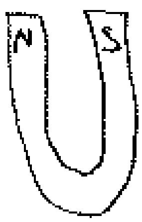
Magnets

You've probably played with them, or seen them in Cartoons. What do we know from playing?

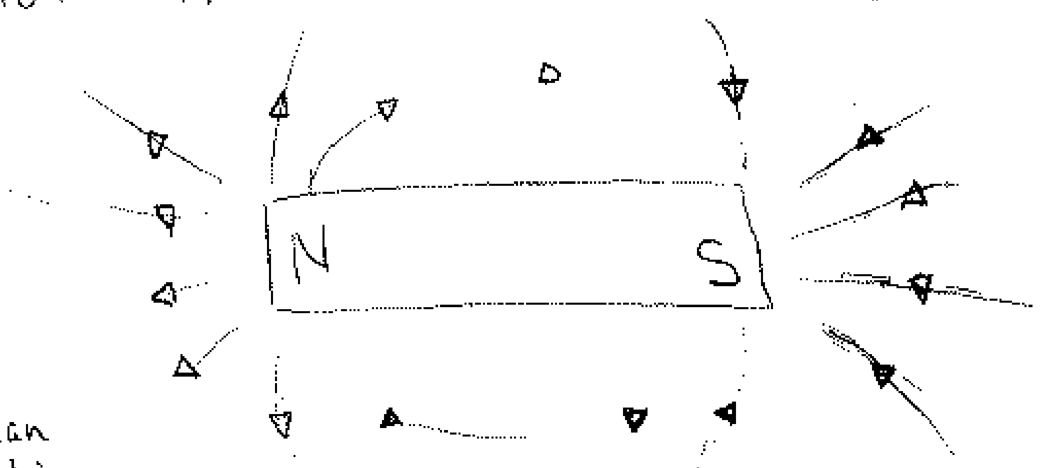


Magnets have 2 poles a north pole & a south pole

like poles repel
opposites attract

Even "Flat" magnets behave this way.
One way you can s tuck them and they stick
one way they repel each other.

In fuct, every magnet has a north and a south pole. The magnetic field looks a lot like that for 2 changes

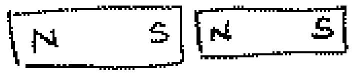


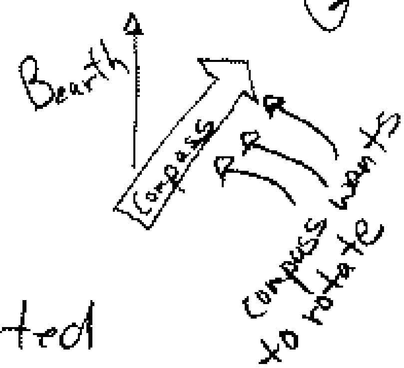
outside the magnet, lines look like this

You can map this out since

a compass points alon the lines

Break a magnet, you get 2 magnets, an isolated north or South pole has never been seen.





North pole attracted to south pole.

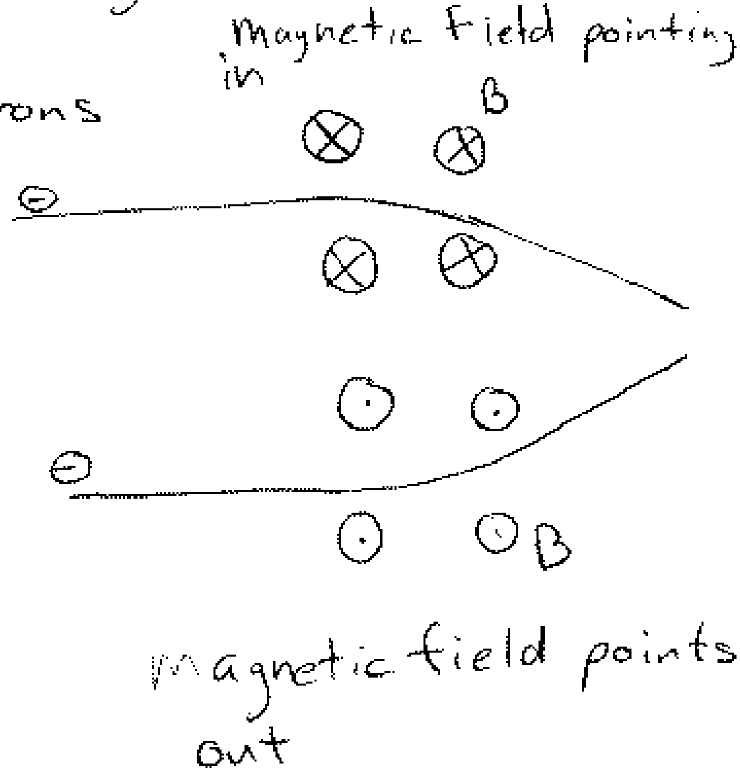
North pole of a compass is attracted to earths south magnetic pole (which is what we call north!) Gets a Torque, but how?

Lets investigate more.

Magnets effect other magnets, a magnetic field has an effect on amoving charge

<u>demo</u> beam of electrons

Notice



Force is $\propto$ velocity,

Force is $\perp$ to the magneticfield. B is defined

So that

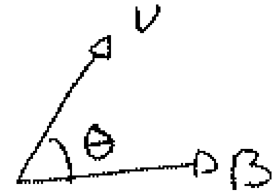
$$\vec{F} = q\vec{v} \times \vec{B}$$

B has units of $\frac{N}{C}\frac{1}{(m/s)}$

or Tesla

$1T = 1 Ns/cm$

Mathematically



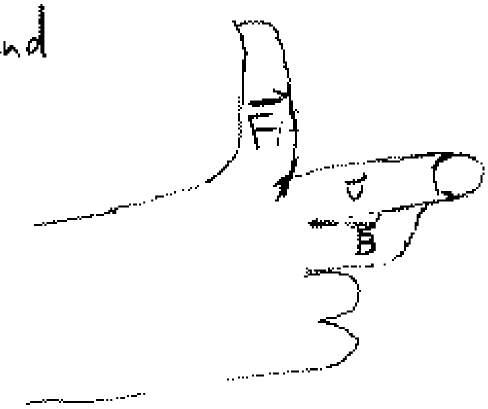
$$\vec{V} = V_x\hat{i} + V_y\hat{j} + V_z\hat{k}$$

$$\vec{B} = B_x\hat{i} + B_y\hat{j} + B_z k$$

$$\vec{F} = q\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ V_x & V_y & V_z \\ B_x & B_y & B_z \end{vmatrix} = \hat{i}\left(V_y B_z - B_y V_z\right) + \hat{j}\left(V_z B_x - B_z V_x\right) + \hat{k}\left(V_x B_y - B_x V_y\right)$$

$$= |V|\,|B| \sin\theta$$

and you can find the direction with your right hand



F is always ⊥ to v
⊥ B

you can think of the v & B vectors defining the xy plane, then F is always pointing inthe (± z direction)

Couple of cool things

1) can get particles to go in a circle

2) can get particles to go in a helix

(important for TV's?

<u>ex</u> What $\vec{B}$ is required to keep an electron, moving 10 m/s in a 10 cm circle?

Force needed to keep electron moving in a circle $\frac{mv^2}{r} = qvB$

$$\frac{mv}{qr} = B = \frac{9.1\times10^{-31}\text{kg}\,(10\frac{m}{s})}{1.6\times10^{-19}\text{C}\,(0.1\text{m})} = 5.7\times10^{-10}\,\text{T}$$

weak

By comparison, huge particle accelerators use many small magnets operating at several tesla to keep protons moving in a circle. very close to c!

#7 $$B = \frac{4.8\times10^{-16}\,\text{kg m/s}}{(1.6\times10^{-19}\,\text{C})(1000\,\text{m})} = 3\,\text{T}$$

Earth's magnetic field is $\frac{1}{20{,}000}$ T or so

now, since moving charges are effected by magnetic fields, we expect that current is too.

$$T = \frac{N}{C\,\text{m/s}} = \frac{N}{(\frac{C}{s})\text{m}} = \frac{N}{A\,\text{m}}$$

or

$$N = A\,\text{m}\,T$$

{ maybe we can think of bunches of charges moving around in material as little loops of current }

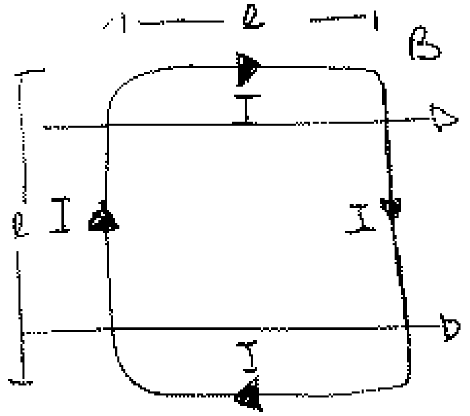
Usually, as we did for a little piece of charged wire, we'll consider a little piece of current

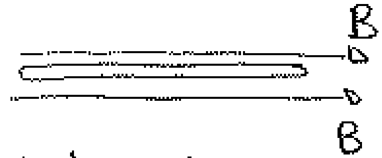
$$d\vec{F} = \underbrace{I\,d\vec{\ell}}_{\text{(direction of current)}} \times \vec{B}$$

<u>demo</u> wire jumps out of a magnet.

consider the following case:

suppose we have a loop of wire carrying a current

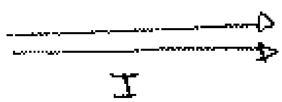




side view

Where are the forces directed?

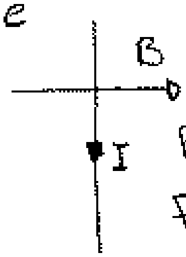
top wire



parallel to

$B \parallel I$ $F = 0$

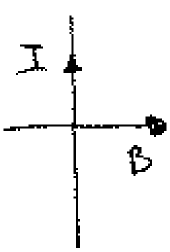
right wire



$B \perp I$

Force is out of the page

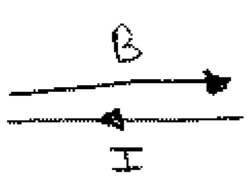
left wire



$B \perp I$

Force is into the page

Bottom wire



$B \parallel I$ $F = 0$

loop rotates! ↳ we've got our torque!

Here's a trick to remember which way the loop rotates.

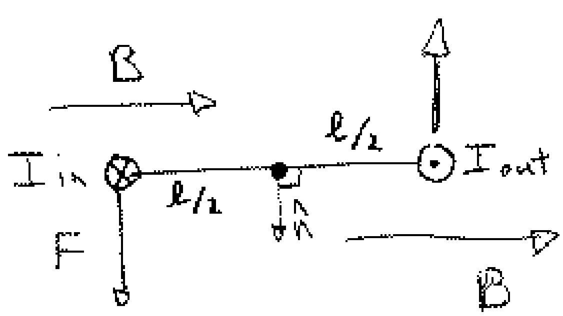
1) Put your fingers along the current direction, your thumb defines a vector, in this case a normal to the loop.

2) This normal wants to point in the direction of the B field.

Lets calculate the torque. Torque is Force times a distance

$$\tau = \text{Force} \times \underbrace{\text{lever arm}}_{\perp \text{ distance from rotation axis}}$$

Since our loop rotates about it's center, we have $\frac{l}{2}$ as a distance, and our force is up in one spot and down at another, looked at from the side



Easier to see here that the magnetic force produces a rotation

If you recall, counter-clockwise torque points out of the page.

$|F| = |I l B|$ for both sides

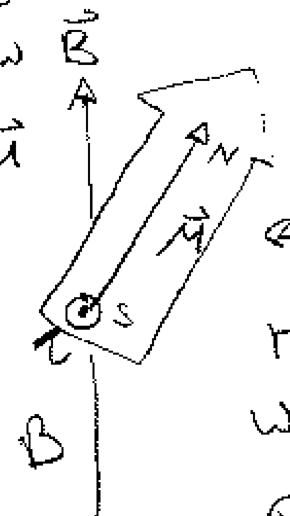
$$|\tau| = |I l B| \frac{l}{2} + |I l B| \frac{l}{2} \quad \left\{ \begin{matrix} \text{Both} \\ \text{rotate} \\ \text{same} \\ \text{way} \end{matrix} \right\}$$

$$= |I l^2 B| = |I A B|$$

In general, the quantity IA is called the magnetic moment, μ, and the direction is defined as stated. $\vec{\tau} = \vec{\mu} \times \vec{B}$

So, if one knows the magnetic moment, one can calculate torque, if you know $\vec{B}$

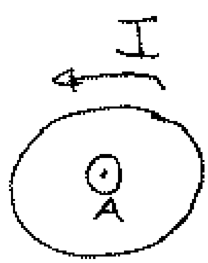
<u>Ex</u> a compass has $\vec{\mu}$



rotates this way as you'd expect.

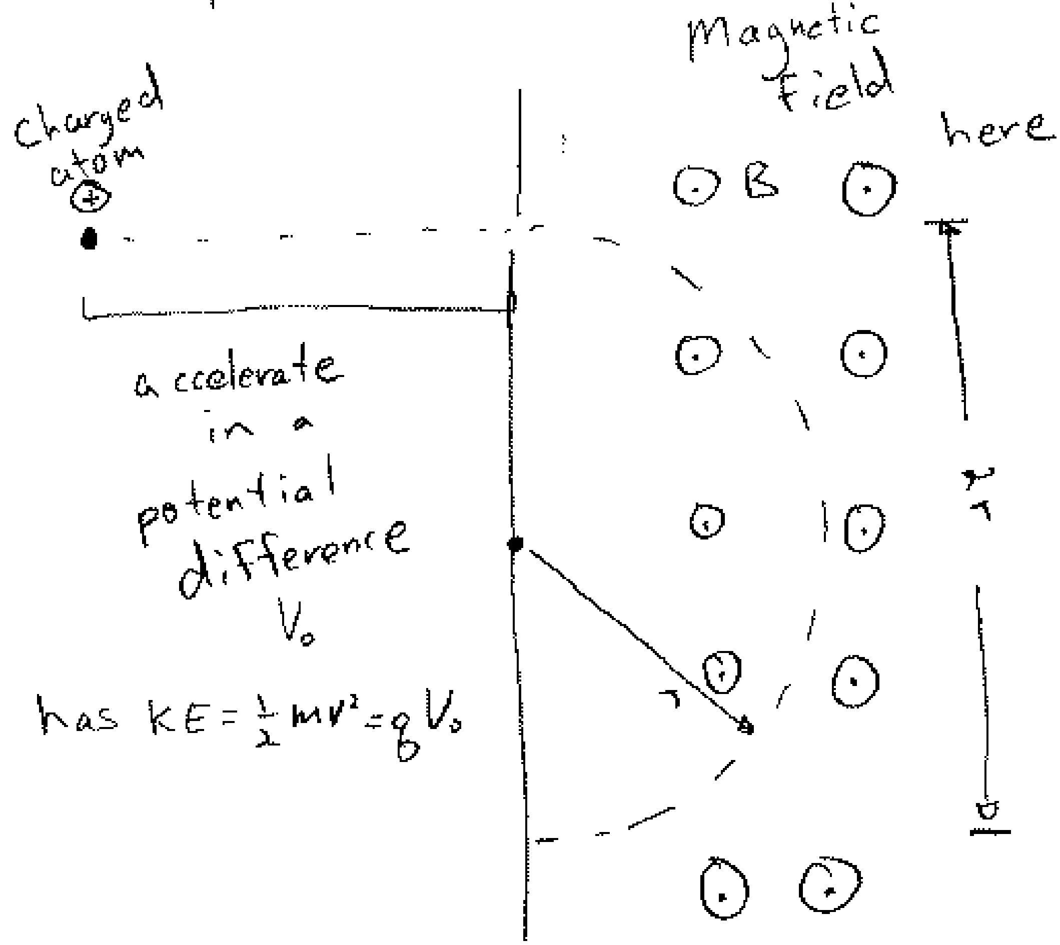
<u>recap</u>

$$\vec{F} = q\vec{v} \times \vec{B}$$
$$= I d\vec{\ell} \times B$$
$$\vec{\tau} = \vec{\mu} \times \vec{B} \quad \vec{\mu} = I\vec{A}$$



one application of magnetic field

Mass spectrometer



$$\left(\frac{r}{2}\right)\frac{mv^2}{r} = qvB\left(\frac{r}{2}\right)$$

$$\frac{1}{2}mv^2 = \left(\cancel{q}vB\frac{r}{2}\right) = \cancel{q}V_0$$

$$v = \frac{2V_0}{Br}$$

$$\frac{1}{2}mv^2 = qV_0$$

$$m = \frac{2qV_0}{v^2} = \frac{2qV_0}{\left(\frac{2V_0}{Br}\right)^2} = \frac{B^2r^2}{2V_0}$$