Chapter 28 – Magnetic Fields Sources

All known magnetic sources are due to magnetic dipoles and inherently macroscopic current sources or microscopic spins and magnetic moments

Goals for Chapter 28

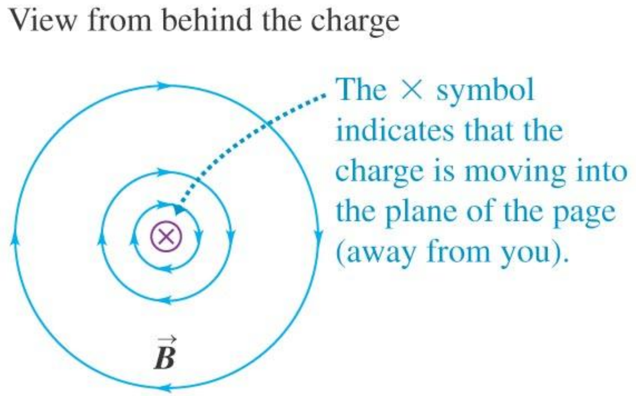
- Study the magnetic field generated by a moving charge
- Consider magnetic field of a current-carrying conductor
- Examine the magnetic field of a long, straight, current-carrying conductor
- Study the magnetic force between current-carrying conductors
- Consider the magnetic field of a current loop
- Examine and use Ampere’s Law

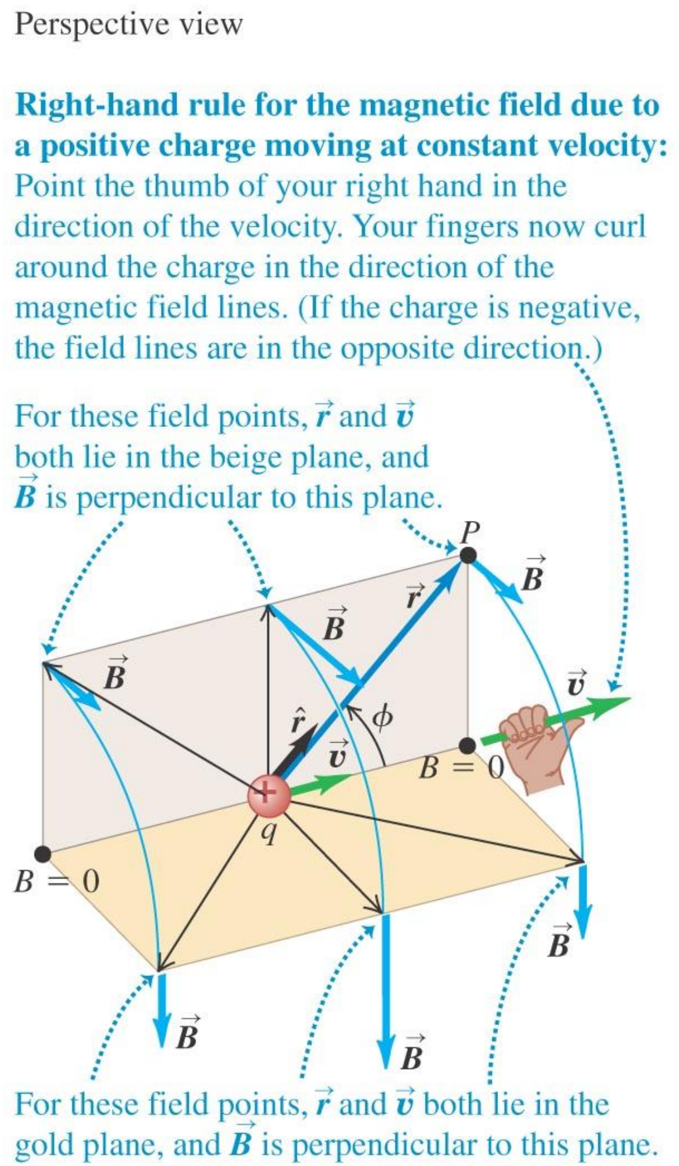
Introduction

- Sources of magnetic fields can be small like a doorbell or car-starter or very large like the photo at right where scientists at CERN are using large scale superconducting electro-magnets to search for the origins of mass.

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

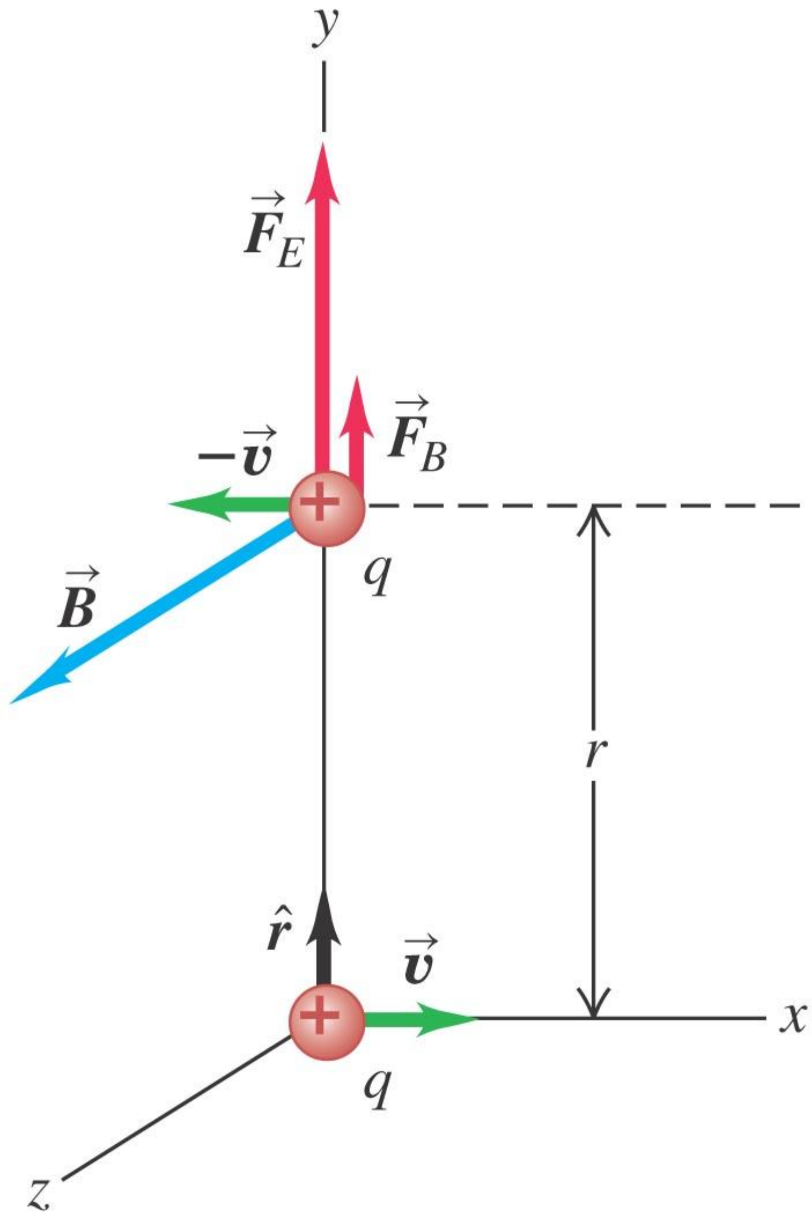
- A moving charge will generate a magnetic field relative to the velocity of the charge. Special Relativity.





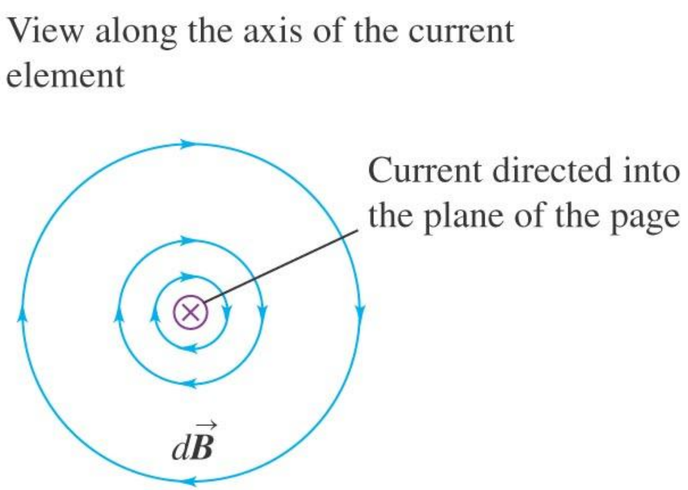
Moving charges—field lines

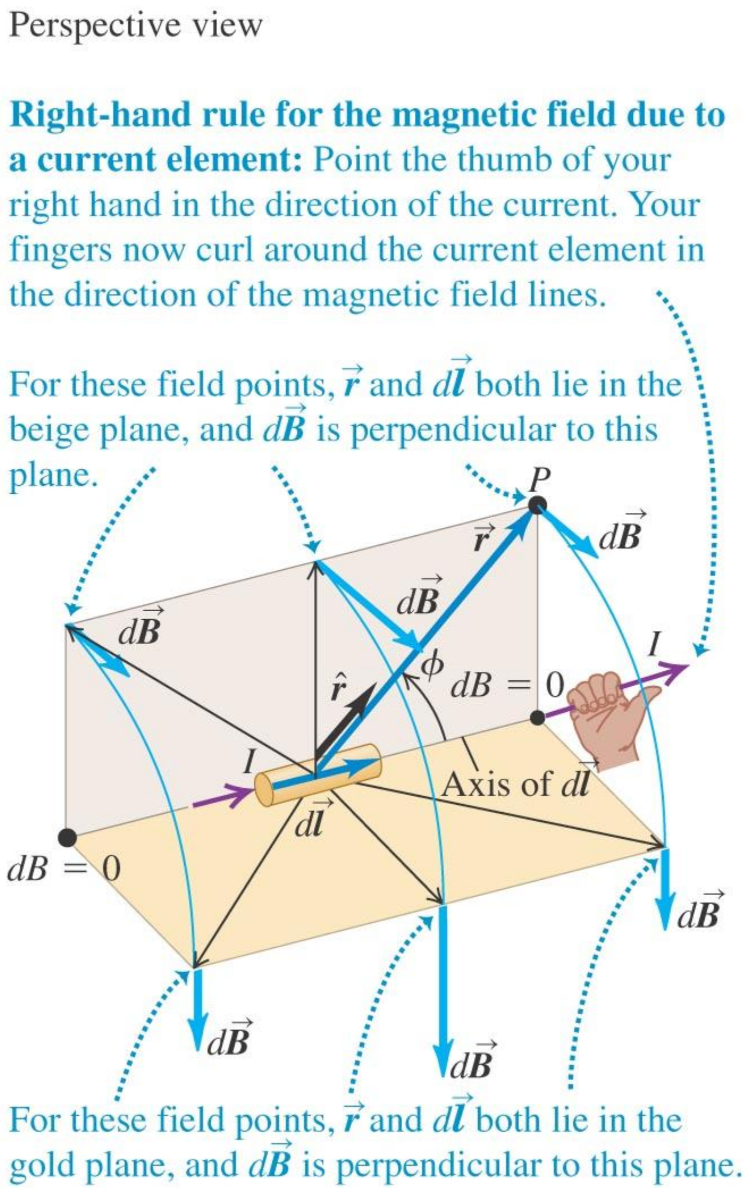
- The moving charge will generate field lines in circles around the charge in planes perpendicular to the line of motion.
- $\mathbf{B} = \mu_0 \, (q \, \mathbf{v} \times \mathbf{r})/4\pi r^2$



Magnetic field of a current element

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

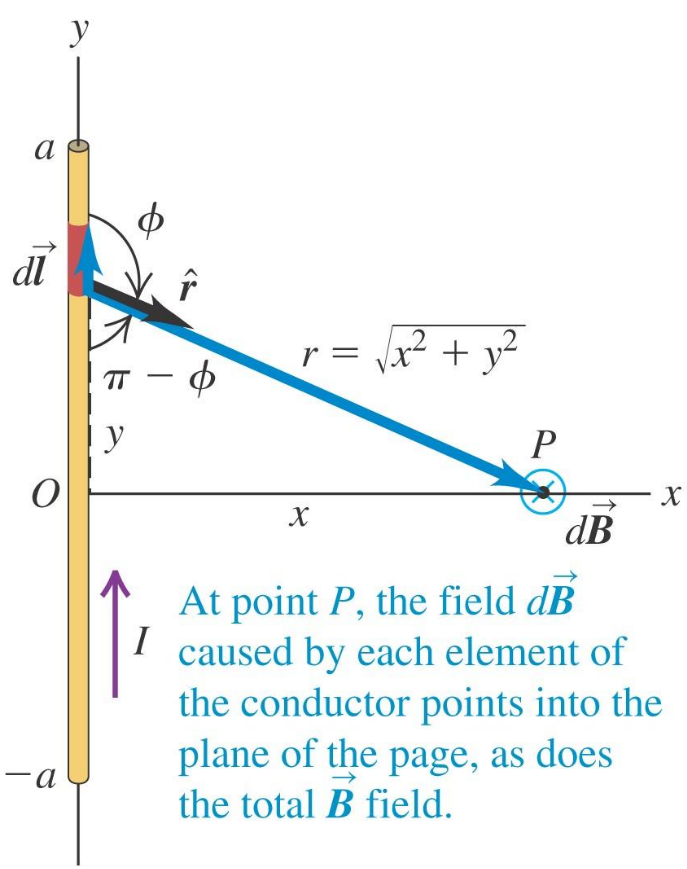


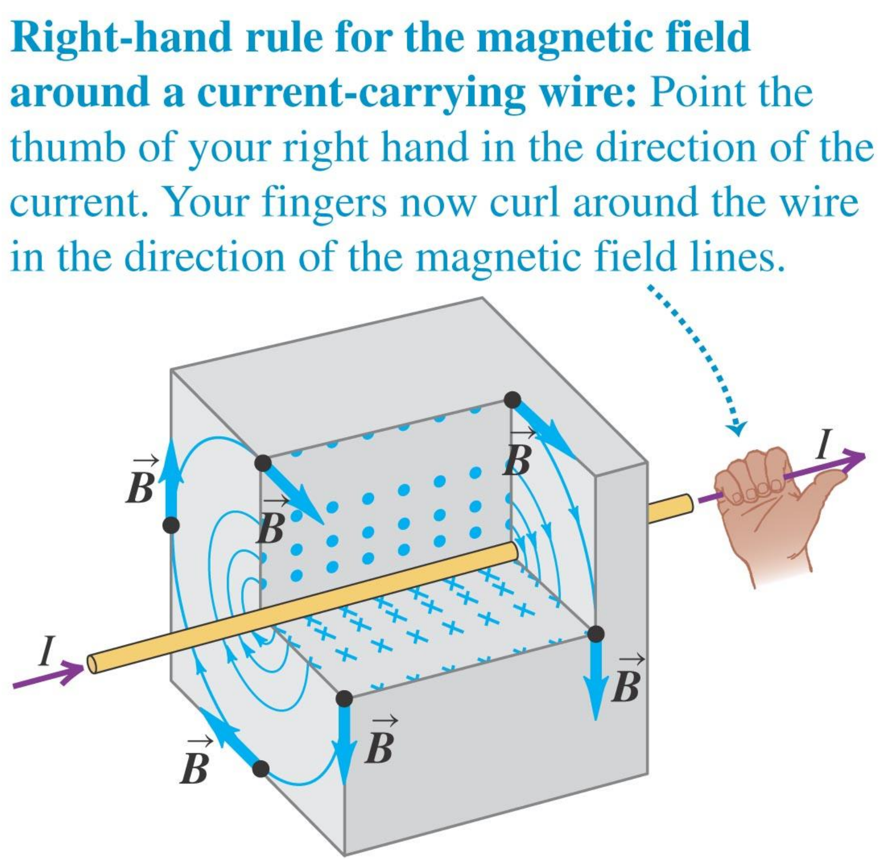


Magnetic field of a straight current-carrying conductor

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

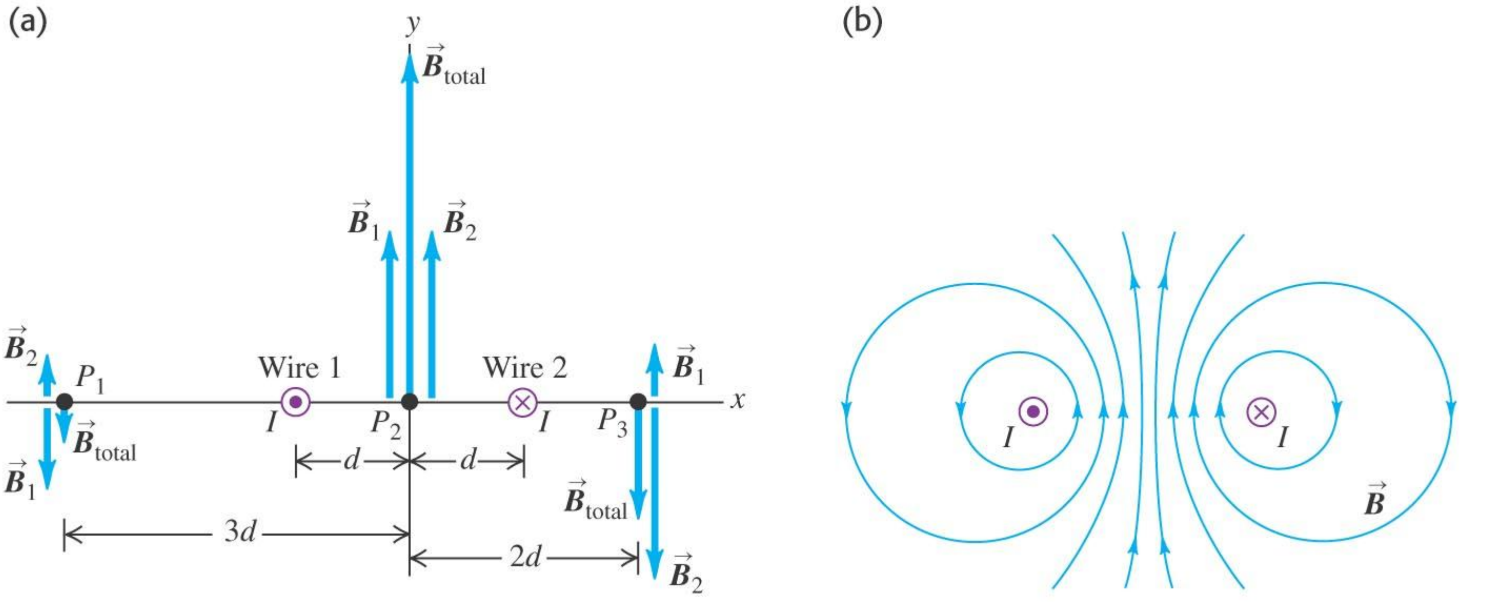
- $\mathbf{B} = \mu_0 \int (I\, \mathbf{dl} \times \mathbf{r})/4\pi r^2$





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"

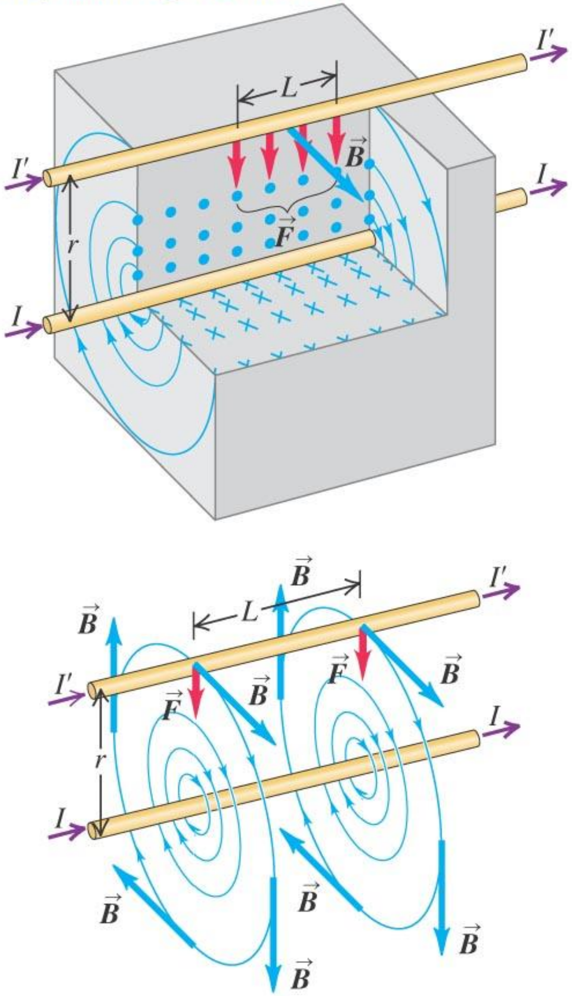


Forces and parallel conductors

- 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.**

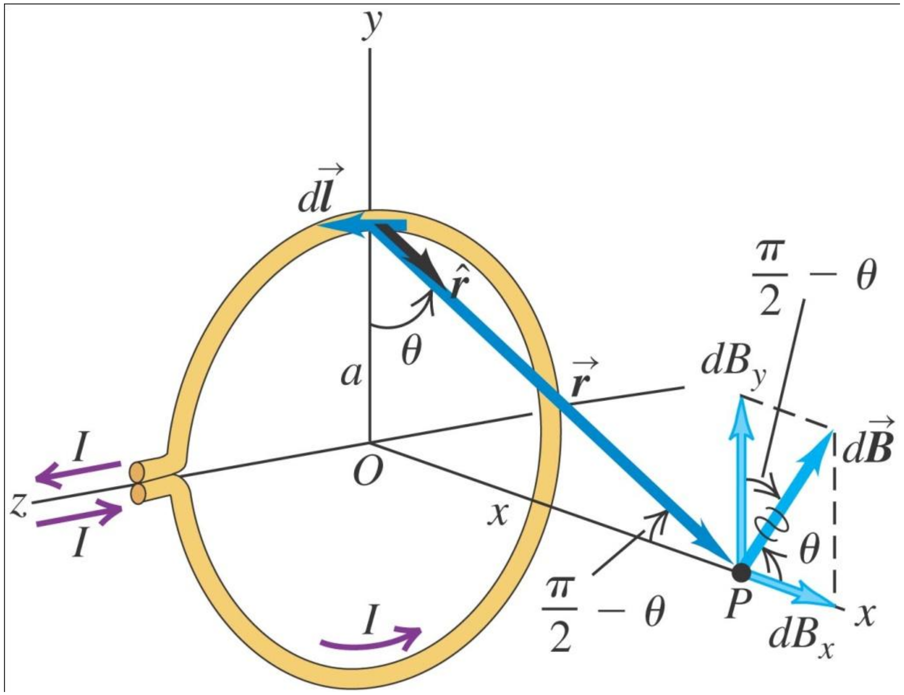
The magnetic field of the lower wire exerts an attractive force on the upper wire. By the same token, the upper wire attracts the lower one.

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



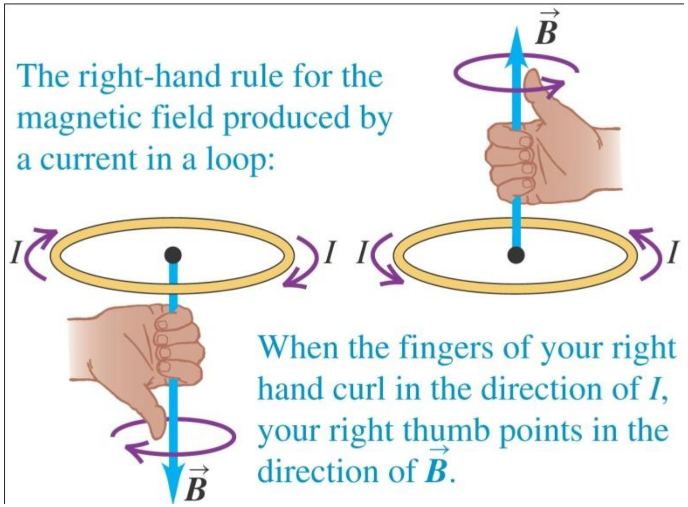
Magnetic field of a circular current loop

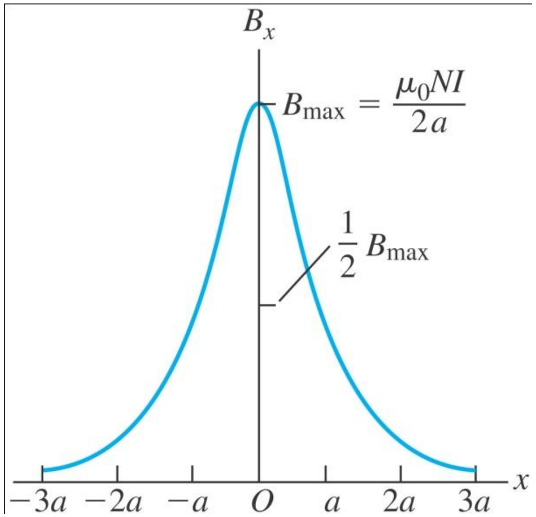
- A loop in the *x*,*y* plane will experience magnetic attraction or repulsion above and below the loop.

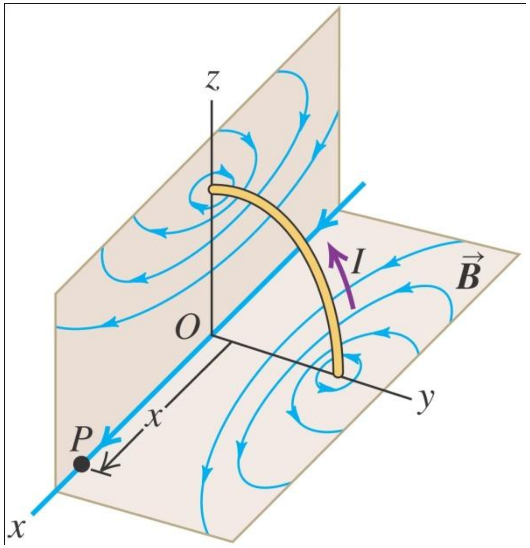


Magnetic fields in coils

- Use the right hand rule to determine B field direction







Ampere’s Law I—specific then general

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

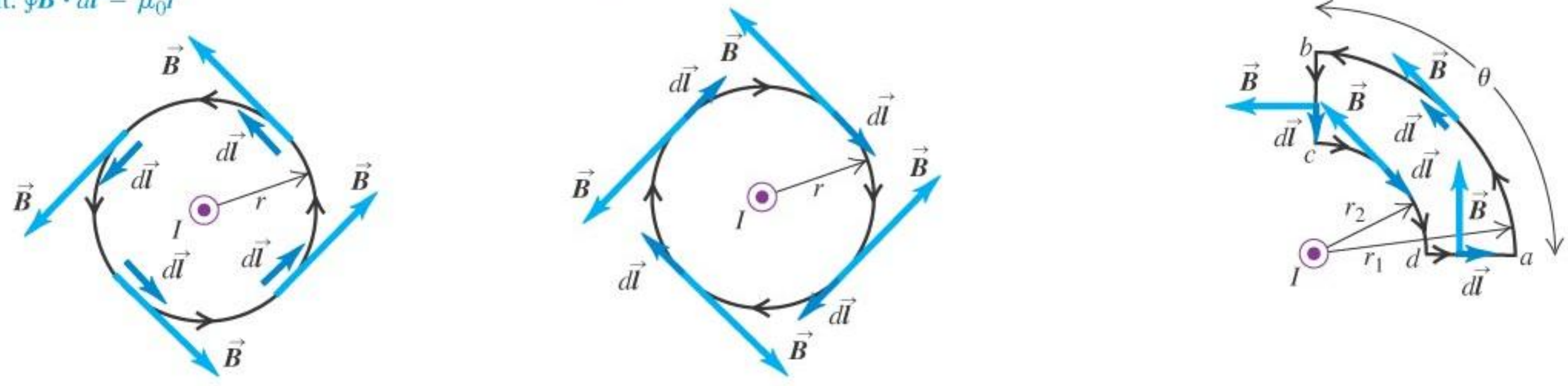
Result: $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$

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

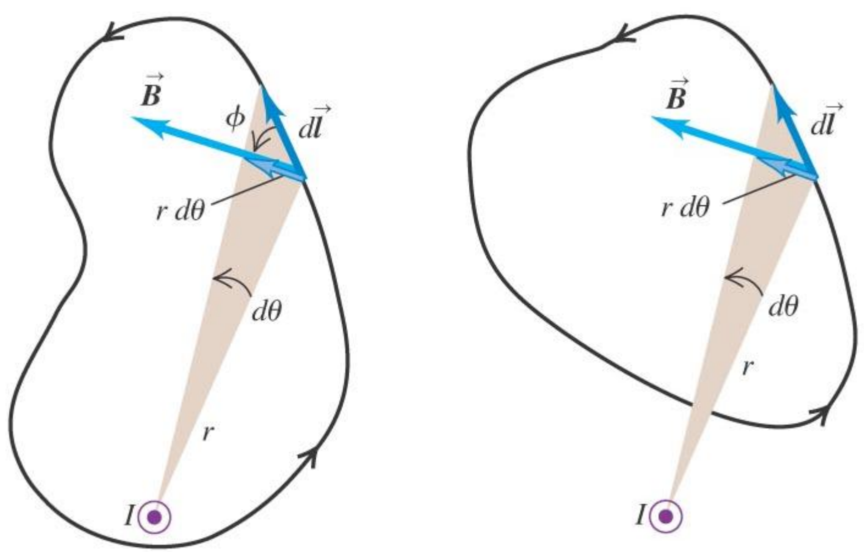
Result: $\oint \vec{B} \cdot d\vec{l} = -\mu_0 I$

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

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

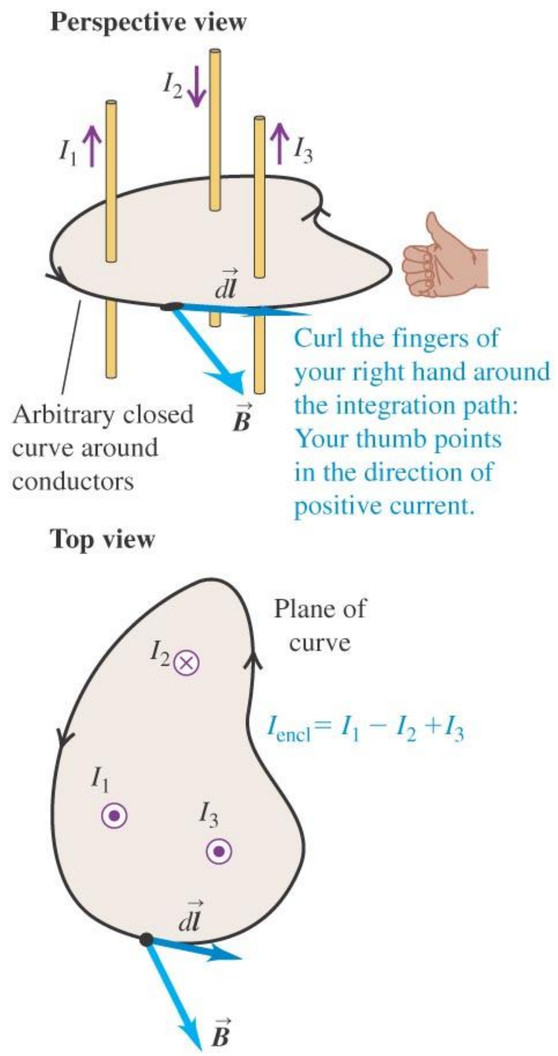


(a) (b)



Ampere's Law II

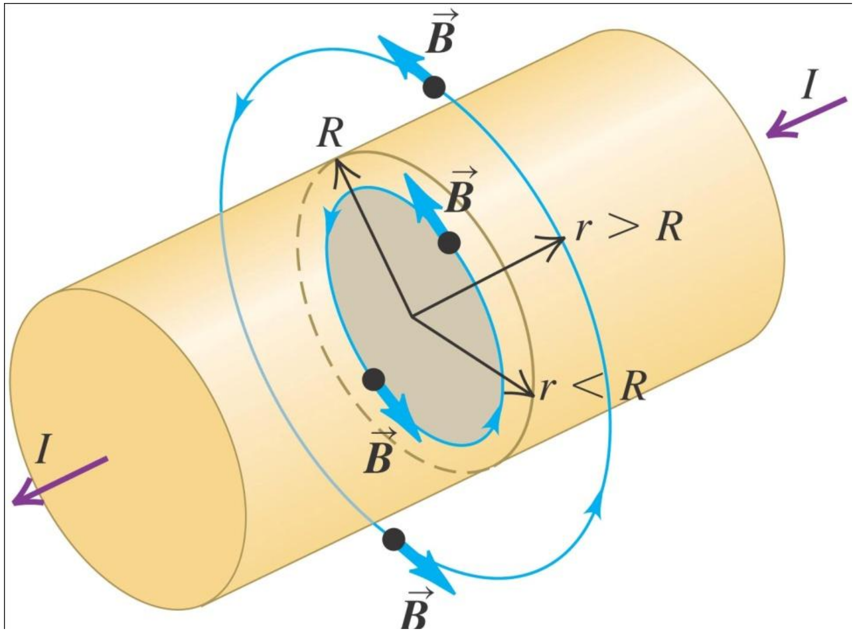
- Line integral of B over closed loop = μ_0 I
- $\int B \bullet dl = \mu_0 I$
- This is part of one of Maxwells Equations.

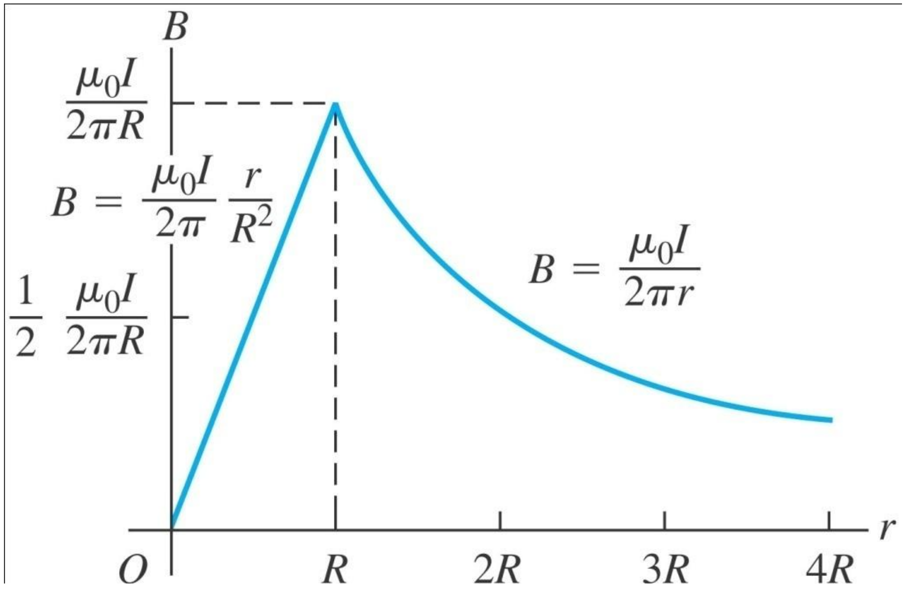


Ampere's law: If we calculate the line integral of the magnetic field around a closed curve, the result equals μ_0 times the total enclosed current: $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{encl}$

Field inside a long cylindrical conductor

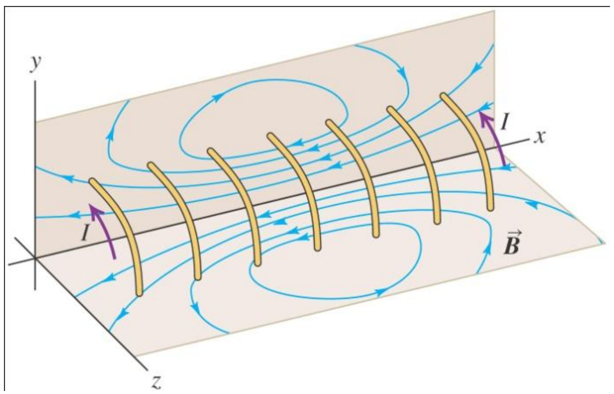
- A cylinder of radius R carrying a current I.
- This is similar to our use of Gauss' Law for electrostatics
- This is sometimes called (badly) magnetostatics

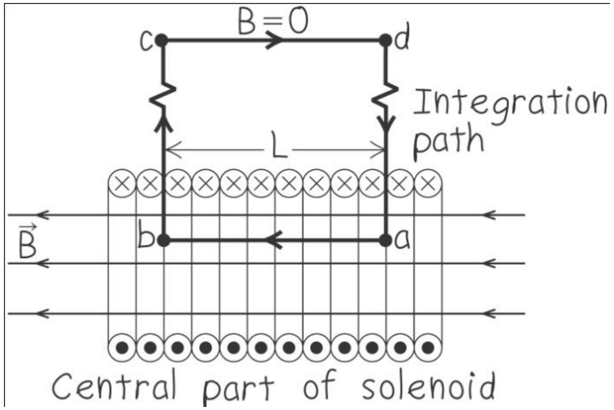


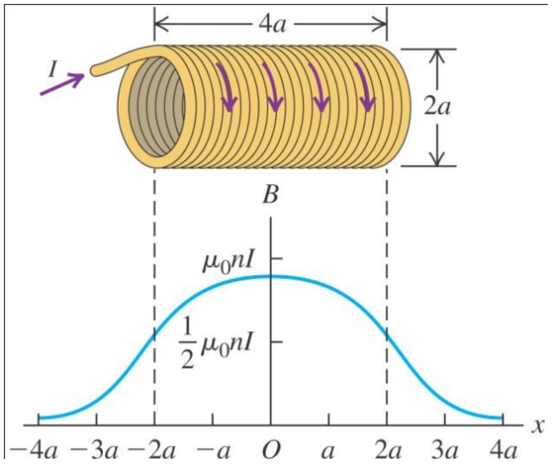


Field of a solenoid

- 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

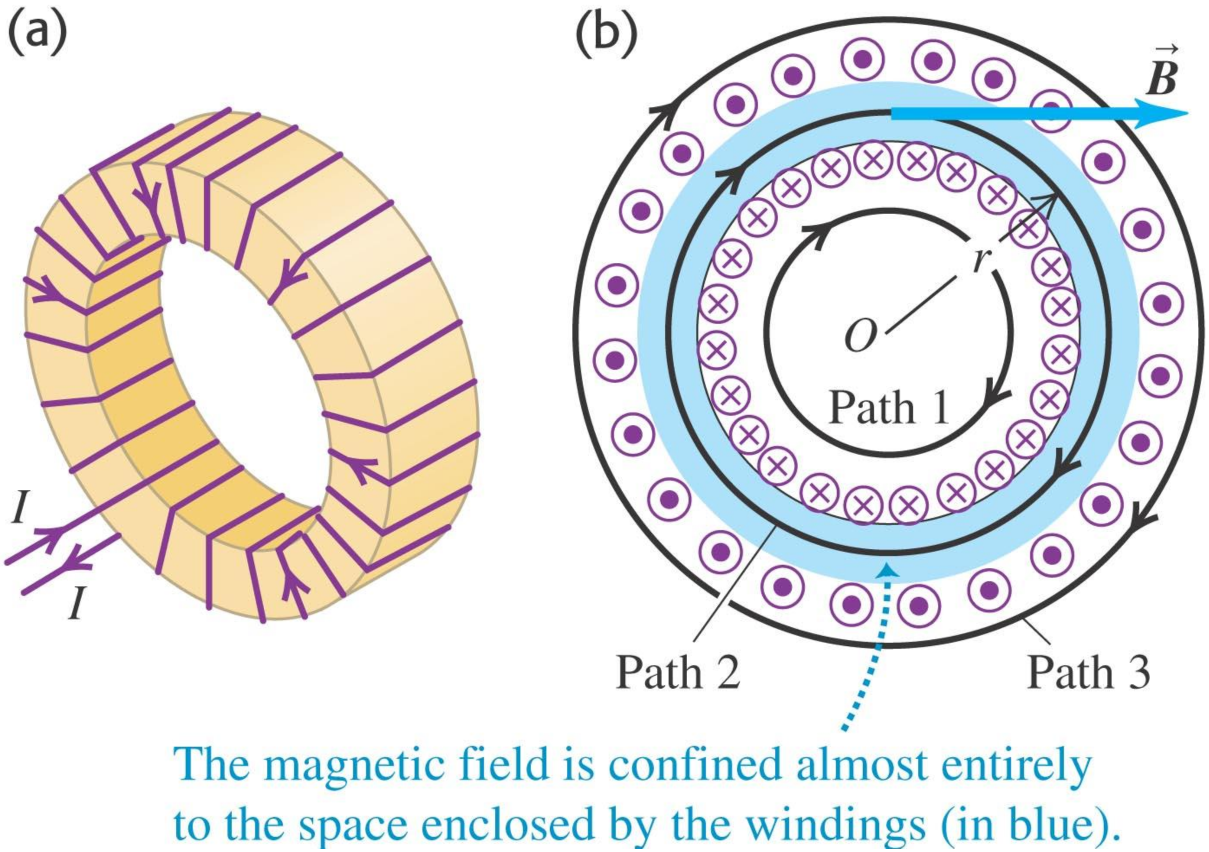






Field of a toroidal solenoid

- A doughnut-shaped solenoid.
- A good example of this is your laptop power supply.
- Most have a toroid near the end of the cable – it is an inductive filter

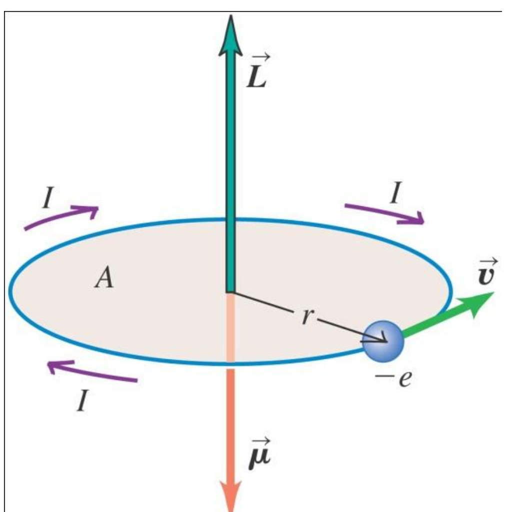


Magnetic materials

- Magnetic materials are really intrinsic and induced magnetic dipoles. Analog to electric dipoles.
- The Bohr magneton will determine how to classify material.
- Ferromagnetic, paramagnetic, and diamagnetic will help us designate material that's naturally magnetized or magnetizable, material that can be influenced by a magnetic field, and finally, material that is not interactive with a magnetic field. Table 28.1 summarizes some common materials.

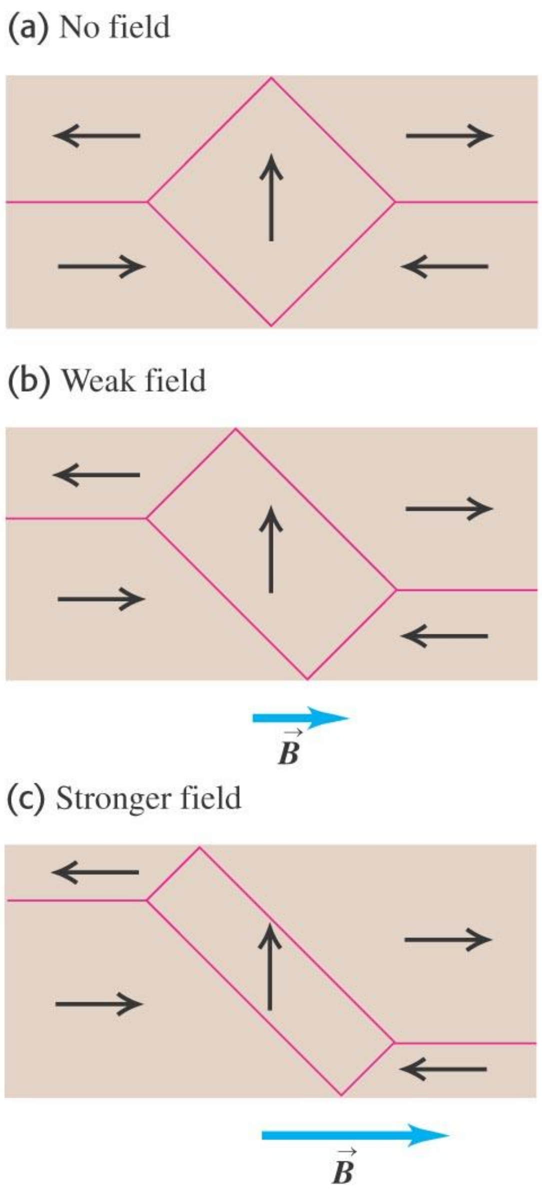
Table 28.1 Magnetic Susceptibilities of Paramagnetic and Diamagnetic Materials at $T = 20°C$

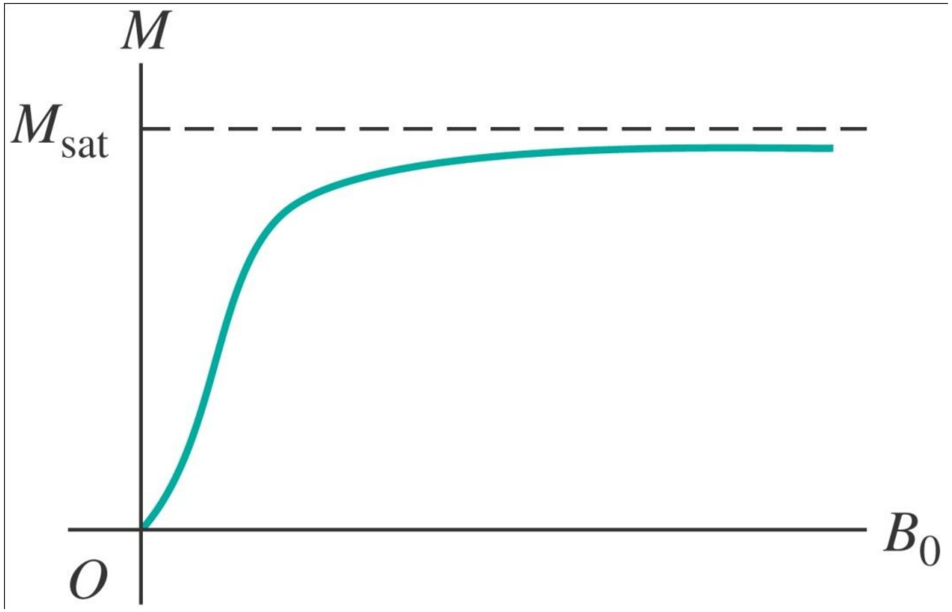
Material	$\chi_m = K_m - 1\ (\times 10^{-5})$
Paramagnetic	
Iron ammonium alum	66
Uranium	40
Platinum	26
Aluminum	2.2
Sodium	0.72
Oxygen gas	0.19
Diamagnetic	
Bismuth	−16.6
Mercury	−2.9
Silver	−2.6
Carbon (diamond)	−2.1
Lead	−1.8
Sodium chloride	−1.4
Copper	−1.0



Magnetic materials II

- Aligning Magnetic domains.
- No external field, weak and strong external fields.
- Common permanent magnets are aligned domains.





Magnetic Hysteresis in materials - saturation

- Hysteresis in magnetic materials
- A common issue and problem
- This is a combination of saturation (you align most of the available magnetic moments (domains here) and they then tend to stay aligned until you force them into a different direction (normally opposite) with an external field