Chapter 29

1

Magnetic Fields

Mustafa Al-Zyout - Philadelphia University 10/5/2025

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Lecture 01

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Magnetic Fields

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Magnetic Poles

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- Every magnet, regardless of its shape, has two poles.
  - Called North and South poles
  - The poles received their names due to the way a magnet behaves in the Earth's magnetic field.
  - Poles exert forces on one another
    - Like poles repel each other
      - N-N or S-S
    - Unlike poles attract each other
      - N-S
  - A single magnetic pole has never been isolated.

Magnetic Fields

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- Reminder: an electric field surrounds any electric charge
- The region of space surrounding any moving electric charge also contains a magnetic field.
- A magnetic field also surrounds a magnetic substance making up a permanent magnet.

Magnetic Fields, cont.

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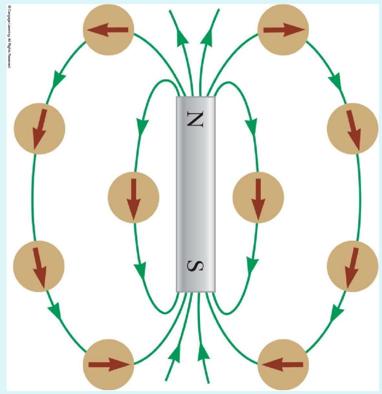
- Symbolized by $\vec{B}$
- A vector quantity
- The lines outside the magnet point from the North pole to the South pole.



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Magnetic Field Lines, Like Poles

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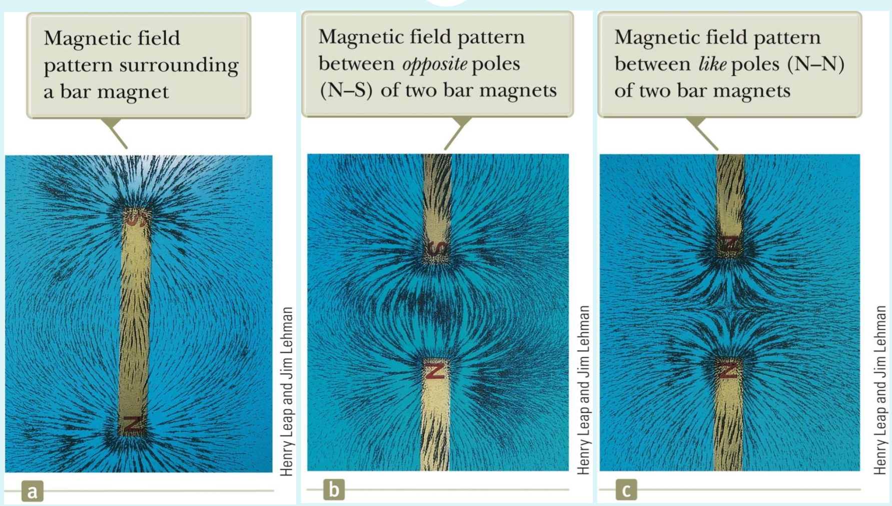

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Definition of Magnetic Field

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- The magnetic field at some point in space can be defined in terms of the magnetic force, $\vec{F}_B$.
- The magnetic force will be exerted on a charged particle moving with a velocity, $\vec{v}$.

Properties of a Force on a Charge Moving in a Magnetic Field

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- The magnitude F_B of the magnetic force exerted on the particle is proportional to the charge, q, and to the speed, v, of the particle.
- When a charged particle moves parallel to the magnetic field vector, the magnetic force acting on the particle is zero.
- The magnetic force exerted on a positive charge is in the direction opposite the direction of the magnetic force exerted on a negative charge moving in the same direction.
- The magnitude of the magnetic force is proportional to $sin\theta$, where θ is the angle the particle's velocity makes with the direction of the magnetic field.

Properties of a Force on a Charge Moving in a Magnetic Field

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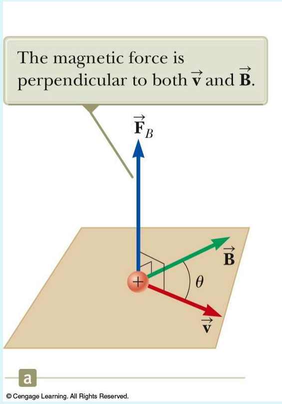
- When the particle's velocity vector makes any angle $\theta \neq 0^{\circ}$ with the field, the force acts in a direction perpendicular to the plane formed by the velocity and the field.



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Force on a Charge Moving in a Magnetic Field, Formula

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- These properties can be summarized in a vector equation:

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

- $\vec{F}_B$ is the magnetic force (in N)
- q is the charge (in C)
- $\vec{v}$ is the velocity of the moving charge (in m/s)
- $\vec{B}$ is the magnetic field (in T)

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Units of Magnetic Field

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- The SI unit of magnetic field is the Tesla (T).

$$T = \frac{Wb}{m^2} = \frac{N}{C.(m/s)} = \frac{N}{A.m}$$

  - Wb is a weber
- A non-SI commonly used unit is a Gauss (G).
  - $1\,T = 10^4\,G$

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More About Magnitude of F

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- The magnitude of the magnetic force on a charged particle is

$$\boxed{F_B = |q|vBsin\theta}$$

θ is the smaller angle between v and B

- F_B is zero when the object is NOT in motion
  - $v = 0$
- F_B is zero when the field and velocity are parallel or antiparallel
  - $\theta = 0^\circ$ or 180°
- F_B is a maximum when the field and velocity are perpendicular
  - $\theta = 90^\circ$

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Direction: Right-Hand Rule #1

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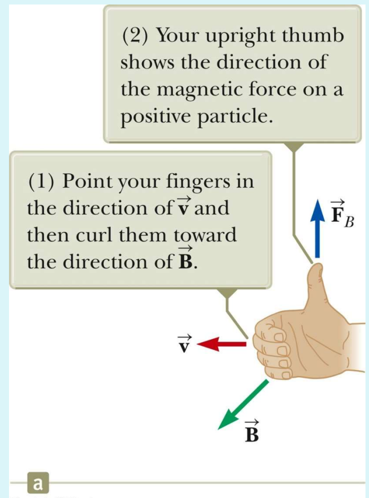
- This rule is based on the right-hand rule for the cross product.
- Your thumb is in the direction of the force if q is positive.
- The force is in the opposite direction of your thumb if q is negative.



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Direction: Right-Hand Rule #2

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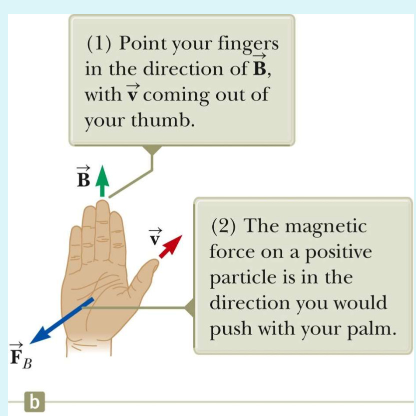
- Alternative to Rule #1
- The force on a positive charge extends outward from the palm.
- The advantage of this rule is that the force on the charge is in the direction you would push on something with your hand.
- The force on a negative charge is in the opposite direction.



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Differences Between Electric and Magnetic Fields

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Direction of force	• The electric force acts along the direction of the electric field. • The magnetic force acts perpendicular to the magnetic field.
Motion	• The electric force acts on a charged particle regardless of whether the particle is moving. • The magnetic force acts on a charged particle only when the particle is in motion.
Work	• The electric force does work in displacing a charged particle. • The magnetic force associated with a steady magnetic field does no work when a particle is displaced. This is because the force is perpendicular to the displacement of its point of application.

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Work in Fields, cont.

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- The kinetic energy of a charged particle moving through a magnetic field cannot be altered by the magnetic field alone.
- When a charged particle moves with a given velocity through a magnetic field, the field can alter the direction of the velocity, but NOT the speed or the kinetic energy.

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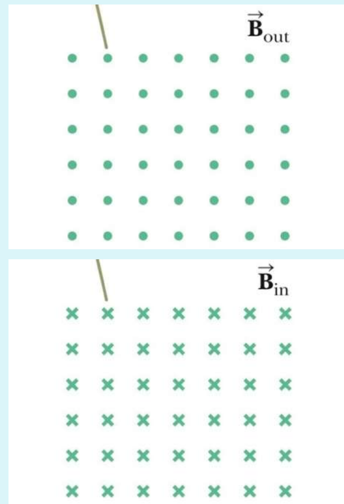
Notation Notes

- When vectors are perpendicular to the page, dots and crosses are used.
  - The dots represent the arrows coming out of the page.
  - The crosses represent the arrows going into the page.
- The same notation applies to other vectors.



An Electron Moving in a B

Friday, 29 January, 2021 21:25

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

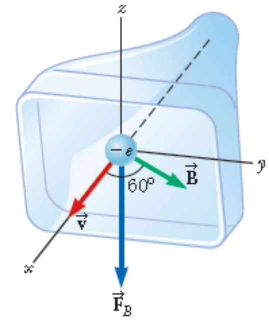
R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.

J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.

H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.

H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

An electron in an old-style television picture tube moves toward the front of the tube with a speed of $8.0 \times 10^6\ m/s$ along the x axis. Surrounding the neck of the tube are coils of wire that create a magnetic field of magnitude $0.025\,T$, directed at an angle of 60^o to the x axis and lying in the xy plane. Calculate the magnetic force on the electron.



SOLUTION

Use one of the right-hand rules to convince yourself that the direction of the force on the electron is downward.

find the magnitude of the magnetic force:

$$F_B = |q|vB\,sin\,\theta$$

$$= (1.60 \times 10^{-19}C)(8.0 \times 10^6 m/s)(0.025T)(sin\,6\,0°)$$

$$= 2.8 \times 10^{-14} N$$

Alternatively, we may evaluate the force by using unit vector notation:

We have:

$$\vec{v} = 8.0 \times 10^6\ \hat{\imath}$$

$$\vec{B} = 0.025\,cos\,60°\,\hat{\imath} + 0.025\,sin\,60°\,\hat{\jmath}$$

$$\vec{B} = 0.0125\hat{\imath} + 0.0217\hat{\jmath}$$

Then:

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

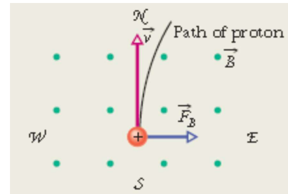
$$\vec{F}_B = (-1.60 \times 10^{-19}C)[(8.0 \times 10^6\ \hat{\imath}) \times (0.0125\hat{\imath} + 0.0217\hat{\jmath})]$$

$$\vec{F}_B = 2.8 \times 10^{-14} N, \hat{k}$$

F_B on a moving charged particle

Monday, 1 March, 2021 21:09

A uniform magnetic field with magnitude $1.2\ mT$, is directed vertically upward throughout the volume of a laboratory chamber. A proton with kinetic energy $5.3\ MeV$ enters the chamber, moving horizontally from south to north. What magnetic deflecting force acts on the proton as it enters the chamber?



To find the magnitude of $\vec{F}_B$, we can use ($F_B = |q|\text{vBsin}\phi$) provided we first find the proton's speed v. We can find v from the given kinetic energy because $K = \frac{1}{2}mv^2$.. Solving for v, we obtain

$$v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{(2)(5.3MeV)(1.60 \times 10^{-13}J/MeV)}{1.67 \times 10^{-27}Kg}} = 3.2 \times 10^7 m/s.$$

then

$$F_B = |q|vB\,sin\,\phi$$

$$= (1.60 \times 10^{-19}C)(3.2 \times 10^7 m/s) \times (1.2 \times 10^{-3}T)(sin\,9\,0°) = 6.1 \times 10^{-15}N.$$

This may seem like a small force, but it acts on a particle of small mass, producing a large acceleration; namely,

$$a = \frac{F_B}{m} = \frac{6.1 \times 10^{-15}N}{1.67 \times 10^{-27}Kg} = 3.7 \times 10^{12} m/s^2.$$

We know that $\vec{v}$ is directed horizontally from south to north and $\vec{B}$ is directed vertically up. The right-hand rule shows us that the deflecting force $\vec{F}_B$ must be directed horizontally from west to east, If the charge of the particle were negative, the magnetic deflecting force would be directed in the opposite direction.