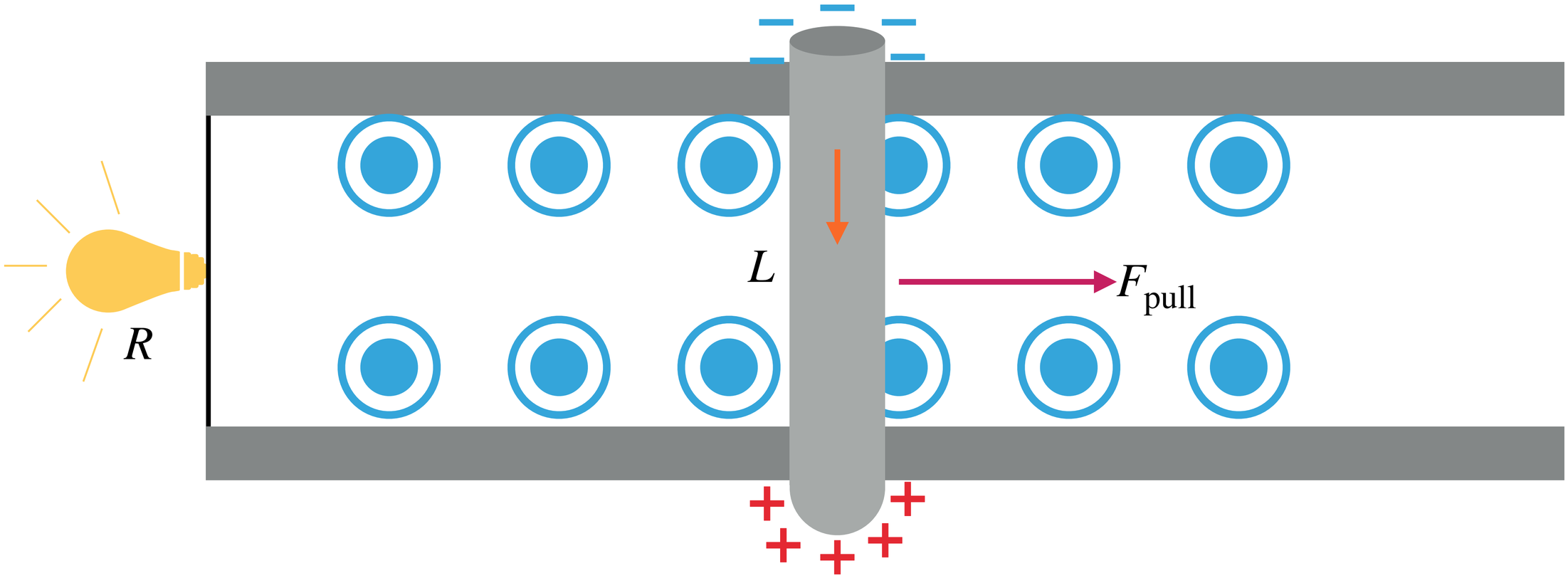


Repeat until bar comes to stop

ENERGY ANALYSIS

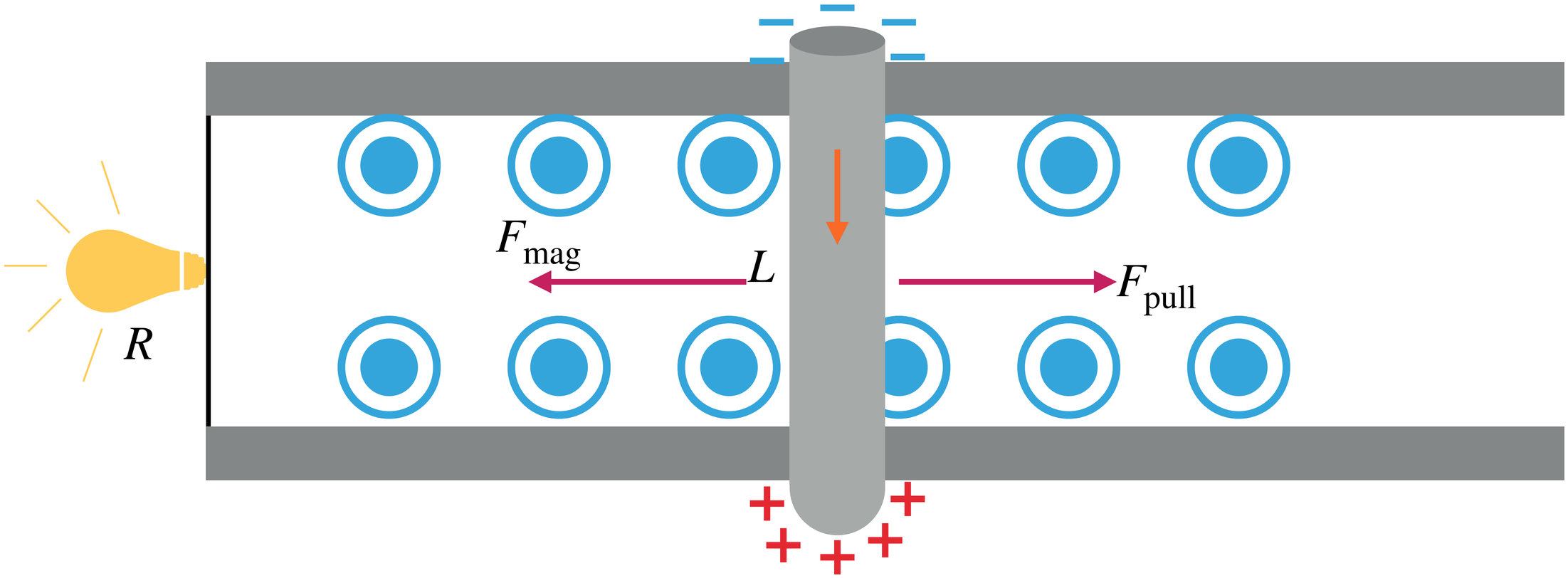
- Magnetic field cannot do work. Where is the energy coming from?

APPLYING CONSTANT FORCE



To continuously generate the same level of electricity, a constant force must be applied to the bar

APPLYING CONSTANT FORCE

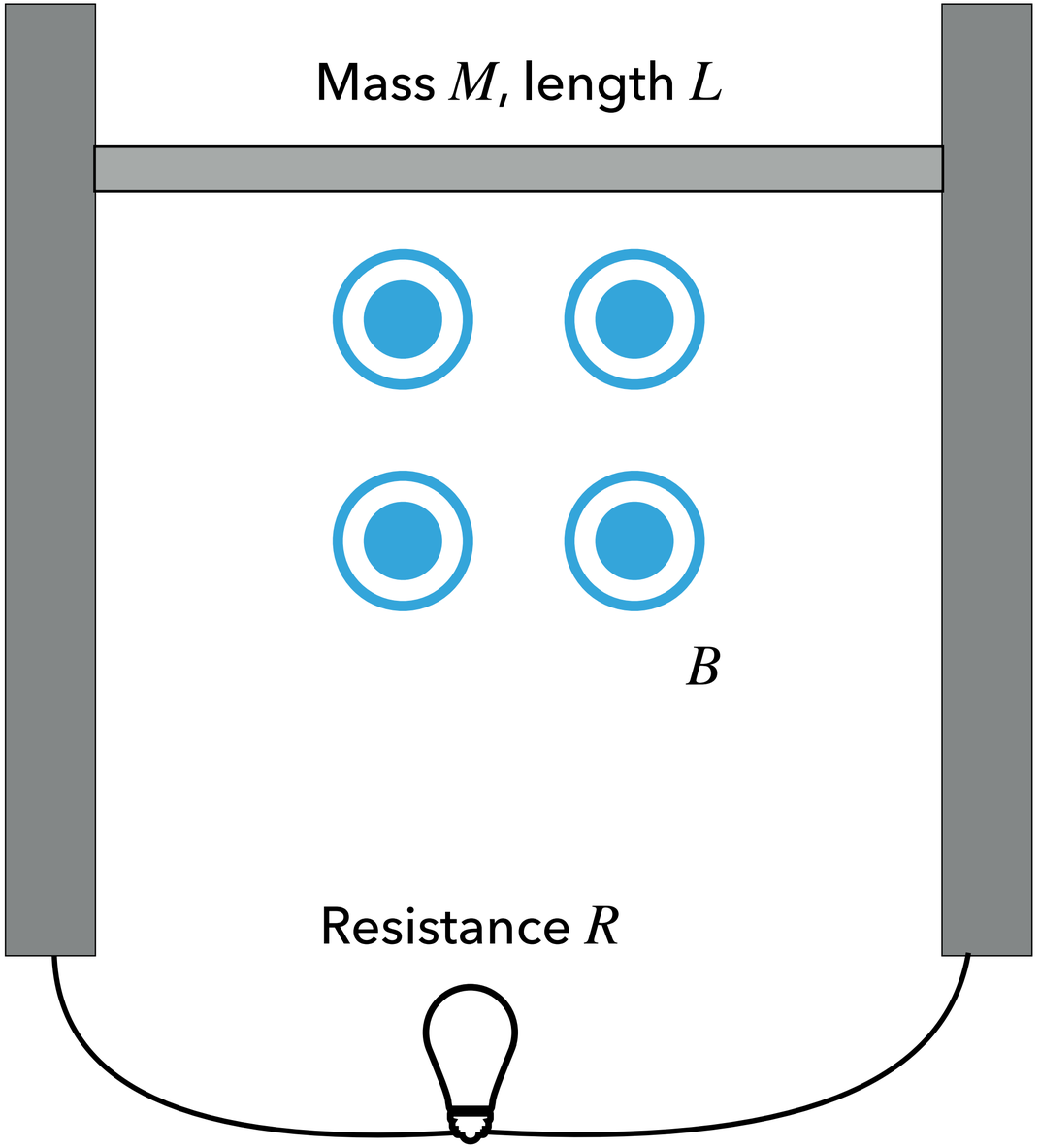


Bar accelerates until forces cancel

ENERGY ANALYSIS

- Magnetic field is not doing work, it is simply *redirecting* the mechanical work being done on the system into electrical work consumed by the lightbulb

EXAMPLE



EXAMPLE

- What is the maximum power available to the bulb?