TURNING POINTS

1-3 Use of electric and magnetic fields to determine e/m

1. Plate length, l = 85.0 mm = 85.0×10^{-3} m
   Plate separation, d = 40.0 mm = 40.0×10^{-3} m
   p.d. between the plates, V = 4000 V

   (a) Magnetic field strength = 2.95 mT = 2.95×10^{-3} T

   Magnetic field strength = electric field strength

$$Bev = eE$$

$$v = \frac{E}{B} \qquad \text{but } E = \frac{V}{d}$$

So

$$v = \frac{V}{Bd}$$

$$= \frac{4000}{2.95 \times 10^{-3} \times 40.0 \times 10^{-3}}$$

$$= 3.3898\ldots.. \times 10^{-7}$$

$$= 3.39 \times 10^{-7}\ \text{ms}^{-1} \text{ to 3 sf}$$

   (b) Time taken to pass through the plates $= \frac{\text{plate length}}{\text{electron speed}}$ (v = s/t)

$$= \frac{85.0 \times 10^{-3}}{3.39 \times 10^{-7}}$$

$$= 2.5075 \times 10^{-9}\ \text{s}$$

$$= 2.51 \times 10^{-9}\ \text{s or 2.51 ns}$$

   Beam is deflected by 55mm = 55×10^{-3} m where it leaves the field

   Motion is under constant acceleration so the equations of motion apply.
   In the vertical direction:
   $s = 55 \times 10^{-3}$ m, $u = 0$ ms^{-1}, v = ? a = ?, $t = 2.51 \times 10^{-9}$ s

   $s = ut + ½ at^2$ but as u = 0, $s = ½ at^2$ and hence

$$a = \frac{2s}{t^2} = \frac{2 \times 55 \times 10^{-3}}{(2.51 \times 10^{-9})^2} = 1.75 \times 10^{16}\ \text{ms}^{-2}$$

$$\frac{e}{m} = \frac{ad}{V} = \frac{1.75 \times 10^{16} \times 40.0 \times 10^{-3}}{4000}$$

$$= 1.75 \times 10^{11}\ \text{Ckg}^{-1}$$

Note the inconsistency that the plates are 40 mm apart yet the beam is 55 mm down by the end of the plates!

2. $v = 1.35 \times 10^{-7}$ ms^{-1} , $B = 1.54 \times 10^{-3}$ T, circle d = 50 mm = 50×10^{-3} m (N.B. This should be the radius value)
$r = 25 \times 10^{-3}$ m

$$Bev = \frac{mv^2}{r}$$ as it is moving in a circle and the magnetic force provides the centripetal force

$$\frac{e}{m} = \frac{v}{Br} = \frac{1.35 \times 10^{-7}}{1.54 \times 10^{-3} \times 25 \times 10^{-3}}$$

$$= 3.506.... \times 10^{11} \text{ Ckg}^{-1}$$
$$= 3.51 \times 10^{11} \text{ Ckg}^{-1} \text{ to 3 sf}$$

If r = 50mm is used then the answer is 1.75×10^{11} Ckg^{-1} which is the correct value for e/m of an electron.

3. v = 550V, B = 2.8 mT = 2.8×10^{-3} T, r = 28 mm = 28×10^{-3} m

When being accelerated by the electric field

kinetic energy increase = work done
$$\tfrac{1}{2} mv^2 = eV$$

When in the magnetic field
$$Bev = \frac{mv^2}{r}$$ as it is moving in a circle and the magnetic force provides the centripetal force

giving $$v = \frac{Ber}{m}$$

Substituting this in the work done equation above gives:

$$\tfrac{1}{2} m \left(\frac{Ber}{m}\right)^2 = eV$$

$$\frac{e}{m} = \frac{2V}{B^2r^2}$$

$$= \frac{2 \times 550}{(2.8 \times 10^{-3})^2 \times (28 \times 10^{-3})^2}$$

$$= 1.7896.... \times 10^{11} \text{ Ckg}^{-1}$$
$$= 1.79 \times 10^{11} \text{ Ckg}^{-1} \text{ to 3 sf}$$

4. Thomson's determination of the electron's specific charge e/m showed that its specific charge was approximately 1860 times as large as that of the hydrogen ion which hitherto had had the largest specific charge.

However, no deduction could be made regarding the masses as neither the mass nor the charge of the electron was known then. It was only possible to conclude that either an electron's charge was greater or that its mass was smaller than that of a hydrogen ion.