Chapter 29

Magnetic Fields

A Brief History of Magnetism

- 13th century BC
  - Chinese used a compass
    - Uses a magnetic needle
    - Probably an invention of Arabic or Indian origin
- 800 BC
  - Greeks
    - Discovered magnetite (Fe_3O_4) attracts pieces of iron

A Brief History of Magnetism, 2

- 1269
  - Pierre de Maricourt found that the direction of a needle near a spherical natural magnet formed lines that encircled the sphere
  - The lines also passed through two points diametrically opposed to each other
  - He called the points poles

A Brief History of Magnetism, 3

- 1600
  - William Gilbert
    - Expanded experiments with magnetism to a variety of materials
    - Suggested the Earth itself was a large permanent magnet

A Brief History of Magnetism, 4

- 1819
  - Hans Christian Oersted
    - Discovered the relationship between electricity and magnetism
    - An electric current in a wire deflected a nearby compass needle

A Brief History of Magnetism, final

- 1820's
  - Faraday and Henry
    - Further connections between electricity and magnetism
    - A changing magnetic field creates an electric field
  - Maxwell
    - A changing electric field produces a magnetic field

Magnetic Poles

- Every magnet, regardless of its shape, has two poles
  - Called north and south poles
  - Poles exert forces on one another
    - Similar to the way electric charges exert forces on each other
    - Like poles repel each other
      - N-N or S-S
    - Unlike poles attract each other
      - N-S

Magnetic Poles, cont.

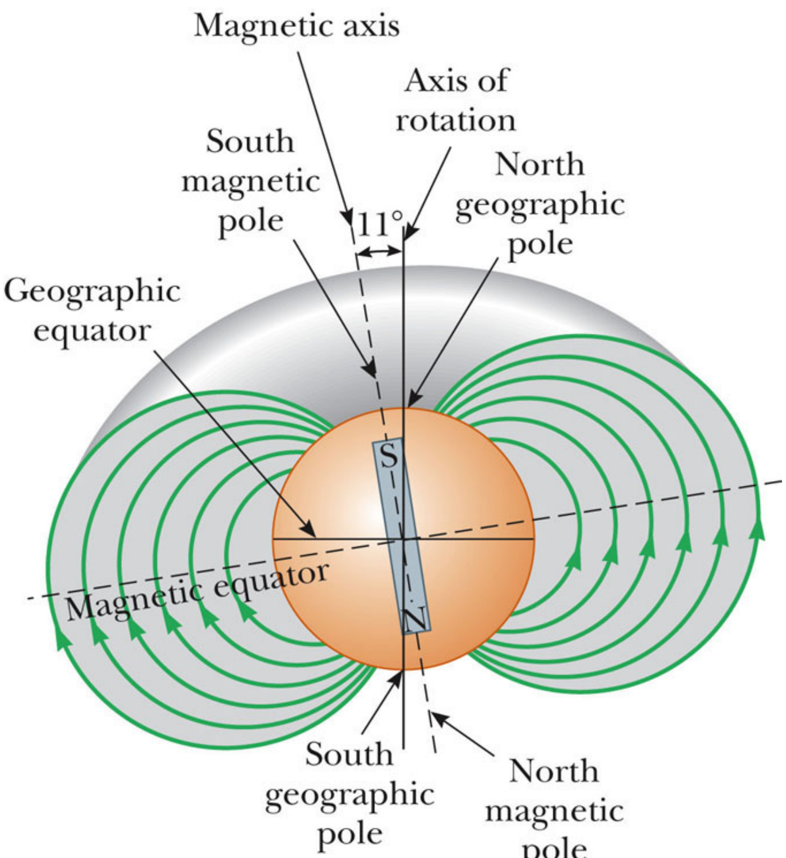
- The poles received their names due to the way a magnet behaves in the Earth’s magnetic field
- If a bar magnet is suspended so that it can move freely, it will rotate
  - The magnetic north pole points toward the Earth’s north geographic pole
    - This means the Earth’s north geographic pole is a magnetic south pole
    - Similarly, the Earth’s south geographic pole is a magnetic north pole

Magnetic Poles, final

- The force between two poles varies as the inverse square of the distance between them
- A single magnetic pole has never been isolated
  - In other words, magnetic poles are always found in pairs
  - All attempts so far to detect an isolated magnetic pole has been unsuccessful
    - No matter how many times a permanent magnetic is cut in two, each piece always has a north and south pole

Earth's Magnetic Field

- The Earth's magnetic field resembles that achieved by burying a huge bar magnet deep in the Earth's interior
- The Earth's south magnetic pole is located near the north geographic pole
- The Earth's north magnetic pole is located near the south geographic pole



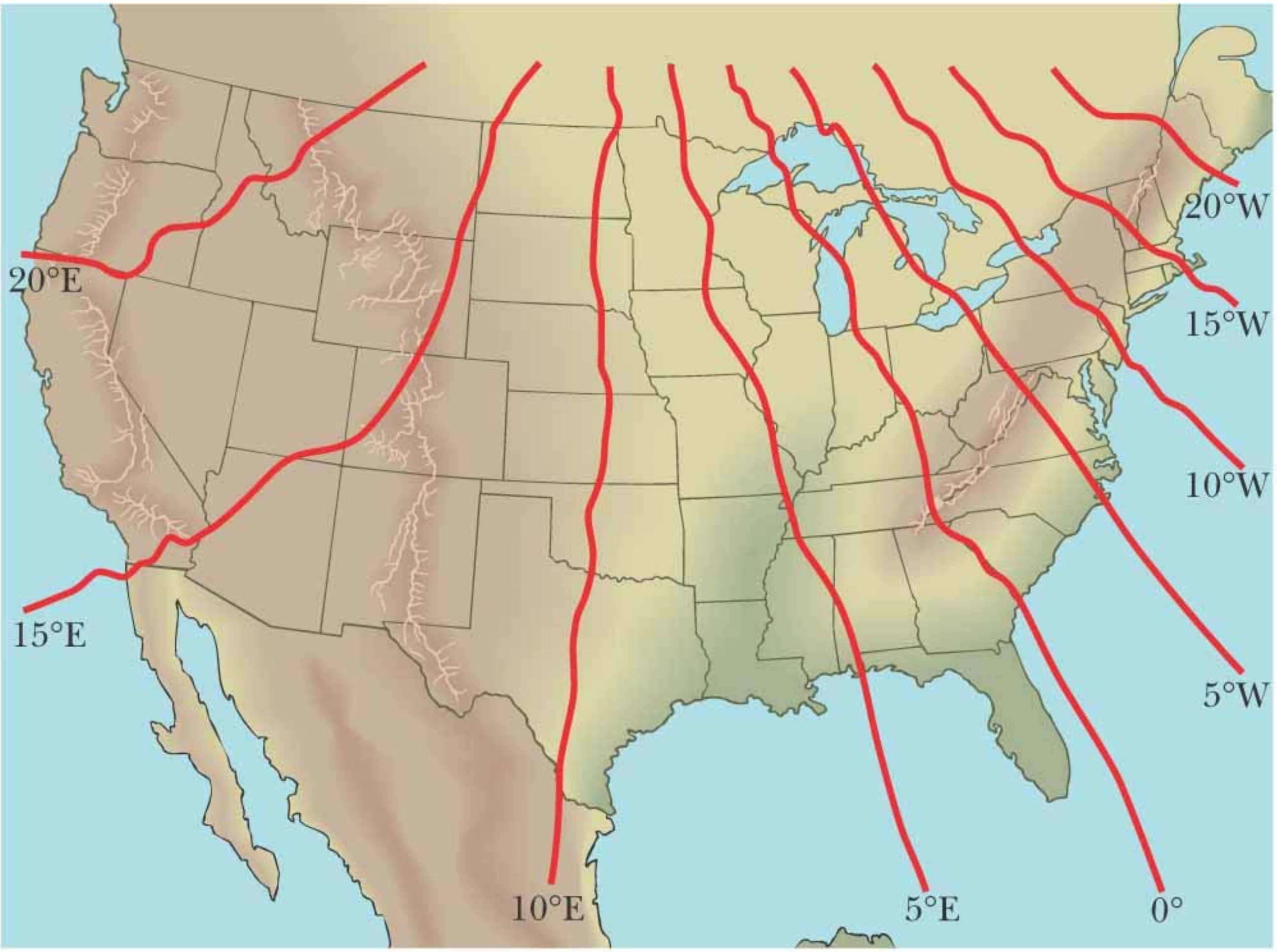
Vertical Movement of a Compass

- If a compass is free to rotate vertically as well as horizontally, it points to the Earth's surface
- The farther north the device is moved, the farther from horizontal the compass needle would be
  - The compass needle would be horizontal at the equator
  - The compass needle would point straight down at the magnetic pole

More About the Earth's Magnetic Poles

- The compass needle with point straight downward found at a point just north of Hudson Bay in Canada
  - This is considered to be the location of the south magnetic pole
  - The exact location varies slowly with time
- The magnetic and geographic poles are not in the same exact location
  - The difference between true north, at the geographic north pole, and magnetic north is called the magnetic declination (about 1300 miles apart)
    - The amount of declination varies by location on the Earth's surface

Earth’s Magnetic Declination



Source of the Earth's Magnetic Field

- There cannot be large masses of permanently magnetized materials since the high temperatures of the core prevent materials from retaining permanent magnetization
- The most likely source of the Earth's magnetic field is believed to be convection currents in the liquid part of the core
- There is also evidence that the planet's magnetic field is related to its rate of

Reversals of the Earth's Magnetic Field

- The direction of the Earth's magnetic field reverses on average every 200,000 years but the last one was 780,000 years ago
  - Evidence of these reversals are found in basalts resulting from volcanic activity
  - The rocks provide a timeline for the periodic reversals of the field
    - The rocks are dated by other means to determine the timeline

Magnetic Fields

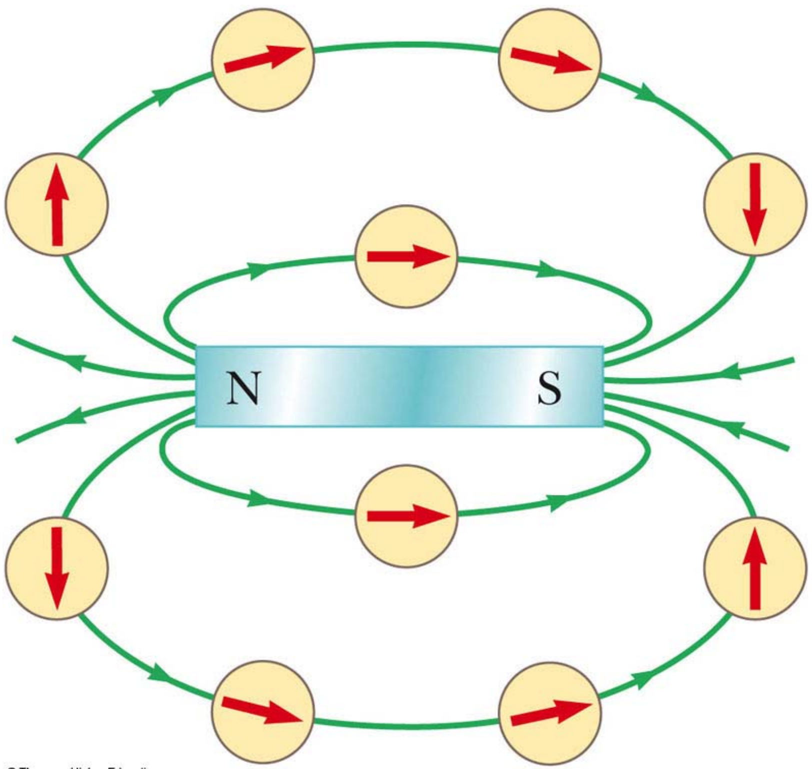
- Reminder: an electric field surrounds any electric charge
- The region of space surrounding any *moving* electric charge also contains a magnetic field
- A magnetic field also surrounds a magnetic substance making up a permanent magnet

Magnetic Fields, cont.

- A vector quantity
- Symbolized by $\vec{\mathbf{B}}$
- Direction is given by the direction a north pole of a compass needle points in that location
- Magnetic field lines can be used to show how the field lines, as traced out by a compass, would look

Magnetic Field Lines, Bar Magnet Example

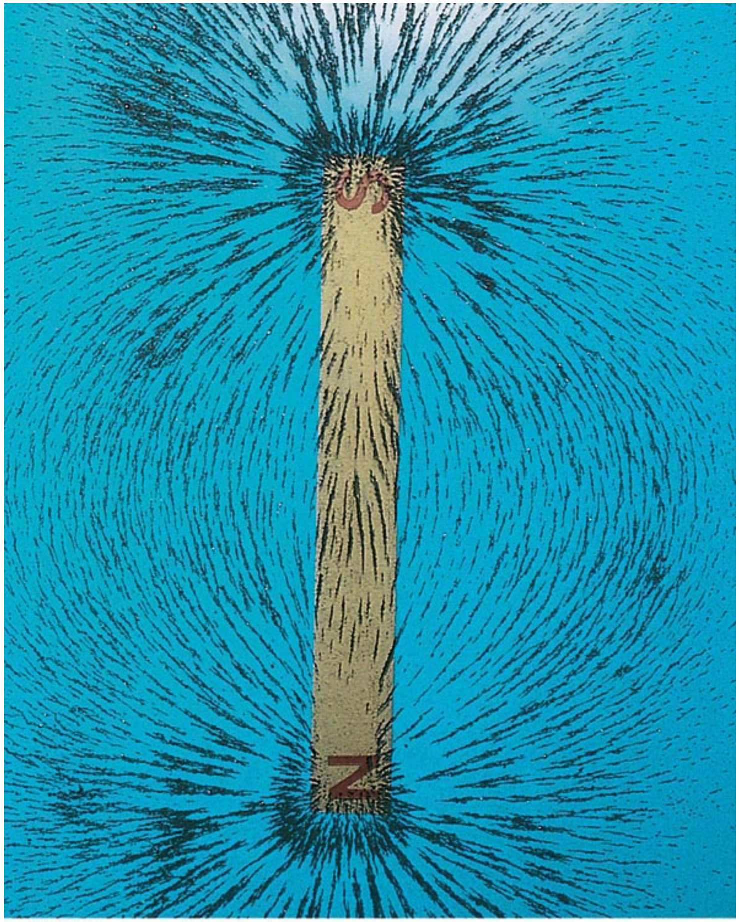
- The compass can be used to trace the field lines
- The lines outside the magnet point from the North pole to the South pole
- Use the active figure to trace the field lines



PLAY
ACTIVE FIGURE

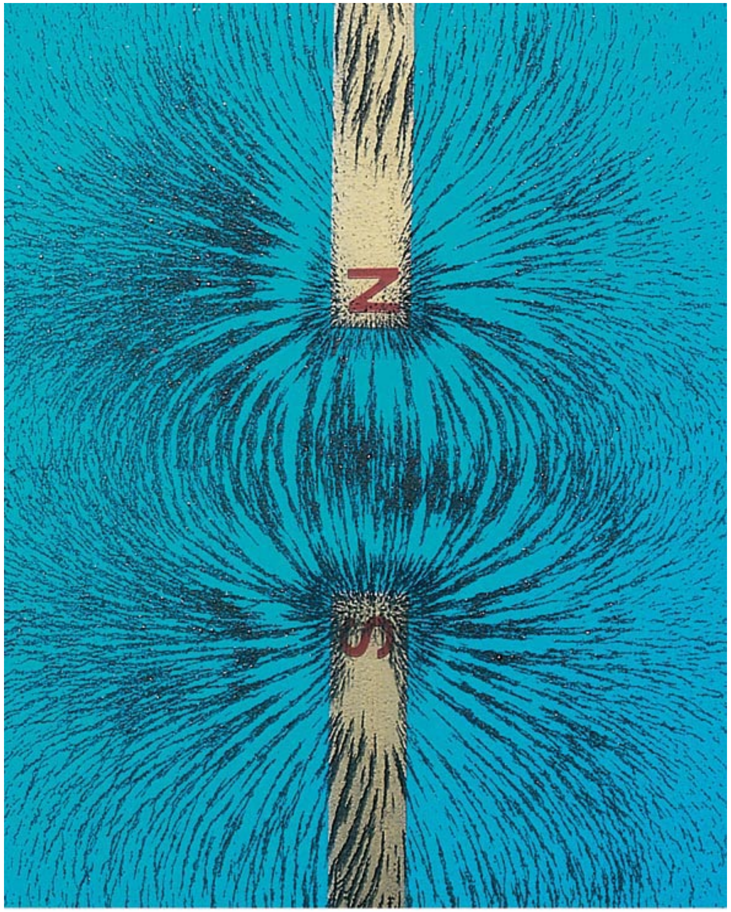
Magnetic Field Lines, Bar Magnet

- Iron filings are used to show the pattern of the magnetic field lines
- The direction of the field is the direction a north pole would point



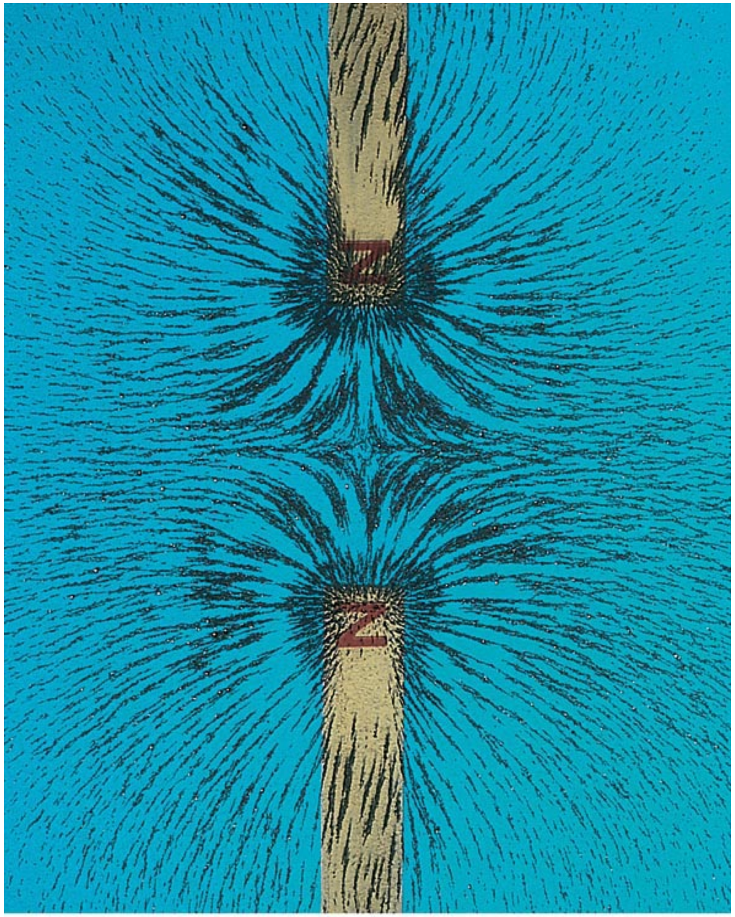
Magnetic Field Lines, Unlike Poles

- Iron filings are used to show the pattern of the magnetic field lines
- The direction of the field is the direction a north pole would point
  - Compare to the electric field produced by an electric dipole



Magnetic Field Lines, Like Poles

- Iron filings are used to show the pattern of the magnetic field lines
- The direction of the field is the direction a north pole would point
  - Compare to the electric field produced by like charges



Definition of Magnetic Field

- The magnetic field at some point in space can be defined in terms of the magnetic force, $\vec{\mathbf{F}}_B$
- The magnetic force will be exerted on a charged particle moving with a velocity, $\vec{\mathbf{v}}$
  - Assume (for now) there are no gravitational or electric fields present

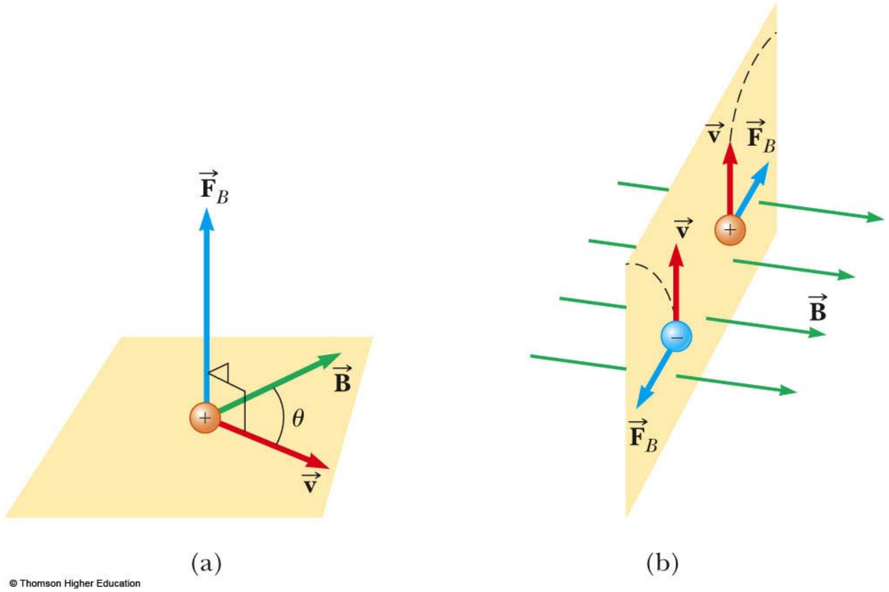
Force on a Charge Moving in a Magnetic Field

- 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
- When the particle's velocity vector makes any angle $\theta \neq 0$ with the field, the force acts in a direction perpendicular to both the velocity and the field

$\mathbf{F}_B$ on a Charge Moving in a Magnetic Field, final

- 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 θ, where θ is the angle the particle's velocity makes with the direction of the magnetic field

More About Direction



- $\vec{F}_B$ is perpendicular to the plane formed by $\vec{v}$ and $\vec{B}$
- Oppositely directed forces exerted on oppositely charged particles will cause the particles to move in opposite directions

Force on a Charge Moving in a Magnetic Field, Formula

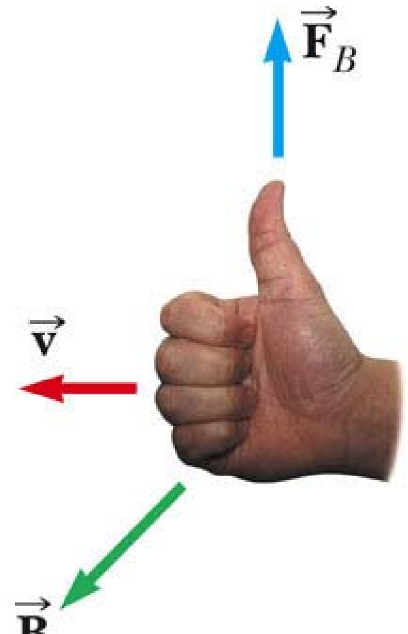
- The properties can be summarized in a vector equation:

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

  – $\vec{\mathbf{F}}_B$ is the magnetic force
  – q is the charge
  – $\mathbf{v}$ is the velocity of the moving charge
  – $\vec{\mathbf{B}}$ is the magnetic field

Direction: Right-Hand Rule #1

- The fingers point in the direction of $\vec{\mathbf{v}}$
- $\vec{\mathbf{B}}$ comes out of your palm
  - Curl your fingers in the direction of $\vec{\mathbf{B}}$
- The thumb points in the direction of $\vec{\mathbf{v}} \times \vec{\mathbf{B}}$ which is the direction of $\vec{\mathbf{F}}_B$



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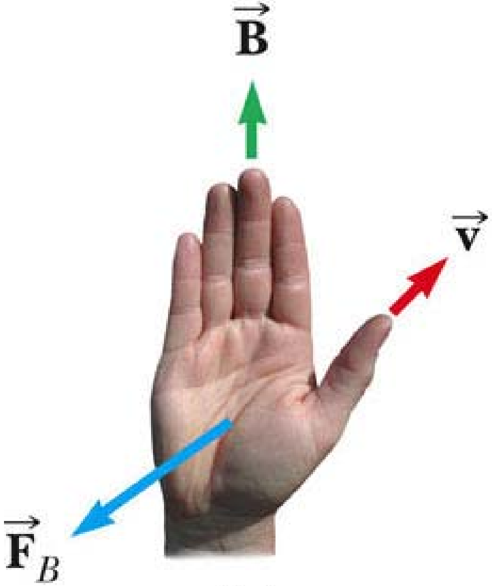
Direction: Right-Hand Rule #2

- Alternative to Rule #1
- Thumb is in the direction of $\vec{\mathbf{v}}$
- Fingers are in the direction of $\vec{\mathbf{B}}$
- Palm is in the direction of $\vec{\mathbf{F}}_B$
  – On a positive particle
  – You can think of this as your hand pushing the particle



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More About Magnitude of F

- The magnitude of the magnetic force on a charged particle is $F_B = |q|\, v\, B \sin\theta$
  - □ θ is the smaller angle between v and B
  - – F_B is zero when the field and velocity are parallel or antiparallel
    - □ $\theta = 0$ or 180^o
  - – F_B is a maximum when the field and velocity are perpendicular
    - □ $\theta = 90^o$

Differences Between Electric and Magnetic Fields

- 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

More Differences Between Electric and Magnetic Fields

- 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

Work in Fields, cont.

- 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

Units of Magnetic Field

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

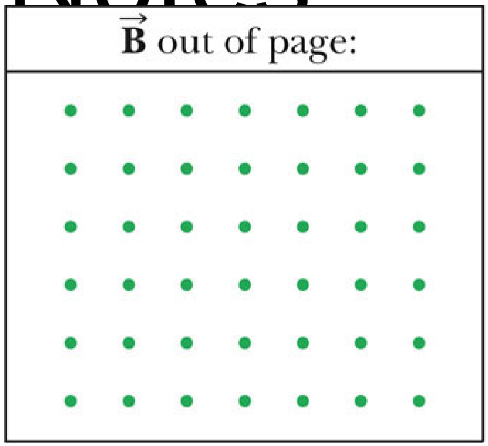
$$T = \frac{Wb}{m^2} = \frac{N}{C \cdot (m/s)} = \frac{N}{A \cdot m}$$

  – Wb is a weber

- A non-SI commonly used unit is a gauss (G)
  – 1 T = 10^4 G

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



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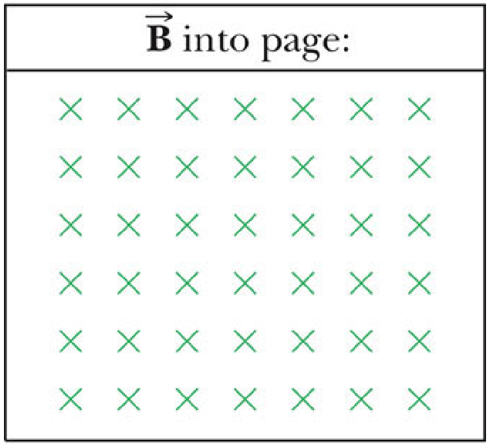

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