4. Electrodynamics

4.1. Motion Of Charged Particles In Electric And Magnetic Field

4.1.1. Motion Of Charged Particles In An Electric Field

A charged particle in an electric field will experience an electric force due to the field. The direction of the force is in the same direction of the electric field if the particle is positively charged, or opposite the direction of the electric field if the particle is negatively charged.

The magnitude of the force is the product of the charge and the electric field strength, E.

$$F = q\,E$$

A uniform electric field is set up between two parallel plates place at a distance apart with a potential difference between the plates. The magnitude of the electric field is then the potential difference between the plates / or points in space divided by the distance between the two plates / or points. The direction of the electric field is from higher to lower potential.

$$E = \Delta V / d$$

(Note: Work done on charge $W = F \,.\, d = qE \,.\, d$
Change in potential energy $U = q\,\Delta V$
$W = U$
$qE \,.\, d = q\,\Delta V$
$E = \Delta V / d$)

By Newton's Second Law of Motion, a force acting on a particle having a mass, will cause the particle to move with an acceleration.

4.1.1.1. Initial Motion Parallel To Field

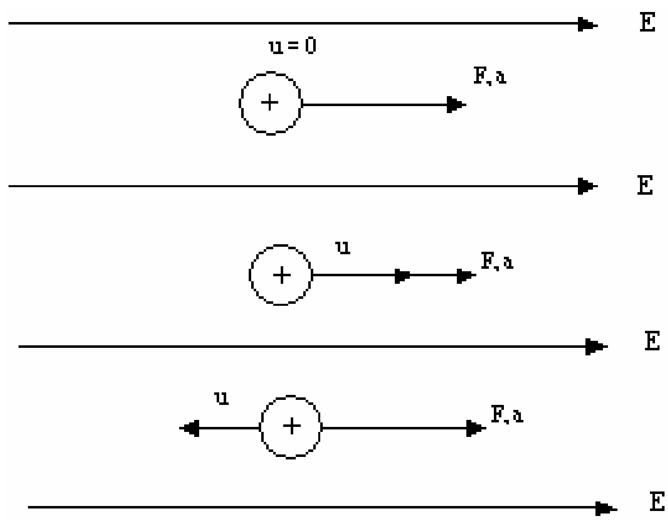
A charged particle released from rest in an electric field will experience an acceleration due to the electric force acting on the charge.
A charged particle moving parallel to the electric field will experience an acceleration if the electric force acting on it is in its direction of travel or a deceleration if the electric force acting on it is in the opposite direction of travel.

$F = q\,E$
$F = m\,a$
$q\,E = m\,a$
If the particle moves between two potential points, V_x and V_y separated by a distance s, then
$E = (V_y - V_x)/s$
The motion of the particle is given as,
$v^2 = u^2 + 2\,as$

from q E = m a
a = q E/m
substituting in the kinematic equation gives

$v^2 = u^2 + 2 q E s / m$
replacing E with the potential then gave,
$v^2 = u^2 + 2 q (V_y - V_x) / m$

Example



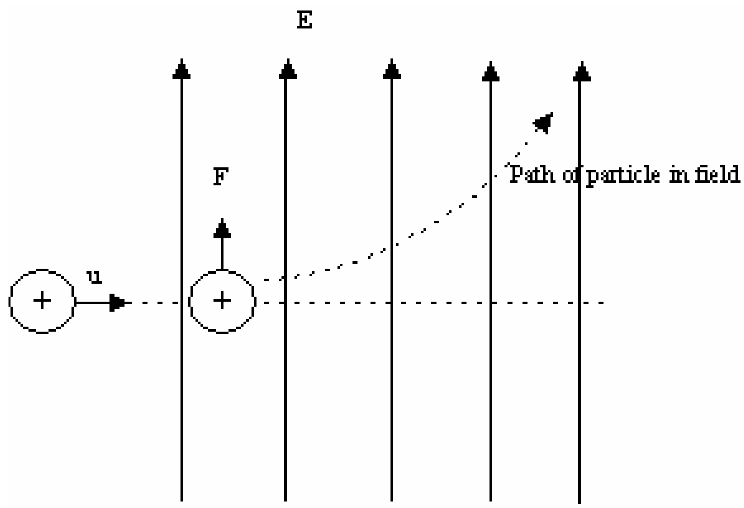
For the top charge, initial velocity u = 0,
$v^2 = u^2 + 2 q (V_y - V_x) / m$ reduces to $v^2 = 2 q (V_y - V_x) / m$

For the middle charge, with initial velocity u,
$v^2 = u^2 + 2 q (V_y - V_x) / m$

For the bottom charge, with initial velocity in opposite direction of a, the charged particle will first undergo deceleration (its speed becomes slower), then stops, and then undergo acceleration. In the diagram above , the particle will move a certain distance to the left before moving to the right.

4.1.1.2.Initial Motion Pependicular To Field

If a particle is initially moving perpendicular to the electric field lines as it enters the electric field region, the force acting on the particle will be perpendicular to its initial direction of travel. Thus in its initial direction of travel, there is no acceleration (constant velocity) while in the direction of the electric field lines it will experince an acceleration. The partilcle will move in a non linear path. (Non linear path in two dimension)



The electric field is given as
$\mathbf{E} = E_x\,\mathbf{i} + E_y\,\mathbf{j}$ but $E_x = 0$
Then $\mathbf{F} = F_x\,\mathbf{i} + F_y\,\mathbf{j}$ is
$\mathbf{F} = q\,E_y\,\mathbf{j}$, with $F_x = 0$
Thus from $\mathbf{F} = m\mathbf{a}$,
$\mathbf{F} = m\,(a_x\,\mathbf{i} + a_y\,\mathbf{j})$

The acceleration $a_x = 0$ and $a_y = (q\,E_y)/m$

The velocity in the x – direction
$v_x = u_x + a_x\,t$ is just a constant velocity $v_x = u_x$ as $a_x = 0$

The velocity in the y direction

$v_y = u_y + a_y\,t$
$v_y = (q\,E_y)\,t\,/m$ (if $u_y = 0$)

The position x,y of the particle after entering the field can be determined as follows.

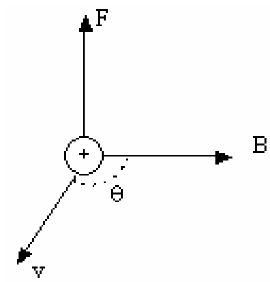
If (0,0) is the point the particle enters the field, then the distance the particle travels in the x – direction,
$x = u_x\,t$ and in the y-direction,
$y = u_y\,t + ½\,a_y\,t^2$ becomes
$y = ½\,(q\,E_y)/m)\,t^2$ as $u_y = 0$

$y = ½\,q\,E_y\,x^2\,/m\,u_x^2$
(y is proportional to x^2 , the path is a parabola)

4.1.2. Motion Of Charged Particles In A Magnetic Field

The magnetic force on a charge in a magnetic field is the charge multiplies by the vector cross product of the velocity of the charge with the magnetic field density / strength.
Thus for a charge at rest the magnetic force acting on it is zero.

$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$ in vector form whose magnitude is given by
$F = qvB \sin \theta$, where θ is the angle between **v** and **B,** where the direction of F is given by Fleming's Left Hand Rule.

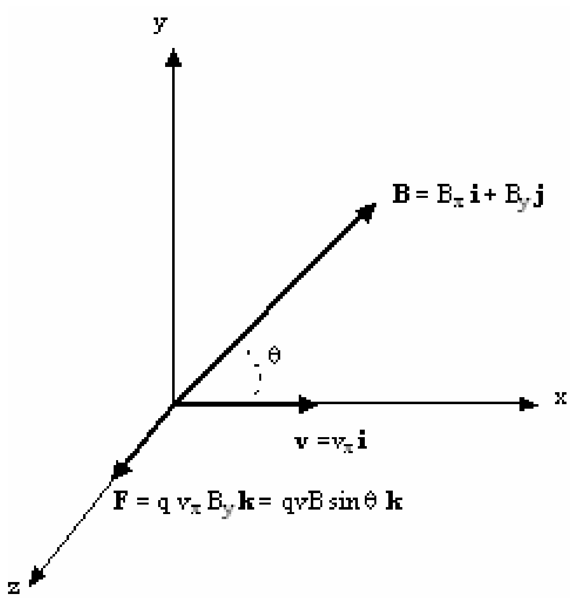


$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$

$$F = q \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ v_x & v_y & v_z \\ B_x & B_y & B_z \end{vmatrix}$$

$\mathbf{F} = q \left((v_yB_z - B_yv_z)\, \mathbf{i} + (v_zB_x - v_xB_z)\, \mathbf{j} + (v_xB_y - v_yB_x)\, \mathbf{k} \right)$

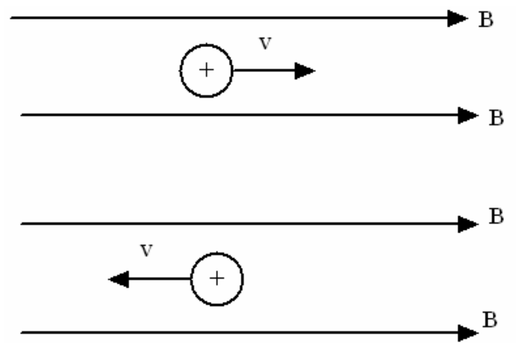
If $\mathbf{v} = v_x\, \mathbf{i}$ and $\mathbf{B} = B_x\, \mathbf{i} + B_y\, \mathbf{j}$, then
$\mathbf{F} = q\, v_xB_y\, \mathbf{k}$
$\mathbf{F} = q\, vB\sin \theta\, \mathbf{k}$



mohdnoormohdali

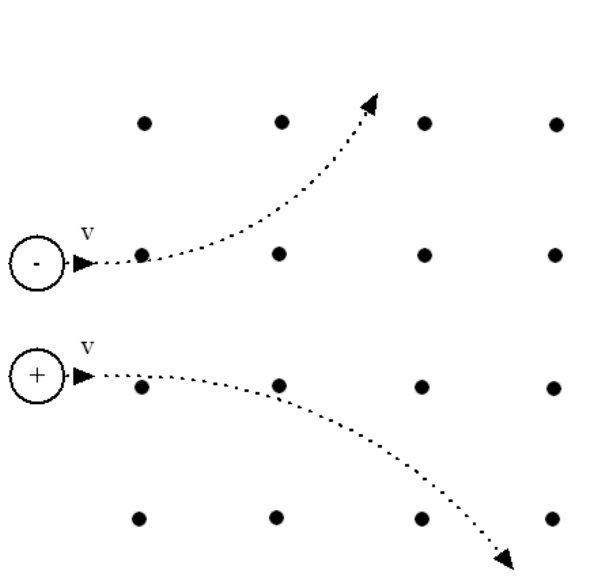
4.1.2.1.Initial Motion Parallel to Field

If the velocity is parallel to the magnetic field, the vector cross product of the velocity and magnetic field is zero. No magnetic force acts on the charge. It will move with the same velocity and direction. θ is 0, $\sin\theta = 0$, thus $F = 0$



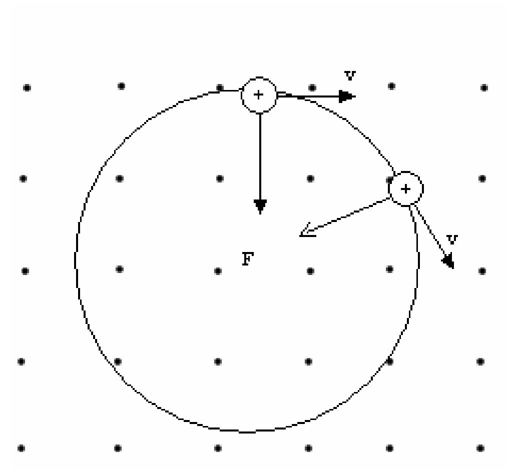
4.1.2.2.Initial Motion Perpendicular to Field

If the velocity is perpendicular to the magnetic field, the vector cross product of the velocity and magnetic field is maximum. θ is 90, $\sin\theta = 1$, thus $F = qvB$



4.1.2.2.1. Uniform circular motion

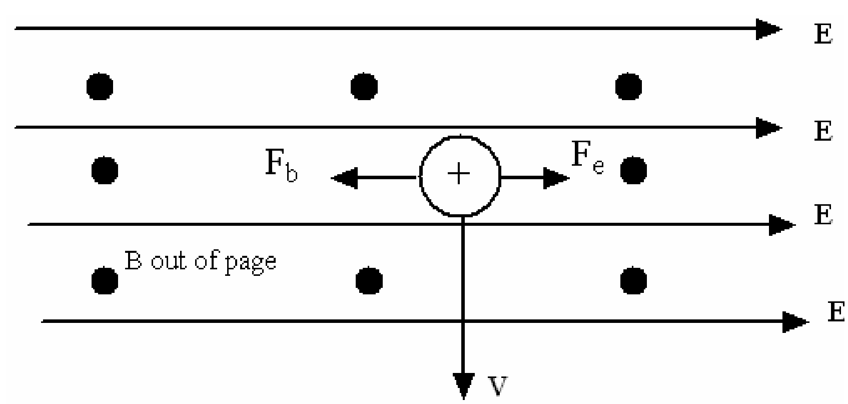
When the force is perpendicular to the velocity, the particle will be bent towards the force, resulting in a uniform circular path of motion. The central force is given as $F_c = mv^2 /r$, where r is the radius of the circular path.



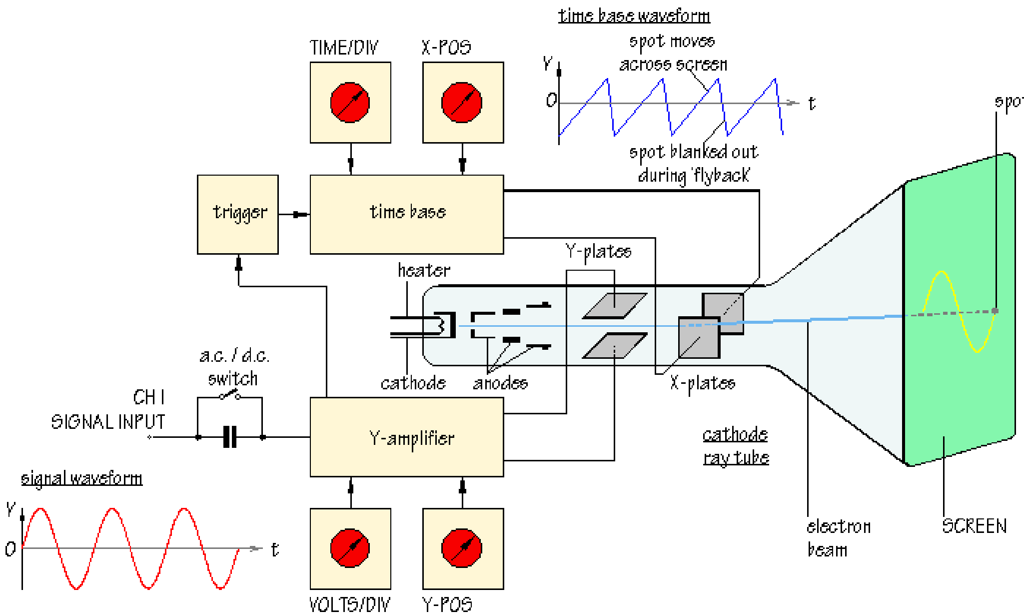
If $F_B = qvB$ and $F_c = mv^2 /r$, and $F_B = F_{C,}$ then
$qvB= mv^2 /r$
or $r = mv /qB$

4.1.3. Crossed Fields

A region where the magnetic field lines are perpendicular to the electric field lines is called a crossed fields region. Crossed fields is set up so that the total force (magnetic and electric) acting on the charged particle add up to zero.
$F = qE$ and $F = qvB$
Thus $qE= qvB$
or $v = E/B$
Thus the velocity of charged particles whose total force are zero is given by the ratio E/B, emerged in a straight line. Charged particles with higher velocity will be deflected more by the magnetic field. Charged particles with lower velocity will be deflected more by the electric field.



4.1.4. Cathode Ray tube



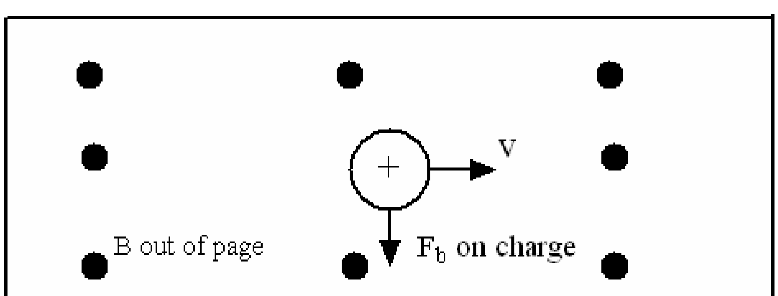
The diagram above shows a cahode ray tube in an oscilloscope.
Thermal electrons (also caled thermions) are produced by the hot cathode. The thermions are accelerated towards the anode which is connected to the +ve terminal of a high voltage supply. The heater, cathode and anode in effect produce a stream of electrons, hence is called an electron gun.

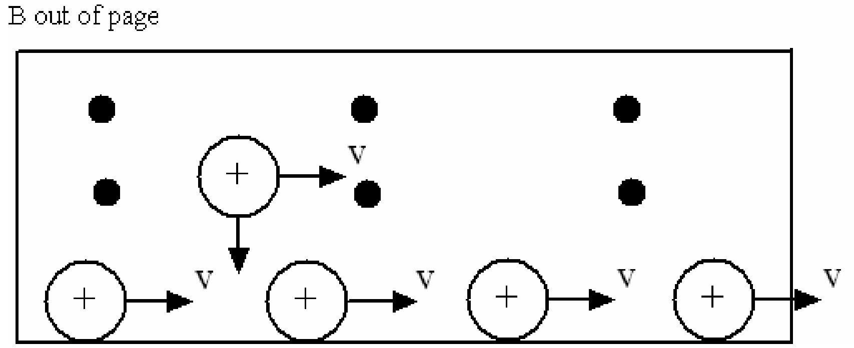
The circular anode allows the electrons to pass through the anode, between two sets of parallel plates which control the deflection of the electron beam in the x and y direction.

In an oscilloscope the y-plates are connected to the measured signal, while the x-plates to a time base circuit.

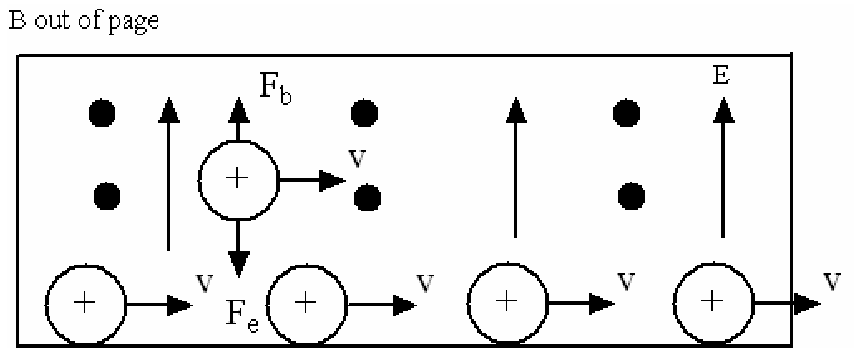
4.1.5. Hall Effect and Hall voltage (crossed field)

Hall effect is a phenomenon where a potential difference is created across the width of a conducting wire placed perpendicularly in a magnetic field.
Magnetic force acts on moving charges, forcing it to one side of the conductor.

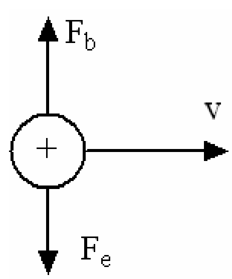




More charges are pushed to one side of conductor. An internal electric field is set up inside the conductor due to the displaced charges



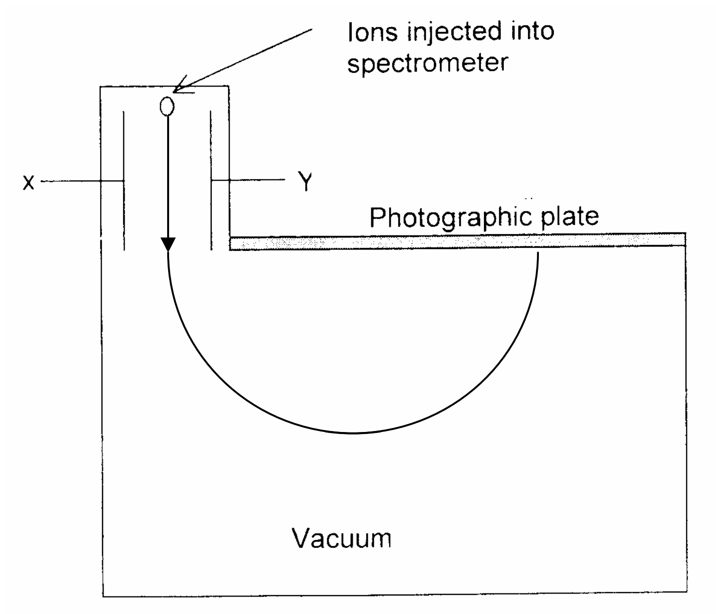
As the electric field increase, the electric force on the charges increase, until an equilibrium is obtain where the electric force balance the magnetic force, ie. total force zero. Thus no more charge is pushed to the side, and the electric field is at maximum strength.



$F_B = F_E$
qvb = qe
v = E / B
$v = V_H /Bd$

where V_H is the Hall voltage taken across the width of the conductor and d is the width of the conductor.

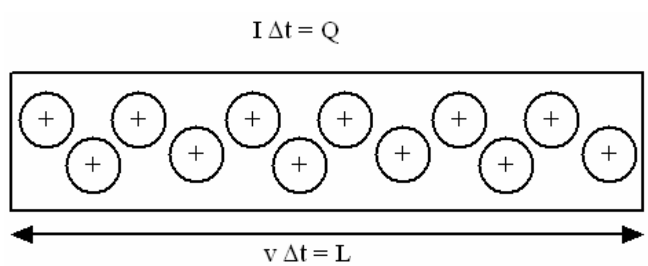
4.1.6. Mass spectrometer (crossed field)



In the mass spectrometer above, the whole spectrometer is in a magnetic field, Ions are injected between the electric plates x-y . The region between x-y plates is a velocity selector where a crossed field exists. Ions with a certain velocity will exit and enter the magnetic field region where the ion beam will be deflected towards the photographic plate.The distance from where the ions enter the magnetic field only region and the point the ions hit the pjotographic plate is 2R, twice the radius of curvature.

4.2.Currents in magnetic field

4.2.1. Force on a wire



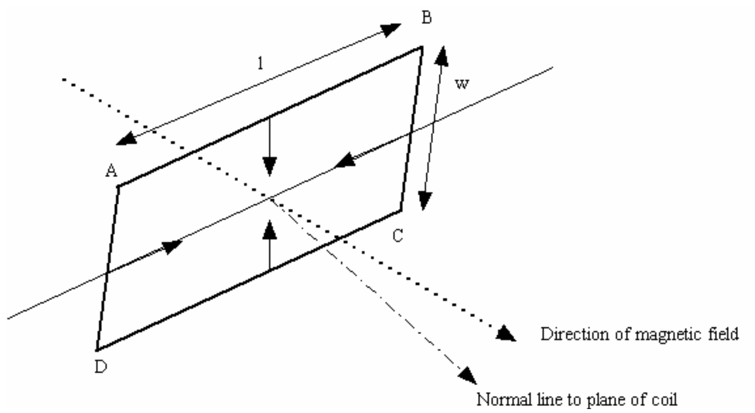
If a piece of current carrying wire of length L is placed in a magnetic field, the wire will be filled with a total charge Q in a time of Δt if the charge move at avelocity v. The charge Q transferred over time Δt is the current in the wire.

From $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$ where $F = qvB \sin\theta$,
Then $F = QvB \sin\theta$, is the force on the wire. Substituting the above relationship,
$F = (I\,\Delta t)\, v\, B \sin\theta$, rearranging
$F = I\,(v\,\Delta t)\, B \sin\theta$,

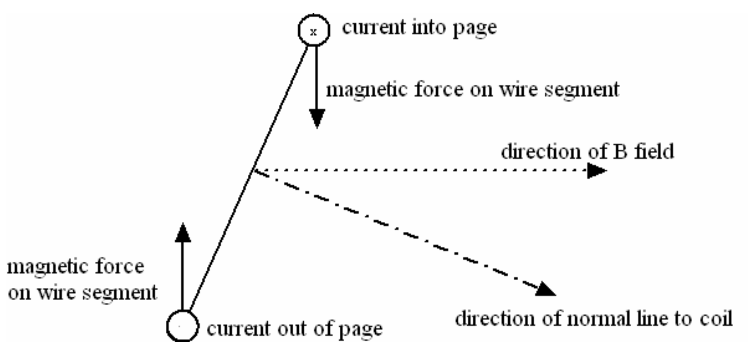
$F = ILB \sin \theta$, where θ is the angle between the direction of the current and the magnetic field. Fleming's Left Hand Rule can still be used to determine the direction of the current by replacing v with I.

4.2.2. Torque on a coil

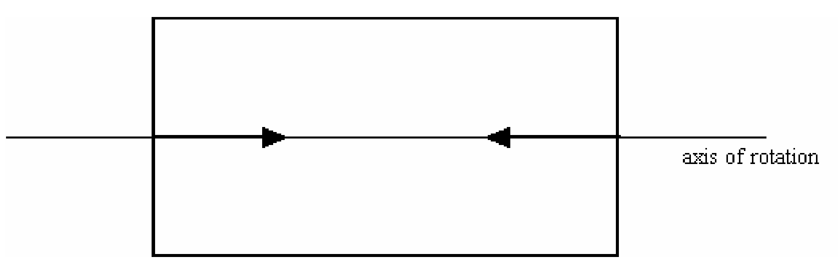
When a piece of current carrying wire is form into a rectangular coil and placed in a magnetic field as shown below, each linear segment of the wire produces a force.



F_{AB} and F_{CD} are equal in magnitude but opposite in direction.
F_{BC} and F_{AD} are also equal in magnitude but opposite in direction

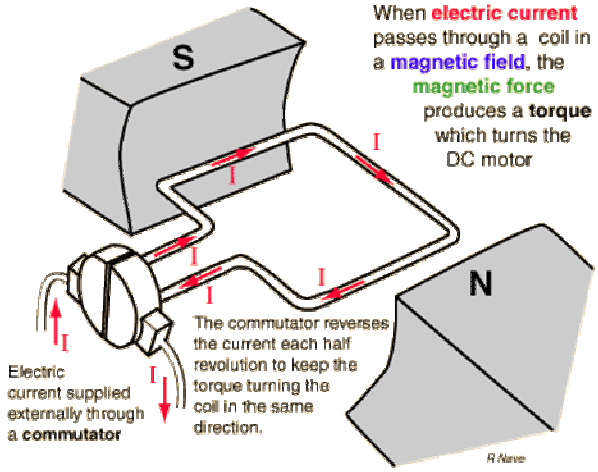


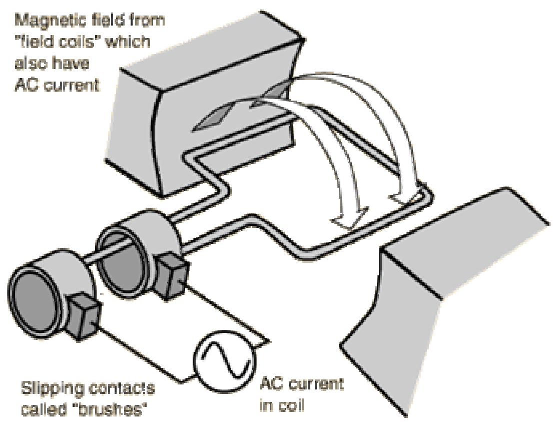
If F_{AB} and F_{CD} are not in line, then a torque is produce due to F_{AB} and $F_{CD.}$ The sum of the torque is $\tau =(ILB \sin \theta) w$ which can be rewritten as $\tau =IAB \sin \theta$ where $A = Lw$ is the area of the coil.



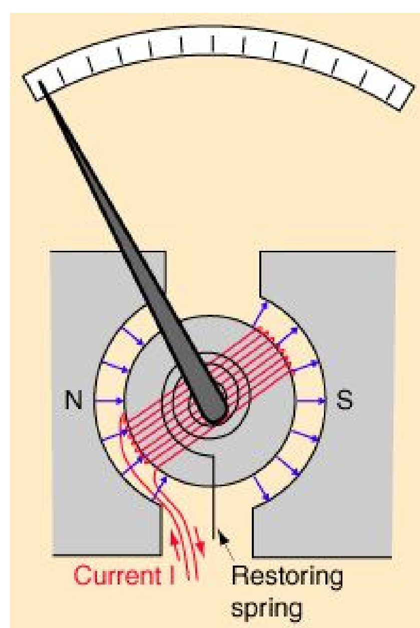
F_{BC} and F_{AD} are also equal in magnitude but opposite in direction. As F_{BC} and F_{AD} are always inline with each other no torque is produced by these forces.

4.2.3. Principle and structure of a d.c. motor and an a.c. motor



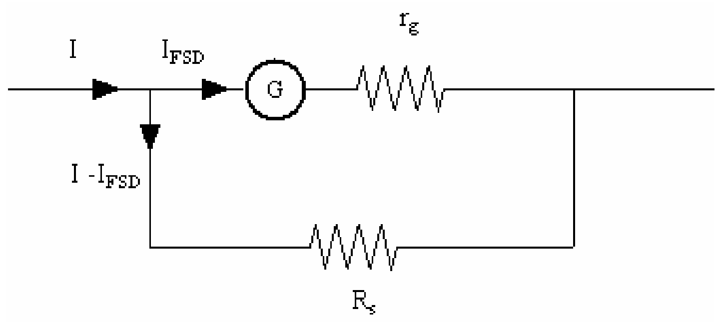


4.2.4. Principle and structure of a simple galvanometer



A coil is wound on an armature which is placed in a magnetic field. A needle is fixed to the coil / armature. When current passes through the coil the armature / coil rotates in the magnetic field. A restoring spring is fixed to the armature / coil to stop the coil when the magnetic torque is equal to the spring's restoring torque.

4.2.4.1. Converting a microammeter to an ammeter

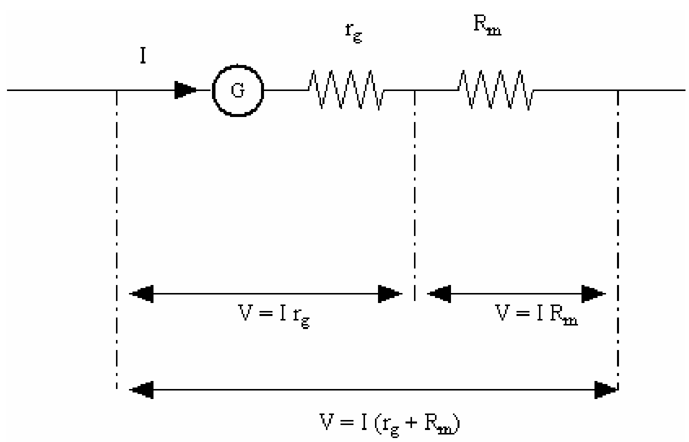


A bypass path is provided to prevent excess current through the galvanometer. The value of the shunt resistor in the bypass is chosen according to the value of the current that need to be measured.
KCL is applied to the junction as shown and KVL is applied to the loop.

$- I_{FSD}\, r_g + (I - I_{FSD})\, R_s = 0$

$R_s = I_{FSD}\, r_g / (I - I_{FSD})$

4.2.4.2.Converting an ammeter into a voltmeter



By adding a resistor in series with the galvanometer, a higher potential difference (voltage) can be measured by the galvanometer.