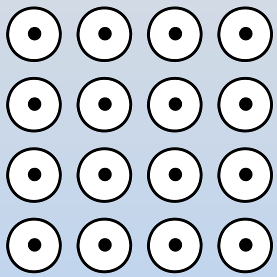
Module 17:
Magnetic Forces

Module 17: Outline

Magnetic Forces on Charges

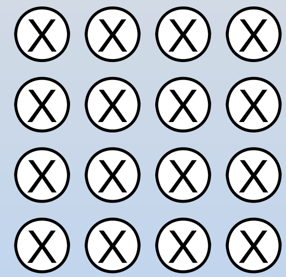
Recall:
Cross Product

Notation Demonstration



OUT of page

“Arrow Head”



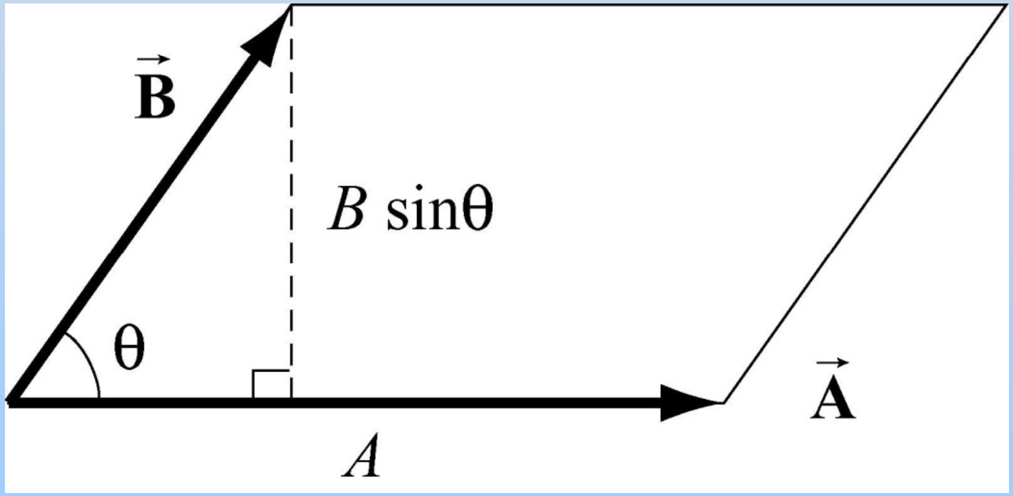
INTO page

“Arrow Tail”

Cross Product: Magnitude

Computing magnitude of cross product A x B:

$$\vec{\mathbf{C}} = \vec{\mathbf{A}} \mathrm{x} \vec{\mathbf{B}} \qquad \left|\vec{\mathbf{C}}\right| = \left|\vec{\mathbf{A}}\right|\left|\vec{\mathbf{B}}\right| \sin\theta$$



$|\vec{\mathbf{C}}|$**:** area of parallelogram

Cross Product: Direction

Right Hand Rule #1:

$$\vec{\mathbf{C}} = \vec{\mathbf{A}} \mathrm{x} \vec{\mathbf{B}}$$

For this method, keep your hand flat!

1) Put Thumb (of right hand) along **A**
2) Rotate hand so fingers point along **B**
3) Palm will point along **C**

Cross Product: Signs

$$\hat{\mathbf{i}} \times \hat{\mathbf{j}} = \hat{\mathbf{k}} \qquad \hat{\mathbf{j}} \times \hat{\mathbf{i}} = -\hat{\mathbf{k}}$$

$$\hat{\mathbf{j}} \times \hat{\mathbf{k}} = \hat{\mathbf{i}} \qquad \hat{\mathbf{k}} \times \hat{\mathbf{j}} = -\hat{\mathbf{i}}$$

$$\hat{\mathbf{k}} \times \hat{\mathbf{i}} = \hat{\mathbf{j}} \qquad \hat{\mathbf{i}} \times \hat{\mathbf{k}} = -\hat{\mathbf{j}}$$

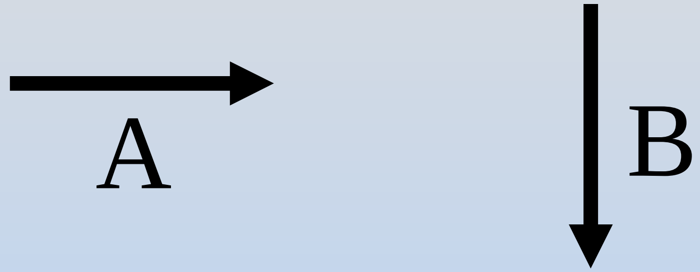
Cross Product is Cyclic (left column)

Reversing **A** & **B** changes sign (right column)

Concept Question Questions: Right Hand Rule

Concept Question: Cross Product

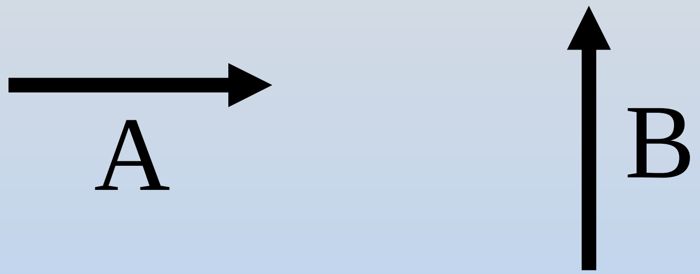
What is the direction of A x B given the following two vectors?



1. up
2. down
3. left
4. right
5. into page
6. out of page
7. Cross product is zero (so no direction)

Concept Question: Cross Product

What is the direction of A x B given the following two vectors?



1. up
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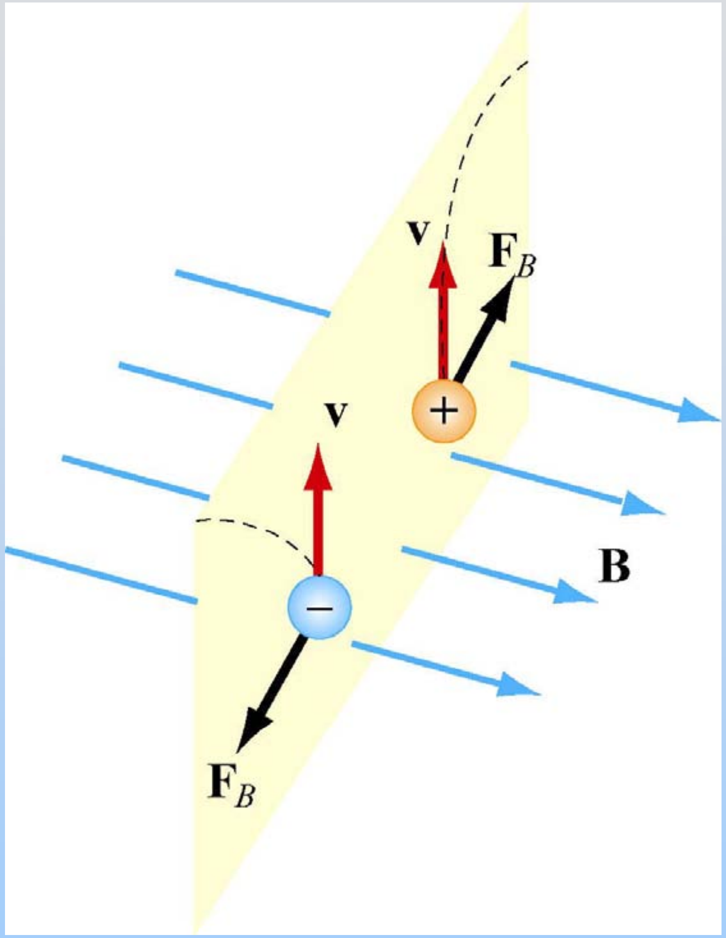
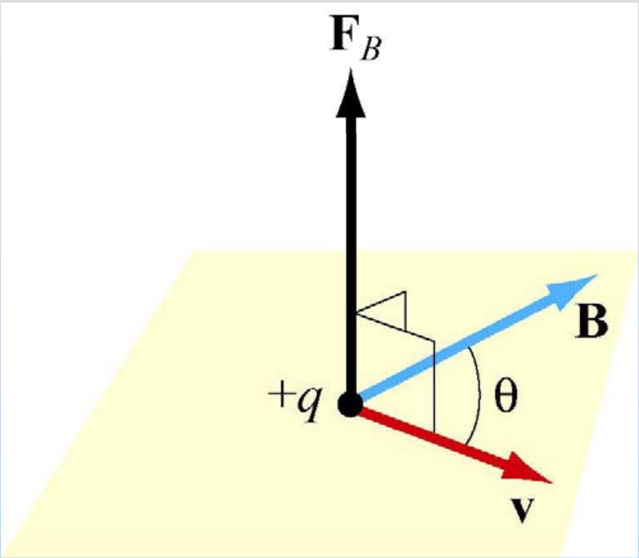
Moving Charges Feel Magnetic Force



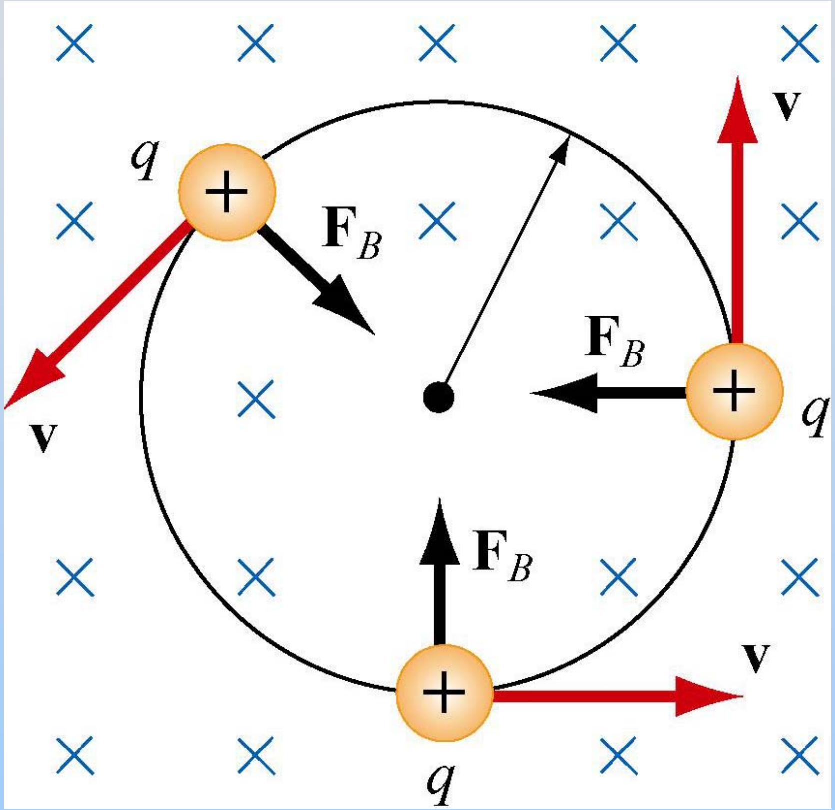


$$\vec{\mathbf{F}}_B = q\,\vec{\mathbf{v}} \times \vec{\mathbf{B}}$$

Magnetic force perpendicular both to:
Velocity **v** of charge and magnetic field **B**

What Kind of Motion in Uniform B Field?

Problem: Cyclotron Motion



A charged particle with charge q is moving with speed v in a uniform magnetic field B pointing into the figure.

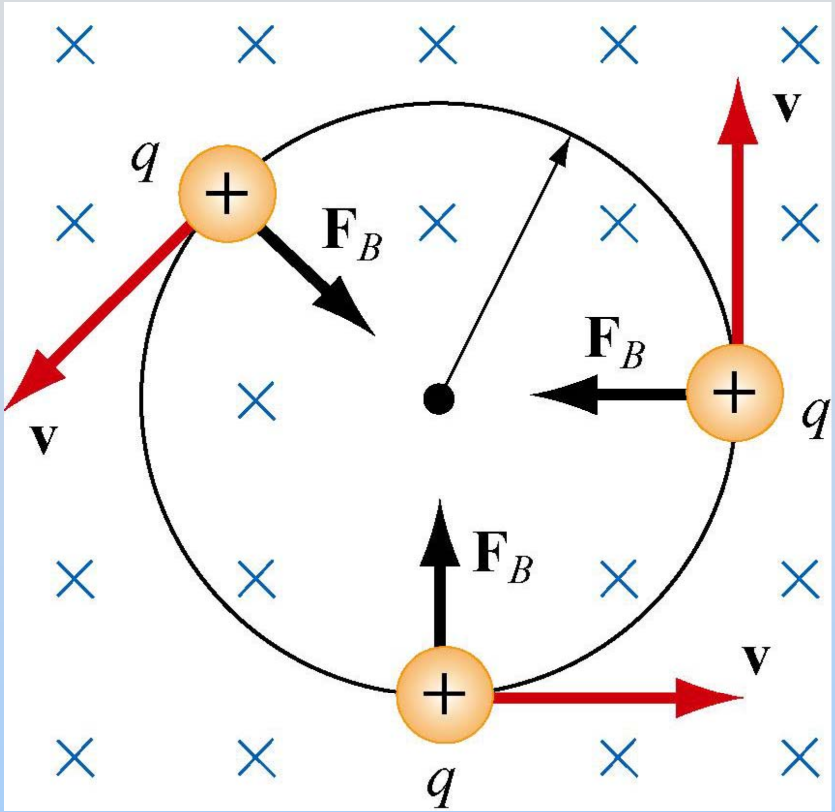
Find

(1) r : radius of the circle

(2) T : period of the motion

(3) ω: cyclotron frequency

Cyclotron Motion: Solution



(1) r : radius of the circle

$$qvB = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{qB}$$

(2) T : period of the motion

$$T = \frac{2\pi r}{v} = \frac{2\pi m}{qB}$$

(3) ω: cyclotron frequency

$$\boxed{\omega = 2\pi f = \frac{v}{r} = \frac{qB}{m}}$$

Putting it Together: Lorentz Force

Charges Feel…

$$\vec{\mathbf{F}}_E = q\vec{\mathbf{E}}$$

Electric Fields

$$\vec{\mathbf{F}}_B = q\,\vec{\mathbf{v}}\times\vec{\mathbf{B}}$$

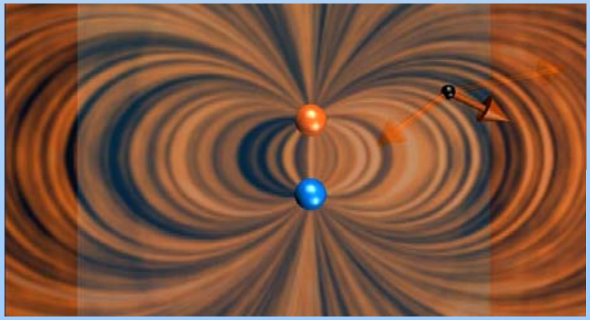
Magnetic Fields

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

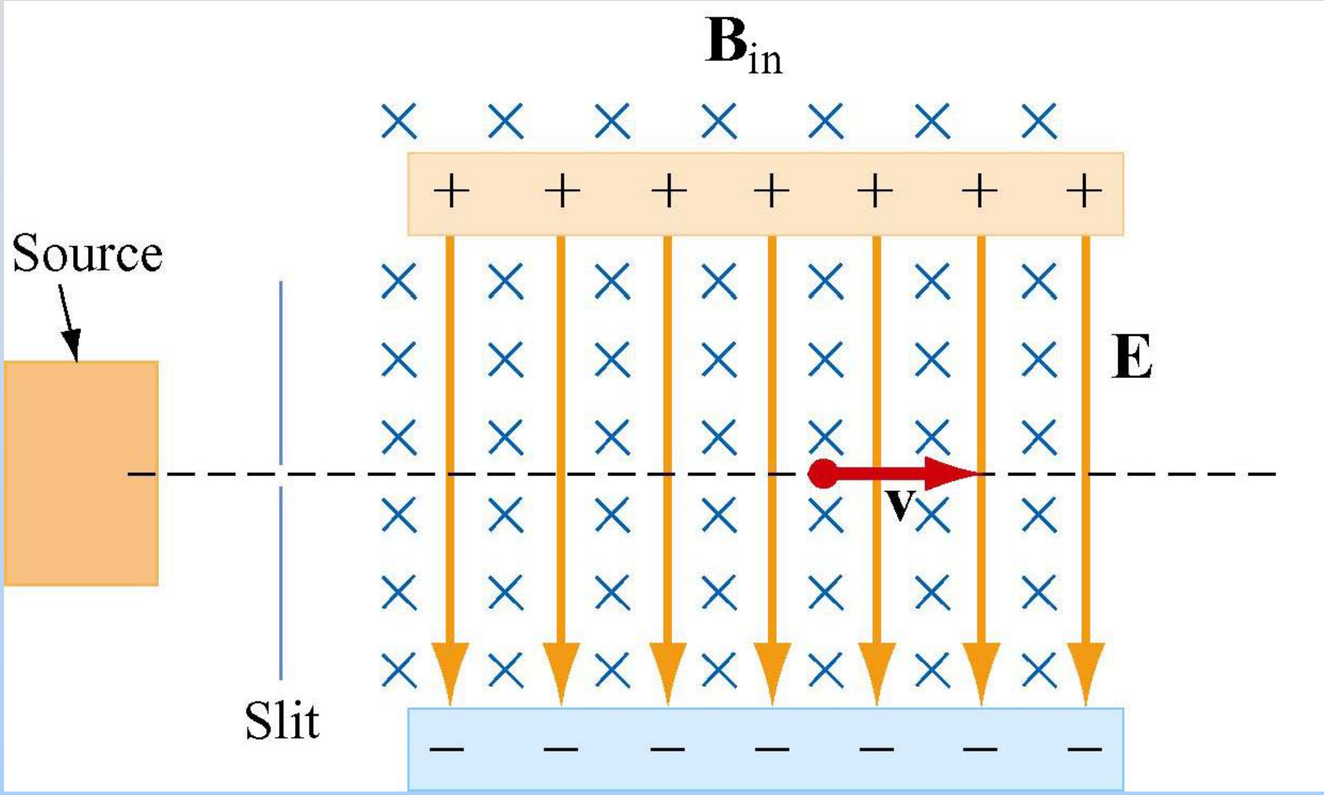
This is the final word on the force on a charge

Fields: Grav., Electric, Magnetic

	Mass m	Charge q (±)	No Magnetic Monopoles!
Create:	$\vec{\mathbf{g}} = -G\dfrac{m}{r^2}\hat{\mathbf{r}}$	$\vec{\mathbf{E}} = k_e \dfrac{q}{r^2}\hat{\mathbf{r}}$	
Feel:	$\vec{\mathbf{F}}_g = m\vec{\mathbf{g}}$	$\vec{\mathbf{F}}_E = q\vec{\mathbf{E}}$	

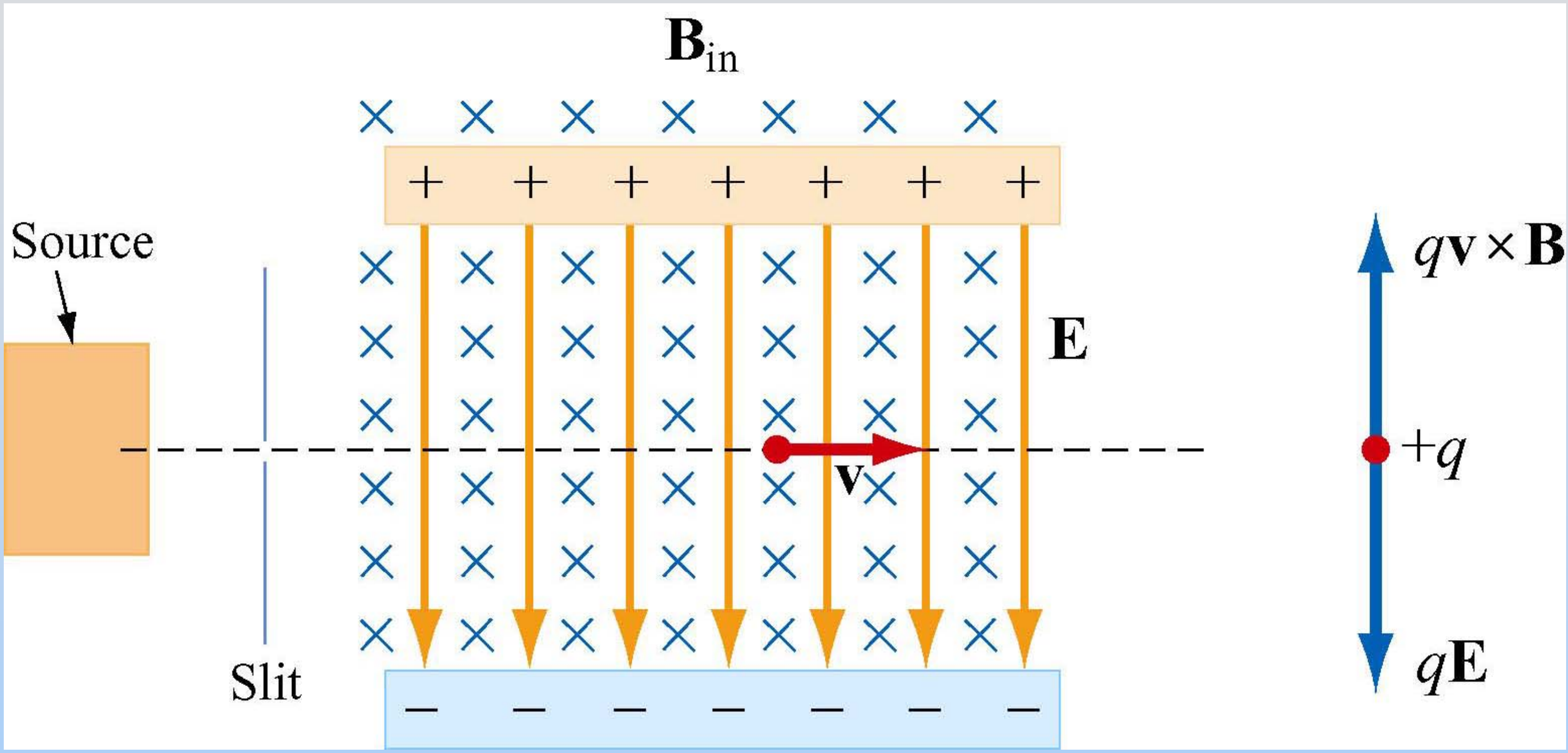
		Dipole **p**	Dipole μ
Create:		$\vec{\mathbf{E}} \rightarrow$ 	$\leftarrow \vec{\mathbf{B}}$
Feel:		$\vec{\boldsymbol{\tau}} = \vec{\mathbf{p}} \times \vec{\mathbf{E}}$	$\vec{\boldsymbol{\tau}} = \vec{\boldsymbol{\mu}} \times \vec{\mathbf{B}}$

Application: Velocity Selector



What happens here?

Velocity Selector



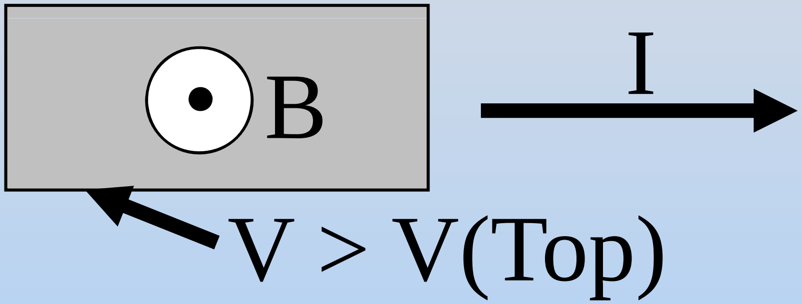
Particle moves in a straight line when

$$\vec{\mathbf{F}}_{net} - q(\vec{\mathbf{E}} + \vec{\mathbf{v}} \times \vec{\mathbf{B}}) - 0 \quad = \quad v - \frac{E}{B}$$

Concept Question Question: Hall Effect

Concept Question: Hall Effect

A conducting slab has current to the right. A B field is applied out of the page. Due to magnetic forces on the charge carriers, the bottom of the slab is at a higher electric potential than the top of the slab.



On the basis of **this** experiment, the sign of the charge carriers carrying the current in the slab is:

1. Positive
2. Negative
3. Cannot be determined
4. I don’t know