Chapter 19

Magnetism

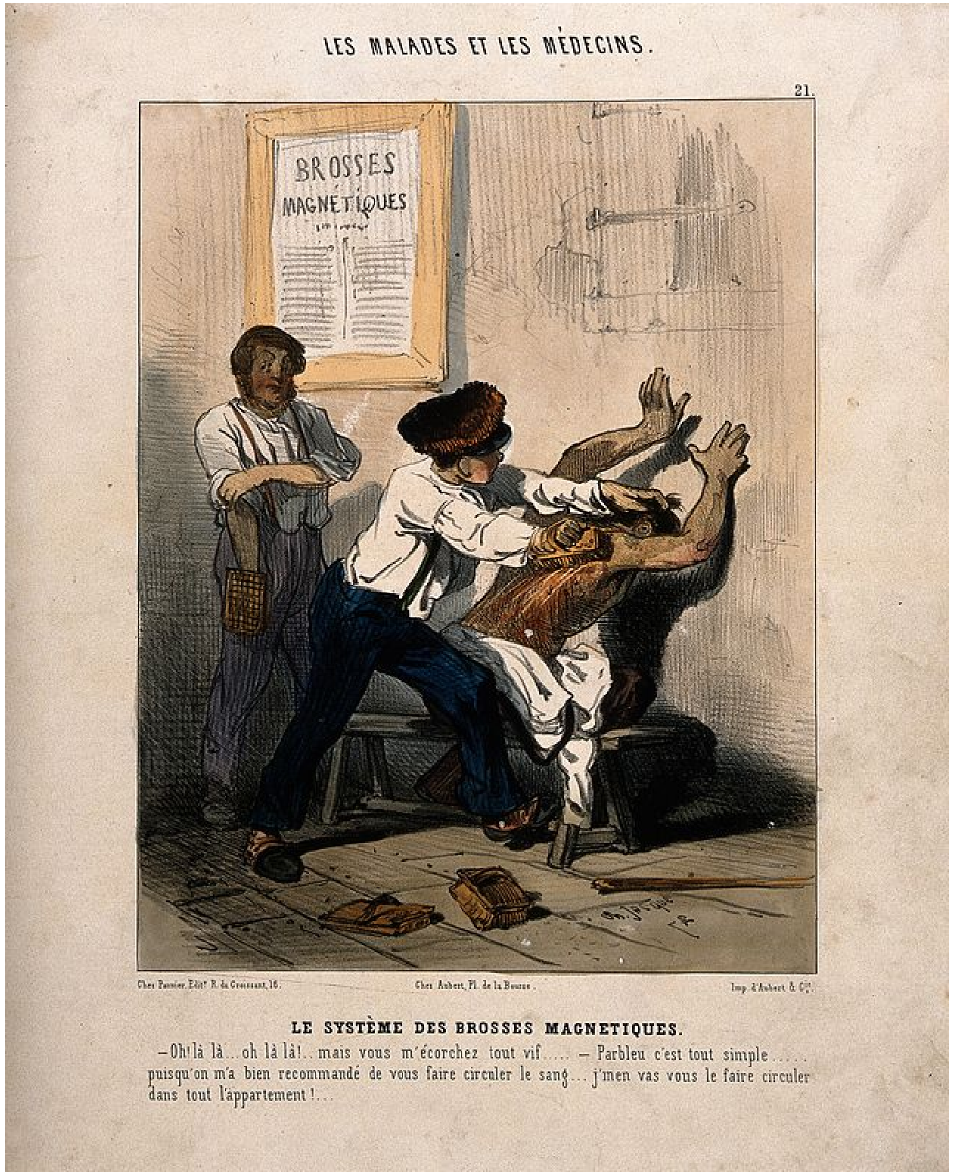
Magnetic Fields and Forces

Fundamentally they do not exist

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

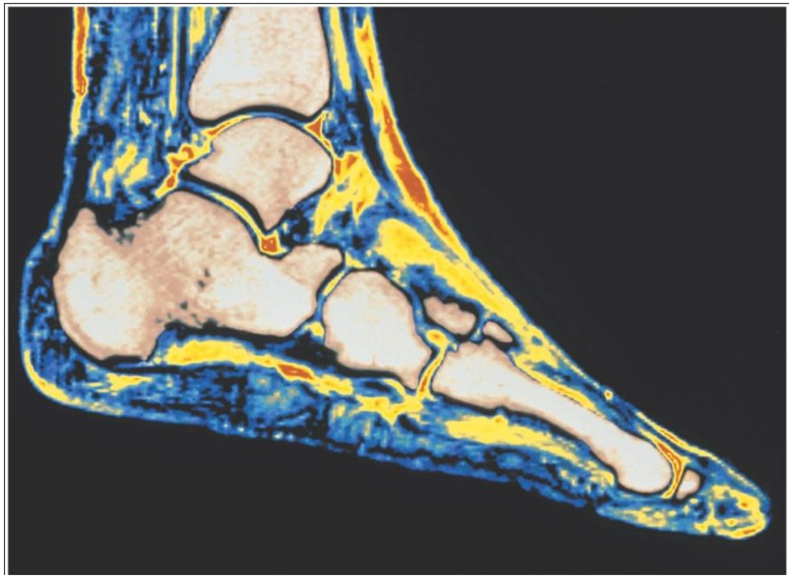
Magnetism and Medical School

Attractive



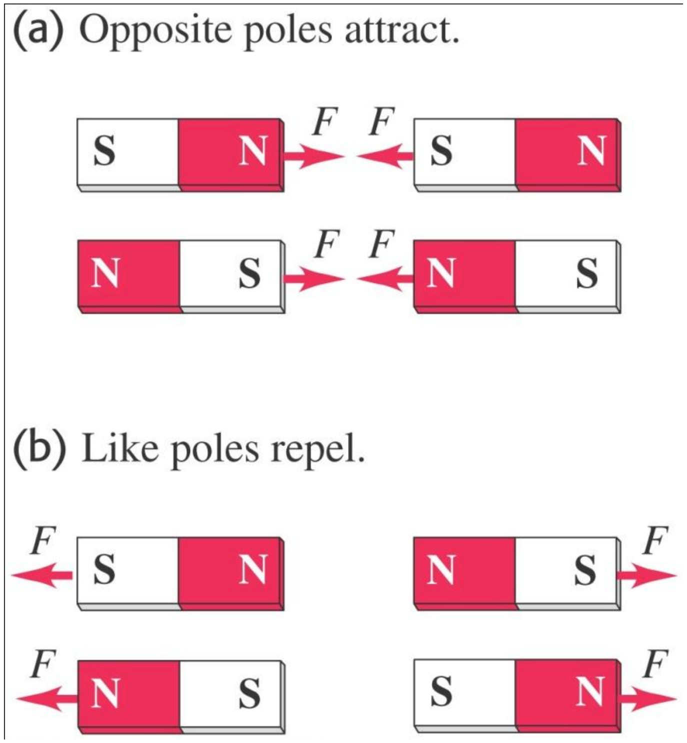
Introduction

- 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.



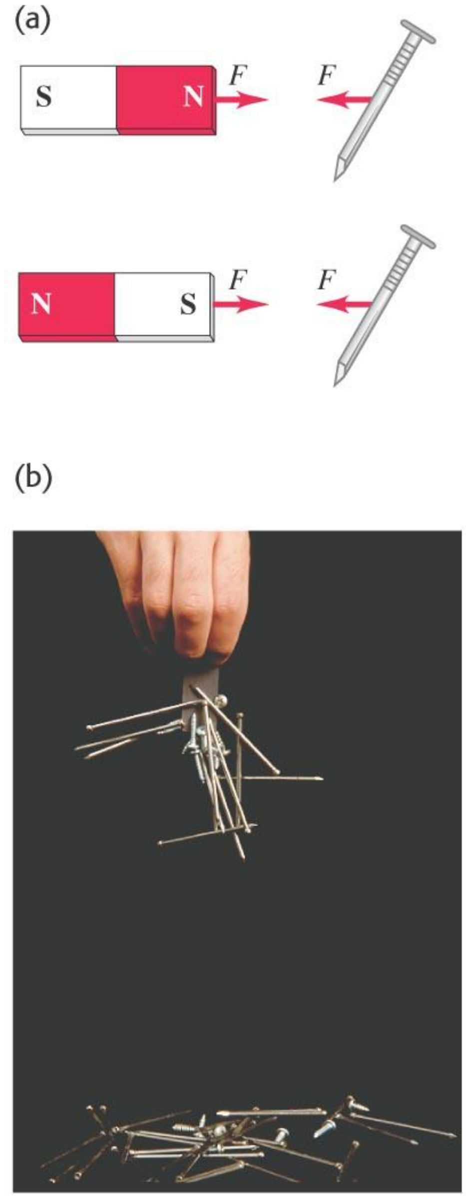
Magnetism

- 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.**

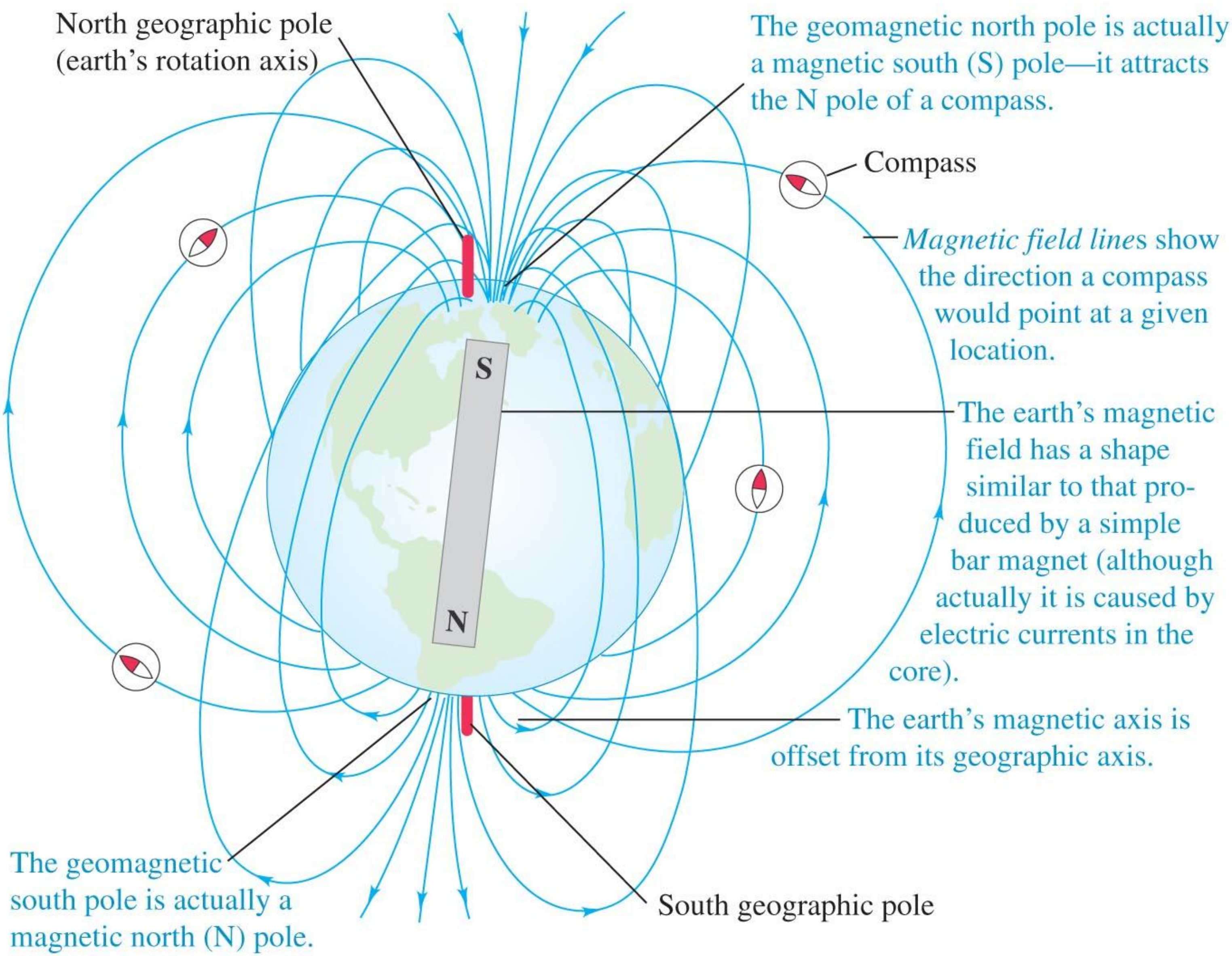


Magnetism and certain metals

- 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.

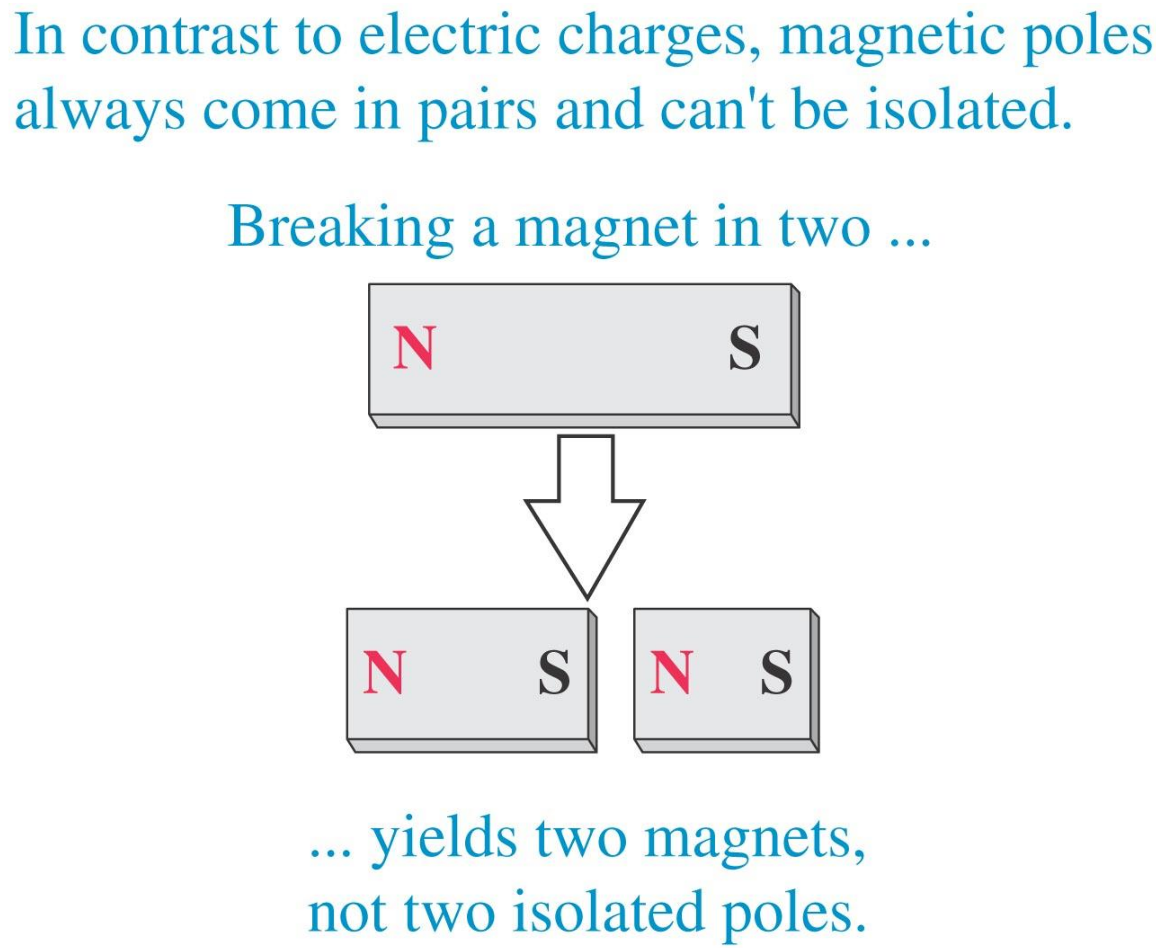


The magnetic poles about our planet North is South



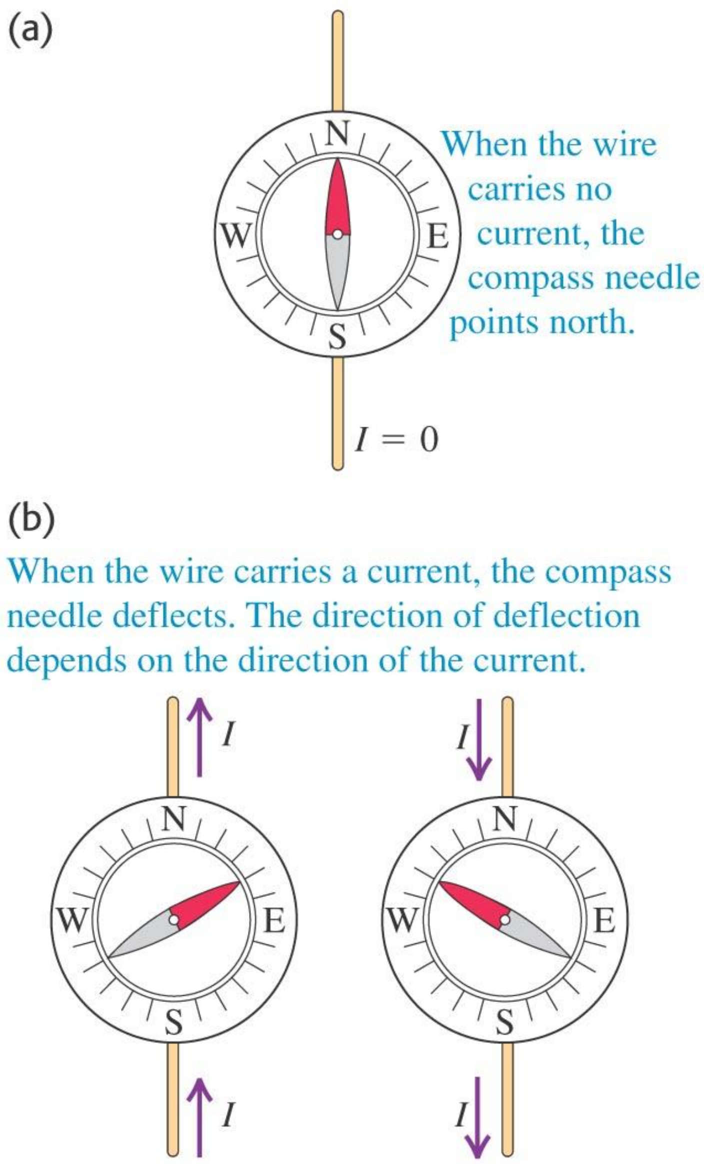
Magnetic pole(s)?

- 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.



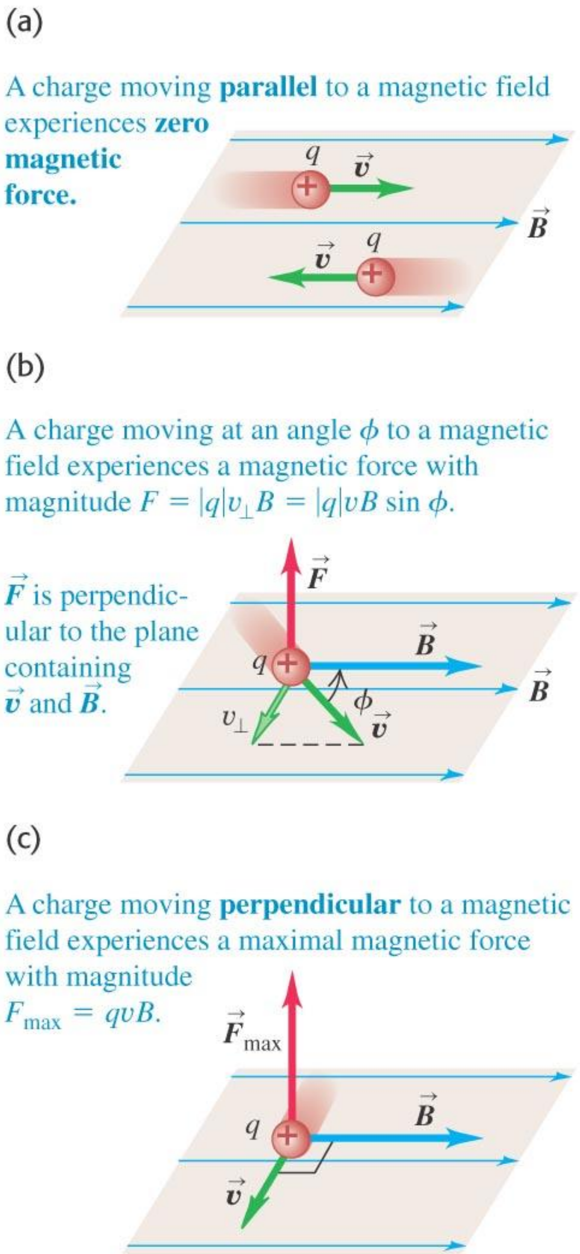
Electric current and magnets

- 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.



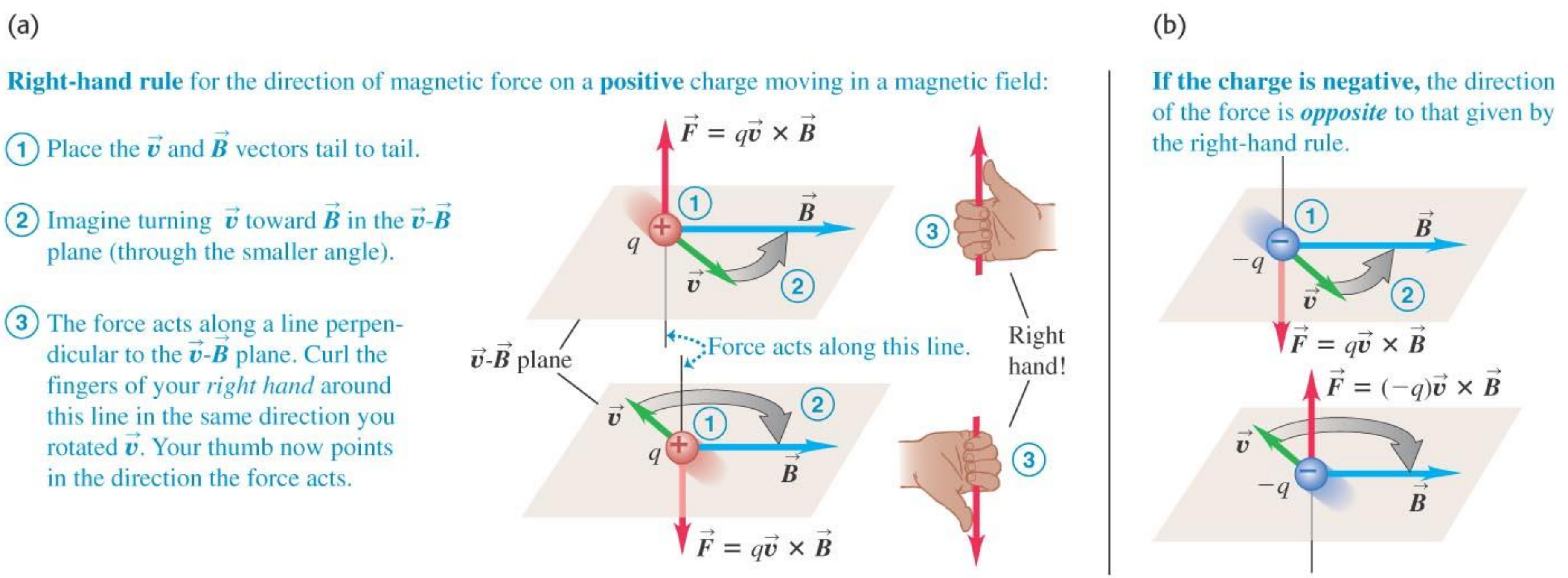
The interaction of magnetic force and charge

- 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.



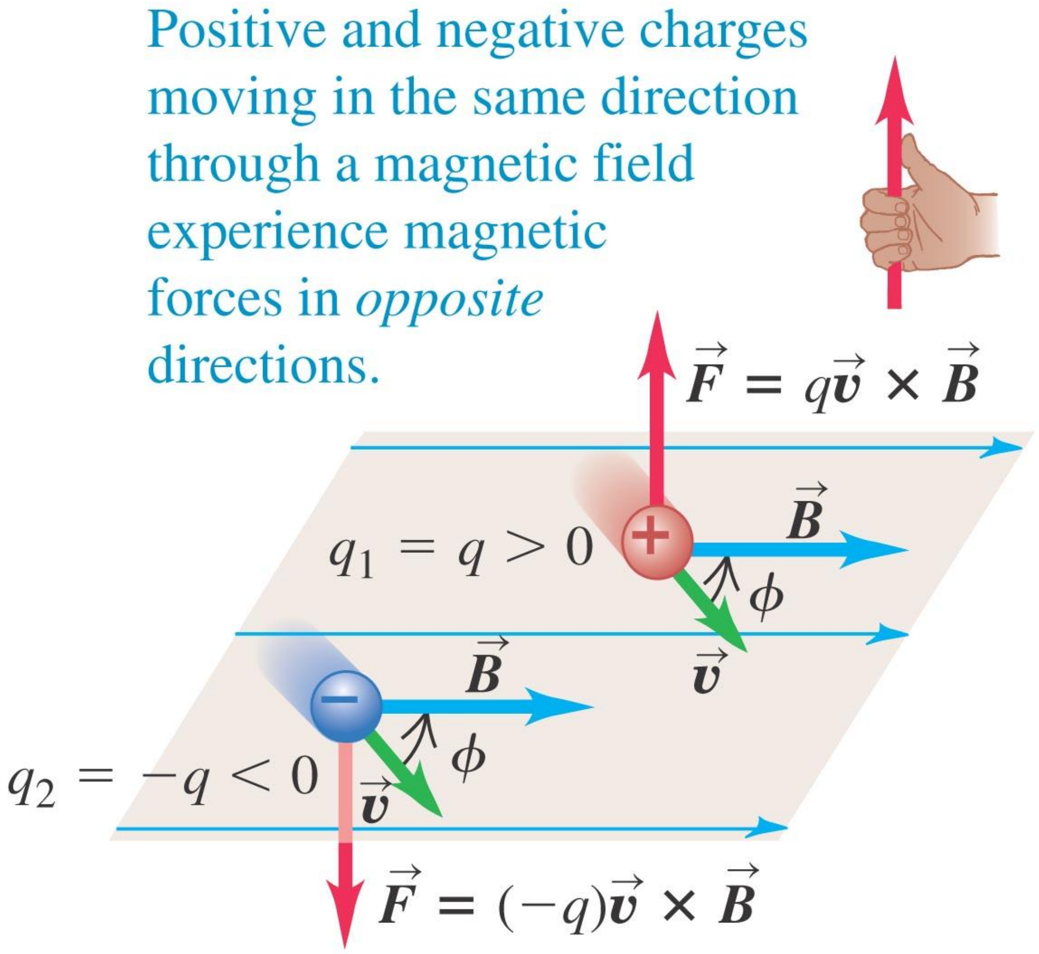
The "right-hand rule" I

- 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.



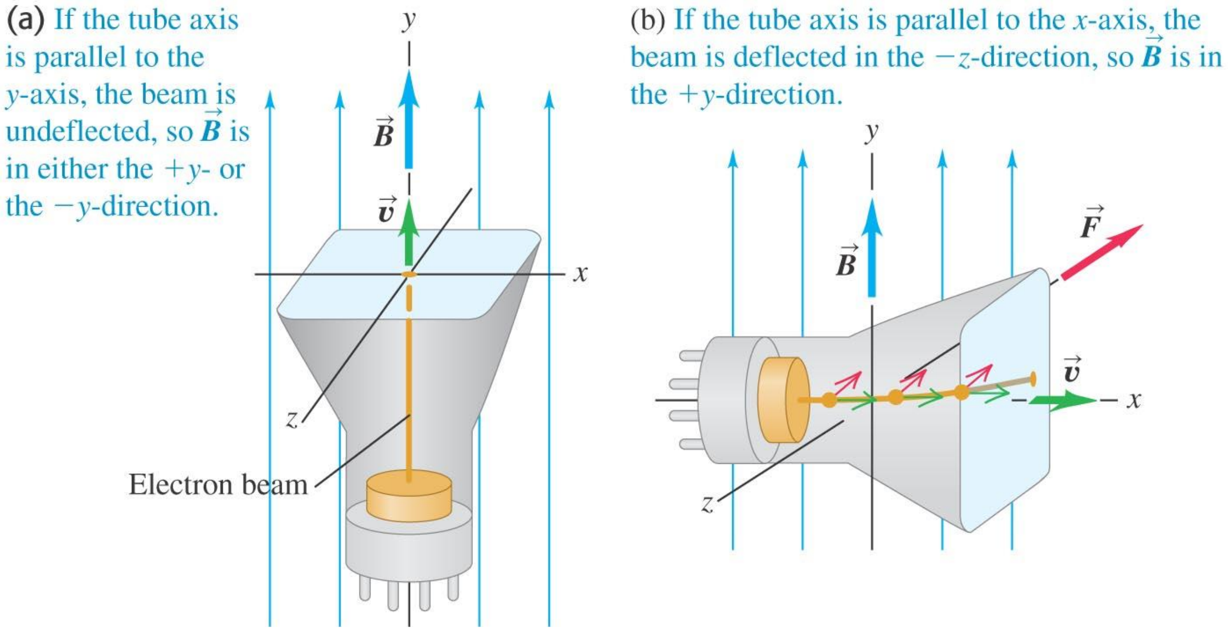
Right-hand rule II

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



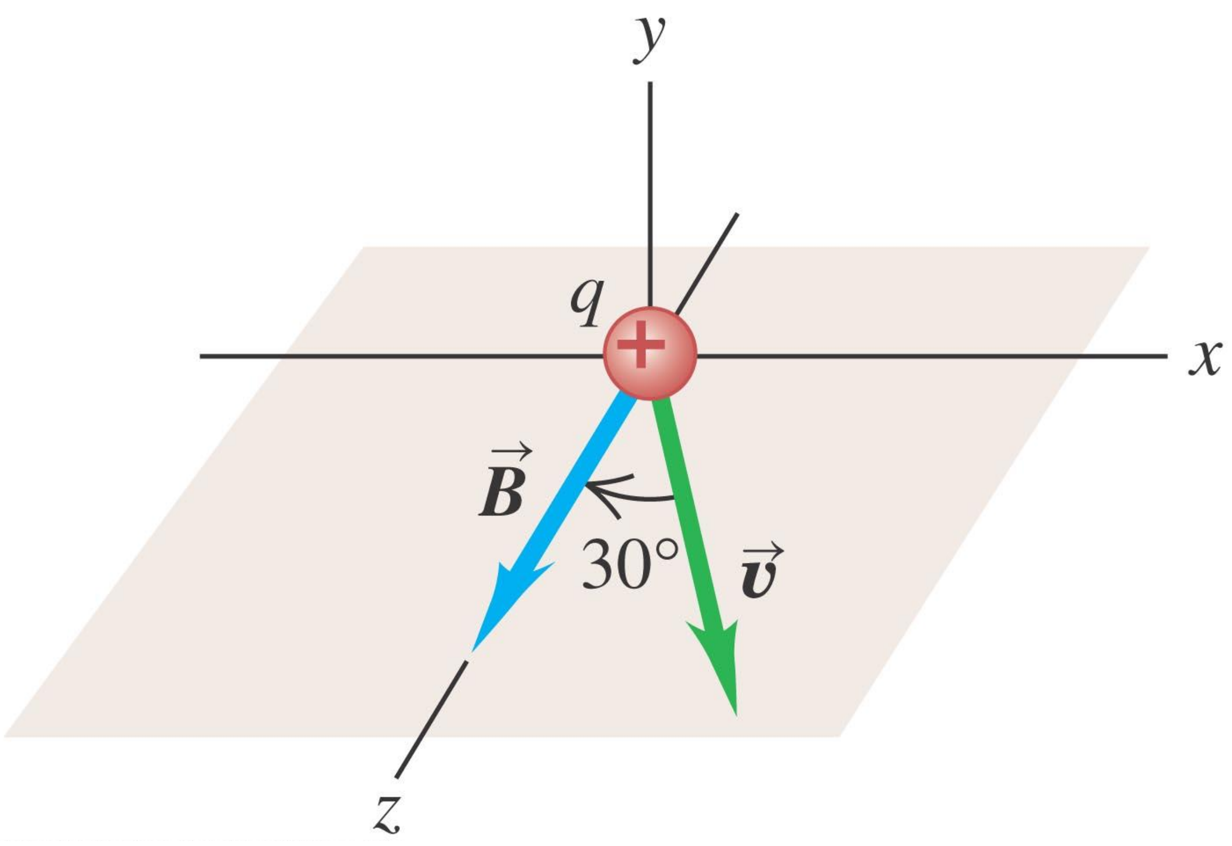
Direction of a magnetic field with your CRT

- 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.



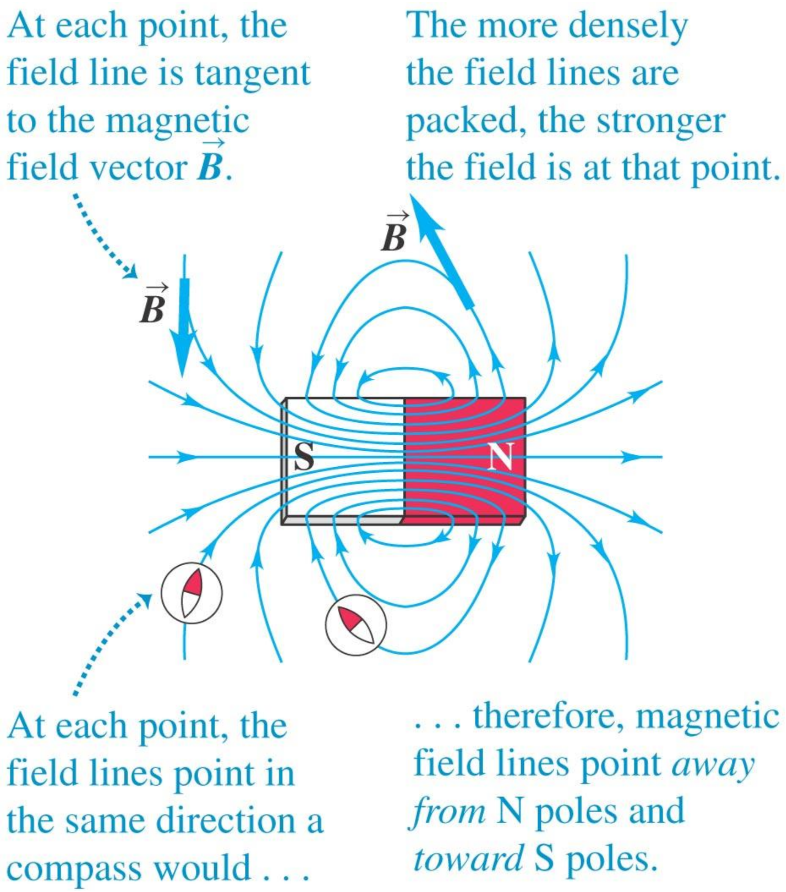
Magnetic forces

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



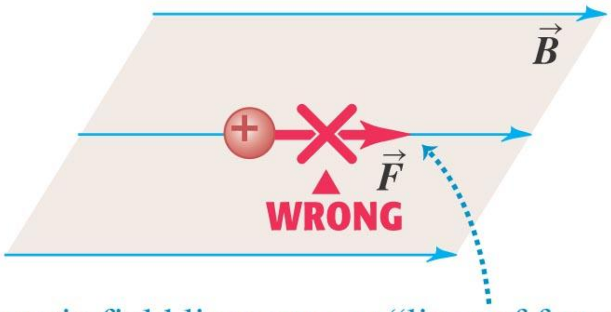
Magnetic field lines may be traced

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

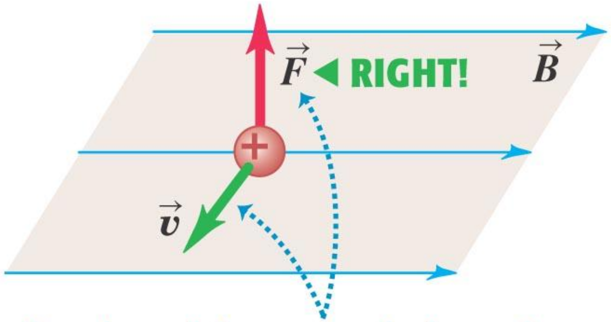


Field lines are not lines of force

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



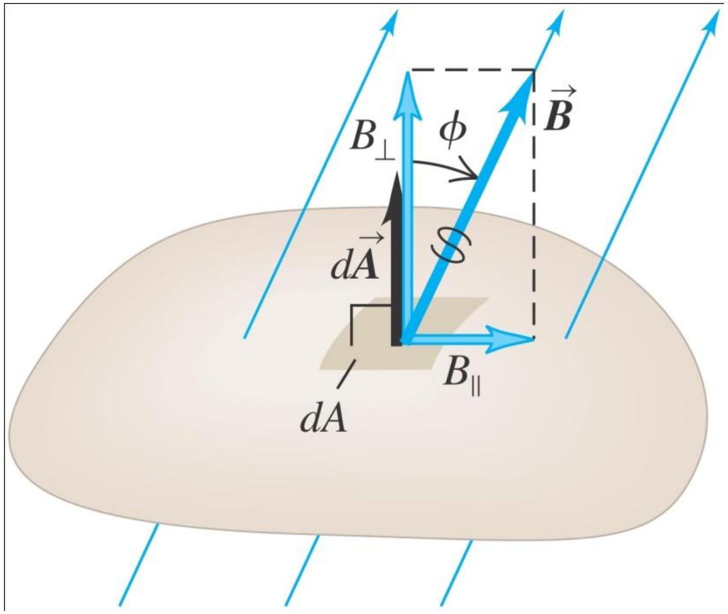
Magnetic field lines are *not* "lines of force." The force on a charged particle is not along the direction of a field line.

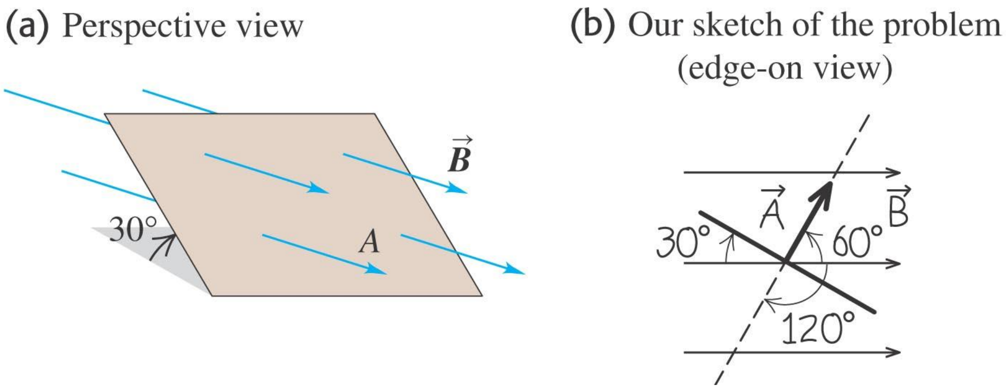


The direction of the magnetic force depends on the velocity $\vec{v}$, as expressed by the magnetic force law $\vec{F} = q\vec{v} \times \vec{B}$.

Magnetic flux through an area

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



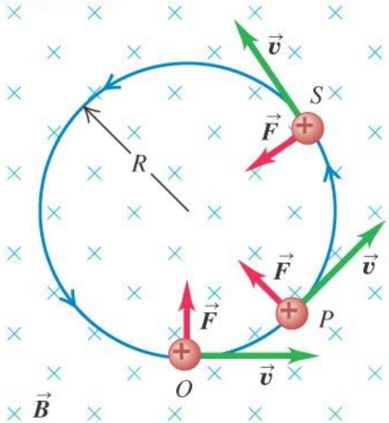


Motion of charged particles in a magnetic field

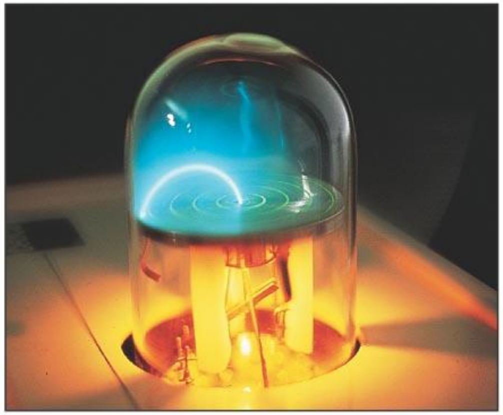
- A charged particle will move in a plane perpendicular to the magnetic field.
- Figure at right illustrates the forces and shows an experimental example.
- Figure below shows the constant kinetic energy and helical path.

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

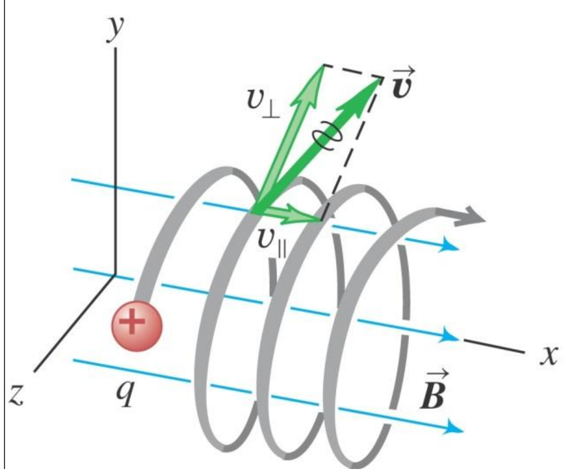
A charge moving at right angles to a uniform $\vec{B}$ field moves in a circle at constant speed because $\vec{F}$ and $\vec{v}$ are always perpendicular to each other.



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

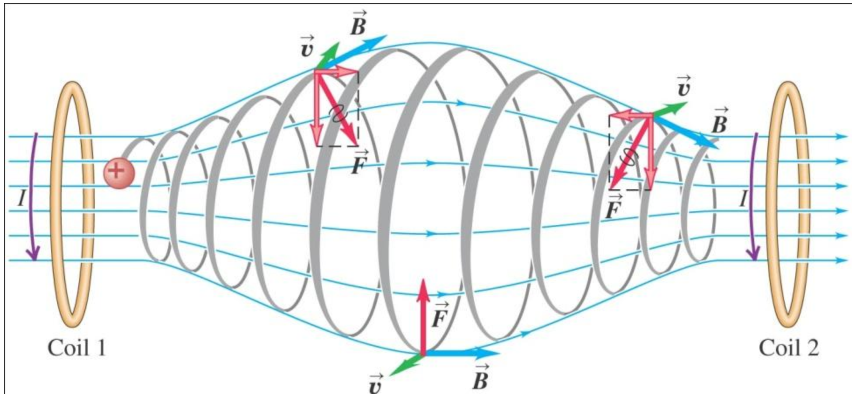


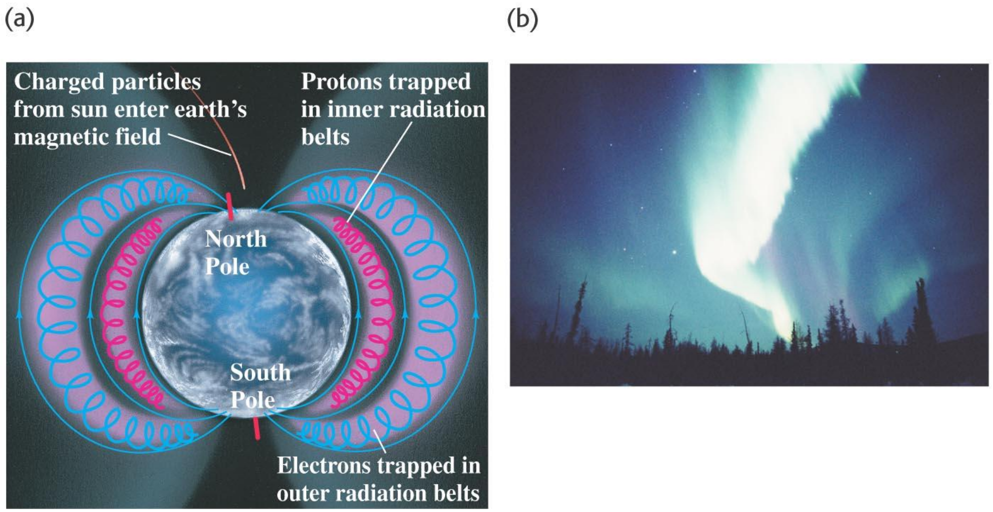
This particle's motion has components both parallel ($v_{\parallel}$) and perpendicular ($v_{\perp}$) to the magnetic field, so it moves in a helical path.



A magnetic bottle

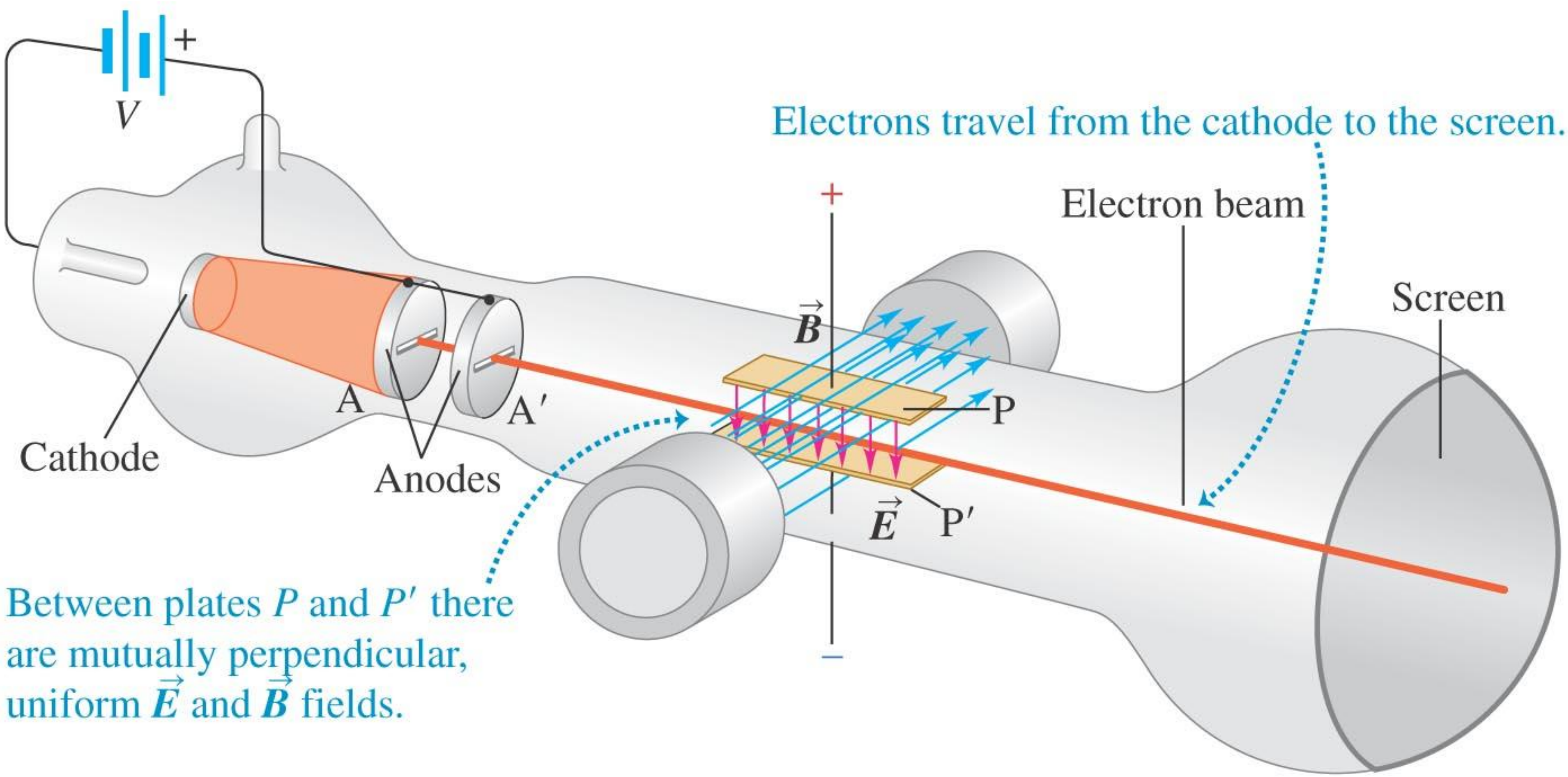
- If we ever get seriously close to small-lab nuclear fusion, the magnetic bottle will likely be the only way to contain the unimaginable temperatures ~ a million K.
- Figure 27.19 diagrams the magnetic bottle and Figure 27.20 shows the real-world examples … northern lights and southern lights.





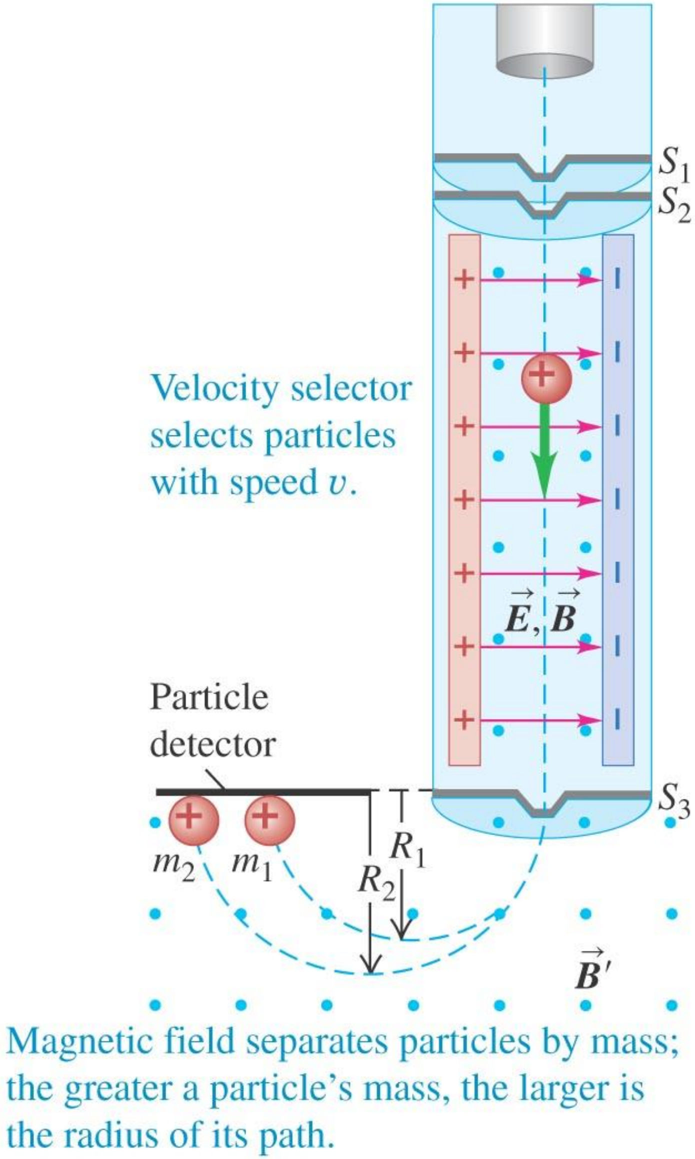
J.J. Thompson was able to characterize the electron

- Thompson’s experiment used a combination of electron linear acceleration and magnetic “steering.”



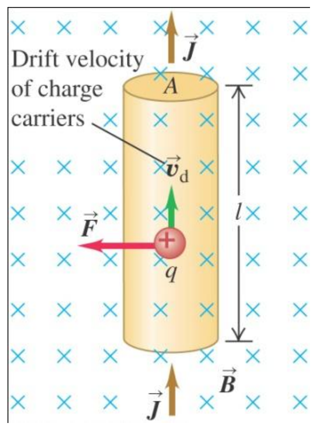
Bainbridge's mass spectrometer

- 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



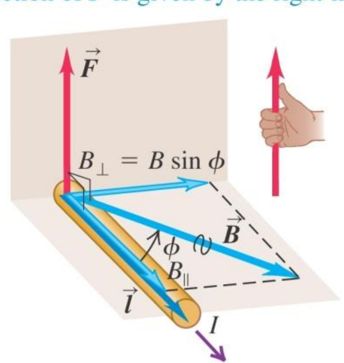
The magnetic force on a current-carrying conductor

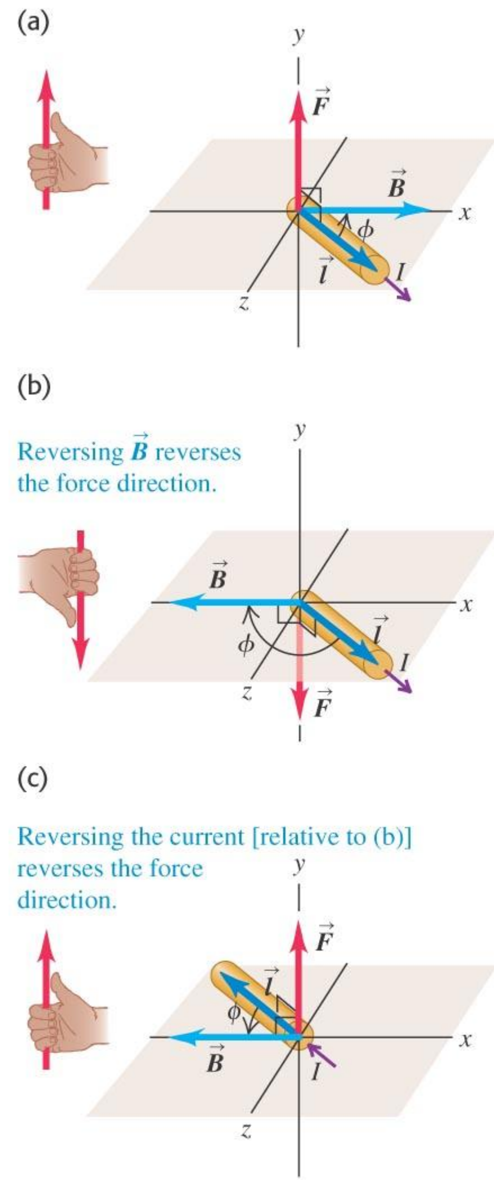
- The force is always perpendicular to the conductor and the field.



Force $\vec{F}$ on a straight wire carrying a positive current and oriented at an angle ϕ to a magnetic field $\vec{B}$:

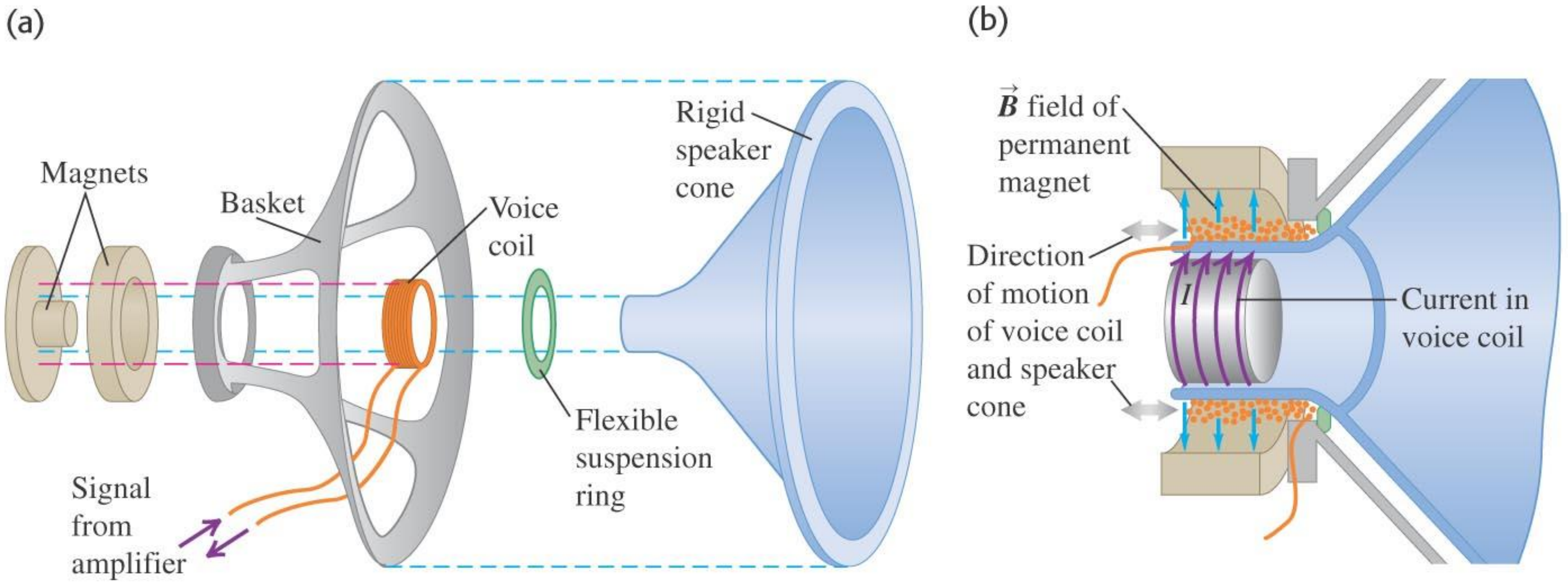
- Magnitude is $F = IlB_{\perp} = IlB \sin\phi$.
- Direction of $\vec{F}$ is given by the right-hand rule.





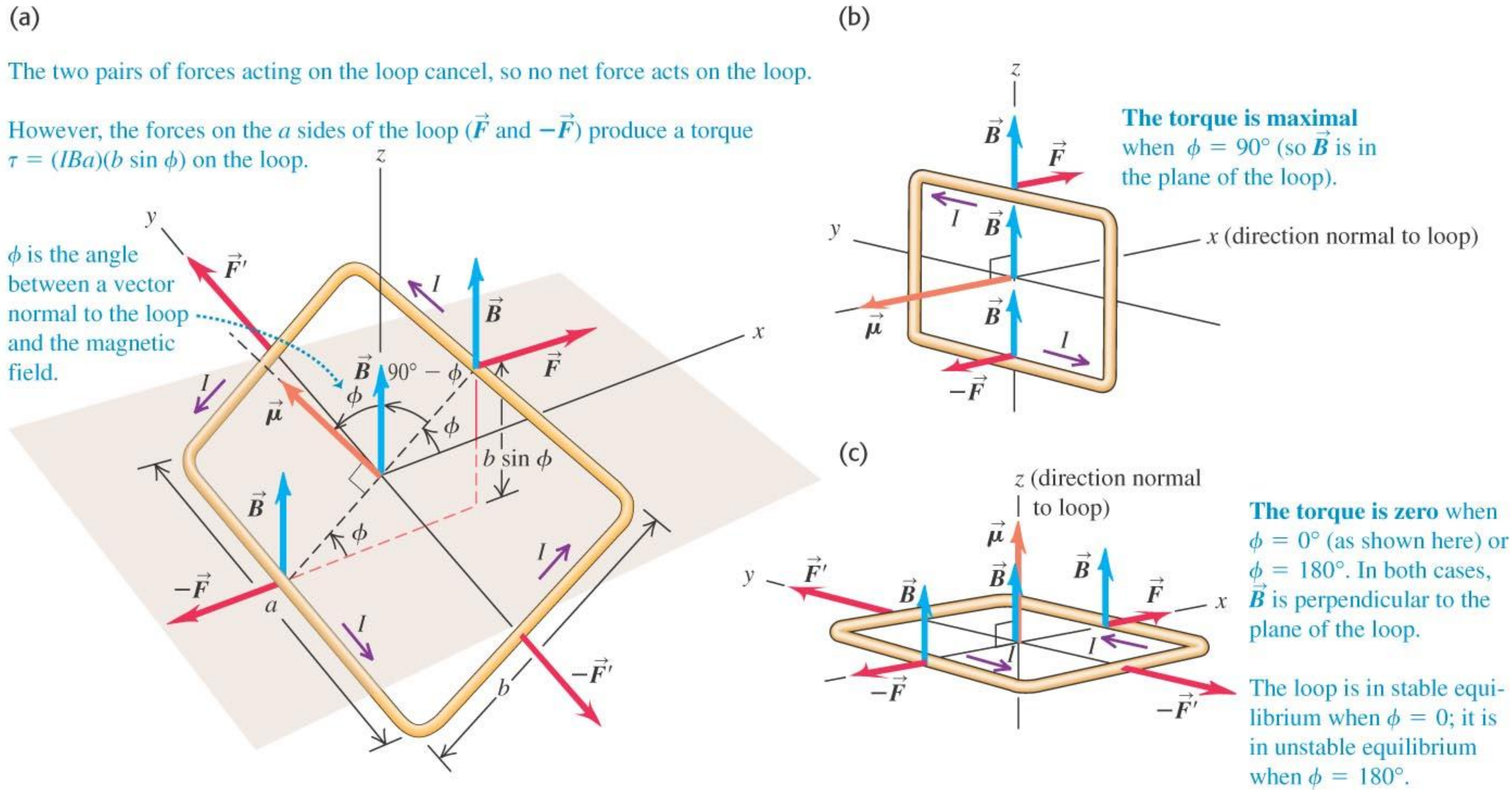
Loudspeakers – Similar to ear buds

- 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



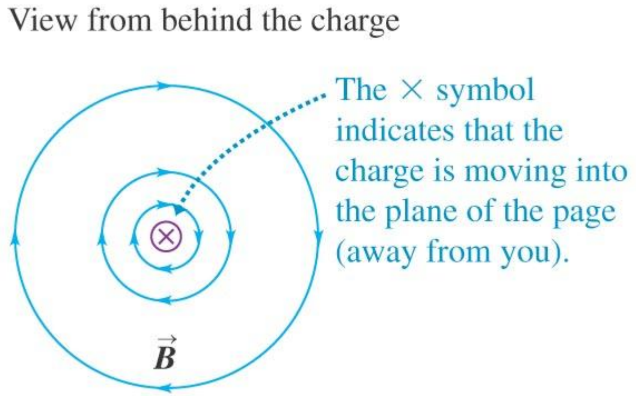
Force and torque on a current loop

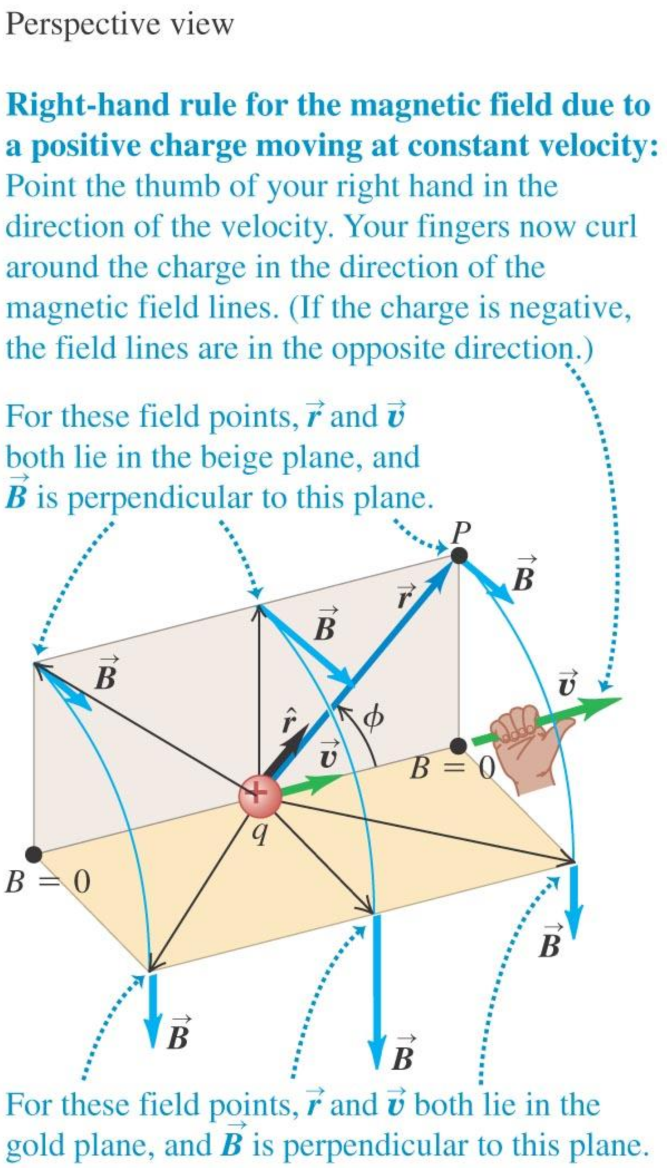
- This is the basis of electric motors.



The magnetic field of a moving charge – all B fields due to relativistic transformation of moving E fields

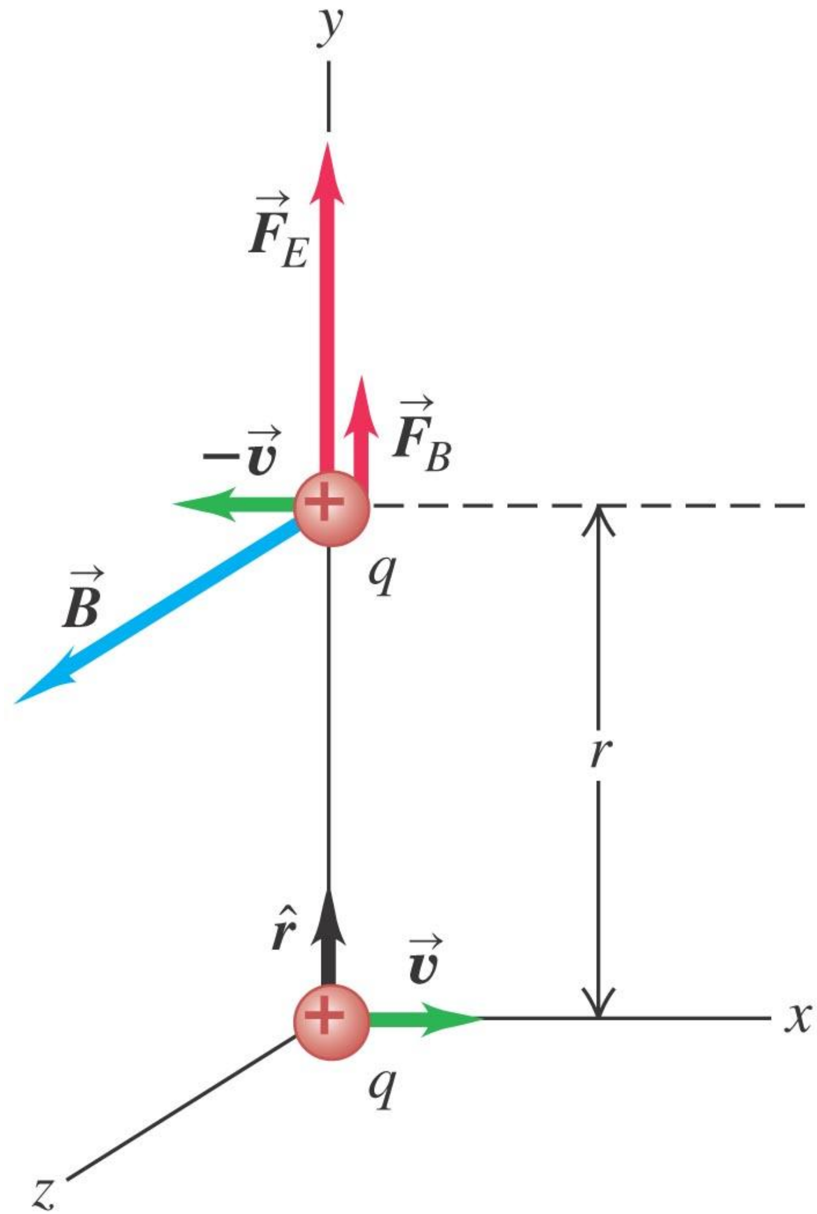
- A moving charge will generate a magnetic field relative to the velocity of the charge. Special Relativity.





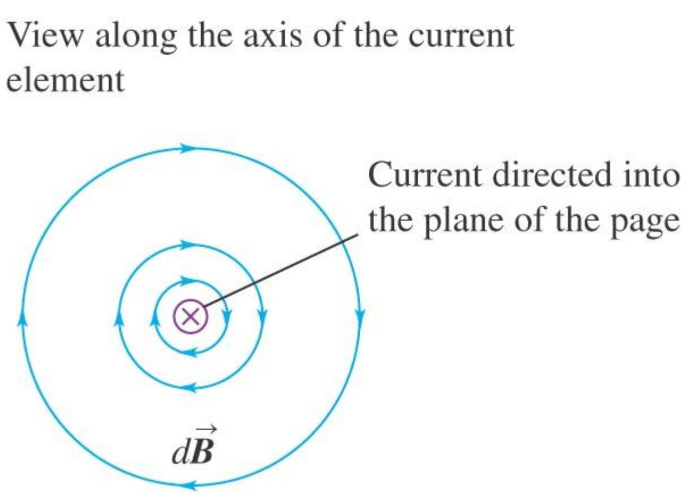
Moving charges—field lines

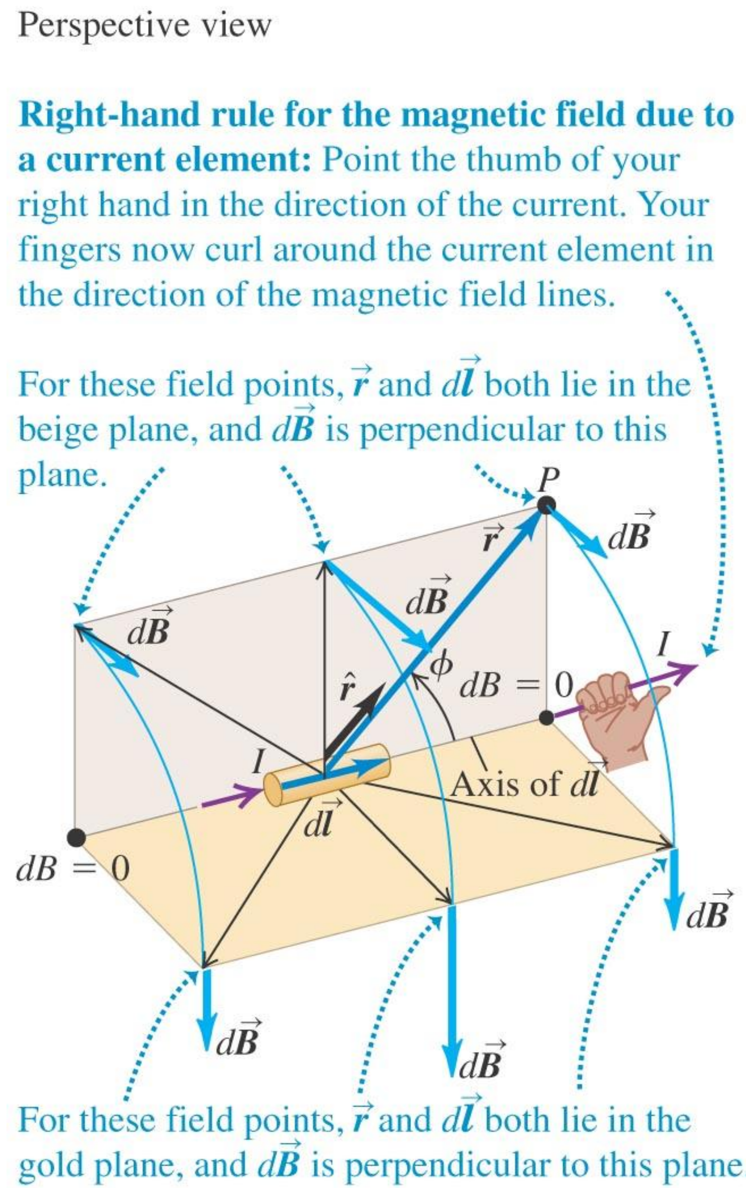
- The moving charge will generate field lines in circles around the charge in planes perpendicular to the line of motion.
- $\mathbf{B} = \mu_0 \,(q\,\mathbf{v}\ \mathbf{x}\ \mathbf{r})/4\pi r^2$



Magnetic field of a current element

- The magnetic field of several moving charges will be the vector sum of each field.
- $d\mathbf{B} = \mu_0 (I\ \mathbf{dl} \times \mathbf{r})/4\pi r^2$

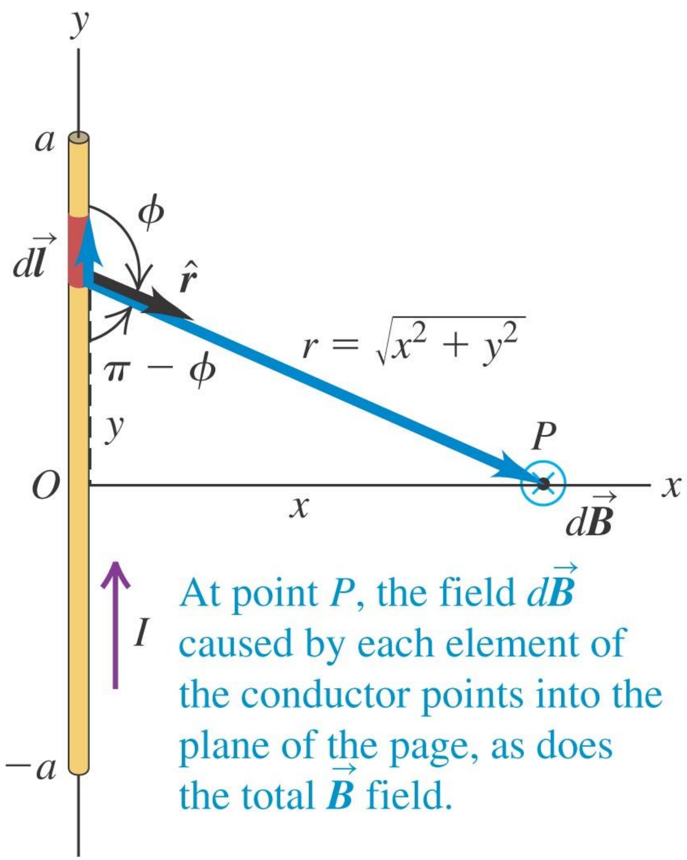


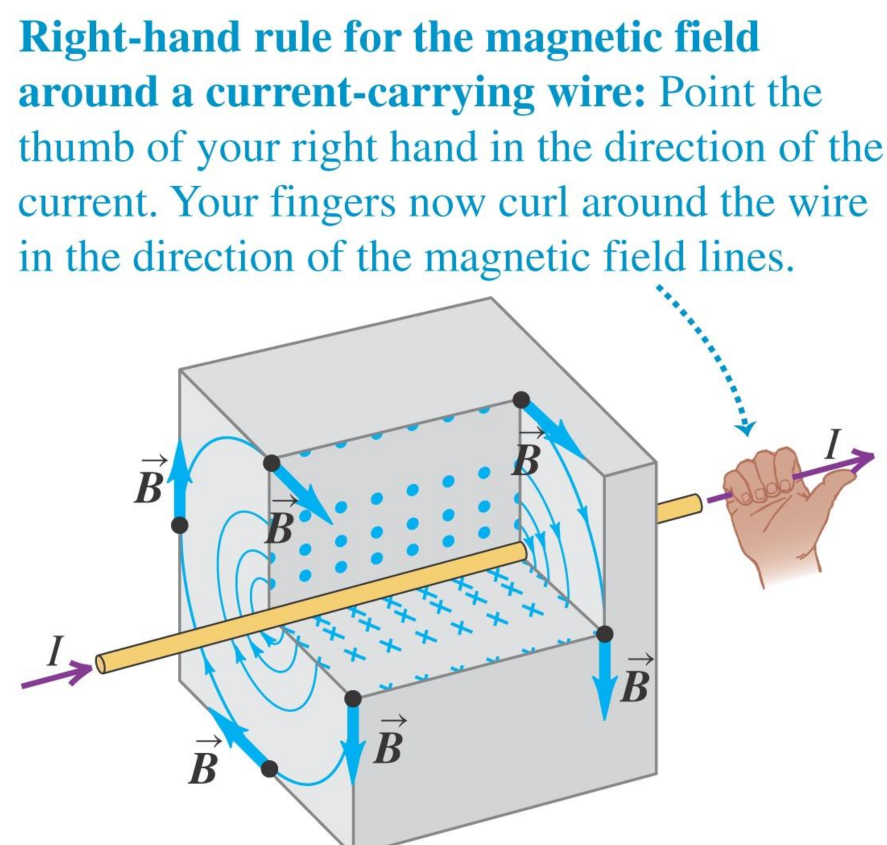


Magnetic field of a straight current-carrying conductor

- Biot and Savart “Law” - finding the magnetic field produced by a single current-carrying conductor. Integrate over the wire

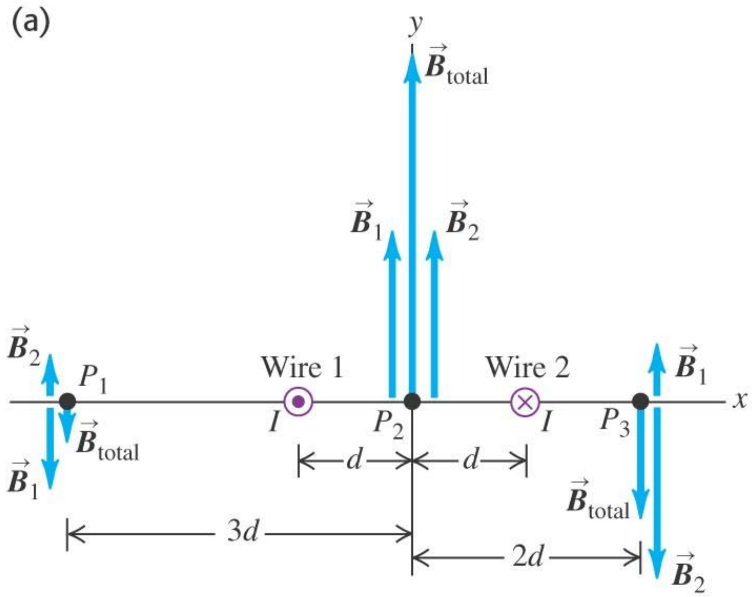
- $\mathbf{B} = \mu_0 \int (I\, \mathbf{dl} \times \mathbf{r})/4\pi r^2$

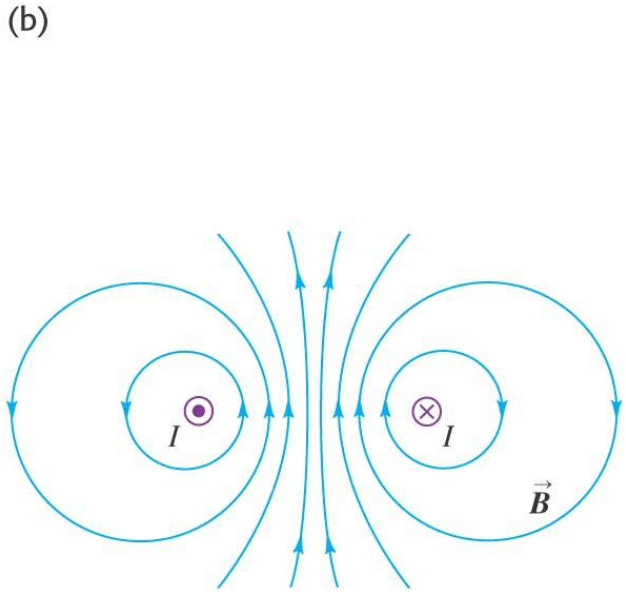




Fields around single wires

- Current carrying wires are common in your life.
- They are in the wires in the wall carry power
- They are in your computer
- In your "ear bud"



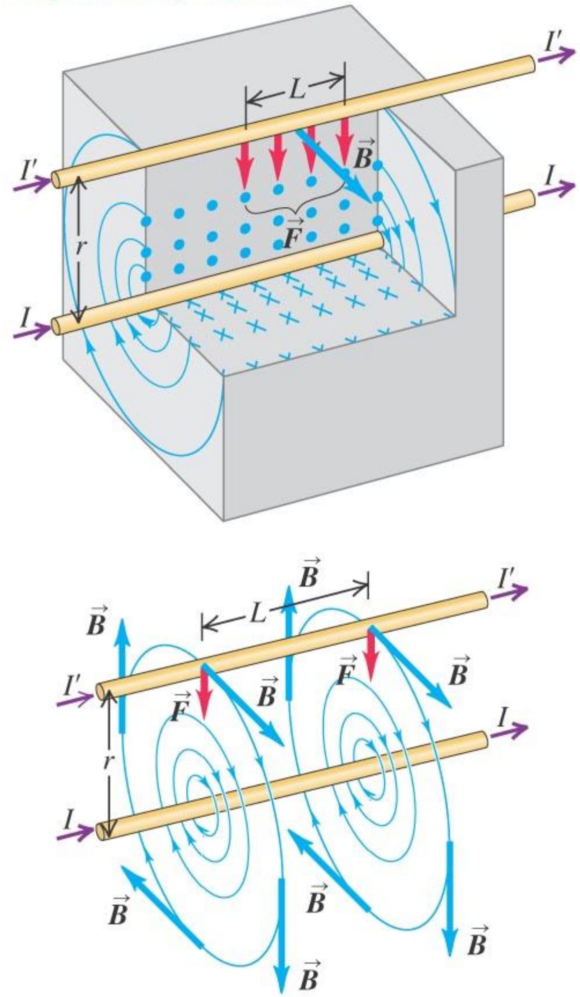


Forces and parallel conductors

- When you run the current one way through one rod and the other way through the second, they will repel each other. If you reverse the connections on one rod so that **both currents run the same way, the rods will be attracted to each other. See diagram.**

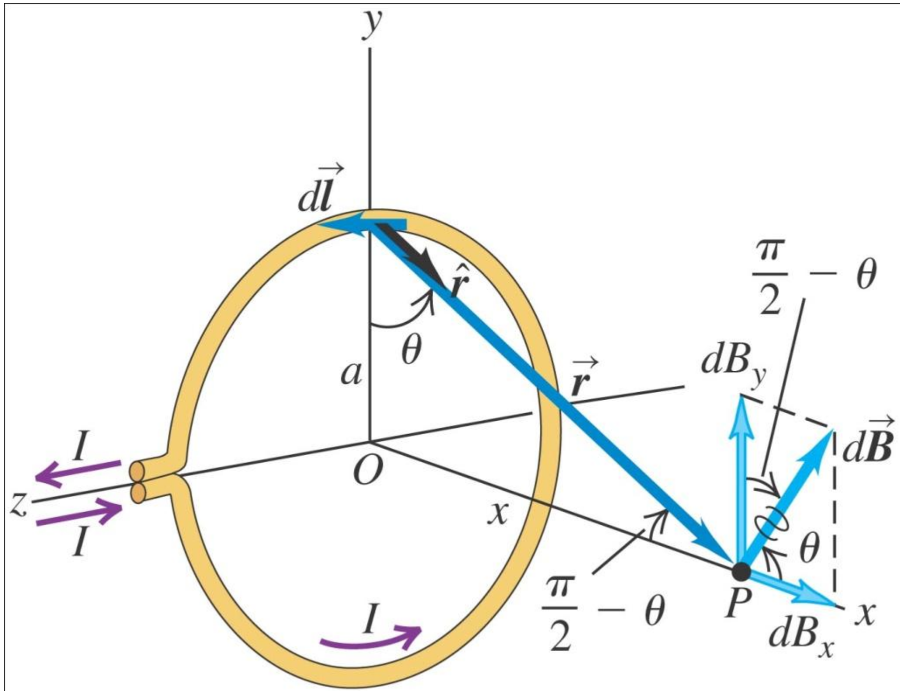
The magnetic field of the lower wire exerts an attractive force on the upper wire. By the same token, the upper wire attracts the lower one.

If the wires had currents in *opposite* directions, they would *repel* each other.



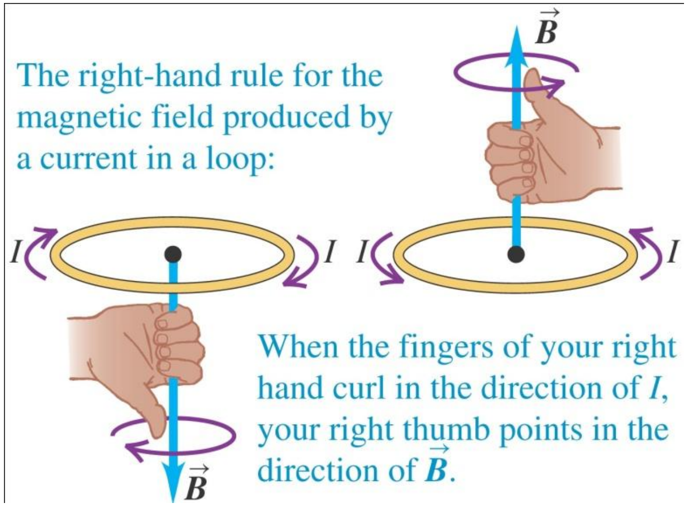
Magnetic field of a circular current loop

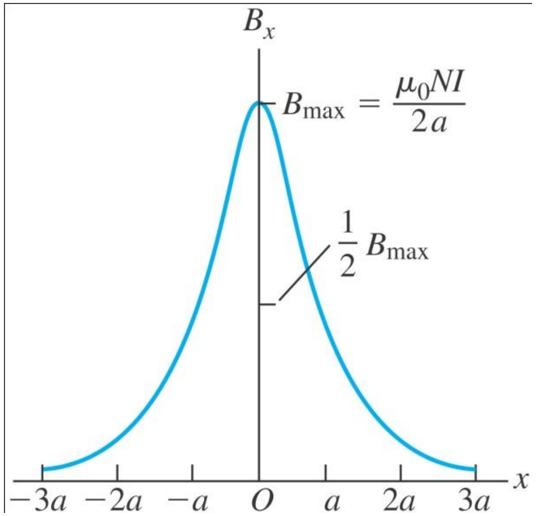
- A loop in the *x*,*y* plane will experience magnetic attraction or repulsion above and below the loop.

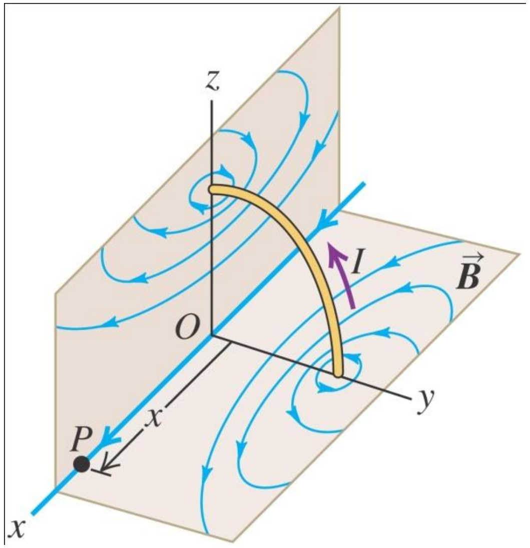


Magnetic fields in coils

- Use the right hand rule to determine B field direction
- Here N is the number of turns in the coil. Below N=1







Ampere's Law I—specific then general

(a) Integration path is a circle centered on the conductor; integration goes around the circle counterclockwise.

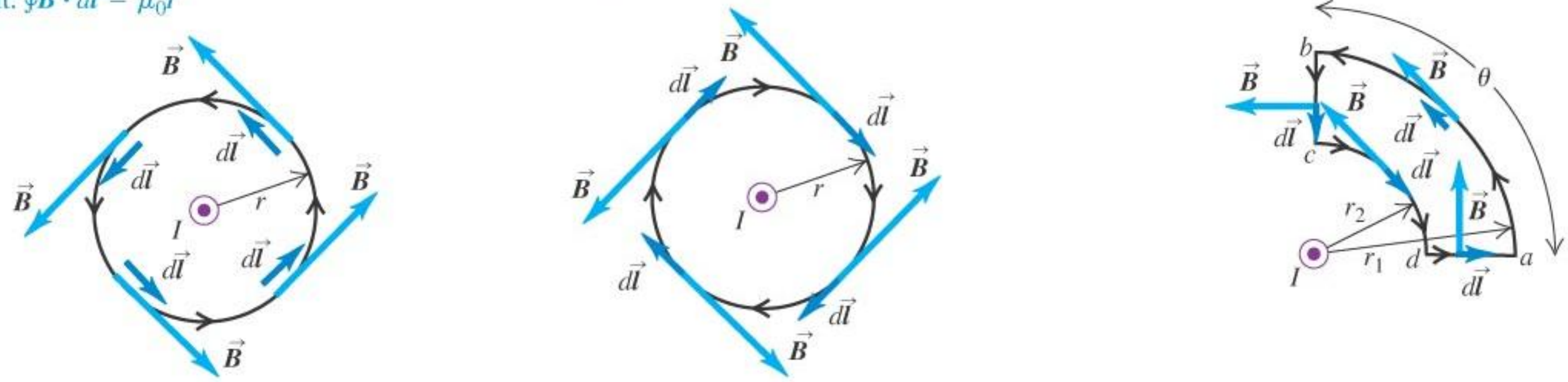
Result: $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$

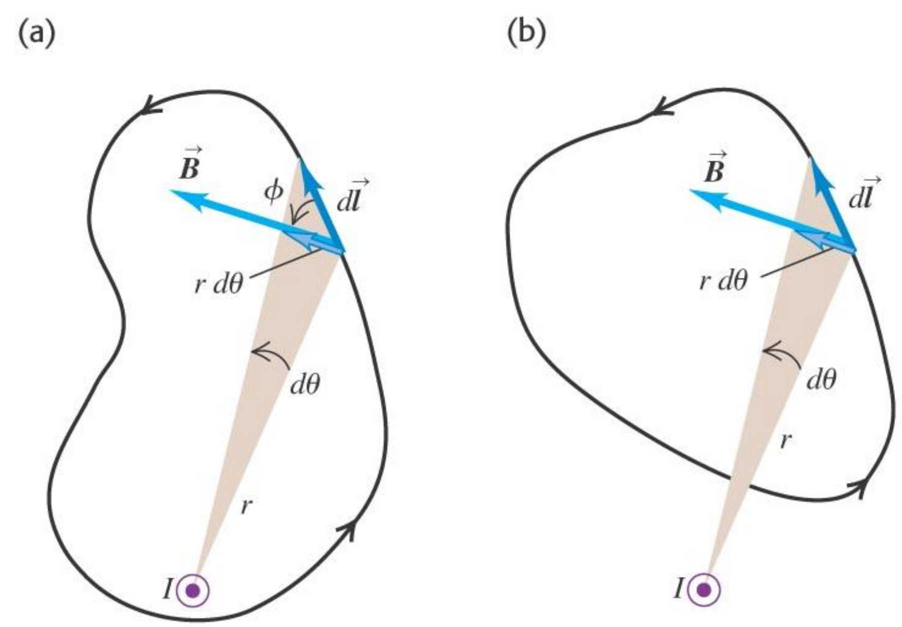
(b) Same integration path as in (a), but integration goes around the circle clockwise.

Result: $\oint \vec{B} \cdot d\vec{l} = -\mu_0 I$

(c) An integration path that does not enclose the conductor.

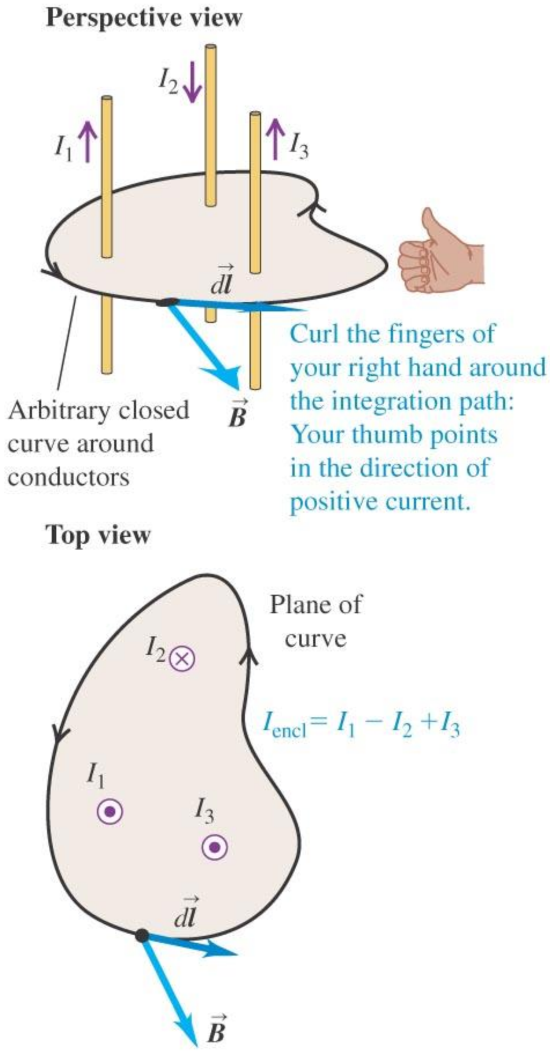
Result: $\oint \vec{B} \cdot d\vec{l} = 0$





Ampere's Law II

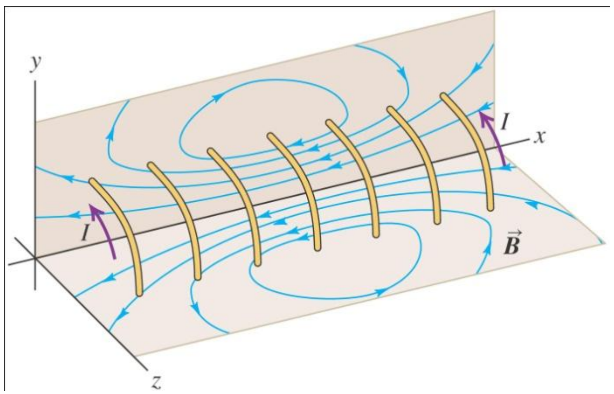
- Line integral of B over closed loop = μ_0 I
- **$\int$B•dl = μ_0 I where I is the sum of ALL currents inside the loop**
- This is part of one of Maxwells Equations
- For a long wire $\int$B•dl =2πrB
- Where r is the radius from the center of the wire to the desired distance r
- **Thus long wire B = μ_0I/2πr**

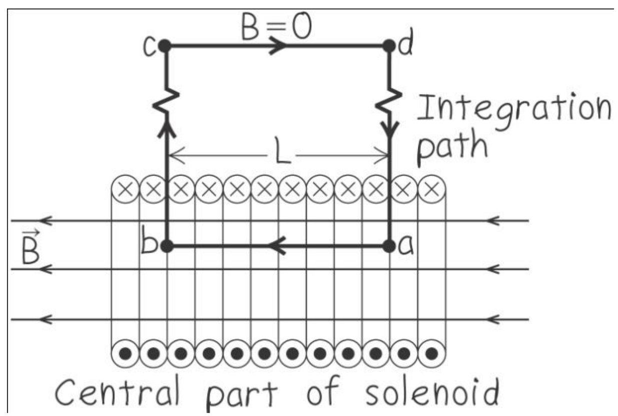


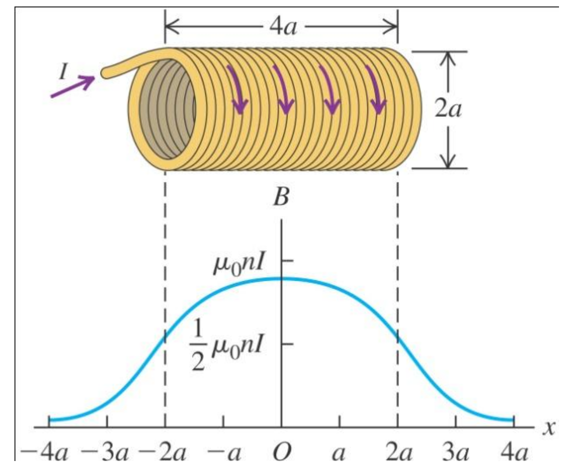
Ampere's law: If we calculate the line integral of the magnetic field around a closed curve, the result equals μ_0 times the total enclosed current: $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{encl}$

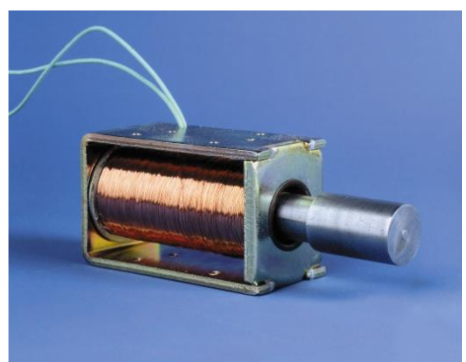
Field of a solenoid

- A helical winding of wire on a cylinder.
- Your car starter has a solenoid to engage the starter motor.
- Every time you start your car you are using a solenoid
- Here n = # wire turns (loops) per meter along solenoid
- In an infinite length solenoid the field inside is uniform – outside B=0
- Apply Ampere's Law $\int B \bullet dl = \mu_0 I$ but note there are n turns per meter hence I→nLI
- $\int B \bullet dl = BL = \mu_0 nLI$
- **→ $B=\square_0 nI$**







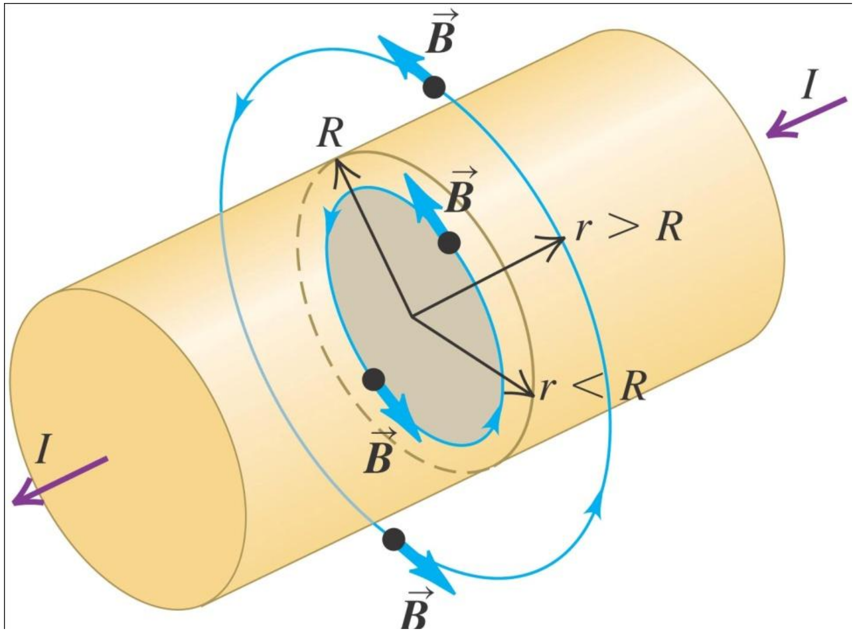


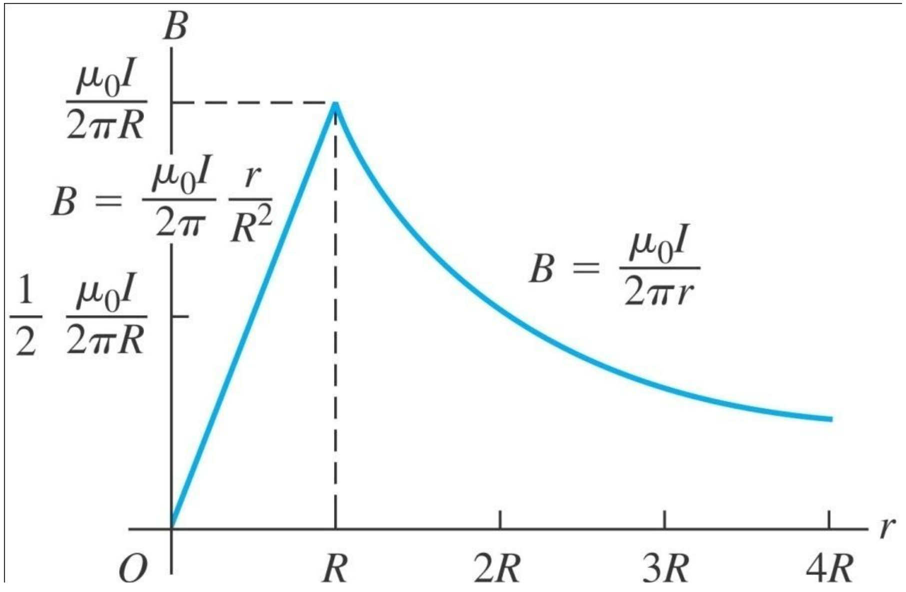
MRI – Magnetic Resonance Imaging

You are inside a large superconducting magnetic solenoid

Field inside a long cylindrical conductor

- A cylinder of radius R carrying a current I – uniform current density.
- This is similar to our use of Gauss' Law for electrostatics
- This is sometimes called (badly) magnetostatics





Coaxial cable – cable for internet "Cox cable", TV etc