Chapter 27 – Magnetic Fields and Forces

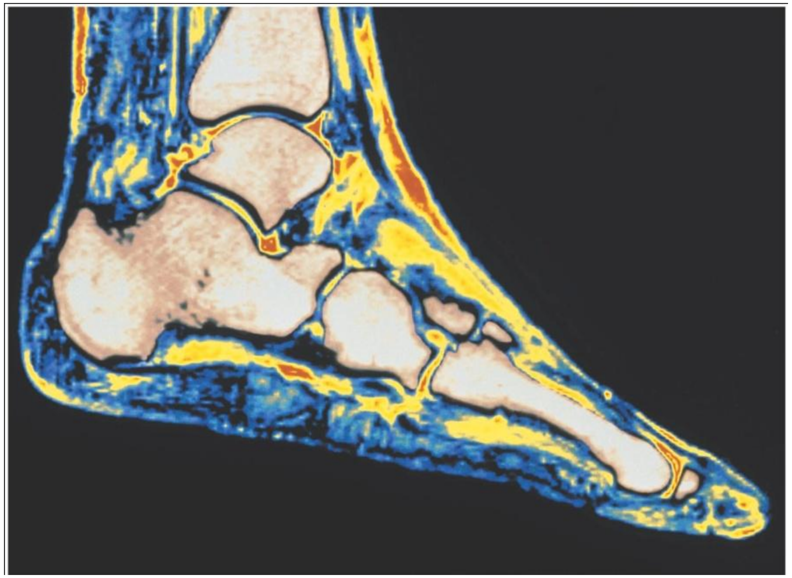
If we had special relativity we would find there is no such thing as a magnetic field. It is only a relativistic transformation of an electric field

Goals for Chapter 27

- To study magnetic forces
- To consider magnetic field and flux
- To explore motion in a magnetic field
- To calculate the magnetic force on a semiconductor
- To consider magnetic torque
- To apply magnetic principles and study the electric motor
- To study the Hall effect

Introduction

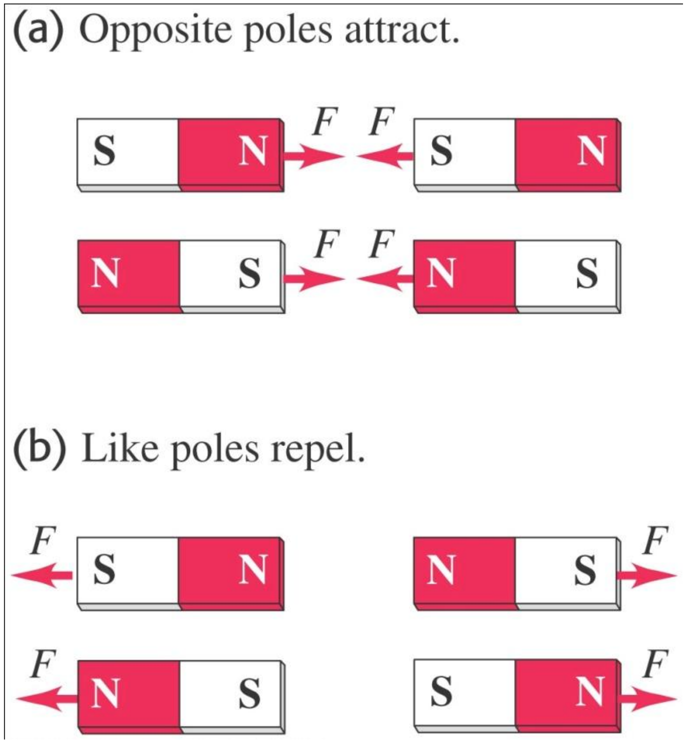
- Magnets exert forces on each other just like charges. You can draw magnetic field lines just like you drew electric field lines.
- Electrostatics, electrodynamics, and magnetism are deeply interwoven.
- MRI scan of a human foot. The magnetic field interacts with molecules in the body to orient spin before radiofrequencies are used to make the spectroscopic map. The different shades are a result of the range of responses from different types of tissue in the body.



Magnetism

– Magnetic north and south poles' behavior is not unlike electric charges. For magnets, like poles repel and opposite poles attract. BUT the poles of a magnet are NOT literally magnetic monopoles. In an electrostatic dipole the "pole ends" are in fact monopoles.

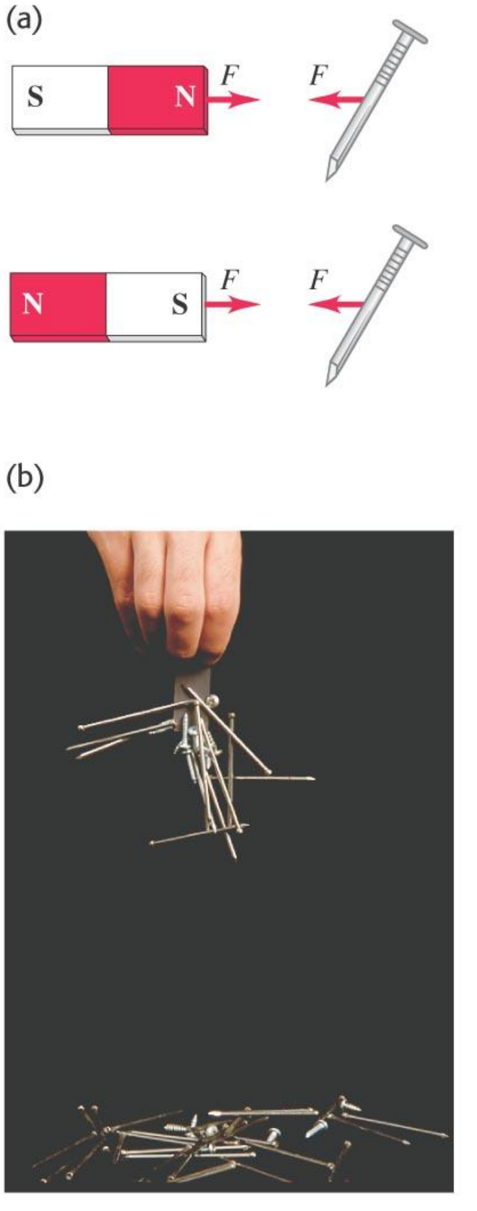
– **We have never found a magnetic monopole.**



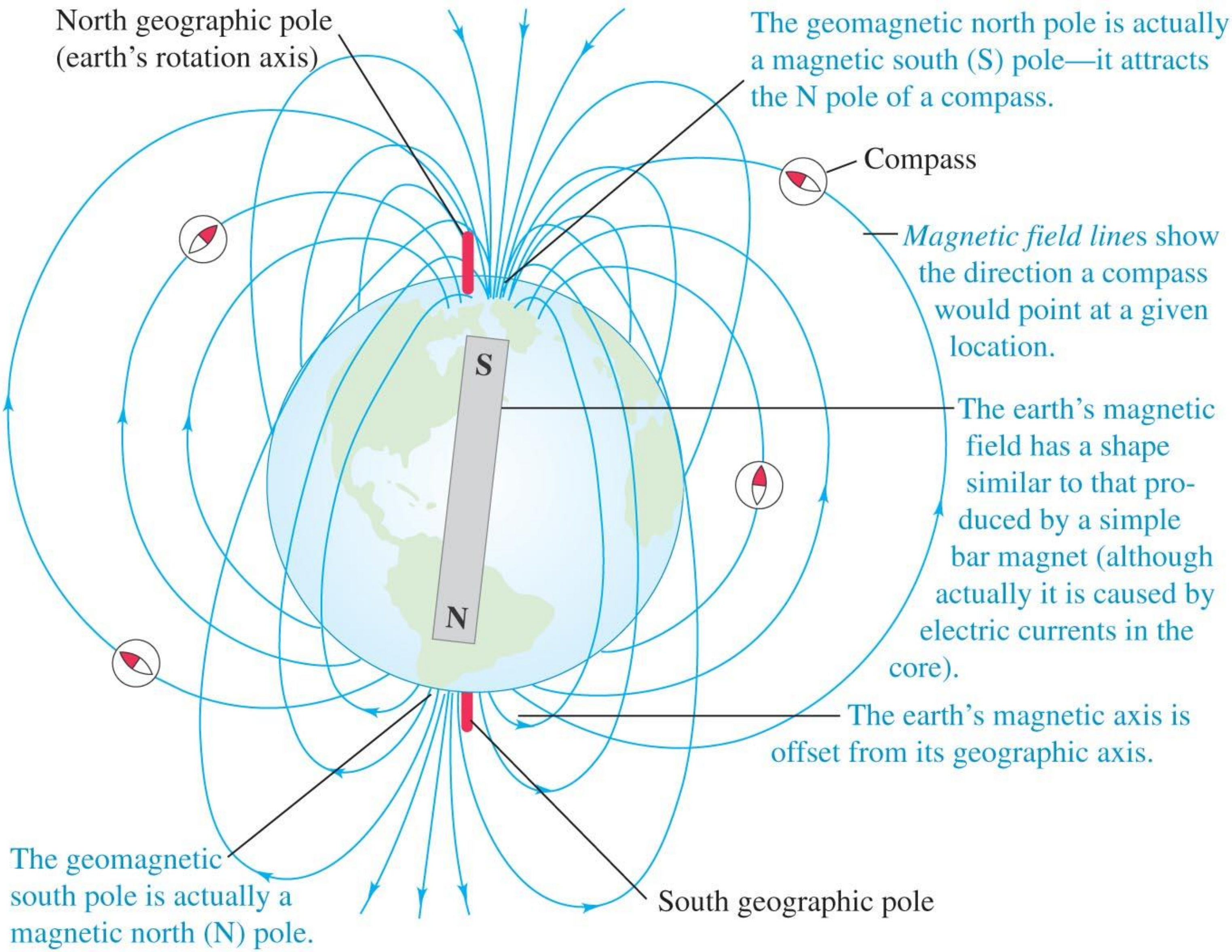
Magnetism and certain metals

– A permanent magnet will attract a metal like iron with either the north or south pole.

– Remember the electrostatic case of “static cling” from induced electric dipoles. Here all magnets are dipoles no monopoles known.

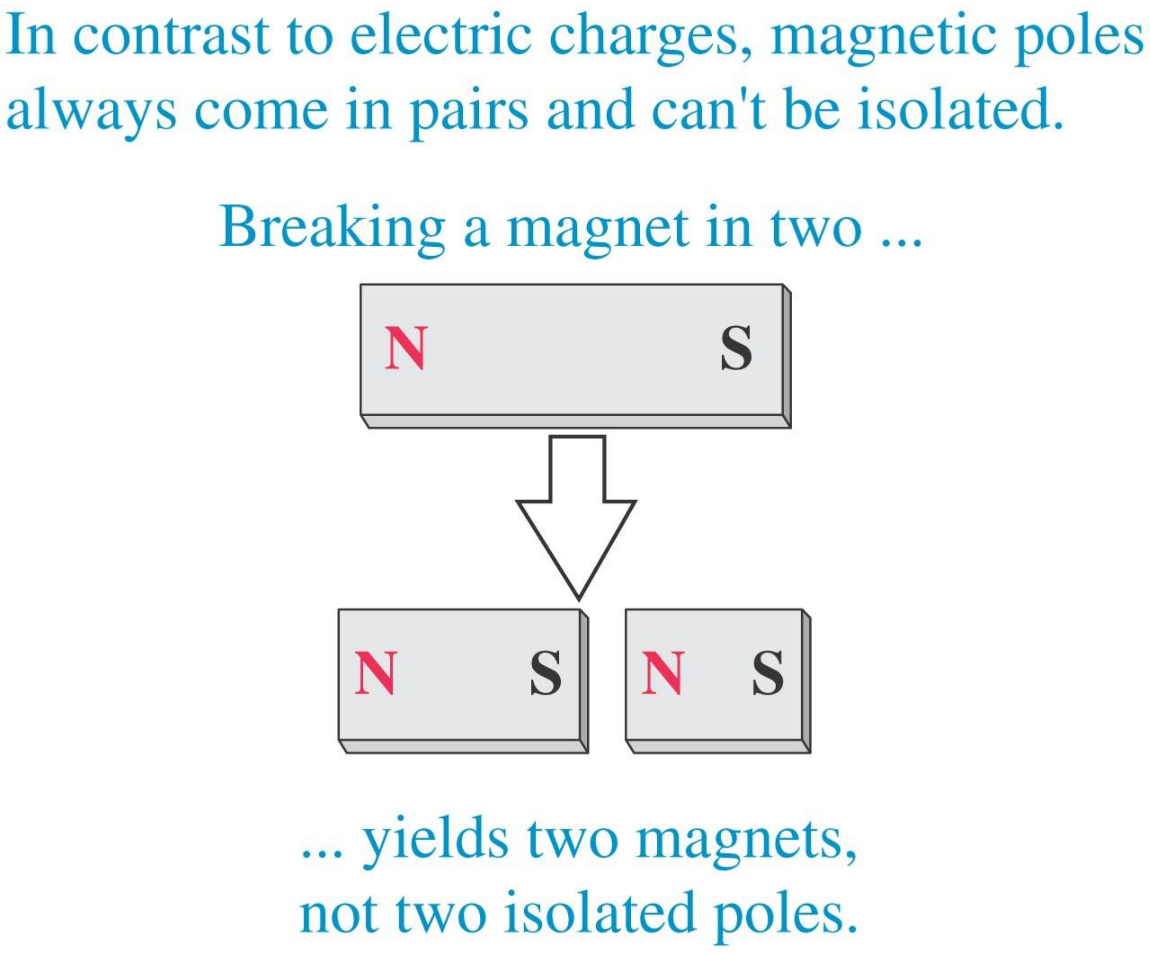


The magnetic poles about our planet North is South



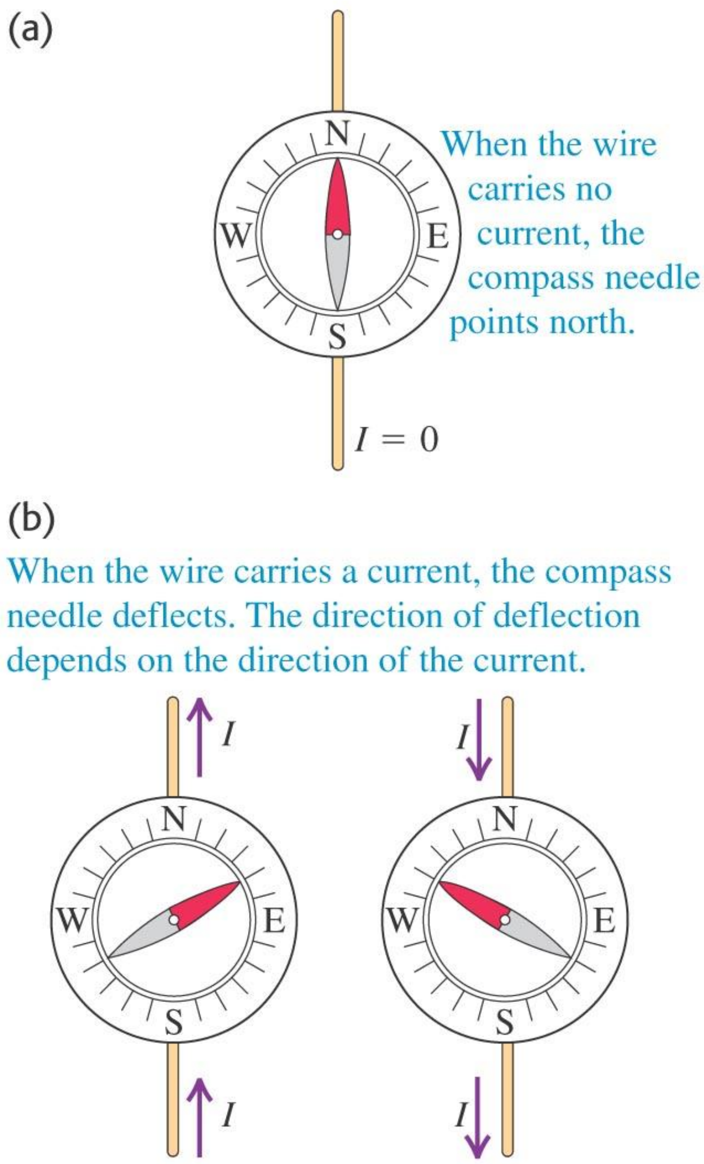
Magnetic pole(s)?

- We observed monopoles in electricity. A (+) or (−) alone was stable and field lines could be drawn around it.
- Magnets cannot exist as monopoles. If you break a bar magnet between N and S poles, you get two smaller magnets, each with its own N and S pole.



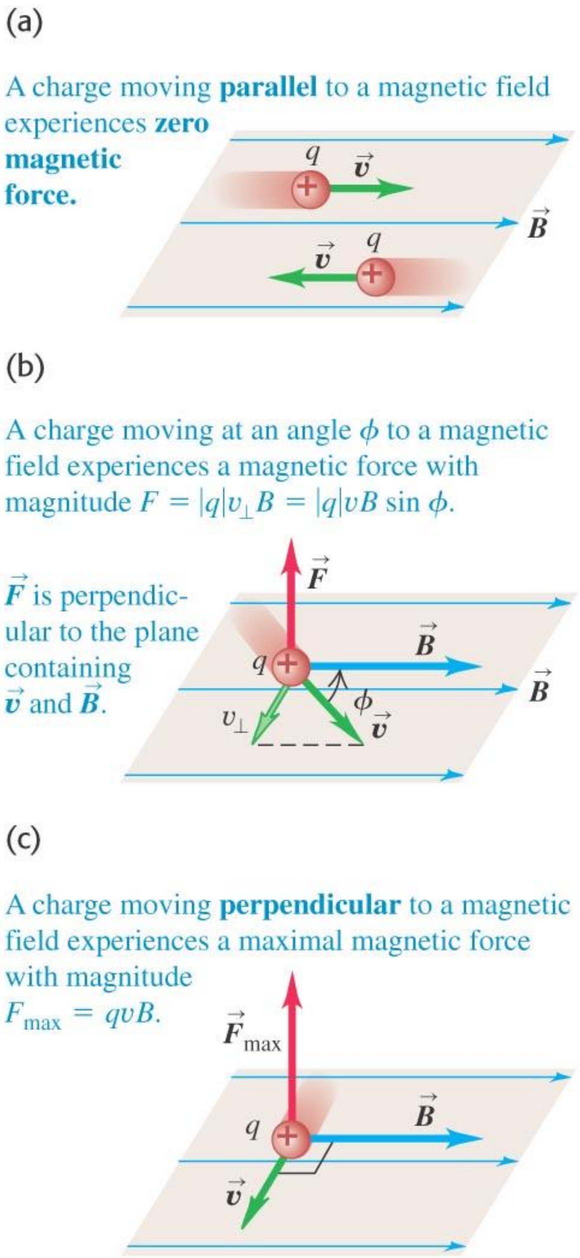
Electric current and magnets

- In 1820, Hans Oersted ran a series of experiments with conducting wires run near a sensitive compass. The result was dramatic. The orientation of the wire and the direction of the flow both moved the compass needle.
- There had to be something magnetic about current flow.



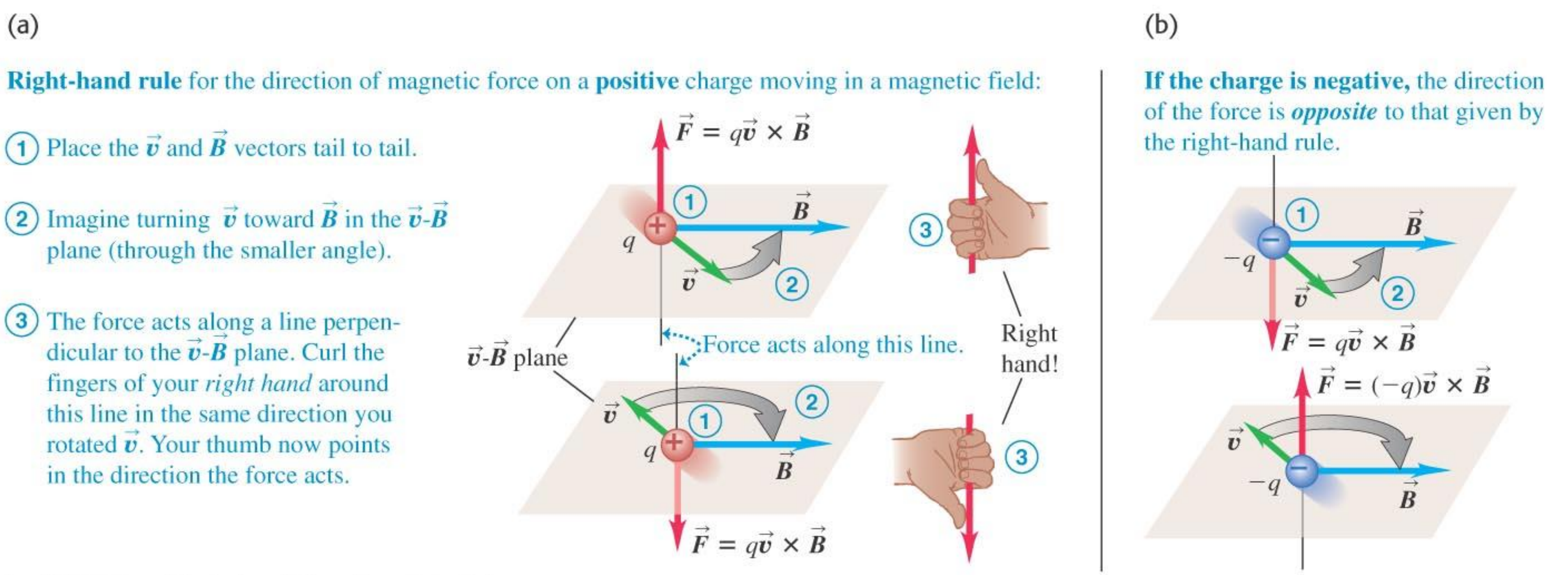
The interaction of magnetic force and charge

- The moving charge interacts with the fixed magnet. The force between them is at a maximum when the velocity of the charge is perpendicular to the magnetic field.



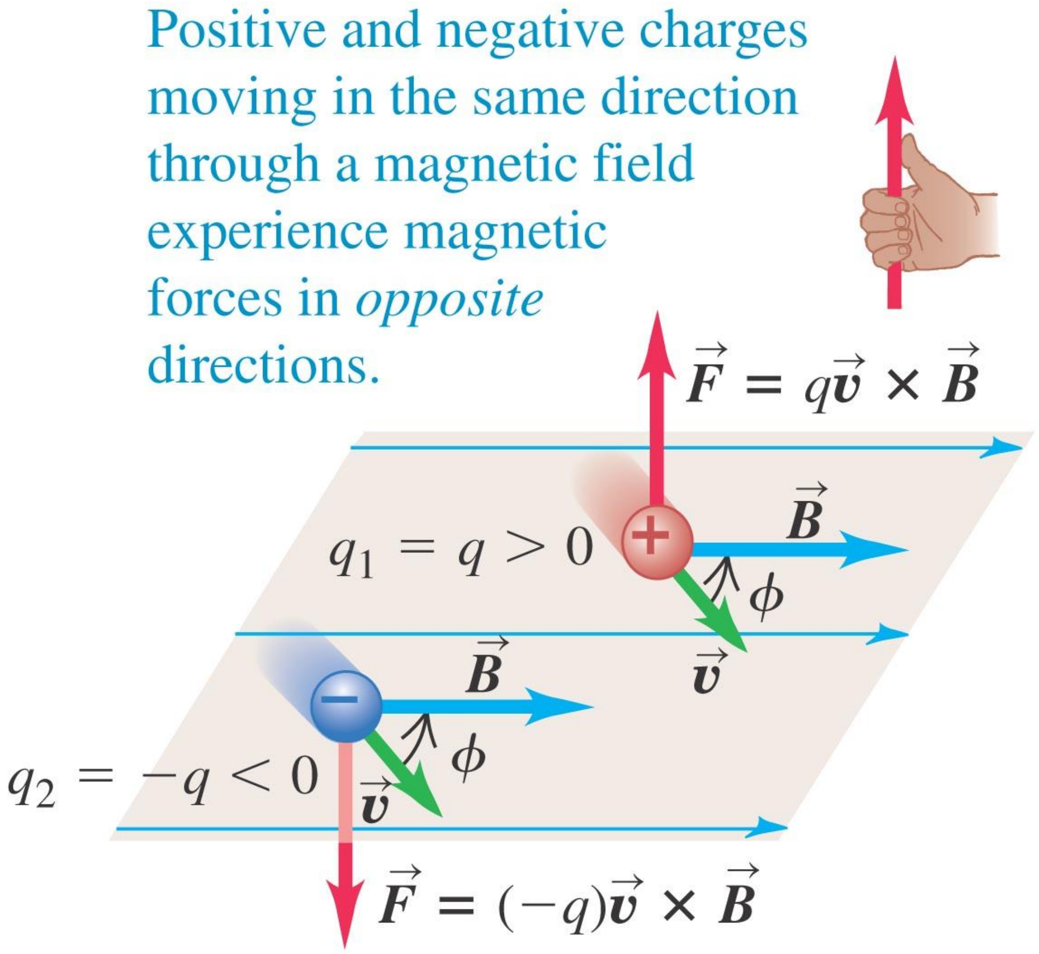
The “right-hand rule” I

- This is for a positive charge moving in a magnetic field.
- Place your hand out as if you were getting ready for a handshake. Your fingers represent the velocity vector of a moving charge.
- Move the fingers of your hand toward the magnetic field vector.
- Your thumb points in the direction of the force between the two vectors.



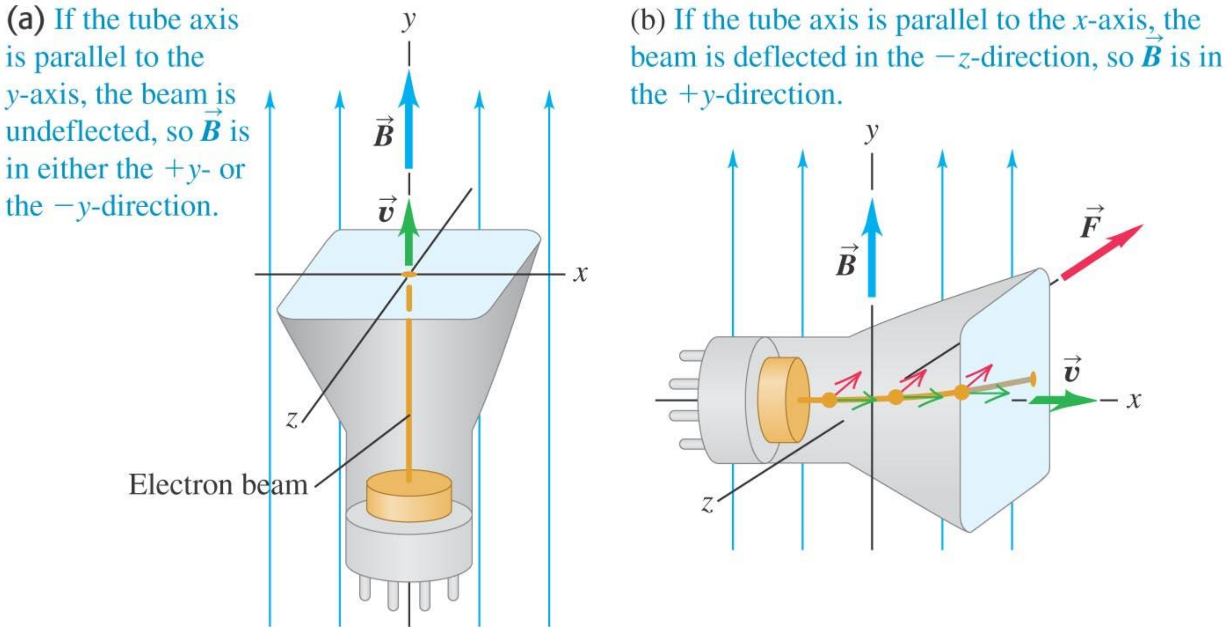
Right-hand rule II

- Two charges of equal magnitude but opposite signs moving in the same direction in the same field will experience force in opposing directions.



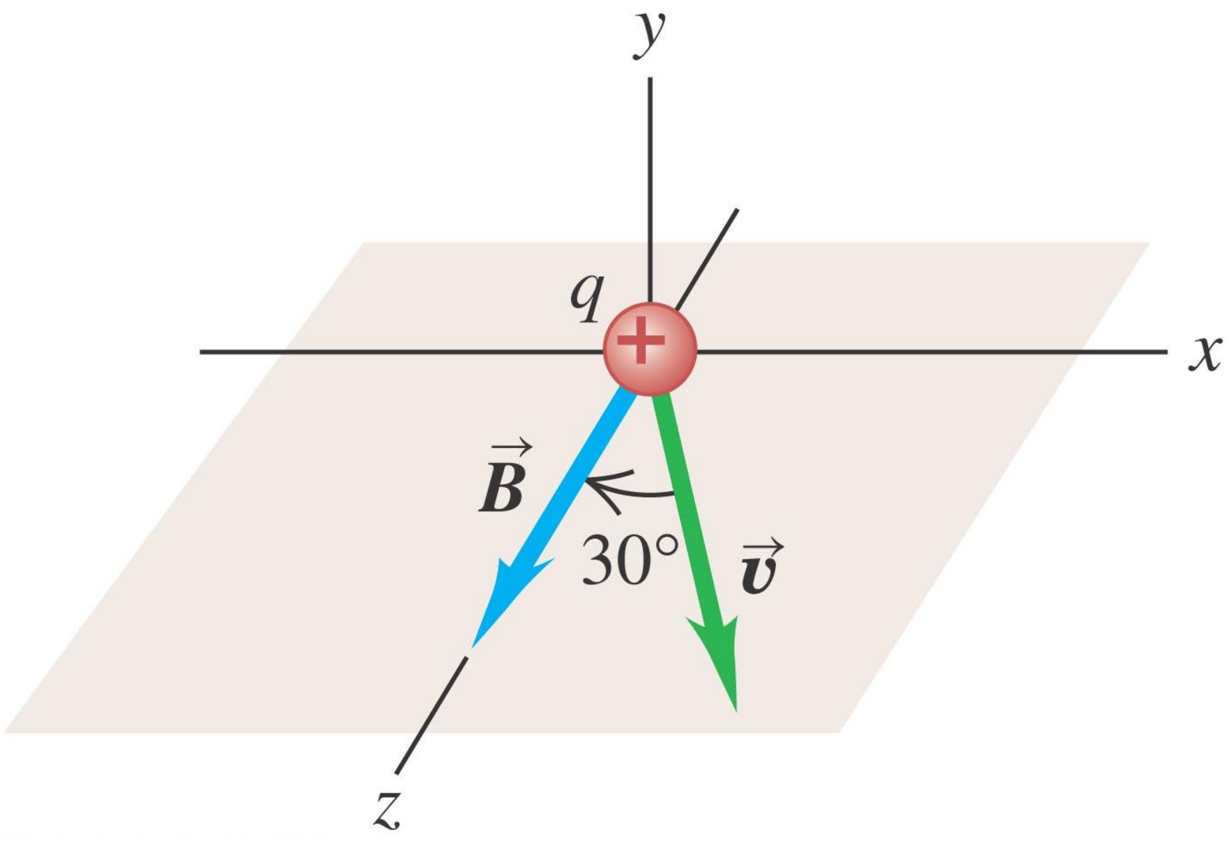
Direction of a magnetic field with your CRT

- A TV or a computer screen is a cathode ray tube, an electron gun with computer aiming control. Place it in a magnetic field going "up and down."
- You point the screen toward the ceiling and nothing happens to the picture. The magnetic field is parallel to the electron beam.
- You set the screen in a normal viewing position and the image distorts. The magnetic force is opposite to the thumb in the RHR.



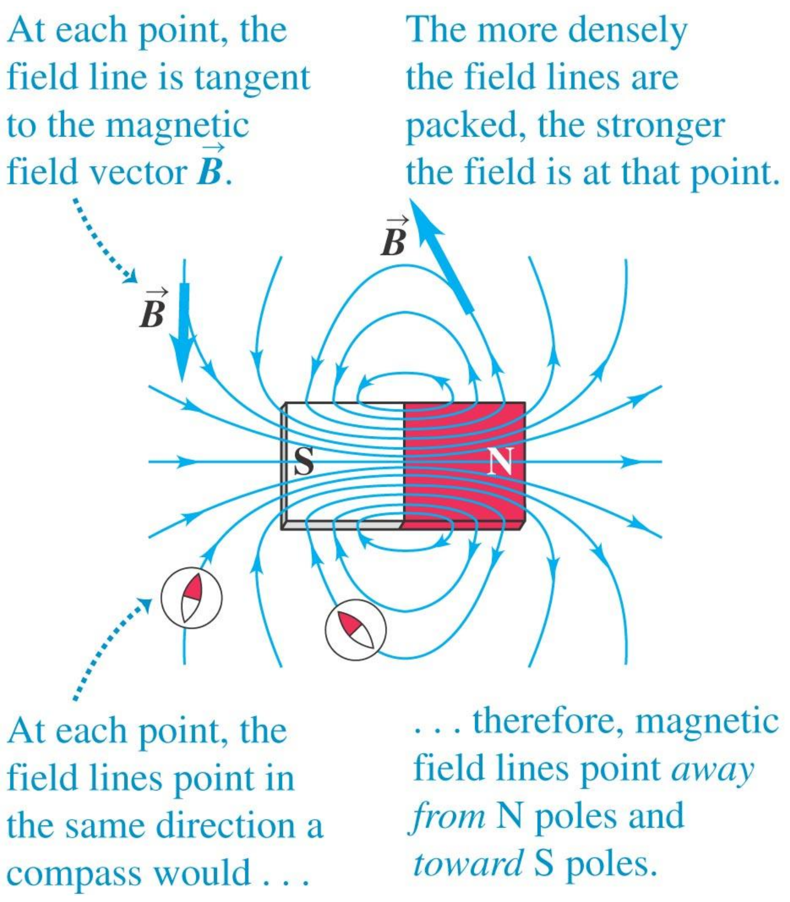
Magnetic forces

- **F = q (V x B)**



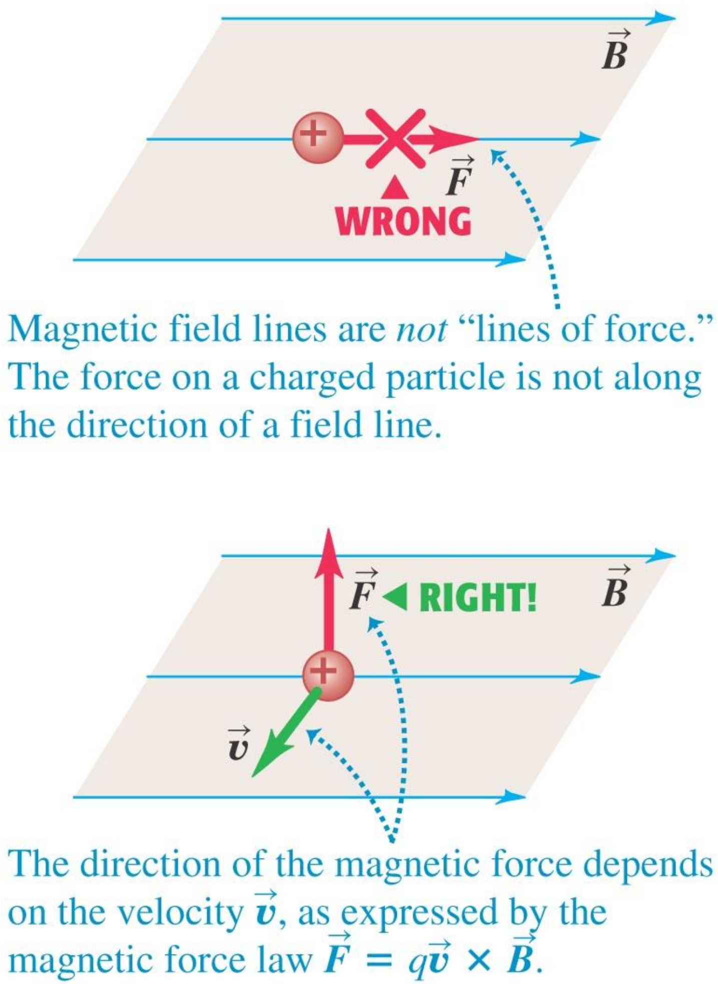
Magnetic field lines may be traced

- Magnetic field lines may be traced from N toward S in analogous fashion to the electric field lines.
- Refer to Figure 27.11.



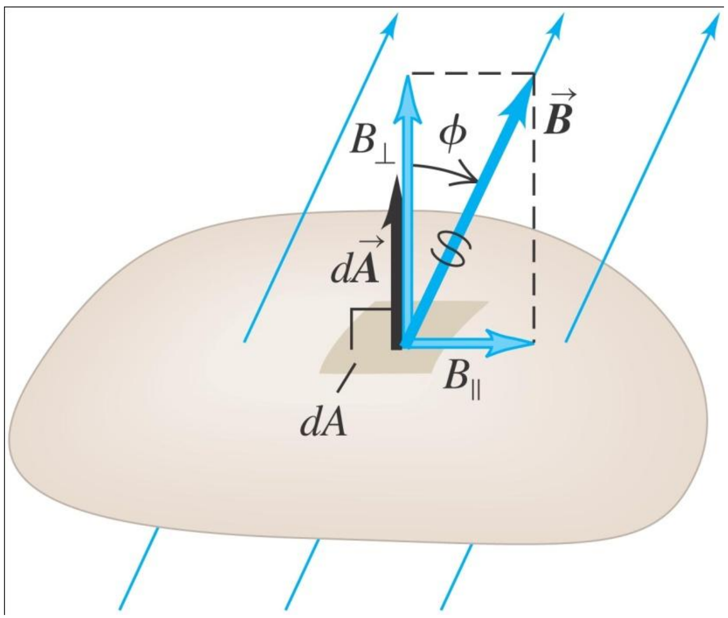
Field lines are not lines of force

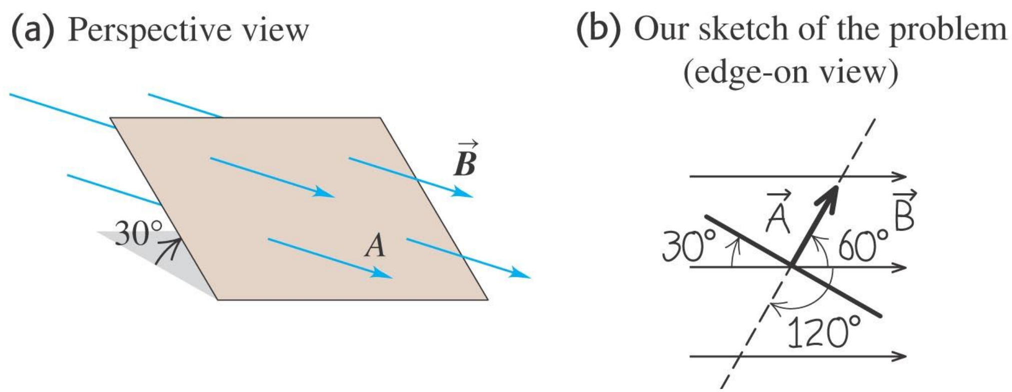
- The lines tracing the magnetic field crossed through the velocity vector of a moving charge will give the direction of force by the RHR.



Magnetic flux through an area

- We define the magnetic flux through a surface just as we defined electric flux.

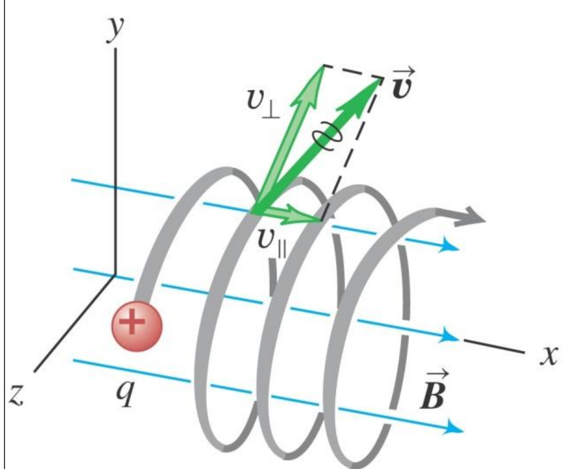




Motion of charged particles in a magnetic field

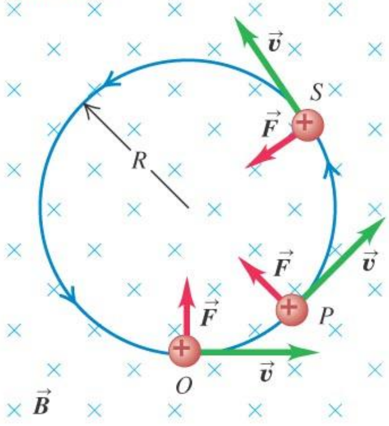
- A charged particle will move in a plane perpendicular to the magnetic field.
- Figure 27.17 at right illustrates the forces and shows an experimental example.
- Figure 27.18 below shows the constant kinetic energy and helical path.

This particle's motion has components both parallel ($v_{\parallel}$) and perpendicular ($v_{\perp}$) to the magnetic field, so it moves in a helical path.

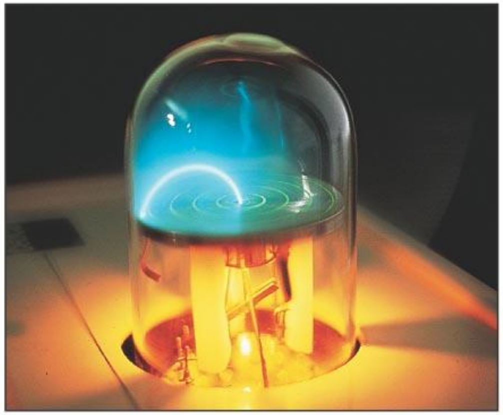


(a) The orbit of a charged particle in a uniform magnetic field

A charge moving at right angles to a uniform $\vec{B}$ field moves in a circle at constant speed because $\vec{F}$ and $\vec{v}$ are always perpendicular to each other.

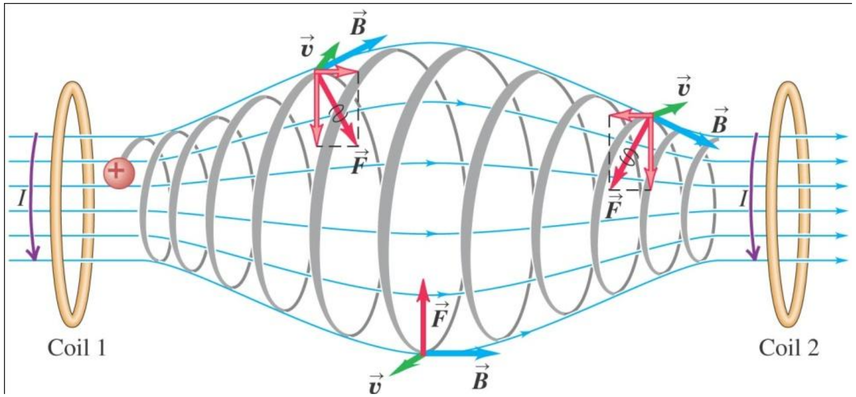


(b) An electron beam (seen as a blue arc) curving in a magnetic field

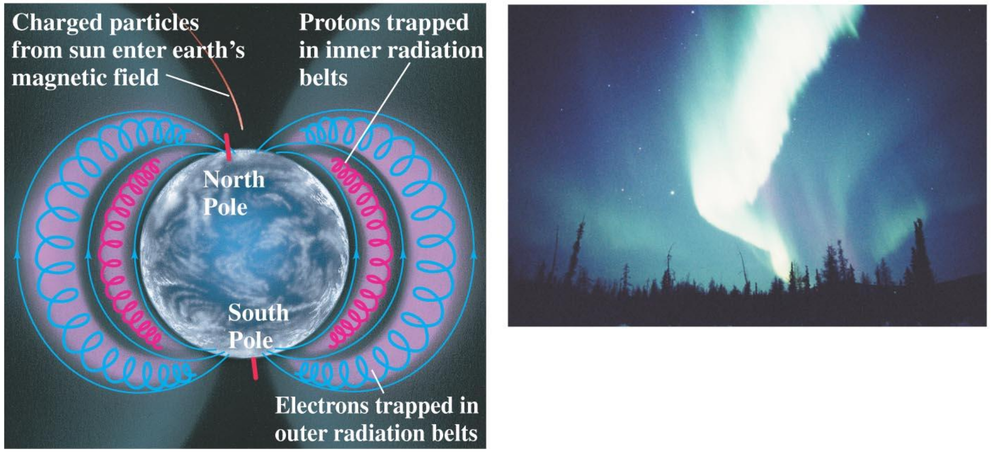


A magnetic bottle

- If we ever get seriously close to small-lab nuclear fusion, the magnetic bottle will likely be the only way to contain the unimaginable temperatures ~ a million K.
- Figure 27.19 diagrams the magnetic bottle and Figure 27.20 shows the real-world examples … northern lights and southern lights.

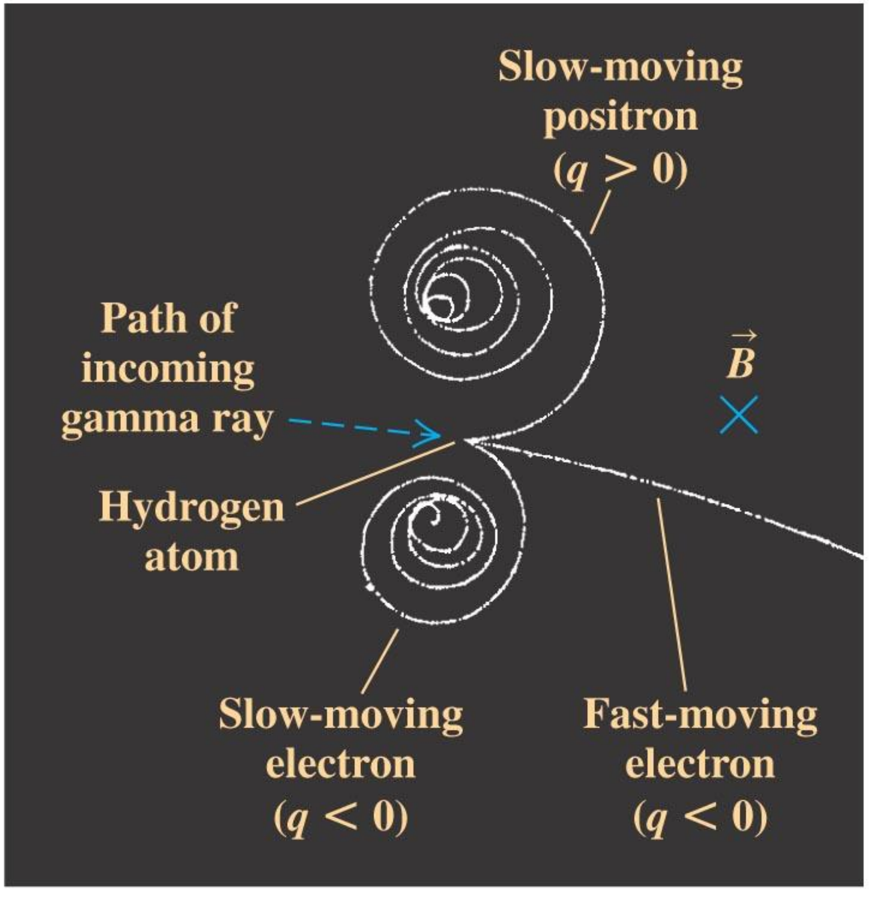


(a) (b)



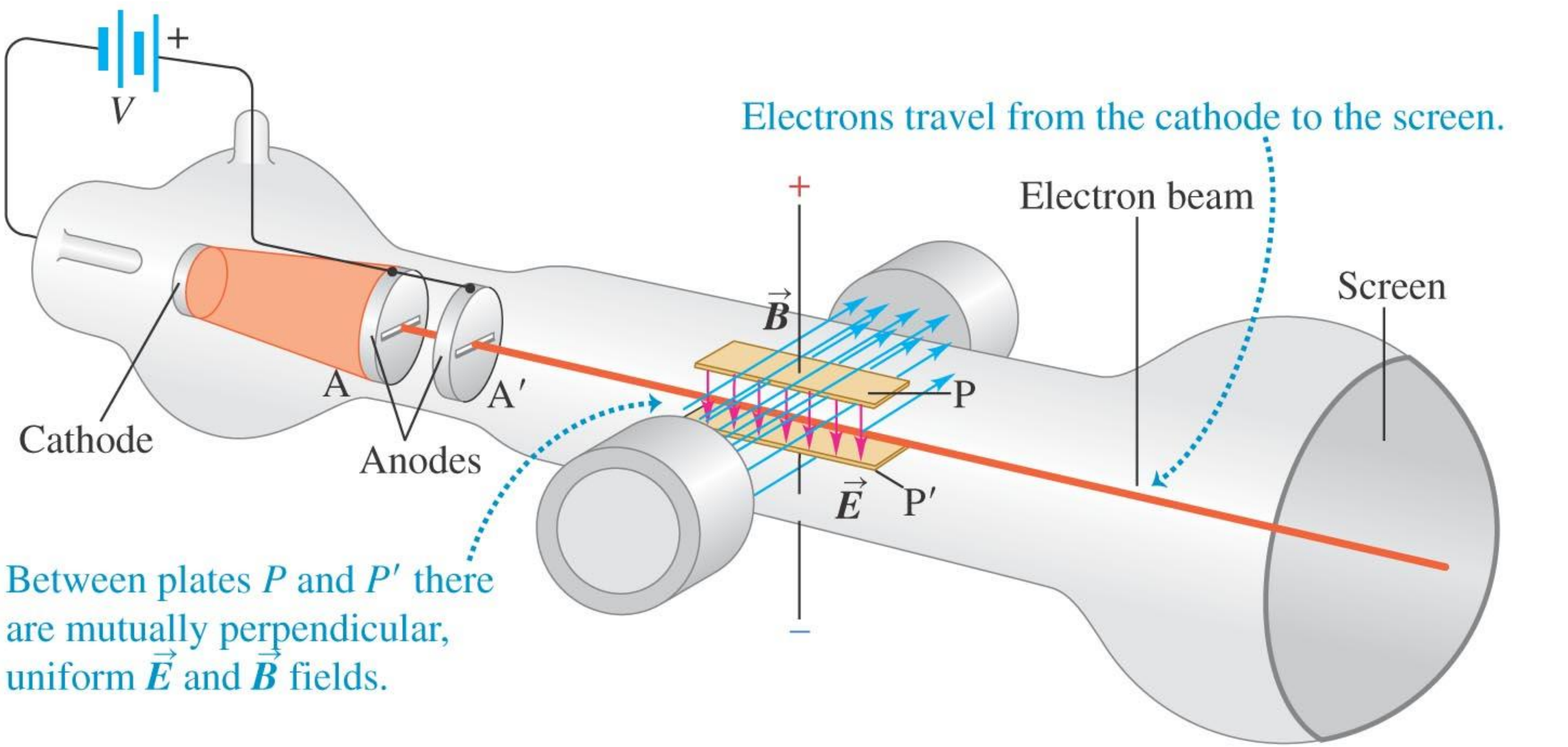
Motion in magnetic fields

- Bubble chambers were used extensively in the 1950 and 60’s to image high energy particle tracks in accelerator collisions.



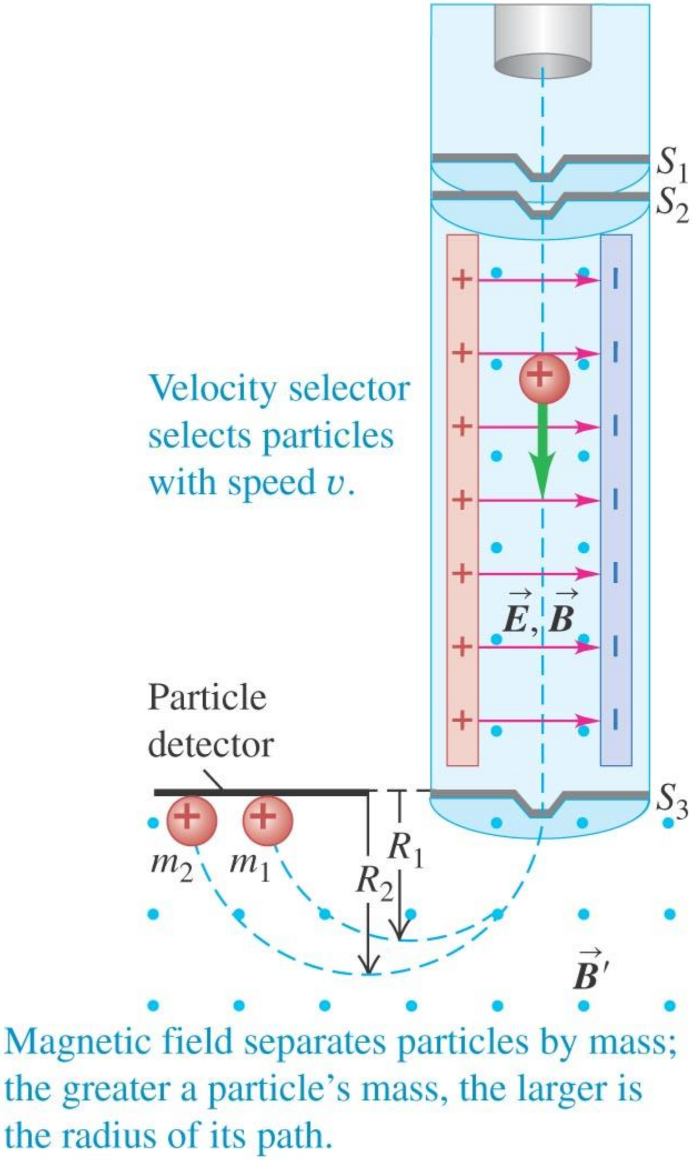
J.J. Thompson was able to characterize the electron

- Thompson's experiment used a combination of electron linear acceleration and magnetic "steering."



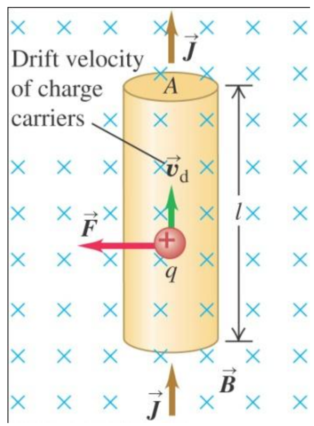
Bainbridge's mass spectrometer

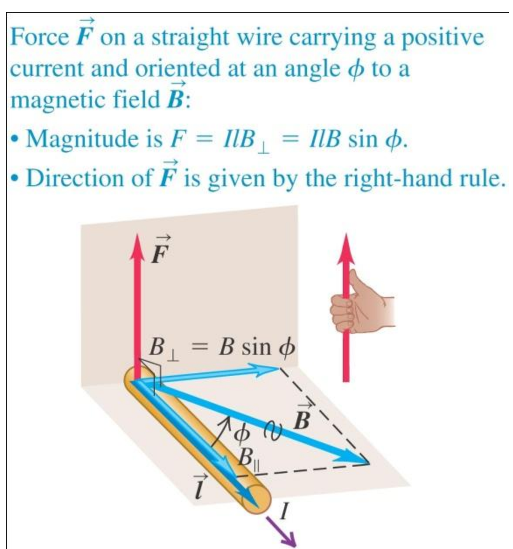
- Using the same concept as Thompson, Bainbridge was able to construct a device that would only allow one mass in flight to reach the detector. The fields could be "ramped" through an experiment containing standards

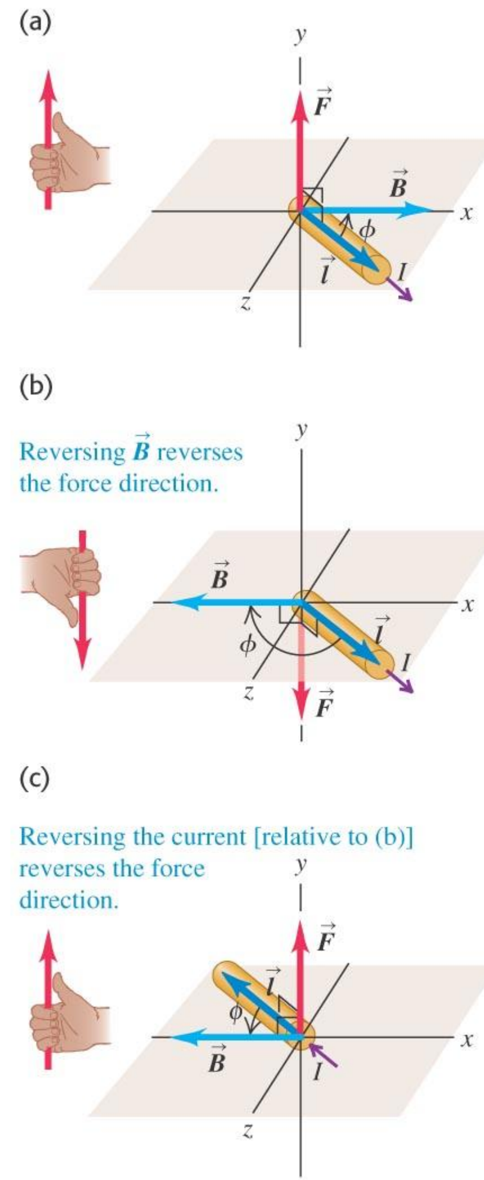


The magnetic force on a current-carrying conductor

- The force is always perpendicular to the conductor and the field.

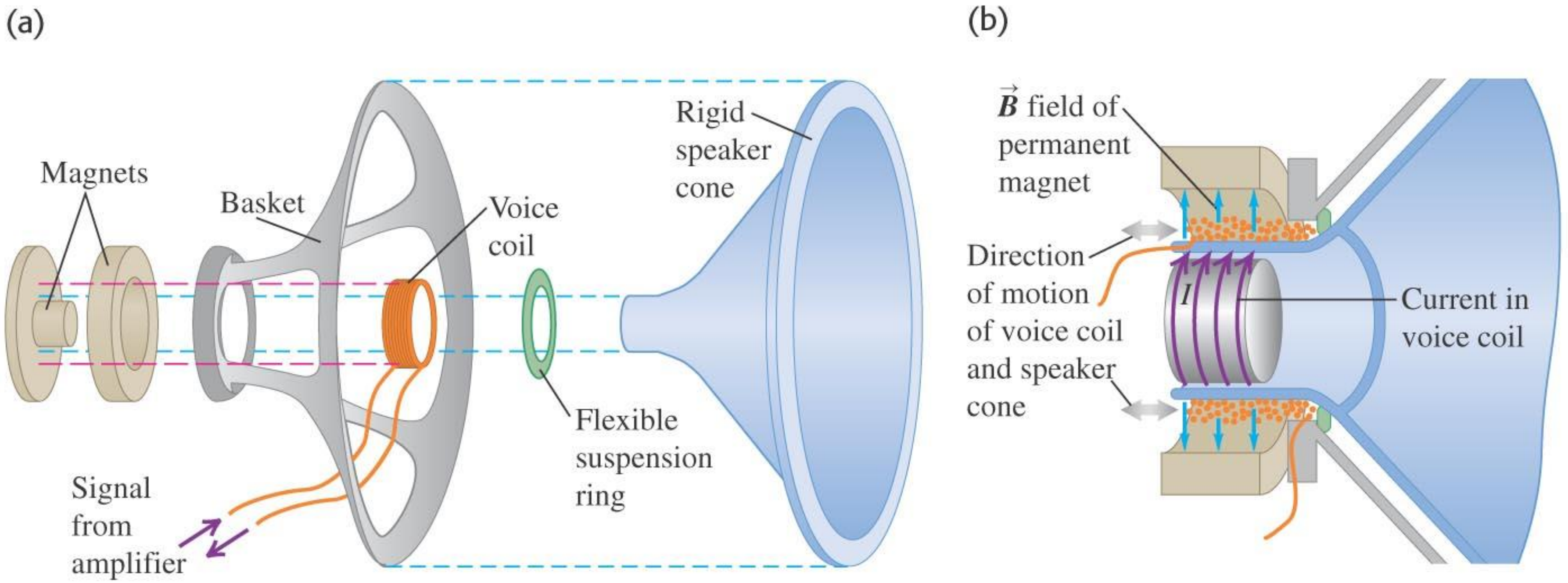




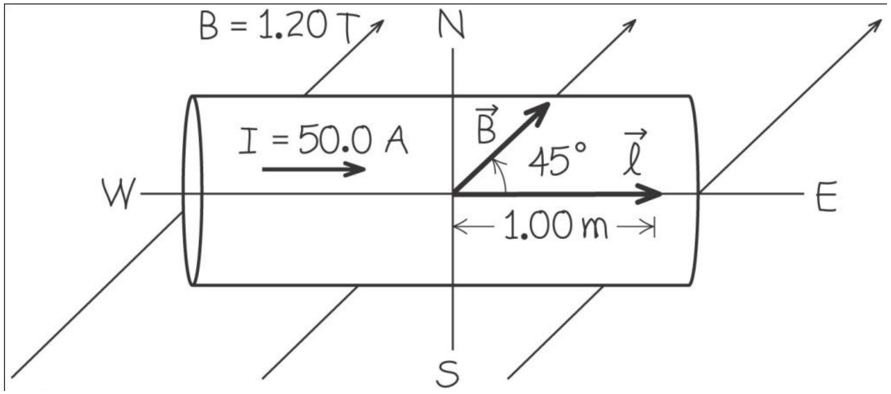


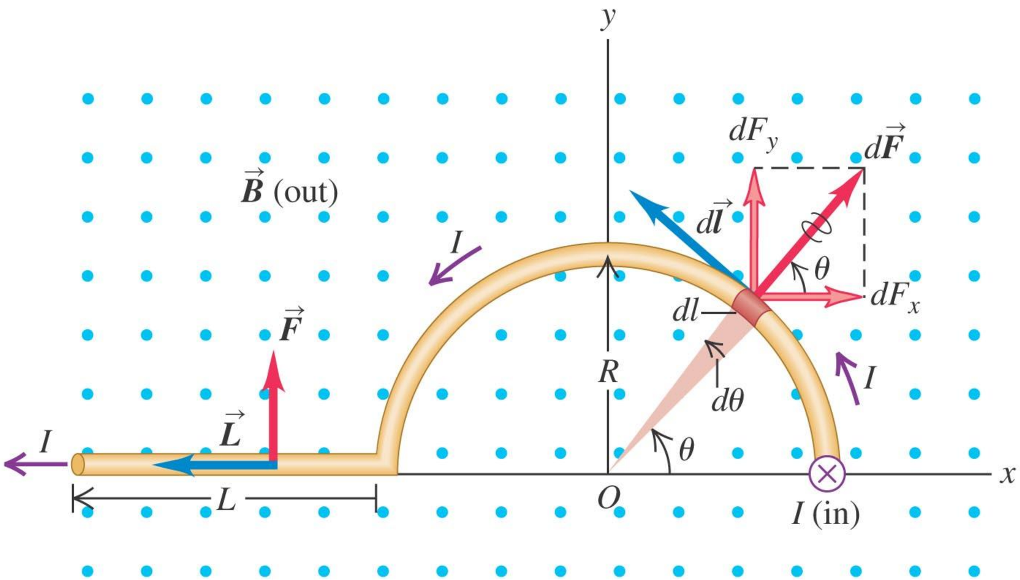
Loudspeakers – Similar to ear buds

- To create music, we need longitudinal pulses in the air. The speaker cone is a combination of induced and permanent magnetism arranged to move the cone to create compressions in the air



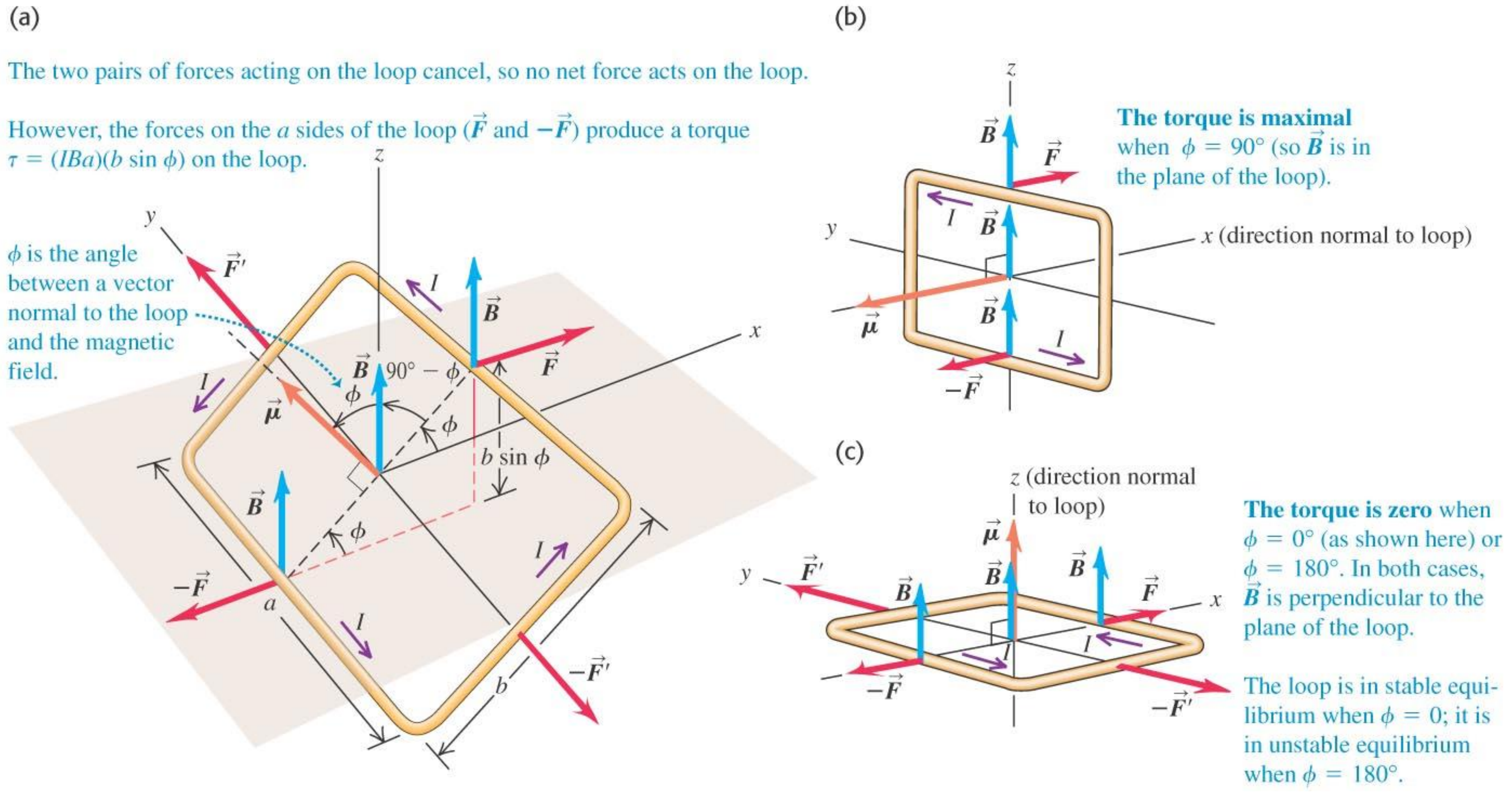
Magnetic force on a straight then curved conductor





Force and torque on a current loop

- This is the basis of electric motors.



The Hall Effect

- Consider the forces on charge carriers as they move through a conductor in a magnetic field. You get charge separation and hence you an measure the voltage. This is called the Hall effect.