

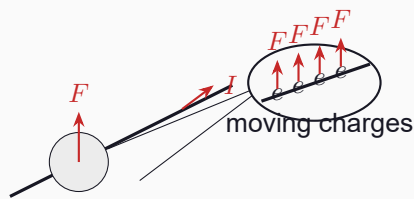
Charged Particles

Chapter 10 / A2 Level / Apollo Physics 9702



Charged Particles in Magnetic Fields

Force on moving charges in a magnetic field



The force on the current-carrying conductor is basically the force on the moving charges in that conductor.

Force on a moving charge

For a current-carrying conductor,

$$F = BIl.$$

Since current is the rate of flow of charge,

$$I = \frac{q}{t}, \quad v = \frac{l}{t}.$$

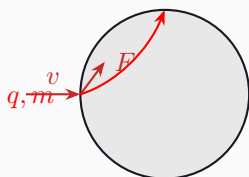
Therefore,

$$F = B \left(\frac{q}{t} \right) l = Bq \left(\frac{l}{t} \right).$$

$$F = Bvq$$

(1)

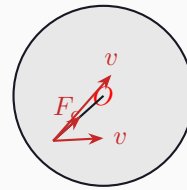
- F : magnetic force / N
- B : magnetic flux density / T
- v : velocity of charged particle / m s^{-1}
- q : magnitude of charge / C



magnetic field into the plane

- The force on the charged particle in a magnetic field acts as a centripetal force.
- Therefore the particle moves in a circular track in the magnetic field.

Magnetic force acting as centripetal force



magnetic force acts as centripetal force

$$F_m = F_c$$

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

Cancel one v :

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

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

(2)

Since momentum $p = mv$,

$$r = \frac{p}{Bq}$$

$\Rightarrow$

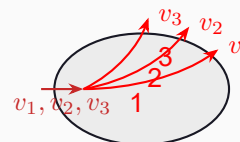
$$p = Bqr$$

If $q = e$ is the elementary charge,

$$p = Ber.$$

How radius changes

- Since $r \propto v$, the greater the speed, the greater the radius and the lesser the deflection.



$$v_1 > v_2 > v_3 \text{ SO } r_1 > r_2 > r_3$$

- A constant decrease in radius shows that the particle is slowing down.



a constant decrease in radius shows particle is slowing down

Charge-to-mass ratio and particle paths

Effect of magnetic field strength

From

$$r = \frac{mv}{Bq},$$

$$r \propto \frac{1}{B}.$$

Stronger magnetic fields bend charged particles more because the particles experience a larger magnetic force. Hence they have a smaller radius.

Effect of charge-to-mass ratio

From the same equation,

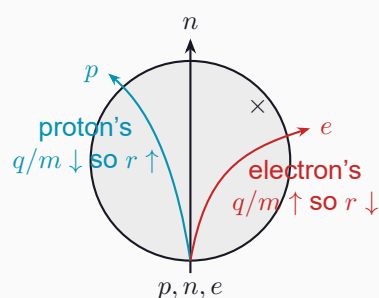
$$r \propto \frac{m}{q} \quad \text{or} \quad r \propto \frac{1}{q/m}.$$

where q/m is the **charge-to-mass ratio**.

Particle	charge q	mass m
proton	$+1.6 \times 10^{-19} \text{ C}$	$1.67 \times 10^{-27} \text{ kg}$
electron	$-1.6 \times 10^{-19} \text{ C}$	$9.11 \times 10^{-31} \text{ kg}$

$$\frac{q}{m} \text{ for proton} \approx 9.6 \times 10^7 \text{ C kg}^{-1}$$

$$\frac{q}{m} \text{ for electron} \approx 1.76 \times 10^{11} \text{ C kg}^{-1}$$

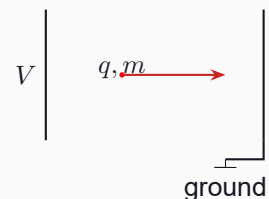


magnetic field into the page: opposite charges bend in opposite directions

Determining charge-to-mass ratio

When a moving charged particle enters a magnetic field, it experiences a magnetic force which acts as a centripetal force.

$$\begin{aligned} F_m &= F_c \\ Bvq &= \frac{mv^2}{r} \\ \frac{q}{m} &= \frac{v}{Br} \end{aligned} \quad (3)$$



To replace v : work done by electric field = gain in kinetic energy

Work done by electric field = gain in kinetic energy.

$$V = \frac{W}{q} \Rightarrow W = Vq$$

$$\Delta K.E. = \frac{1}{2}m(v^2 - u^2)$$

If the particle is initially at rest, $u = 0$:

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

$$2Vq = mv^2$$

$$v = \sqrt{\frac{2Vq}{m}}$$

Replacing v in Eq. (3),

$$\frac{q}{m} = \frac{1}{Br} \sqrt{\frac{2Vq}{m}}$$

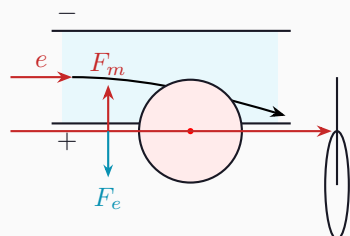
Squaring both sides,

$$\left(\frac{q}{m}\right)^2 = \frac{2V}{B^2 r^2} \cdot \frac{q}{m}$$

$$\frac{q}{m} = \frac{2V}{B^2 r^2} \quad (4)$$

Velocity selector

Velocity selector



The electron will pass straight, as fields tried to deflect it in opposite directions.

A magnetic field and an electric field are placed perpendicular to one another. Their field strengths are adjusted such that the **electric force** is balanced by the **magnetic force**.

Only particles with one particular speed pass straight through. Others are deflected and filtered out.

Condition for straight motion

For a selected charged particle,

$$F_e = F_m.$$

Electric force:

$$F_e = Eq.$$

Magnetic force:

$$F_m = Bvq.$$

Therefore,

$$Eq = Bvq.$$

Cancel q :

$$E = Bv.$$

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

Using a specific value of E and B , a particular speed of charged particle is filtered out.

Summary box

Magnetic force	$F = Bvq$
Circular radius	$r = \frac{mv}{Bq} = \frac{p}{Bq}$
Momentum	$p = Bqr$; for charge e , $p = Ber$
Charge-to-mass ratio	$\frac{q}{m} = \frac{v}{Br} = \frac{2V}{B^2r^2}$
Velocity selector	$v = \frac{E}{B}$