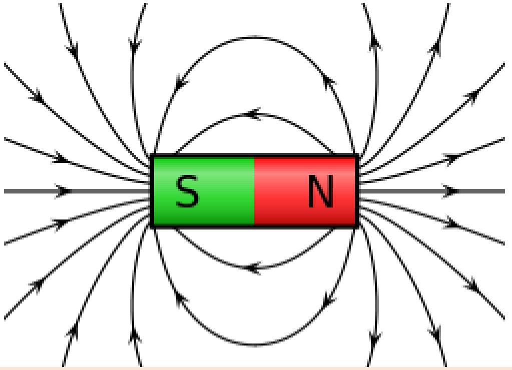
Chapter 27: Magnetic Field and Magnetic Forces

- Magnetic field and magnets
- Magnetic flux and Gauss's law for magnetic field
- Magnetic force on moving charged objects
- Magnetic force on current-carrying wires
- Magnetic potential energy and torque
- Hall effect

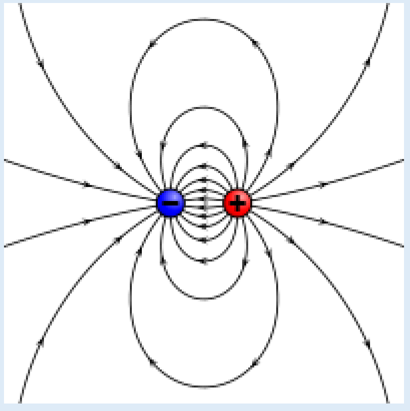
Magnetic field and magnets

The magnet and the magnetic field produced by it

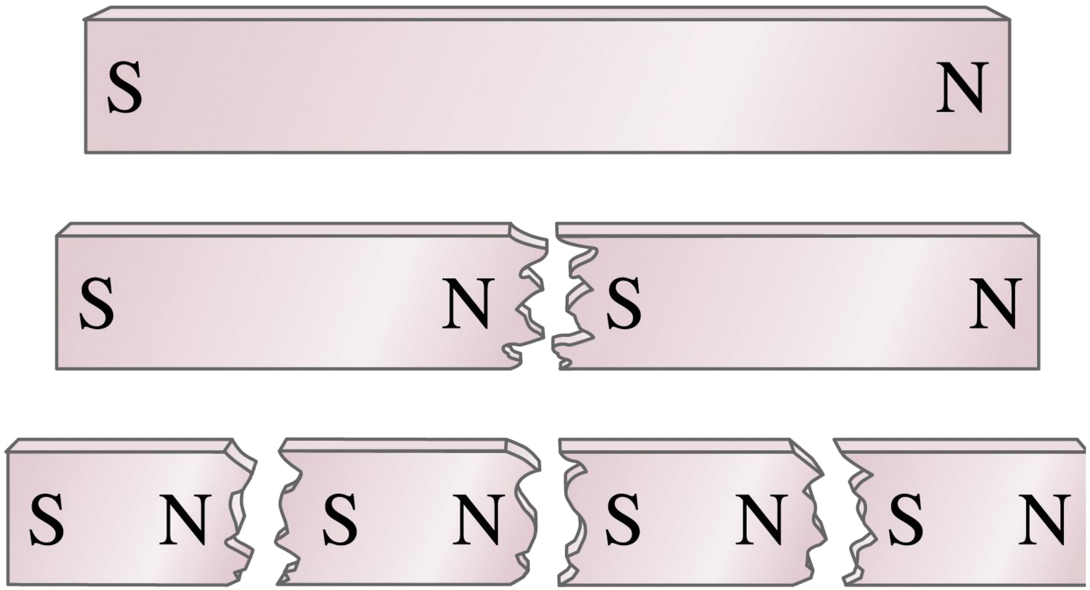


The magnetic field, $\vec{B}$, has a unit of Tesla $(1T = 1N/A \cdot m)$

Very similar to the electric dipole and the electric field produced by it



Breaking the magnets



Is that possible to break the magnet until you have single “N” or “S”?

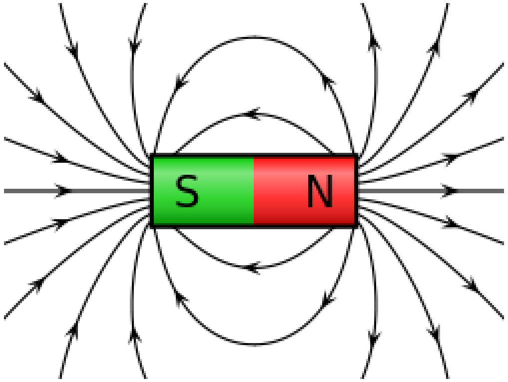
No! ➔ There is no magnetic monopole exist!!

Magnetic flux and Gauss's law for magnetic field

Gauss's law for electric field: for an closed surface, the electric flux passing through the surface only depends on the total enclosed charges in it.

$$\Phi_E = \oint_S \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$$

Gauss's law for magnetic field: for an closed surface, the magnetic flux passing through the surface only depends on the total enclosed poles in it.



$$\Phi_B = \oint_S \vec{B} \cdot d\vec{A} = 0$$

(since any "N" is accompanied by an "S")

Magnetic force on moving charged objects

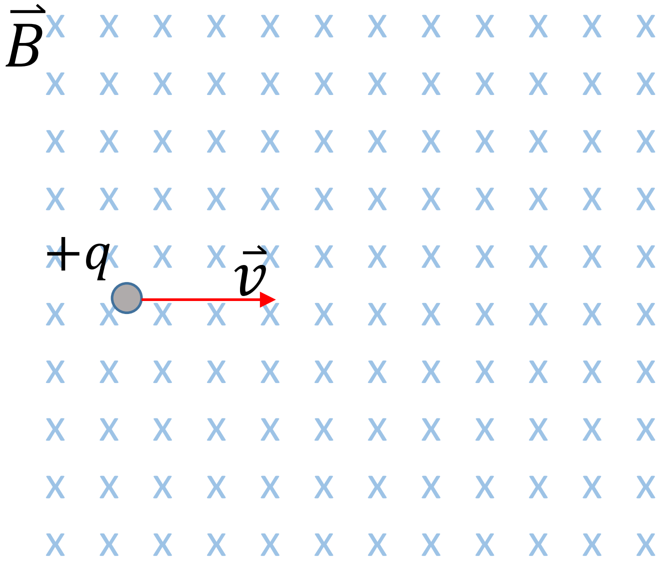
Charged particles “moving” in magnetic field will feel a magnetic force:

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

Charged particles “moving” in magnetic field and electric field will feel both magnetic and electric forces:

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

When a particle with charge, +q, moving with a velocity toward right direction in a uniform magnetic field with the direction pointing into the screen, what direction of the magnetic force will this particle feels?

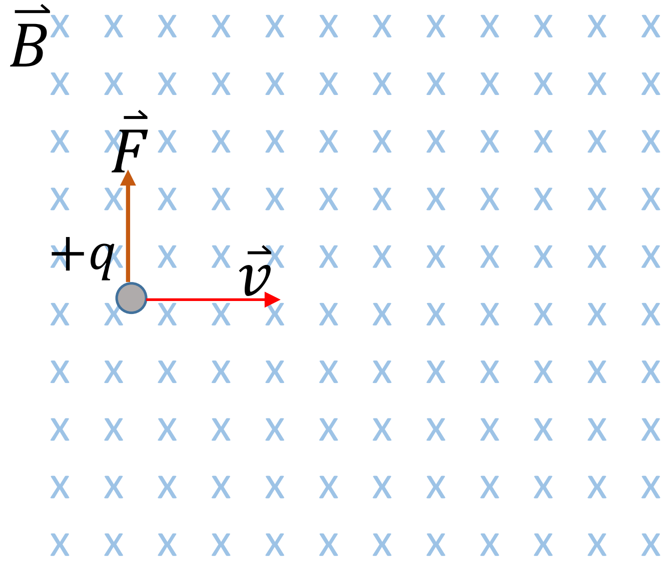


A. Upward
B. Downward
C. Same as the velocity direction
D. Opposite of the velocity direction
E. Out of the screen
F. Into the screen

Example:

A beam of proton ($q = 1.6 \times 10^{-19} C$) moves at $3.0 \times 10^{5} m/s$ through a uniform 2.0-T magnetic field directed along the positive *z*-axis. The velocity of each proton lies in the *xz*-plane and is directed at $30°$ to the +*z*-axis. Find the force on a proton.

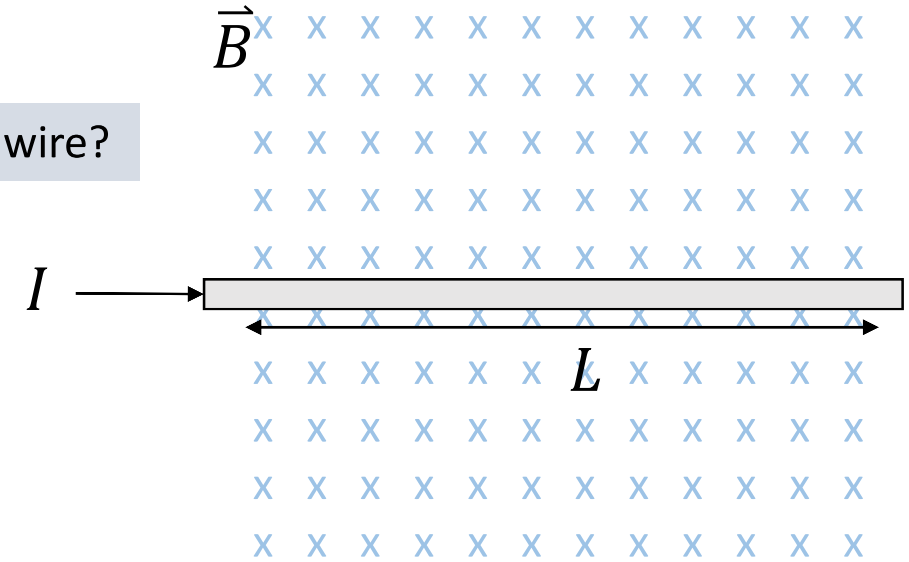
When a particle with charge, +q, moving with a velocity toward right direction in a uniform magnetic field with the direction pointing into the screen, what type of the motion does this charged particle move?



A. Circular motion with counterclockwise direction
B. Circular motion with clockwise direction
C. Parabolic motion toward upward
D. Parabolic motion toward downward
E. Straight motion with positive acceleration
F. Straight motion with negative acceleration

Worksheet for R and ω

Magnetic force on current-carrying wires



What is the force feel by the current-carrying wire?

Each electron has a force:

$$d\vec{F}_m = -e\vec{v}_d \times \vec{B}$$

The total force for electrons in the length L

$$\vec{F}_m = -e\vec{v}_d \times \vec{B} \cdot N$$

(*N*: the total number of electrons in the length L)

The total number of the electrons in the length L

$$N = n \cdot V = n \cdot A \cdot L$$

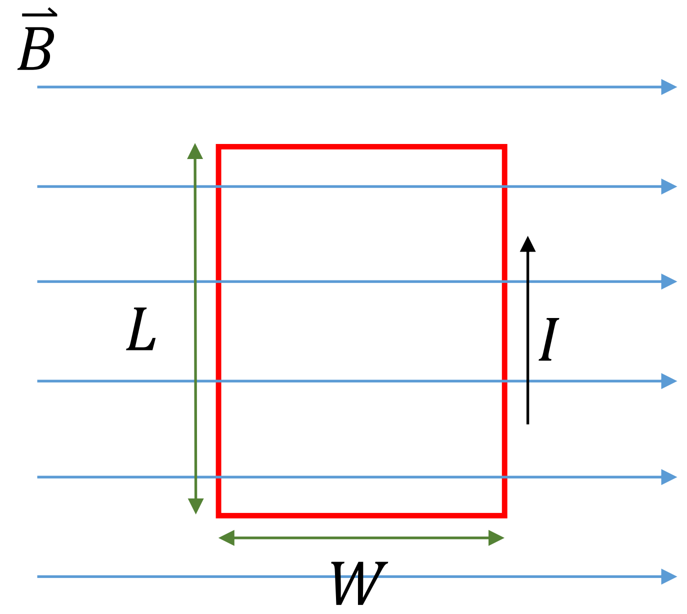
(*V*: Volume; *A*: Cross-section area; *L*: Length)

The total force feels by the wire

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

What is the total force of this current-carrying loop in an uniform magnetic field?

And what is the total torque of this current-carrying loop in an uniform magnetic field?



$$\vec{F} = 0$$

$$\vec{\tau} = IAB\ (up\ direction)$$

A: the loop area

$$\vec{\tau} = I\vec{A} \times \vec{B}$$

Define: Magnetic dipole moment

$$\vec{\mu} = I\vec{A}$$

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

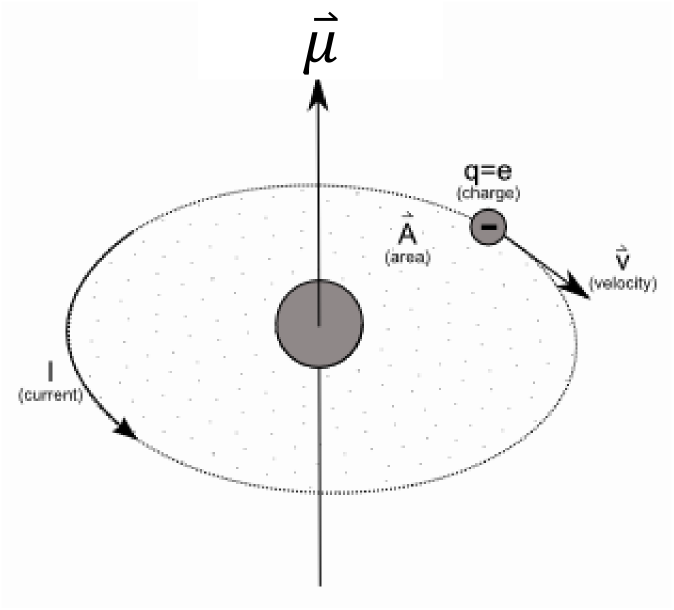
Magnetic dipole moment

Define: Magnetic dipole moment

$$\vec{\mu} = I\vec{A}$$

A loop of current is a magnetic dipole moment!!

Electrons in an atom

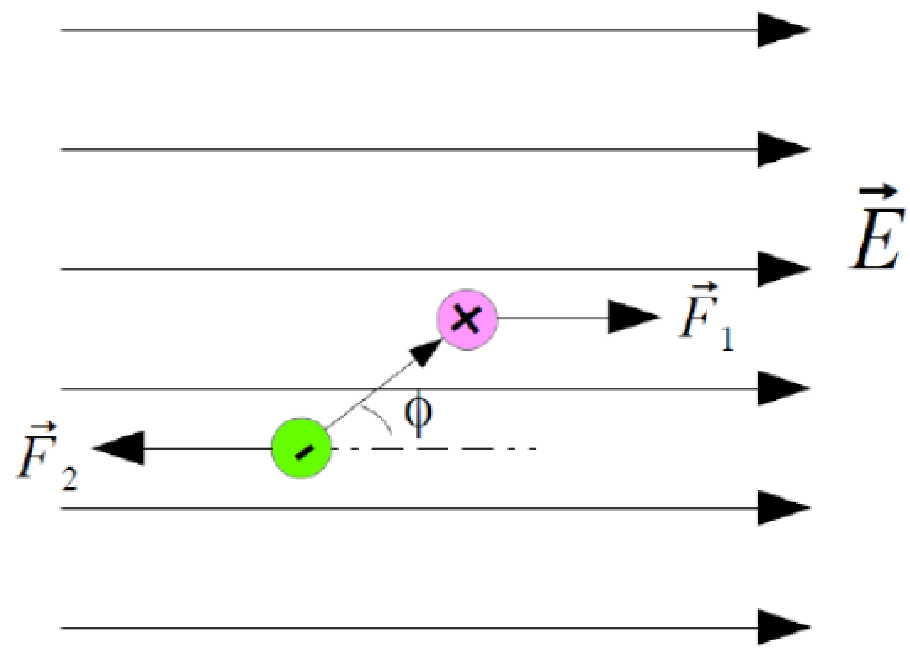


Magnetic torque and potential energy of a magnetic dipole moment in magnetic field

Do you remember the electric torque and potential energy of a electric dipole moment in electric field?

$$\vec{\tau} = \vec{p} \times \vec{E}$$

$$U_e = -\vec{p} \cdot \vec{E}$$



Magnetic torque and potential energy of a magnetic dipole moment in magnetic field

Do you remember the electric torque and potential energy of a electric dipole moment in electric field?

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

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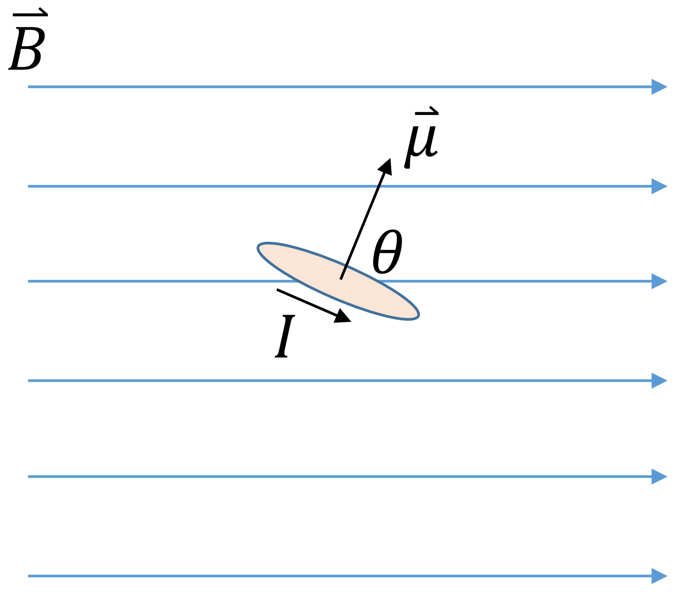
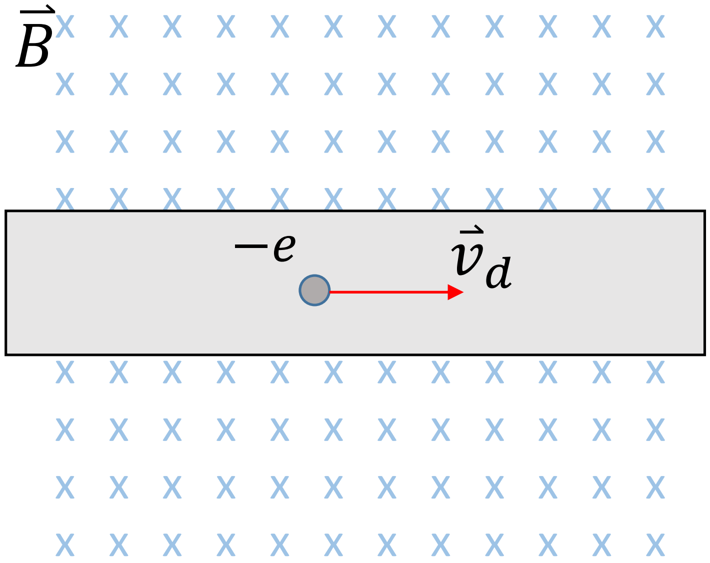


At this moment, how will this electron move? Assuming the size of the wire is smaller than the radius of the circular motion of the electron.



A. Move upward and stay on top edge of the wire
B. Move upward then straight to the right after hitting the top edge of the wire
C. Move downward and stay on bottom edge of the wire
D. Move downward then straight to the right after hitting the bottom edge of the wire
E. Move straight

Hall effect

- The accumulated charges on the top/bottom of the wire will build up an electric field to prevent further charge build up.
- The built-up electric field could be measured by the potential difference between the top and bottom edges of the wire.
- This could be used to measure the magnetic field strength and the polarity of the moving charges.