CHAPTER 10

From cathode ray tubes to CROs and TVs

Answers to revision questions

1. (a) $\boldsymbol{F} = q\boldsymbol{vB}\sin\theta$

$q =$ charge of a proton $= 1.60 \times 10^{-19}$ C
$v = 50$ m s^{-1}
$\boldsymbol{B} = 0.10$ T
$\theta = 35°$
$\boldsymbol{F} = ?$
$\boldsymbol{F} = 1.60 \times 10^{-19} \times 5 \times 0.1 \times \sin 35°$
$= 4.6 \times 10^{-20}$ N into the page

Right-hand palm rule:
Fingers: to the right
Thumb: right – top
Palm (force): into the page

(b) $\boldsymbol{F} = q\boldsymbol{vB}\sin\theta$

$q =$ charge of an electron $= 1.60 \times 10^{-19}$ C
$v = 7.5$ m s^{-1}
$\boldsymbol{B} = 0.03$ T
$\theta = 90°$
$\boldsymbol{F} = ?$
$\boldsymbol{F} = 1.60 \times 10^{-19} \times 7.5 \times 0.03 \times \sin 90°$
$= 3.6 \times 10^{-20}$ N down the page

Right-hand palm rule:
Fingers: into the page
Thumb: to the left
Palm (force): down the page

(c) $\boldsymbol{F} = q\boldsymbol{vB}\sin\theta$

An alpha particle has two protons and two neutrons, thus it is double positively charged.

$q = 2 \times 1.60 \times 10^{-19}$ C
$\boldsymbol{v} = 2.5$ cm/s $= 0.025$ m s^{-1}
$\boldsymbol{B} = 2$ T
$\theta = 90°$
$\boldsymbol{F} = ?$
$\boldsymbol{F} = \left(2 \times 1.60 \times 10^{-19}\right) \times 0.025 \times 2 \times \sin 90°$
$= 1.6 \times 10^{-20}$ N to the left

Right-hand palm rule:
Fingers: out of the page
Thumb: down the page
Palm (force): to the left

(d) The lead (II) ion is a lead atom missing two electrons, thus it is double positively charged. However, since the charged particle is travelling parallel to the magnetic field, the force will be 0 N.

2. (a) To accelerate the electrons across the air gap.

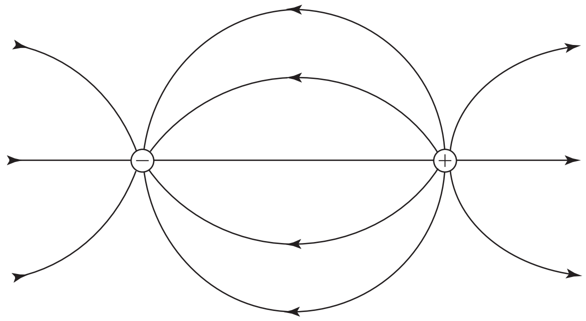
(b) By using an induction coil.

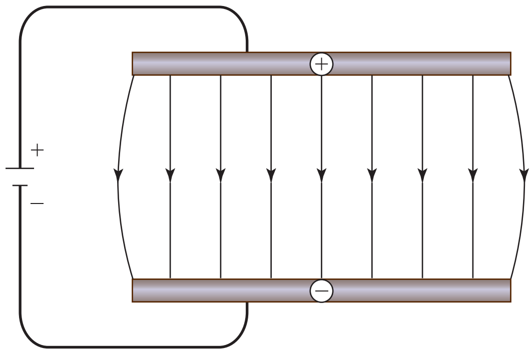
(c) (i) High voltage used, therefore careful with handling.

(ii) X-rays produced when the electrons hit the tube or the electrodes. Minimise the time of exposure.

3. Hertz performed an experiment using a pair of electric plates, however, this experiment failed to detect any deflection of the cathode ray. Therefore it led German scientists to believe that cathode rays were waves.

4.





5. (a) $\boldsymbol{E} = \frac{V}{d}$

$V = 100$ V

$d = 2.5$ cm $= 0.025$ m

$\boldsymbol{E} = ?$

$\boldsymbol{E} = \frac{100}{0.025}$

$= 4.0 \times 10^3$ Vm^{-1} down

(b) The particle will experience a weight force downwards due to gravity.

$\boldsymbol{W} = mg$

$m = 2.02 \times 10^{-3}$ kg

$g = 9.8$ m s^{-2}

$\boldsymbol{W} = ?$

$\boldsymbol{W} = 2.02 \times 10^{-3} \times 9.8$

$= 0.020$ N downwards

The force due to the electric field:

$\boldsymbol{F}_E = q\boldsymbol{E}$

$q = 3.2 \times 10^{-4}$ C

$\boldsymbol{E} = 4000$ Vm^{-1}

$\boldsymbol{F}_E = ?$

$= 4000 \times 3.2 \times 10^{-4}$

$= 1.28$ N upwards

(Negative particles are attracted by the positive plate.)
Therefore, net force = 1.28 – 0.020 = 1.26 N up

(c) Net force = 1.26 N

$\boldsymbol{F} = ma$

$m = 2.02 \times 10^{-3}$ kg

$\boldsymbol{F} = 1.26$ N

$a = ?$

$$a = \frac{1.26}{2.02 \times 10^{-3}}$$

$= 624$ m s^{-2} up

6. (a) The kinetic energy of this electron will be derived from the electrical energy supplied by the voltage, $\boldsymbol{E}_k = \boldsymbol{E}_E$

Kinetic energy: $E_k = \frac{1}{2}mv^2$

Electrical energy: $E_E = qV$

That is:

$$\frac{1}{2}m\boldsymbol{v}^2 = qV$$

$m = 9.11 \times 10^{-31}$ kg

$\boldsymbol{v} = 10^6$ m s^{-1}

$q = 1.60 \times 10^{-19}$ C

$V = ?$

$$\frac{1}{2} \times 9.11 \times 10^{-31} \times \left(10^6\right)^2 = (1.60 \times 10^{-19}) \times V$$

$V = 2.85$ V

Note: This voltage is the voltage across the electrodes.

(b) $\boldsymbol{E} = \frac{V}{d}$

$V = 150$ V

$d = 50$ mm $= 0.05$ m

$\boldsymbol{E} = ?$

$$\boldsymbol{E} = \frac{150}{0.05}$$

$= 3.0 \times 10^3$ Vm^{-1}

$$\boldsymbol{F}_E = q\boldsymbol{E}$$
$$q = 1.6 \times 10^{-19}\ \text{C}$$
$$\boldsymbol{E} = 3000\ \text{Vm}^{-1}$$
$$\boldsymbol{F}_E = ?$$
$$= 3000 \times 1.60 \times 10^{-19}$$
$$= 4.8 \times 10^{-16}\ \text{N upwards}$$

Since the electron is negatively charged, it will be attracted by the positive plate (up).

(c) The magnetic force needs to have the same magnitude as the electrical force but deflects the particle to the opposite direction (downwards).

$$F_B = F_E$$
$$\cancel{q}vB = \cancel{q}E$$
$$\boldsymbol{B} = \frac{\boldsymbol{E}}{\boldsymbol{v}}$$
$$\boldsymbol{E} = 3000\ \text{Vm}^{-1}$$
$$\boldsymbol{v} = 10^6\ \text{m s}^{-1}$$
$$\boldsymbol{B} = ?$$
$$\boldsymbol{B} = \frac{3000}{10^6}$$
$$= 3.0 \times 10^{-3}\ \text{T} \quad \text{into the page}$$

Right-hand palm rule:
Thumb: to the left (since e is negative)
Palm (force): down the page
Fingers: into the page

7. (a) The centripetal force experienced by the alpha particle is provided by the magnetic force, which causes it to describe an arc of a circle.

$$\boldsymbol{F}_C = \boldsymbol{F}_B$$
$$\frac{m\cancel{\boldsymbol{v}}^2}{r} = q\cancel{\boldsymbol{v}}\boldsymbol{B}$$
$$mv = rq\boldsymbol{B}$$
$$r = \frac{m\boldsymbol{v}}{q\boldsymbol{B}}$$
$$m = 2 \times 1.675 \times 10^{-27} + 2 \times 1.67 \times 10^{-27}\ \text{kg}$$
$$= 6.69 \times 10^{-27}\ \text{kg}$$

(since alpha is composed of two neutrons and two protons)

$$\boldsymbol{v} = 780\ \text{m s}^{-1}$$
$$\boldsymbol{B} = 10\ \text{T}$$
$$q = 2 \times 1.60 \times 10^{-19}\ \text{C}$$

(Alpha has two protons and is thus double positively charged.)

$$\text{r} = ?$$
$$r = \frac{m\boldsymbol{v}}{q\boldsymbol{B}}$$
$$= \frac{6.69 \times 10^{-27} \times 780}{10 \times \left(2 \times 1.60 \times 10^{-19}\right)}$$
$$= 1.63 \times 10^{-6}\ \text{m}$$

(b) (i) At point O, the magnetic force is directed to the right, therefore we need the electric force to direct to the left. To do this, we will have to put the positive plate on the right of 'O' and the negative plate on the left.

(ii) The magnitude of the forces have to balance:

$$\boldsymbol{F}_B = \boldsymbol{F}_E$$
$$\cancel{q}vB = \cancel{q}E$$
$$\boldsymbol{E} = \boldsymbol{vB}$$
$$\boldsymbol{v} = 780\ \text{m s}^{-1}$$
$$\boldsymbol{B} = 10\ \text{T}$$
$$\boldsymbol{E} = ?$$
$$\boldsymbol{E} = 780 \times 10$$
$$= 7.8 \times 10^3\ \text{Vm}^{-1}$$

8. (a) Using the right-hand palm rule:
Thumb: to the right
Palm (force): down the page
Fingers: out of the page perpendicularly
Therefore, the magnetic field needs to be out of the page perpendicularly.

(b) A moving charge entering a magnetic field will describe an arc of a circle inside the magnetic field. The centripetal force is provided by the magnetic force.

$$\boldsymbol{F}_C = \boldsymbol{F}_B$$
$$\frac{m\boldsymbol{v}^2}{r} = q\boldsymbol{v}B$$
$$\frac{m\cancel{\boldsymbol{v}}^2}{r} = q\cancel{\boldsymbol{v}}B$$
$$m = \frac{rq\boldsymbol{B}}{\boldsymbol{v}}$$
$$r = 0.6\ \text{m}$$
$$q = 1.60 \times 10^{-19}\ \text{C}$$
$$\boldsymbol{B} = 2.5\ \text{T}$$
$$\boldsymbol{v} = 200\ \text{m s}^{-1}$$
$$m = ?$$
$$m = \frac{0.6 \times 1.60 \times 10^{-19} \times 2.5}{200}$$
$$= 1.2 \times 10^{-21}\ \text{kg}$$

9. As the hydrogen is entering the magnetic field at an angle, its velocity can be resolved into 2 components – one that is running up the page and another running to the right. The component that is to the right is perpendicular to the magnetic field, hence will describe a circle which has a plane that is perpendicular to the magnetic field as it enters the field. The component that is running up the page will be added onto the circular motion. The net result of the two is that the hydrogen ion will describe a spiral motion up the page; that is, moving in a circular motion and also moving up the page at the same time.

10. (a) For detail of the experimental procedure, please refer to Chapter 10. It is important to realise that there are two parts to this particular experiment. One part is to determine the velocity of the cathode ray and the other is to determine the charge to mass ratio. It is actually much easier to write these 2 parts out separately.

(b) The impacts of this experiment were:

i. It determined the charge to mass ratio, hence showing that the cathode rays were particles.

ii. It provided Thomson the information for his later development of the 'Plum Pudding' Model.

iii. With a known charge to mass ratio and Milikan's oil drop experiment to determine charge of electrons, the mass of electrons was then calculated.

11. (a) A tube that shows cathode rays travel in a straight line is a Maltese cross tube. For more details and a diagram, please see Chapter 10.

(b) A tube that shows cathode rays carry momenta is a paddle wheel tube. For more details and a diagram, please see Chapter 10.

12. A Cathode Ray Oscilloscope is able to display an electric signal in the form of a wave by the deflection of cathode rays. The oscilloscope uses an electron gun to emit a beam of cathode rays, the rays are then passed through two sets of parallel electric plates. The plates carry out vertical deflection and horizontal deflection at the same time, hence making a wavefront. The vertical deflection is done by Y plates which are controlled by the external signal inputs. The bigger the external signal input, the larger the wave amplitude. The horizontal deflection is done by X plates, which are controlled by the time-based voltage, this voltage is adjusted internally, which adjusts the period of the wave.

13. The major differences between a CRO and a colour TV are:

i. CRO has a single electron gun whereas the colour TV has 3 electron guns in order to produce the 3 different primary colours.

ii. The CRO uses electric plates to deflect the electron beam whereas the colour TV uses magnetic fields to deflect the electron beam.