Physics 1502Q:
8.1 Introduction to Magnetism
Magnetic Force on Particles

Announcements & Reminders

- Complete prelab **before lab**
- Homework is due **Monday at 11:59pm**
- Next Reading Assignment is due **Sunday at 11:59pm**

Preview of this week and next two weeks

Su	M	T	W	Th	F	Sa
6 Reading Assignment Due 11:59 PM	7 HW Due 11:59 PM	8 Intro to Magnetism/ Magnetic Force I	9	10 Magnetic Force II	11 Lab 6: Kirchhoff's Laws Pre-lab 6 Due before lab	12
13	14	15 SPRING RECESS	16	17	18	19
20 Reading Assignment Due 11:59 PM	21 HW Due 11:59 PM	22 Magnetic Torque/Biot-Savart Law	23	24 Biot-Savart Law II + Exam 2 Review	25 MIDTERM EXAM #2 4 PM NO LAB/NO PRELAB	26

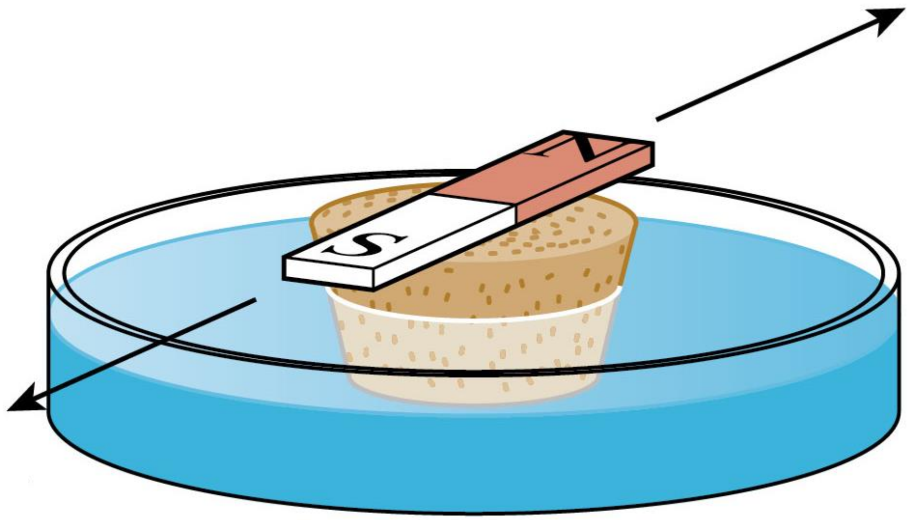
Magnetism

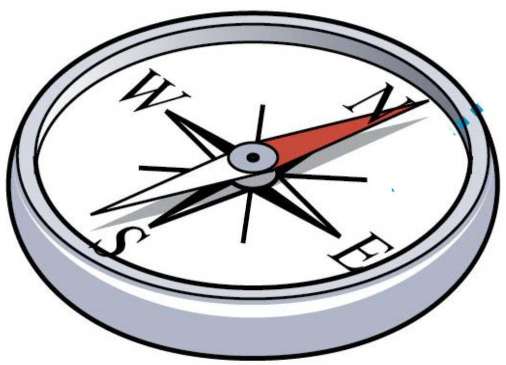
LEARNING GOALS

By the end of this unit, you should be able to:

- Explain qualitatively magnetism as a force of interaction between moving charges
- Understand qualitatively what originates a magnetic field
- Model quantitatively how charged particles respond to magnetic fields

Experiments with Magnetism - 1





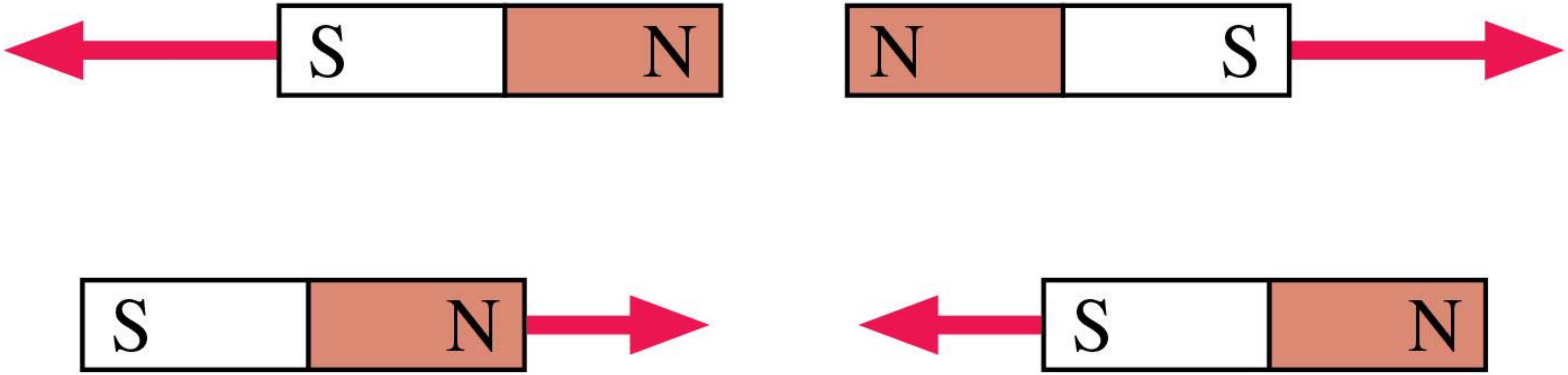
- Tape a bar magnet to a piece of cork and allow it to float in a dish of water.
- It always turns to align itself in an approximate north-south direction.

- The end of a magnet that points north is called the *north-seeking pole*, or simply the **north pole**.
- The end of a magnet that points south is called the **south pole**.

Experiments with Magnetism - 2

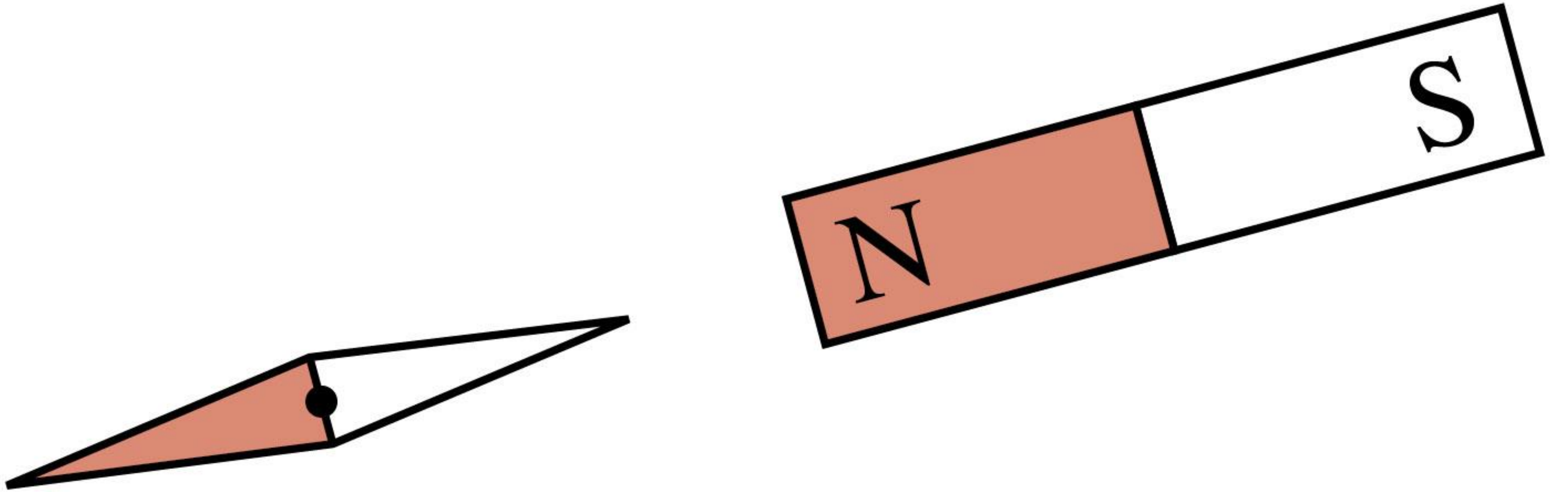
- If the north pole of one magnet is brought near the north pole of another magnet, they repel each other.

- Two south poles also repel each other, but the north pole of one magnet exerts an attractive force on the south pole of another magnet.



Experiments with Magnetism - 3

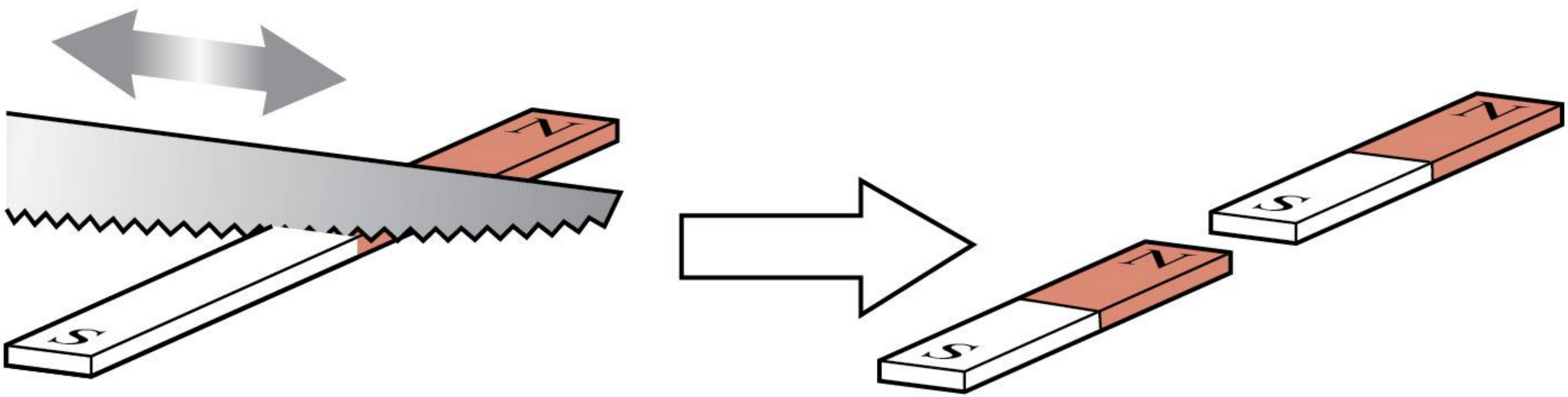
- The north pole of a bar magnet attracts one end of a compass needle and repels the other.
- Apparently, the compass needle itself is a little bar magnet with a north pole and a south pole.



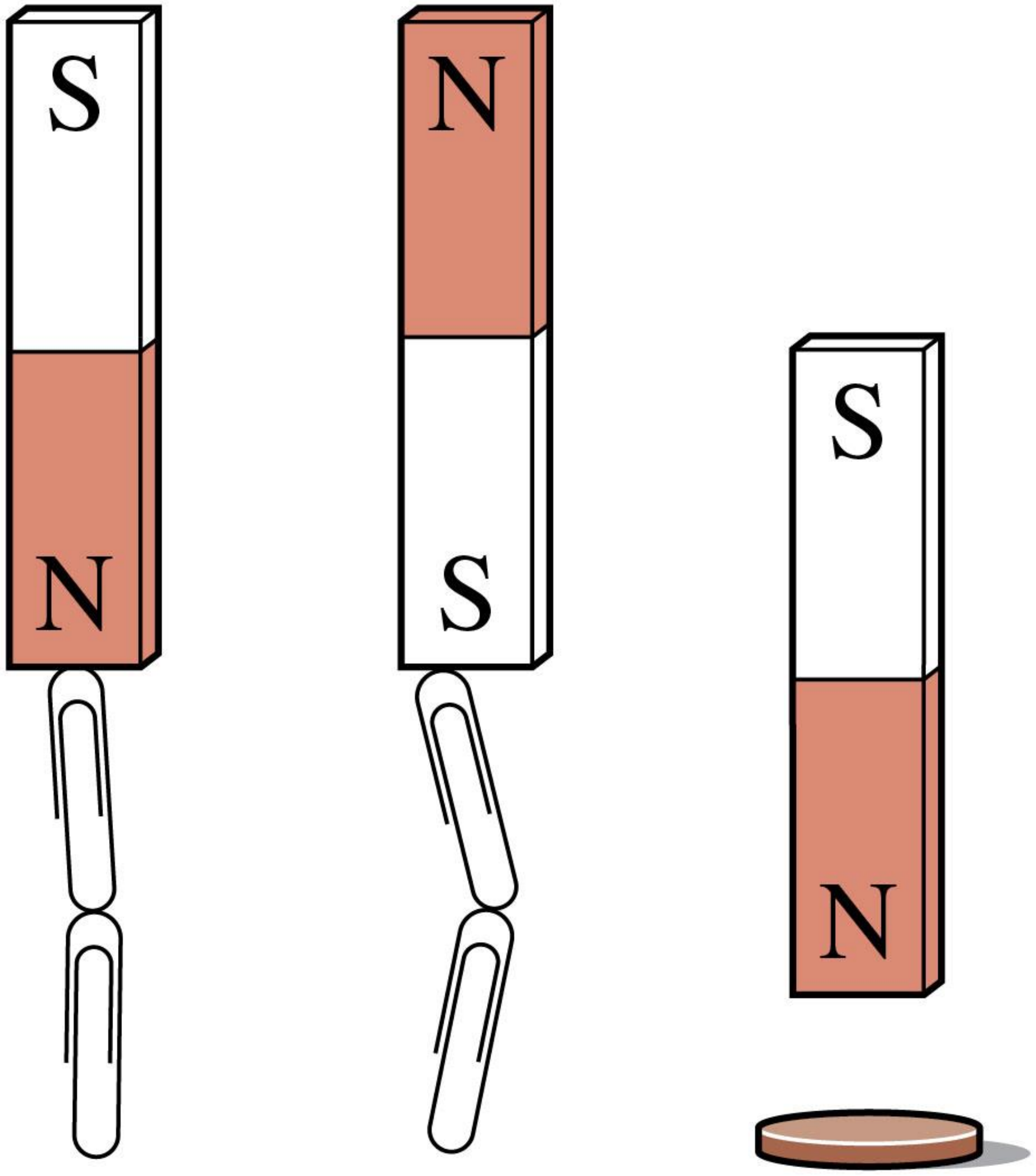
Experiments with Magnetism - 4

- Cutting a bar magnet in half produces two weaker but still complete magnets, each with a north pole and a south pole.

- No matter how small the magnets are cut, even down to microscopic sizes, each piece remains a complete magnet with two poles.

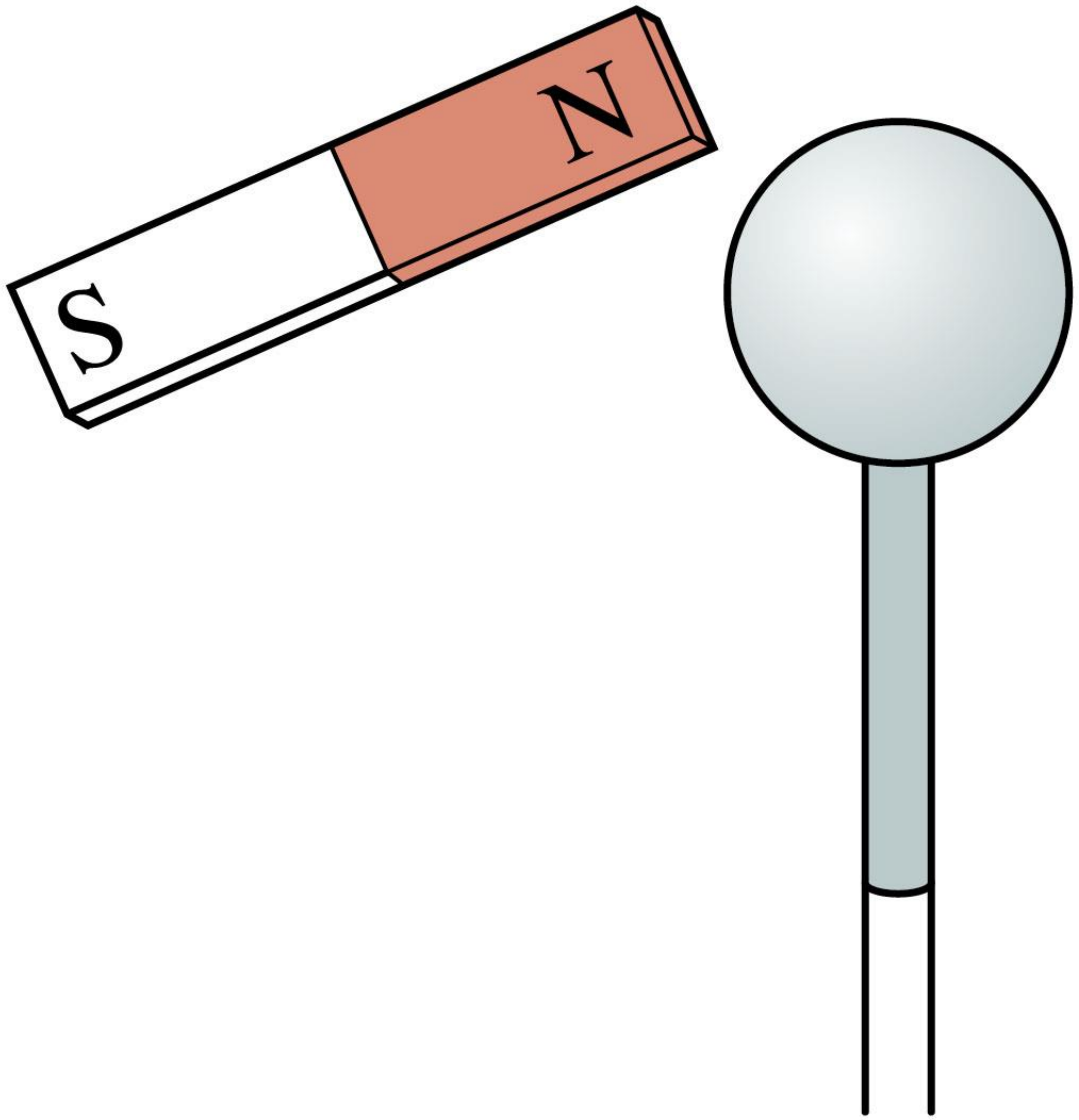


Experiments with Magnetism - 5



- Magnets can pick up some objects, such as paper clips, but not all.
- If an object is attracted to one end of a magnet, it is also attracted to the other end.
- Most materials, including copper (a penny), aluminum, glass, and plastic, experience no force from a magnet.

Experiments with Magnetism - 6



- A magnet does not affect an electroscope.
- A charged rod exerts a weak *attractive* force on *both* ends of a magnet.
- However, the force is the same as the force on a metal bar that isn't a magnet, so it is simply a polarization force like the ones we studied in the beginning of the course.

- Other than polarization forces, charges have *no effects* on magnets.

Conclusions from these Experiments with Magnetism

1. Magnetism is ***<u>not</u>*** the same as electricity.

2. Magnetism is associated with forces at a distance.

3. All magnets have two poles, called north and south poles. Two like poles exert repulsive forces on each other; two opposite poles attract.
   – There are no magnetic monopoles

4. Materials that are attracted to a magnet are known as magnetic materials (ferromagnetic, paramagnetic). <u>The most common magnetic material is iron.</u>
   – Good magnetic materials are not necessarily good conductors of electricity and vice versa.

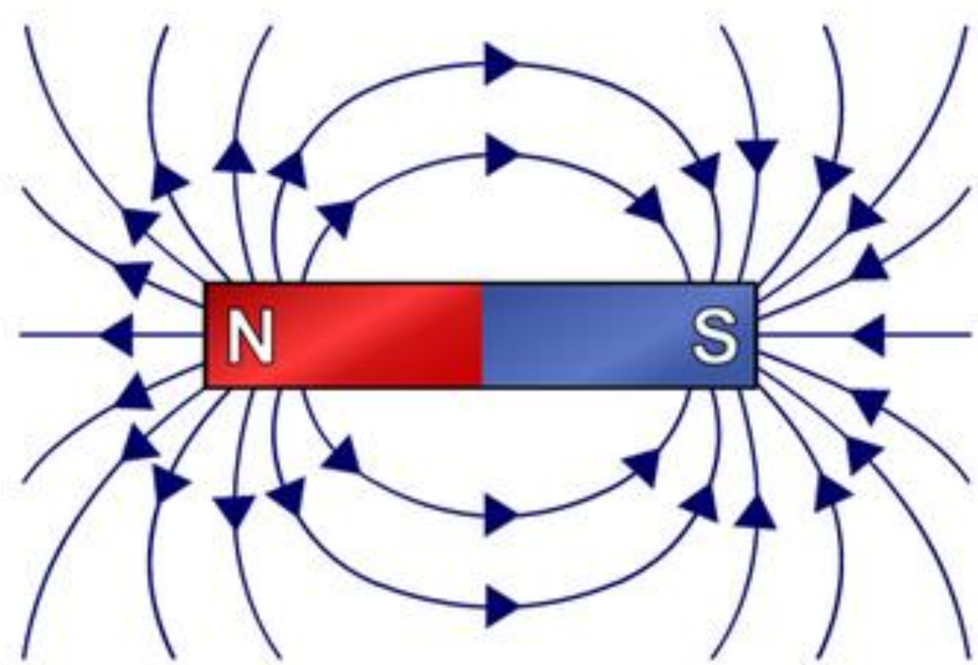
Magnetic Fields

Magnets have a magnetic field associated with them.

- Symbol, **B**
- Units: Tesla [T]
- Magnetic Field is a VECTOR
- Direction goes out of the North pole and into the South pole.

A Few Typical B Values

- Fridge Magnet = 0.01 T
- MRI = 1.5T
- Conventional laboratory magnets = 2.5 T
- Superconducting magnets = 30 T



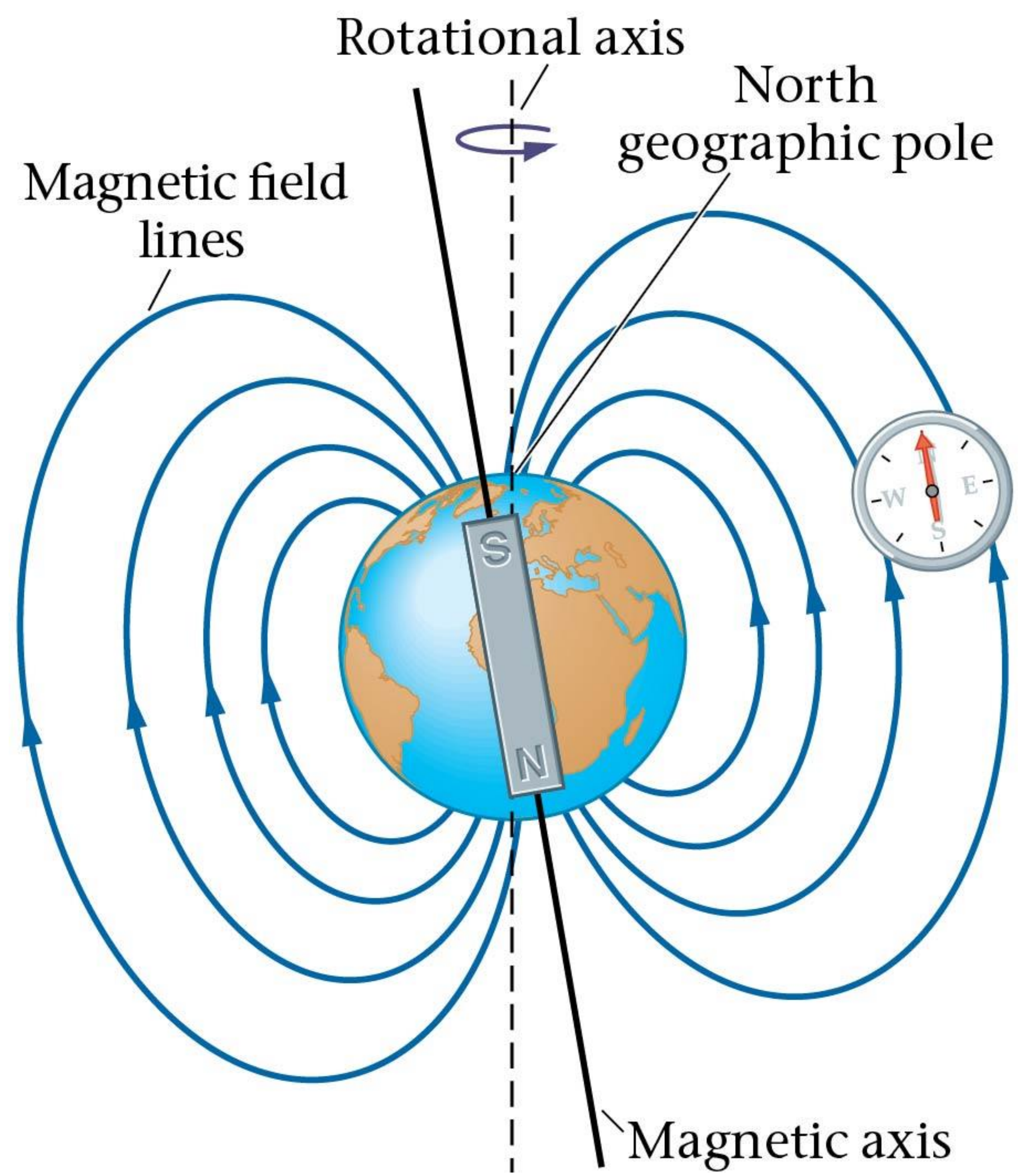
Magnetic Earth

The Earth's magnetic field resembles that achieved by burying a huge bar magnet deep in the Earth's interior

The Earth's geographic north pole corresponds to a magnetic south pole

The Earth's geographic south pole corresponds to a magnetic north pole

Earth's magnetic field = 5×10^{-5} T



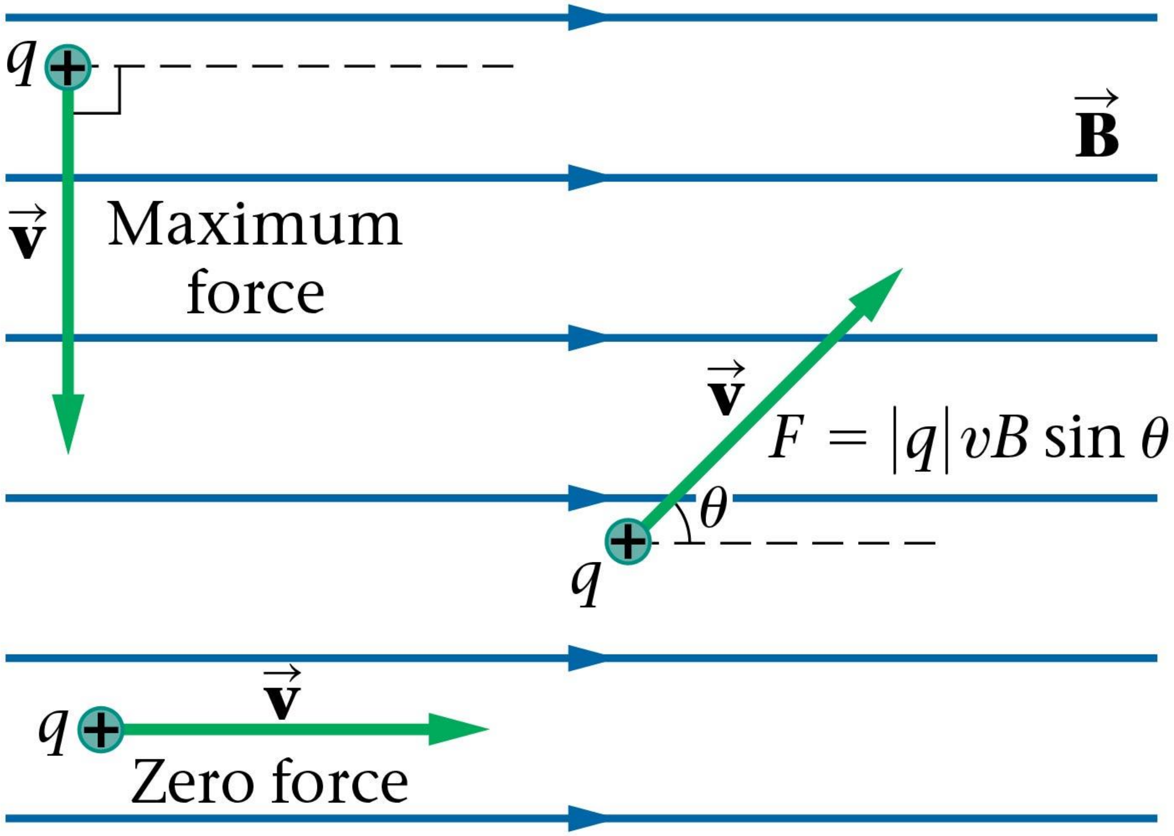
Magnetic Field Line Demo

Motion of Charge Particles in Magnetic Fields

- When a charged particle moves through a magnetic field is experiences a force:

$$\vec{F} = q\vec{v} \times \vec{B}$$

$$F_B = |q| v B \sin\phi$$



- The force, F_B, acting on a charged particle, q, moving with velocity, v, through a magnetic field, B, is *always* perpendicular to v and B.

Cross Product Calculation Review

Method 1: Determinants

$$\vec{A} \times \vec{B} = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

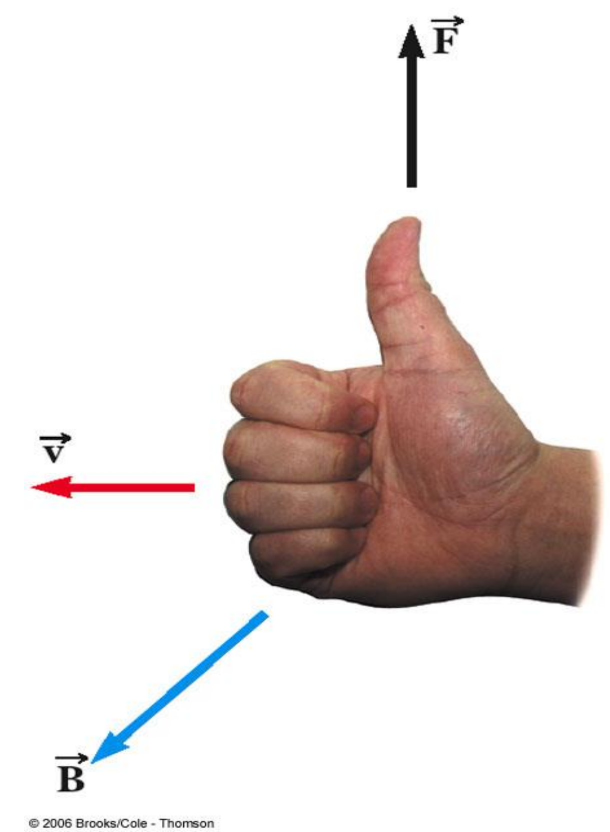
$$\vec{A} \times \vec{B} = (A_y B_z - A_z B_y)\hat{\imath} - (A_x B_z - A_z B_x)\hat{\jmath} + (A_x B_y - A_y B_x)\hat{k}$$

Method 2: Distributive Method

$$\vec{A} \times \vec{B} = (A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}) \times (B_x\hat{\imath} + B_y\hat{\jmath} + B_z\hat{k})$$

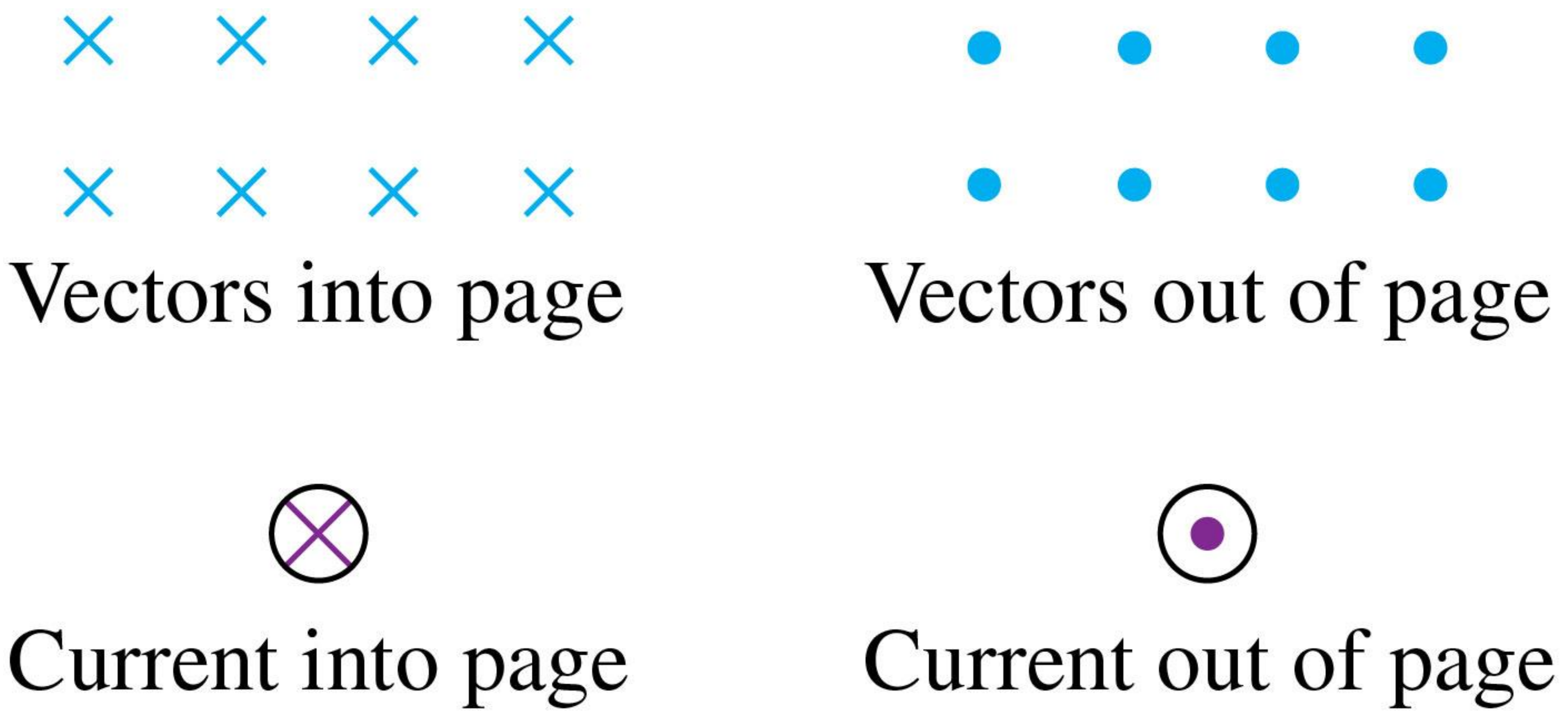
$$\mathbf{i} \times \mathbf{i} = \mathbf{j} \times \mathbf{j} = \mathbf{k} \times \mathbf{k} = \mathbf{0}$$

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



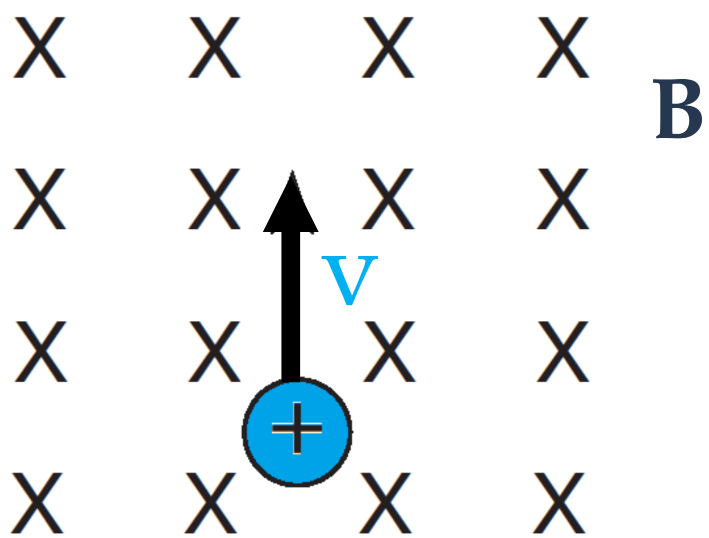
Notation for Vectors and Currents Perpendicular to the Page

- Magnetism requires a three-dimensional perspective, but two-dimensional figures are easier to draw.
- We will use the following notation:



Question: Magnetic Force Direction

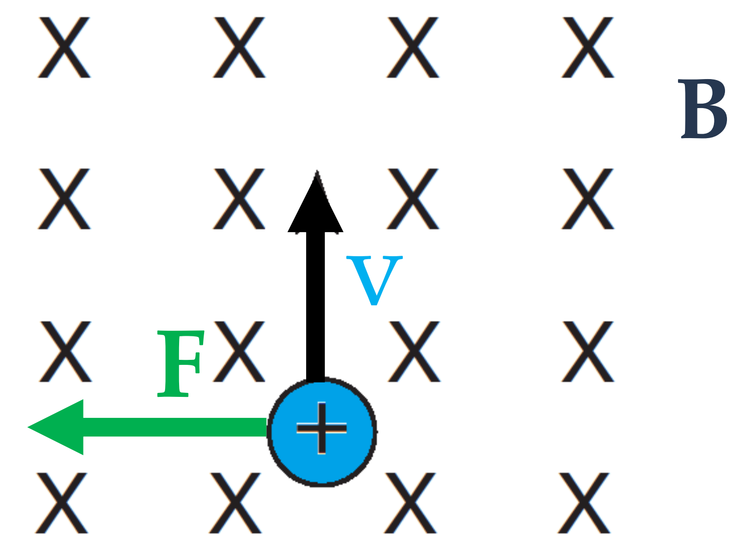
A positive charge enters a uniform magnetic field as shown. What is the direction of the magnetic force?



A. Out of the page
B. Into the page
C. Downward
D. To the right
E. To the left

Question: Magnetic Force Direction Answer

A positive charge enters a uniform magnetic field as shown. What is the direction of the magnetic force?



A. Out of the page
B. Into the page
C. Downward
D. To the right
E. To the left

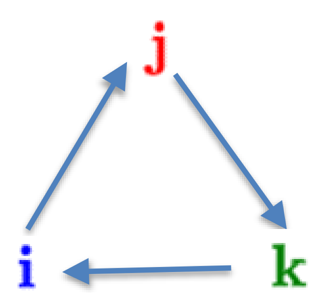
Using the right-hand rule, the magnetic force is directed to the left. Remember that the magnetic force must be perpendicular to BOTH the *B* field and the velocity.

Example: Magnetic Force

An electron has a velocity of $6.0 \times 106\ \mathrm{m}/s$ in the positive x-direction at a point where the magnetic field has the components $B_x = 0\ \mathrm{T}$, $B_y = 1.5\ \mathrm{T}$, and $B_z = 2.0\ \mathrm{T}$. What is the force due to the magnetic field acting on the electron at this point?

$$\vec{v} = 6.0 \times 10^6\ \hat{i}\ m/s$$

$$\vec{B} = (1.5\hat{j} + 2.0\hat{k})\ T$$



$$\vec{F} = q\vec{v} \times \vec{B}$$

$$= (-e)\left[v\hat{i} \times (1.5\hat{j} + 2.0\hat{k})\right]\mathrm{T}$$

$$= -ev\left[1.5(\hat{i} \times \hat{j}) + 2.0(\hat{i} \times \hat{k})\right]\mathrm{T}$$

$$= -ev\left[1.5\hat{k} + 2.0(-\hat{j})\right]\mathrm{T}$$

$$\vec{F} = (1.9\hat{j} - 1.4\hat{k}) \times 10^{-12} N$$

Motion of Charges in a Perpendicular B Field

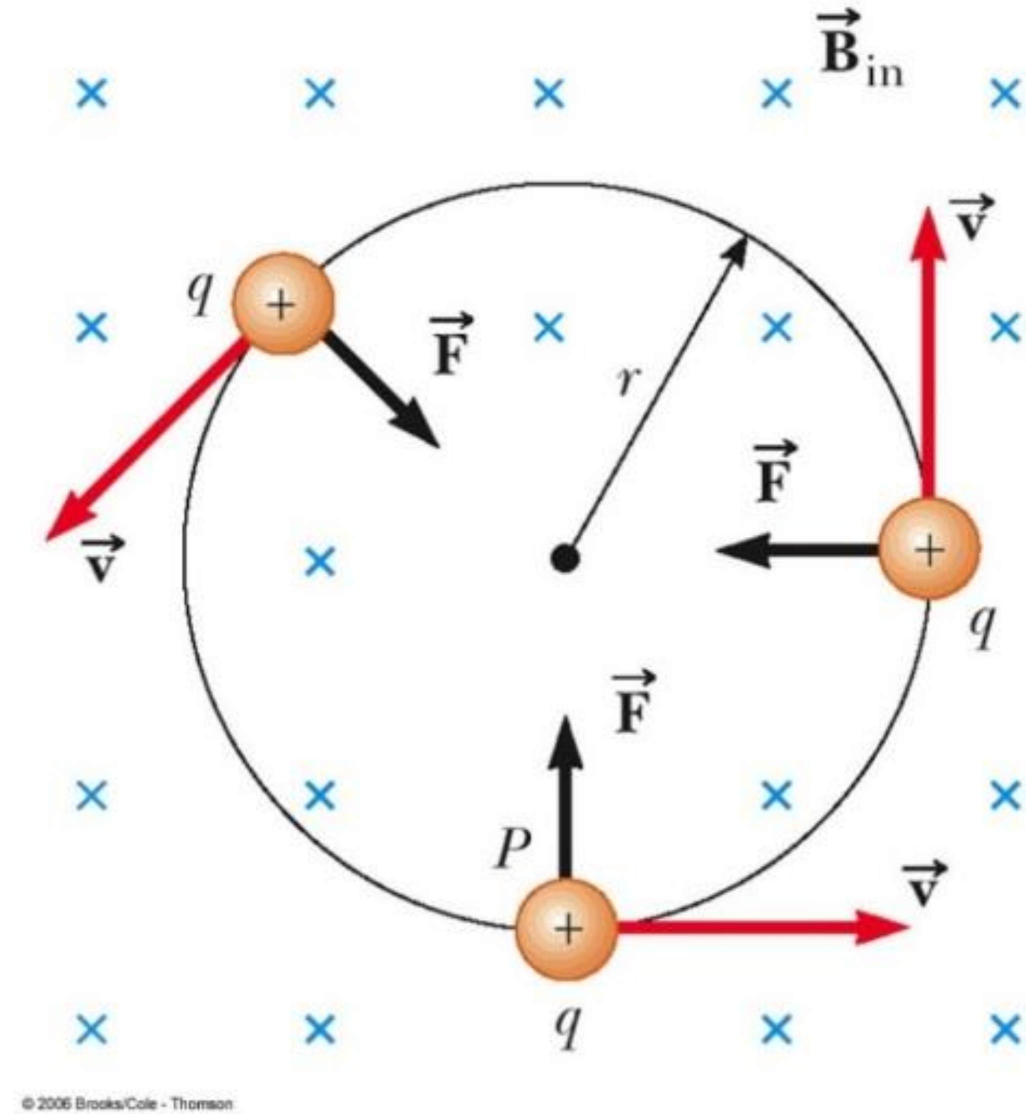
- Force is perpendicular to *v*
  - Speed does not change
  - Uniform Circular Motion

- Solve for R:

$$F_B = |q| v B \sin\phi \quad \Rightarrow F = qvB$$

$$F = F_c = \frac{mv^2}{R}$$

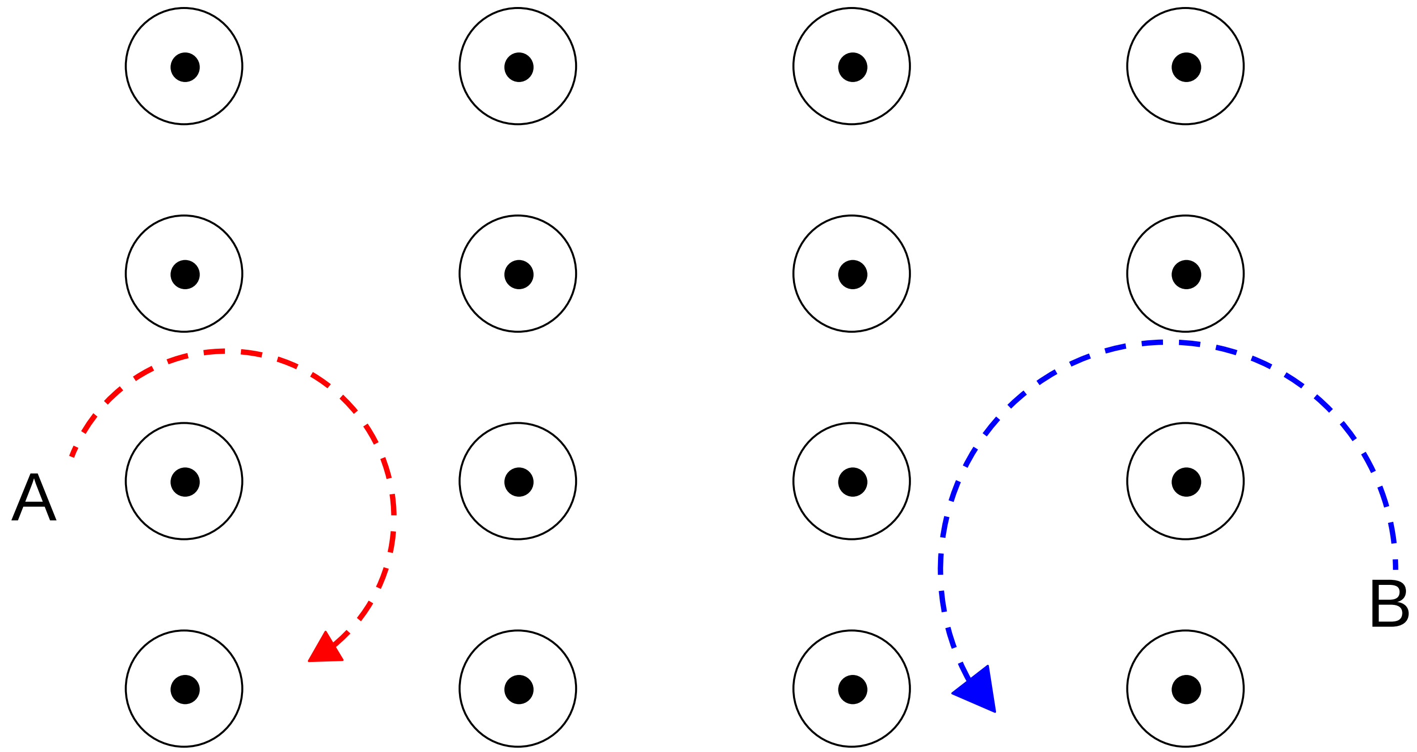
$$|q| vB = m\frac{v^2}{R} \longrightarrow \boxed{R = \frac{mv}{|q|B}}$$



- Particle's speed doesn't change.
- Particle's direction changes.

Question: Motion of Charges

- The figure at right shows the paths of two charged particles (A and B) in a uniform magnetic field. Which particle is negatively charged?



A. A
B. B
C. Both
D. Neither
E. There’s not enough information to tell.

Question: Motion of Charges Answer

- The figure at right shows the paths of two charged particles (A and B) in a uniform magnetic field. Which particle is negatively charged?

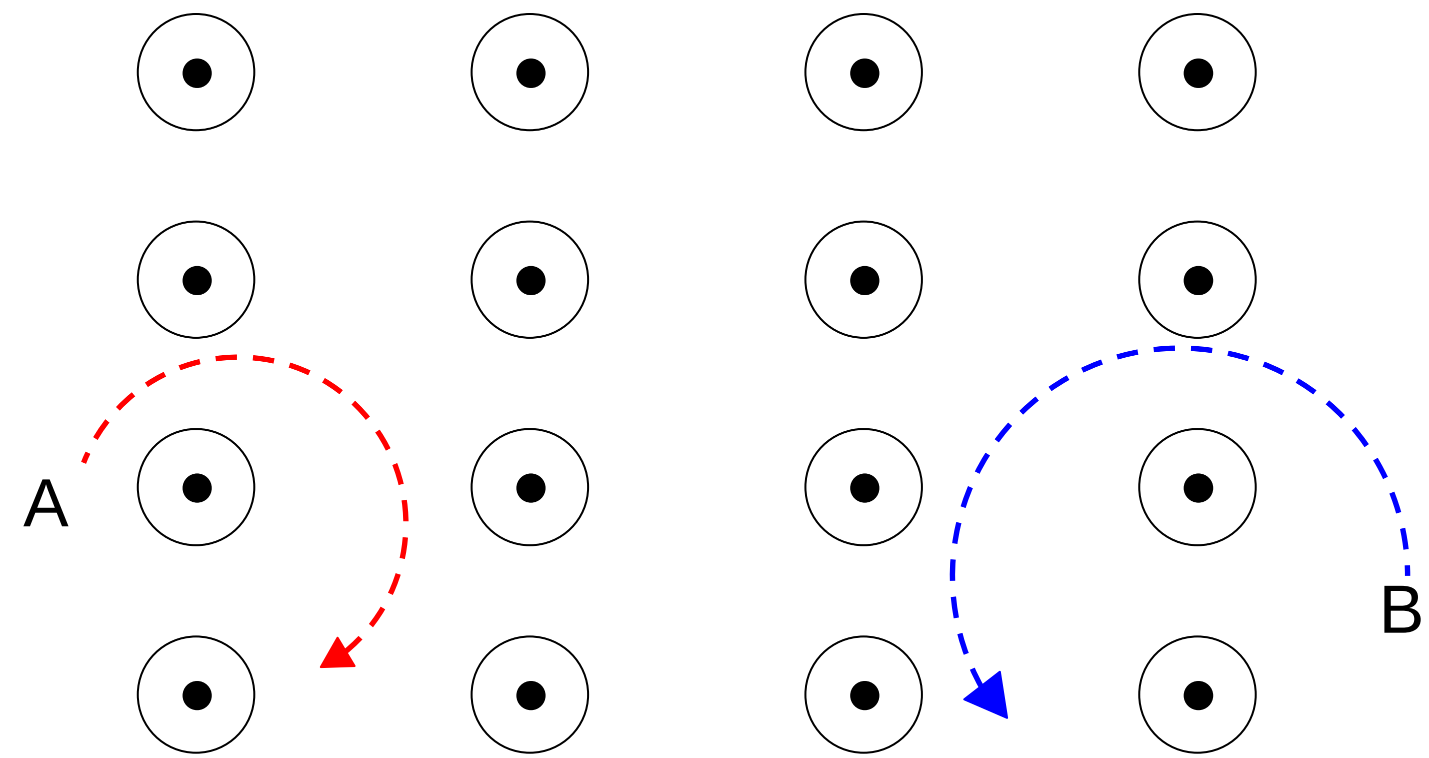
A. A

$\boxed{\text{B. B}}$

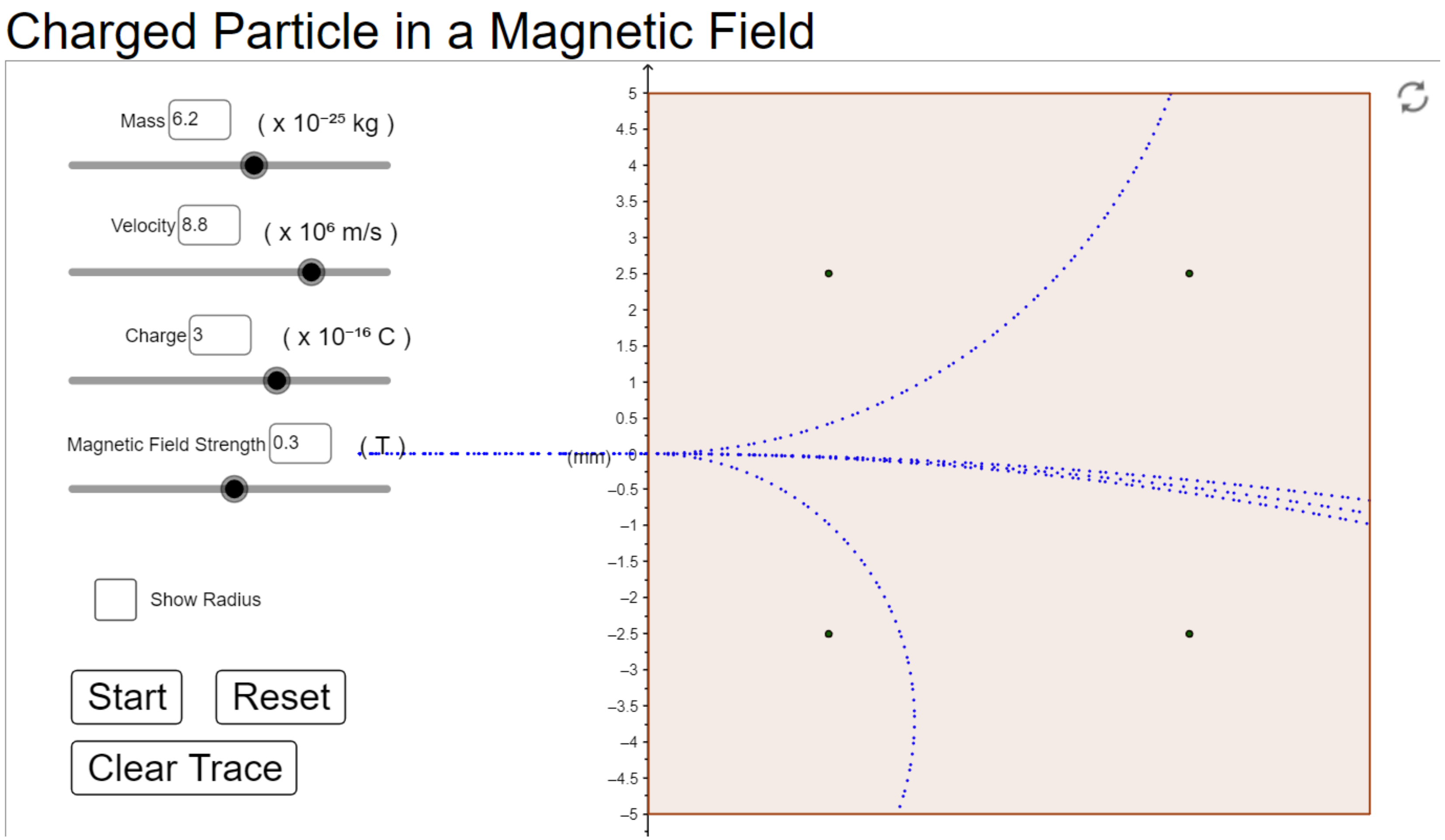
C. Both

D. Neither

E. There's not enough information to tell.



Force on Charges in Magnetic Fields: Simulation



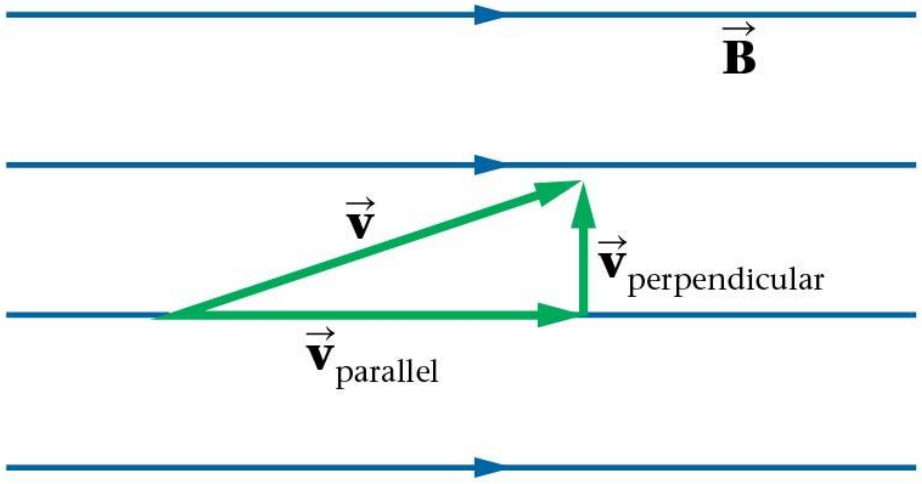
https://www.ophysics.com/em7.html

Questions:

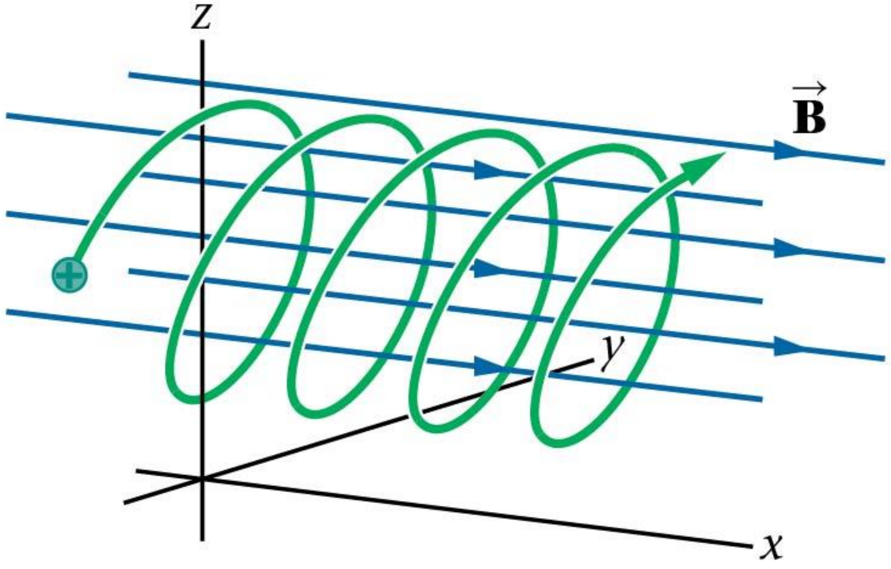
1. What effect does changing the <u>sign of the particle</u> have?
2. What effect does changing the <u>velocity of the particle</u> have?
3. What effect does changing the <u>mass of the particle</u> have?
4. What effect does changing the <u>charge of the particle</u> have?

Motion of Charged Particles in a B Field

If a particle's velocity makes an angle with the magnetic field, the component of the velocity along the magnetic field will not change; a particle with an initial velocity at an angle to the field will move in a helical path.



(a)



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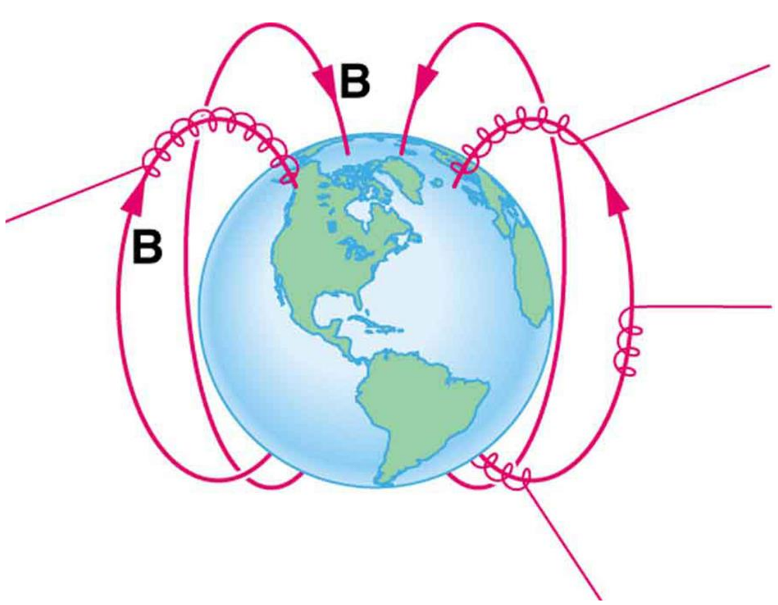
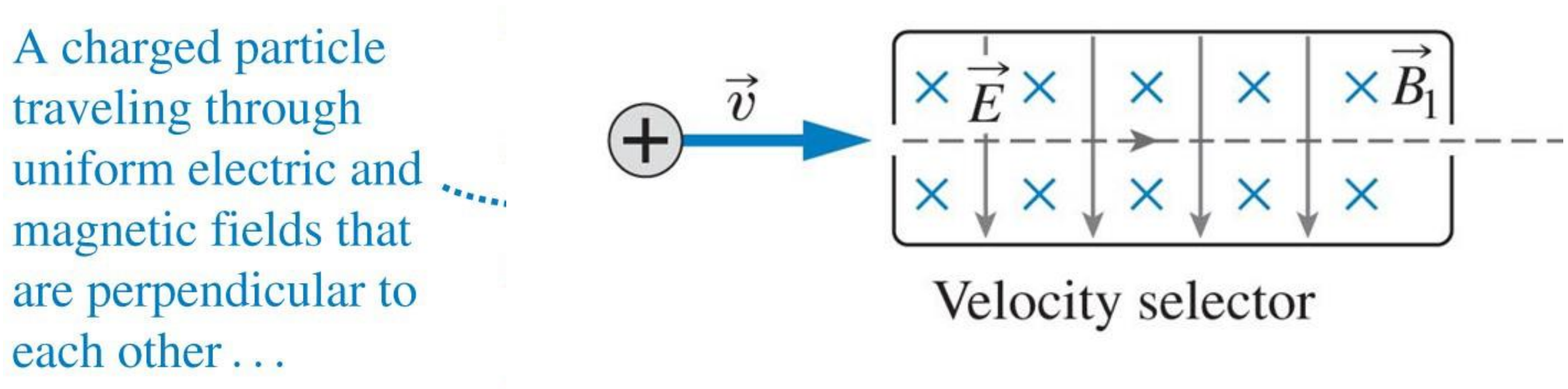


Applications: Velocity Selector



$$F = qE$$ points down

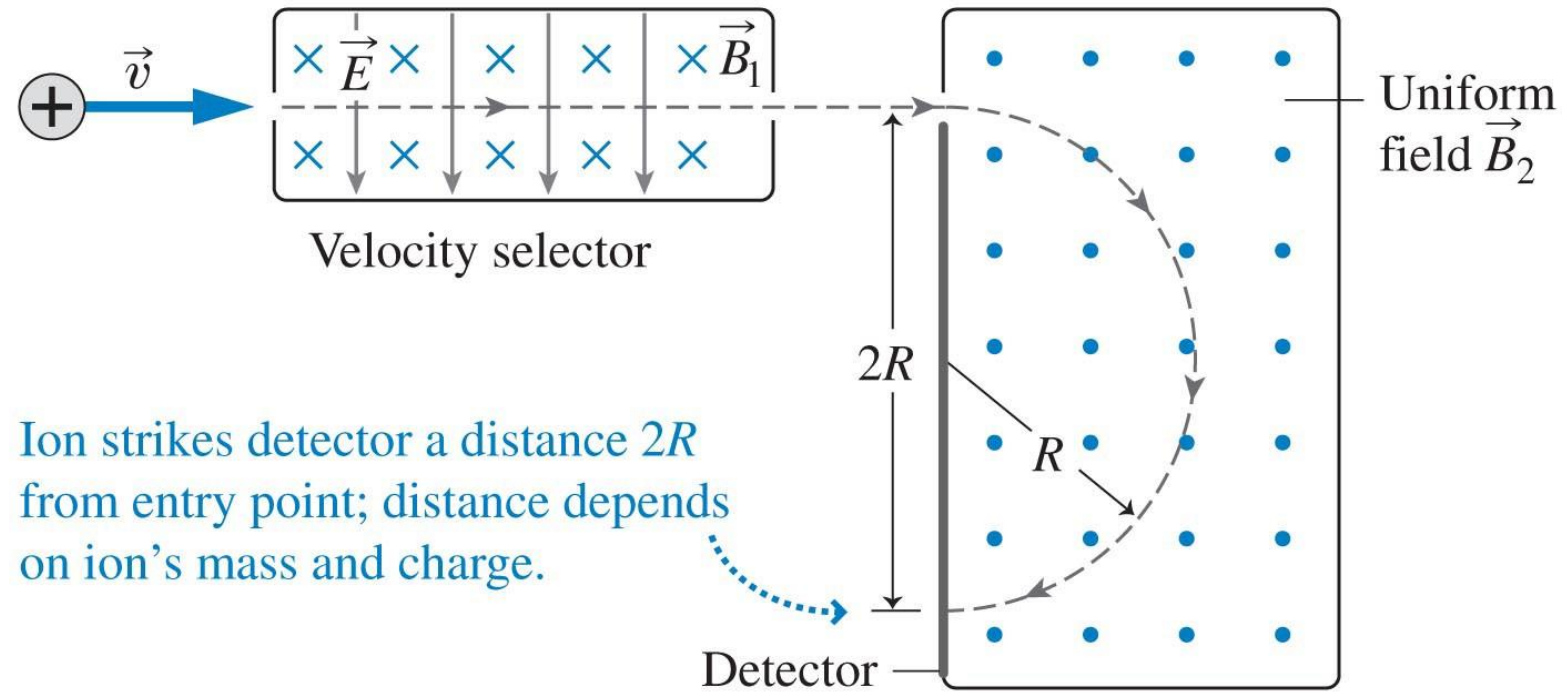
$$F = qvB$$ points up

$\Rightarrow \; F_{\mathrm{NET}} = 0$ if $\boxed{v = \dfrac{E}{B}}$

- Only particles with the precise speed $v = E/B$ pass through the chamber undeflected.
- Particles with different speeds get deflected up or down due to the imbalance of the magnetic and electric forces acting on them.

Applications: Mass Spectrometer

$$\boxed{R = \frac{mv}{|q|B_2} \qquad F = qvB_1 = qE}$$



Velocity selector: $v = \dfrac{E}{B_1}$

Detector: Þ $\boxed{R = \dfrac{mE}{|q|B_1B_2}}$

Charge-to-mass ratio in a mass spectrometer $\boxed{\dfrac{|q|}{m} = \dfrac{E}{B_1B_2R}}$

Only particles with the speed $v = E/B_1$ pass through the first chamber (the velocity selector).

In the second chamber, different particles traveling with the same speed v are separated according to their charge-to-mass ratio, which determines the radius of the arc traveled.

PRACTICE PROBLEMS