

PHYSICS 1442-003

Fall 2011

Lecture 9

Magnetism

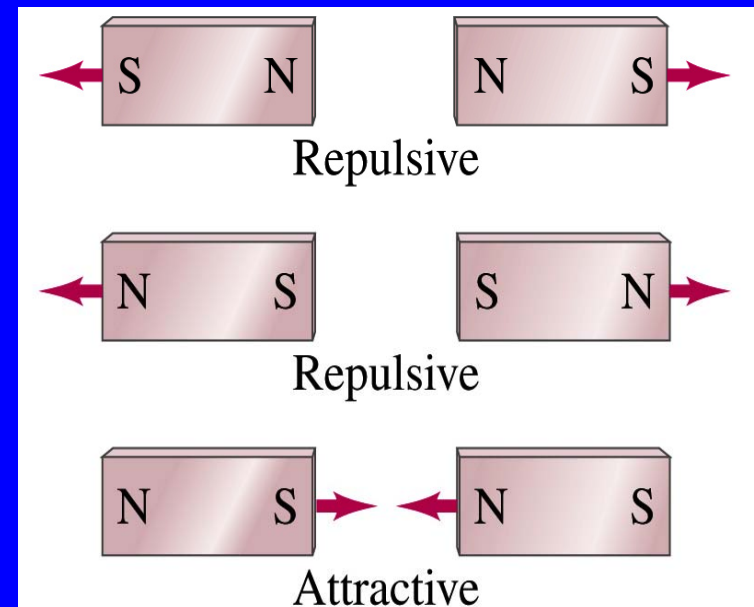
# Magnetism

## ■ What are magnets?

- Magnets have two ends, where objects are most strongly attracted – poles – called north and south.
  - The pole that points to geographical north is the north pole and the other is the south pole - Principle of compass
- These objects are called magnets due to the name of the region, Magnesia, where rocks that attract each other were found

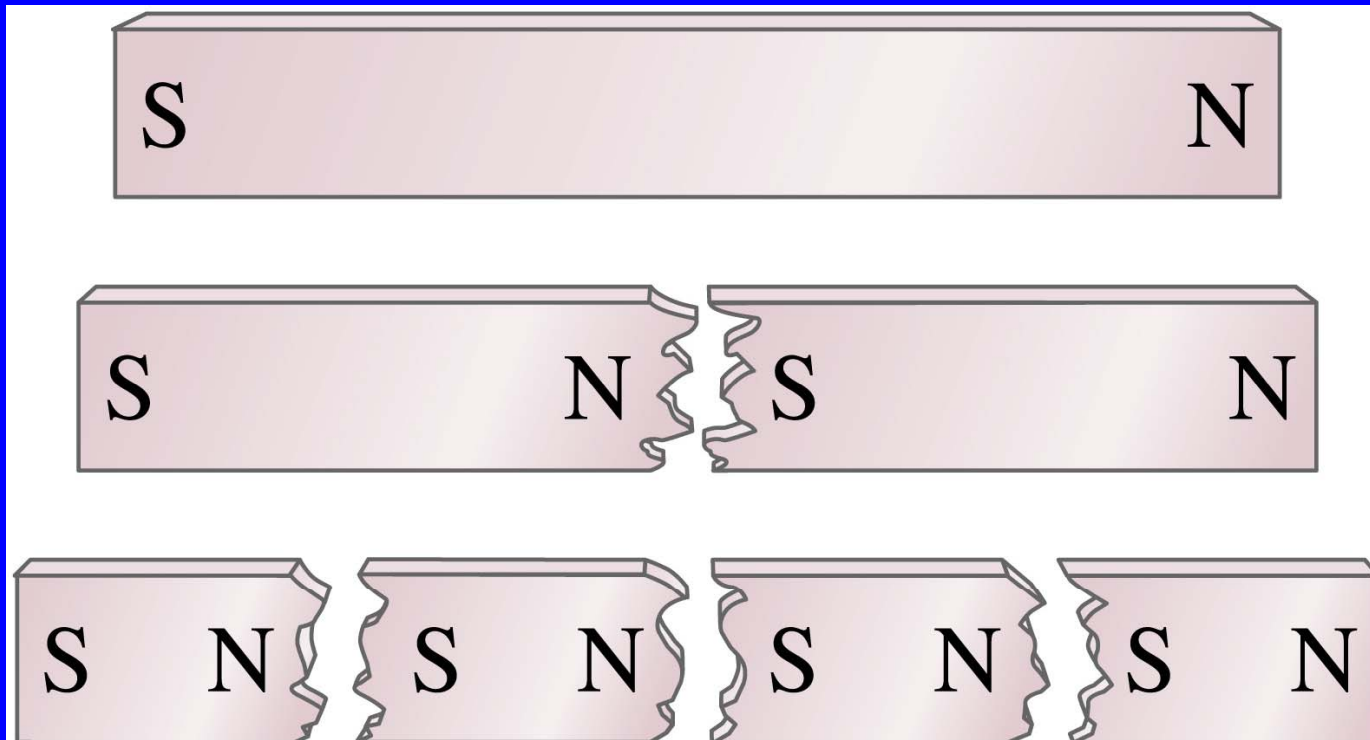
## ■ What happens when two magnets are brought to each other?

- They exert force on each other
- What kind?
- Both repulsive and attractive forces depending on the configurations
  - Similar to electric charges like poles repel each other while the unlike poles attract



# Magnets and Magnetic Fields

While electric charges (positive and negative) can be isolated magnetic poles cannot be isolated: if you cut a magnet in half repeatedly, you don't get a north pole and a south pole – you get smaller magnets. This differs from electric charges.



# More About Magnetism

- An unmagnetized piece of iron can be magnetized by stroking it with a magnet
  - Somewhat like stroking an object to charge an object
- Magnetism can be induced
  - If a piece of iron, for example, is placed near a strong permanent magnet, it will become magnetized

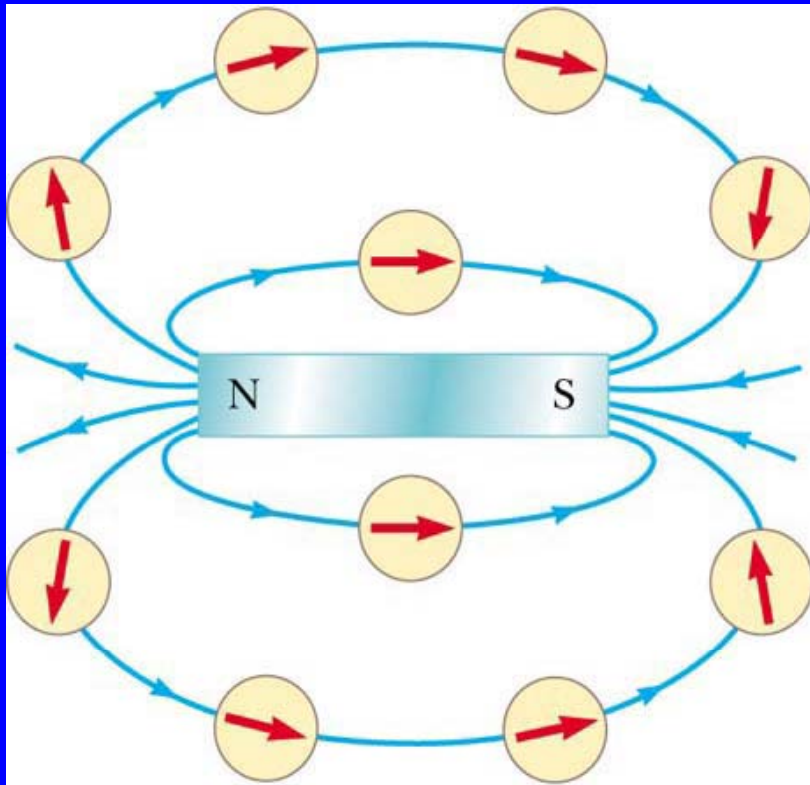
# Types of Magnetic Materials

- *Soft magnetic* materials, such as iron, are easily magnetized
  - They also tend to lose their magnetism easily
- *Hard magnetic* materials, such as cobalt and nickel, are difficult to magnetize
  - They tend to retain their magnetism

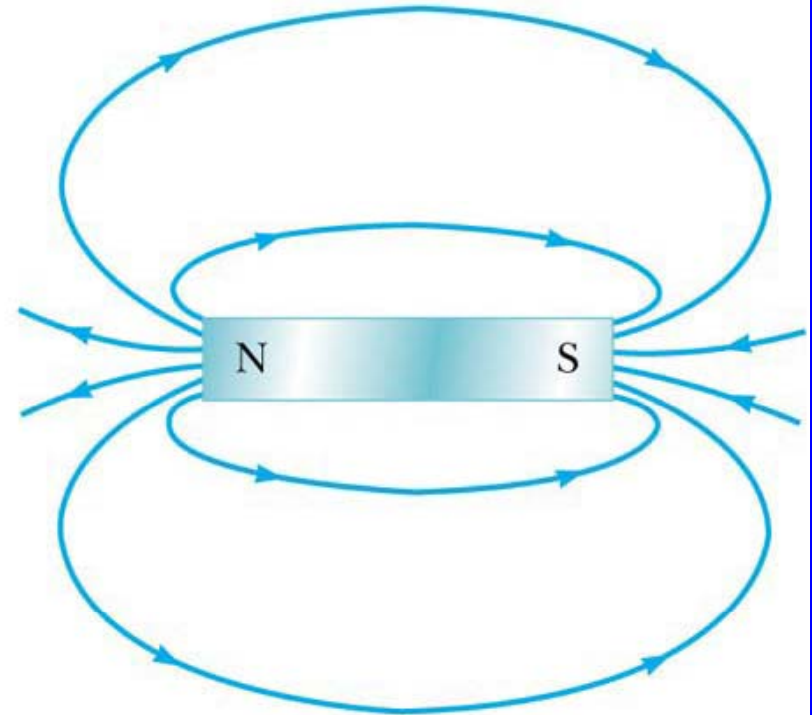
# Magnetic Fields

- Just like the electric field that surrounds electric charge, a magnetic field surrounds a magnet
- A vector quantity
- Symbolized by **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, sketch



(a)

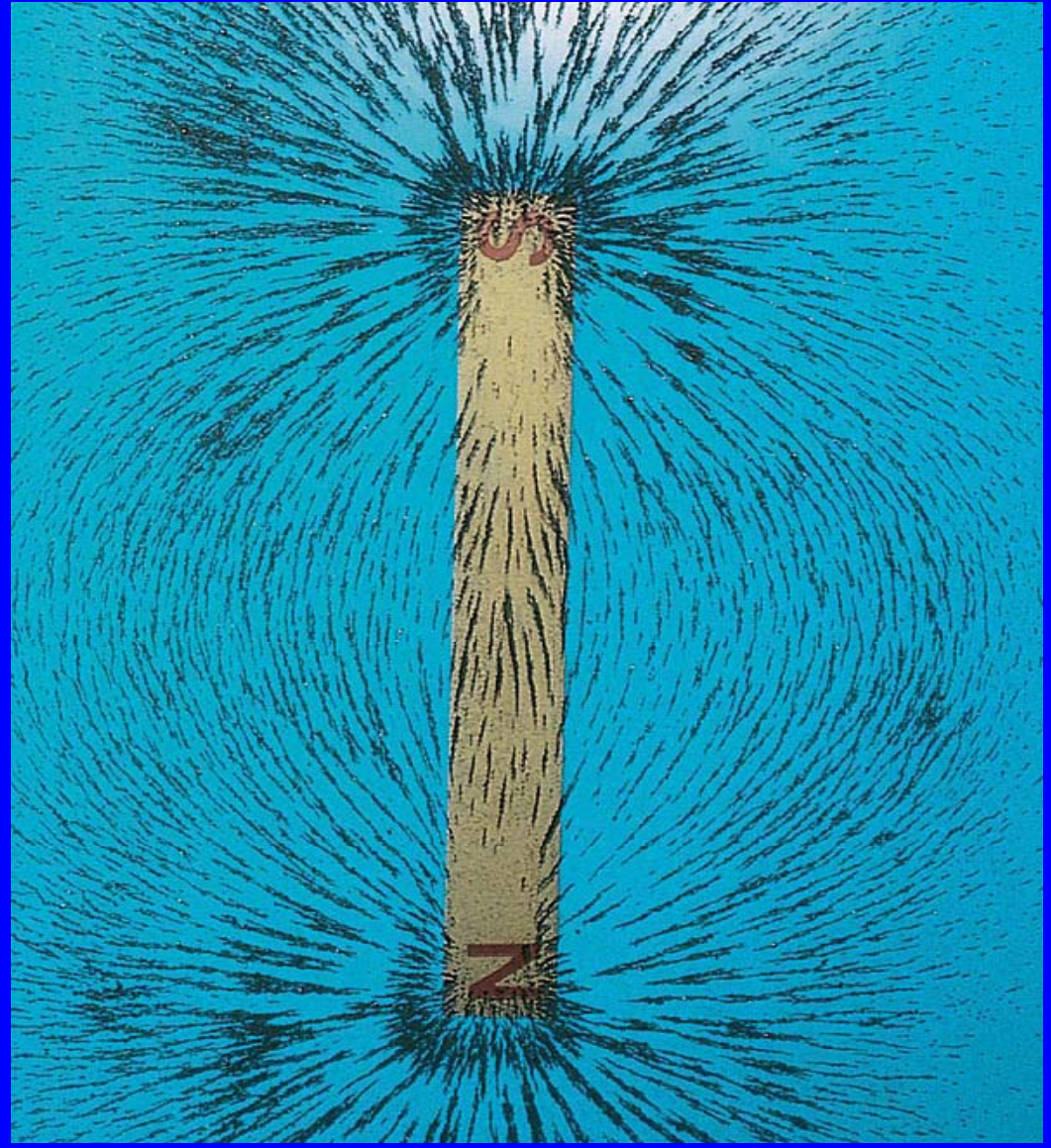


(b)

- A compass can be used to show the direction of the magnetic field lines (a)
- A sketch of the magnetic field lines (b)

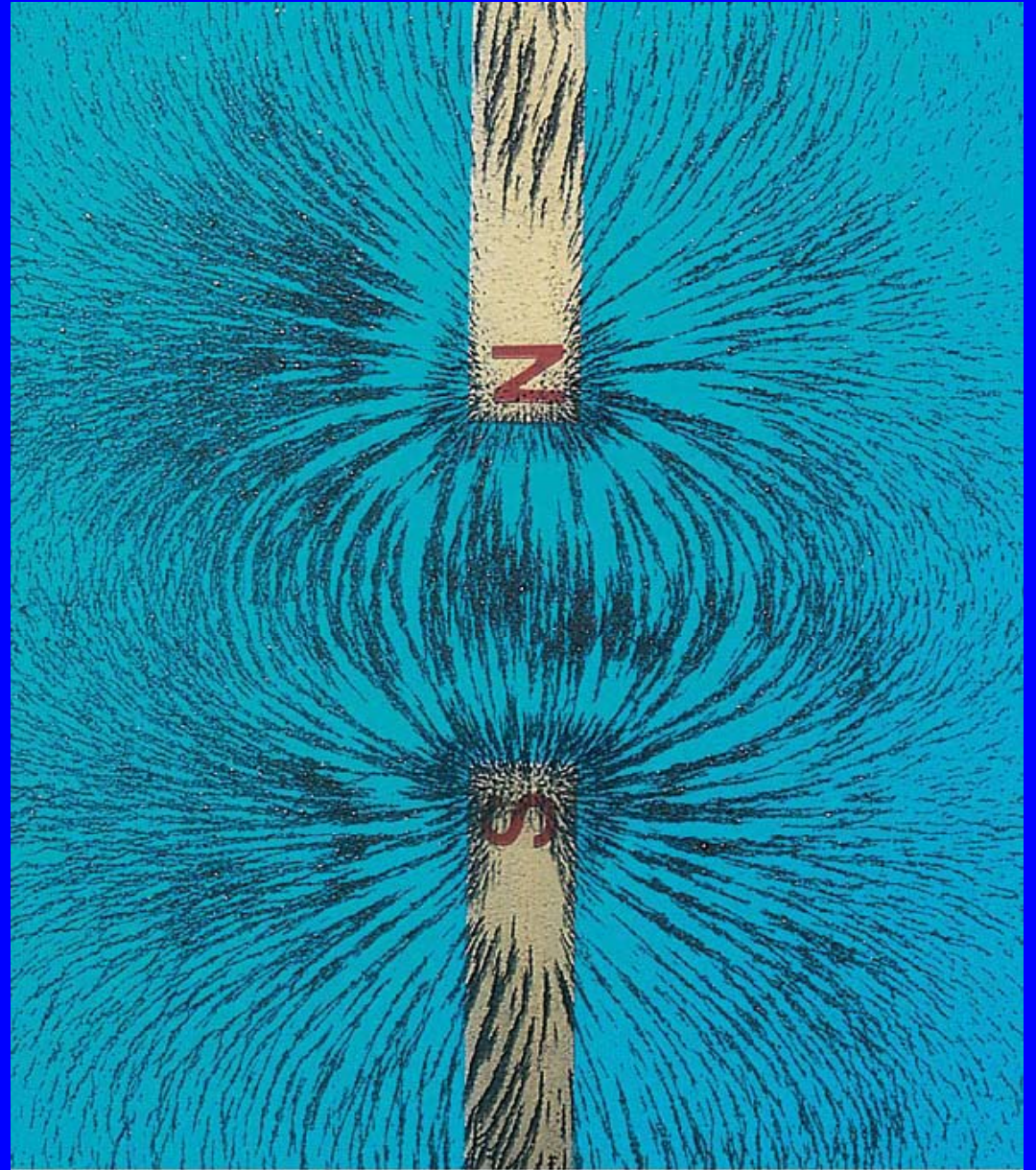
# Magnetic Field Lines, Bar Magnet

- 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



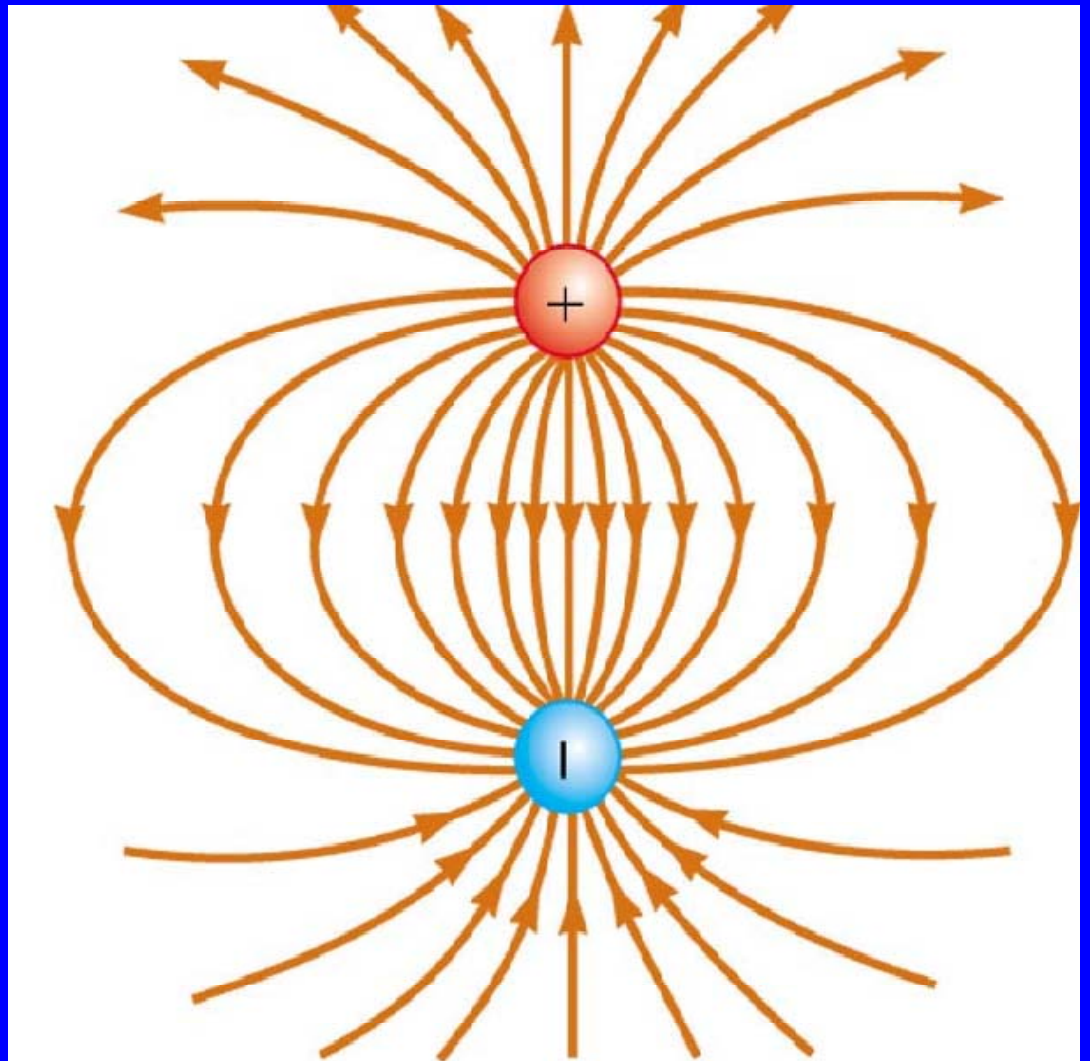
# Magnetic Field Lines, Unlike Poles

- Iron filings are used to show the pattern of the electric 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



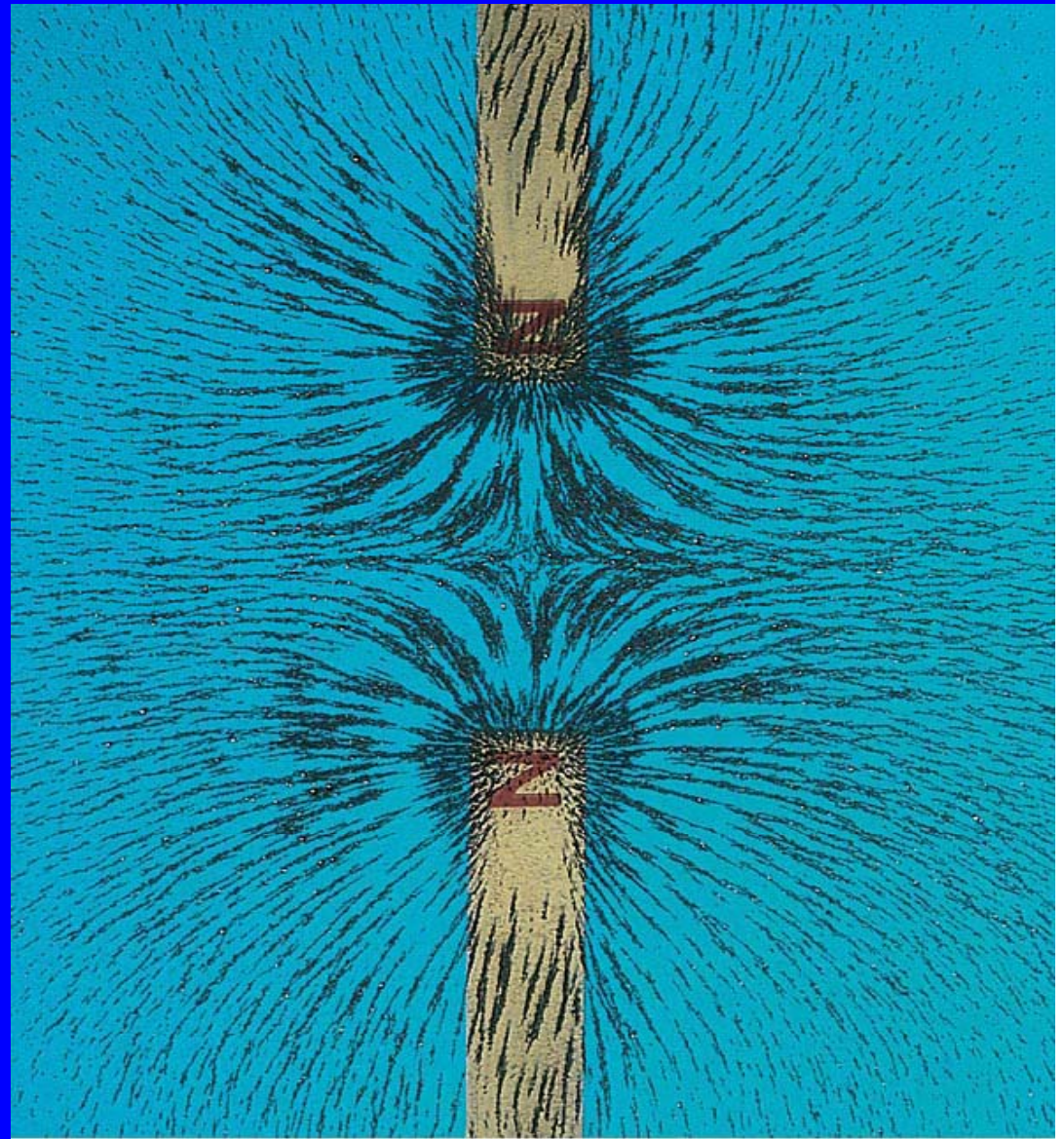
# Electric Field Line Patterns

- An electric *dipole* consists of two equal and opposite charges
- The high density of lines between the charges indicates the strong electric field in this region



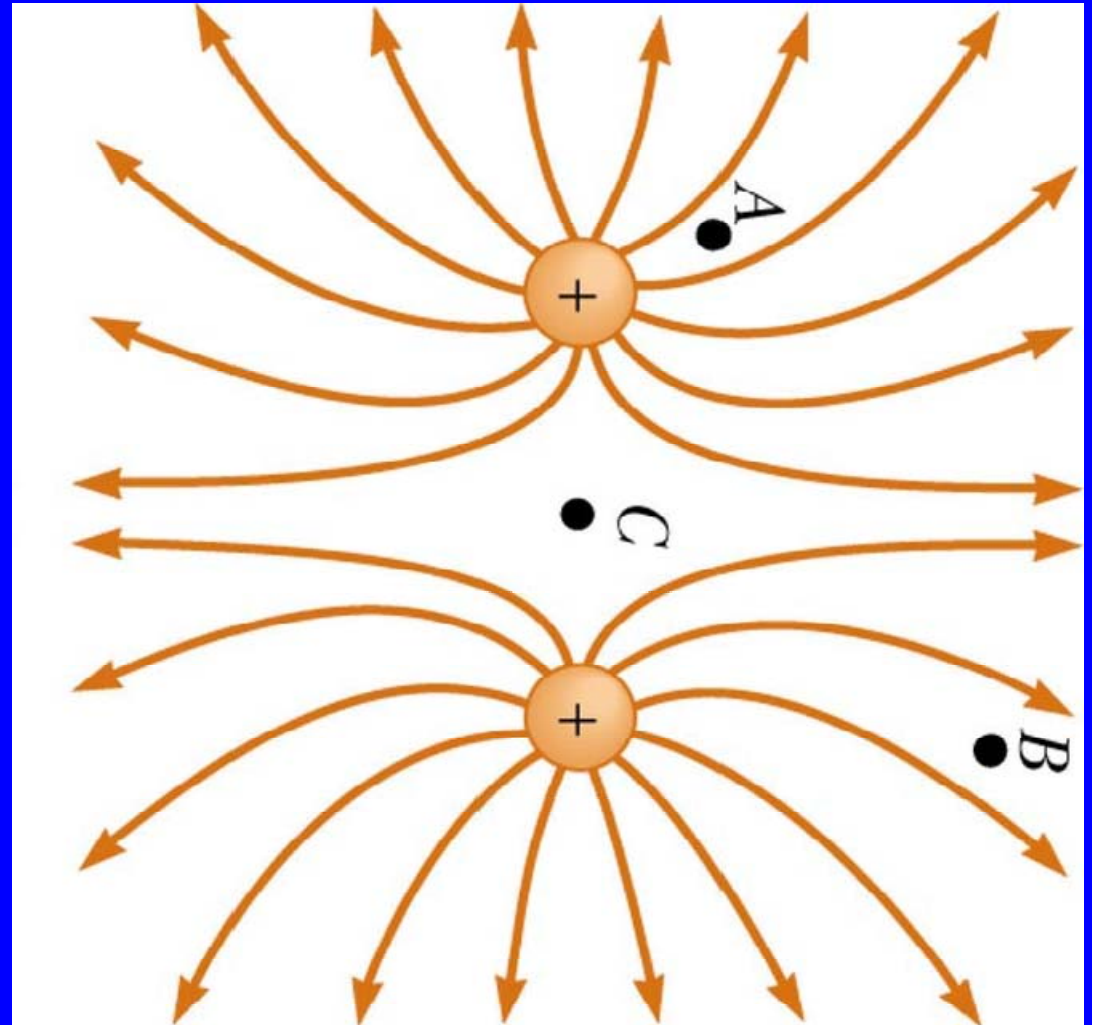
# Magnetic Field Lines, Like Poles

- 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



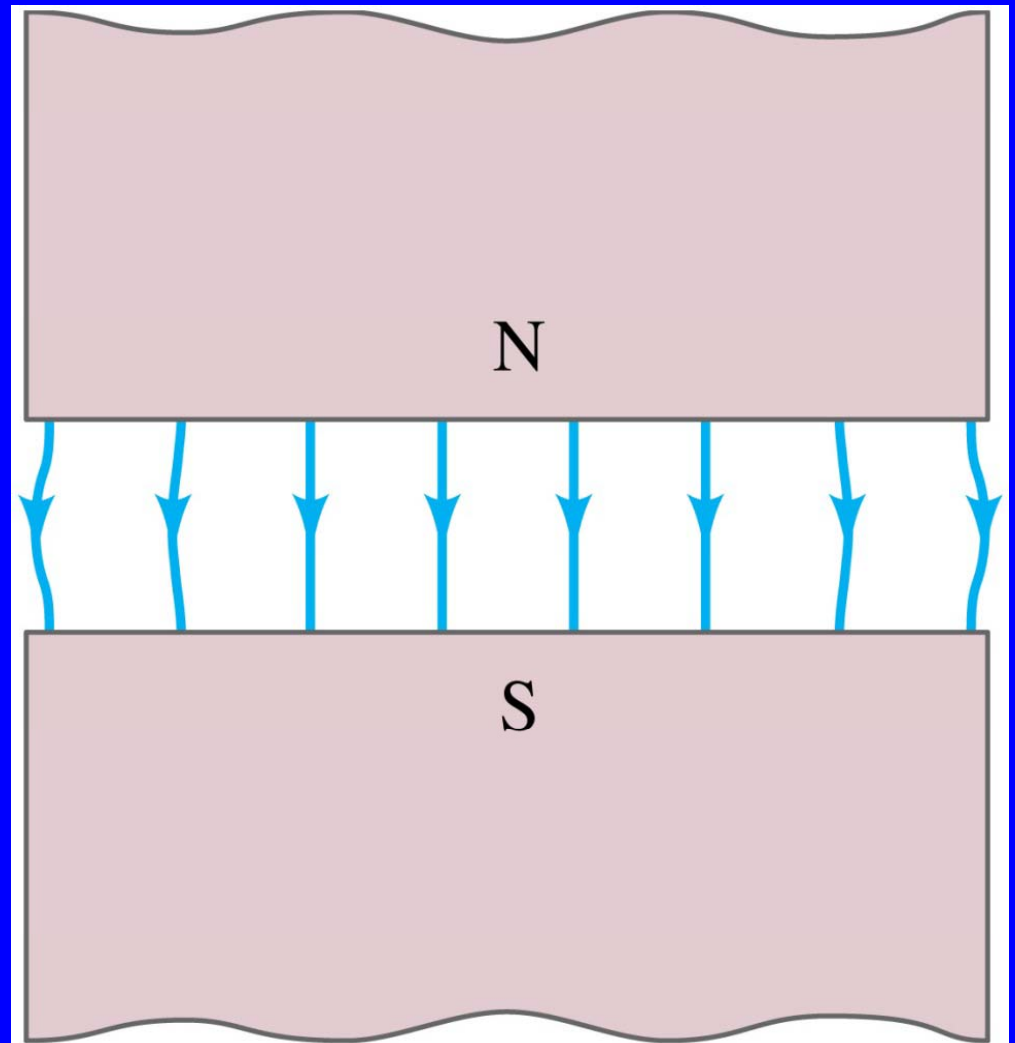
# Electric Field Line Patterns

- Two equal but like point charges
- At a great distance from the charges, the E field would be approximately that of a single charge of  $2q$
- The bulging out of the field lines between the charges indicates the repulsion between the charges
- The low field lines between the charges indicates a weak field in this region



A uniform magnetic field is constant in magnitude and direction.

The field between these two wide poles is nearly uniform.

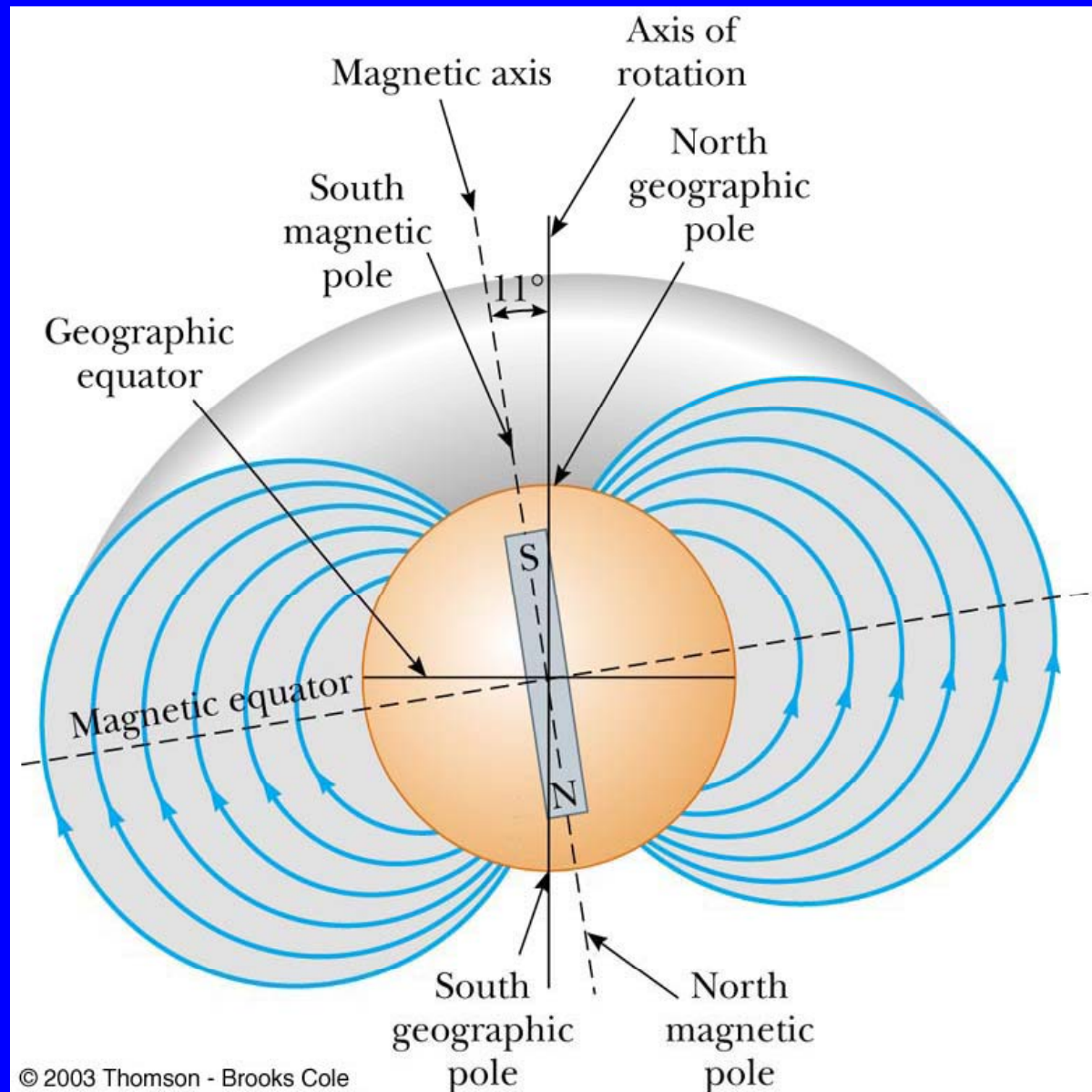


# Magnetic and Electric Fields

- An electric field surrounds any stationary electric charge
- A magnetic field surrounds any magnetic material
- The direction of the field is the direction the north pole of a compass would point to
- The number of lines per unit area is proportional to the strength of the magnetic field
- Magnetic field lines continue inside the magnet
- Since magnets always have both the poles, magnetic field lines form closed loops unlike electric field lines

# Earth's Magnetic Field

- The Earth's magnetic field resembles that achieved by burying a huge bar magnet deep in the Earth's interior
- Note that the Earth's "North Pole" is really a south magnetic pole, as the north ends of magnets are attracted to it.



# Earth's Magnetic Field

- The Earth's geographic north pole corresponds to a magnetic south pole
- The Earth's geographic south pole corresponds to a magnetic north pole
  - Strictly speaking, a north pole should be a "north-seeking" pole and a south pole a "south-seeking" pole

# 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 electric currents in the liquid part of the core

# Dip Angle of Earth's Magnetic Field

- If a compass is free to rotate vertically as well as horizontally, it points to the earth's surface
- The angle between the horizontal and the direction of the magnetic field is called the *dip angle*
  - 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 and the dip angle would be  $0^\circ$
    - The compass needle would point straight down at the south magnetic pole and the dip angle would be  $90^\circ$

# More About the Earth's Magnetic Poles

- The dip angle of  $90^\circ$  is found at a point just north of Hudson Bay in Canada
  - This is considered to be the location of the south magnetic pole
- 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*
    - The amount of declination varies by location on the earth's surface

# Earth's Magnetic Declination



# Reversals of the Earth's Magnetic Field

- The direction of the Earth's magnetic field reverses every few million years
  - Evidence of these reversals are found in basalts resulting from volcanic activity
  - The origin of the reversals is not understood

# Magnetic Fields

- When moving through a magnetic field, a charged particle experiences a magnetic force
  - This force has a maximum value when the charge moves perpendicularly to the magnetic field lines
  - This force is zero when the charge moves along the field lines

# Magnetic Field

- One can define a magnetic field in terms of the magnetic force exerted on a test charge
  - Similar to the way electric fields are defined

$$\mathbf{B} \equiv \frac{\mathbf{F}}{qv \sin \theta}$$

# Units of Magnetic Field

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

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

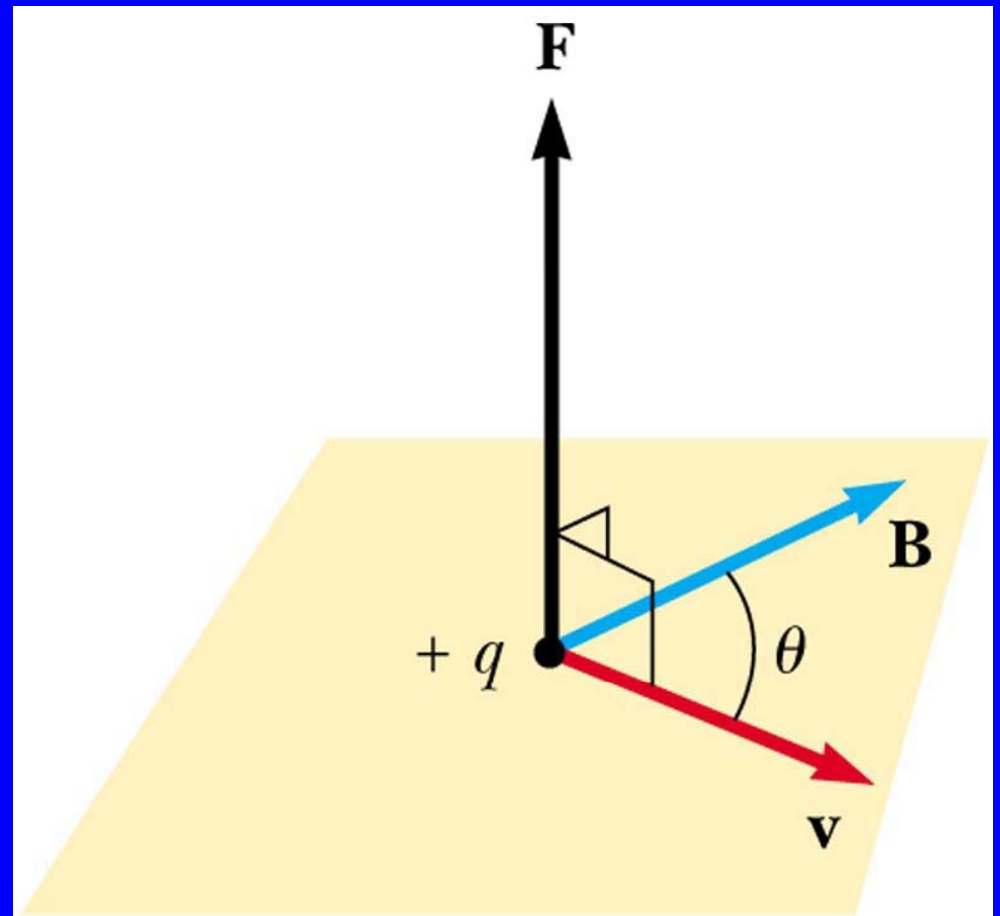
- Wb is a Weber
- The cgs unit is a *Gauss* (G)
  - $1 \text{ T} = 10^4 \text{ G}$

# A Few Typical B Values

- Conventional laboratory magnets
  - 25000 G or 2.5 T
- Superconducting magnets
  - 300000 G or 30 T
- Earth's magnetic field
  - 0.5 G or  $5 \times 10^{-5}$  T

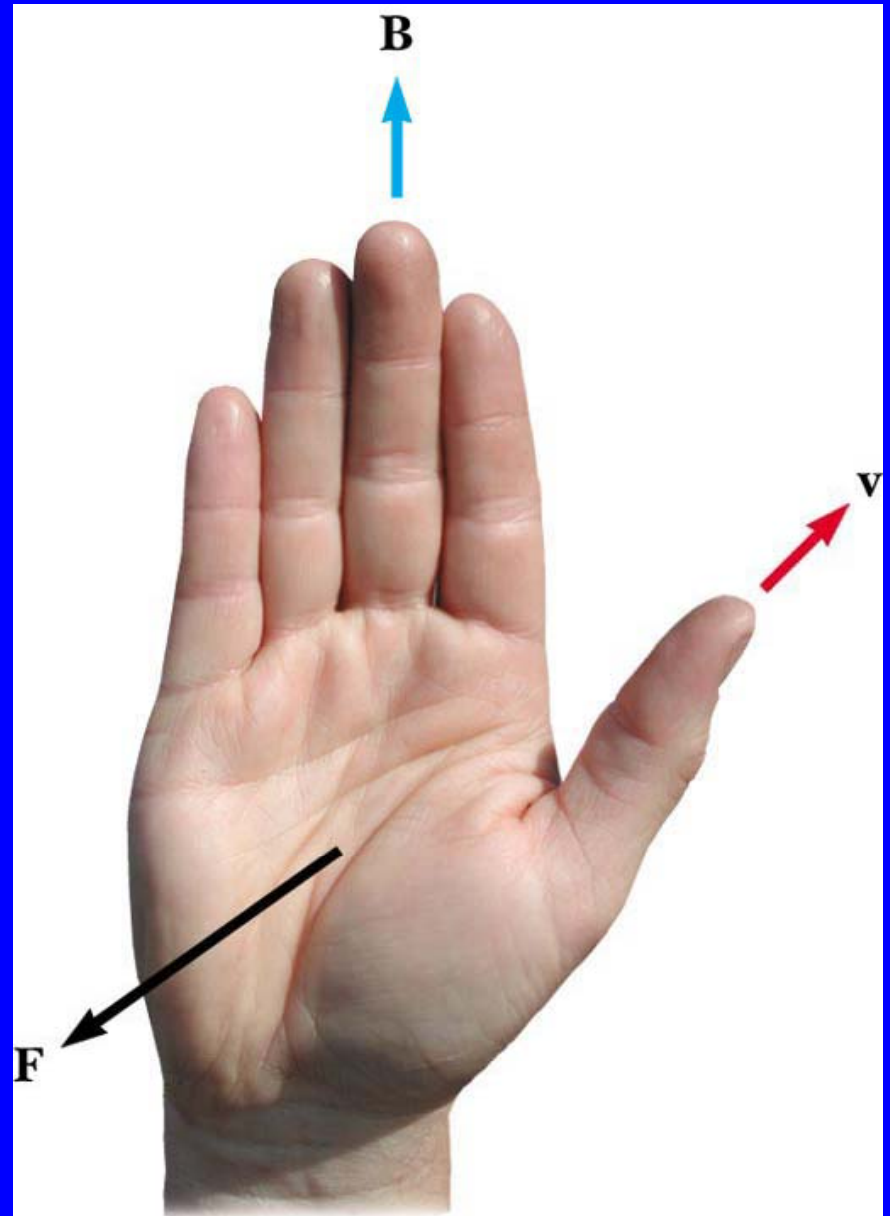
# Finding the Direction of Magnetic Force

- Experiments show that the direction of the magnetic force is always perpendicular to both  $\mathbf{v}$  and  $\mathbf{B}$
- $F_{\max}$  occurs when  $\mathbf{v}$  is perpendicular to  $\mathbf{B}$
- $F = 0$  when  $\mathbf{v}$  is parallel to  $\mathbf{B}$



# Right Hand Rule #1

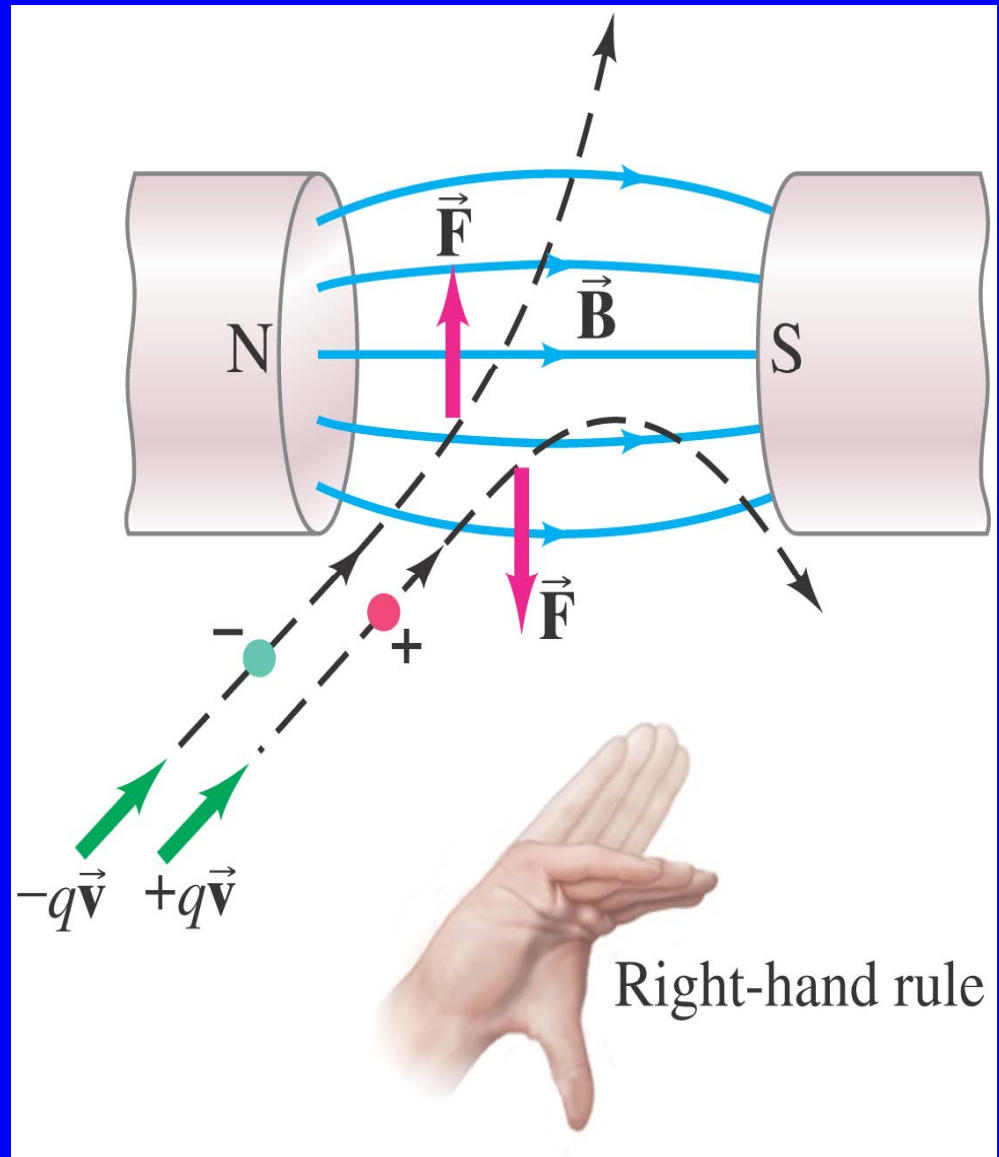
- Hold your right hand open
- Place your fingers in the direction of  $\mathbf{B}$
- Place your thumb in the direction of  $\mathbf{v}$
- The direction of the force on a positive charge is directed out of your palm
  - If the charge is negative, the force is opposite that determined by the right hand rule



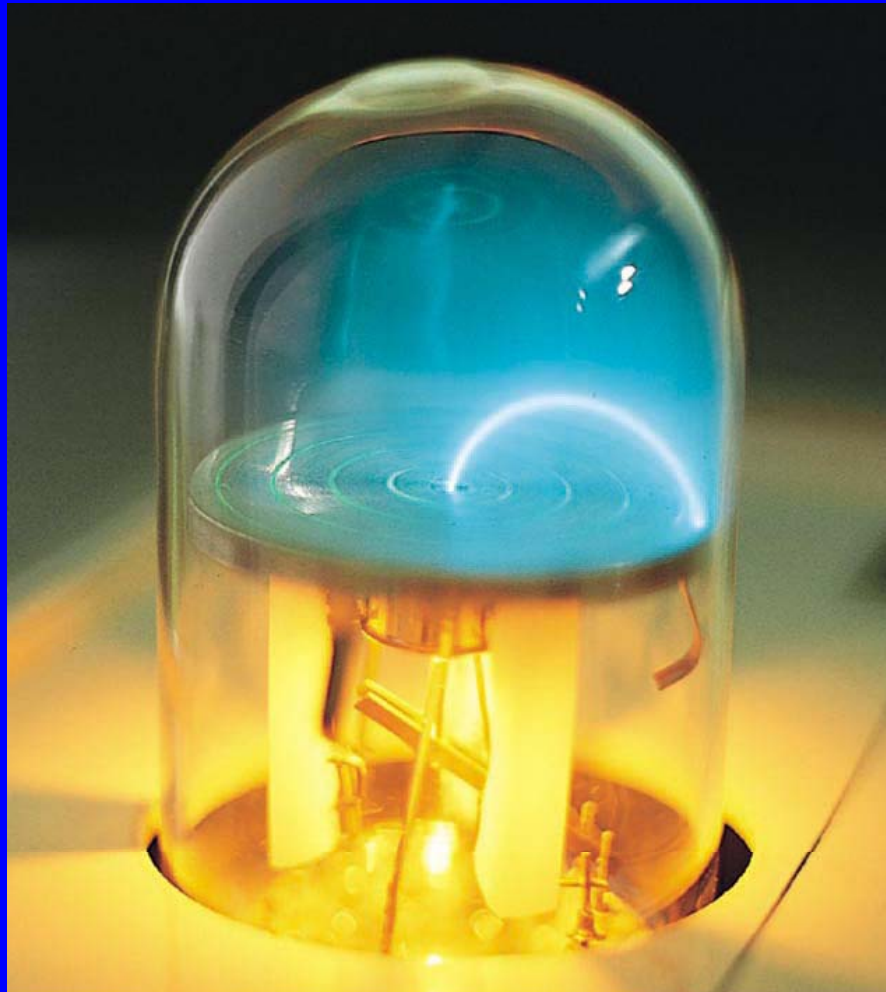
The force on a moving charge is related to the force on a current:

$$F = qvB \sin \theta$$

Once again, the direction is given by a right-hand rule.

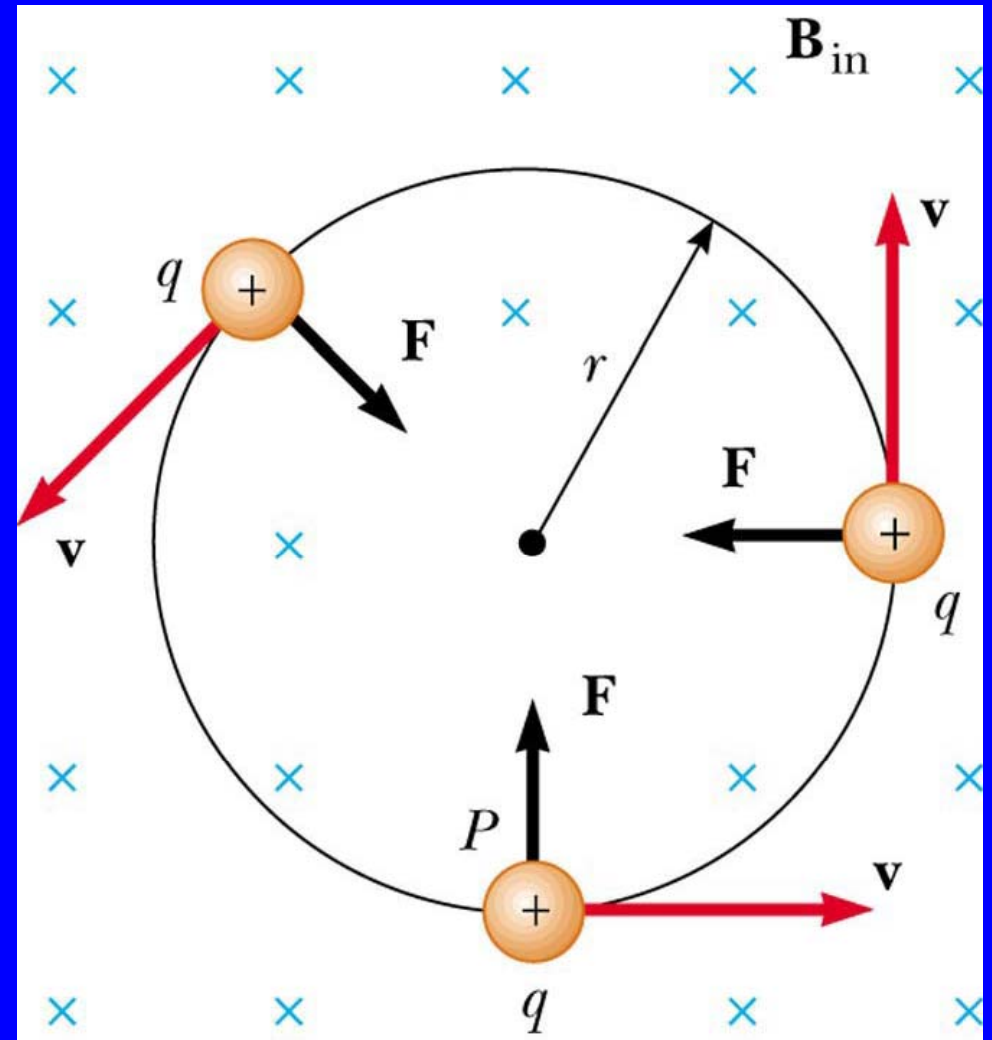


# Bending an Electron Beam in an External Magnetic Field



# Force on a Charged Particle in a Magnetic Field

- Consider a particle moving in an external magnetic field so that its velocity is perpendicular to the field
- The force is always directed toward the center of the circular path
- The magnetic force causes a centripetal acceleration, changing the direction of the velocity of the particle



# Force on a Charged Particle

- Equating the magnetic and centripetal forces:

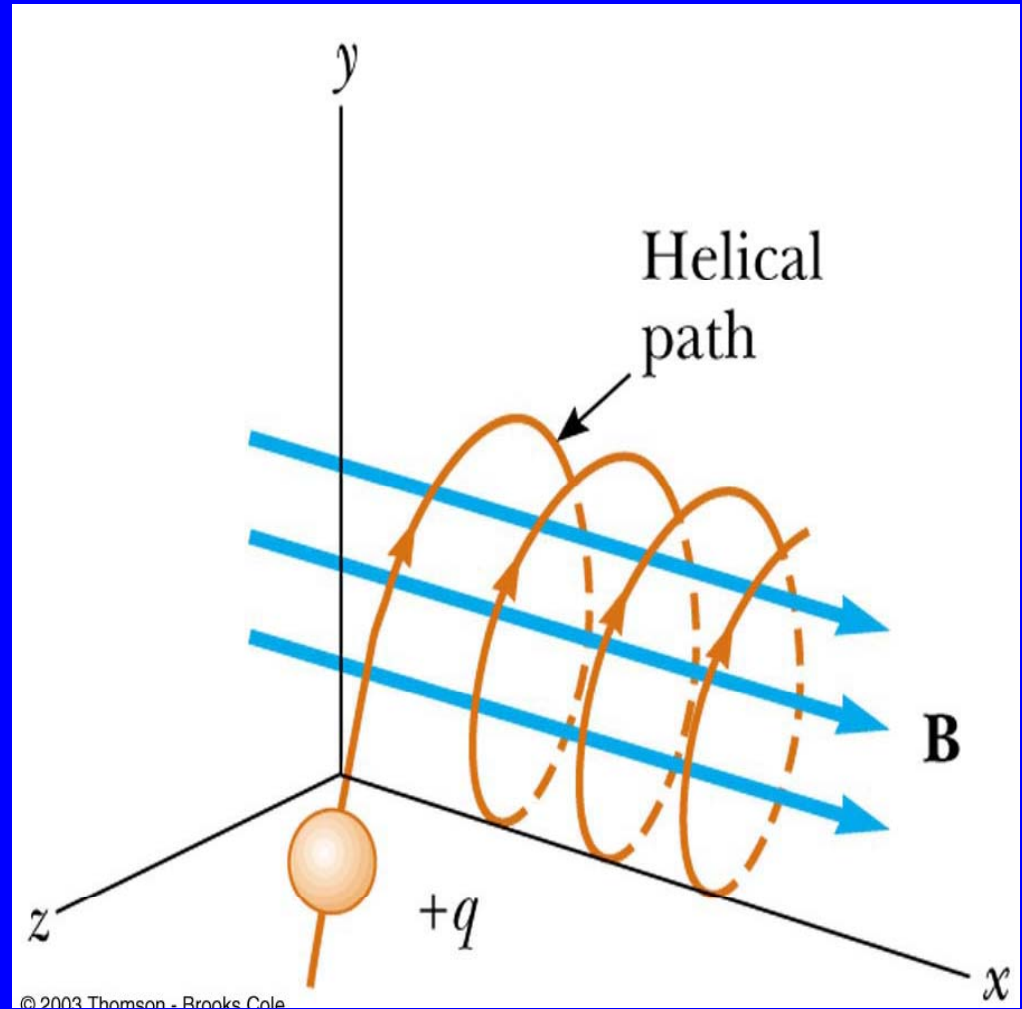
$$F = qvB = \frac{mv^2}{r}$$

- Solving for r:  $r = \frac{mv}{qB}$

- r is proportional to the momentum of the particle and inversely proportional to the magnetic field

# Particle Moving in an External Magnetic Field

- If the particle's velocity is *not* perpendicular to the field, the path followed by the particle is a spiral
  - The spiral path is called a *helix*



# QUICK QUIZ 1

The north-pole end of a bar magnet is held near a stationary positively charged piece of plastic.

Is the plastic (a) attracted, (b) repelled, or (c) unaffected by the magnet?

# QUICK QUIZ 1 ANSWER

(c). The magnetic force exerted by a magnetic field on a charge is proportional to the charge's velocity relative to the field. If the charge is stationary, as in this situation, there is no magnetic force.