1. (a) (i) What are cathode rays? (01marks)

   Cathode rays are streams of fast moving electrons

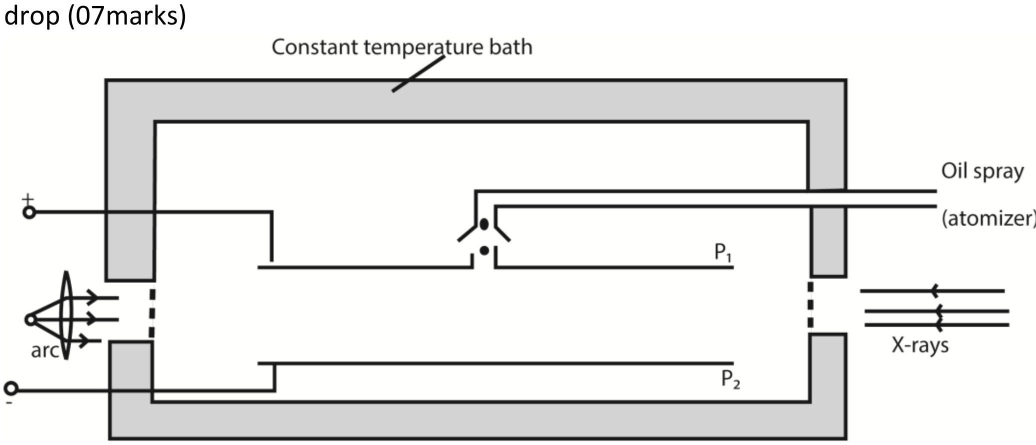
   (ii) State two properties of cathode rays (01mark)

   - They are negatively charged
   - Travel in straight lines
   - Travel with the same speed
   - Affect photographic plates

   (iii) Explain two disadvantages of using the discharge tube in producing cathode rays. (02marks)

   - a discharge tube is operated at very high voltage which is not safe to handle
   - gas required at very low pressure which may not be achieved practically

   (b) With the aid of a diagram, describe Millikan's experiment to determine the charge on an oil drop (07marks)



   - Separation between the plates P_1 and P_2 is measured
   - Oil is sprayed through the hole in plate P_1.
   - Oil drops are ionized by friction and /or X-rays
   - With no p.d applied a drop is selected and its terminal velocity v_1 is calculated
   - For known density ρ of oil, density σ of air and coefficient of viscosity, η of air, radius of the drop is calculated from

     $\frac{4}{3}\pi r^3\rho g = \frac{4}{3}\pi r^3\sigma g + 6\pi\eta r v_1$

- The p.d is now applied between the plates and varied until the selected drop remain stationary
- The p.d V is read and recorded.
- The charge Q carried by the drop is determined from
  Q = $\frac{6\pi r v_1 d}{V}$

(c) A beam of electrons is accelerated through a potential difference of 1.98kV and directed mid-way between two horizontal plates of length 4.8cm and separated by a distance of 2.0cm. The potential difference applied across the plates is 80.0V.

(i) Calculate the speed of the electrons as they enter the region between the plates (03marks)

From $\frac{1}{2}mu^2 = eV$

$\frac{1}{2} x\ 9.11\ x\ 10^{-31} x\ u^2 = 1.6\ x\ 10^{-19}\ x\ 1.98\ x\ 10^3$

u = $2.64 \times 10^7 ms^{-1}$

(ii) Explain the motion of the electrons between the plates (02marks)

- The horizontal velocity is unaffected because the net force is zero
- The vertical component of velocity changes with time due to electric force. Thus electron beam describes a parabolic path.

(iii) Find the speed of electrons as they emerge from the region between the plates (04marks)

$v_x = 2.64 \times 10^7 ms^{-1}$

From v = u + at; t = $\frac{L}{u}$

$v_y = \frac{Ee}{m} \cdot \frac{L}{u} = \frac{80\ x\ 1.6\ x\ 10^{-19}\ x\ 4.8\ x\ 10^{-2}}{2\ x\ 10^{-2}\ x\ 9.11\ x\ 10^{-31}\ x\ 2.6\ x\ 10^7}$ = $1.277 \times 10^6 ms^{-1}$

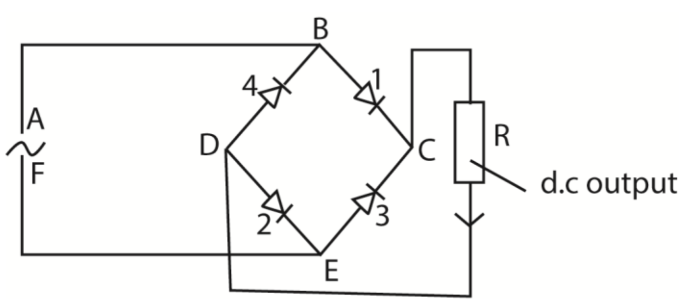
Speed of the electron

v = $\sqrt{(v_x^2 + v_y^2)}$ = $\sqrt{(2.64\ x\ 10^7)^2 + (1.277\ x\ 10^6)^2}$ = $2.643 \times 10^7 ms^{-1}$

2. (a)(i) What is meant by thermionic emission? (01marks)

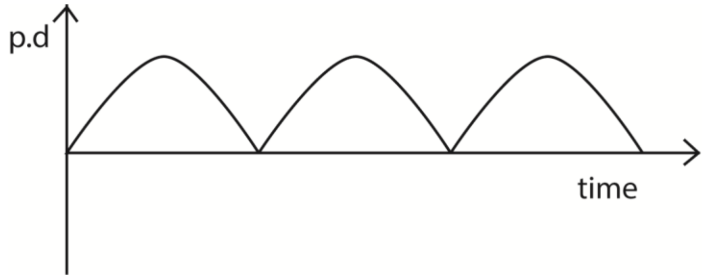
Thermionic emission is the ejection of electrons from metal surface when heated

(ii) Describe how full-wave rectification of a.c can be achieved using four semiconductor diodes. (04marks)

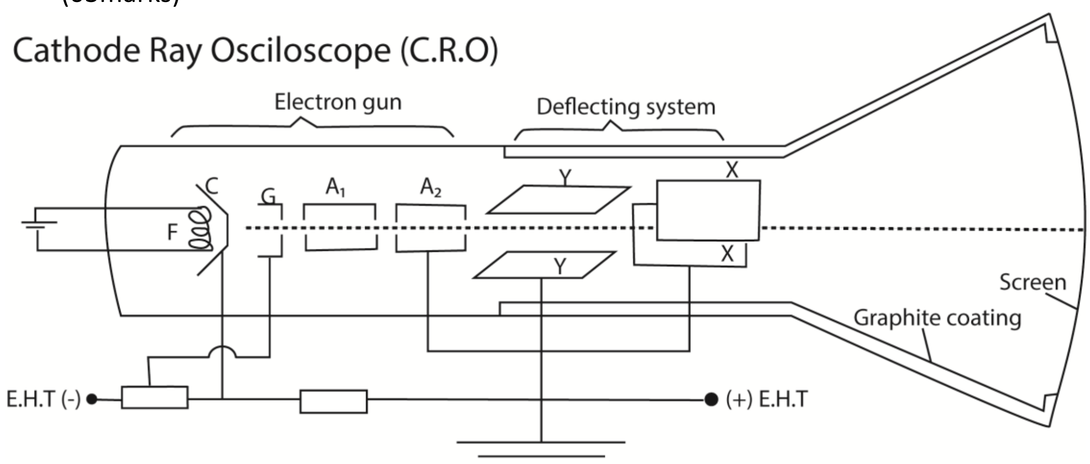


- Four diodes are arranged n a bridge network as shown above.
- If A s positive during the first half cycle, diode 1 and 2 conduct and current takes the path ABCRDEF

- In the next half cycle when F is positive, diode 3 and 4 conduct and current flows through the path FECRDBA
- Once again current flows through R in the same direction during both cycle of input and d.c output is obtained.



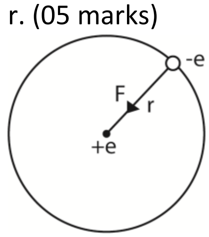
(b) (i) Draw a labelled diagram to show the main parts of a cathode ray oscilloscope (C.R.O) (03marks)



(ii) Describe how a C.R.O can be used as an a.c voltmeter. (02marks)

- Unknown a.c voltage V is connected to the Y-plates.
- The Y-sensitivity gain setting is adjusted to a suitable value V_0 volts per centimeter
- When the time base is off, the vertical line on the screen is centered and its length L measured
- The unknown a.c voltage, V = V_0L

(c) (i) an electron of charge –e and mass m moves in circular orbit round a central hydrogen nucleus of charge +e. Derive an expression for total energy of electron in an orbit of radius r. (05 marks)



Kinetic energy of electron = $\frac{1}{2}mv^2$

From circular motion,

Centripetal force = electrostatic force

$\frac{1}{2}mv^2 = \frac{e^2}{4\pi\varepsilon_0 r^2}$

$mv^2 = \frac{e^2}{4\pi\varepsilon_0 r}$

Multiplying by ½ both sides

Kinetic energy = $\frac{1}{2}mv^2 = \frac{e^2}{8\pi\varepsilon_0 r}$

Electrical energy = $\int_{\infty}^{r} F dx = \int_{\infty}^{r} \frac{e^2}{4\pi\varepsilon_0 x^2} dx = \frac{-e^2}{4\pi\varepsilon_0 r}$

Total energy E = K.E + P.E

$= \frac{e^2}{8\pi\varepsilon_0 r} + \frac{-e^2}{4\pi\varepsilon_0 r}$

$= \frac{-e^2}{8\pi\varepsilon_0 r}$

(ii) Why is this energy always negative (01marks)

The energy is always negative because the electron s bound to the nucleus by electrostatic force.

(d) (i) what is meant by excitation potential of an atom? (01marks)

Excitation potential of an atom is the potential required to raise atom from ts ground state to excited state.

(ii) Some of the energy levels in mercury spectrum are shown in the figure below.

Calculate the wavelength of the radiation emitted when electron makes a transition from level A to level C. (03marks)

$E_A - E_C$ = hf = $\frac{hc}{\lambda}$

λ = $\frac{6.6 \, x \, 10^{-34} \, x \, 3 \, x \, 10^8}{(0-10.4) \, x \, 1.6 \, x \, 10^{-19}}$ = 1.19 x 10^{-7}m

3. (a) What is meant by the following as applied to radioactivity?

(i) Activity (01marks)

Activity is the number of atoms disintegrating per second

(ii) Half-life of a radioactive material (01marks)

Half-life is the time taken by the number of atoms to decay to half original value.

(b) Using the radioactive decay law N = $N_0e^{-\lambda t}$, show that the half-life $T_{\frac{1}{2}} = \frac{1}{\lambda}$ (02marks)

From N = $N_0e^{-\lambda t}$

t = T ½ , N = $\frac{N_o}{2}$

$\frac{N_o}{2} = N_0 e^{-\lambda T_{\frac{1}{2}}}$

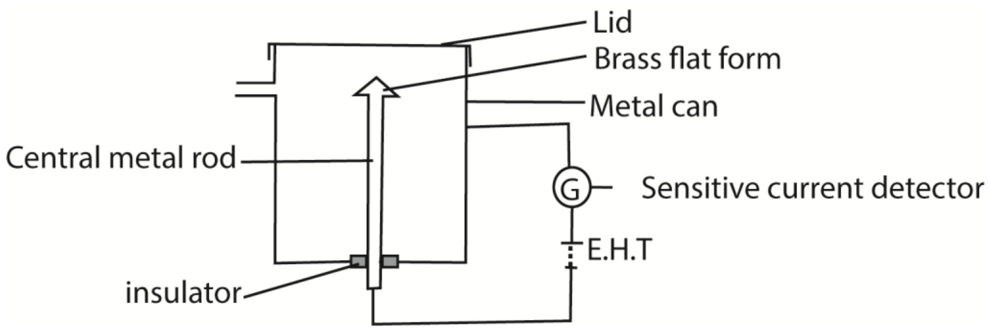
$\frac{1}{2} = e^{-\lambda T_{\frac{1}{2}}}$

$In\frac{1}{2} = -\lambda T_{\frac{1}{2}} Ine$

In2 = $\lambda T_{\frac{1}{2}}$

$T_{\frac{1}{2}} = \frac{0.693}{\lambda}$

(c) With the aid of a labelled diagram, describe the action of an ionization chamber. (05marks)



- A radiation source on the brass flat form causes ionization of air in the chamber producing electrons and positive ions.
- The electrons move to the metal can and positive ions drift to the central metal rod.
- Movement of the ions to the electrodes causes discharge and current pulse flows in external circuit.
- The current sensitive detector detects current.
- The magnitude of current detected shows the extent to which ionization takes place.

(d) What is meant by unified atomic unit and electron volt? (02marks)

Unified atomic mass unit is $\frac{1}{12}$ $of\ the\ mass\ of\ 1\ atom\ of\ carbon - 12\ isotope$

Electron volt is the kinetic energy gained by electron which has been accelerated through a p.d of 1volt.

(e) (i) The nucleus $^{212}_{83}Bi$ decays by alpha emission as follows

$^{212}_{83}Bi \rightarrow {}^{208}_{81}Tl + {}^{4}_{2}He$

Calculate the energy released by 2g of $^{212}_{83}Bi$. (05marks)

Mass defect= Δm (cannot be obtained since unified atomic mass units of the products are not given.

Energy released = Δmc^2

(ii) Explain two uses of radioactive isotopes. (04marks)

- Carbon dating: activity of fresh and dad material samples are obtained and the age of the dead material obtained.
- Treatment of cancer, A dose of the radioactive isotope is administered to a patient. The isotope emits radiation which destroy cancer cells
- Detection of leakage in underground sewage and water pipes.

4. (a) Define the following

(i) Binding energy (01marks)

Binding energy is the energy required to split the nucleus into protons and neutrons.

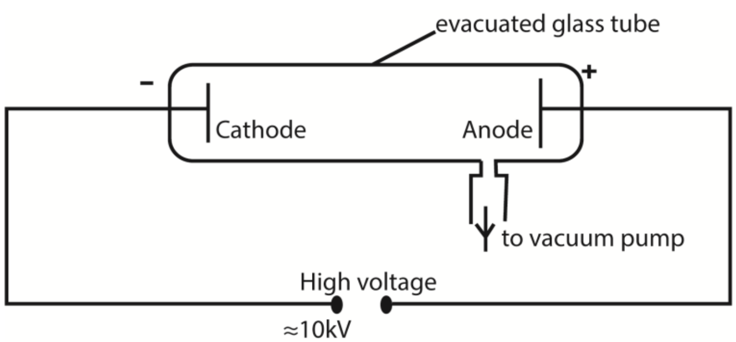
(ii) Unified Atomic Energy (01marks)

Unified atomic mass unit is a twelfth of the mass of one atom of carbon-12 isotope.

(b) Explain how energy is released in a nuclear fusion process. (03marks)

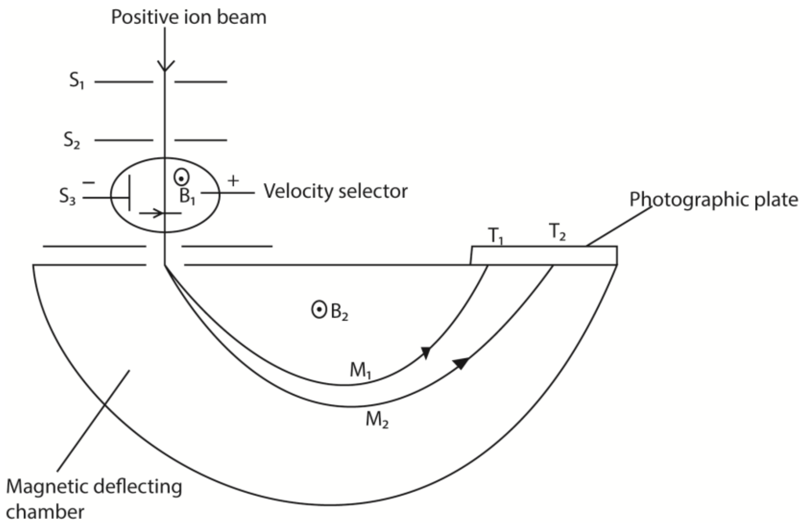
When two small nuclei combine, the total mass of the two nuclei is greater than the mass of the resulting heavy nucleus. The difference in the mass accounts for the energy released.

(c) Explain what is observed in a discharge tube when the pressure is gradually reduced to low values? (05marks)



- At 100mmHg, thin streamer of luminous gas appear between the electrodes.
- Between 10mHgand 0.1mmHg, the discharge becomes a steady glow spreading throughout the tube. Four regions appear

(d) With the aid of a diagram, describe the operation of Bainbridge mass spectrometer in the determination of charge to mass ratio. (07marks)



T_1 and T_2 are tracers on photographic plate, S_1, S_2 and S_3 are slits

Mode of action

- Positive ions are produced in a discharge tube and admitted as a beam through slits S_1 and S_2.
- The beam then passes between insulated plates P, Q, connected to a battery, which create an electric field of intensity E.
- A uniform magnetic field B_1, perpendicular to E is applied over the region of the plates and all ions, charge e with the same velocity, v given by B_1ev =Ee will then pass undeflected through the plates and through a slit S_3.
- The selected ions are deflected in a circular path of radius r by a uniform perpendicular magnetic field B_2 and an image is produced on a photographic plate as shown.
  In this case
  $$\frac{mv^2}{r} = B_2ev$$
  $$\therefore \frac{m}{e} = \frac{rB_2}{v}$$
  But for the ions selected v = $\frac{E}{B_1}$ from above
  $$\therefore \frac{m}{e} = \frac{rB_2B_1}{E}$$

(e) An ion of mass 2.6 x 10^{-26} kg moving at a speed of 4 x 10^4ms^{-1} enter a region of uniform magnetic field of flux density 0.05T. Calculate the radius of the circle described by the ion.

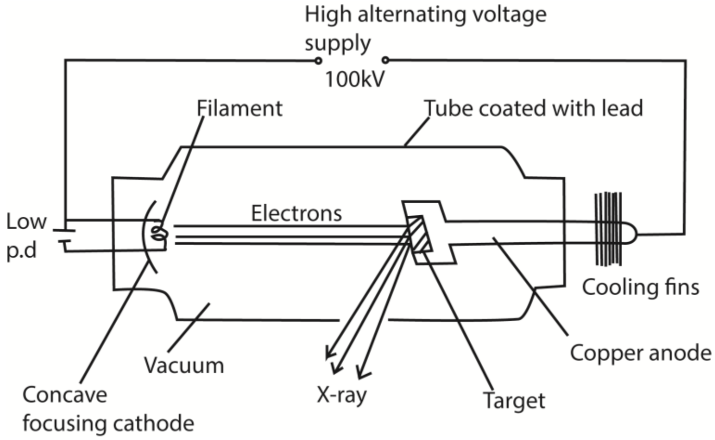
$$\frac{mv^2}{r} = Bev$$
$$r = \frac{mv}{Be} = \frac{2.6\ x\ 10^{-26}\ x\ 4\ x\ 10^4}{0.05\ x\ 1.6\ x\ 10^{-19}} = 0.13m$$

5. (a)(i) State three differences between X-rays and cathode rays. (03marks)

X-rays	Cathode rays
Electrical magnetic wave of very short wavelength	Streams of fast moving electrons

Have no charge	Are negatively charged
Are not deflected by electric and magnetic field	Are deflected by both magnetic and electric field
Move with high speed	Move with low speed
Affect photographic plates	Have no effect on photographic plates

(ii)Describe using a labelled diagram, the mode of operation of an X-ray tube (06marks)



Mode of operation

- The filament is heated by a low voltage supply and the electrons are emitted by thermionic emission.
- The concave focusing cathode focuses the electrons from the filament onto the target.
- These electrons are accelerated towards the anode by the high voltage between the filament and the Anode.
- When the electrons (cathode rays) strike the metal target, about only 1% their kinetic energy is converted to X-rays and the 99% of their kinetic energy is converted to heat, which is conducted away by the cooling fins.

(iii) What is the difference between soft and hard X-rays (01mark)

- Hard X-rays have higher penetrating power than soft X-rays
- Hard X-rays have shorter wavelength than soft X-ray.

(b) (i) What is the main distinction between work function and ionization energy? (02marks)

Ionization energy is the minimum energy required to remove its most loosely bound electron from the atom while work function is the minimum energy required to liberate an electron from a metal surface.

(ii) An electron of charge, e, enters at right angles into a uniform magnetic field of flux density B and rotates at frequency, f, n a circle of radius, r.

Show that the frequency, f, is given by; f = $\frac{Be}{2\pi m}$. (03marks)

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

$$Be = \frac{mv}{r} = \frac{m}{r}(2\pi fr) \text{ since } v = 2\pi fr$$

$$f = \frac{Be}{2\pi m}$$

(c) An X-ray beam is produced when electrons are accelerated through 50kV are stopped by the target of an X-ray tube. When the beam falls on a set of parallel atomic plates of a certain metal at glancing angle of 16^0, a first order diffraction maximum occurs. Calculate the atomic spacing of the planes. (05marks)

From $\frac{hc}{\lambda} = eV$

$\lambda = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 50000} = 2.48 \times 10^{-11}$m

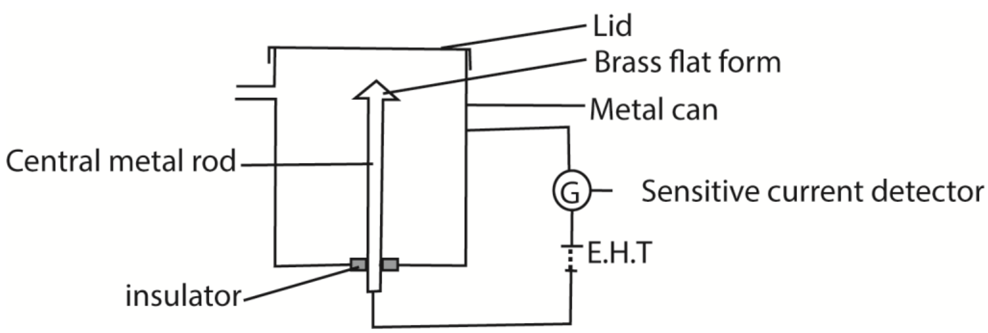
$2d\sin\theta = n\lambda$

d = $\frac{1 \times 2.48 \times 10^{-11}}{2 \sin 16^0} = 4.5 \times 10^{-11}$m

6. (a) State two differences between alpha and beta particles

Alpha particle	Beta particles
Positively charged	Negatively charged
Low penetrating power	High penetrating power
High ionizing power	Low ionizing power
Helium nucleus	An electron

(b) Describe with the aid of a diagram, the structure and mode of operation of an ionization chamber. (06marks)



- A radiation source on the brass flat form causes ionization of air in the chamber producing electrons and positive ions.
- The electrons move to the metal can and positive ions drift to the central metal rod.
- Movement of the ions to the electrodes causes discharge and current pulse flows in external circuit.
- The current sensitive detector detects current.
- The magnitude of current detected shows the extent to which ionization takes place.

(c)(i) Explain the application of carbon-14 in carbon dating. (03marks)

- Carbon-14 isotope is radioactive with half-life $t_{½}$ = 5600years
- It is absorbed and maintained at constant concentration by plants during photosynthesis.
- When plants die carbon- 14 decays and its concentration falls due to lack of renewal by photosynthesis.
- If N_0 is the activity of fresh plant and N is the activity of dead plant after time t, the age of the dead plant t is deduced from $N = N_0 e^{\frac{0.693}{5600}t}$

(ii) A sample of dad wood was found to have activity of 20units due to carbon-14 isotope whose half-life is 5600 years. If activity of wood just cut is 47.8 units, estimate the age of the sample. (03marks)

From $N = N_0 e^{\frac{0.693}{5600}t}$

47.8 = 20$e^{\frac{0.693}{5600}t}$

In$\frac{47.8}{20} = \frac{0.693}{5600}t$

t = 7040.8years

(d) The photoelectric work function of potassium is 2.25eV. Light having a wavelength of 360mm falls on a potassium metal.

(i) Calculate the stopping potential (04marks)

$hf = w_0 + \frac{1}{2}mv^2$

$but\ \frac{1}{2}mv_{max}{}^2 = eV_s$

- $\frac{hc}{\lambda e} = w_0 + V_s$

$\frac{6.6\ x\ 10^{-34}\ x\ 3\ x\ 10^8}{360\ x\ 10^{-3}}$ = 2.25 x 10^{-19} + eVs

$V_s = -2.25V$

(ii) Calculate the speed of the most energetic electron emitted by the metal (02marks)

$\frac{1}{2}mv_{max}{}^2 = eV_s$

$v_{max} = \sqrt{\frac{2\ x\ 2.25\ x\ 10^{-19}}{9.11\ x\ 10^{-31}}}$ = 8.89 x 10^5ms^{-1}

7. (a) What is meant by the following

(i) Radioactivity (01mark)

Radioactivity is the spontaneous disintegration of radioactive nuclide or atoms accompanied by emission of radiation

(ii) Isotopes (01marks)

Isotopes are atoms of the same atomic number but difference atomic mass

(b) (i) Define mass defect (01mark)

Mass defect is the difference in mass of constituent nucleons and the nucleus of an atom

(ii) State the conditions for a heavy nucleus to be unstable (01mark)

A heavy nucleus is unstable if there are too many neutrons or too many protons.

(iii) Explain your answer in (b)(ii) (02marks)

- Large number of protons increase electrostatic repulsion between themselves in a nucleus
- Large number of neutrons lead to unbalanced nuclear forces

(c) A sample of $^{226}_{88}Ra$ emits both α-particles and γ-rays. A mass defect of 0.0053u occurs in the decay.

(i) Calculate the energy released in joules. (03 marks)

E =mc^2 = 0.0053 x 1.66 x 10^{-27} x (3 x 10^8)^2 = 7.92 x 19^{-13}J

(ii) If the sample decays by emission of α-particle, each of energy 4.60MeV and γ-rays, find the frequency of the γ-rays emitted. (04marks)

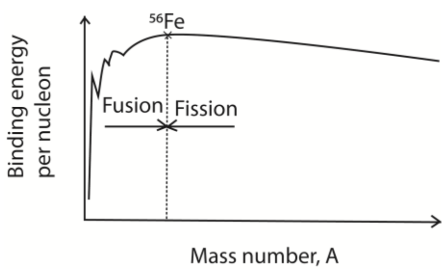
4.60MeV = 4.60 x 10^6 x 1.6 x 10^{-19} = 7.36 x 10^{-13}J

Energy of a photon of γ – rays = 7.9 x 19^{-13} - 7.36 x 10^{-13} = 0.56 x 10^{-13}

From E = hf

f = $\frac{0.56\ x\ 10^{-13}}{6.6\ x\ 10^{-34}}$ = 8.5 x 10^{19}Hz

(d) (i) Sketch a graph showing the variation of binding energy per nucleon with mass number, clearly showing the fusion and fissions. (02marks)



(ii)Use the sketch in (d)(i) to explain how energy is released in each of the process of fusion and fission

- Two small nuclei with atomic mass less than 56 fuse to give a heavier nucleus with a higher binding energy per nucleon to increase nuclear stability
- A nucleus with atomic mass higher than 56 split to form two small nuclei each with higher binding energy per nucleon and thus with higher nuclear stability

(e) State two

(i) applications of radioisotopes (01marks)

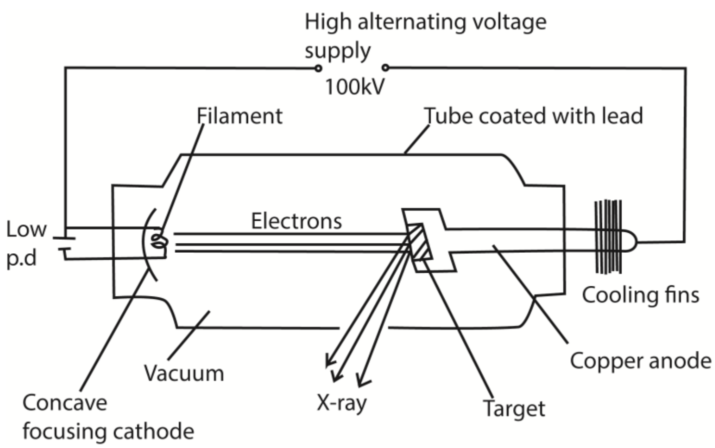
- Treatment of cancer
- Production of energy in nuclear reaction
- Detection of links in pipes
- Carbon dating

(ii) health hazards of radioisotopes (01mark)

- Cause genetic mutation
- Cause cancer
- Cause deep seated wounds in humans

8. (a) What are X-rays? (01marks)
X- rays are electromagnetic radiations of very high frequency (short wavelength) produced when cathode rays strike metal target.

(b) (i) With the aid of a diagram explain how X-rays are produced in an X-ray tube (05marks)



Mode of operation

- The filament is heated by a low voltage supply and the electrons are emitted by thermionic emission.
- The concave focusing cathode focuses the electrons from the filament onto the target.
- These electrons are accelerated towards the anode by the high voltage between the filament and the Anode.
- When the electrons (cathode rays) strike the metal target, about only 1% their kinetic energy is converted to X-rays and the 99% of their kinetic energy is converted to heat, which is conducted away by the cooling fins.

(ii) State the energy changes that take place in the production of X-rays in an X-ray tube. (02marks)

Electrical energy → kinetic energy → X-rays + heat

(c) In an X-ray tube, the electrons strike the target with a velocity of $3.75 \times 10^7 ms^{-1}$ after travelling a distance of 5.0cm from the cathode. If a current of 10mA flows through the tube, find the

(i) tube voltage (02marks)

From $eV = \frac{1}{2}mv^2$

$$V = \frac{1}{2e}mv^2 = \frac{9.11 \times 10^{-31} \times (3.75 \times 10^7)^2}{2 \times 1.6 \times 10^{-19}} = 4003V$$

(ii) number of electrons striking the target per second. (02marks)

I = ne

n = $\frac{10 \times 10^{-3}}{1.6 \times 10^{-19}}$ = 6.25 x 10^{16} electrons

(iii) Number of electrons within the space of 1cm length between the anode and the cathode. (05marks)

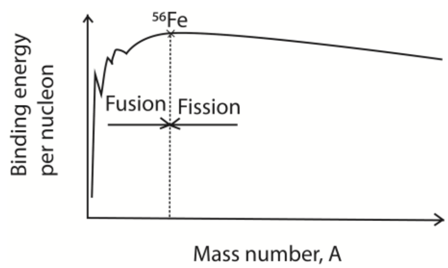
Number of electron in space of 1cm length = 6.25 x 10^{16} x $\frac{1}{100}$ = 6.25 x 10^{14}

(d) Briefly explain one medical application of x-rays (03marks)

X-rays are used to kill cancer cells

9. (a) (i) Distinguish between mass defect and binding energy of an atomic nucleus (01mark)
Mass defect s the difference between the mass of nucleons that make up a nucleus and the mass of a nucleus.
Binding energy of an atomic nucleus is the minimum energy to break up a nucleus into its constituent nucleons.

(ii) Sketch a graph of nuclear binding energy per nucleon versus mass number for naturally occurring isotopes and use it to distinguish between nuclear fission and fusion. (04marks)

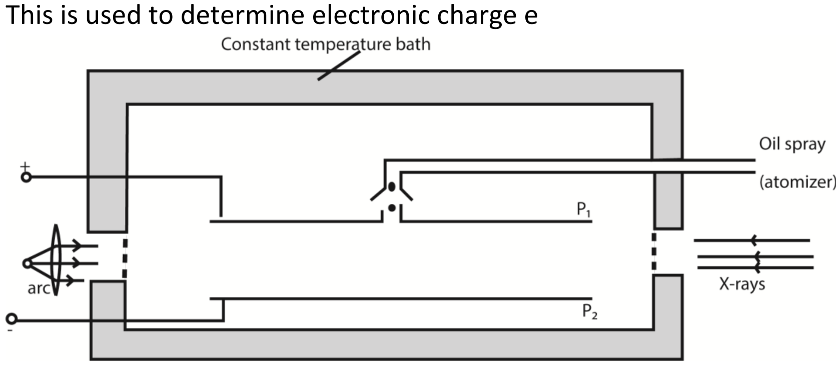


- Two Small nuclei with atomic mass less than 56 each fuse to give a heavier nuclei with smaller mass by higher binding energy to increase stability of nucleon
- A nucleus with atomic mass higher than 56 split to form lighter nuclei of higher binding energy per nuclei.

(b) Describe with the aid of a diagram, Millikan's oil drop experiment to determine charge on oil drop. (07marks)

Millikan's Oil drop experiment

This is used to determine electronic charge e



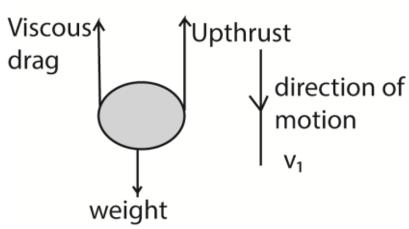
Procedure

- Set up of the apparatus is as shown above
- Oil drops are introduced between the plates P_1 and P_2 by spraying using the atomizer.
- These oil drops are charged in the process of spraying by friction but the charge may be increased further ionization due to X-rays.
- The oil drops are strongly illuminated by an intense light from the arc lamp so that they appear as bright spots when observed through a low power microscope.
- With no electric field between the plates, record the time t_1 taken for drop to fall from P_1 to P_2.
- The electric field between the plates is turned on and adjusted so that the drop becomes stationary.

Case 1

With no electric field, the oil drop falls with a uniform velocity v_1 called terminal velocity

Forces of falling oil drop



Weight = Upthrust + viscous drag ……………………………. (i)

= volume of the oil drop x density x gravity

= $\frac{4}{3}\pi r^3 \rho g$ (ρ = density of oil, r = radius of oil drop)

Upthrust = weight of air displaced by oil drop

= volume of the air displaced by oil drop x density x gravity

= $\frac{4}{3}\pi r^3 \sigma g$ (σ = density of air)

Viscous drag = $6\pi r\eta v_1$ (From strokes' law)

From 1

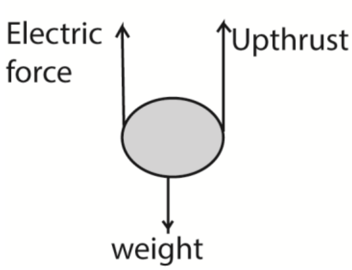
$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + 6\pi r\eta v_1$ ………………….. (ii)

$r = \left[\frac{9\eta v_1}{2g(\rho-\sigma)}\right]^{\frac{1}{2}}$

Case 2

When the electric field is applied so that the drop is stationary, the drop has no velocity and no acceleration.

Forces of stationary oil drop



Weight = Upthrust + electric force

$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + \mathrm{qE}$ ……………………. (iii)

From (ii) and (iii)

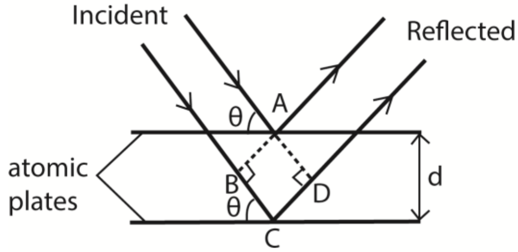
q = $\frac{6\pi r\eta v_1}{E}$ but E = $\frac{V}{d}$

Substituting for r

q = $\frac{6\pi\eta d v_1}{V}\left[\frac{9\eta v_1}{2g(\rho-\sigma)}\right]^{\frac{1}{2}}$

(c) (i) Explain briefly diffraction of X-rays by crystals and derive Bragg's law. (06marks)

- A parallel beam of monochromatic X-rays incident on a crystal is reflected from successive atomic planes and super-imposed, forming an interference pattern.



For constructive interference to occur, the path difference is equal to the whole number of wavelength

Thus BC + CD = nλ

⇨ dsinθ + dsinθ = nλ

or 2dsinθ = nλ where n = 1, 2, 3, 4 …

(ii) A second order diffraction image by reflection of X-rays at atomic plates of crystal for glancing angle of $11^0 24'$. Calculate the atomic spacing of the plates if the wavelength of X-ray is 4.0 x 10^{-11}m. (02marks)

From 2dsinθ = nλ

d = $\frac{2 \times 4 \times 10^{-11}}{2 \times \sin 11^0 24'}$ = 2.02 x 10^{-1}0m

10. (a) state Bohr's postulates of an atom (03marks)

Bohr's model state that electrons move in allowed orbits round the nucleus and while in orbits, they do not radiate any energy

(b) An electron of mass m and charge –e, is considered to move in circular orbit about a proton.

(i) Write down the expression for the electric force on the electron. (02marks)

Force = $\frac{e^2}{4\pi\varepsilon_0 r^2}$ where e = electronic charge, r = orbit radius

(ii) Derive an expression for total energy given that the angular momentum for the electron is equal to $\frac{nh}{2\pi}$ where n is an integer and h is Plank's constant. (06marks)

In the orbit, $\frac{mv^2}{r} = \frac{e^2}{4\pi\varepsilon_0 r^2}$

=> Kinetic energy = $\frac{e^2}{8\pi\varepsilon_0 r}$ ………… (i)

Potential energy = $\int_{\infty}^{r} \frac{-e^2}{4\pi\varepsilon_0 r^2} dr = -\frac{e^2}{4\pi\varepsilon_0 r}$

Total energy, E_t = P.E + K.e

$$= -\frac{e^2}{4\pi\varepsilon_0 r} + \frac{e^2}{8\pi\varepsilon_0 r} = -\frac{e^2}{8\pi\varepsilon_0 r} \text{ ………. (ii)}$$

Angular momentum = mvr

mvr = $\frac{nh}{2\pi}$

$\therefore m^2v^2r^2 = \frac{n^2h^2}{4\pi^2}$

$\frac{1}{2}mv^2 = \frac{n^2h^2}{8\pi^2 mr^2}$

From (i) $\frac{e^2}{8\pi\varepsilon_0 r} = \frac{n^2h^2}{8\pi^2 mr^2}$

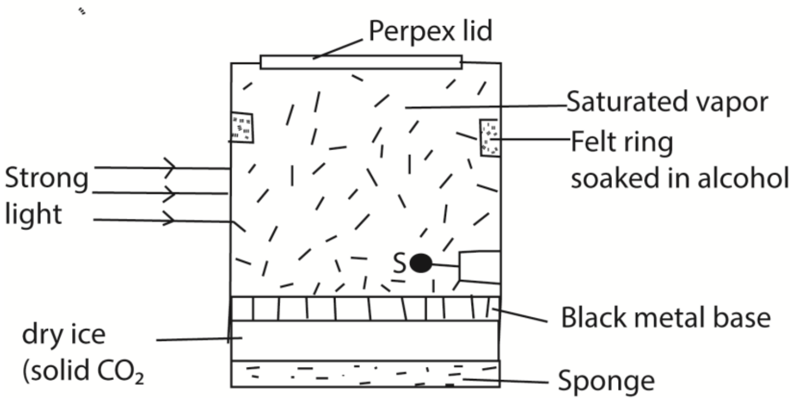
r = $\frac{n^2h^2\varepsilon_0}{\pi me^2}$

Substituting for r in equation (ii)

$E_t = -\frac{e^2}{8\pi\varepsilon_0} x \frac{\pi me^2}{n^2h^2\varepsilon_0}$

$= \frac{-me^4}{8n^2h^2\varepsilon_0^2}$

(c) With the aid of a labelled diagram, describe the operation of a diffusion type cloud chamber. (06marks)



- The base of the chamber is maintained at low temperature, about -80^{0}c by the solid carbon dioxide while the top of the chamber is at room temperature, and so there is a temperature gradient between the top and the bottom of the chamber.

- The air at the top of the chamber is saturated with alcohol vapor from the felt ring. This vapor continuously diffuse downwards into the cooler regions so that the air at the chamber is super saturated with alcohol vapor.
- Radiations from the radioactive source S cause the ionization of the vapor.
- The ionizations from the radioactive source S cause condensation of the vapor on the ions formed, hence the path of the ionizing radiations are traced by series of small droplets of condensation.
- The thickness and length of the path indicate the extent to which ionization has taken place.
- Alpha particles produce short, thick, continuous straight tracks
- Beta particles which are less massive produce longer, thin but straggly paths owing to collisions with gas molecules
- Gamma radiations are uncharged and for ionization to take place, it must collide with an atom and eject an electron which then ionizes the vapor.

(d) The energy levels of an atom have values

E_1 = - 21.4eV

E_2= -4.87 eV

E_3 = -2.77 eV

E4 = -0.81eV

E_∞ = 0.00eV

(i) Calculate the wavelength of radiation emitted when an electron makes a transition from E_3 to E_2 (03marks)

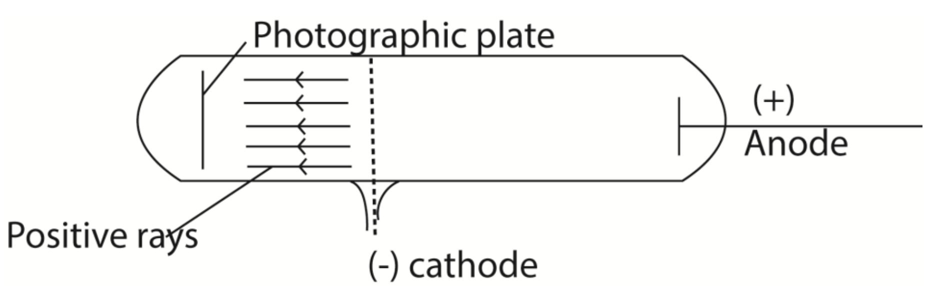
$E_3 - E_2 = hf = \frac{hc}{\lambda}$

$\lambda = \frac{6.6 \ x\ 10^{-34}\ x\ 3\ x\ 10^{8}}{(-2.77-(-4.87)\ x\ 10^{-19}}$ = 5.97 x 10^{-7}m

(ii) State the region of the electromagnetic spectrum where the radiation lies (01mark)

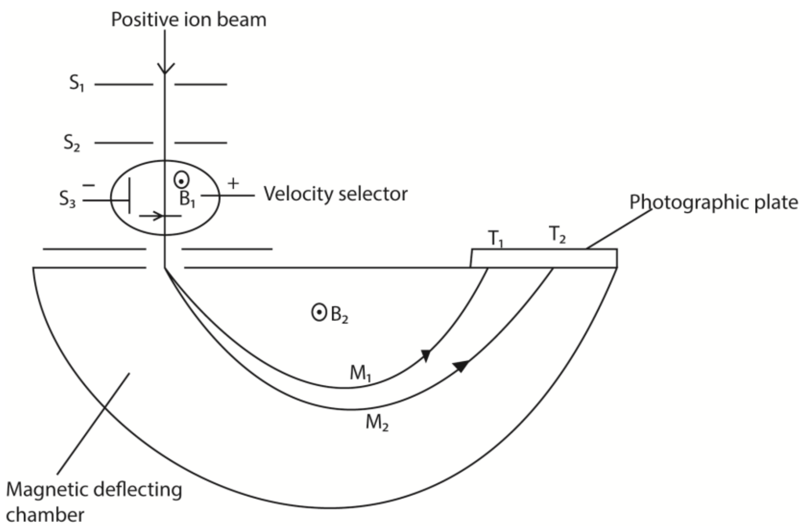
Visible spectrum

11. (a) Describe how positive rays are produced. (03marks)



Positive rays are produced when a stream of electrons is passed through a vapor (gas) in discharge tube. The electrons dislodge electrons from the atoms producing positively charged ions. The positive ions are accelerated towards perforated cathode. The ions pass through the slits and are further accelerated. These ions constitute a stream of positive rays.

(b) Describe how a Bainbridge spectrometer can be used to detect isotopes. (05marks)

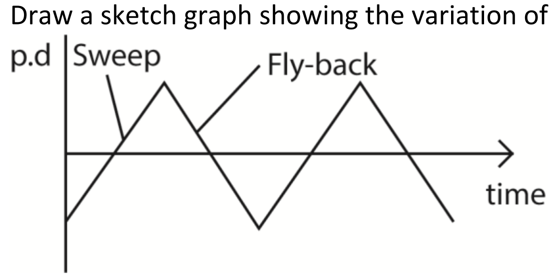


- Positive ions are directed through slits S_1 and S_2.
- The ions enter a velocity selector carrying crossed electric and magnetic field.
- Selected ions enter a region of uniform magnetic field in circular paths and strike the photographic plate at different points

(c) (i) What is time base as applied to a Cathode Ray Oscilloscope? (01mark)

Is a circuit connected to the x-plate of cathode ray oscilloscope to sweep the electron beam across a screen of a C.R.O

(iii) Draw a sketch graph showing the variation of time base voltage with time (01mark)



(d) An alternating p.d applied to the Y-plate of an oscilloscope produces five complete waves on a 10cm length of the screen when the time base setting is 10mscm^{-1}. Find the frequency of the alternating voltage. (03marks)

Period, T = $\frac{10 \; x \; 10 \; x \; 10^{-3}}{5}$ = 0.02s

Frequency = $\frac{1}{T} = \frac{1}{0.02}$ =50Hz

(e) (i) Explain the motion of an electron projected perpendicularly into a uniform magnetic field. (03marks)

By Fleming's left hand rule, the electrons experience a force which is always at right angles to the magnetic field and the direction of motion. The speed of electrons remain unaltered but the electrons is deflected by from its original path by this force. The motion of electrons in a magnetic field is a circular path.

(ii) An electron accelerated from rest by a p.d of 100V, enters perpendicularly into a uniform electric field intensity 105Vm-1. Find the magnetic field density, B, which must be applied perpendicularly to the electric field so that the electron passes undeflected through the fields. (04marks)

$\frac{1}{2}mu^2 = eV$

u = $\sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \ x \ 1.6 \ x \ 10^{-19} \ x \ 100}{9.11 \ x \ 10^{-31}}}$ = 5.93 x 10^6ms^{-1}

when the electron passes through crossed field undeflected

Beu = eE

B = $\frac{E}{u} = \frac{10^6}{5.93 \ x \ 10^6}$ = 0.0169T

12. (a) (i) Define Avogadro's constant and Faraday's constant. (02marks)
Avogadro's constant is the number of atoms in one mole of substance.
Faradays constant is the charge required to liberate one mole of monovalent ions during electrolysis.

(ii) Show that the charge carried by a monovalent ion is 1.6 x 10^{-19}C. (02marks)

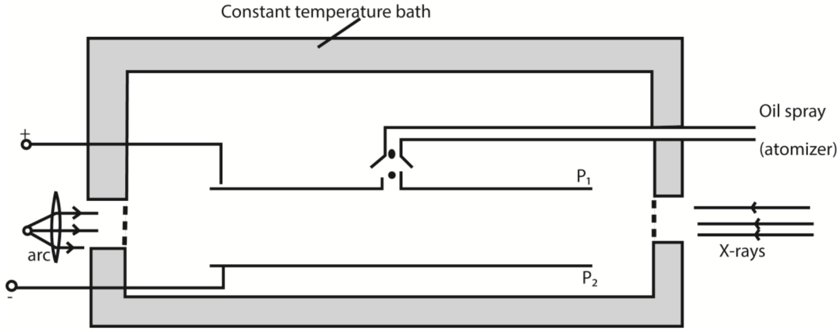
1F = nq (q = electronic charge)

q = $\frac{96500}{6.02 \ x \ 10^{23}}$ = 1.6x 10^{-19}C

(b) With the use of a labelled diagram, describe Millikan's oil drop experiment for the determination of the charge of an electron. (07marks)

Millikan's Oil drop experiment

This is used to determine electronic charge e

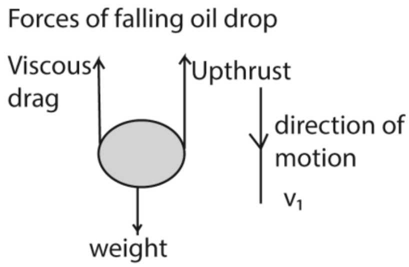


Procedure

- Set up of the apparatus is as shown above
- Oil drops are introduced between the plates P_1 and P_2 by spraying using the atomizer.
- These oil drops are charged in the process of spraying by friction but the charge may be increased further ionization due to X-rays.
- The oil drops are strongly illuminated by an intense light from the arc lamp so that they appear as bright spots when observed through a low power microscope.
- With no electric field between the plates, record the time t_1 taken for drop to fall from P_1 to P_2.
- The electric field between the plates is turned on and adjusted so that the drop becomes stationary.

Case 1

With no electric field, the oil drop falls with a uniform velocity v_1 called terminal velocity



Weight = Upthrust + viscous drag …………………………… (i)

= volume of the oil drop x density x gravity

= $\frac{4}{3}\pi r^3 \rho g$ (ρ = density of oil, r = radius of oil drop)

Upthrust = weight of air displaced by oil drop

= volume of the air displaced by oil drop x density x gravity

= $\frac{4}{3}\pi r^3 \sigma g$ (σ = density of air)

Viscous drag = $6\pi r\eta v_1$ (From strokes' law)

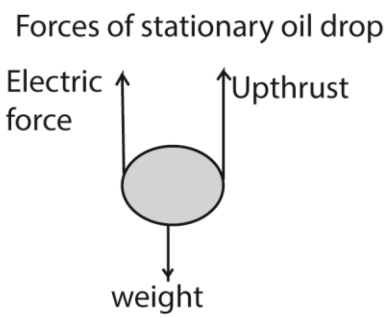
From 1

$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + 6\pi r\eta v_1$ ………………….. (ii)

$r = \left[\frac{9\eta v_1}{2g(\rho-\sigma)}\right]^{\frac{1}{2}}$

Case 2

When the electric field is applied so that the drop is stationary, the drop has no velocity and no acceleration.



Weight = Upthrust + electric force

$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + qE$ .... (iii)

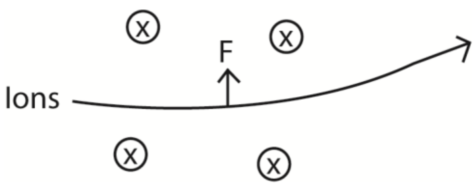
From (ii) and (iii)

q = $\frac{6\pi r\eta v_1}{E}$ but E = $\frac{V}{d}$

Substituting for r

q = $\frac{6\pi\eta d v_1}{V}\left[\frac{9\eta v_1}{2g(\rho-\sigma)}\right]^{\frac{1}{2}}$

(c) A beam of positive ions moving with velocity v enters a region of a uniform magnetic field density B with the velocity at right angles to the field B. By use of a diagram, describe the motion of ions. (03marks)



Magnetic force, F = BQV acts on the ions. The force is perpendicular to both B and V according to Fleming's rule. The ion describe a circular path of radius, r, given by

BQV = $\frac{mV^2}{r}$

r = $\frac{mV}{BQ}$ where Q is the charge on the ions.

(d) A charged oil drop of density 880kgm^{-3} is held stationary between two parallel plates 6.0mm apart held at a potential difference of 10^3V. When the electric field is switched off, the drop is observed to fall a distance of 2.0mm in 35.7s. (Viscosity of air = 1.8 x 10^{-5}Nsm^{-2}, Density of air = 1.29kgm^{-3}).

(i) Calculate the radius of the drop. (03marks)

$V_0 = \frac{2\ x\ 10^{-3}}{35.7}$ = 5.6 x 10^{-5}ms^{-1}

r = $\left(\frac{9\eta V_0}{2g(\rho-\sigma)}\right)^{\frac{1}{2}}$= $\left(\frac{9\ x\ 1.8\ x\ 10^{-3}\ x\ 5.6\ x\ 10^{-5}}{2\ x\ 9.81\ (880-1.29)}\right)^{\frac{1}{2}}$ = 7.254 x 10^{-7}m

(ii) Estimate the number of excess electrons on the drop. (03marks)

Q = $\frac{4\pi r^3 g}{3E}(\rho - \sigma) = \frac{4\pi r^3 gd}{3V}$

$$= \frac{4\pi\ (7.254\ x\ 10^{-7})^3\ x\ 9.81\ x\ 6\ x\ 10^{-3}}{3\ x\ 103}(880 - 1.29)$$

= 8.029 x 10^{-19}C

Q = ne

n = $\frac{8.026\ x\ 10^{-19}}{1.6\ x\ 10^{-19}}$5

13. (a) (i) State the laws of photoelectric emission (04marks)

- The time lag between irradiation of the metal surface and emission of the electrons by the metal surface is negligible.
- For a given metal, surface there is a minimum value of frequency of radiation called threshold frequency (f_0) below which no photo electrons are emitted from the metal however intense the incident radiation may be.
- The number of photoelectrons emitted from the surface per second is directly proportional to the intensity of incident radiation for a particular incident frequency
- The K.E of the photoelectrons emitted is independent of the intensity of the incident radiation but depends only on its frequency

(ii) Explain briefly one application of photoelectric effect. (04marks)

Use in a photocell in a burglar alarm: when an intruder intercepts infrared radiation incident on the photocell, the flow of current is interrupted. The alarm is set off

(b) In a photoelectric set up. A point source of light of power 3.2×10^{-3}W emits mono-energetic photons of energy 5.0eV. The source is located at a distance of 0.8m from the center of a stationary metallic sphere of work function 3.0eV and radius 8.0×10^{-3}m. The efficiency of photoelectron emission is one in every 10^6 incident photons.

Calculate

(i) Number of photoelectrons emitted per second. (04marks)

The number of photons emitted per second by the lamp = $\frac{3.2 \; x \; 10^{-3}}{5.0 \; c \; 1.6 \; x \; 10^{-19}}$ = 4.0×10^{15}

Photons incident on the sphere = $\frac{4.0 \; x \; 10^{15} \; x \; \pi \; x \; (8.0 \; x \; 10^{-3})^2}{4\pi \; x \; 0.8^2}$ = 1.0×10^{11} photons

Number of electrons emitted per second = $\frac{10^{11}}{10^6}$ = 10^5

(ii) Maximum kinetic energy in joules, the photo electrons. (02marks)

Maximum kinetic energy = 5- 3 = 2eV = $2 \times 1.6 \times 10^{-19}$ = 3.2×10^{-19}J

(c) (i) State Bragg's law of X-ray diffraction (01marks)

It states that for constructive interference of diffracted X-rays to occur, the path difference s an integral multiple of the wavelength of the X-ray.

Or

$2d\sin\theta = n\lambda$

Where d = interatomic spacing

θ = glancing angle

λ = wavelength of X-rays

n = integral number

(ii) Show that density, ρ, of a crystal can be given by

$$\rho = \frac{M\sin^3\theta}{125N_A(n\lambda)^3}$$

where θ is the glancing angle, n, is the order of diffraction, λ is the X-ray wavelength and M is the molecular weight of the crystal. (05marks)

Density, $\rho = \frac{M}{V}$

Volume of crystal molecule with interatomic spacing d= d^3

1mole weight M g

∴ 1 molecule weigh $\frac{M\,x\,10^{-3}}{N_A}$

Density of a molecule, $\rho = \frac{M\,x\,10^{-3}}{N_A d^3}$

From Bragg's law, $d = \frac{n\lambda}{2\sin\theta}$

$$\rho = \frac{M\,x\,10^{-3}}{N_A\left(\frac{n\lambda}{2\sin\theta}\right)^3} = \frac{M\sin^3\theta}{125N_A(n\lambda)^3}$$

14. (a) With reference to a Geiger-Muller tube, define the following

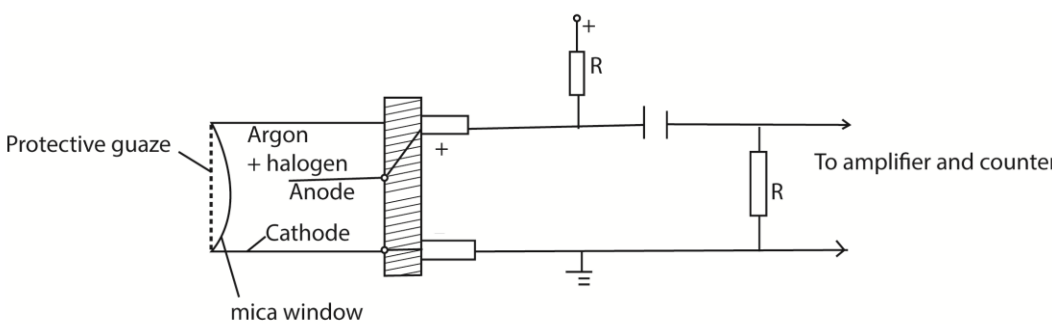
(i) quenching agent (01mark)

It is a halogen gas placed in a Geiger-Muller tube to prevent positive ions from causing the release of electrons from the cathode.

(ii) back ground count rate (01mark)

It is the activity detected by the GM tube in absence of the radioactive source.

(b) (i) With the aid of a labelled diagram, describe the operation of a Geiger-Muller (GM) tube (06marks)



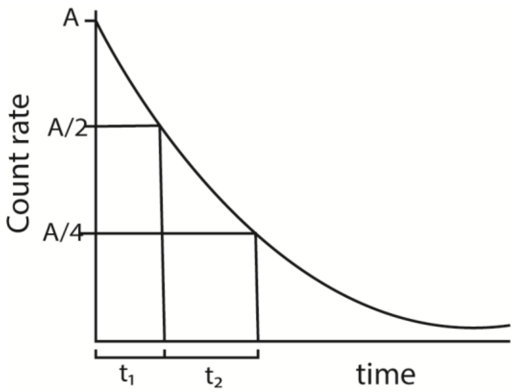
The thin mica window allows the passage and detection of the weak penetrating alpha particles. The GM tube is first evacuated then filled with Neon, Argon plus Halogen gas which is used as a quenching agent.

Mode of operation

- When an ionizing particle enters the tube through the window, argon atoms are ionized.
- The electrons move to the anode while the positive ions drift to the cathode.
- A discharge occurs and the current flows in the external circuit.
- A p.d is obtained across a large resistance, R which is amplified and passed to the scale.
- The magnitude of the pulse registered gives the extent to which ionization occurred.

(ii) Explain how the half-life of a short lived radioactive source can be obtained by use of a Geiger-Muller tube. (04marks)

- Switch on the GM-tube, note and record the background count rate, A.
- Place a source of ionizing radiation near the GM-window.
- Note and record the count rate recorded the count rate at equal intervals.
- For each count rate recorded subtract the background count rate to get the true rate.
- Plot a graph of the count rate against time.



Find time t_1 taken for the activity to reduce to A/2 and t_2 taken for activity to reduce to A/4 from A/2

Half-life = $\frac{1}{2}(t_1 + t_2)$

(c) A radioactive isotope $^{32}_{15}P$ which has a half-life of 14.3days, disintegrates to form a stable product. A sample of the isotope is prepared with initial activity of 2.0 x $10^6 s^{-1}$. Calculate the

(Assume $N = N_0 e^{-\lambda t}$)

(i) the number of ^{32}P atoms present (03marks)

Activity, $A_0 = \lambda N_0$ but $\frac{0.693}{t_{\frac{1}{2}}}$

$2.0 \times 10^6 = \frac{0.693 \, x \, N_0}{14.3 \, x \, 24 \, x \, 60 \, x \, 60}$

$N_0 = 3.56 \times 10^{12}$ atoms

(ii) activity after 30 days (03marks)

From $In\frac{A_0}{A} = \lambda t$ where λ= $\frac{0.693}{t_{\frac{1}{2}}}$

$$\ln\frac{2 x 10^6}{A} = \frac{0.693 x 30 x 24 x 60 x 60}{14.2 x 24 x 60 x 60}$$

A = 4.67 x $10^5 s^{-1}$

(iii) number of ^{32}P atoms after 30 days (02marks)

Activity, A = λN

4.67 x $10^5 = \frac{0.693 x N}{14.2 x 24 x 60 x 60}$ = 3.49 x 10^{12} atoms

Number of atoms N= 8.3 cx 10^{11}

15. (a) State Rutherford's model of the atom. (02marks)
The positive charge of an atom and nearly all the mass is concentrated in a small volume at the center. Electrons are in motion in circular orbits around the nucleus and the volume of the atom is accounted for by the electron cloud.

(b) Explain how Bohr's model of the atom addresses the two main failures of Rutherford's model. (07marks)

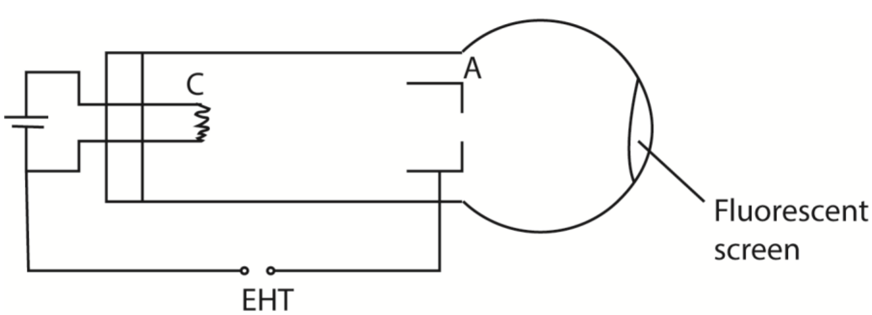
Orbiting electrons experience centripetal acceleration. Therefore they continuously emit electromagnetic radiation hence would lose energy. This therefore implies that the electrons would spiral towards the nucleus and the atom ceases to exist. Yet the atom is stable Thus Rutherford model cannot explain the stability of the atom.

Since electron continuously accelerating around the nucleus, a continuous emission spectra should be emitted by the atom. However experimental observation reveals that it is atomic emission spectrum

From Bohr's model, electrons move around the nucleus in circular orbits. In these orbits the electron does not radiate energy. Electromagnetic radiation is emitted when the electron makes a transition between orbits

The electron can only move in allowed orbits in which their angular momentum is equal to $\frac{nh}{2\pi}$

(c) With the aid of a labelled diagram, describe how cathode rays are produced. (05marks)



Hot Cathode C produces electrons by thermionic emission. The electrons are accelerated by p.d between cathode C and anode A

(d) (i) What is binding energy of a nucleus? (01mark)

Binding energy is the energy released when a nucleus is formed from its components (protons and neutrons)

(ii) Calculate the energy in MeV released by fusing four protons to form an alpha particle and two beta particles.

Mass of beta particle = 0.000549u

Mass of hydrogen atom = 1.007825u

Mass of helium atom = 4.002664u

[1u = 931MeV] (05marks)

Solution

$4{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2{}_{-1}\beta + Q$

Mass of the reactant = 4 x 1.00782 = 4.031300

Mass of the products = 4.002664 + 2 x 0.000549= 4.003762

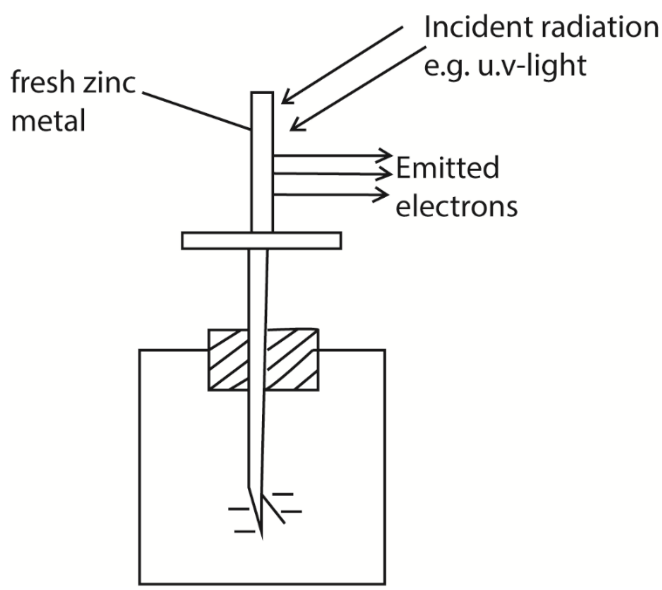
Decrease in mass= 4.0031300 - 4.003762 =0.027538U

= 0.027538 x 931

= 25.64MeV

16. (a) What is photo electric emission? (01mark)
Is the emission of electrons from a clean surface of a metal when irradiated by electromagnetic radiation of light

(b)(i) Describe an experiment to demonstrate photo electric effect. (04marks)



- Freshly cleaned zinc plate is placed on top of a negatively charged electroscope.
- Ultraviolet radiation is directed onto the zinc plate
- The leaf gradually falls indicating the electroscope has lost charge which are electrons.

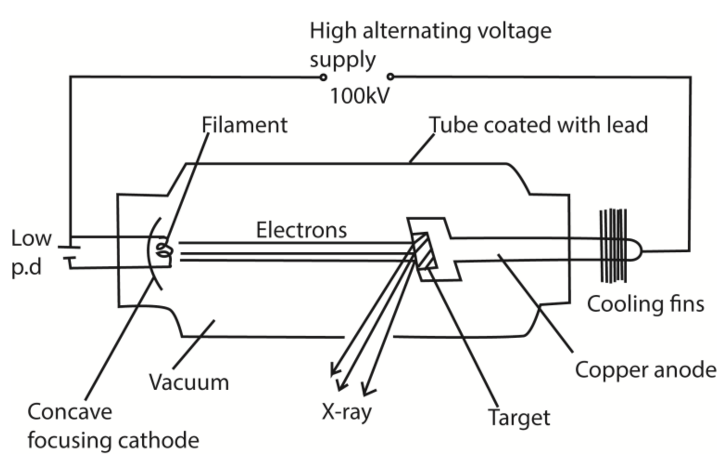
(ii) When a clean surface of a metal in a vacuum is irradiated with light of wave length 5.5 x 10^{-7}m, electrons just emerge from the surface. However when light of wavelength 5 x 10^{-7}m is incident on the metal surface, electrons are emitted each with energy 3.62 x 10^{-20}J. Find Plank's constant. (04marks)

K.E = $\frac{hc}{\lambda} - \frac{hc}{\lambda_0}$

3.62 x 10^{-20} = $h\ x\ 3\ x\ 10^8 \left(\frac{1}{5\ x\ 10^{-7}} - \frac{1}{5.5\ x\ 10^{-7}}\right)$

$\therefore h = 6.64\ x\ 10^{-34} Js$

(c) (i) With the aid of a labelled diagram, describe an X-ray tube and how X-rays are produced. (05marks)



Mode of operation

- The filament is heated by a low voltage supply and the electrons are emitted by thermionic emission.
- The concave focusing cathode focuses the electrons from the filament onto the target.
- These electrons are accelerated towards the anode by the high voltage between the filament and the Anode.
- When the electrons (cathode rays) strike the metal target, about only 1% their kinetic energy is converted to X-rays and the 99% of their kinetic energy is converted to heat, which is conducted away by the cooling fins.

(ii) Describe how the intensity and quality of X-rays is controlled in an X-ray tube. (02marks)

- Intensity of X-rays is controlled by varying the filament current
- Quality of X-rays is controlled by the high voltage

(d) An X-ray tune operates at 1.5 x 10^{-3}V and the current through it is 1.0 x 10^{-3}A.

Find the

(i) number of electrons crossing the tube per second. (02marks)

n = $\frac{I}{e} = \frac{1.0\ x\ 10^{-3}}{1.6\ x\ 10^{-19}}$ = 6.15 x 10^{15}

(ii) kinetic energy gained by electron traversing the tube (02marks)

K.E = eV 1.6 x 10-19 x 1.5 x 10^{-3} = 2.4 x 10^{-16}J

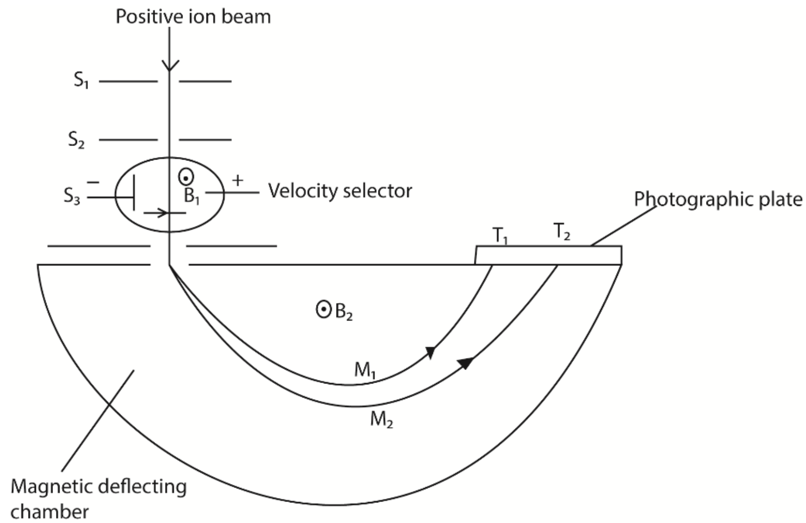
17. (a)(i) What is specific charge? (01mark)

Specific charge is the ratio of charge to mass of a particle

(ii) State the **unit** of specific charge (01mark)

Unit = Ckg^{-1}

(iii) Describe with the aid of a diagram how the specific charge of positive ions can be determined using a mass spectrometer. (06marks)



T_1 and T_2 are tracers on photographic plate, S_1, S_2 and S_3 are slits

Mode of Action

- Positive ions are produced in a discharge tube and admitted as a beam through slits S_1 and S_2.
- The beam then passes between insulated plates P, Q, connected to a battery, which create an electric field of intensity E.
- A uniform magnetic field B_1, perpendicular to E is applied over the region of the plates and all ions, charge e with the same velocity, v given by $B_1ev = Ee$ will then pass undeflected through the plates and through a slit S_3.
- The selected ions are deflected in a circular path of radius r by a uniform perpendicular magnetic field B_2 and an image is produced on a photographic plate as shown.
  In this case
  $$\frac{mv^2}{r} = B_2ev$$
  $$\therefore \frac{m}{e} = \frac{rB_2}{v}$$

  But for the ions selected $v = \frac{E}{B_1}$ from above

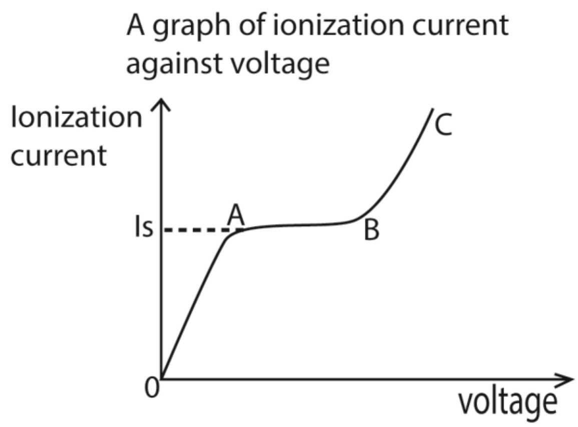
Specific charge, $\frac{e}{m} = \frac{E}{rB_2B_1}$,

(b) A beam of strongly ionized carbon atoms passes undeflected through a region of crossed magnetic and electric field of 0.10T and $1.0 \times 10^4 NC^{-1}$ respectively. When it enters a region of uniform magnetic field, it is deflected through an arc of radius 0.75m. Calculate the magnetic flux density of this magnetic field. (Mass of carbon atom = 2.0×10^{-26}kg) (05marks)

$B_1qv = qE$, $v = \frac{E}{B_1}$ and $B_2qv = \frac{mv^2}{R}$

$$\therefore B_2 = \frac{mE}{qRB_1} = \frac{2.0 \, x \, 10^{-26} \, x \, 1.0 \, x \, 10^4}{1.6 \, x \, 10^{-19} \, x \, 0.75 \, x \, 0.1} = 0.0167T$$

(c) (i) Draw a graph to illustrate the variation of ionization current and p.d across an ionization chamber and explain its features. (03marks)



Region OA:

Current detected increases gradually but p.d is not large enough to prevent recombination of the ions.

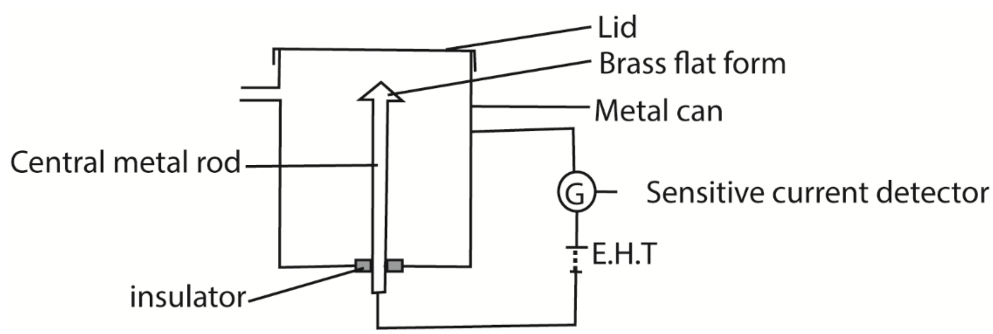
Region AB. (saturation region)

Current is almost constant, all ions reach the electrode before recombination but there is no secondary ionization.

Region BC (gas amplification)

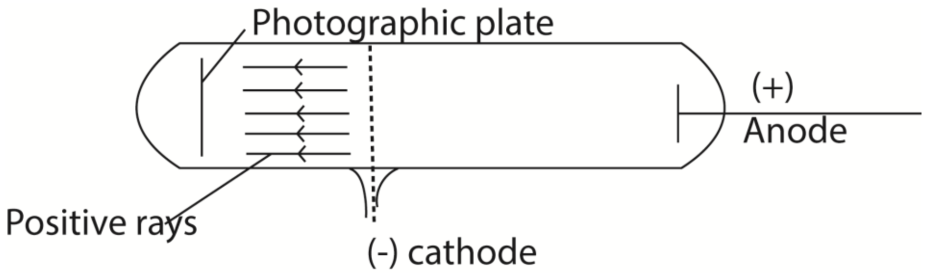
Current increases rapidly for small increase (change) in p.d. because secondary ionization takes place due to primary ions being produced. This implies many ion pairs, thus a larger current detected.

(ii) Explain how ionization chamber can be used to detect ionization radiation (04marks)



- A radiation source on the brass flat form causes ionization of air in the chamber producing electrons and positive ions.
- The electrons move to the metal can and positive ions drift to the central metal rod.
- Movement of the ions to the electrodes causes discharge and current pulse flows in external circuit.
- The current sensitive detector detects current.
- The magnitude of current detected shows the extent to which ionization takes place.

18. (a) Explain briefly how positive rays are produced (03marks)



- Positive rays are produced when a stream of electrons is passed through a vapor (gas) in discharge tube.
- The electrons dislodge electrons from the atoms producing positively charged ions.
- The positive ions are accelerated towards perforated cathode.
- The ions pass through the slits and are further accelerated.
- These ions constitute a stream of positive rays.

(b) An electron of charge, e, and mass, m, is emitted from a hot cathode and then accelerated by an electric field towards the anode. If the potential difference between the cathode and the anode is V, show that the speed of the electron, u, is given by

u = $\sqrt{\left(\frac{2eV}{m}\right)}$ (03marks)

Gain in K.E = work done on an electron by the accelerating p.d, V

$\frac{1}{2}mu^2 = eV$

$\therefore u = \sqrt{\frac{2eV}{m}}$

(c) An electron starts from rest and moves in an electric field intensity of 2.4 x 10^3Vm^{-1}.

Find the

(i) force on the electron (02 marks)

Force, F, on electron

F = eE = 1.6 x 10^{-19} x 2.4 x 10^3 = 3.84 x 10^{-16}N

(ii) acceleration of the electron. (02marks)

From F =ma

a = $\frac{F}{a} = \frac{3.84\ x\ 10^{-16}}{9.11\ x\ 10^{-31}}$ = 4.22 x 10^{14}ms^{-1}

(iii) velocity acquired in moving through a p.d of 90V (02marks)

From $u = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2\ x\ 1.6\ x\ 10^{-19} x\ 90}{9.11\ x\ 10^{-31}}}$ = 5.62 x 10^6ms^{-1}

(d) A beam of electrons each of mass, m, and charge, e, is directed horizontally with speed, u, into an electric field between two horizontal metal plates separated by a distance, d.

(i) If the p.d between the plates is V, show that the deflection y of the beam is given by

$$y = \frac{1}{2m}\left(\frac{eV}{du^2}\right)x^2$$

where, x, is the horizontal distance travelled. (06marks)

Horizontal motion, x =ut

In the same time, t, vertical displacement

$y = \frac{1}{2}at^2$

from F =ma = eE

$$\therefore a = \frac{eE}{m}$$

$$y = \frac{eE}{2m}t^2 = \frac{eE}{2m}\left(\frac{x}{u}\right)^2 = \frac{eEx^2}{2mu^2}$$

$$But\ E = \frac{V}{d}$$

$$y = \frac{eEx^2}{2mu^2} = \frac{1}{2m}\left(\frac{eV}{du^2}\right)x^2$$

(ii) Explain the path of the electron beam as it emerges out of the electric field. (02marks)

The electron beam continues in a straight path with constant velocity since the electric force on it is zero.

19. (a) The table below shows the energy levels of a hydrogen atom.

Principal quantum number, n	Energy, eV
6	-0.38
5	-0.54
4	-0.85
3	-1.51
2	-3.39
1	-13.60

(i) Why are the energies for the different levels negative? (01mark)
Work is done in order to remove an electron to infinity.

(ii) Calculate the wavelength of the line arising from a transition from the third to the second level. (03marks)

$$E_3 - E_2 = hf = \frac{hc}{\lambda}$$

$\lambda = \frac{hc}{E_3 - E_2} = \frac{6.6 \ x \ 10^{-34} \ x \ 3.0 \ x \ 10^{8}}{(-1.51+3.39) \ x \ 1.6 \ x \ 10^{-19}}$ = 6.58 x 10^{-7}m

(iii) Calculate the ionization energy in joules of hydrogen atom. (02marks)

Ionization energy = 13.6 x 1.6 x 10^{-19} = 2.18 x 10^{-18}J

(b) Explain the physical processes in an X-ray tube that account for

(i) cut off wavelength (03marks)

Electrons from the cathode strike the target and lose all their kinetic energy in single encounter with the target atoms. This results in the production of the most energetic X-rays photon of maximum frequency and corresponding minimum wavelength (λ_{min}) called the cut off wavelength.

(ii) characteristic lines (04marks)

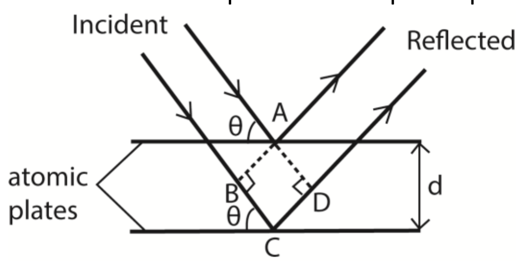
At high tube voltages, the bombarding electron penetrate deep into the atom and knock out the electron from inner shell. The knocked out electron can either be ejected completely out of the atom or it occupies any of the higher shell. This puts an atom in an excited state and the atom therefore becomes unstable. Electron transition from higher shell to a vacancy left in the lower shell results in emission of an X-ray photon of energy equal to the difference between the energy levels.

(c) Calculate the maximum frequency of radiation emitted by an X-ray tube using an accelerating voltage of 33.0kV (03marks)

$$f_{max} = \frac{eV}{h} = \frac{1.6 \ x \ 10^{-19} \ x \ 33 \ x \ 10^{3}}{6.6 \ x \ 10^{-34}} = 8.0 \ x \ 10^{18} Hz$$

(d) Derive Bragg's law of X-ray diffraction in crystals. (04marks)

- A parallel beam of monochromatic X-rays incident on a crystal is reflected from successive atomic planes and super-imposed, forming an interference pattern.



For constructive interference to occur, the path difference is equal to the whole number of wavelength

Thus BC + CD = nλ

⇨ dsinθ + dsinθ = nλ

or 2dsinθ = nλ where n = 1, 2, 3, 4 …

20. (a) A beam of α-particles is directed normally to a thin metal foil

Explain why

(i) Most of the α-particles passed straight through the foil (02marks)

The atoms of the foil contain concentrated mass in a very tiny nuclei surrounded by empty space containing electrons

(ii) Few α-particles are deflected through angles more than 90^0. (02marks)

The nucleus a very small space of an atom. Therefore very few α-particles are incident close to it that are strongly repelled.

(b) Calculate the least distance of approach of a 3.5MeV α-particles to the nucleus of a gold atom. (Atomic number of gold= 79) (04marks)

Initial K.E = eV = P.E at the closest distance of approach; Z = 79

$$eV = \frac{2e\ x\ Ze}{4\pi\varepsilon_0 d}$$

$$= \frac{2e^2 Z}{4\pi\varepsilon_0 d}$$

$$3.5 \times 10^6 \times 1.6 \times 10^{-19} = \frac{2(1.6\ x\ 10^{-19})^2\ x\ 79}{4\pi\varepsilon_0\ x\ d}$$

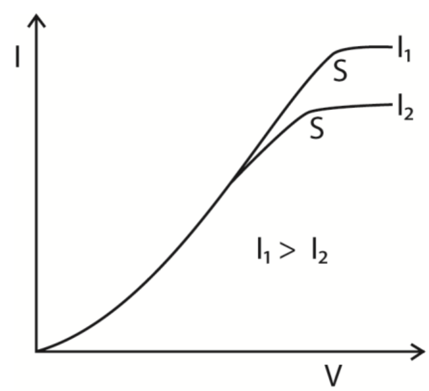
$$d = \frac{2\ x\ 1.6\ x\ 10^{-19}\ x\ 79\ x\ 9\ x\ 10^9}{3.5\ x\ 10^6}$$

$= 6.5 \times 10^{-14}$m

(c) (i) Define space charge as applied to thermionic diodes. (01mark)

Space charge is cloud of negative charge around the cathode at low anode potential difference.

(ii) Draw anode current-diode voltage curves of a thermionic diode for two different filament currents and explain their main features. (06marks)



The current increases with the positive anode potential as far as the point S. Beyond this point the current does not increase, because the anode is collecting all the electrons emitted by the filament ; the current is said to be saturated.

(d) (i)What is a decay constant?

Decay constant is the fractional number of disintegrations per second.

(ii) A sample from fresh wood of a certain species of tree has activity of 16.0 counts per minute per gram. However, the activity of 5g of dead wood of the same species of tree is 10 counts per minute. Calculate the age of the deadwood. (Assume half-life of 5730years) (04marks)

From $N = N_0e^{-\lambda t}$

$\lambda = \frac{0.693}{5730} = 1.21 \times 10^{-4}$ per year

$A = \frac{10}{5} = 2.0 min^{-1} g^{-1}$

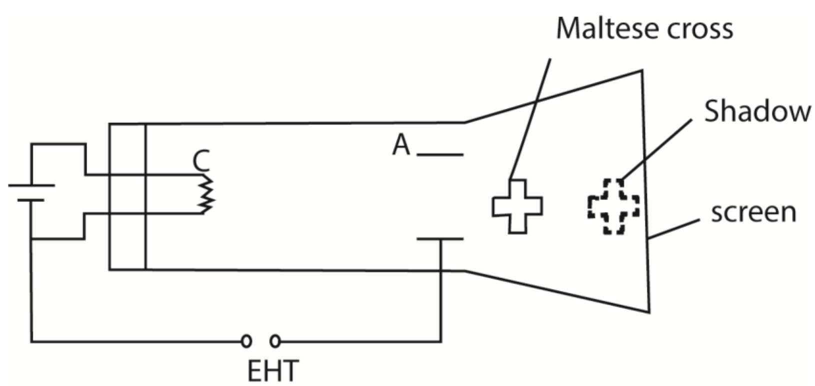
$2 = 16e^{-1.21 \times 10^{-4} t}$

$t = 1.719 \times 10^4 years$

21. (a) (i) What are cathode rays?

Cathode rays are stream of fast moving electrons

(ii) With the aid of a diagram, describe an experiment to show that cathode rays travel in straight line (04mrks)



Electrons emitted from the cathode, C are accelerated by the anode A towards a Maltese cross placed in the center of the glass tube. A sharp shadow of the Maltese cross is cast on the screen at the end of the tube. This shows that cathode rays travel in a straight line.

(b) A beam of electrons is accelerated through a potential difference of 500V. The beam enters midway between two similar parallel plates of length 10cm and are 3cm apart. If the potential difference across the plates is 600V, find the velocity of an electron as it leaves the region between the plates. (08marks)

$eV = \frac{1}{2}mu^2$

$1.6 \times 10^{-19} \times 500 = \frac{1}{2} \times 9.11 \times 10^{-31} \times u^2$

$u = 1.33 \times 10^7 ms^{-1}$

Horizontal component s constant = $u_x = 1.33 \times 10^7 ms^{-1}$

Vertically, F = eE =ma, but $E = \frac{V}{d}$

$$a = \frac{eV}{md} = \frac{1.6 \ x \ 10^{-19} \ x \ 600}{9.11 \ x \ 10^{-31} x \ 3 \ x \ 10^{-2}} = 3.5 \times 10^{15} ms^{-2}$$

$v_y = u_y + at$ where $t = \frac{L}{u_x}$

$$v_y = 3.5 \ x \ 10^{15} \ x \ \frac{0.1}{1.33 \ x \ 10^{7}} = 2.6 \times 10^{7} ms^{-1}$$

$$v = \sqrt{v_y^2 \ x \ u_x^2} = \sqrt{(2.6 \ x \ 10^7)^2 + (1.33 \ x \ 10^7)^2}$$

$= 2.92 \times 10^{7} ms^{-1}$

Direction

$$\tan\theta = \frac{v_y}{v_x} = \frac{2.6 \ x \ 10^7}{1.33 \ x \ 10^7} = 1.7$$

$\theta = 86.6^0$ to the horizontal

(c) State the laws of photoelectric emission (04marks)

- The time lag between irradiation of the metal surface and emission of the electrons by the metal surface is negligible.
- For a given metal, surface there is a minimum value of frequency of radiation called threshold frequency (f_0) below which no photo electrons are emitted from the metal however intense the incident radiation may be.
- The number of photoelectrons emitted from the surface per second is directly proportional to the intensity of incident radiation for a particular incident frequency
- The K.E of the photoelectrons emitted is independent of the intensity of the incident radiation but depends only on its frequency

(d) Explain how line emission spectra are produced. (03marks)

When a gas is heated to high temperature, atoms are excited and electrons jump to high energy levels. When the electrons fall back to the lower energy levels, they emit radiations of definite wavelength.

Alternatively

When energetic electrons penetrate the atoms, electrons from innermost energy levels are displaced to high energy levels. When the electrons fall back to lower energy levels, they emit radiations of definite wavelength of frequency

22. (a) (i) what is meant by terms: radioactive decay, half-life and decay constant? (03marks)
Radioactive decay is the spontaneous disintegration of unstable radioactive nuclei into stable nuclei with emission of radiations.
Half-life is the time taken for half the number of nuclei present to disintegrate.
Decay constant is the fraction of number of nuclei disintegration per second.

(ii) Show that the half-life, $t_{\frac{1}{2}}$ of a radioactive isotope is given by $t_{1/2} = \frac{0.693}{\lambda}$ where λ is the decay constant

(Assume the decay law $N = N_0e^{-\lambda t}$)

At $t = t_{½}$, $N = \frac{N_0}{2}$

=> $\frac{N_0}{2} = N_0e^{-\lambda t_{\frac{1}{2}}}$

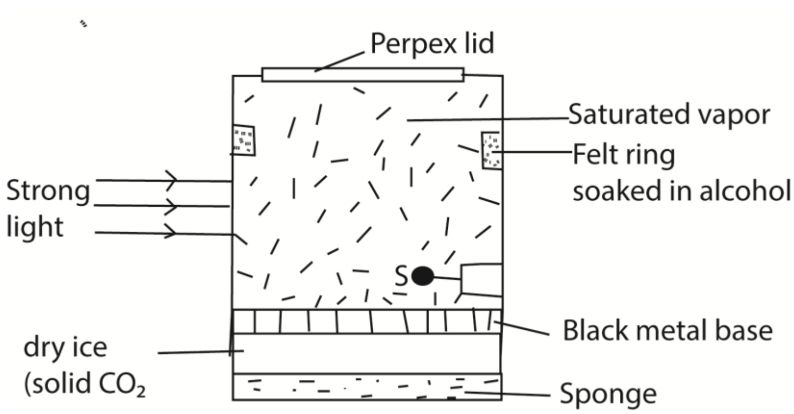
$\frac{1}{2} = e^{-\lambda t_{\frac{1}{2}}}$

$In2 = \lambda t_{\frac{1}{2}}$

$t_{½} = \frac{In2}{\lambda} = \frac{0.683}{\lambda}$

(b) With the aid of a labelled diagram, describe the structure and action of a cloud chamber (05marks)

The diffusion cloud chamber

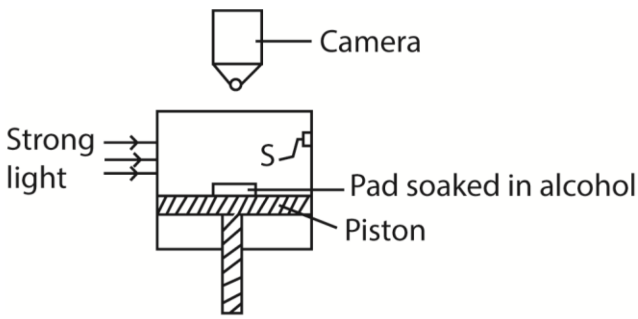


- The base of the chamber is maintained at low temperature, about -80^{0}c by the solid carbon dioxide while the top of the chamber is at room temperature, and so there is a temperature gradient between the top and the bottom of the chamber.
- The air at the top of the chamber is saturated with alcohol vapor from the felt ring. This vapor continuously diffuse downwards into the cooler regions so that the air at the chamber is super saturated with alcohol vapor.
- Radiations from the radioactive source S cause the ionization of the vapor.
- The ionizations from the radioactive source S cause condensation of the vapor on the ions formed, hence the path of the ionizing radiations are traced by series of small droplets of condensation.
- The thickness and length of the path indicate the extent to which ionization has taken place.

- Alpha particles produce short, thick, continuous straight tracks
- Beta particles which are less massive produce longer, thin but straggly paths owing to collisions with gas molecules
- Gamma radiations are uncharged and for ionization to take place, it must collide with an atom and eject an electron which then ionizes the vapor.

Alternatively

The Wilson cloud chamber



Mode of action

When the piston is quickly moved, the air in the chamber is saturated with alcohol vapour undergoes an adiabatic expansion and it cools.

The dust particles are carried away leaving behind air which is dust free. This is the subjected to controlled expansion making it super saturated.

It is then simultaneously subjected to ionizing radiation from a source, S. the vapour condenses on the ions formed to form water droplets around the ions

These are then illuminated and photographed by the camera.

The nature of the path formed reveals the type of ionizing agent.

(c) A radioactive isotope ${}^{99}_{43}X$ decays by emission of a gamma ray. The half-life of the isotope is 360minutes. What is the activity of 1mg of the isotope? (06marks)

$$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$$

99g of X contain 6.02 x 10^{23} atoms

1mg of X contains $\frac{1 x 10^{-3}}{99}$ $x\ 6.02\ x\ 10^{23}$ = 6.08 x 10^{18} atoms

Activity = λN = $\frac{0.693}{360\ x\ 60}$ $x\ 6.08\ x\ 10^{18}$ = 1.95 x $10^{14}$$s^{-1}$

(d) Explain the term avalanche as applied to an ionization chamber. (03marks)

A n avalanche is a large number of moving ionized particle created as a result o secondary ionization due to collision between ions and gaseous atoms when electrons are accelerated by high p.d whereby each ion pair formed cause further ionization of the gas.

23. (a) Define the terms below as applied to a triode

(i) space charge (01mark)

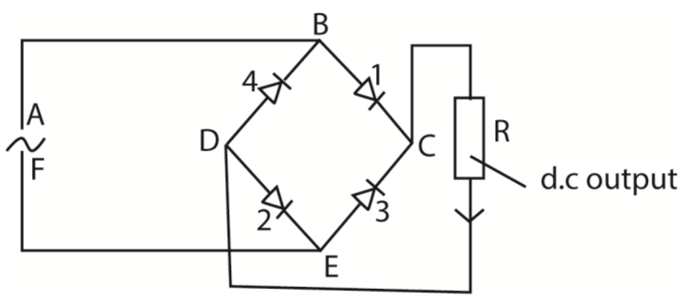
Space charge is the cloud of electrons formed around the cathode when the p.d across the tube is not enough to attract all emitted electrons.

(ii) Amplification factor (01mark)

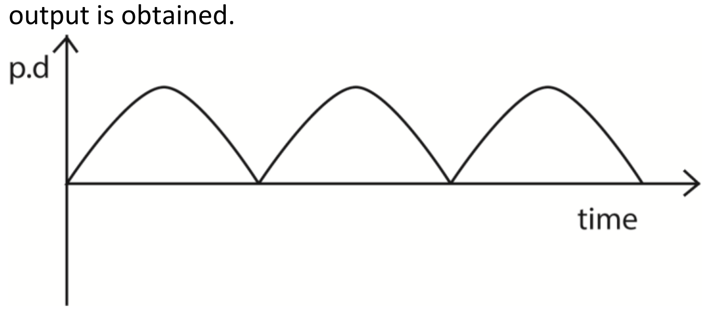
Amplification factor is the ratio of change in anode voltage to change in grid voltage at constant current

(iii) Mutual conductance (01mark)
Mutual conductance is the ratio of change in anode current to change in grid voltage at constant anode voltage

(b) With the aid of a labelled diagram explain full wave rectification. (07marks)



- Four diodes are arranged in a bridge network as shown above.
- If A s positive during the first half cycle, diode 1 and 2 conduct and current takes the path ABCRDEF
- In the next half cycle when F is positive, diode 3 and 4 conduct and current flows through the path FECRDBA
- Once again current flows through R in the same direction during both cycle of input and d.c output is obtained.



(c) Derive an expression for the amplification factor, μ, in terms of anode resistance, R_a and mutual conductance, g_m, for a triode valve. (03marks)

Amplification factor, μ = $\frac{\Delta V_a}{\Delta V_g} x \frac{\Delta I_g}{\Delta I_a}$

$= \frac{\Delta V_a}{\Delta I_a} x \frac{\Delta I_g}{\Delta V_g}$

But $\frac{\Delta V_a}{\Delta I_a} = R_a$ and $\frac{\Delta I_g}{\Delta V_g} = g_m$

$\therefore \mu = R_a \, x \, g_m$

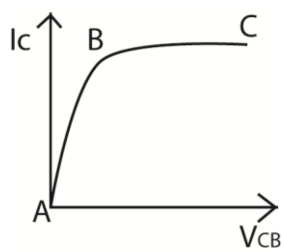
(d) A triode with mutual conductance $3mAV^{-1}$ and anode resistance of 10kΩ is connected to a load resistance of 20kΩ, Calculate the amplitude of output signal, if the input signal is 25mV. (04marks)

$g_m = 3.0 \, x \, 10^{-3} AV^{-1}, R_a = 10 \, x \, 10^3 \Omega, R_L = 20 \, x \, 10^3 \Omega$

Voltage gain = $\frac{\mu R_L}{R_L + R_a} = \frac{R_a \, x \, g_m \, x \, R_L}{R_L + R_a} = \frac{10 \, x \, 10^3 \, x \, 3 \, x \, 10^{-3} \, x \, 20 \, x \, 10^3}{20 \, x \, 10^3 + 10 \, x \, 10^3}$ = 20

Magnitude of output signal = 20 x 25 x 10^{-3} = 0.50V

(e) (i) Sketch the output characteristics of a transistor. (02marks)

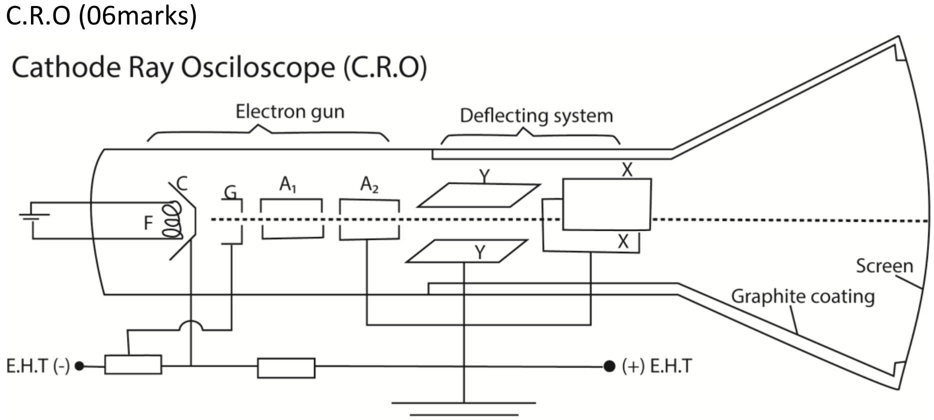


(ii) Identify on the sketch in (e)(i), the region over which the transistor can be used as amplifier. (01).

Linear region BC

24. (a) (i) Describe with the aid of a well labelled diagram, the structure and mode of operation of a C.R.O (06marks)

Cathode Ray Osciloscope (C.R.O)



A- Anodes

G- Grids

B- Cathode

C- Y and X- deflecting system

The cathode ray oscilloscope consists of

(i) Electron gun produces electron by thermionic emission
(ii) Anodes accelerate electrons
(iii) Y and X- plates deflect electrons vertically and horizontally respectively
(iv) The screen is coated with zinc sulphide to glow when hit by electron
(v) Time base is connected to X- plates and provides a saw tooth p.d that sweep the electron spot from left to right of the screen at steady speed

(ii) State the advantages of C.R.O over a moving coil voltmeter. (02marks)

- draws very little current
- measures both alternating and direct voltages
- has no coil to burn out
- gives instantaneous response

(b) In the determination of the electron charge by Millikan's method, a potential difference of 1.5kV is applied between horizontal metal plates, 12mm apart. With the field switched off, a drop of oil of mass 1.0x 10^{-14} kg is observes to fall with constant velocity, 4 x $10^{-4}ms^{-1}$ between two metal plates. When a potential difference of 1.5kV is applied across the plates, the drop rises with constant velocity of 8.0 x $10^{-5}ms^{-1}$.

How many electron charges are there on the drop? (Assume air resistance is proportional to the velocity of the drop and neglect air buoyancy.

mg = kv_1

k = $\frac{9.81\ x\ 10^{-14}}{4\ x\ 10^{-4}}$

EQ-mf= kv_2 But E = $\frac{V}{d} = \frac{1.5\ x\ 10^{3}}{12\ x\ 10^{-3}}$

=> $\frac{1.5\ x\ 10^{3}}{12\ x\ 10^{-3}}Q - 9.81\ x\ 10^{-14} = \frac{9.81\ x\ 10^{-14}}{4\ x\ 10^{-4}}\ x\ 8.0\ x\ 10^{-5}$

Q = 9.4176 x 10^{-19}C

But Q =ne

n = $\frac{9.4176\ x\ 10^{-19}}{1.6\ x\ 10^{-19}} = 6$

(c) Explain why

(i) the apparatus in Millikan's experiment is surrounded with a constant temperature enclosure, (03marks)

- to keep the density oil and air constant
- to eliminate conventional currents

(ii) low vapor-pressure oil is used. (02marks)

- to maintain the size of the drop by minimizing evaporation

(d) In Millikan's experiment, the radius, r, of the drop is calculated from

$$r = \sqrt{\frac{9\eta v}{2\rho g}}$$

where η is the viscosity of air and ρ is the density of oil.

Identify the symbol v and describe briefly how it is measured. (02mark)

v = terminal velocity; it is measure by measuring the time t taken by the drop to fall through a known distance S. then $v = \frac{S}{t}$.

25. (a) (i) Explain how X-rays are produced in an X-ray tube (04 marks)
  - The cathode is heated and electrons emitted by thermionic emission.
  - The electrons are accelerated by tube voltage towards the metal target.
  - When the high energy electrons strike the metal target X-rays are produced with liberation of heat

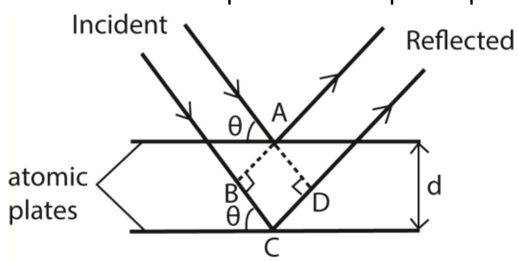
(ii) Explain the emission of X-ray characteristic spectra. (03 marks)

When an energetic electron strikes the metal target, it dislodges electrons from the innermost shell of the atom of the metal target. This creates vacancies in the inner shell making the atom unstable.

When electrons fall back to occupy the vacant orbits left, X-rays are produced of definite frequency characteristic of the atoms of target metal.

(iii) Derive the Bragg X-ray diffraction equation (04marks)

- A parallel beam of monochromatic X-rays incident on a crystal is reflected from successive atomic planes and super-imposed, forming an interference pattern.



- For constructive interference to occur, the path difference is equal to the whole number of wavelength

  Thus BC + CD = nλ

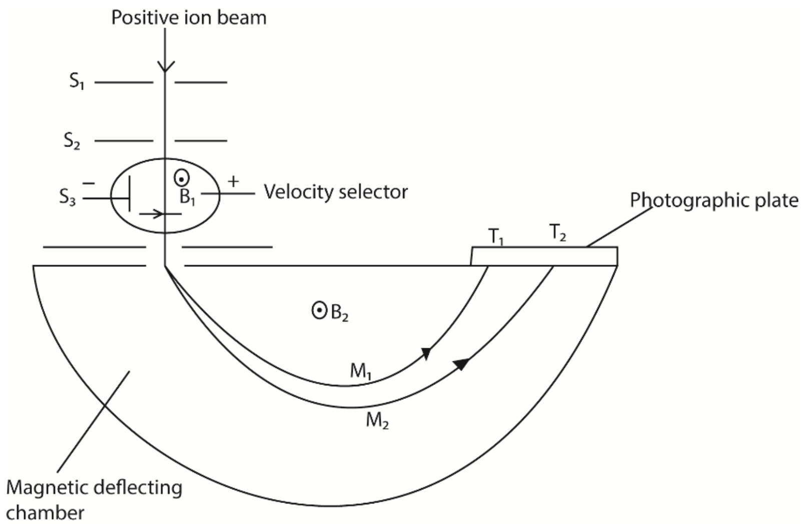
  ⇨ dsinθ + dsinθ = nλ

  or 2dsinθ = nλ where n = 1, 2, 3, 4 …

(iv) Under what conditions does X-ray diffraction occurs? (02marks)

- Wavelength of X-ray must be of the same order as the interplanar spacing.
- Parallel beam of X-ray must be incident on the planes

(b) With the aid of a labelled diagram, describe how a Bainbridge mass spectrometer is used to measure specific charge. (07marks)



T_1 and T_2 are tracers on photographic plate, S_1, S_2 and S_3 are slits

Mode of Action

- Positive ions are produced in a discharge tube and admitted as a beam through slits S_1 and S_2.
- The beam then passes between insulated plates P, Q, connected to a battery, which create an electric field of intensity E.
- A uniform magnetic field B_1, perpendicular to E is applied over the region of the plates and all ions, charge e with the same velocity, v given by B_1ev =Ee will then pass undeflected through the plates and through a slit S_3.
- The selected ions are deflected in a circular path of radius r by a uniform perpendicular magnetic field B_2 and an image is produced on a photographic plate as shown.
  In this case
  $$\frac{mv^2}{r} = B_2ev$$
  $$\therefore \frac{m}{e} = \frac{rB_2}{v}$$

  But for the ions selected v = $\frac{E}{B_1}$ from above

  Specific charge, $\frac{e}{m} = \frac{E}{rB_2B_1}$

26. (a) What is meant by unified atomic mass unit? (01mark)
    Unified atomic unit is one twelfth the mass of one atom of carbon-12

(b) (i) Distinguish between nuclear fusion and nuclear fission (02marks)

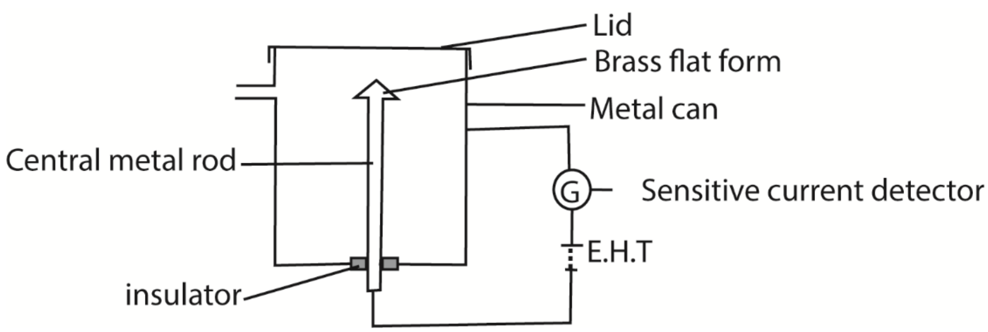
Nuclear fusion is the process where two light nuclei combine to form a heavier nuclei accompanied by release of energy

Nuclear fission is a process where a heavy nucleus splits into two lighter nuclei accompanied by release of energy.

(ii) State the conditions necessary for each of the nuclear reaction in (b) (i) to occur. (02marks)

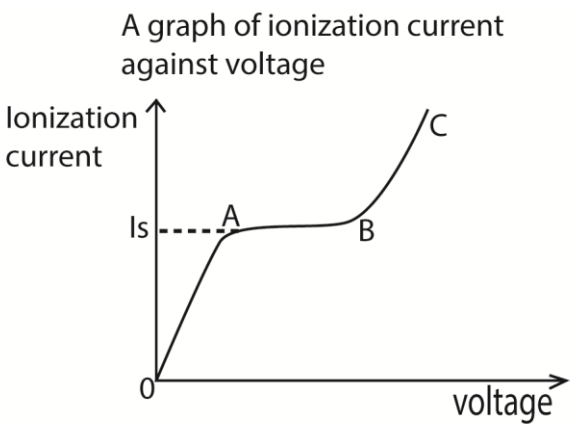
- Fusion requires very high temperature
- Fission requires energetic bombarding particles or heavy unstable nuclei.

(c) (i) With the aid of a labelled diagram, describe the operation of an ionization chamber. (06marks)



- A radiation source on the brass flat form causes ionization of air in the chamber producing electrons and positive ions.
- The electrons move to the metal can and positive ions drift to the central metal rod.
- Movement of the ions to the electrodes causes discharge and current pulse flows in external circuit.
- The current sensitive detector detects current.
- The magnitude of current detected shows the extent to which ionization takes place.

(ii) Sketch the curve of ionization current against applied p.d and explain its main features. (04marks)



Region OA:

Current detected increases gradually but p.d is not large enough to prevent recombination of the ions.

Region AB. (saturation region)

Current is almost constant, all ions reach the electrode before recombination but there is no secondary ionization.

Region BC (gas amplification)

Current increases rapidly for small increase (change) in p.d. because secondary ionization takes place due to primary ions being produced. This implies many ion pairs, thus a larger current detected.

(d) A typical nuclear reaction is given by:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{95}_{42}Mo + ^{139}_{57}La + 2^{1}_{0}n + 7^{0}_{-1}e$$

Calculate the total energy released by 1g of uranium. (05marks)

Mass of $^{1}_{0}n = 1.009\mu$

$^{0}_{-1}e = 0.00055\mu$

$^{95}_{42}Mo = 94.906\mu$

$^{139}_{57}La = 138.906\mu$

$^{235}_{92}U = 235.044\mu$

$1\mu = 1.66 \, x \, 10^{-27} kg$

Solution

Total mass on the left hand side= 235.044 +1.009 = 236.053U

Total mass on the right hand side = (94.906 +138.906 +2 x 1.009 + 0.00055)U=235.83385U

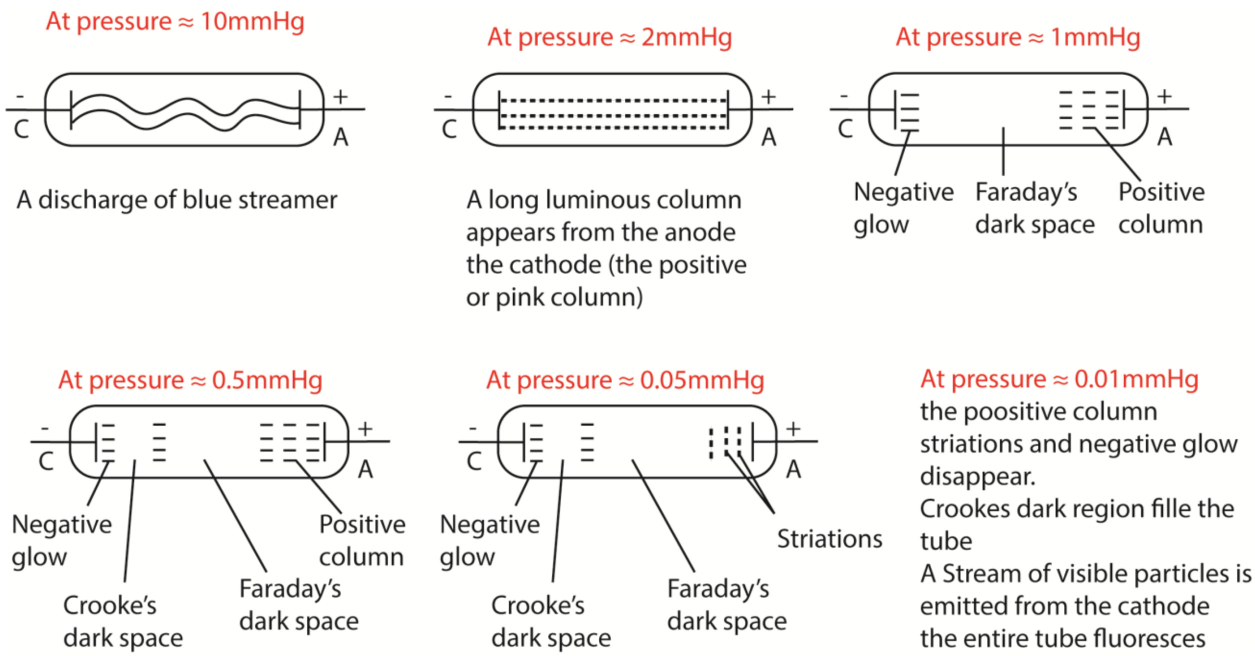
Mass defect = 236.053 – 235.83385 = 0.21915U

Energy released = mc^2 = 0.21915 x 1.66 x 20^{-27} x $(3 \times 10^8)^2$ = 3.274 x 10^{-11}J

Number of atoms in 1g of uranium = $\frac{1}{235} \, x \, 6.02 \, x \, 10^{23}$

Total energy released = $\frac{1}{235} \, x \, 6.02 \, x \, 10^{23} x \, 3.274 \, x \, 10^{-11} = 8.387 \, x \, 10^{10} J$

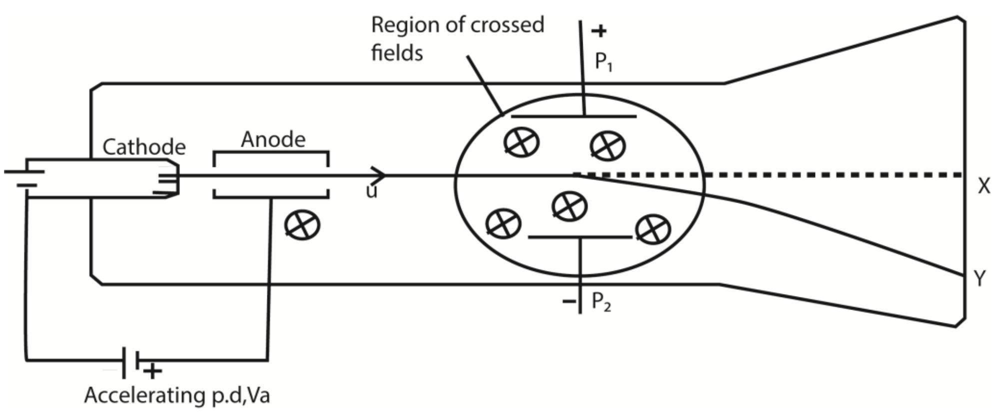
27. (a) (i) With the aid of a labelled diagram, describe what is observed when a high tension voltage is applied across a gas tube in which pressure is gradually reduced to vary low value. (05marks)



(ii) Give two applications of discharge tubes. (01mark)

- Making mercury lamps, sodium lamps
- Neon signs
- Florescent tubes

(b) Describe Thomson's experiment to determine the specific charge of an electron. (06marks)



- The electrons are produced thermionically by a hot filament cathode and are accelerated towards a cylindrical anode and pass through it.
- The small hole on the anode confines the electrons to a narrow beam.

- When both the electric field and the magnetic field are off, the electrons reach the screen at X and cause fluorescence.
- If the velocity of the electrons on emerging from the anode is u then

  eVa = $\frac{1}{2}mu^2$

  ⇨ $\frac{e}{m} = \frac{u^2}{2Va}$ ………………………………………. (i)

  Where Va is the accelerating voltage between the cathode and anode.
- The magnetic field is switched on and the beam is deflected to position Y.
- In order to bring the beam back to the original position X, the electric field is switched on and adjusted until the beam is at X again.
- This implies that The magnetic force = the electric force

  Beu = eE

  ∴u = $\frac{E}{B}$ ……………………………..(ii)

  Substituting eqn. (ii) in (i)

  $\frac{e}{m} = \frac{E^2}{2B^2Va}$ but E = $\frac{V}{d}$

  ∴ $\frac{e}{m} = \frac{V^2}{2B^2d^2Va}$ where, V is the p.d between the plates at separation of d apart

(c) In a Millikan's experiment, a charged oil drop of radius 9.2 x 10^{-7}m and density 800kgm^{-3} is held stationary in an electric field of intensity 4.0 x 10^4Vm^{-1}.

[Density of air = 1.29kgm^{-3}, coefficient of viscosity of air = 1.8 x 10^{-5}Nsm^{-1}]

(i) How many electron charges are on the drop? (04marks)

mg = U + Eq

$\frac{4}{3}\pi r^3\rho g = \frac{4}{3}\pi r^3\sigma g$ + Eq

q = $\frac{\frac{4}{3}\pi r^3(\rho - \sigma)g}{E} = \frac{\frac{4}{3}\pi\ x\ (9.2\ x\ 10^{-7})^3(800-1.29) x\ 9.81}{4\ x\ 10^4} = 6.39\ x\ 10^{-19}$

n = $\frac{q}{e} = \frac{6.39\ x\ 10^{-19}}{1.6\ x\ 10^{-19}}$ =4

(ii) Find the electric field intensity that can be applied vertically to move the drop with velocity 0.005ms^{-1} upwards.

Mg + Fv = U + Eq

E = $\frac{mg-U+Fv}{q}$ = $\frac{\frac{4}{3}\pi r^3(\rho - \sigma)g+Fv}{q}$ = $\frac{\frac{4}{3}\pi r^3(\rho - \sigma)g+6\pi\eta r v_0}{q}$

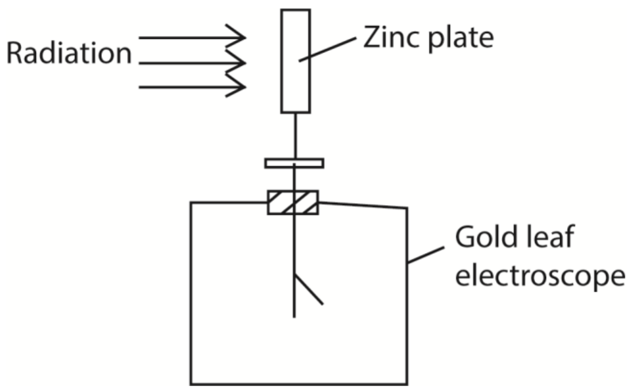
= $\frac{\frac{4}{3}\pi\ x\ (9.2\ x\ 10^{-7})^3(800-1.29) x\ 9.81\ x\ 6\pi\ x\ 1.8\ x\ \ 10^{-5}\ x\ 9.2\ x\ \ 10^{-7}\ x\ 0.005}{1.6\ x\ 10^{-19}}$

= 2.48 x 106Vm^{-1}

28. (a) Explain what is meant by photoelectric effect. (02marks)

Emission of electrons from clean metal surface struck by electromagnetic radiations of high energy.

(b)



Ultraviolet and infrared radiations are directed in turns on to a zinc plate which is attached to a gold leaf electroscope as shown in the figure above

Explain that happens when

(i) Ultraviolet radiation falls on the zinc plate (02marks)
Electrons will be emitted and a net positive charge will be left on the zinc plate. Both the plate and the leaf acquire a positive charge and the leaf diverge.

(ii) Infrared falls on the zinc plate. (01mark)
Infrared has low frequency, therefore no electrons will be emitted from the zinc plate and the leaf will not diverge.

(iii) The intensity of each radiation is increased. (02marks)
In case of ultraviolet, more electrons will be emitted per second and the leaf diverges rapidly
In case of infrared, the leaf does not diverge because the frequency is low

(c) An X-ray of wavelength 10^{-10}m is required for the study of its diffraction in a crystal. Find the least accelerating voltage to be applied on an X-ray tube in order to produce these X-rays. (04marks)

E = $h\frac{c}{\lambda} = 6.6 x 10^{-34} x \frac{3 x 10^8}{10^{-10}}$ = 1.98×10^{-15}J

Energy of electron = eV = 1.98×10^{-15}J

$$V = \frac{1.98 x 10^{-15}}{1.6 x 10^{-19}} = 1.24 \times 10^4 V$$

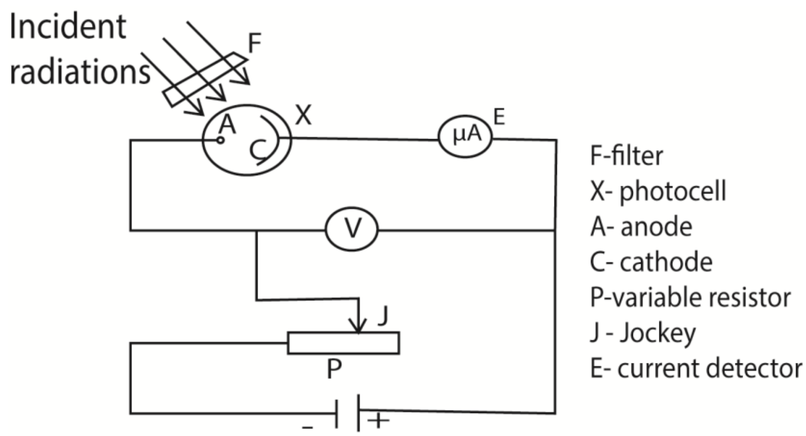
(d) Sodium has a work function of 2.0eV and is illuminated by radiation of wavelength 150nm. Calculate the maximum speed of the emitted electrons. (04marks)

K.E = $h\frac{c}{\lambda e} - w_0$

$$\frac{1}{2} x\, 9.11\, x\, 10^{-31} v^2 = \left(\frac{6.6\, x\, 10^{-34}}{1.6\, x\, 10^{-19}}\, x\, \frac{3\, x\, 10^{8}}{150\, x\, 10^{-9}} - 2.0\right) x 1.6\, x\, 10^{-19}$$

$v = 1.48 \times 10^6 ms^{-1}$

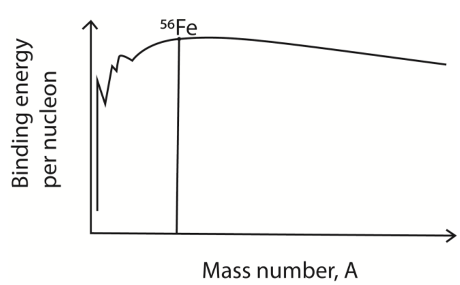
(e) With the aid of a well labelled diagram, describe how stopping potential of a metal can be measured. (05marks)



- An evacuated electric cell X that has inside it a photo-emissive metal cathode, C of large surface area and an anode A for collecting the electron produced
- A is made negative in potential relative to C.
- The photoelectrons emitted from C when illuminated with a suitable beam experience a retarding potential.
- The p.d V is increased negatively until the current become zero and the stopping potential Vs is noted from the voltmeter.

29. (a) (i) What is meant by mass defect? (01marks)
Mass defect is the is the difference in sum of mass of the components of the nucleus and the mass of the nucleus

(ii) Sketch a graph showing how binding energy per nucleon varies with mass number and explain its features. (03marks)



Binding energy increases rapidly from mass number=1 to a peak of mass number, A = 56 and then decreases gradually.

(iii) Find the binding energy per nucleon of ${}^{56}_{26}Fe$ given that

Mass of 1 proton = 1.007825u

Mass of 1neutron = 1.008665u

[1u = 931MeV) (03marks)

Solution

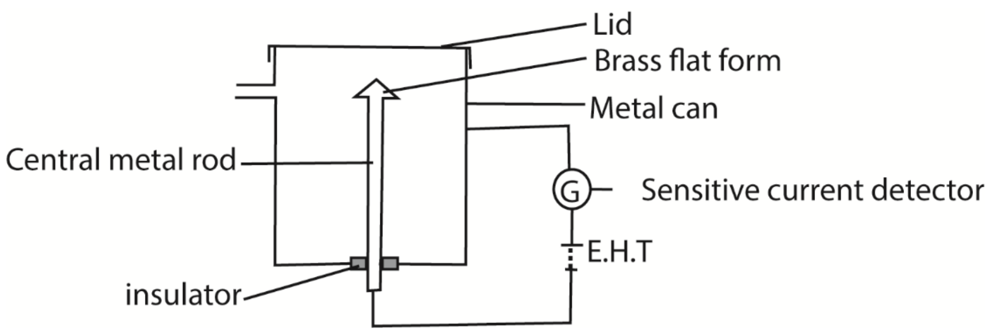
Binding energy = (26 x 1.007825 + 30 x 1.008665 - m_f)U

where mf is the mass of the nucleus of Fe-56

Binding energy = (56.4634- m_f) x 931eV

Binding energy per nucleon = $\frac{(56.4634 - m_f)\ x\ 931}{56}$eV

(b) With the aid of a diagram, explain how an ionization chamber works (06marks)



- A radiation source on the brass flat form causes ionization of air in the chamber producing electrons and positive ions.
- The electrons move to the metal can and positive ions drift to the central metal rod.
- Movement of the ions to the electrodes causes discharge and current pulse flows in external circuit.
- The current sensitive detector detects current.
- The magnitude of current detected shows the extent to which ionization takes place.

(c) (i) Show that an alpha particle collides head on with an atom of atomic number, Z, the closest distance of approach to the nucleus X_0 is given by

$$X_0 = \frac{ze^2}{\pi\varepsilon_0 mv^2}$$

Where

e is electronic charge

ε_0 is permittivity of fee space

m is mass of alpha particle

v is initial speed of alpha particle (04marks)

charge on ${}^{4}_{2}He$ = 2e

charge on atomic nucleus = Ze

kinetic energy of ${}^{4}_{2}He = \frac{1}{2}mv^2\ where\ v$= speed of collision

Electrostatic potential energy = $\frac{1}{4\pi\varepsilon_0}\ x\ \frac{(Ze)(2e)}{X_0}$

At closest distance x0 of approach;

Kinetic energy = electrostatic potential energy

$$\frac{1}{2}mv^2 = \frac{2Ze^2}{4\pi\varepsilon_0 x_0}$$

$$x_0 = \frac{Ze^2}{\pi\varepsilon_0 v^2}$$

(ii) In a head on collision between an alpha particle and a gold nucleus, the minimum distance of approach is 5 x 10^{-14}m. Calculate the energy of alpha particle (in MeV)

[atomic number of gold= 79]

Kinetic energy = $\frac{1}{2}mv^2 = \frac{2Ze^2}{4\pi\varepsilon_0 x_0} = \frac{9\ x\ 10^9\ x\ 2\ x\ 79\ x\ (1.6\ x\ 10^{-19})^2}{5\ x\ 10^{-15}}$ = 7.28 x 10^{-13}J =4.55MeV

30. (a) State four differences between cathode rays and positive rays (02marks)

Cathode ray	Positive ray
Negatively charged	Positively charged
Produce X-rays on striking matter	Do not produce x-ray on striking matter
Deflected towards anode and north pole of the magnet	Deflected towards cathode and south pole of the magnet

(b) An electron having energy of 4.5 x 10^2eV moves at right angles to a uniform magnetic field of flux density 1.5 x 10^{-3}T. Find the

(i) radius of the path followed by the electron. (04marks)

$$\frac{1}{2}m_e v^2 = eV$$

$$u = \sqrt{\frac{2eV}{m_e}}$$

$Beu = \frac{m_e u^2}{r}$ => r = $\frac{m_e u}{eB}$

$r = \frac{1}{B}\sqrt{\frac{2m_e V}{e}}$ but $\frac{e}{m_e} = 1.8\ x\ 10^{11}$

$\therefore r = \frac{1}{1.5\ x\ 10^{-3}}\sqrt{\frac{2\ x\ 450}{1.8\ x\ 10^{11}}}$ = 4.71 x 10^{-2}m

(ii) period of the motion. (03marks)

T = $\frac{2\pi r}{u} = 2\pi r\sqrt{\frac{m_e}{2eV}}$ = 2π x 4.71 x 10-2 $\sqrt{\frac{1}{2}\ x\ \frac{1}{1.8\ x\ 10^{11}}\ x\ \frac{1}{450}}$ = 2.32 x 10^{-8}s

(c) (i) Define the term Avogadro constant and Faraday constant (02marks)

Avogadro constant is the number of atoms or molecules in one mole of a substance.

Faraday's constant is the quantity of charge required to deposit one mole of a monovalent element.

(ii) Use the Avogadro constant and Faraday constants to calculate the charge on anion of monatomic element. (03marks)

Charge = $\frac{F}{N_A} = \frac{96500}{6.02\ x\ 10^{23}}$ = 1.6 x 10^{-19}C

(d) Explain the meaning of the following terms as applied to a Geiger-Muller tube.

(i) threshold potential difference (02marks)

Threshold p.d is the minimum p.d below which no pulse can be detected. This is because there is no sufficient gas amplification.

(ii) Dead time (02marks)

Dead time is the time ions take to travel towards the cathode before the electric field at the cathode returns to level large enough for an avalanche to start. Ionizing particles arriving within this time will not be detected.

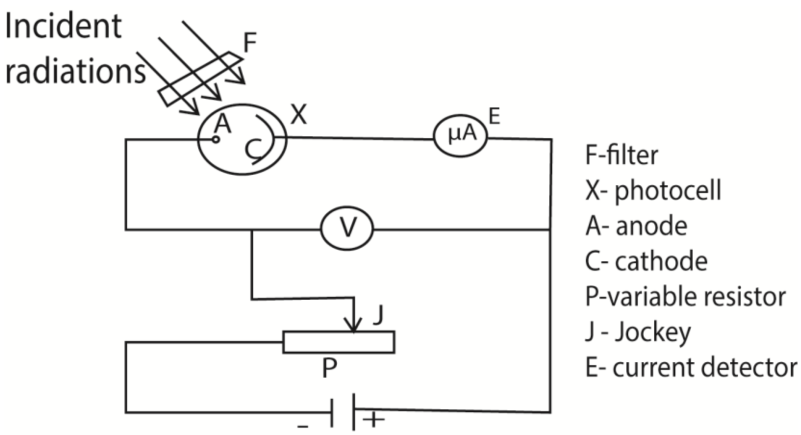
(iii) A quenching agent (02marks)

A quenching agent is a gas or vapour inside a Geiger-Muller tube to ensure that only one pulse is produced by each ionizing particle that enter the tube. It slows down the positive ions and prevent further ionization.

31. (a) State the laws of photoelectric effect (04marks)

- The time lag between irradiation of the metal surface and emission of the electrons by the metal surface is negligible.
- For a given metal, surface there is a minimum value of frequency of radiation called threshold frequency (f_0) below which no photo electrons are emitted from the metal however intense the incident radiation may be.
- The number of photoelectrons emitted from the surface per second is directly proportional to the intensity of incident radiation for a particular incident frequency
- The K.E of the photoelectrons emitted is independent of the intensity of the incident radiation but depends only on its frequency

(b) Describe an experiment to determine the stopping potential of a metal surface. (05 marks)



- An evacuated electric cell X that has inside it a photo-emissive metal cathode, C of large surface area and an anode A for collecting the electron produced
- A is made negative in potential relative to C.
- The photoelectrons emitted from C when illuminated with a suitable beam experience a retarding potential.
- The p.d V is increased negatively until the current become zero and the stopping potential Vs is noted from the voltmeter.

(c) A 100mW beam of light of wavelength 4.0×10^{-7}m falls on caesium surface of a photocell.

(i) How many photons strike the caesium surface per second? (03marks)

$$P = \frac{nhc}{\lambda} \Rightarrow n = \frac{P\lambda}{hc} = \frac{100 \ x\ 10^{-3}\ x\ 4.0\ x\ 10^{-7}}{6.6\ x\ 10^{-34}\ x\ 3.0\ x\ 10^{8}} = 2.02 \times 10^{17}$$

(ii) If 65% of the photons emit photoelectrons, find the resulting photocurrent. (03marks)

$$65\% \text{ of } n = \frac{65}{100}\ x\ 2.02\ x\ 10^{17}$$

$$I = ne = \frac{65}{100}\ x\ 2.02\ x\ 10^{17} x\ 1.6\ x\ 10^{-19} = 2.1 \times 10^{-2}\text{A}$$

(iii) Calculate the kinetic energy of each photon if the work function of caesium is 2.20eV. (03marks)

$$hf = w_o + \frac{1}{2}mv^2$$

$$K.E = \frac{6.6\ x\ 10^{-34}\ x\ 3.0\ x\ 10^{8}}{4\ x\ 10^{-7}} - 2.2\ x\ 1.6\ x\ 10^{-19} = 1.43 \times 10^{-19}\text{J}$$

(d) Distinguish between continuous and line spectra in an X-ray tube. (02marks)

Continuous spectrum is produced by multiple collision of electrons with target atoms.

Line spectrum is a result of electron transition from higher to lower energy levels.

32. (a) (i) Explain the observation made in the Rutherford α-particle scattering experiment. (06marks)

- Most alpha particle passed through metal foil undeflected. This is because most space in an atom is empty.
- A few alpha particles are deflected through small angles less than 900. This is because the positive alpha particle are repelled by the positive nucleus of the gold atom.
- Very few particles are scattered through large angle greater than 900. This is because the chances of head-on collision are very minimal. This implies the nucleus occupies a small portion of the available space.

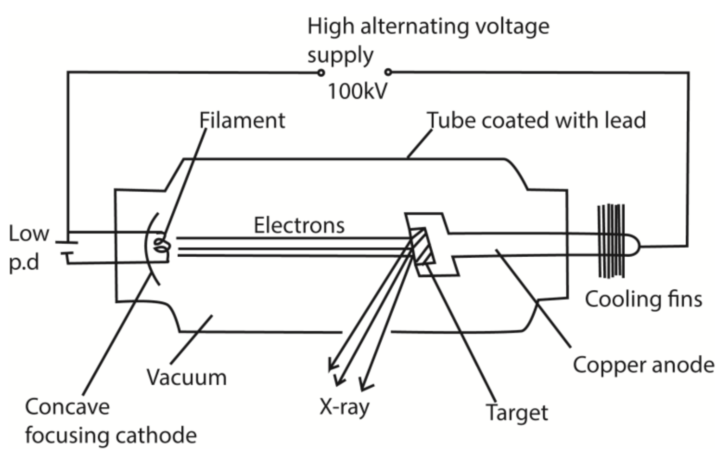
(ii) Why is a vacuum necessary in this experiment? (01mark)

- To enable the alpha particle to reach the detector.

(b) Distinguish between excitation and ionization energies of an atom. (02marks)

- **Excitation energy** is the energy required to remove an electron from an atom in its ground state to a higher energy level.
- **Ionization energy** is the energy required to remove an electron from an atom in its ground state that is completely lost

(c) Draw a labelled diagram showing the main components of an X-ray tube (03marks)



(d) An X-ray tube is operated at 50kV and 20mA. If 1% of the total energy supplied is emitted as X-radiation, calculate the

(i) maximum frequency of emitted radiation (03marks)

$eV = hf_{max}$

$1.6 \times 10^{-19} \times 50 \times 10^{3} = 6.6 \times 10^{-34} \times f_{max}$

$f_{max} = 1.21 \times 10^{19}$Hz

(ii) rate at which heat must be removed from the target in order to keep it at a steady temperature. (03marks)

Power supplied = IV = $20 \times 10^{-3} \times 50 \times 10^{3} = 1000$W

Power converted to heat and removed = $\frac{99}{100}\ x\ 1000 = 990W$

(e) A beam of X-ray of wavelength 0.2nm is incident on a crystal at glancing angle 30^0. If the interplanar separation is 0.20nm, find the order of diffraction. (02marks)

2dsinθ = nλ

2 x 2 x 10^{-10}sin30 = n x 10^{-10}

n = 1

33. (a) What is meant by a line spectrum? (02marks)
Line spectrum are discontinuous lines produced by electronic transitions within the atom as the electrons fall back to lower energy levels.

(b) Explain how line spectrum accounts for existence of discrete energy levels in an atom. (04marks)

Atoms of a particular element emit radiation with definite frequencies or wavelengths. When an atom is in excited state, an electron may fall into a vacant position in lower energy level. This is accompanied by emission of electromagnetic radiation with the characteristic E= hf;

Where E is the difference in the energy of involved energy level and h is Plank's constant. Since the frequencies are definite for a particular element, it implies that the energy levels are discrete.

(c) The energy levels in mercury atom are -10.4eV, -5.5eV, -3.7eV and -1.6eV.

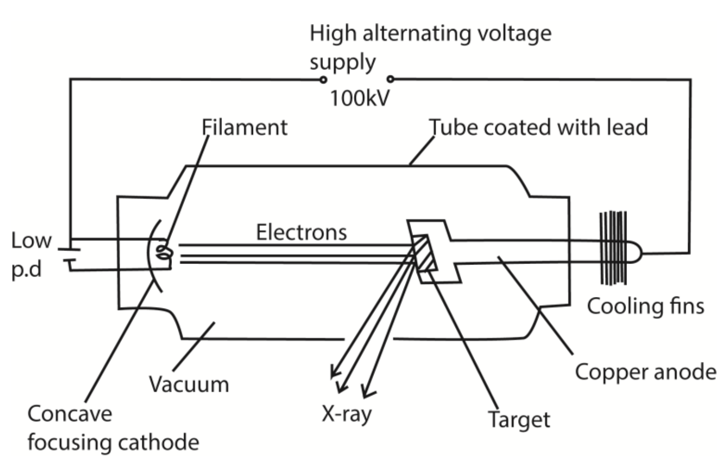
(i) Find the ionization energy of mercury in joules (02marks)

10.4 x 1.6 x 10^{-19} = 1.664 x 10^{-18}J

(ii) What is likely to happen if mercury atom in unexcited state is bombarded with an electron of energy 4.0eV, 6.7eV or 11.0eV? (03marks)

- With 4.0eVand 11.0eV no observable change
- With 6.7eV electron transits from -3.7eV to -10.4eV energy level.

(d) Describe with the aid of a diagram, the action of an X-ray tube. (05marks)



Mode of operation

- The filament is heated by a low voltage supply and the electrons are emitted by thermionic emission.
- The concave focusing cathode focuses the electrons from the filament onto the target.
- These electrons are accelerated towards the anode by the high voltage between the filament and the Anode.
- When the electrons (cathode rays) strike the metal target, about only 1% their kinetic energy is converted to X-rays and the 99% of their kinetic energy is converted to heat, which is conducted away by the cooling fins.

(e) An X-ray tube is operated at 20kVwith electron current 16mA in the tube. Estimate the:

(i) the number of electrons hitting the target per second. (02marks)

n = $\frac{I}{e} = \frac{16 \, x \, 10^{-3}}{1.6 \, x \, 10^{-19}}$ = 1.0 x10^{17} electrons per second

(ii) rate of production of heat, assuming 99.5% of the kinetic energy of electron is converted to heat. (e = 1.6 x 10^{-19}C)

For single electron, energy = eV

Energy per second = 1.0 x 10^{17}eV

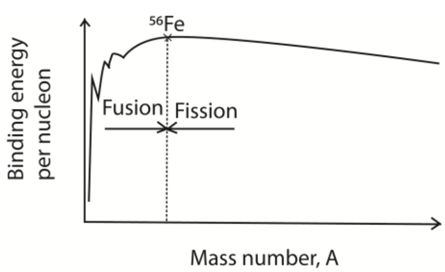
= 1.0 x10^{17} x 1.6 x 10^{-19} x 20 x 10^{3} = 320W

The rate of heat production = $\frac{99.5}{100} \, x \, 320 = 318.4W$

34. (a) (i) Define the term binding energy (01marks)

Binding energy of the nucleus is the energy required to split the nucleus into its constituent nucleons.

(ii) Sketch a graph showing the variation of binding energy per nucleon with mass number (02marks)



(ii) Use the sketch in (d)(i) to explain how energy is released in each of the process of fusion and fission. (03marks)

- Two Small nuclei with atomic mass less than 56 each fuse to give a heavier nuclei with smaller mass by higher binding energy to increase stability of nucleon

- A nucleus with atomic mass higher than 56 split to form lighter nuclei of higher binding energy per nuclei.

(b) Explain why a high temperature is required during fusion of nuclides. (01mark)

High temperature provides enough kinetic energy to fusing particles to overcome electrostatic repulsive forces

(c) The isotope ${}^{238}_{92}U$ emits an alpha particle and forms an isotope of thorium (Th), while the isotope ${}^{235}_{92}U$ when bombarded by a neutron, forms ${}^{144}_{56}Ba$, ${}^{90}_{36}Kr$ and neutrons.

(i) Write the nuclear equation for the reaction of ${}^{238}_{92}U$ and ${}^{235}_{92}U$. (02marks)

$${}^{238}_{90}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}Th + Energy$$

$${}^{235}_{90}U + {}^{1}_{0}n \rightarrow {}^{144}_{56}Ba + {}^{90}_{36}Kr + 2{}^{1}_{0}n + \text{energy}$$

(ii) How does the reaction of ${}^{235}_{92}U$ differ from that of ${}^{238}_{92}U$ (03marks)

Uranium-235	Uranium-238
Non-radioactive	Radioactive since it emits alpha particles
It undergoes chain reaction (since it is initiated by a neutron and neutrons are part of the product.	It does not undergo chain reaction
It is artificial, so it is controllable	It is natural and cannot be controlled.

(d) A steel piston ring contains 15g of radioactive iron, ${}^{54}_{26}Fe$. The activity of ${}^{54}_{26}Fe$ is 3.7 x 10^5 disintegration per second.

After 100 days of continuous use, the crankcase oil was found to have a total activity of 1.23 x 10^3 disintegrations per second. Find the

(i) Half-life of ${}^{54}_{26}Fe$ (05marks)

Activity, A = λN, but $\lambda = \frac{In\,2}{t_{\frac{1}{2}}}$

$$A = \frac{In\,2}{t_{\frac{1}{2}}}N$$

$$t_{\frac{1}{2}} = \frac{N}{A}In2 \text{ .... (i)}$$

54g of Fe has 6.02 x 10^{23} atoms

15g contain $\frac{15}{54}\,x\,6.02\,x\,10^{23}$ = 1.67 x 10^{23} atoms

Thus, N_0 = 1.67 x 10^{23} atoms

$t_{½} = \frac{1.67 \times 10^{23} \times In2}{3.7 \times 10^5}$ = 3.13 x 10^{17}s

(ii) Average mass of iron worn off the ring per day, assuming that all the metal from the ring accumulates in the oil. (03marks)

From A = $\frac{In\ 2}{t_{\frac{1}{2}}} N$

1.23 x 10^{23} = $\frac{In\ 2}{3.13 \times 10^{17}} N$

N = 5.55 x 10^{20}atoms

6.02 x 10^{23} atoms ≡ 54g

5.55 x 10^{20} atoms ≡ $\frac{5.55 \times 10^{20}}{6.02 \times 10^{23}} \times 54$ = 4.9 x 10^{-2}g

Mass worn off in 100days = 4.9 x 10-2g

For 1day, mass worn off = $\frac{4.9 \times 10^{-2}}{100}$ = 4.9 x 10^{-4}g

35. (a) Describe briefly the mechanism of thermionic emission (03marks)

(b)(i) Draw a labelled circuit to show a triode being used as a single gate voltage a single-stage voltage amplifier. (03marks)

(ii) With the aid of an equivalent circuit of the triode as an amplifier, obtain an expression for the voltage gain. (04marks)

(iii) A triode with mutual conductance of 3.0 x $10^{-3}AV^{-1}$ and anode resistance of 1 x 10^4 is used as a single-stage amplifier. If the load resistance is 3 x 10^4Ω. Calculate the voltage gain of amplifier. (05marks)

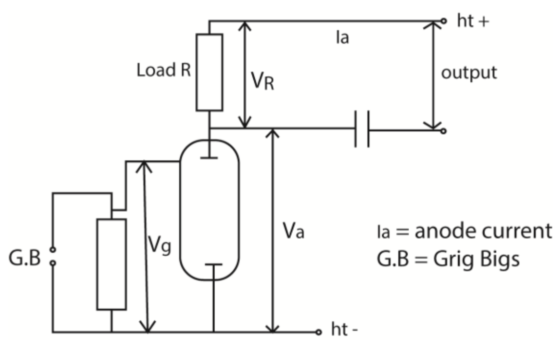
(c) (i) Describe the structure of a junction transistor. (02marks)

(ii) Sketch and describe the collector-current against collector emitter voltage characteristic of a junction transistor.

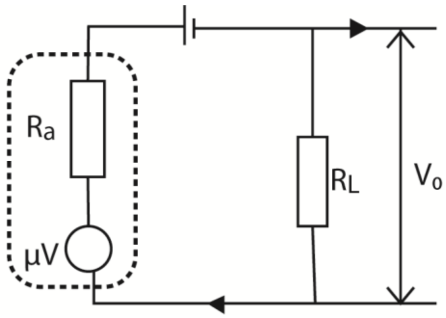
36. (a) Describe briefly the mechanism of thermionic emission (03marks)

High temperature raises the kinetic energy of free electrons in metallic lattice and make electrons to escape from the surface of the metal against the attraction of positive ions

(b) (i) Draw a labelled circuit to show a triode being used as a single-stage voltage amplifier. (03maks)



(ii) With the aid of an equivalent circuit of a triode as an amplifier, obtain an expression for voltage gain (04marks)



If Vi is input voltage, μ amplification factor,

⇨ e.m.f = μV_i

Output voltage = $I_a R_L$

Ia = $\frac{\mu V_i}{R_a + R_L}$

Thus $V_0 = \frac{\mu V_i R_L}{R_a + R_L}$

Voltage gain = $\frac{V_0}{V_i} = \frac{\mu V_i}{R_a + R_L}$

(iii) A triode with mutual conductance of 3.0×10^{-3} AV^{-1} and anode resistance of $1 \times 10^4 \Omega$, is used as a single-stage amplifier. If the load resistance is $3 \times 10^4 \Omega$, calculate the voltage gain of the amplifier. (05marks)

From $\mu = R_a g_m = 3.0 \times 10^{-2} \times 1 \times 10^4 = 30$

From A = $\frac{V_0}{V_i} = \frac{\mu V_i}{R_a + R_L}$

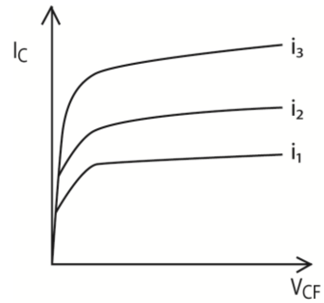
$= \frac{30 \; x \; 3 \; x \; 10^4}{1 \; x \; 10^4 + 3 \; x \; 10^4}$

= 22.5

(c) (i) Describe the structure of a junction transistor. (02marks)

A transistor consist of 3 layers of P- and n- semiconductors called respectively emitter, base and collector. The base is thinner. It can be PnP type or nPn transistor.

(ii) Sketch and describe the collector-current against collector-emitter voltage characteristic of a junction transistor. (03marks)

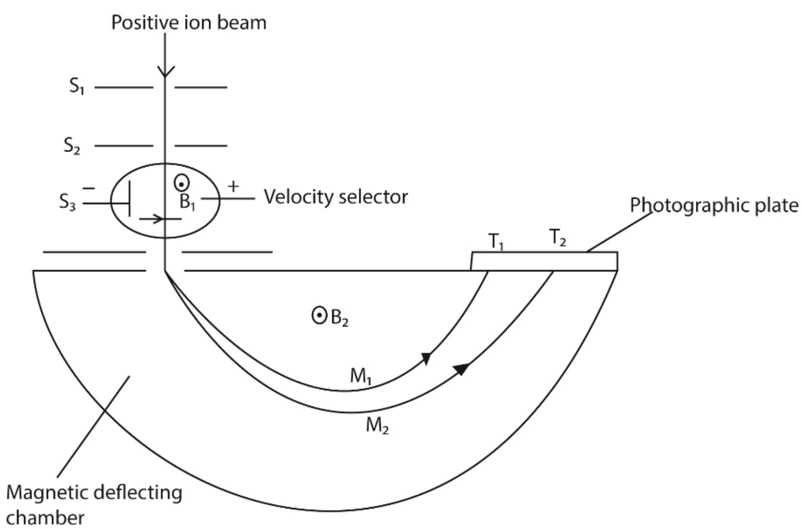


For small values of V, Ic increases linearly with V but strongly dependent on i.

37. (a) What are isotopes? (01mark)

Isotopes are atoms of the same element with the same atomic number but different atomic mass.

(b) With the aid of a diagram, describe the operation of Bainbridge spectrometer in determining the specific charge of ions. (06marks)



T_1 and T_2 are tracers on photographic plate, S_1, S_2 and S_3 are slits

Mode of Action

- Positive ions are produced in a discharge tube and admitted as a beam through slits S_1 and S_2.
- The beam then passes between insulated plates P, Q, connected to a battery, which create an electric field of intensity E.
- A uniform magnetic field B_1, perpendicular to E is applied over the region of the plates and all ions, charge e with the same velocity, v given by B_1ev =Ee will then pass undeflected through the plates and through a slit S_3.
- The selected ions are deflected in a circular path of radius r by a uniform perpendicular magnetic field B_2 and an image is produced on a photographic plate as shown.

  In this case

  $$\frac{mv^2}{r} = B_2ev$$

$\therefore \frac{m}{e} = \frac{rB_2}{v}$

But for the ions selected v = $\frac{E}{B_1}$ from above

Specific charge, $\frac{e}{m} = \frac{E}{rB_2B_1}$

(c) Explain the purpose of each of the following in a Geiger-Muller tube

(i) a thin mica window

To allow easy entry of ionizing particles in the GMT

(ii) Argon gas at low pressure

Argon form ions when it is struck by ionizing particle.

Low pressured reduces resistance to ion movement to respective electrodes.

(iii) Halogen gas mixed with argon gas

Form quenching agent to prevent secondary ionization.

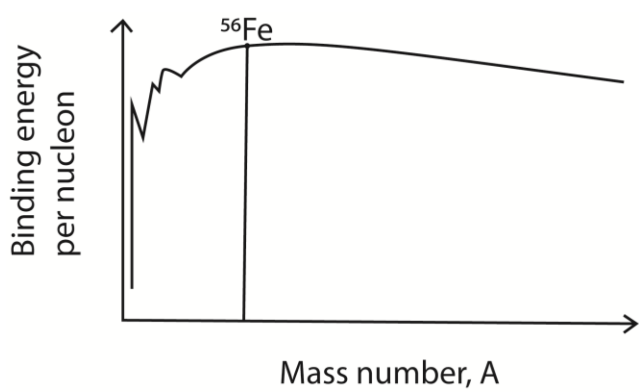
(iv) An anode in the form of a wire (04marks)

Anode in form of a wire increases strength of electric field intensity

(d) (i) What is meant by binding energy per nucleon of a nucleus? (01mark)

Binding energy per nucleon is the ratio of the energy required to split a nucleus into the individual nucleons to the number of nucleon in the nucleus.

(ii) Sketch a graph of binding energy per nucleon against mass number for naturally occurring nuclides (01marks)



(iii) State one similarity between nuclear fusion and nuclear fission. (01mark)

Both release energy

(e) (i) At a certain time, an α-particle detector registers a count rate of $32s^{-1}$. Exactly 10days later, the count rate dropped to $8s^{-1}$. Find the decay constant. (04marks)

$A = A_0e^{-\lambda t}$

$8 = 32e^{-10\lambda}$

$\lambda = 0.1386$ per day

(ii) State two industrial uses and two health hazards of radioactivity. (04marks)

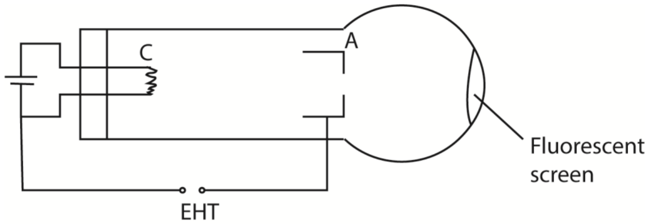
Industrial uses

- Estimate the rate of wear in machinery
- Automatic control of thickness of paper, plastic or metal sheeting
- Investigating the flow of liquids in chemical plants or underground water and sewage pipeline.

Hazards

- May cause skin burn
- Cancers
- Gene mutation

38. (a) (i) Describe, with aid of a diagram, the production of cathode rays



- Cathode C produces electrons by thermionic emission.
- Electrons are accelerated by p.d between cathode and anode

(ii) State and justify two properties of cathode rays (02marks)

- carry negative charge because they are attracted towards a positive potential

- move in straight line because the cast a shadow when intercepted by Maltase cross

(b) Explain each of the following terms as applied to photoelectric emission:

(i) stopping potential (01marks)

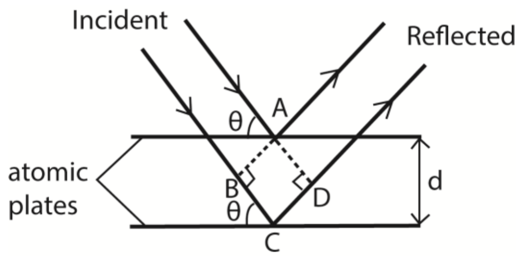
Stopping potential is a minimum potential that reduces photocurrent to zero.

(ii) threshold frequency (01mark)

It is the frequency of radiation below which no electron emission takes place.

(c) Explain X- ray diffraction by crystals and derive Bragg's law (06marks)

- A parallel beam of monochromatic X-rays incident on a crystal is reflected from successive atomic planes and super-imposed, forming an interference pattern.



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For constructive interference to occur, the path difference is equal to the whole number of wavelength

Thus BC + CD = nλ

⇨ dsinθ + dsinθ = nλ

or 2dsinθ = nλ where n = 1, 2, 3, 4 …

(d) The potential difference between the cathode and anode of an X-ray tube is 5.0 x 10^{-4}V. If only 0.4% of the kinetic energy of the electrons is converted into X-rays and the rest is dissipated as heat in the target at a rate of 600W, find the

(i) current that flows (03marks)

99% of energy is converted to heat.

Power converted to heat = 0.99IV = 600W

⇨ 0.99 x I x 5.0 x 10^{-4} = 600
I = 1.21 x 10^{6}A

(ii) speed of the electrons striking the target. (03marks)

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

u = $\sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \, x \, 1.6 \, x \, 10^{-19} x \, 5 \, x \, 10^{-4}}{9.11 \, x \, 10^{-34}}}$ = 1.33 x 10^{4}ms^{-1}

39. (a) (i) What is a photon? (01mark)
A photo is a packet of energy that is carried by electromagnetic radiation equal to hf where h id Plank's constant and f is the frequency of the radiation

(ii) Explain, using quantum theory, the experimental observation on the photoelectric effect. (06marks)

Observations:

- Photoelectric effect starts at the instant metal surface receives radiation
- The photocurrent is proportional to the intensity of radiation
- The maximum kinetic energy of photoelectrons is proportional to the frequency of the incident radiation and is independent of the intensity of the radiation.
- For a given metal surface, there exist a minimum frequency below which photoelectric emission occurs regardless of the intensity of the radiation

Explanation

- According to the quantum theory, radiation is emitted and absorbed in quanta.
- When a single quantum (photon) interacts with an electron on a metal surface, it gives it all or none of its energy implying that only one electron absorbs the energy of a photon. Therefore the number of photo-electrons is proportional to the number of incident photons (intensity of radiation) of energy.
- Part of this energy is used to overcome attraction of the electron by the metal surface and the rest is kinetic energy of the emitted electrons.
- Minimum energy is required to emit an electron, and thus there is minimum frequency of a radiation that emit electrons since the energy of a radiation is proportional to frequency.

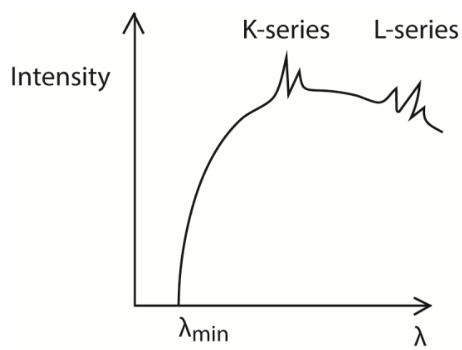
(iii) When light of wavelength 450nm falls on a certain metal, electrons of maximum kinetic energy 0.76eV are emitted. Find the threshold frequency for the metal. (04marks)

$hf_0 = \frac{hc}{\lambda} - kinetic\ energy$

6.6 x 10^{-34} x $hf_0 = \frac{6.6\ x\ 10^{-34}\ x\ 3\ x\ 10^{8}}{450\ x\ 10^{-9}} - 0.76\ x\ 1.6\ x\ 10^{-19}$

f_0 = 4.83 x 10^{14}Hz

(b) Explain, using suitable sketch graph, how X-ray spectrum in an X-ray tube are formed. (06marks)



The spectrum consists of two major components, i.e. the continuous (background) spectrum and the very sharp line spectrum superimposed onto the background spectrum.

The continuous spectrum is produced when electrons make multiple collisions with the target atoms in which they are decelerated. At each deceleration, X-rays of differing wavelength are produced.

The shortest Wavelength X-rays are produced when electrons lose all their energy as X-ray photon in a single encounter with the target atoms. The wavelength of the X-rays at this point is known as the cut off wavelength. At cut off wavelength, energy in an X-ray photon equals kinetic energy of the electron;

i.e. hf = eV or $\frac{hc}{\lambda_{max}} = eV$ where V = p.d

The line spectrum

At high tube voltages, the bombarding electrons penetrate deep into the target atoms and knock out electrons from inner shell. The knocked out electrons occupy vacant spaces in higher unfilled shells putting the atom in excited state and making them unstable.

Transition of an electron from higher to lower energy levels results in an emission of X-ray photon of energy equal to energy difference between the energy levels.

If the transition ends in the K-shell, it produces K-series and if the transition ends in L-shell. It produces L-series.

(c) A beam of X-rays of wavelength 8.42 x 10^{-11}m is incident on a sodium chloride crystal of interplanar separation 2.82 x 10^{-10}m. Calculate the first order of diffraction angle. (03marks)

From 2dsinθ = nλ

$$\theta = \sin^{-1}\left(\frac{1 \times 8.42 \times 10^{-11}}{2 \times 2.82 \times 10^{-10}}\right) = 8.58^0$$

40. (a) (i) A beam of electrons, having a common velocity, enters a uniform magnetic field in a direction normal to the field. Describe and explain the subsequent path of the electrons (04marks)

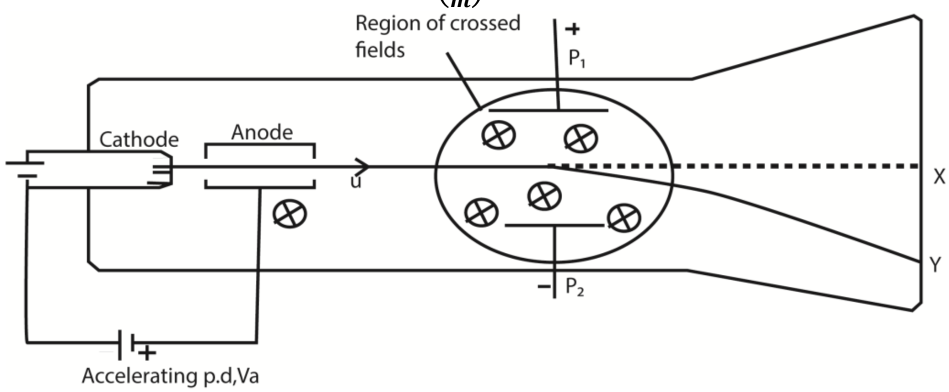
The electrons will describe a circular path, since they experience a magnetic force (F = Bev) at right angle to their direction of motion and to the field. This provides a centripetal force.

(ii) Explain whether a similar path would be followed if a uniform electric field were substituted for magnetic field (01mark)

The electrons experience an electric force (F= eE) in direction opposite that of magnetic field. Thus causes them to describe a parabolic force

(b) Describe an experiment to measure the ratio of the charge to mass of an electron (07marks)

Determination of Specific Charge $\left(\frac{e}{m}\right)$ of an electron: (J.J Thomson's Method)



- The electrons are produced thermionically by a hot filament cathode and are accelerated towards a cylindrical anode and pass through it.
- The small hole on the anode confines the electrons to a narrow beam.
- When both the electric field and the magnetic field are off, the electrons reach the screen at X and cause fluorescence.
- If the velocity of the electrons on emerging from the anode is u then

  eVa = $\frac{1}{2}mu^2$

  ⇨ $\frac{e}{m} = \frac{u^2}{2Va}$ ………………………………………. (i)

  Where Va is the accelerating voltage between the cathode and anode.

- The magnetic field is switched on and the beam is deflected to position Y.
- In order to bring the beam back to the original position X, the electric field is switched on and adjusted until the beam is at X again.
- This implies that The magnetic force = the electric force

  Beu = eE

  ∴u = $\frac{E}{B}$ ……………………………… (ii)

  Substituting eqn. (ii) in (i)

  $\frac{e}{m} = \frac{E^2}{2B^2Va}$ but E = $\frac{V}{d}$

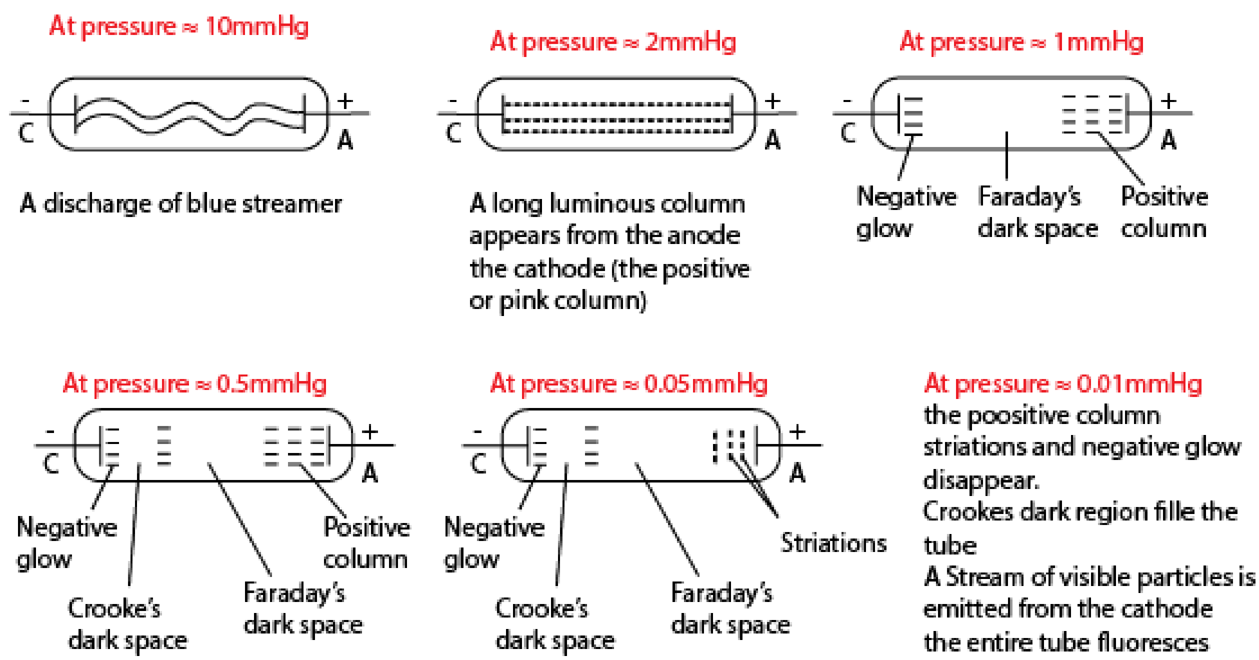
  ∴ $\frac{e}{m} = \frac{V^2}{2B^2d^2Va}$ where, V is the p.d between the plates at separation of d apart

(c) Electrodes are mounted at opposite ends of low pressure discharge tube and a potential difference of 1.20kV applied between them. Assuming the electrons are accelerated from rest, calculate the maximum velocity which they could acquire. [Specific electron charge =-1.76 x 10^{11} Ckg^{-1}) (02marks)

From $\frac{1}{2}mv^2 = eV$

$$v = \sqrt{\frac{2eV}{m}} = \sqrt{2x\ 1.7\ x\ 10^{11}\ x1.2\ x\ 10^3} = 2.06 \times 10^7 ms^{-1}$$

(d) (i) Give an account of the stages observed when an electric discharge passes through a gas at pressure varying from atmospheric to about 0.01mmHg as air is pumped out when the p.d across the tube is maintained at extra high tension. (05marks)



(ii) State two disadvantages of discharge tubes when used to study cathode rays. (01mark)

- A gas is needed at very low pressure which may not be easy to achieve practically.
- A very high p.d is needed across tube which may not be safe to handle
- X-rays may be produced and these are unsafe.

41. (a) (i) What is meant by half-life of a radioactive material? (01mark)
    - Half-life is the time taken for the activity of a material to decrease to half its original value.

(ii) Given the radioactive law, $N_t = N_0e^{-\lambda t}$, obtain the relationship between λ and half-life $T_{\frac{1}{2}}$ (02marks)

$In\frac{N_0}{N} = \lambda t$ at t =$T_{\frac{1}{2}}$, N = $\frac{N_0}{2}$

⇨ $In\frac{N_0}{\frac{N_0}{2}} = \lambda T_{\frac{1}{2}}$

$\lambda = \frac{In2}{T_{\frac{1}{2}}}$

(iii) What are radioisotopes? (01mark)

Radioisotope are radioactive atoms of the same element having the same atomic number but different atomic mass

(iv) The radioisotope $^{90}_{38}Sr$ decays by emission of β-particles. The half-life of the radioisotope is 28.8years. Determine the activity of 1g of the isotope (05marks)

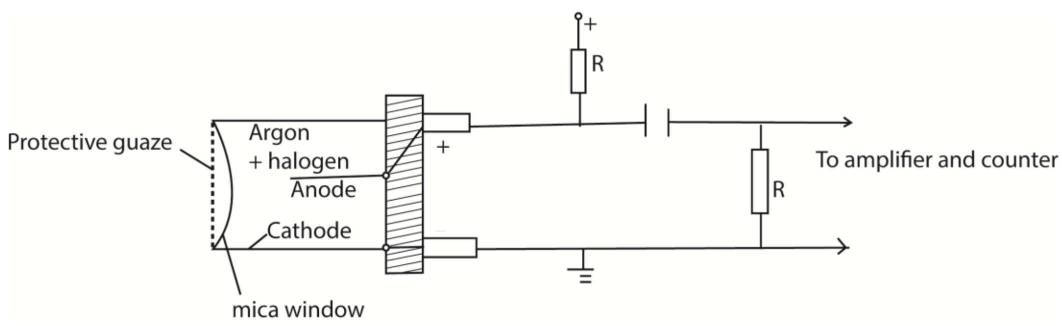
Activity, A = λN, where N = $\frac{N_{AM}}{M}$ and $\lambda = \frac{In2}{T_{\frac{1}{2}}}$

Activity, A = $\frac{In2}{28.8 \, x \, 365 \, x \, 24 \, x \, 3600 \, x \, 1}$ = 7.63 x $10^{-10}s^{-1}$

(b) (i) With aid of a diagram describe the structure and action of Geiger-Muller tube. (06marks)

The GMT is used to detect the presence of X- rays, Gamma rays, beta particles and if the window of the tube used is very thin, it detects even alpha particles.

Structure



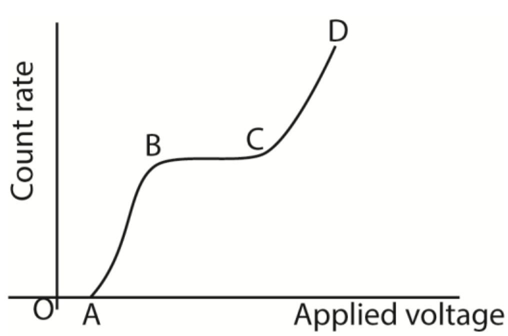
The thin mica window allows the passage and detection of the weak penetrating alpha particles. The GM tube is first evacuated then filled with Neon, Argon plus Halogen gas which is used as a quenching agent.

Mode of operation

Mode of operation

- When an ionizing particle enters the tube through the window, argon atoms are ionized.
- The electrons move to the anode while the positive ions drift to the cathode.
- A discharge occurs and the current flows in the external circuit.
- A p.d is obtained across a large resistance, R which is amplified and passed to the scale.
- The magnitude of the pulse registered gives the extent to which ionization occurred.

(ii) Sketch the current –voltage characteristic of the Geiger- Muller tube and explain its main features. (03marks)



OA – the operating voltage is not enough to attract the ions to the respective electrodes and hence the counter registers no reading. This voltage (i.e. at A) is called the threshold voltage.

AB – the applied p.d not enough to attract all electrons; hence increasing the p.d increases the number of electrons being attracted and hence increase in counter rate.

BC – here the count rate is constant. This is called the plateau region.

- Between BC, all the negative ions are able to reach the anode because the operating voltage is large enough to attract them.

- Full avalanche is obtained along the entire length of the anode.

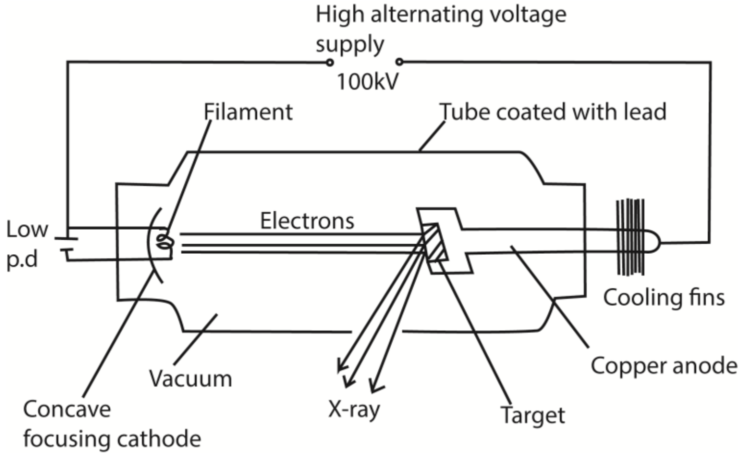
- Here the tube is said to be operating normally.

CD: - The count rate increases rapidly because the quenching process becomes ineffective and eventually a continuous discharge occurs which might damage the tube.

(iii) Identify, giving reasons, the suitable range in (b) (ii) of operation of the tube (02marks)

The suitable region is BC, in this range, every particle which produces ionization is detected.

42. (a)(i) Draw a labelled diagram of an X-ray tube. (02marks)



(ii) Use the diagram in (a)(i) to describe how X-rays are produced. (03marks)

- The filament is heated by a low voltage supply and the electrons are emitted by thermionic emission.
- The concave focusing cathode focuses the electrons from the filament onto the target.
- These electrons are accelerated towards the anode by the high voltage between the filament and the Anode.
- When the electrons (cathode rays) strike the metal target, about only 1% their kinetic energy is converted to X-rays and the 99% of their kinetic energy is converted to heat, which is conducted away by the cooling fins.

(iii) State one industrial and one biological use of X-rays. (01marks)

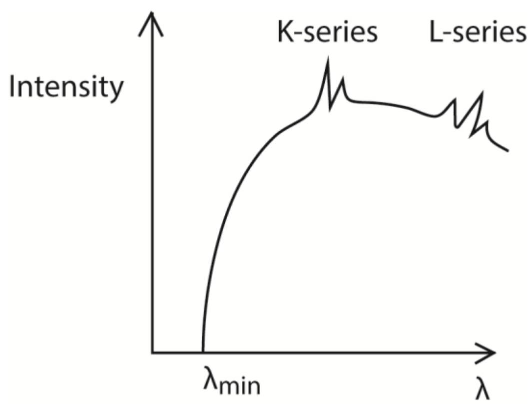
Industrial use

1. Inspecting metal casting and welding joints for perfection
2. Structural analysis, stresses, fractures in solids, castings and welded joints can be analyzed by examining X-ray photograph.
3. Crystallography; Orientation and identification of minerals by analysis of diffraction patterns using Bragg's law.

Biological use

- Identifying fractures
- Treatment of cancer

(b)(i) Sketch a graph of intensity versus wavelength of X-rays from an X-ray tube and describe its main features. (04marks)



The spectrum consists of two major components, i.e. the continuous (background) spectrum and the very sharp line spectrum superimposed onto the background spectrum.

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The line spectrum

At high tube voltages, the bombarding electrons penetrate deep into the target atoms and knock out electrons from inner shell. The knocked out electrons occupy vacant spaces in higher unfilled shells putting the atom in excited state and making them unstable.

Transition of an electron from higher to lower energy levels results in an emission of X-ray photon of energy equal to energy difference between the energy levels.

If the transition ends in the K-shell, it produces K-series and if the transition ends in L-shell. It produces L-series.

(ii) Calculate the maximum frequency of X-rays emitted by an X-ray tube operating on voltage of 34.0kV. (03marks)

From $hf_{max} = eV$

$f_{max} = \frac{1.6 \ x\ 10^{-19}\ x\ 34\ x\ 10^{3}}{6.63\ x\ 10^{-34}}$ = 8.205 x 10^{18}Hz

(c) In the measurement of electron charge by Millikan's apparatus, a potential difference of 1.6kV is applied between two horizontal plates 14mm apart. With the potential difference switched off, an oil drop is observed to fall with constant velocity 4.0 x 10^{-4}ms^{-1}. When the potential difference is switched on, the drop rises with constant velocity 8.0 x 10^{-5}ms^{-1}.

If the mass of the oil drop is 1.0 x 10^{-14}kg, find the number of electron charges on the drop. [assume air resistance is proportional to velocity of the oil drop and neglect the up thrust due to air] (07marks)

Neglecting up thrush due to air resistance

mg = 6πηav_0

$\eta a = \frac{mg}{6\pi v_0} = \frac{1.0\ x\ 10^{-14} x\ 9.81}{6\pi\ x\ 4\ x\ 10^{-4}}$ = 1.3 x 10^{-11}Nsm^{-1}.

When p.d of 1.6 x 10^{3}V is applied, v = 8 x 10^{-5}ms^{-1}

mg = F + F_E

mg = 6π$\eta a v$ + qE

q = $\frac{mg - 6\pi\eta a\ v}{E} = \frac{mg-6\pi\eta a\ v}{V} d = \frac{(1.0\ x\ 10^{-14} x\ 9.81 - (6\pi\ x\ 1.3\ x 10^{-11} x\ 8.5\ x\ 10^{-5}))\ x\ 14\ x\ 10^{-3}}{1.6\ x\ 10^{3}}$

= 6.76 x 10^{-19}C

But q = ne

n = $\frac{q}{e} = \frac{6.76\ x\ 10^{-19}}{1.6\ x\ 10^{-19}}$ =4

43. (a) (i) State the laws of photo-electric emission. (04marks)

- The time lag between irradiation of the metal surface and emission of the electrons by the metal surface is negligible.
- For a given metal, surface there is a minimum value of frequency of radiation called threshold frequency (f_0) below which no photo electrons are emitted from the metal however intense the incident radiation may be.
- The number of photoelectrons emitted from the surface per second is directly proportional to the intensity of incident radiation for a particular incident frequency
- The K.E of the photoelectrons emitted is independent of the intensity of the incident radiation but depends only on its frequency

(ii) Write down Einstein's equation for photo electric emission. (02marks)

hf= w_0 + ½ mv^2 ;

where h = Plank's constant, f = frequency of radiation, w0 = work function, m = mass of electron, v = velocity of electron

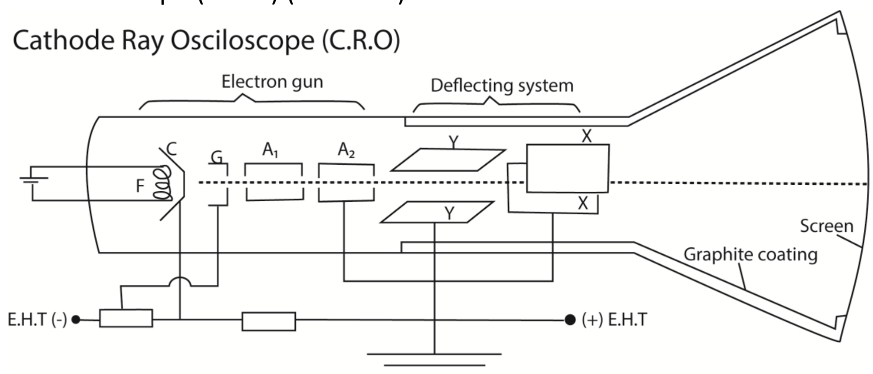
(iii) Ultra –violet light of wavelength 3.3 x 10^{-8}m is incident on a metal. Given the work function of the metal is 3.5eV, calculate the maximum velocity of the liberated electron. (03marks)

From hf = w0 + $\frac{1}{2}mv^2$

$$v = \sqrt{\frac{2\left(\frac{hc}{e\lambda} - w_0\right)e}{m}} = \sqrt{\frac{2\left(\frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{1.6 \times 10^{-19} \times 3.3 \times 10^{-8}} - 3.5\right) \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}} = 3.47 \times 10^{6} ms^{-1}$$

(b) Describe, with aid of a diagram, the structure and mode of operation of a cathode ray oscilloscope (C.R.O) (06marks)

Cathode Ray Osciloscope (C.R.O)



The following are the main features of CRO

- a hot filament emits electrons
- The grid G has a negative potential with respect to the filament and controls the number of electrons entering and reaching anode A_1
- Anodes A1 and A2 accelerate the electron beam at a high speed the screen
- Deflecting system consist of Y- and X-plates; Y-plated deflect the beam vertically while X-plates deflect the beam horizontally.
- The screen is coated with zinc sulphide to display the arrival of the beam by emitting light when struck by the beam
- Carbon coating prevents the electron beam from the influence of any external electric field.

(c) A C.R.O has its y-sensitivity set to 10Vm^{-1}. A sinusoidal input voltage is suitably applied to give a steady trace with time base switched on so that the electron beam takes 0.01s to traverse the screen. If the trace seen has a peak-to-peak height of 4.0cm and contains two complete cycles, find the

(i) r.m.s value of the input voltage. (03marks)

Peak to peak voltage = y-sensitivity x height

= 10 x 4

= 40V

$$V_{r.m.s} = \frac{V_{max}}{\sqrt{2}} = \frac{20}{\sqrt{2}} = 14V$$

(ii) frequency of the input signal. (02marks)

Period T = time for one oscillation

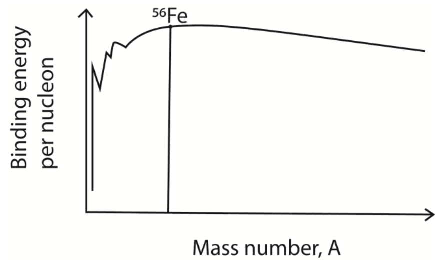
= $\frac{0.01}{2}$ = 0.005s

Frequency, f = $\frac{1}{T} = \frac{1}{0.005}$ = 200Hz

44. (a) Define binding energy of nuclide (01mark)

Binding energy is the energy required to split the nucleus into its individual nucleons, i.e. protons and neutrons.

(b) (i) Sketch a graph showing how binding energy per nucleon varies with mas number (01mark)



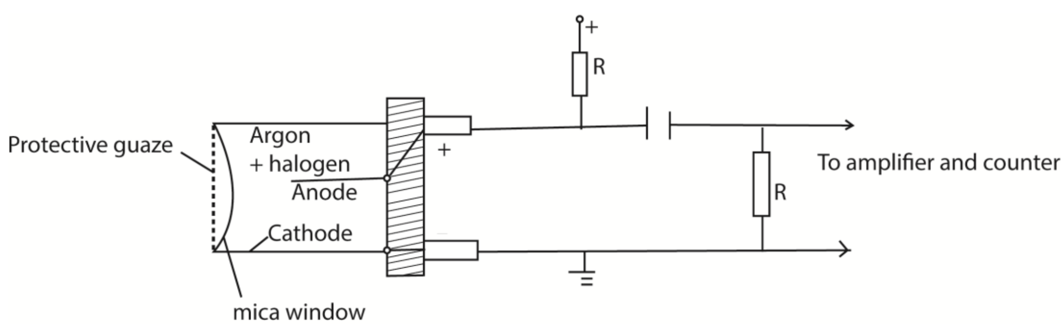
(ii) Describe the main features of the graph in (b)(i). (03marks)

Binding energy per nucleon increases with a few peaks up to the maximum mass number = 56 and then decreases gradually.

(c) Distinguish between nuclear fission and nuclear fusion and account for the energy released. (03mark)

- Nuclear fusion is the combination of two light nuclei to form heavier nucleus accompanied with release of energy.
- Nuclear fission is the splitting of a heavy unstable nucleus into small stable nuclei accompanied by release of energy.

(d) (i) with the aid of a labelled diagram describe the working of the Geiger-Muller tube. (05marks)



The thin mica window allows the passage and detection of the weak penetrating alpha particles. The GM tube is first evacuated then filled with Neon, Argon plus Halogen gas which is used as a quenching agent.

Mode of operation

Mode of operation

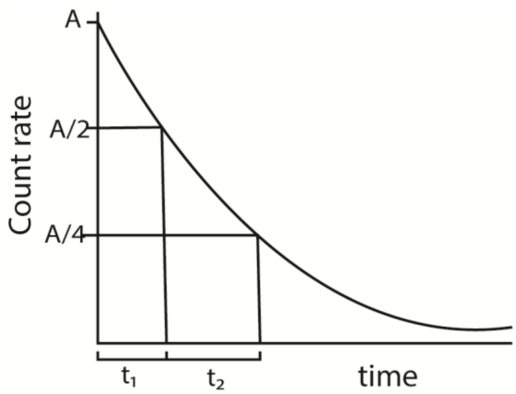
- When an ionizing particle enters the tube through the window, argon atoms are ionized.
- The electrons move to the anode while the positive ions drift to the cathode.
- A discharge occurs and the current flows in the external circuit.

- A p.d is obtained across a large resistance, R which is amplified and passed to the scale.
- The magnitude of the pulse registered gives the extent to which ionization occurred.

(ii) How would you use a Geiger-Muller tube to determine the half-life of a radioactive sample? (04marks)

Experiment to determine a half-life of radioactive substance using GM- tube

- Switch on the GM-tube, note and record the background count rate, A.
- Place a source of ionizing radiation near the GM-window.
- Note and record the count rate recorded the count rate at equal intervals.
- For each count rate recorded subtract the background count rate to get the true rate.
- Plot a graph of the count rate against time.



Find time t_1 taken for the activity to reduce to A/2 and t_2 taken for activity to reduce to A/4 from A/2

Half-life = $\frac{1}{2}(t_1 + t_2)$

(e) A radioactive source produces alpha particles each of energy 60eV. If 20% of the alpha particles enter an ionization chamber a current of 0.2μA flows. Find the activity of the alpha source, if the energy needed to make an ion pair in the chamber is 32MeV. (03marks)

The charge of 1e = 1.6 x 10^{-19} per second is produced by an energy of 32eV

Ie amperes is produced by 32MeV

0.2μA is produced by $\frac{32MeV}{e}$ x 0.2μA = y

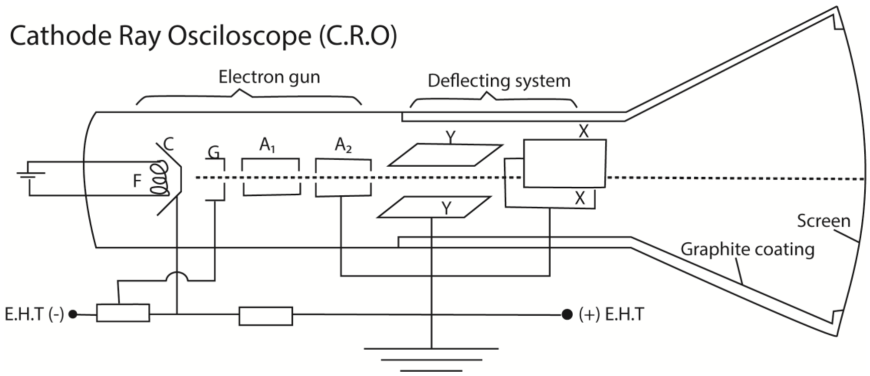
$\therefore 20\%\ of\ x = y$

Where x is the energy that would be required to ionize all alpha particles

⇨ X =5y

Number of alpha particles = $\frac{x}{60MeV}$= $\frac{5x\ 32MeV\ x\ 0.2\ x\ 10^{-6}}{e\ x\ 60MeV}$ = 3.3 x 10^{12}Bq

45. (a) (i) Describe with the aid of a labelled diagram the main features of a cathode ray oscilloscope (C.R.O) (08marks)



The following are the main features of CRO

- a hot filament emits electrons
- The grid G has a negative potential with respect to the filament and controls the number of electrons entering and reaching anode A_1
- Anodes A1 and A2 accelerate the electron beam at a high speed the screen
- Deflecting system consist of Y- and X-plates; Y-plated deflect the beam vertically while X-plates deflect the beam horizontally.
- The screen is coated with zinc sulphide to display the arrival of the beam by emitting light when struck by the beam
- Carbon coating prevents the electron beam from the influence of any external electric field.

(ii) State two uses of C.R.O (01mark)

- Display waveforms
- Measuring both a.c and d.c voltage
- Measuring phase differences

(iii) The gain control of a C.R.O is set on $0.5Vcm^{-1}$ and an alternating voltage produces a vertical trace of 2.0cm long with the time base off. Find the root mean value of the applied voltage. (02marks)

Peak to peak voltage, V = 2 x 0.5V= 1V

Peak voltage $V_0 = \frac{V}{2} = \frac{1}{2} = 0.5V$

$$V_{r.m.s} = \frac{V_0}{\sqrt{2}} = \frac{0.5}{\sqrt{2}} = 0.354V$$

(b) A beam of electrons is accelerated through a potential difference of 2000V and is directed mid-way between two horizontal plates of length 5.0cm and separation of 2.0cm. The potential difference across the plates is 80V.

(i) Calculate the speed of the electron as they enter the region between the plates. (03marks)

$\frac{1}{2}mu^2 = eV$

$$u = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \, x \, 1.6 \, x \, 10^{-19} \, x \, 2000}{9.11 \, x \, 10^{-31}}} = 2.65 \text{ x } 10^7 ms^{-1}$$

(ii) Explain the motion of the electrons between the plates. (02marks)

It is parabolic

(iii) find the speed of electrons as they emerge from the region between the plates. (04marks)

$v_x = 2.65 \times 10^7 ms^{-1}$

$v_y = at$

$a = \frac{Ee}{m} = \frac{Ve}{dm}$

$t = \frac{L}{u} = \frac{5 \times 10^{-2}}{2.65 \times 10^7} = 1.89 \times 10^{-9}s$

⇨ $v_y = \frac{Ve}{dm} \times 1.89 \times 10^{-9}$

$= \frac{80 \times 1.6 \times 10^{-19}}{2 \times 10^{-2} \times 9.11 \times 10^{-31}} \times 1.89 \times 10^{-9}$

$= 1.33 \times 10^6 ms^{-1}$

$v = \sqrt{v_x^2 + v_y^2} = \sqrt{(2.65 \times 10^7)^2 + (1.33 \times 10^6)^2} = 2.65 \times 10^7 ms^{-1}$

46. (a) Explain the term stopping potential as applied to photo electric effect. (02marks)

It is the minimum potential difference between the anode and the cathode that reduces the photocurrent to zero.

(b) Explain how intensity and penetrating power of X-rays from X-ray tube would be affected by changing:

(i) the filament current (02marks)

When the filament current is increased, the intensity of the X-rays increases since the number of electrons hitting the target increases but the penetrating power remains constant since the kinetic energy of the electrons is not changed.

(ii) the high tension potential difference across the tube (02marks)

Penetrating power increases with potential difference.

(c) When a p.d of 60kV is applied across an X-ray tube, a current of 30mA flows. The anode is cooled by water flowing at a rate of $0.060kgs^{-1}$. If 99% of the power supplied is converted into heat at the anode, calculate the rate at which the temperature of the water rises. {Specific heat capacity of water = $4.2 \times 10^3 Jkg^{-1}K^{-1}$] (05marks)

Electrical energy supplied per second = $IV = 30 \times 10^{-3} \times 60 \times 10^3 = 1.8 \times 10^3 W$

Since 99% of this energy is converted to heat

=> the rate of heat production = $0.99 \times 1800 = 1.782 \times 10^3 W$

Rate of heat gain by water = $\frac{dm}{dt} x\ c\ x\ \Delta\theta$ where Δθ is temperature change

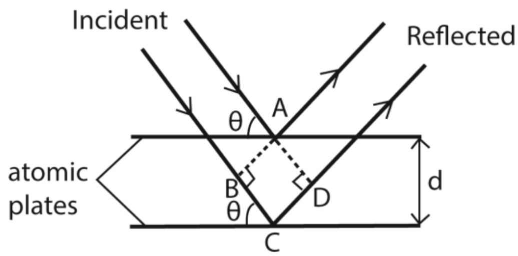
All the heat produced is removed by water.

Then $\frac{dm}{dt} x\ c\ x\ \Delta\theta = 1.782 \times 10^3 W$

$\Delta\theta = \frac{1.782 \times 10^3}{0.060 \times 4.2 \times 10^3} = 7.07^0$

(d) (i) Derive Bragg's law of X-ray diffraction. (05marks)

- A parallel beam of monochromatic X-rays incident on a crystal is reflected from successive atomic planes and super-imposed, forming an interference pattern.



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For constructive interference to occur, the path difference is equal to the whole number of wavelength

Thus BC + CD = nλ

⇨ dsinθ + dsinθ = nλ

or 2dsinθ = nλ where n = 1, 2, 3, 4 …

(ii) Calculate the atomic spacing of sodium chloride if the relative atomic mass of sodium is 23.0 and that of chlorine is 35.5.

[Density of sodium chloride = $2.18 \times 10^3 kgm^{-3}$] (04marks)

From volume = $\frac{mass}{\rho}$

Volume of 1 mole = $\frac{(23+35.5)x\ 10^{-3}}{2.18\ x\ 10^3}\ m^3$

1 mole of NaCl contains 6.02×10^{23} molecules

Volume of 1 molecule =$\frac{(23+35.5)x\ 10^{-3}}{2.18\ x\ 10^3\ x\ 6.02\ x\ 10^{23}}$

Volume of 1 atom = $\frac{(23+35.5)x\ 10^{-3}}{2.18\ x\ 10^3\ x\ 6.02\ x\ 10^{23}}\ x\ \frac{1}{2}$ = $2.23 \times 10^{-29} m^3$

It the interatomic spacing is d,

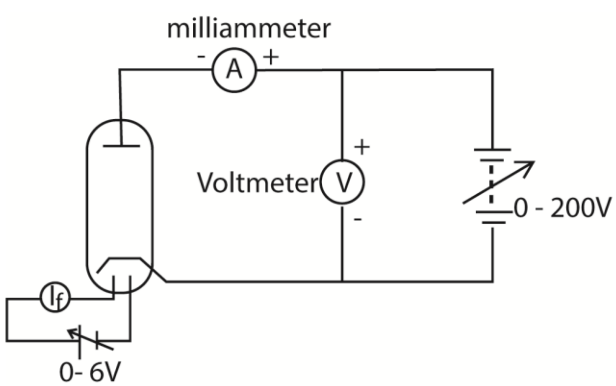
$d^3 = 2.23 \times 10^{-29} m^3$

$d = 2.81 \times 10^{-10} m$

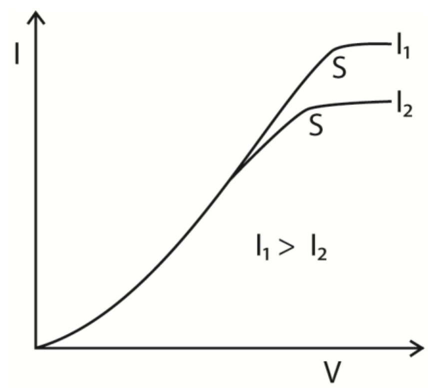
47. (a) (i) Explain briefly the mechanism of thermionic emission. (02marks)

When a metal is heat electron surface electrons acquire enough kinetic energy to overcome the nuclear attraction and escape from the surface. The escape of electrons from hot metal surface is termed thermionic emission.

(ii) Draw a labelled diagram of the circuit used to determine the anode current and anode voltage characteristics of a thermionic diode. (02marks)

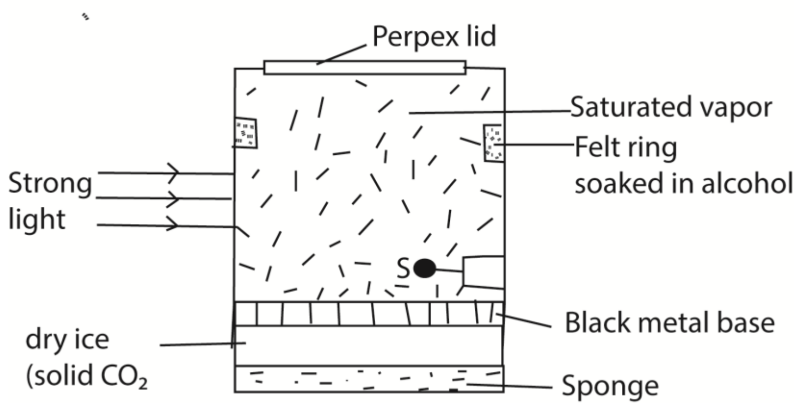


(iv) Sketch the characteristic expected in (a) (ii) at constant filament current, and account for its special features. (04marks)



The current increases with the positive anode potential as far as the point S. Beyond this point the current does not increase, because the anode is collecting all the electrons emitted by the filament ; the current is said to be saturated.

(b) Describe, with the aid of a labelled diagram, the structure and action of a diffusion cloud chamber (06marks)



- The base of the chamber is maintained at low temperature, about -80^0c by the solid carbon dioxide while the top of the chamber is at room temperature, and so there is a temperature gradient between the top and the bottom of the chamber.
- The air at the top of the chamber is saturated with alcohol vapor from the felt ring. This vapor continuously diffuse downwards into the cooler regions so that the air at the chamber is super saturated with alcohol vapor.
- Radiations from the radioactive source S cause the ionization of the vapor.

- The ionizations from the radioactive source S cause condensation of the vapor on the ions formed, hence the path of the ionizing radiations are traced by series of small droplets of condensation.
- The thickness and length of the path indicate the extent to which ionization has taken place.
- Alpha particles produce short, thick, continuous straight tracks
- Beta particles which are less massive produce longer, thin but straggly paths owing to collisions with gas molecules
- Gamma radiations are uncharged and for ionization to take place, it must collide with an atom and eject an electron which then ionizes the vapor.

(c) (i) Define radioactivity and half-life of a radioactive substance (02marks)

Radioactivity is the spontaneous disintegration of unstable nucleus acquire a more stable state by emission of α, β or γ –rays.

Half-life of a radioactive substance is the time taken for half the number of radioactive nuclei to disintegrate.

(ii) A radioactive isotope of strontium of mass 5.0μg has a half-life of 28years. Find the mass of the isotope left after 14 years.

[Assume the decay law $N = N_0e^{-\lambda t}$]

$\lambda = \frac{In2}{t_{\frac{1}{2}}}$

$N = 5 x 10^{-6}e^{-\frac{In 2}{28} x 14}$ = 3.54×10^{-6}g = 3.54μg

48. (a) (i) State Rutherford's model of the atom. (02marks)

- The atom consists of positive charges confined to the center where most mass is concentrated
- Electrons orbit around the nucleus just like planets around the sun
- It is the electron cloud that accounts for the volume of an atom

(ii) Explain two main failures of Rutherford's model of the atom. (03marks)

- Much as electrons resolve around the nucleus, they do so only in certain allowed orbit. While in these orbits, they do not emit energy. Rutherford failed to explain this.
- Electrons can jump from one orbit to another of lower energy and energy emitted equal to energy difference between the energy levels equal hf, where f is the frequency of radiation emitted and h= Plank's constant. Rutherford failed to explain this.

(b) (i) Explain how Millikan's experiment for measuring the charge of an electron proves that charge is quantized. (04marks)

Millikan found out that the charge on every other droplet was always a multiple of basic unit 1.6×10^{-19}C and a whole number. Thus the charge carried by an electron is -1.6×10^{-19}C. A drop carrying charge of $N \times 10^{-19}$C has either N electrons to many or too few. Thus Millikan concluded that charge is quantized.

(ii) Oil droplets are introduced into the space between two flat horizontal plates, set 5.0mm apart. The plate voltage is then adjusted to exactly 780V so that one of the droplets is held stationary. Then the plate voltage is switched off and the selected droplet is observed to fall a measured distance of 1.5mm in 11.2s. Given the density of oil used is

900kgm^{-3} and the viscosity of air is 1.8 x 10^{-5}Nsm^{-2}, calculate the charge on the droplet. (06marks)

When the uncharged drop is falling steadily under gravity with terminal velocity. v_o.

$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + 6\pi r \eta v_1$

Where σ is density of air, ρ is density of oil and η is viscosity of air

⇨ $r = \left[\frac{9\eta v_1}{2g(\rho - \sigma)}\right]^{\frac{1}{2}}$

But $v_1 = \frac{distance\ moved\ by\ oil\ drop}{time} = \frac{1.5\ x\ 10^{-3}}{11.2}$ = 1.339 x 10^{-4}ms^{-1}

Neglecting density of air, i.e. σ = 0

r = $\frac{9\ x\ 1.8\ x\ 10^{-5}\ \ x\ 1.339\ x\ \ 10^{-4}}{2\ x\ 9.81\ x\ 900}$ = 1.09 x 10^{-16}m

When an electric field is applied across the plates,

$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + 6\pi r \eta v_2 - Eq$ where v_2 is the new speed

Eq = $\frac{4}{3}\pi r^3(\rho - \sigma)$ - $6\pi r \eta v_2$

= $6\pi r \eta v_1 - 6\pi r \eta v_2$

Also E = $\frac{V}{d} = \frac{780}{50\ x\ 10^{-3}}$ = 1.56 x 10^5Vm^{-1}

Since the charged drop is held stationary by the field v_2 = 0

Hence q = $\frac{6\pi r \eta v_1}{E}$

= $\frac{6\pi\ x\ 1.8\ x\ 10^5\ x\ 1.1\ x\ 10^{-6}\ x\ 1.339\ x\ 10^{-4}}{1.56\ x\ 10^5}$

= 3.204 x 10^{-19}C

= 2e

(c) A beam of positive ions is accelerated through a potential difference of 1 x 103V into a region of uniform magnetic field of flux density 0.2T. While in magnetic field it moves in a circle of radius 2.3cm. Derive an expression for the charge to mass ration of the ions, and calculate the value. (05marks)

When positive ions are accelerated through a p.d they acquire kinetic energy equal to ½ mv^2. The force, F, on an electron moving normal to magnetic field is given by F = Bqu. This force provides the required centripetal force, F_C.

Thus F_C= F_B

Now $\frac{mu^2}{r} = Bqu$

$u = \frac{Bqr}{m}$

The kinetic energy should balance the energy due to the electric field

K.E = ½ mu^2 = qV

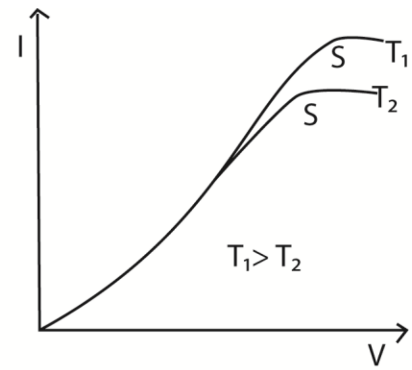
$\frac{B^2q^2r^2}{2m}$ = qV

$\frac{q}{m} = \frac{2V}{r^2B^2} = \frac{2\ x\ 1x\ 10^3}{(2.3\ x\ 10^{-2})^2\ x\ 0.2^2}$ = 9.5 x 107Ckg^{-1}

49. (a) (i) What is meant by thermionic emission? (01mark)

It emission of electrons from a metal surface when heated.

(ii) Sketch the current-potential difference characteristics of a thermionic diode for two different operating temperature and explain their main features. (05marks)



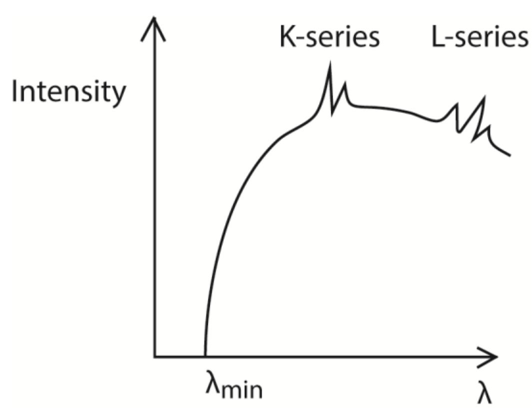
The current increases with the positive anode potential as far as the point S. Beyond this point the current does not increase, because the anode is collecting all the electrons emitted by the filament ; the current is said to be saturated. More electrons are emitted at a higher temperature T_1 than T_2.

(v) Describe one application of a diode. (02marks)
Diodes are used in rectification of a.c into d.c since they conduct n one direction only.

(b) (i) What features of an x-ray tube make it suitable for continuous production of X-rays. (03marks)

- low voltage source for heating the cathode an electron source by thermionic emission
- accelerating p.d
- high melting point target
- highly conducting copper anode and cooling fins to dissipate heat by radiation and convection to prevent damage to apparatus due to overheating.

(ii) Sketch a graph of intensity versus frequency of a radiation produced in an X-ray tube and explain its main feature. (05marks)



The spectrum consists of two major components, i.e. the continuous (background) spectrum and the very sharp line spectrum superimposed onto the background spectrum.

The continuous spectrum is produced when electrons make multiple collisions with the target atoms in which they are decelerated. At each deceleration, X-rays of differing wavelength are produced.

The shortest Wavelength X-rays are produced when electrons lose all their energy as X-ray photon in a single encounter with the target atoms. The wavelength of the X-rays at this point is known as the cut off wavelength. At cut off wavelength, energy in an X-ray photon equals kinetic energy of the electron; i.e. hf = eV or $\frac{hc}{\lambda_{max}} = eV$ where V = p.d

The line spectrum

At high tube voltages, the bombarding electrons penetrate deep into the target atoms and knock out electrons from inner shell. The knocked out electrons occupy vacant spaces in higher unfilled shells putting the atom in excited state and making them unstable.

Transition of an electron from higher to lower energy levels results in an emission of X-ray photon of energy equal to energy difference between the energy levels.

If the transition ends in the K-shell, it produces K-series and if the transition ends in L-shell. It produces L-series.

(iii) A mono chromatic X-ray beam of wavelength 1.0 x 10^{-10}cm is incident on a set of planes in a crystal of spacing 2.8 x 10^{-10}m.What is the maximum order possible with these X-rays? (04marks)
From 2dsinθ = nλ
For n maximum sinθ = 1
n = $\frac{2 \, x \, 2.8 \, x \, 10^{-10}}{1 \, x \, 10^{-10}}$ = 5

50. (a) What is meant by the following terms:
(i) nuclear number (01mark)
Nuclear number is the number of nucleons in the nucleus of an atom

(ii) binding energy (01marks)

This is the energy rquire to split the nucleus into its constituent nucleons

(b) Calculate the energy released during the decay of ${}^{220}_{86}Rn$ nucleus into ${}^{216}_{84}P_0$ and α-particle

Mass of ${}^{220}_{86}Rn$ = 219.964176u

Mass of ${}^{216}_{84}Po$ = 215.955794u

Mass of ${}^{4}_{2}He$ = 4.001566u

(1u = 931eV) (04marks)

$^{220}_{86}Rn \rightarrow \, ^{216}_{84}Po + \, ^{4}_{2}He + Energy$

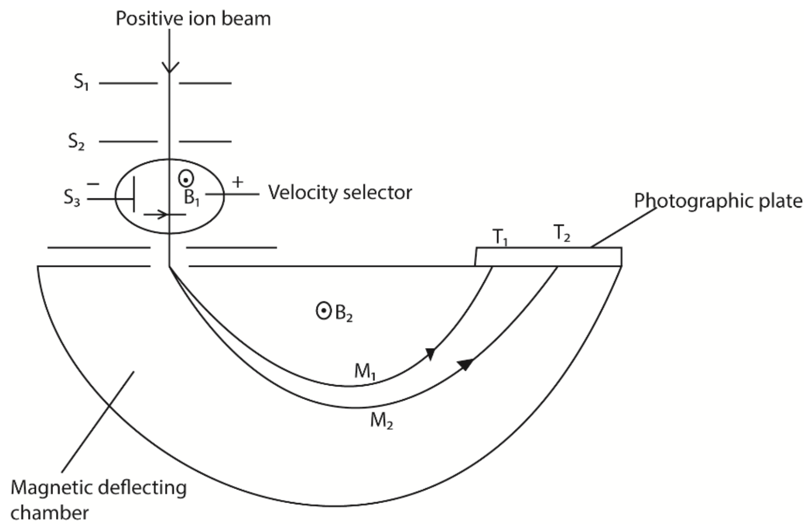
$219.964U = 215.955U + 4.0015U + E$

E = 6.816×10^{-3}U

= $6.816 \times 10^{-3} \times 931$MeV

= 6.35MeV

(c) Describe the Bainbridge mass spectrometer and explain how it can be used to distinguish between isotopes (07marks)



T_1 and T_2 are tracers on photographic plate, S_1, S_2 and S_3 are slits

Mode of Action

- Positive ions are produced in a discharge tube and admitted as a beam through slits S_1 and S_2.
- The beam then passes between insulated plates P, Q, connected to a battery, which create an electric field of intensity E.
- A uniform magnetic field B_1, perpendicular to E is applied over the region of the plates and all ions, charge e with the same velocity, v given by $B_1ev = Ee$ will then pass undeflected through the plates and through a slit S_3.
- The selected ions are deflected in a circular path of radius r by a uniform perpendicular magnetic field B_2 and an image is produced on a photographic plate as shown.
  In this case
  $\frac{mv^2}{r} = B_2ev$

But for the ions selected v = $\frac{E}{B_1}$ from above

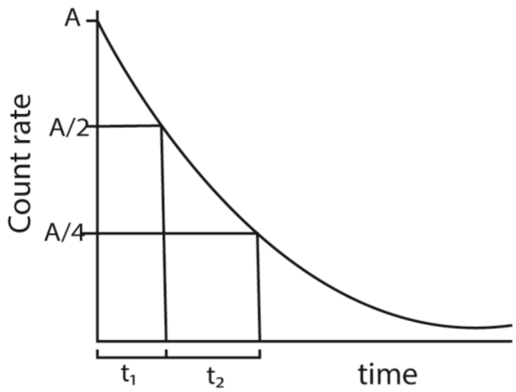
$\therefore \frac{m}{e} = \frac{rB_2B_1}{E}$

r = $\left(\frac{E}{B_1B_2Q}\right)m$

thus different isotopes strike the photographic plate at different points.

(d) (i) Explain how you would use a decay curve for a radioactive material to determine its half-life. (02marks)

The curve is defined by $N = N_0e^{-\lambda t}$



Find time t_1 taken for the activity to reduce to A/2 and t_2 taken for activity to reduce to A/4 from A/2, where A is the initial count rate.

Half-life = $\frac{1}{2}(t_1 + t_2)$,

(ii) A radioactive source contain 1.0μg of plutonium of mass number 239. If the source emits 2300 α-particles per second, calculate the half-life of plutonium.

[Assume the decay law $N + N_0e^{-\lambda t}$] (05mark)

Activity A = λN

⇨ 2300 = λN…………………………..(i)

239g of Plutonium ≡ 6.02×10^{23} atoms

1μg 0f Plutonium = $\frac{6.02 \times 10^{23}}{239} \times 10^{-6}$ = 2.52×10^{15} atoms

$\therefore number\ of\ atoms\ N = 2.52 \times 10^{15}$

From eqn. (i)

$\lambda = \frac{2300}{2.52 \times 10^{15}} = 9.126 \times 10^{-13} s^{-1}$

$t_{½} = \frac{In\ 2}{\lambda} = \frac{In2}{9.126 \times 10^{-13}} = 7.50 \times 10^{11}$seconds

51. (a) What is meant by

(i) Bohr atom (01mark)

A Bohr atom is an atom with small central positive nucleus with electrons resolving round it only in certain allowed orbits; while in orbits they do not emit radiations.

(ii) binding energy of a nucleus (02marks)

Binding energy is the energy required to split the nucleus into constituent nucleons

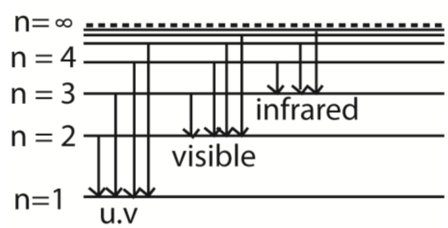
(b) The total energy, E, of an electron n an atom may be expressed as

$E = \frac{-mq^4}{8\varepsilon_0^2 n^2 h^2}$

(i) Identify the quantities, m, q, n and h in this expression (02marks)
m- mass of electron
q- charge on electron
n – principle quantum number
h – Plank's constant

(ii) Explain the physical implication of the fact that E is always negative (02marks)
Electrons are bound to the nucleus. Work must be done to remove an electron from the atom. This work is done against nuclear attraction binding electrons in the atom.

(iii) Draw an energy level diagram for hydrogen to indicate emission of ultraviolet, visible and infrared spectral lines. (03marks)



(c)(i) Explain briefly the sources and absorption of infrared radiation. (04 marks)

Source: Surfaces of all bodies emit infrared radiations in continuous range of wavelengths with relative amount of each wavelength depending mainly on temperature and nature of the surface.

Absorption: Infrared radiations is absorbed by matter. Like all other types of electromagnetic radiations, it causes increase of internal energy which leads to temperature rise. They thus produce a sensation of warmth when they fall on the skin.

Except red wavelength near to that of red light, infrared is absorbed by glass but transmitted by rock salt. Water vapour and carbon dioxide in the lower layers of the atmosphere collectively absorb infrared emitted by the earth.

(ii) Describe briefly, the method of detecting infrared radiation (03marks)

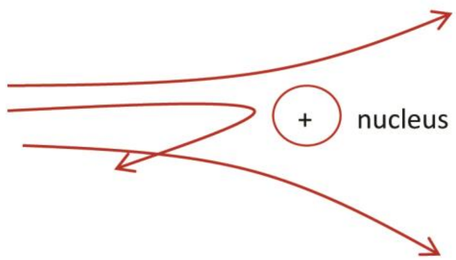
By thermopiles radiation falling on a hot junction produces e.m.f. the e.m.f is detected by the galvanometer connected across thermopile

(d) The atomic nucleus may be considered to be a sphere of positive charge with a diameter very much less than that of an atom. Discuss the experimental evidence which supports this view. (03marks)

In alpha particle experiment by Rutherford, most α- alpha particles passed through with negligible deflection. Some suffered various deviations. Very few were deflected back through angles greater than 90^0 due to head on collision with nucleus.

Majority of α-particles went through undeflected implying that most part of the atom is empty space.

About 1 in 8000 suffered deflection greater than 90^0 implying that the nucleus has a very small diameter compared to that of an atom



52. (a) (i) What are cathode rays? (01mark)

Cathode rays are abeam of fast moving electrons

(ii) An electron gun operating at 3 x 10^3V is used to project electrons into the space between two oppositely charged parallel plates of length 10cm and separation 5cm.

Calculate the deflection of the electrons as they emerge from the region between the charged plates when the potential difference is 1 x 10^3V. (03marks)

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

$v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2\ x\ 1.6\ x\ 10^{-19}\ \ x\ 3\ x\ 10^3}{9.11\ x\ 10^{-31}}}$ = 3.25 x 10^7ms^{-1}

$v_x = 3.25\ x\ 10^7 ms^{-1}$

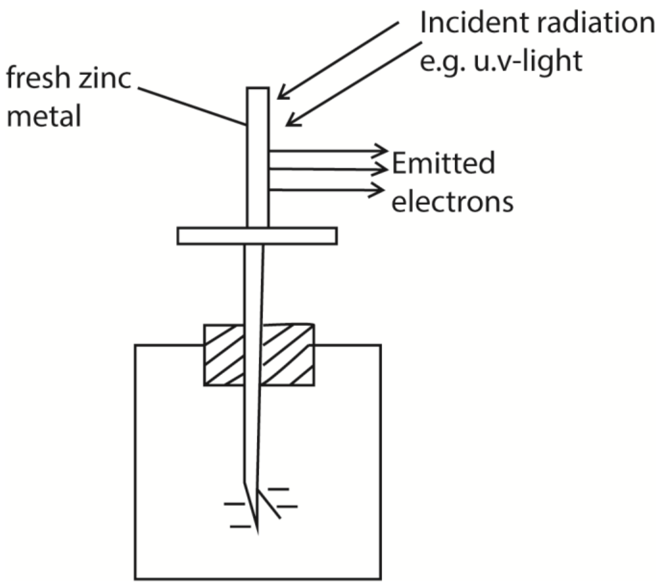
Deflection, y = $\frac{1}{2}at^2$ where t = $\frac{L}{u}$, a = $\frac{eE}{m}$, E = $\frac{V}{d}$

$= \frac{1.6\ x\ 10^{-19}\ x\ 1\ x\ 10^3\ x\ (10\ x\ 10^{-2})^2}{2\ x\ 9\ x\ 10^{-31}\ x\ 5\ x\ 10^{-2}\ x\ (3.25\ x\ 10^7)^2}$

= 1.67 x 10^{-2}m

(b) (i) Describe a simple experiment to demonstrate photoelectric emission. (04marks)

- A freshly cleaned Zinc plate is connected to the cap of a negatively charged gold leaf electroscope.
- Ultra violet radiations are allowed to fall on the zinc plate



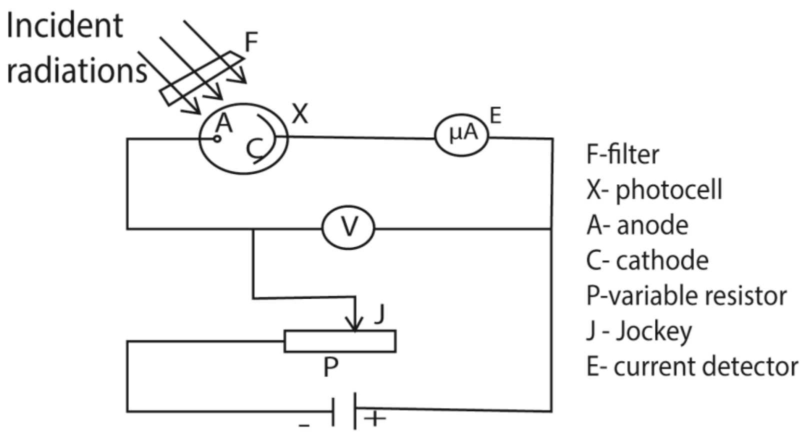
Observations

- The leaf of the electroscope gradually falls
- This shows that both the zinc plate and the electroscope have lost charges.
- The lost charges are found to be electrons, hence photoelectric effect has occurred.

(ii) Explain why the wave theory of light fails to account for the photoelectric effect. (06marks)

- Instantaneous emission: according to the wave theory radiation energy is uniformly spread over the whole wave front. Since the amount of energy incident on any electron would be extremely small, sometime would elapse before an electron escapes from the metal surface. On the contrary, no such a time lag between the start of radiation and start of emission is observed even when the radiation is weak.
- Variation of kinetic energy: by the wave theory, increasing intensity would mean more energy and hence greater value of maximum kinetic energy. But maximum kinetic energy depends on frequency of incident radiation and not intensity.
- Existence of threshold frequency: the wave theory predicts continuous absorption and accumulation of energy. Radiation of high enough intensity should cause emission even when the frequency is below minimum value. Hence the theory cannot account for threshold frequency.

(iii) Describe an experiment to verify Einstein's equation for the photoelectric effect and explain how Plank's constant may be obtained from the experiment. (06marks)



- A radiation of known frequency, f, is made incident on the photocathode
- Emitted electrons travel to the anode and cause a current to flow, detected at E.
- The p.d V is adjusted until the reading of E is zero (i.e. no current flows).
- The value of this p.d is the stopping potential (Vs) and is recorded from the voltmeter V.
- The procedure is repeated with light of different frequencies, f.
- A graph of stopping potential (Vs) against frequency (f) is plotted
- A straight line graph is obtained which verifies Einstein's equation; $V_s = \frac{h}{e}f - \frac{h}{e}f_0$
- The slope of the graph is $\frac{h}{e}$ from which Plank's constant, h, can be obtained.

53. (a) What is meant by

(i) half-life of radioactive element (01mark)

This the time taken for the number of active nuclei present in the source at a given time to fall to half its value

(ii) nuclear fission (01mark)

Nuclear fission is the splitting of heavy unstable nucleus into two nuclei accompanied by release of energy.

(iii) Nuclear fusion

Nuclear fusion is the combination of light nuclei to form a heavier nucleus accompanied by release of energy.

(b) An atom of ^{222}Ra emits an α-particle of energy 5.3eV. Given that the half-life of ^{222}Ra is 3.8days. Use the decay law, $N = N_0e^{-\lambda t}$ to calculate the:

(i) decay constant (03marks)

Decay constant, $\lambda = \frac{In\ 2}{t_{\frac{1}{2}}} = \frac{0.693}{3.8 \times 24 \times 60 \times 60} = 2.11 \times 10^{-6}s^{-1}$

(ii) amount of energy released by 3.0×10^{-9}kg of ^{222}Ra after 3.8days (05marks)

1mole of Radium weighs 222g = 0.222kg ≡ 6.02×10^{23} atoms

3.0×10^{-9}kg ≡ $\frac{6.02 \times 10^{23} \times 3 \times 10^{-9}}{0.222}$ = 8.135×10^{15} atoms

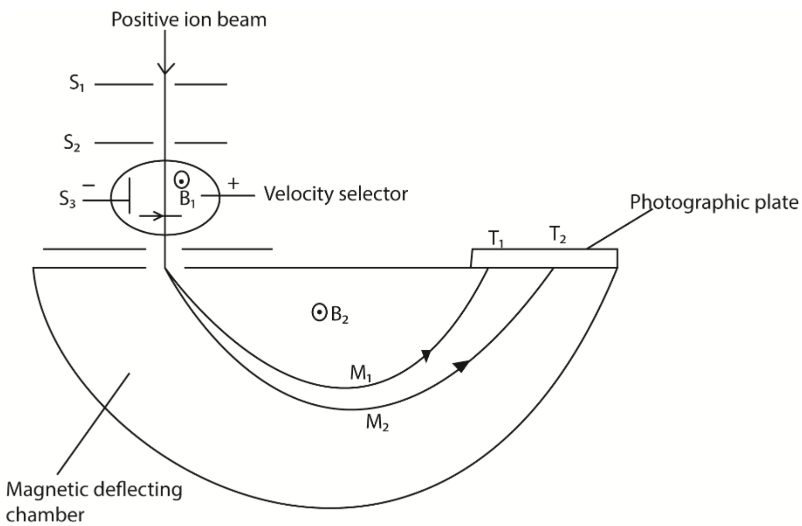
After 3.8 days, the number decays to half its original value

=> number of decayed atoms = $\frac{N_0}{2} = \frac{8.135\ x\ 10^{15}}{2}$ = 4.068 x 10^{15}

0ne atom releases 5.3MeV = 5.3 x 10^6 x 1.6 x 10^{-19} = 8.48 x 10^{-13}J

∴ 4.068 x 10^{15} atoms release 4.068 x 10^{15} x 8.48 x 10^{-13} = 3449J

(c) Describe a simple form of a mass spectrometer and explain how it is used to distinguish between isotopes (07marks)



T_1 and T_2 are tracers on photographic plate, S_1, S_2 and S_3 are slits

Mode of Action

- Positive ions are produced in a discharge tube and admitted as a beam through slits S_1 and S_2.
- The beam then passes between insulated plates P, Q, connected to a battery, which create an electric field of intensity E.
- A uniform magnetic field B_1, perpendicular to E is applied over the region of the plates and all ions, charge e with the same velocity, v given by B_1ev =Ee will then pass undeflected through the plates and through a slit S_3.
- The selected ions are deflected in a circular path of radius r by a uniform perpendicular magnetic field B_2 and an image is produced on a photographic plate as shown.
  In this case
  $$\frac{mv^2}{r} = B_2ev$$

But for the ions selected v = $\frac{E}{B_1}$ from above

$$\therefore \frac{m}{e} = \frac{rB_2B_1}{E}$$

r = $\left(\frac{E}{B_1B_2Q}\right)m$

thus different isotopes strike the photographic plate at different points.

(d) the nucleus of $^{37}_{17}Cl$ emits an α-particle followed by two β-particles. Show that the final nucleus is an isotope of chlorine (02mark)

$$^{37}_{17}Cl \rightarrow\ ^{4}_{2}He + 2\,^{0}_{-1}e +\ ^{33}_{17}Cl$$

54. (a) (i) Write down the Einstein photo-electric equation (01mark)

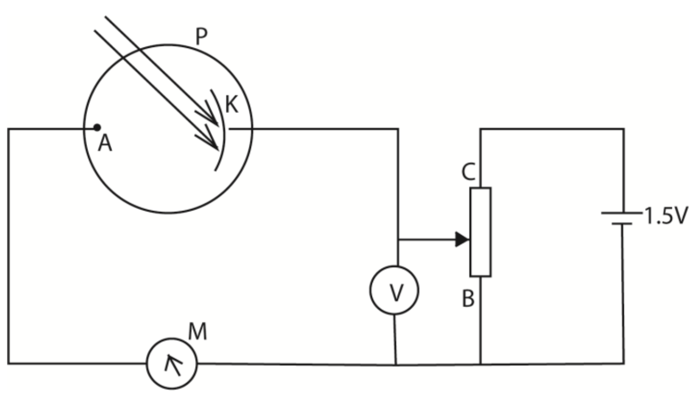
hf = hf$_0$ + ½ mv$^2_{max}$ where h = Plank's constant, f = frequency of incident radiation, f$_0$ = threshold frequency and v$_{max}$ is the maximum velocity of a photoelectron

(ii) Explain how the equation in (a)(i) above accounts for the emission of electrons from metal surfaces illuminated by radiation. (04marks)

Radiation consists of discrete packets of energy called photons, each of energy, hf, where f is the frequency. A free electrons absorb the whole amount of energy of a single photon or none.

If the energy is sufficient, part of it, hf$_0$, goes into overcoming nuclear attraction and the rest become kinetic energy of photoelectron. Thus the electron can escape from the metal.

(b)



P is a vacuum photocell with anode, A, and cathode, K, made from the same metal of work function 2.0eV. The cathode is illuminated by monochromatic light of constant intensity and wavelength 4.4 x 10^{-7}m

(i) Describe and explain how the current shown by the micro ammeter, M will vary as the slider of potential divider is moved from B to C. (03marks)
As the slider moves towards C, the cathode becomes more positive. This reduces the number of photoelectrons, photoelectric current decreases.

(ii) What will the reading of the high-resistance voltmeter, V, be when photo-electric emission just ceases? (03marks)

$$V = \frac{1}{e}\left(\frac{hc}{\lambda} - w_0\right) = \frac{1}{1.6 \times 10^{-19}}\left(\frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{4.4 \times 10^{-7}} - 2 \times 1.6 \times 10^{-19}\right) = 0.8125\text{V}$$

(c) With the slider set mid-way between B and C, describe and explain how the reading of M would change if

(i) the intensity of the light was increased, (03marks)

Increasing intensity increases the number of photons reaching the cathode per unit time. This in turn increases the number of electron emitted per second. At this point, the p.d across the photo cell is $\frac{1.5}{2} = 0.75V$. this is below the stopping potential (0.825V) reading. Therefore M also increases.

(ii) the wavelength of the light was changed to 5.5 x 10^{-7}m

$$w_0 = \frac{hc}{\lambda_o}$$

$\lambda_0 = \frac{6.6 \, x \, 10^{-34} \, x \, 3 \, x \, 10^{8}}{2 \, x \, 1.6 \, x \, 10^{-19}}$ = 6.1875 x 10^{-7}m

Since the new frequency is greater than the previous one, but greater than threshold, electrons will be emitted but with lower kinetic energy. The number of electrons emitted per second remain the same if the intensity remains constant. Hence reading of M remains the same.

55. (a) What is meant by the following

(i) an alpha particle, (01mark)

An alpha particle is helium nucleus

(ii) radioactivity (01mark)

Radioactivity is spontaneous disintegration of the nucleus with emission of radiation.

(b) Show that when an alpha particle collides head –on with an atom of atomic number Z, the closest distance of approach to the nucleus b_o, is given by

$$b_o = \frac{Ze^2}{\pi \varepsilon_0 m v^2}$$

where e is the electronic charge, ε0 is the permittivity of free space, m, mass of the alpha particle and v is the initial velocity of the particle. (06marks)

Initial K.E of alpha particle = ½ mv^2

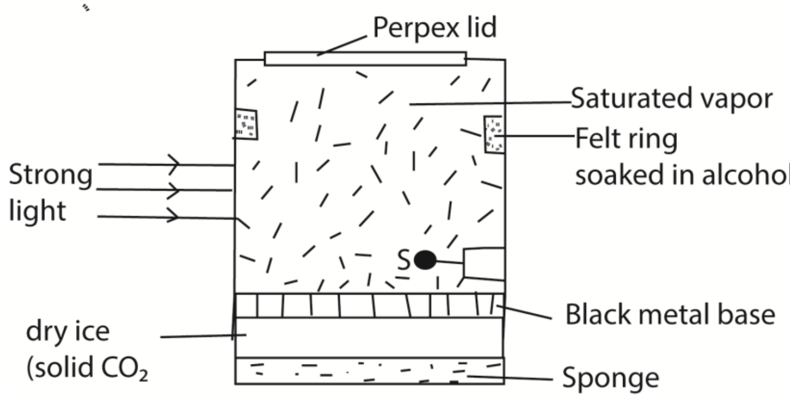
Electrostatic P.E of alpha particle and the nucleus at closet distance of approach = $\frac{Ze(2e)}{4\pi\varepsilon_0 b_0}$

At closest distance of approach, the α-particle is instantaneously at rest and its initial kinetic energy = electrostatic potential energy

Therefore $\frac{1}{2}mv^2 = \frac{Ze(2e)}{4\pi\varepsilon_0 b_0}$

$$b_0 = \frac{Ze^2}{\pi \varepsilon_0 m v^2}$$

(c) Describe the structure and action of a cloud chamber. (06marks)



- The base of the chamber is maintained at low temperature, about -80^{0}c by the solid carbon dioxide while the top of the chamber is at room temperature, and so there is a temperature gradient between the top and the bottom of the chamber.
- The air at the top of the chamber is saturated with alcohol vapor from the felt ring. This vapor continuously diffuse downwards into the cooler regions so that the air at the chamber is super saturated with alcohol vapor.
- Radiations from the radioactive source S cause the ionization of the vapor.
- The ionizations from the radioactive source S cause condensation of the vapor on the ions formed, hence the path of the ionizing radiations are traced by series of small droplets of condensation.
- The thickness and length of the path indicate the extent to which ionization has taken place.
- Alpha particles produce short, thick, continuous straight tracks
- Beta particles which are less massive produce longer, thin but straggly paths owing to collisions with gas molecules
- Gamma radiations are uncharged and for ionization to take place, it must collide with an atom and eject an electron which then ionizes the vapor.

(d) State four uses of radioactive isotopes (02marks)

- Detecting leakage in underground pipes
- Measuring rate of flow of liquids
- Tracing fertilizers using phosphorus-32
- Treatment of cancer

(e) one kilogram of wood from a ship wreck has activity of 1.2 x 10^2 counts per second due to ^{14}C, whereas the same amount of wood had an activity of 2.0 x 10^2counts per second. Find the age of the ship wreck. [Half-life of 14C = 5.7 x 10^3years] (04 marks)

λ = $\frac{In\ 2}{t_{\frac{1}{2}}} = \frac{0.693}{5.7\ x\ 10^3}$ = 1.22 x 10^{-4}year^{-1}

Using A = $A_0e^{-\lambda t}$

In $\left(\frac{2\ x\ 10^2}{1.2\ x\ 10^2}\right) = 1.22\ x\ 10^{-4}t$

t = 4187years

56. (a) What is meant by emission line spectra?

When a gas is heated to high temperatures, electronic transition occur from low to high energy levels. As electrons return to lower energy levels radiation of wavelength λ are emitted such that $\frac{hc}{\lambda}$ = energy difference between the initial and final levels is given off. The radiation consists of a series of lines when viewed through grating.

E_∞ …………………………………………………………	0eV
E_4…………………………………………………………	-0.81eV
E_3…………………………………………………………	-2.77eV
E_2…………………………………………………………	-4.87eV
E_1…………………………………………………………	-27.47eV

(ii) The figure above shows some energy levels of neon. Determine the wavelength of the radiation emitted in an electron transition from E_4 to E_3. In what region of the electromagnetic spectrum does the radiation lie? (04marks)

$$\frac{hc}{\lambda} = E_4 - E_3$$

$$\lambda = \frac{6.6 \ x \ 10^{-34} \ x \ 3 \ x \ 10^{8}}{(2.77-0.81) \ x \ 1.6 \ x \ 10^{-19}} = 6.31 \times 10^{-7}\text{m}$$

(b) Outline the principles of generation of continuous line spectra of X-rays in X-ray tube. (05marks)

Electrons make multiple collisions with the target atoms. During the collision, X-rays of different wavelength are produced. This gives a continuous X-ray spectrum.

When energetic electrons strike a target atom, an electron from innermost energy levels is displaced to higher energy levels leaving a vacancy and making an atom unstable. When the electron returns to the lower energy level, X-rays characteristic to target atoms are given off leading to X-ray line spectra

(c) State Bragg's law of X-ray diffraction. (01mark)

For two neighboring crystal planes separated by a distance, d, for diffraction, 2dsinθ = nλ; where λ = wavelength of incident radiation, θ = glancing angle, and n = order of diffraction.

(d) A beam of X-rays of wavelength 1.0×10^{-10}m is incident on a set of cubic planes in a sodium chloride crystals. The first order diffraction m is obtained for a grazing angle of 10.2^0.

Find

(i) The spacing between consecutive planes (03marks)
From 2dsinθ = nλ

$d = \frac{1 \, x \, 1 \, x \, 10^{-10}}{2sin10.2}$ = 2.82 x 10^{-10}m = 2.82 x 10^{-8}cm

(ii) The density of the sodium chloride (04marks)

Molecular mass of NaCl = 58.5g

1mole contain 6.02 x 10^{23}molecules

6.02 x 10^{23} molecules weigh 58.5g

1molecule weighs = $\frac{58.5}{6.02 \, x \, 10^{23}} g$

Volume occupied by 1molecule (2atoms- Na and Cl) = $\frac{mass}{density}$

$$= \frac{58.5}{6.02 \, x \, 10^{23} \, x \, density \, of \, NaCl}$$

Volume associated with each atom = $\frac{1}{2} \, x \, \frac{58.5}{6.02 \, x \, 10^{23} \, x \, density \, of \, NaCl}$ for cubic lattice

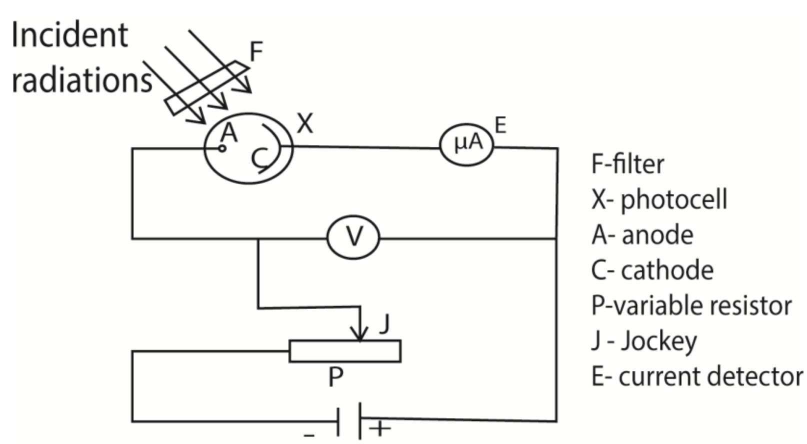
$d^3 = \frac{1}{2} \, x \, \frac{58.5}{6.02 \, x \, 10^{23} \, x \, density \, of \, NaCl}$

density of NaCl = $\frac{58.5}{6.02 \, x \, 10^{23} \, x \, (2.82 \, x \, 10^{-8})^3}$ = 2.165gcm^{-3}

57. (a) State the laws of pho electric emission. (04marks)

- The time lag between irradiation of the metal surface and emission of the electrons by the metal surface is negligible.
- For a given metal, surface there is a minimum value of frequency of radiation called threshold frequency (f_0) below which no photo electrons are emitted from the metal however intense the incident radiation may be.
- The number of photoelectrons emitted from the surface per second is directly proportional to the intensity of incident radiation for a particular incident frequency
- The K.E of the photoelectrons emitted is independent of the intensity of the incident radiation but depends only on its frequency

(b) (i) Describe an experiment Plank's constant. (05marks)



- A radiation of known frequency, f, is made incident on the photocathode
- Emitted electrons travel to the anode and cause a current to flow, detected at E.
- The p.d V is adjusted until the reading of E is zero (i.e. no current flows).
- The value of this p.d is the stopping potential (Vs) and is recorded from the voltmeter V.
- The procedure is repeated with light of different frequencies, f.

- A graph of stopping potential (Vs) against frequency (f) is plotted
- A straight line graph is obtained which verifies Einstein's equation; $V_s = \frac{h}{e}f - \frac{h}{e}f_0$
- The slope of the graph is $\frac{h}{e}$ from which Plank's constant, h, can be obtained.

(ii) Violet light wavelength 0.4µm is incident on a metal surface of threshold wavelength 0.65µm. Find the maximum speed of emitted electrons

From $hf = hf_0 + ½ mv^2$

$$v = \sqrt{\frac{2hc}{m}\left(\frac{\lambda_0 - \lambda}{\lambda_0\lambda}\right)} = \sqrt{\frac{2x\ 6.6\ x\ 10^{-34}\ x\ 3\ x\ 10^{8}}{9.11\ x\ 10^{31}}\left(\frac{0.65-0.4}{0.4\ x\ 0.65}\right)x\ 10^{-6}} = 6.48 \times 10^6 ms^{-1}$$

(iii) Explain why light whose frequency is less than the threshold frequency cannot cause photoemission. (02marks)
According to the quantum theory, radiation is absorbed or emitted in discrete packets of energy called quanta with energy hf. Therefore light of frequency less than threshold would not be absorbed.

(c) (i) What are X-rays? (01marks)

X-ray are electromagnetic radiation of very short wavelength produced when fast moving electrons are stopped by metal target.

(ii) Explain how the intensity and penetrating power of X-rays produced by an X-ray tune can be varied. (04marks)

Intensity is the power transmitted per unit area. It is controlled by the filament current which determines the number of electrons striking the anode per second. The greater the filament current, the greater the number of electrons striking the anode per second and the greater the intensity.

Penetrating power is controlled by p.d between the filament and the anode which determines the kinetic energy with which electrons strike the anode.

58. (a)(i) Define the terms half-life and decay constant as applied to radioactivity. (02marks)
Half-life is the time taken for the number of active nuclie in a source at a given time to fall to half its value.
Decay constant is the number of nuclei decaying per unit time.

(ii) State relationship between half-life and decay constant. (01mark)

Half-life, $t_{½} = \frac{In\ 2}{decay\ constant,\ \lambda}$

(b) The radioisotope ^{60}Co decays by emission of a β-particle and γ-rays. Its half-life is 5.3years.

(i) find the activity of a source containing 0.10g of ^{60}Co. (04marks)

60g of cobalt contains 6.02×10^{23} atoms

0.1g of cobalt contain $\frac{6.02\ x\ 10^{23}\ x\ 0.1}{60}$ = 1 x 10^{21}atoms

From activity = λN = $\frac{In\ 2N}{decay\ constant,\ \lambda}$ = $\frac{0.693\ x\ 1\ x\ 10^{21}}{5.3\ x\ 365\ x\ 24\ x\ 60\ x\ 60}$ = 4.15 x $10^{12}s^{-1}$

(ii) In which ways do γ-rays differ from β-particles (03marks)

Beta particle	Gamma rays
Negatively charges	No charge
Deflected by electric and magnetic field	Not affected by magnetic and electric field

(c) (i) What is meant by mass defect in nuclear physics? (01mark)

Mass defect is the difference in the mass of the constituents of a nucleus and mass of the nucleus

(ii) Calculate the mass defect for $^{59}_{26}Fe$, given the following information

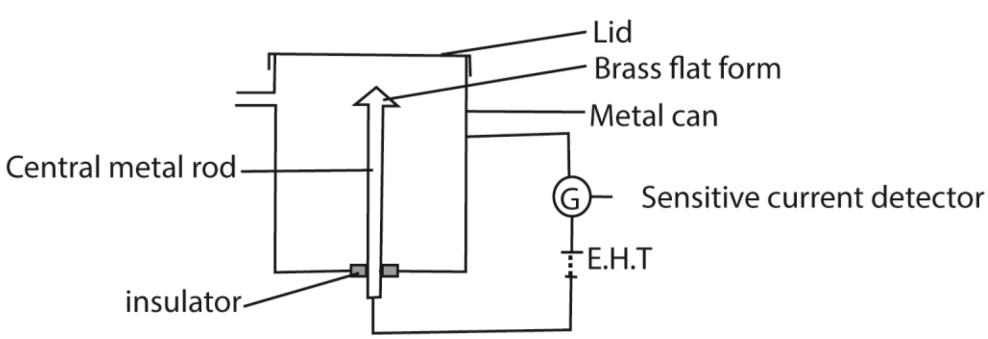
Mass of $^{59}_{26}Fe$ nucleus = 58.93488u

Mass of a proton = 1.00728u

Mass of neutron = 1.00867u (04marks)

Mass defect = (26 x 1.0072 + 33 x 1.00867) – 58.93488 = 0.53733U

(d) Describe the structure and action of ionization chamber. (05marks)

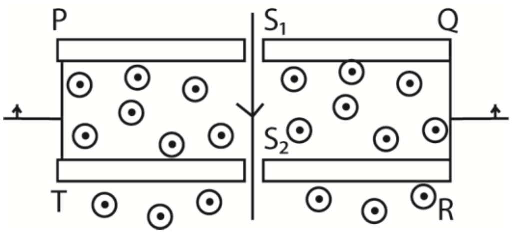


- A radiation source on the brass flat form causes ionization of air in the chamber producing electrons and positive ions.
- The electrons move to the metal can and positive ions drift to the central metal rod.
- Movement of the ions to the electrodes causes discharge and current pulse flows in external circuit.
- The current sensitive detector detects current.
- The magnitude of current detected shows the extent to which ionization takes place.

59. (a) What is meant by specific charge of an ion? (01mark)

It is the ratio of the charge to the mass of an ion.

(b)



Positive ions of the same charge are directed through slit S_1 into a region PQRT as shown in the figure above. There is a uniform electric field of intensity 300NC^{-1} between the plate PT and QR. A uniform magnetic field of flux density 0.6T is directed perpendicularly out of the paper as shown above.

(i) Calculate the velocity of the ions which go through slit S_2. (03marks)

Since the ions follow a straight line it implies that electrostatic force = magnetic force

qE = Bqv

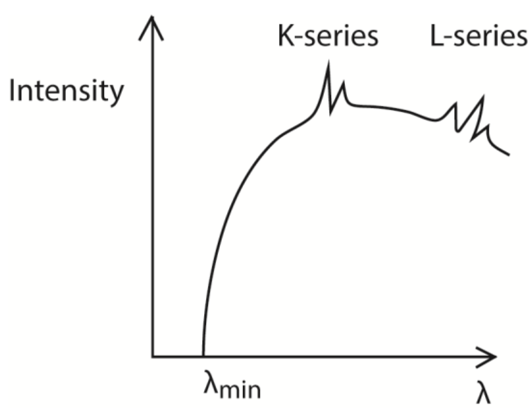
$v = \frac{E}{B} = \frac{300}{0.6} = 500ms^{-1}$

(ii) Describe the motion of ions in the region TR. (3marks)

The path of ions in magnetic field is circular and the path is perpendicular to magnetic field due to the magnetic force producing a centripetal force.

(c) When fast moving electrons strike a metal target in X-ray tube, two type of X-ray spectra are produced

(i) Draw a sketch graph of intensity against wavelength of the X-rays (02marks)



(ii) Account for the occurrence of the two types of spectra (05marks)

The spectrum consists of two major components, i.e. the continuous (background) spectrum and the very sharp line spectrum superimposed onto the background spectrum.

The continuous spectrum is produced when electrons make multiple collisions with the target atoms in which they are decelerated. At each deceleration, X-rays of differing wavelength are produced.

The shortest Wavelength X-rays are produced when electrons lose all their energy as X-ray photon in a single encounter with the target atoms. The wavelength of the X-rays at this point is known as the cut off wavelength. At cut off wavelength, energy in an X-ray photon equals kinetic energy of the electron; i.e. hf = eV or $\frac{hc}{\lambda_{max}} = eV$ where V = p.d

The line spectrum

At high tube voltages, the bombarding electrons penetrate deep into the target atoms and knock out electrons from inner shell. The knocked out electrons occupy vacant spaces in higher unfilled shells putting the atom in excited state and making them unstable.

Transition of an electron from higher to lower energy levels results in an emission of X-ray photon of energy equal to energy difference between the energy levels.

If the transition ends in the K-shell, it produces K-series and if the transition ends in L-shell. It produces L-series.

(d) Outline the experimental evidences for the quantum theory of matter. (06marks)

The quantum theory of matter states that energy of a radiation exists in discrete packets of magnitude hf where h is Plank's constant and f is the frequency. Some evidences are

- Photoelectric effect: to liberate an electron from a metal surface, a quantum (or packet) of energy called work function which is characteristic of the metal has to be supplied.
- Optical spectra: a line in optical emission spectrum indicates presence of a particular frequency, f, of light considered to arise from loss of energy which occurs in an excited atom when electron jumps directly or in steps from a higher energy level E_2 to lower energy level (s), E_1. The frequency of a photon= hf = $E_1 - E_2$.
- X-ray line spectra: electron transition from one shell to another leads to liberation of energy in packets which are characteristic of the target atom