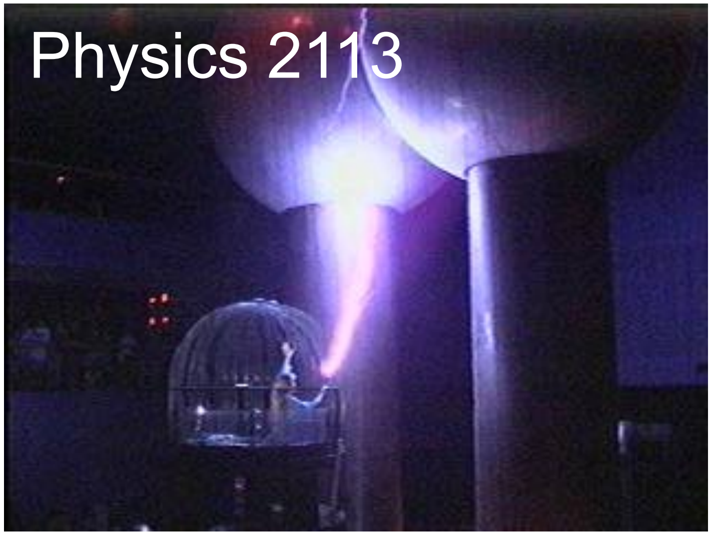


Physics 2113
Lecture 23: WED 22 OCT

CH28: Magnetism

Magnetic versus electrostatic forces:

An important difference in electric and magnetic fields is how they act on charges.

For electrostatic forces : $\vec{F} = q\vec{E}$

For magnetic forces, $\vec{F} = q\vec{v} \times \vec{B}$

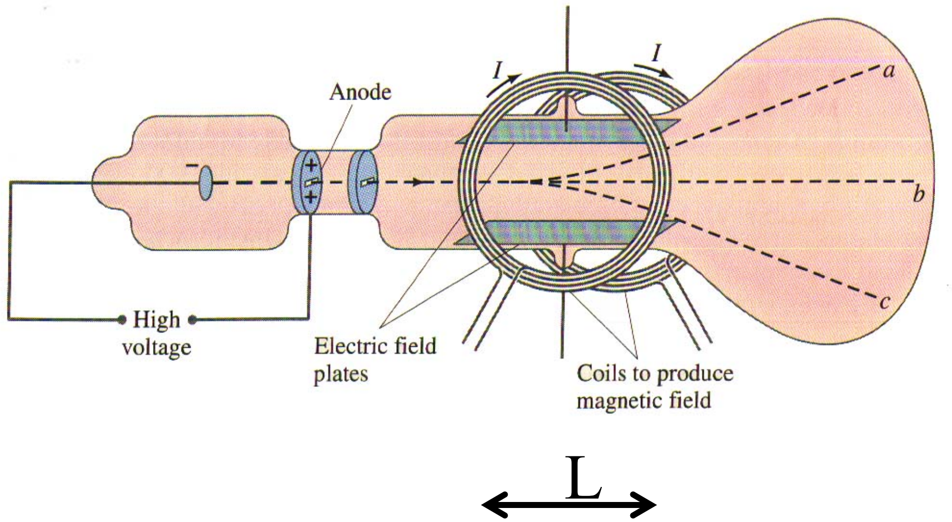
Charges that do not move, do not feel magnetic forces.

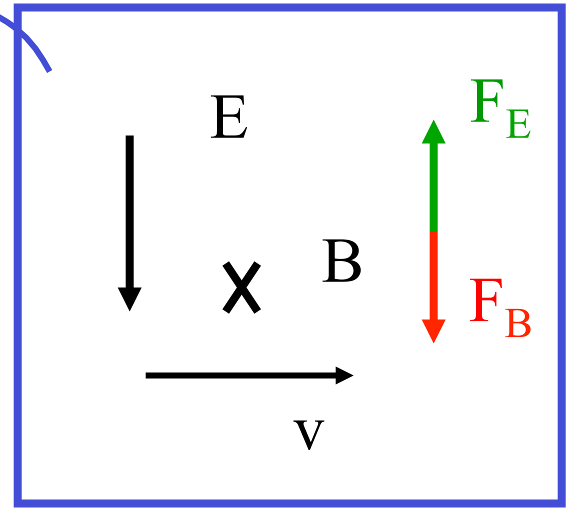
Magnetic forces are perpendicular to both the velocity of charges and to the magnetic field (electric forces are parallel to the field).

Since magnetic forces are perpendicular to the velocity, they do no work!

Speed of particles moving in a magnetic field remains constant in magnitude, the direction changes. Kinetic energy is constant (no work).

Crossed electric/magnetic fields and the discovery of the electron





$$a_y = \frac{qE}{m} \qquad L = vt \qquad y = \frac{1}{2}a_y t^2 = \frac{1}{2}a_y \frac{L^2}{v^2} = \frac{1}{2}\frac{qEL^2}{mv^2}$$

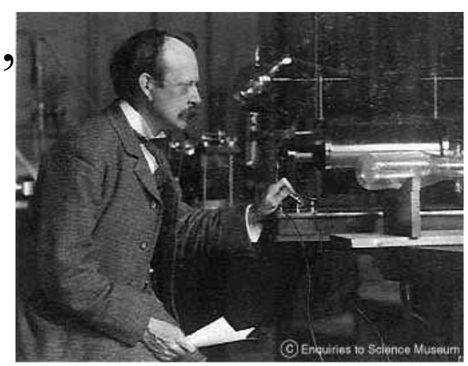
J.J. Thomson 1897 discovered e.

If forces due to E and B are equal,

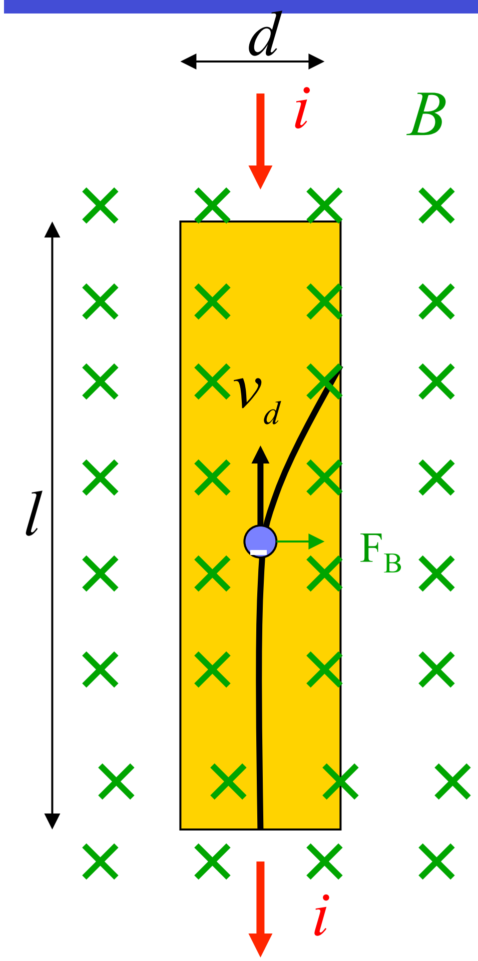
$$qE = qvB, \text{ therefore, } v = \frac{E}{B}$$

Combining, we get,

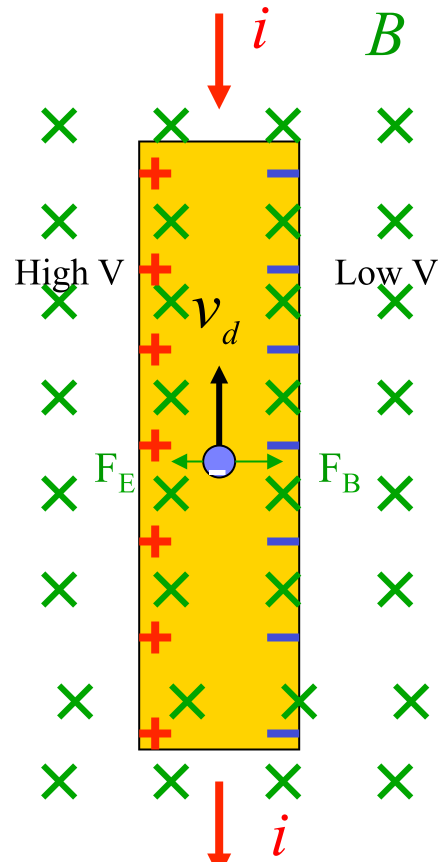
$$\frac{m}{q} = \frac{B^2L^2}{2yE}$$



Crossed electric/magnetic fields: the Hall effect.

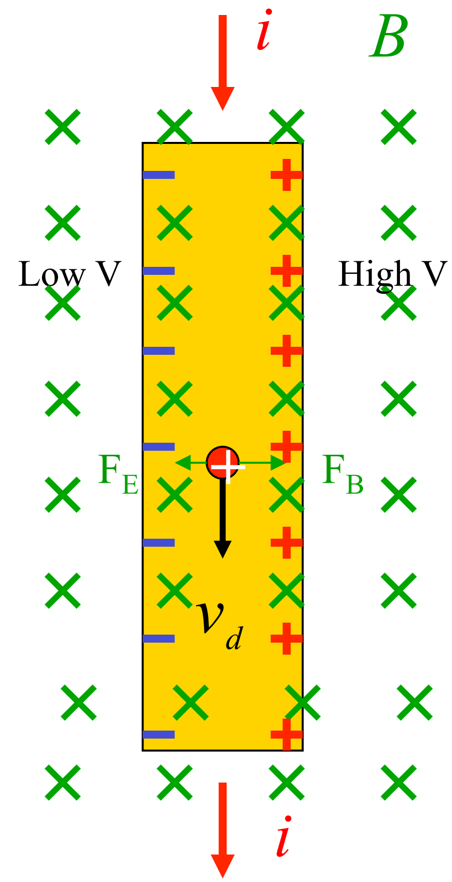


As electrons move through B



They pile up on the right producing an electric field that cancels the magnetic sideway pull.

$$eE = ev_d B \Rightarrow \frac{V}{d} = v_d B$$



This proves that charge carriers are negative, if they were positive, the ΔV, which is something we can measure, would have the opposite sign.

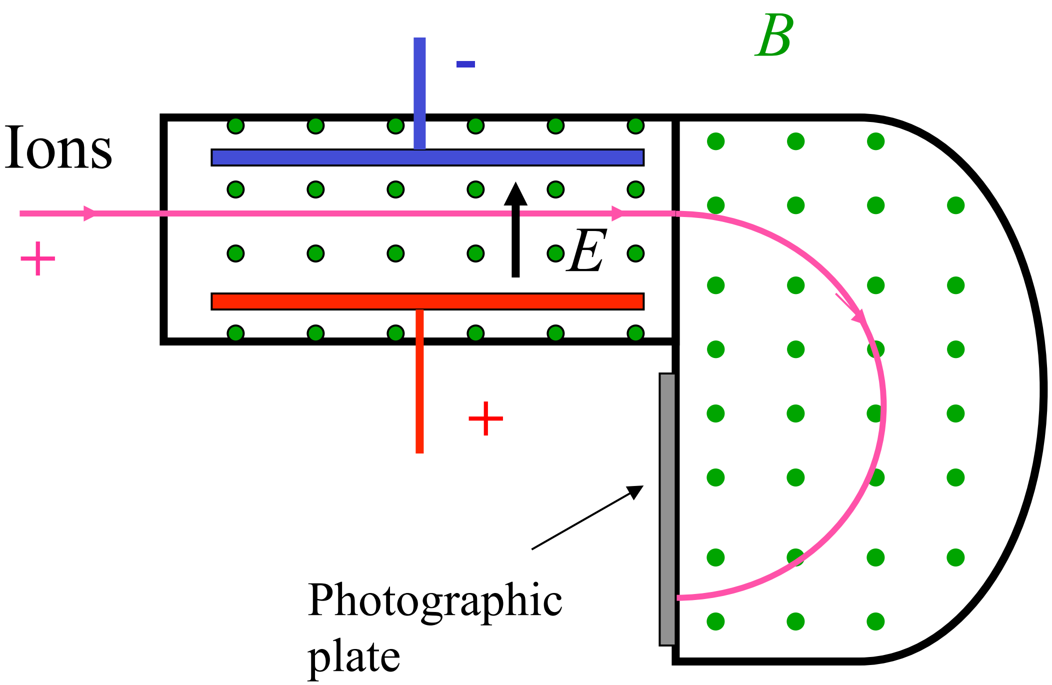
$$v_d = \frac{J}{ne} = \frac{i}{neA}$$

$$n = \frac{Bi}{Vle}$$

We get micro information from macroscopic measurements!

You can measure v_d directly!

Mass spectrometer



Ions are injected in the region of crossed E and B fields, which fixes their velocity.

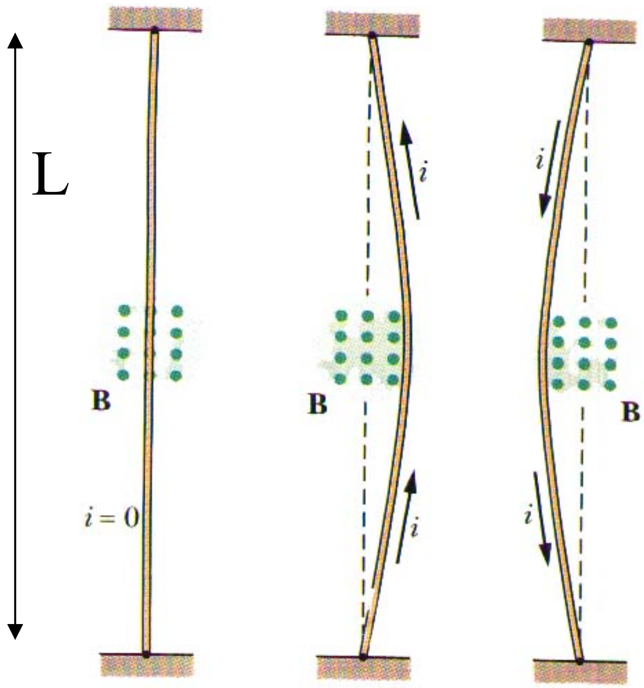
$$qE = qvB \Rightarrow v = \frac{E}{B}$$

Then they enter the region of pure B field, where the radius of their trajectory depends on q/m,

$$r = \frac{mv}{qB} = \frac{mE}{qB^2}$$

$$\boxed{\frac{q}{m} = \frac{E}{rB^2}}$$

Magnetic force on a wire.



$$q = i\,t = i\frac{L}{v_d}$$

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

$$\vec{F} = q\frac{i\,\vec{L}}{q} \times \vec{B} = i\,\vec{L} \times \vec{B}$$

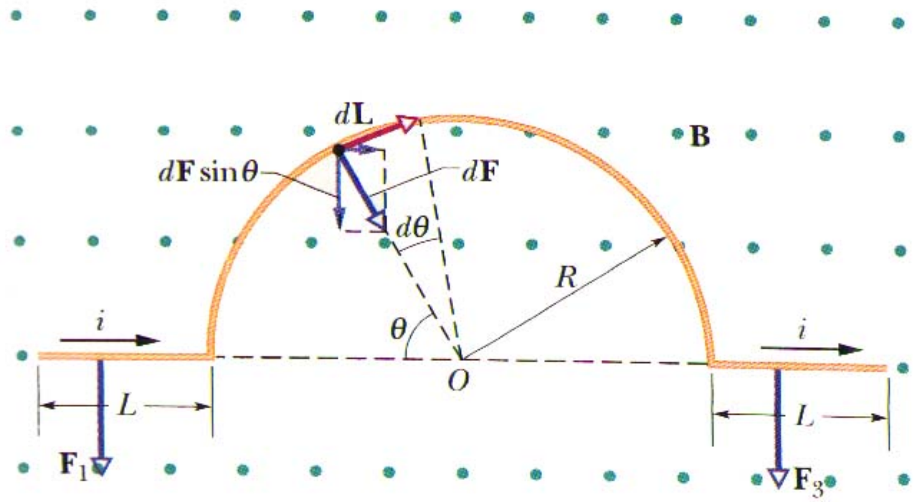
$$\vec{F} = i\,\vec{L} \times \vec{B}$$

$$d\vec{F} = i\,d\vec{L} \times \vec{B}$$

If wire is not straight.

Demo

Sample problem 29-7



$$F_1 = F_3 = iLB$$

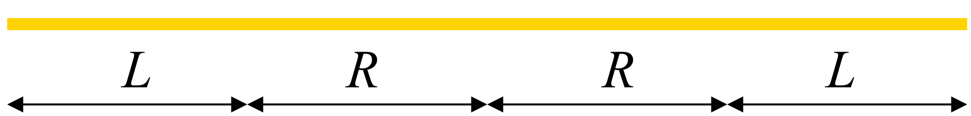
$$dF = iBdL = iBRd\theta$$

By symmetry, F2 will only have a vertical component,

$$F_2 = \int_0^{\pi} \sin(\theta)dF = iBR\int_0^{\pi} \sin(\theta)d\theta = 2iBR$$

$$F_{\text{total}} = F_1 + F_2 + F_3 = iLB + 2iRB + iLB = 2B(L+R)$$

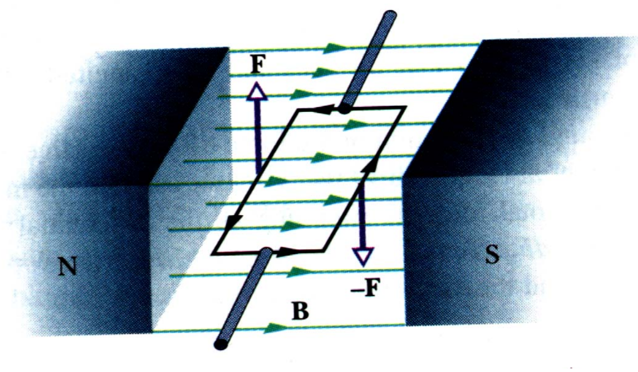
Notice that the force is the same as that for a straight wire,

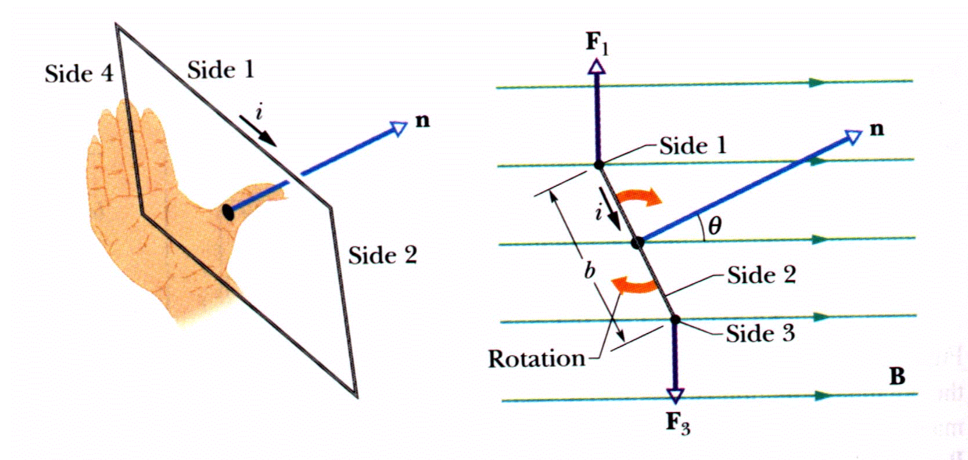


and this would be true no matter what the shape of the central segment.

Torque on a current loop:

The basic principle behind electric motors.





(b) (c)

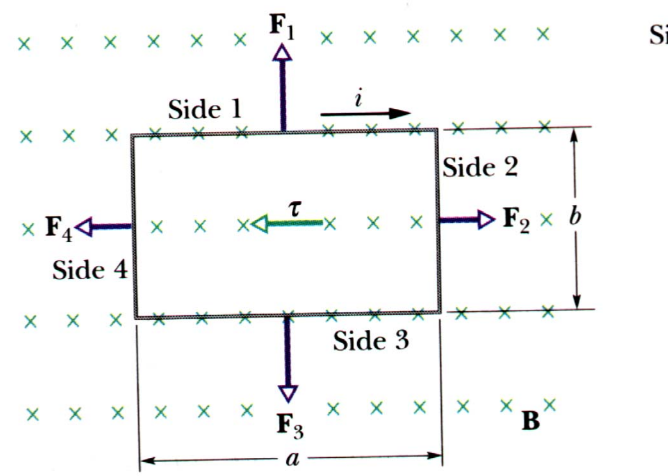
Same kind of idea as dipoles in electric fields, no net force, but a net torque.

$$F_1 = F_3 = iaB \qquad F_\perp = F_1 \sin(\theta)$$

$$\text{Torque} = \tau = F_\perp b = iabB\sin(\theta)$$

For a coil with N turns,

$\tau = NiAB,$ with A the area of the coil.



(a)

Magnetic dipole:

Exploiting the analogy with electric dipoles of the construction we just presented, we define,

$$\text{Magnetic dipole} = \mu = NiA$$

N=number of turns in coil
A=area of coil.

$$\text{Torque} = \tau = \mu B \sin(\theta), \text{ or in vector language, } \vec{\tau} = \vec{\mu} \times \vec{B}$$

Where $\vec{\mu}$ is a vector of magnitude μ and direction perpendicular to the area of the coil, orientation given by right hand rule.

As in the electric case, dipoles tend to align with the field.

$$\text{Energy} = U(\theta) = -\vec{\mu} \cdot \vec{B}$$

$$\text{Units:} \quad [\tau] = N \cdot m = J$$

$$[\mu] = \frac{\text{J}}{\text{T}}$$

Summary:

- Crossed electric and magnetic fields can be used to control precisely the velocity of moving charges as a function of mass and charge.
- Moving charges within wires interact with magnetic field producing forces proportional to the current and length of wire.
- Loops of wire behave like dipoles in magnetic fields.