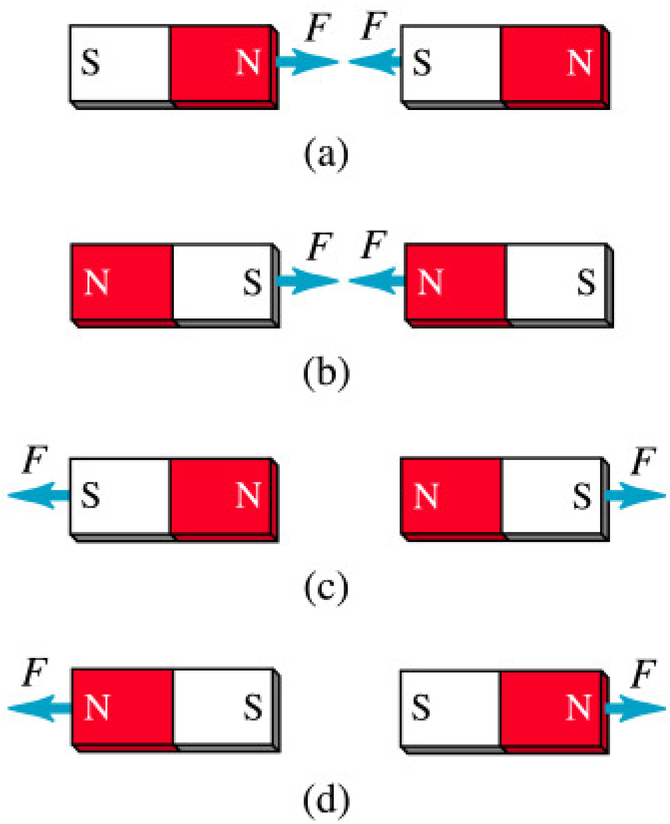
Magnetic Fields and Forces

AP Physics C

Facts about Magnetism



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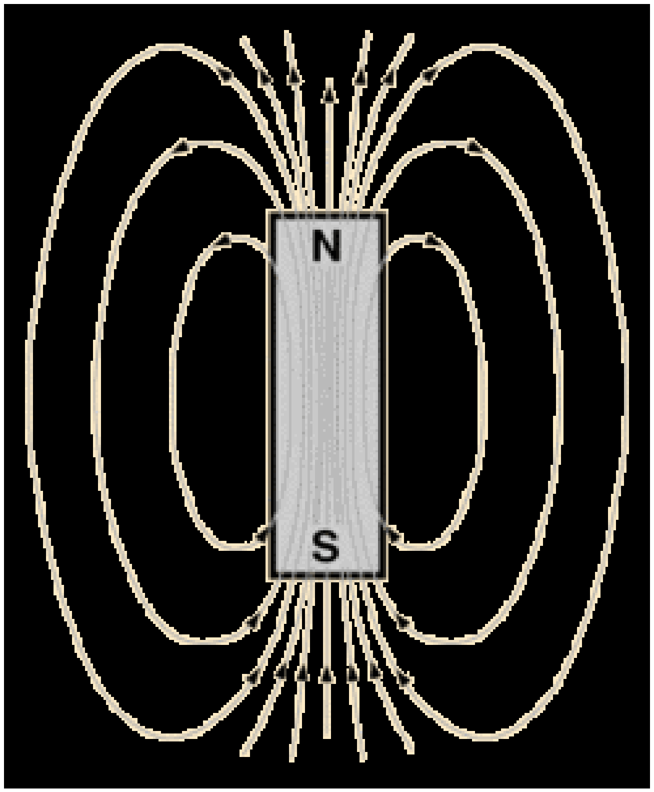
- Magnets have 2 poles (north and south)
- Like poles repel
- Unlike poles attract
- Magnets create a MAGNETIC FIELD around them

Magnetic Field



A bar magnet has a magnetic field around it. This field is 3D in nature and often represented by lines LEAVING north and ENTERING south

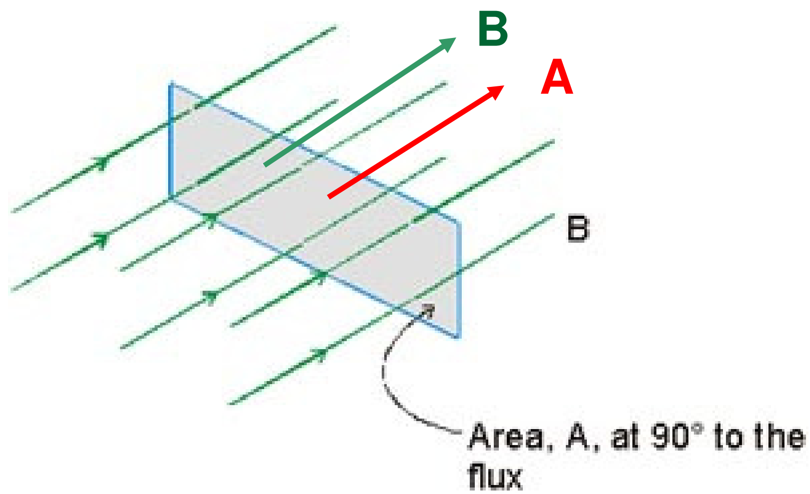
To define a magnetic field you need to understand the MAGNITUDE and DIRECTION

We sometimes call the magnetic field a B-Field as the letter "B" is the SYMBOL for a magnetic field with the TESLA (T) as the unit.

Magnetic Flux

The first step to understanding the complex nature of electromagnetic induction is to understand the idea of magnetic flux.

Flux is a general term associated with a FIELD that is bound by a certain AREA. So MAGNETIC FLUX is any AREA that has a MAGNETIC FIELD passing through it.



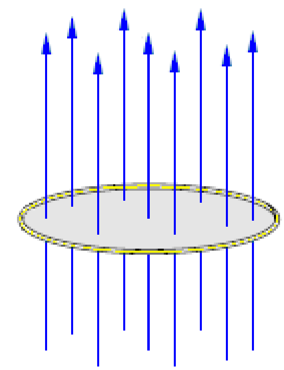
We generally define an AREA vector as one that is perpendicular to the surface of the material. Therefore, you can see in the figure that the AREA vector and the Magnetic Field vector are **PARALLEL**. This then produces a DOT PRODUCT between the 2 variables that then define flux.

Magnetic Flux – The DOT product

$$\Phi_B = B \bullet A$$

$$\Phi_B = BA\cos\theta$$

$$\text{Unit}: \text{Tm}^2 \text{ or } \text{Weber(Wb)}$$



How could we CHANGE the flux over a period of time?

- We could move the magnet away or towards (or the wire)
- We could increase or decrease the area
- We could ROTATE the wire along an axis that is PERPENDICULAR to the field thus changing the angle between the area and magnetic field vectors.

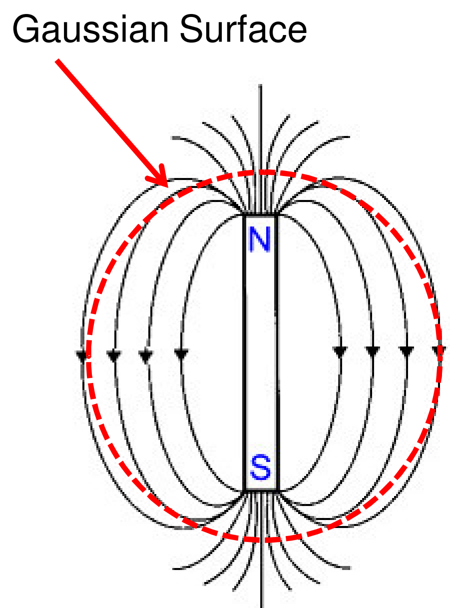
Magnetic Flux & Gauss' Law

If we use Gauss's law to compare ELECTRIC FLUX with MAGNETIC FLUX we see a major difference. You can have an isolated charge that is enclosed produce electric flux.

$$\Phi_B = B \bullet A = BA\cos\theta$$

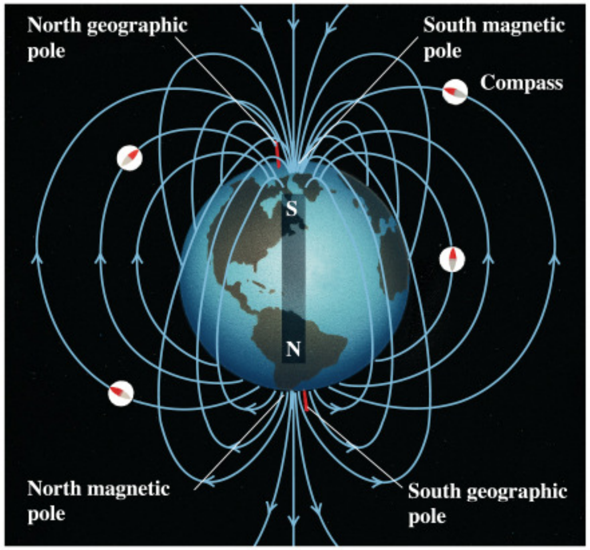
$$\Phi_E = \oint E \bullet dA = \frac{q_{enc}}{\varepsilon_o}$$

$$\Phi_B = \oint B \bullet dA = 0$$



But if we enclose a MAGNET, we have the same # of magnetic field lines entering the closed surface as we have leaving, thus the NET MAGNETIC FLUX = ZERO!

Earth is a magnet too!



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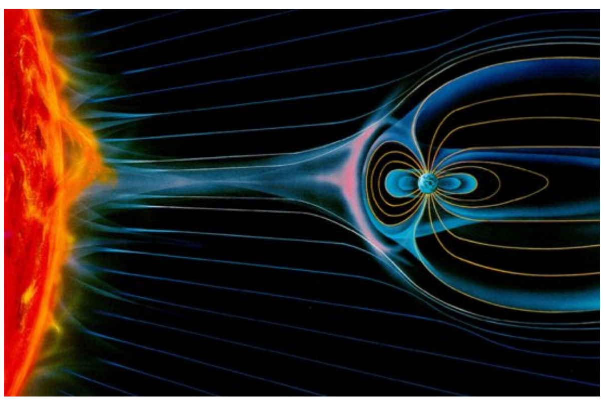


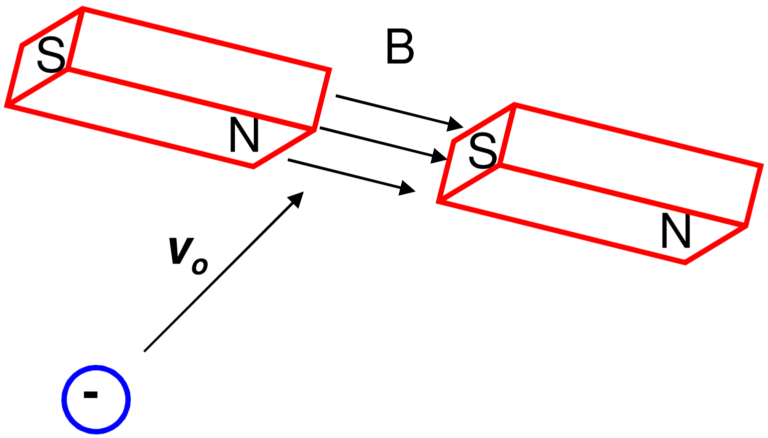
The magnetic north pole of the EARTH corresponds with geographic south and vice versa.

So when you use a compass the NORTH POLE of the compass must be attracted to a South Pole on the earth if you wanted to travel north.

This magnetic field is very important in that it prevents the earth from being bombarded from high energy particles.

This key to this protection is that the particles MUST be moving!

Magnetic Force on a moving charge



If a MOVING CHARGE moves into a magnetic field it will experience a MAGNETIC FORCE. This deflection is 3D in nature.

$$\vec{F}_B = q\vec{v} \otimes \vec{B}$$

$$F_B = qvB\sin\theta$$

The conditions for the force are:

- Must have a magnetic field present
- Charge must be moving
- Charge must be positive or negative
- Charge must be moving **PERPENDICULAR** to the field.

Example

A proton moves with a speed of $1.0x10^5$ m/s through the Earth's magnetic field, which has a value of 55μT at a particular location. When the proton moves eastward, the magnetic force is a maximum, and when it moves northward, no magnetic force acts upon it. What is the magnitude and direction of the magnetic force acting on the proton?

$$F_B = qvB, \theta = 90, \sin 90 = 1$$

$$F_B = (1.6x10^{-19})(1.0x10^5)(55x10^{-6})$$

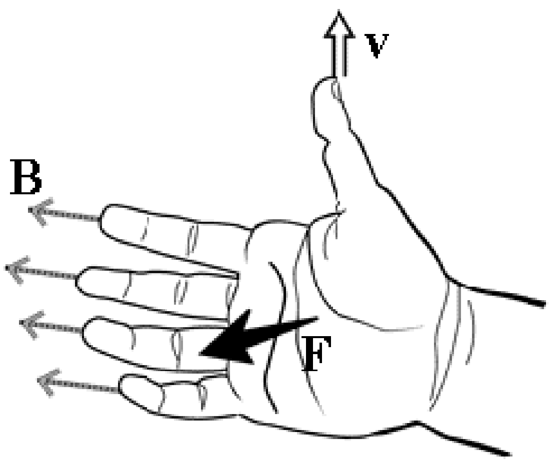
$$F_B = \textbf{8.8x10}^{\textbf{-19}}\textbf{ N}$$

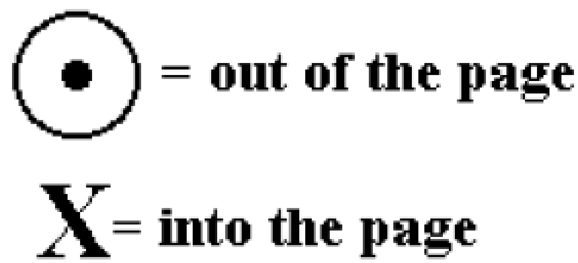
The direction cannot be determined precisely by the given information. Since no force acts on the proton when it moves northward (meaning the angle is equal to ZERO), we can infer that the magnetic field must either go northward or southward.

Direction of the magnetic force?

Right Hand Rule

To determine the DIRECTION of the force on a **POSITIVE** charge we use a special technique that helps us understand the 3D/perpendicular nature of magnetic fields.





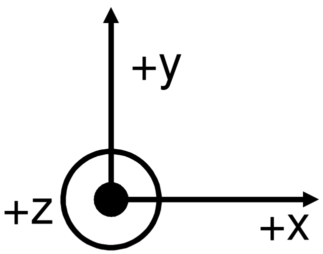
Basically you hold your right hand flat with your thumb perpendicular to the rest of your fingers

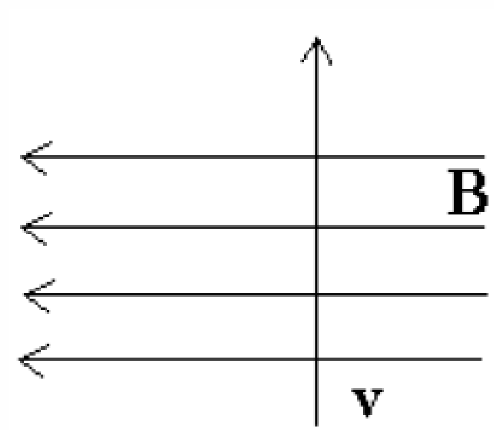
- The Fingers = Direction B-Field
- The Thumb = Direction of velocity
- The Palm = Direction of the Force

For **NEGATIVE** charges use left hand!

Example

Determine the direction of the unknown variable for a proton moving in the field using the coordinate axis given

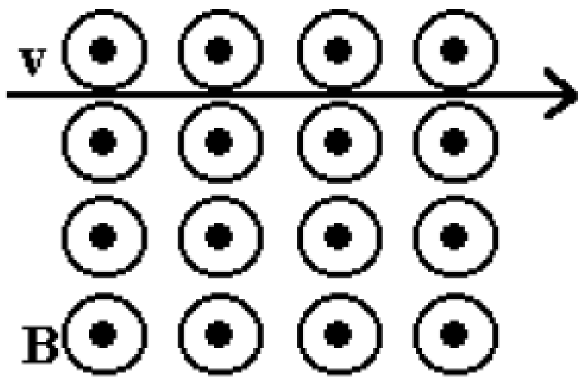




B = -x

v = +y

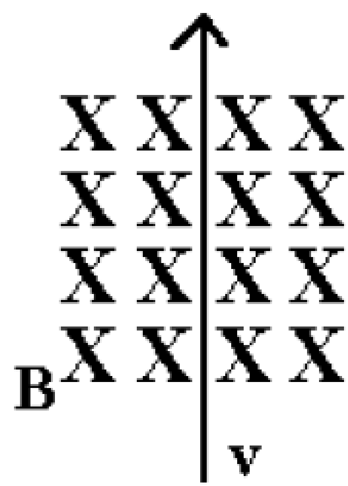
F = **+z**



B =+Z

v = +x

F = **-y**



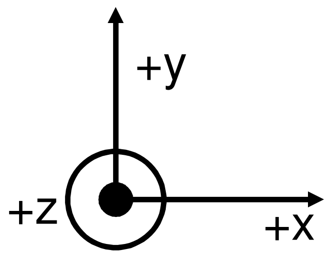
B = -z

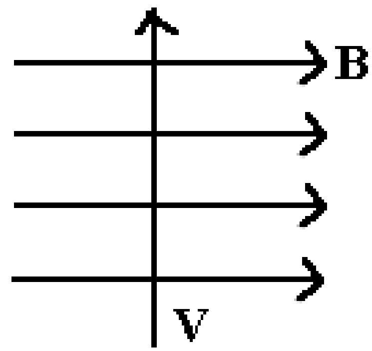
v = +y

F = **-x**

Example

Determine the direction of the unknown variable for an electron using the coordinate axis given.

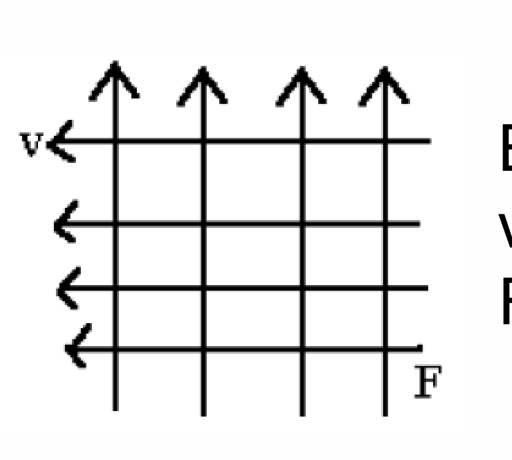




B = +x

v = +y

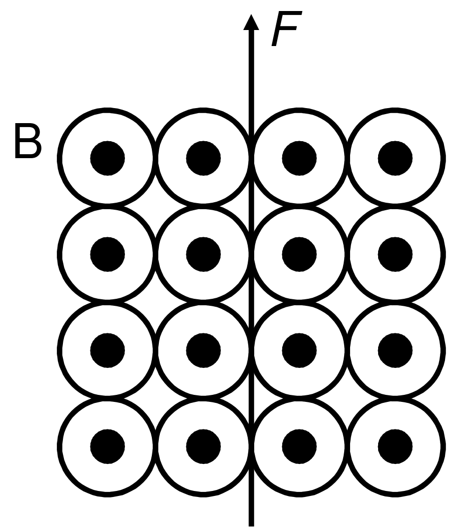
F = **+z**



B = **-z**

v = - x

F = +y

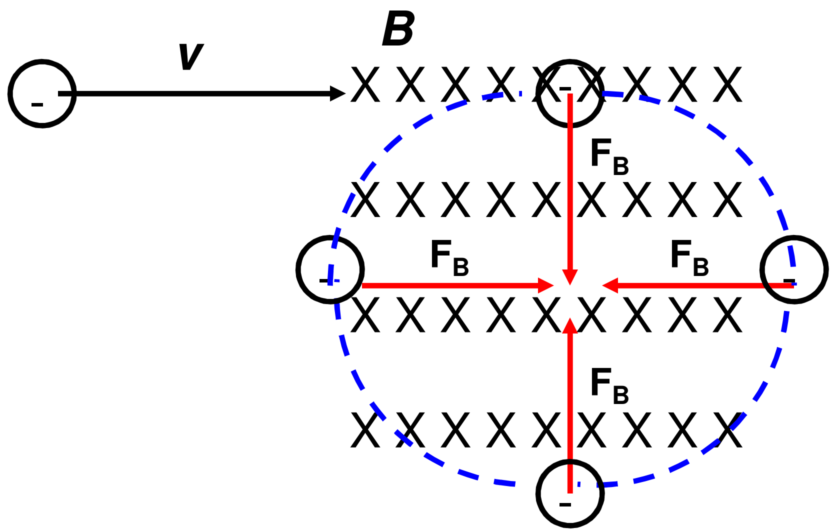


B = +z

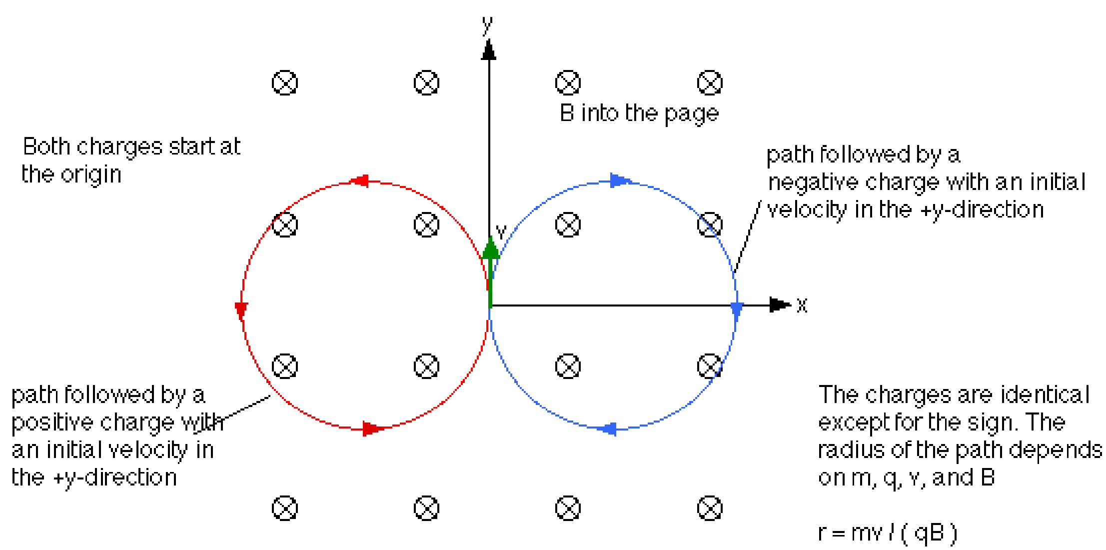
v = **+x**

F = +y

Magnetic Force and Circular Motion



Suppose we have an electron traveling at a velocity , ***v***, entering a magnetic field, ***B***, directed into the page. What happens after the initial force acts on the charge?



Magnetic Force and Circular Motion

$$F_B = qvB,\ F_c = \frac{mv^2}{r},\ F_B = F_c$$

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

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

The magnetic force is equal to the centripetal force and thus can be used to solve for the circular path. Or, if the radius is known, could be used to solve for the MASS of the ion. This could be used to determine the material of the object.

There are many “other” types of forces that can be set equal to the magnetic force.

$$F_B = qvB$$

$$mg = qvB$$

$$ma = qvB$$

Example

A singly charged positive ion has a mass of 2.5 x 10^{-26} kg. After being accelerated through a potential difference of 250 V, the ion enters a magnetic field of 0.5 T, in a direction perpendicular to the field. Calculate the radius of the path of the ion in the field.

$$q = 1.6x10^{-19}\,C$$

$$m = 2.5x10^{-26}\,kg$$

$$\Delta V = 250V$$

$$B = 0.5T$$

$$r = ?$$

$$F_B = F_c \qquad qvB = \frac{mv^2}{r} \qquad r = \frac{mv}{qB}$$

We need to solve for the velocity!

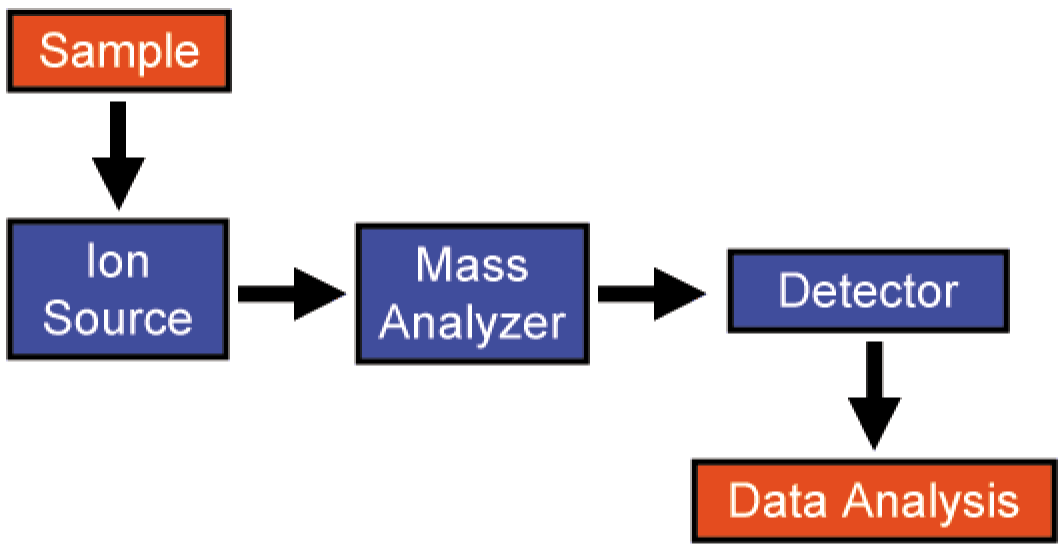
$$r = \frac{(2.5x10^{-26})(56{,}568)}{(1.6x10^{-19})(0.5)} =$$ **0.0177 m**

$$\Delta V = \frac{W}{q} = \frac{\Delta K}{q} = \frac{\frac{1}{2}mv^2}{q}$$

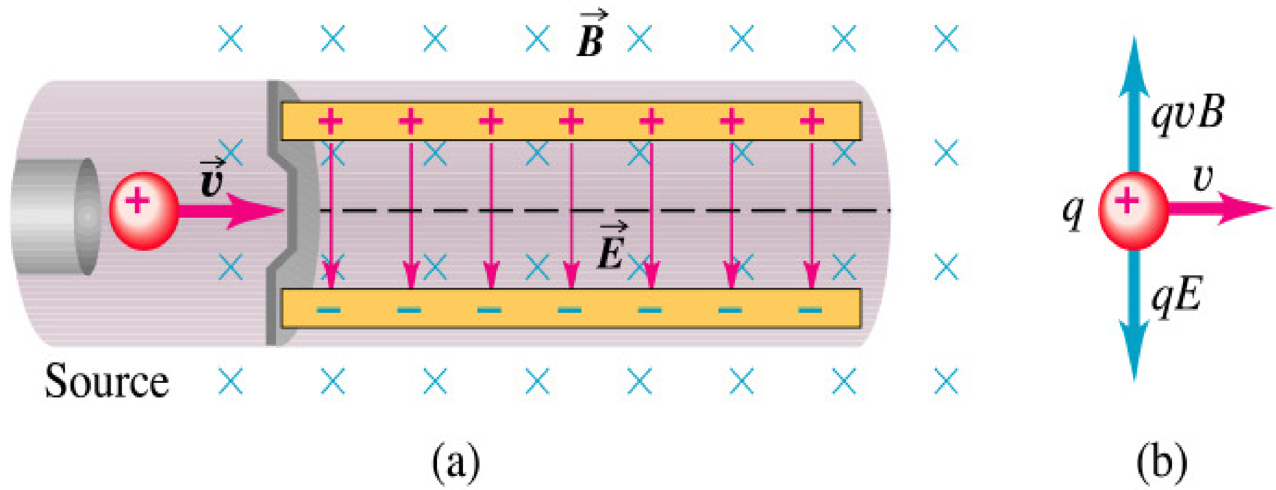
$$v = \sqrt{\frac{2\Delta V q}{m}} = \sqrt{\frac{2(250)(1.6x10^{-19})}{2.5x10^{-26}}} =$$ **56,568 m/s**

Mass Spectrometers

Mass spectrometry is an analytical technique that identifies the chemical composition of a compound or sample based on the **mass-to-charge ratio** of charged particles. A sample undergoes chemical fragmentation, thereby forming charged particles (ions). The ratio of charge to mass of the particles is calculated by passing them through **ELECTRIC** and **MAGNETIC** fields in a mass spectrometer.



M.S. – Area 1 – The Velocity Selector



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$$F_B = F_E \qquad qvB = qE$$

$$E = vB \qquad v = \frac{E}{B}$$

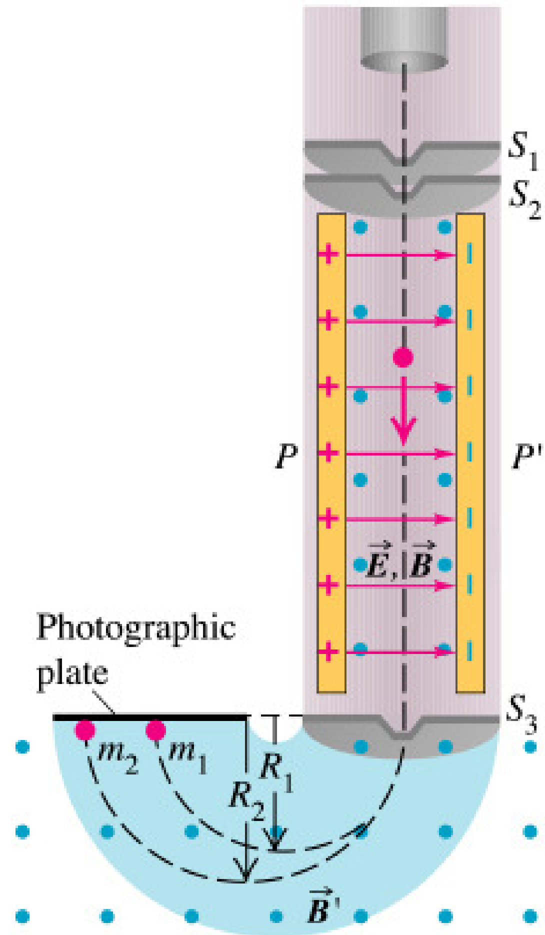
When you inject the sample you want it to go STRAIGHT through the plates. Since you have an electric field you also need a magnetic field to apply a force in such a way as to CANCEL out the electric force caused by the electric field.

M.S. – Area 2 – Detector Region

After leaving region 1 in a straight line, it enters region 2, which ONLY has a magnetic field. This field causes the ion to move in a circle separating the ions separate by mass. This is also where the charge to mass ratio can then by calculated. From that point, analyzing the data can lead to identifying unknown samples.

$$F_B = F_c \qquad qvB = \frac{mv^2}{r}$$

$$\frac{q}{m} = \frac{Bv}{r}$$



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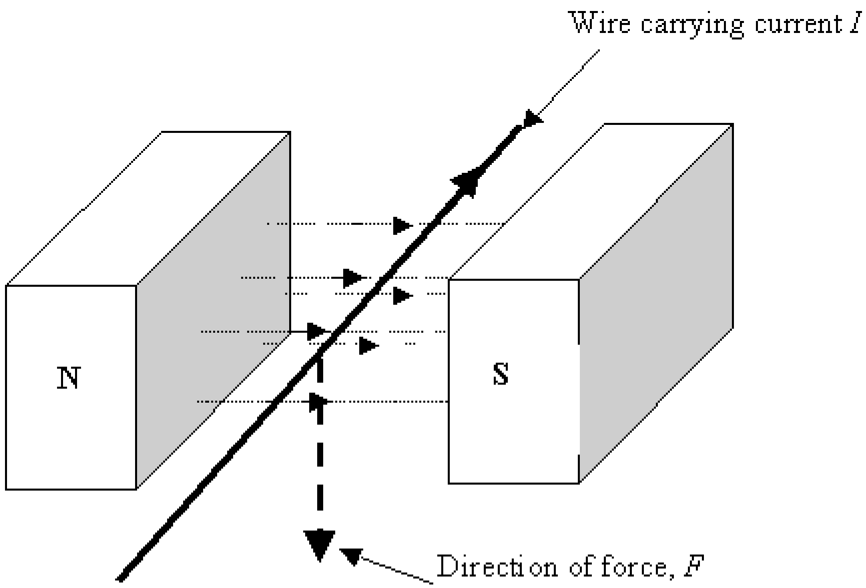
Charges moving in a wire

Up to this point we have focused our attention on PARTICLES or CHARGES only. The charges could be moving together in a wire. Thus, if the wire had a CURRENT (moving charges), it too will experience a force when placed in a magnetic field.



You simply used the RIGHT HAND ONLY and the thumb will represent the direction of the CURRENT instead of the velocity.

Charges moving in a wire

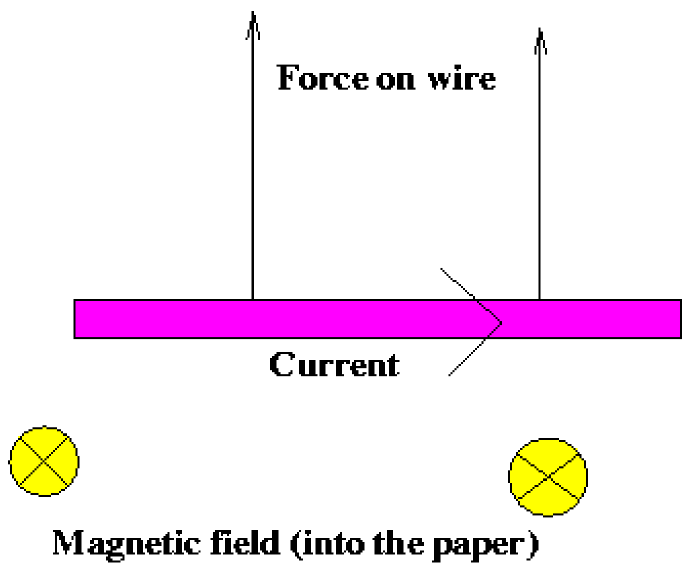
At this point it is VERY important that you understand that the MAGNETIC FIELD is being produced by some **EXTERNAL AGENT**

$$F_B = qvB\sin\theta \rightarrow dqvB\sin\theta \qquad v = \frac{dx}{dt}$$

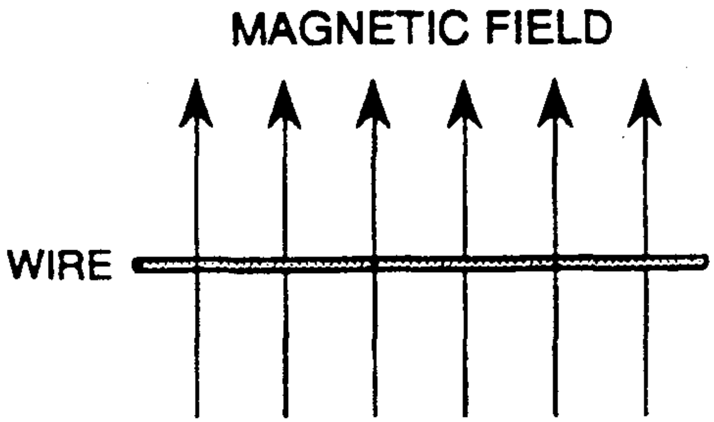
$$F_B = dq\frac{dx}{dt}B\sin\theta = \frac{dq}{dt}dxB \qquad I = \frac{dq}{dt}$$

$$F_B = IdxB\sin\theta \rightarrow \int dx = l = length$$

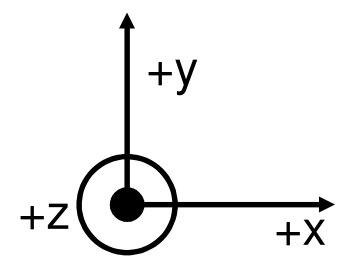
$$F_B = IlB\sin\theta$$



Example



A 36-m length wire carries a current of 22A running from right to left. Calculate the magnitude and direction of the magnetic force acting on the wire if it is placed in a magnetic field with a magnitude of 0.50 x10^{-4} T and directed up the page.



$$F_B = ILB\sin\theta$$

$$F_B = (22)(36)(0.50x10^{-4})\sin 90$$

$F_B =$ **0.0396 N**

B = +y

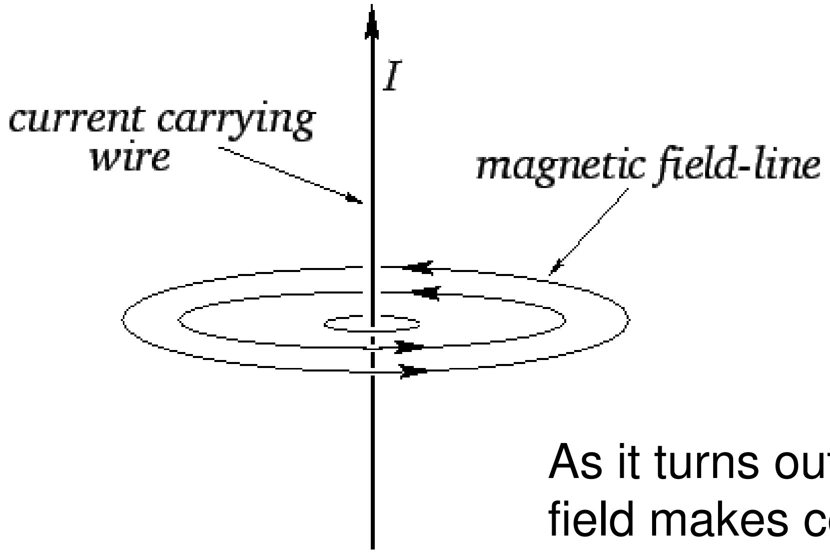
I = -x

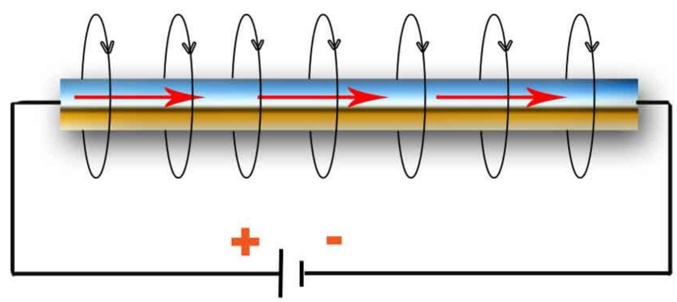
F = **-z, into the page**

WHY does the wire move?

The real question is WHY does the wire move? It is easy to say the EXTERNAL field moved it. But how can an external magnetic field FORCE the wire to move in a certain direction?

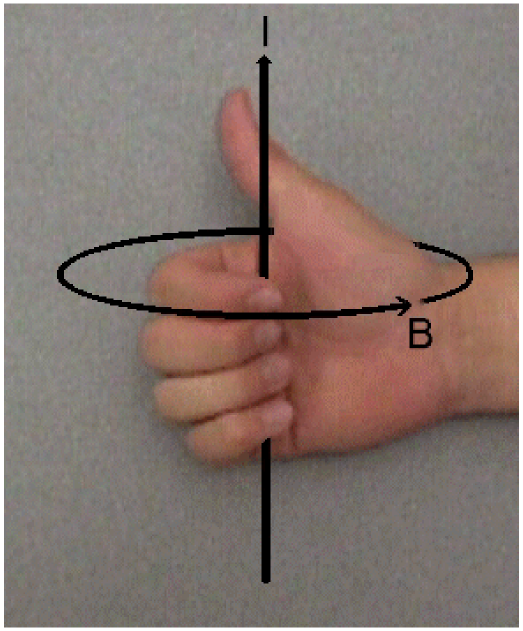
THE WIRE ITSELF MUST BE MAGNETIC!!! In other words the wire has its own INTERNAL MAGNETIC FIELD that is attracted or repulsed by the EXTERNAL FIELD.



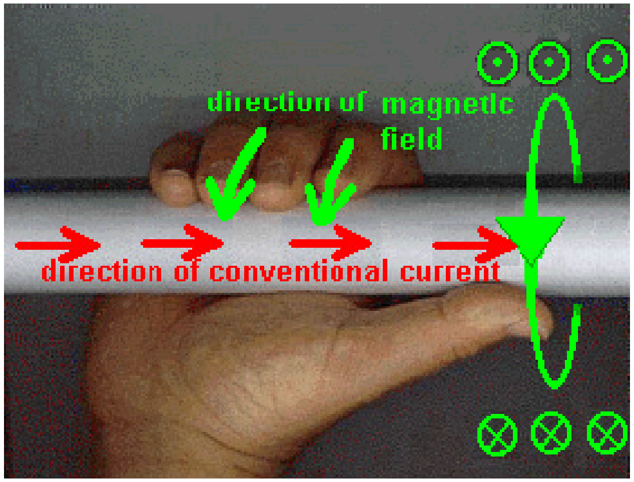


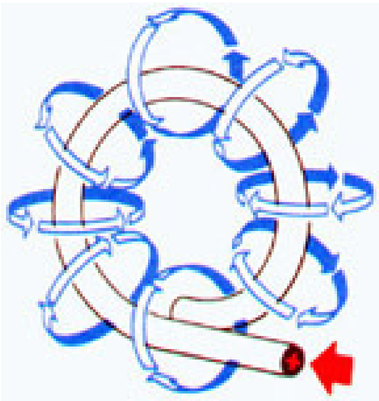
As it turns out, the wire's OWN internal magnetic field makes concentric circles round the wire.

A current carrying wire's INTERNAL magnetic field



To figure out the DIRECTION of this INTERNAL field you use the right hand rule. You point your thumb in the direction of the current then CURL your fingers. Your fingers will point in the direction of the magnetic field





The MAGNITUDE of the internal field

The magnetic field, B, is directly proportional to the current, I, and inversely proportional to the circumference.

$$B \alpha I \qquad B \alpha \frac{1}{2\pi r}$$

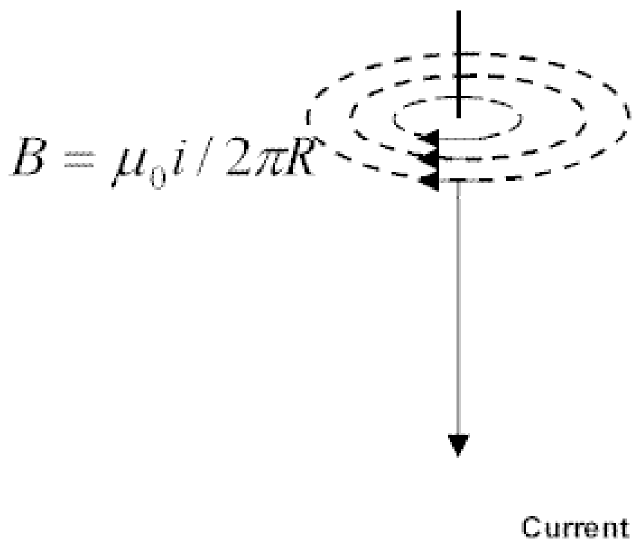
$$B \alpha \frac{I}{2\pi r}$$

$$\mu_o = \text{constant of proportionality}$$

$$\mu_{\mathrm{o}} = \text{vacuum permeability constant}$$

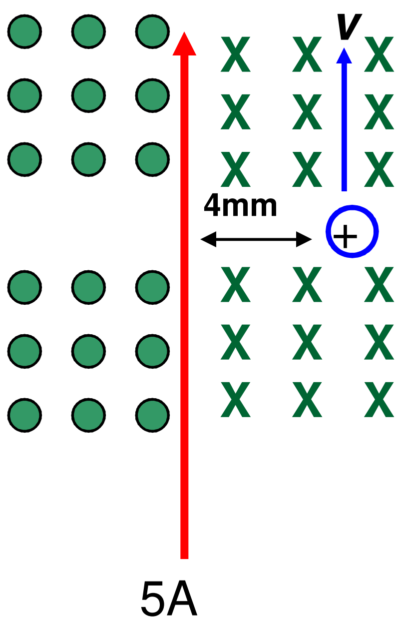
$$\mu_{\mathrm{o}} = 4\pi\, x 10^{-7} (1.26 x 10^{-6}) \frac{Tm}{A}$$

$$\boxed{B_{\text{internal}} = \frac{\mu_o I}{2\pi r}}$$



Example

A long, straight wires carries a current of 5.00 A. At one instant, a proton, 4 mm from the wire travels at 1500 m/s parallel to the wire and in the same direction as the current. Find the **magnitude** and **direction** of the magnetic force acting on the proton due to the field caused by the current carrying wire.



$$F_B = qvB_{EX} \qquad B_{IN} = \frac{\mu_o I}{2\pi r}$$

$$B_{IN} = \frac{(1.26x10^{-6})(5)}{2(3.14)(0.004)} =$$ **2.51 x 10^{-4} T**

B = +z

v = +y

F = **-x**

$$F_B = (1.6x10^{-19})(1500)(B_{wire}) =$$

6.02 x 10^{-20} N