Magnetic Force and Field

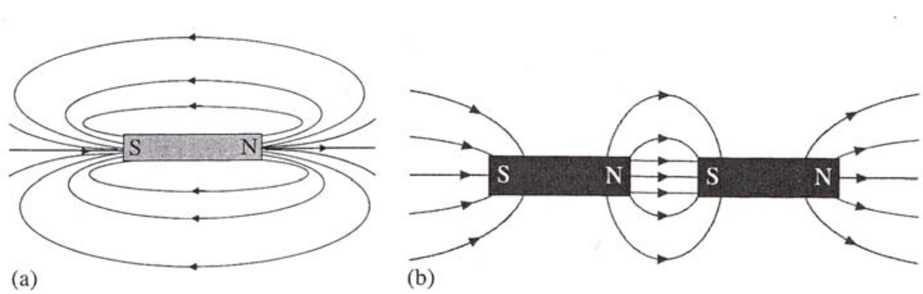
Magnetic Field

- Magnets and electric currents create magnetic fields around themselves
- When another magnet or moving charge enters this magnetic field it will experience a magnetic force
- The magnetic field is a vector quantity

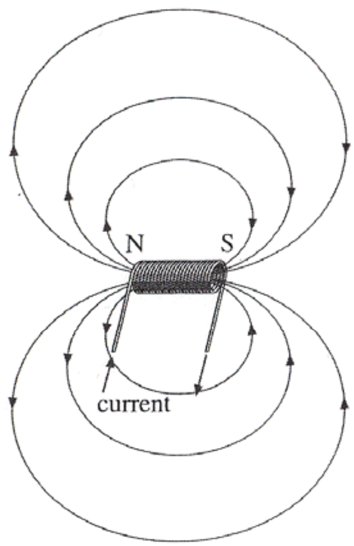
Magnetic Field Lines

- Imaginary lines around magnets and currents
- Tangents to the field lines give the direction
- Field lines go from "North" to "South"

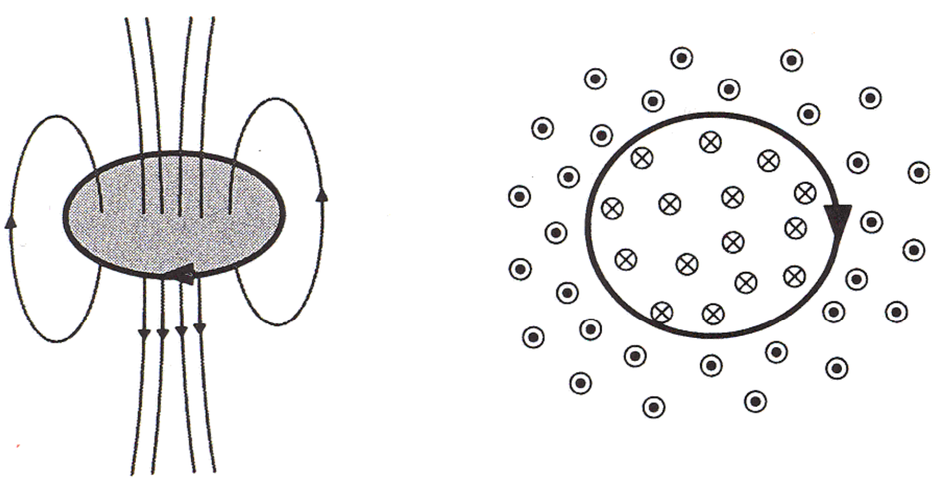
Permanent Magnet



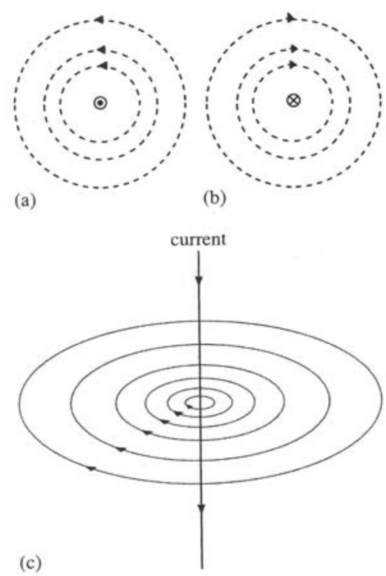
Solenoid (Coil)



Single Loop of Wire



Straight Wire

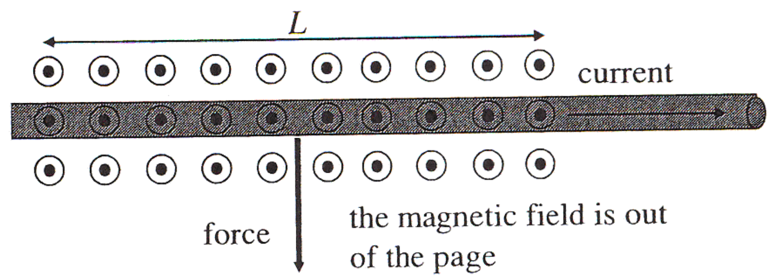


Other Information

- The magnetic field of the earth resembles that of a bar magnet except that the bar magnet does not coincide with the line through the geographic north and south poles of the earth.
- A monopole is an isolated north or south pole
  - Predicted by modern theories of particle physics but have never been found

Magnetic Force on Current

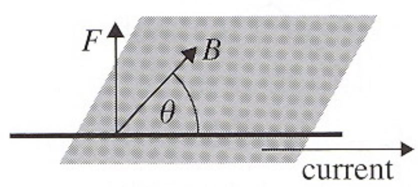
- If a current is placed in a region of magnetic field, it will experience a magnetic force.



- The magnitude of the force is proportional to the current, *I*, the magnetic field magnitude, *B*, and the length *L* of the wire that is in the magnetic field.

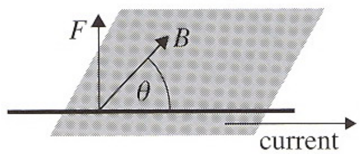
$$F = BIL\sin\theta$$

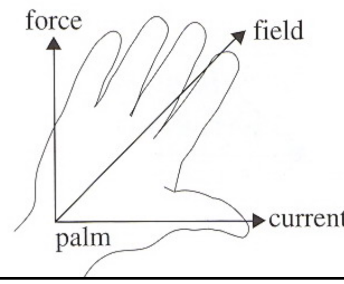
θ is the angle between the current and the direction of the magnetic field



Direction of Magnetic Force On a Wire

- Using the right hand, place the thumb in the direction of the current and the fingers in the direction of the magnetic field.
- The direction *away* from the palm is the direction of the magnetic force.





Magnetic Force on a Moving Charge

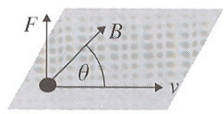
- A moving charge will experience a magnetic force
- A charge *q* moving with speed *v* in a magnetic field of magnitude *B* will experience a force *F* given by

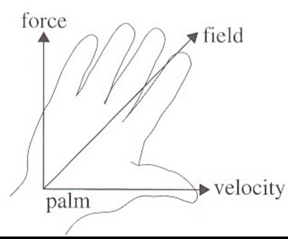
$$F = qvB\sin\theta$$

Where θ is the angle between the direction of the velocity and the magnetic field

Direction of Magnetic Force on a Moving Charge

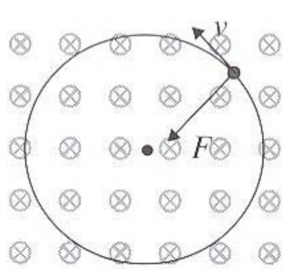
- Using the right hand, place the thumb in the direction of the velocity and the fingers in the direction of the magnetic field.
- The direction *away* from the palm is the direction of the magnetic force on a **positive** charge.

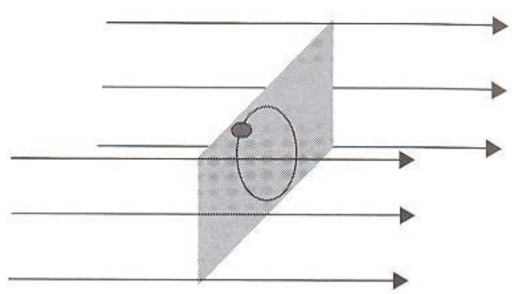




Motion of Charges in Magnetic Fields

- The magnetic force on a charge is always normal to the velocity
- Therefore, the path of a charge in a magnetic field must be a circle





- Consider a charge q moving with speed v in a magnetic field B.
- Assuming the charge's velocity is normal to the magnetic field, the force on the charge is

$$F = qvB$$

And so by Newton's second law: $qvB = m\frac{v^2}{R}$

Therefore…

$$R = \frac{mv}{qB}$$

Work Done and Magnetic Forces

- Since the magnetic force is always normal to the velocity of the charge
- It cannot do any work
- The big magnets in particle accelerators are used only to deflect particles not to increase the particles' kinetic energy
  - Electric fields are used to increase the kinetic energy of the particles

Ørsted's Discovery

- The magnitude of the magnetic field B created by the current in a wire varies linearly with the current in the wire and inversely with the perpendicular distance from the wire.

$$B = \frac{\mu_o}{2\pi}\frac{I}{r}$$

μ_o is the magnetic permeability of free space

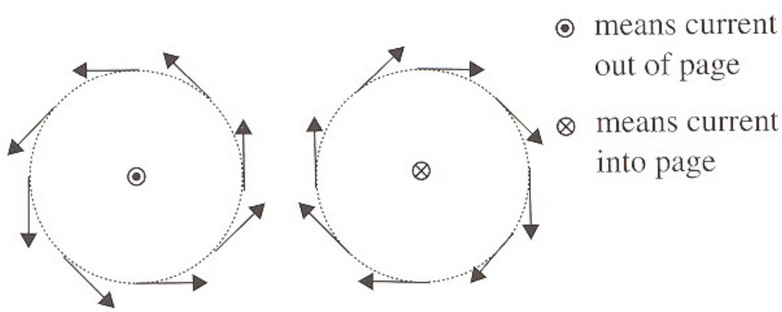
$$\mu_o = 4\pi \text{ x } 10^{-7} \text{ TmA}^{-1}$$

Units

- The unit of the magnetic field is the tesla (T)
- The tesla is a big unit
- The magnetic field of the earth is about 10^{-4} T
- A wire carrying a current of about 2000 A produces a magnetic field of 8 x 10^{-5} T at a distance of 5 m from the wire

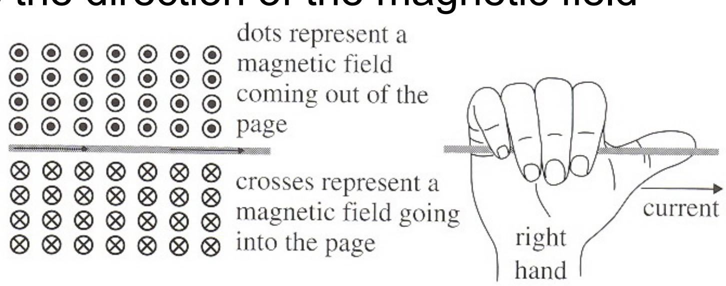
Direction of Magnetic Fields

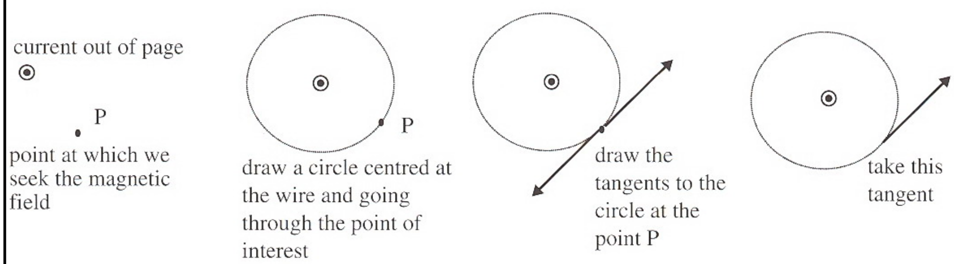
- The direction of the magnetic field at a given point in space is found by placing magnetic needles around the wire and seeing they align themselves



"Right-hand Rule"

- Grip the wire with the fingers of the right hand in such a way that the thumb points in the direction of the current
- Then the direction in which the fingers curl is the direction of the magnetic field



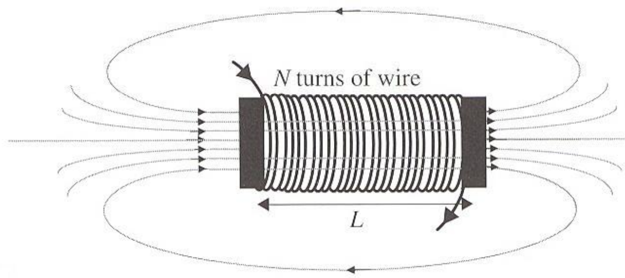


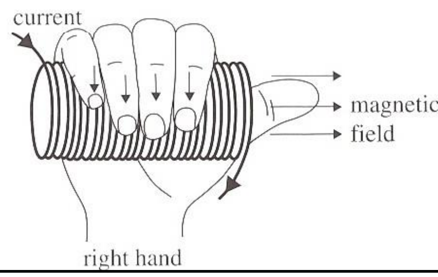
Single Current Loop

- The magnetic field strength B at the center of a circular loop of radius R carrying current I is

$$B = \frac{\mu_o I}{2R}$$

The Solenoid





- In the interior of the solenoid, the magnetic field is uniform in magnitude and direction

$$B = \mu_o \frac{NI}{L}$$

N is the number of turns

L is the length of the solenoid

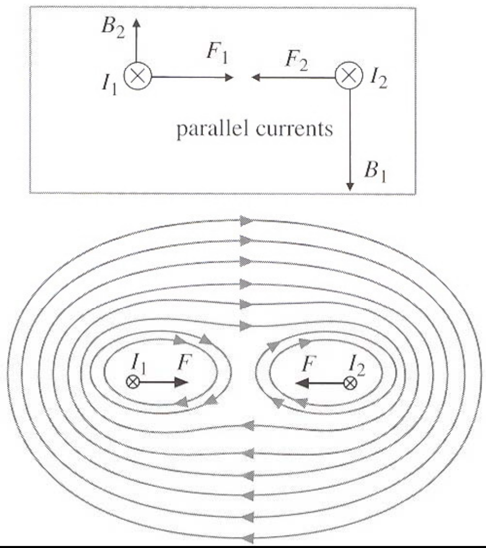
I is the current through it

The Force Between Two Current-carrying Wires

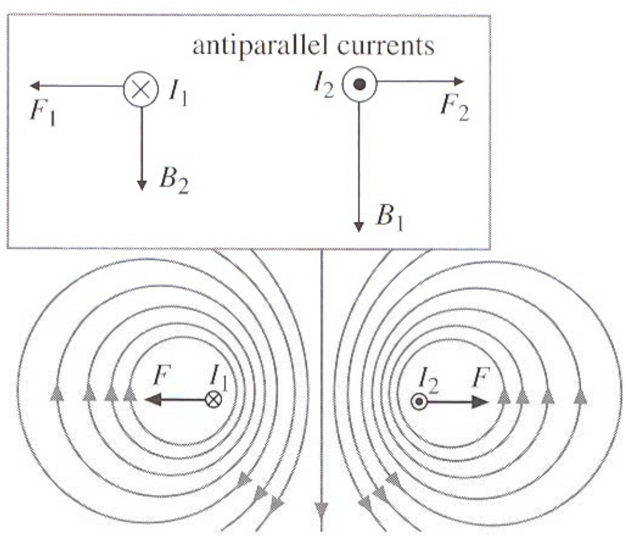
- Consider two long, straight, parallel wires each carrying a current, I_1 and I_2
- The first wire (wire 1) creates a magnetic field in space at the position of the second wire (wire 2)
- Thus, wire 2 will experience a magnetic force

- Similarly, wire 2 will produce a magnetic field at the position of wire 1
- So wire 1 will also experience a magnetic force
- Newton's third law tells us that these forces should be equal and opposite

- If the currents run in the same direction, the forces are attractive



- If the currents are in the opposite direction, the forces are repulsive



The magnetic fields generated by the wires separated by a distance *r* are given by

$$B_1 = \mu_o \frac{I_1}{2\pi r}$$

$$B_2 = \mu_o \frac{I_2}{2\pi r}$$

The forces on the wires can be calculated as follows:

$$F_2 = B_1 I_2 L$$

$$F_2 = \mu_o \frac{I_1}{2\pi r} I_2 L$$

$$F_1 = B_2 I_1 L$$

$$F_1 = \mu_o \frac{I_2}{2\pi r} I_1 L$$

The forces are equal in magnitude consistent with Newton's third law

Side Note

- The ampere is defined through the magnetic force between two parallel wires.
- If the force on a 1 m length of two wires that are 1 m apart and carrying equal currents is 2×10^{-7} N, then the current in each wire is defined to be 1 A.