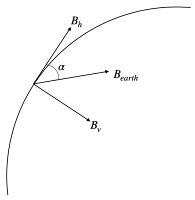
Topic 16 - Electromagnetism

1 Magnetic field

A **magnetic field** is a region in space where a **moving charge** or a **charge carrying conductor** or any ferromagnetic object will experience a magnetic force when it is placed in it

- the strength of magnetic field is expressed by a quantity called **magnetic flux density**, with units in **tesla, T**
- only **moving charge** in magnetic field experiences a magnetic force
- note that when representing a magnetic field, field lines point **away** from north and towards the south pole

Earth's magnetic field



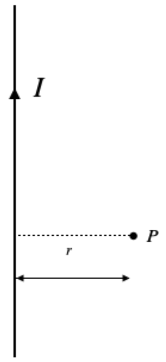
The magnetic field of earth can be resolved into two components

$$B_H = B_{earth} cos\alpha$$

$$B_v = B_{earth} sin\alpha$$

2 Magnetic fields due to currents

2.1 Magnetic force due to long straight wire

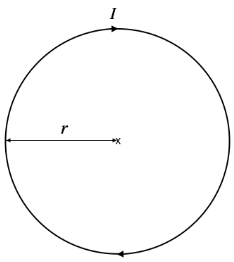


- the diretion of magnetic field is given by **Maxwell's right-hand grip rule**
- at point P, a distance r away from the conductor, B is given by

$$B = \frac{\mu_0 I}{2\pi r}$$

where $\mu_0 = 4\pi \times 10^{-7} Hm^{-1}$

2.2 Magnetic fields due to circular coil



- direction given by right-hand grip rule
- the magnetic flux density at the center of the coil is given by

$$B = \frac{\mu_0 NI}{2r}$$

2.3 Magnetic field due to solenoid

- direction given by right-hand grip rule
- the magnetic flux density at the center of the solenoid is given by

$$B = \mu_0 n I$$

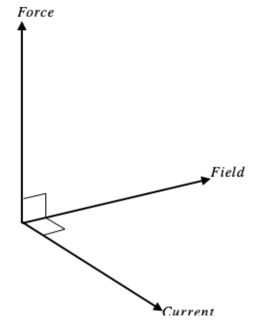
- the magnetic flux density at either end is

$$B = \frac{1}{2}\mu_0 n I$$

where n is the number of turns per unit length

3 Force on a current carrying conductor

The directions of current, field and force are given by **Fleming's left-hand rule**



3.1 Magnetic flux density, B

the **magnetic flux density** of a magnetic field is numerically equal to the **force per unit length** of a long straight conductor carrying a unit current at right angle to a uniform magnetic field

$$B = \frac{F}{IL}$$

hence,

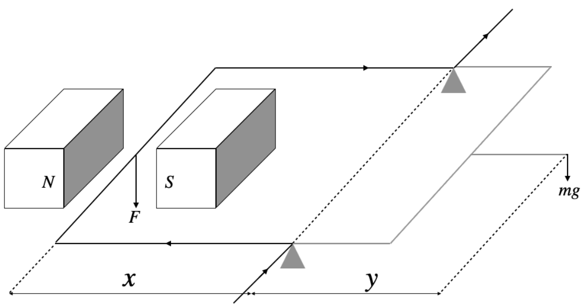
$$F = BIL$$

For case in which magnetic field is at an angle θ to the current, the force on conductor is given by

$$F = BILsin\theta$$

the S.I. unit is tesla
one tesla is the uniform magnetic flux density which, acting normally to a long straight wire carrying a current of $1A$, causes a force per unit legnth of $1Nm^{-1}$

3.2 Measuring magnetic flux density with a current balance

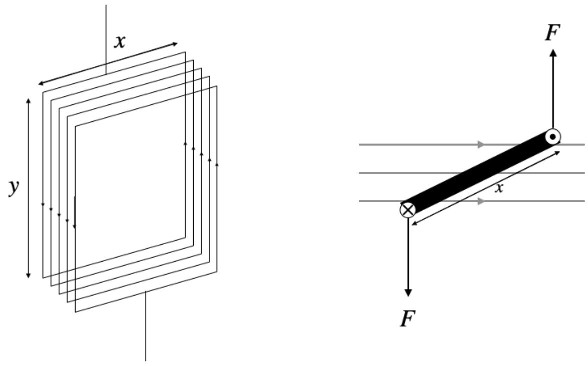


By principle of moments,

$$\text{sum of CW moments} = \text{sum of ACW moments}$$

$$mgy = BILx$$
$$B = \frac{mgy}{ILx}$$

3.3 torque on current carrying coil in a magnetic field



- the forces on vertical sides give rise to turning effect. the magnitude of each force is given by

$$F = NBIy$$

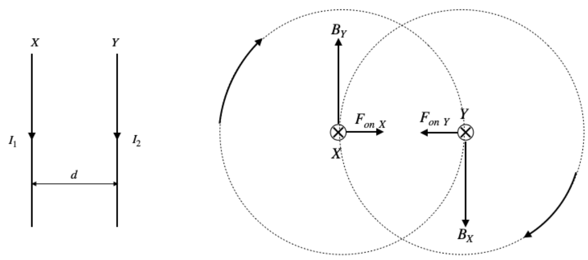
- since the force on each vertical side are **equal in magnitude** and **opposite in direction**, the costitute a couple.
- the force on the verticle sides remain **constant in magnitude** throughout the rotation
- the torque of a couple is given by

$$\tau = Fd$$

  where d is the perpendicular distance between the lines of action of the forces
- the torque τ due to the conducting coil is thus

$$\begin{aligned}\tau &= Fd \\ &= NBIy \times xcos\theta \\ &= NBIyxcos\theta \\ &= NBIAcos\theta\end{aligned}$$

4 Force between current-carrying conductor



The current in X produces a magnetic field B_X, whose magnitude at Y is given by

$$B_X = \frac{\mu_0 I_1}{2\pi d}$$

Wire Y thus experiences a magnetic force **towards X** and its magnitude is given by

$$F_{XonY} = B_X I_2 L = \left(\frac{\mu_0 I_1}{2\pi d}\right) I_2 L$$

Likewise, X experiences a force **towards Y**, given by

$$F_{YonX} = B_Y I_1 L = \left(\frac{\mu_0 I_2}{2\pi d}\right) I_1 L$$

The two wires with currents in the same direction **attract** each other, and the **force per unit length** on each wire is

$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

In general

For 2 parallel current-carrying conductors

- the force per unit length is

$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

- currents in the same direction attract, current in opposite directions repel

5 Force on moving charge

For a charged particle travelling distance L in time t,

$$v = \frac{L}{t}$$

The moving charge constitutes a current where

$$I = \frac{q}{t}$$

Hence force on charge is given by

$$F = BIL = \left(\frac{BqL}{t}\right) = Bqv$$

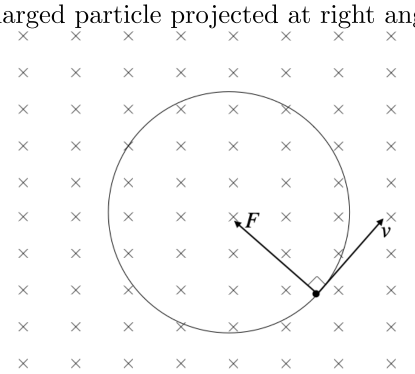
If velocity and field are inclined to each other by angle θ,

$$F = Bqvsin\theta$$

Note that direction of current is that of **conventional current**

5.1 Motion of charged particle in magnetic field

For a charged particle projected at right angle into a magnetic field



the **magnetic force** on moving charge provides for centripetal force

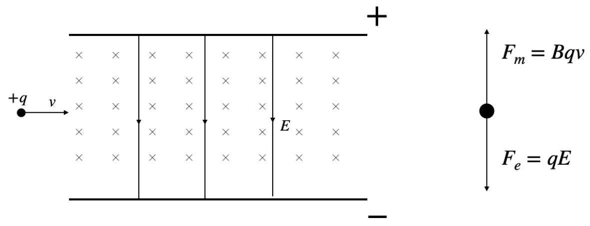
$$Bqv = \frac{mv^2}{2}$$

For a charged particle projected at some angle θ,

$$v_{parallel} = v\ cos\theta$$

$$v_{perpendicular} = v\ sin\theta$$

6 the velocity selector



Particles deflect upwards or downwards depending on F_m and F_e
Particles experience no deflection when

$$Bqv = qE$$

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