CHAPTER - 18
MODERN PHYSICS

SYNOPSIS

Introduction

At normal conditions most of the gases do not conduct electricity. However, it can be made conducting by (i) applying a very high voltage (ii) by reducing the pressure of the gas to a very low value, or (iii) by irradiating the gas with certain radiations such as γ-rays, X-rays, u-v rays etc. The process of splitting up gas molecule into +ve and –ve ions is called ionisation. If the ionisation is taking place in a tube having +ve and –ve electrodes the arrangement is called a discharge tube. Then +ve and –ve ions move in opposite directions constituting an electric current called ionisation current. The flow of electric current through gases is called discharge of electricity through gases.

The experiments with discharge tubes led to the discovery of X-rays by Roentgen in 1895 and cathode rays (electron) by J.J Thomson in 1897.

Electrons and Photons

Experimental studies on conduction of electricity through gases at low pressures led to the discovery of electrons by J. J. Thomson.

1. The specific charge $\left(\frac{e}{m}\text{value}\right)$ of the electron is determined by Thomson as 1.76×10^{11} C/kg

2. The charge of the electron is determined by Millikan as 1.602×10^{-19} C

3. The mass of the electron is then calculated as 9.11×10^{-31} kg

4. The electron is the integral part of all constituents of matter in all forms and the charge carried by it is considered as the basic unit of charge

According to ***Planck's quantum theory,*** light consists of tiny packets of energy called quanta or photons of energy $h\upsilon$ and momentum h/λ

Electron Emission

Free electrons in the metals are responsible for their electrical conductivity. But, the free electrons normally, can not escape from the metal. A certain energy is required for the emission of electron.

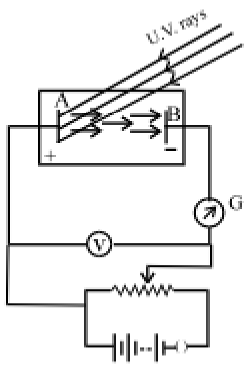
The minimum energy required to escape an electron from a metal surface is called the **work function** ϕ_0 of that metal, and is expressed in eV (electron volt) [One eV is the KE acquired by an electron when it is accelerated through a p.d of 1 volt ie, 1eV = 1.602 × 10^{-19}C × 1V = 1.602 × 10^{-19}J].

Metal	ϕ_o ***in eV***	***Metal***	ϕ_o ***in eV***
Cs	2.14	Al	4.25
K	2.30	Cu	4.65
Na	2.75	Ag	4.75
Ca	3.20	Ni	5.15
Pb	4.25	Pt	5.65

The minimum energy required for the electron emission can be supplied by one of the following methods (i) By heating (thermionic emission) (ii) By applying very strong electric field of the order of 10^8 V m^{-1} (field emission) (iii) By irradiating the surface with light rays of suitable frequencies (Photoelectric emission)

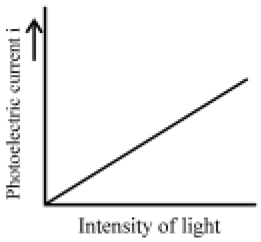
Photoelectric Emission : Discovered by Hertz. The phenomenon of emission of electrons from the surface of the metals when irradiated with γ rays, X-rays, U.V rays or visible rays is called Photoelectric emission.

Experimental Study



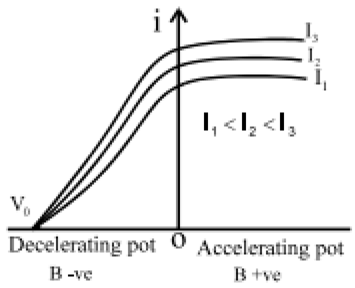
As p.d between A and B is increased, photoelectric current i decreases and becomes zero at a p.d V_0. This p.d is called cut off potential or stopping potential. At this conditions, the maximum KE of the emitted electron $\frac{1}{2}mv_{max}^2 = eV_0$

Effect of intensity of light



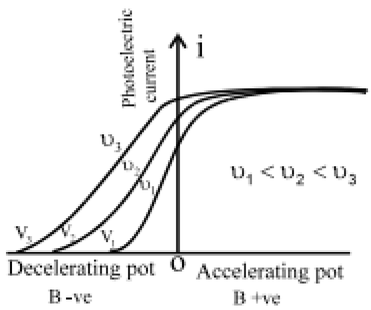
Photoelectric current i or number of photoelectrons emitted is directly proportional to intensity of light.

Effect of p.d between A and B



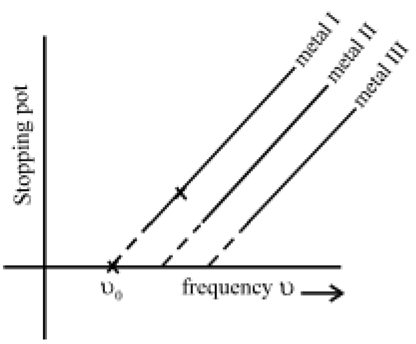
1. Saturation current value increases with intensity I of incident light
2. Cut-off potential V_0 is independent of intensity

Effect of Frequency



1. Saturation current is same for all frequencies when intensity remains constant
2. Below saturation value photoelectric current depends on frequency - the higher the frequency the larger the current.
3. Stopping potential is different for different frequencies - the higher the frequency the greater (-ve value) the stopping potential.

Frequency and stopping potential



The graph with stopping potential against frequency is a straight line for all metals. These lines are parallel and are having same slope $\frac{h}{e}$ (h is Planck's constant and e is the charge of electron). Frequency ν_0 is called the **threshold frequency** the minimum frequency for photo electric emission.

Einstein's Equation

The electron absorbs the entire energy of only one photon. Part of this is used as work function $(\phi_0 = h\upsilon_0)$ and the rest remains as KE.

Then $\frac{1}{2}mv_{max}^2 = h\nu - h\nu_0$

Also $\frac{1}{2}mv_{max}^2 = h(\nu - \nu_0) = eV_0$

Discussion

1. Velocity and hence KE of photoelectrons depends on the frequency ν of incident lights.

2. If $\nu \le \nu_0$ there is no emission of photoelectrons

3. When intensity of light increases, number of photoelectrons emitted increases and hence photoelectric current increases

4. When frequency of light increases stopping potential increases (-ve value).

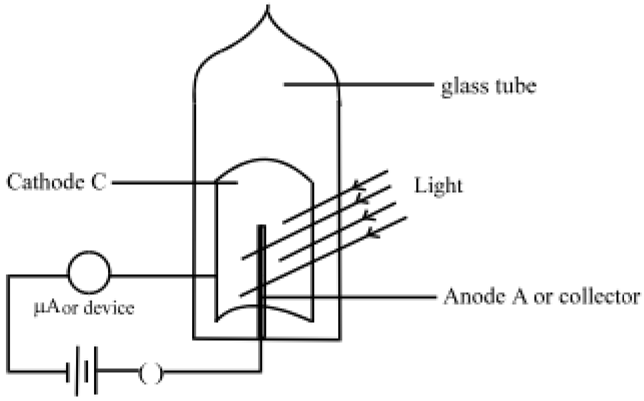
5. If V_0 is the stopping potential, $\frac{1}{2}mv_{max}^2 = eV_0 = h\nu - h\nu_0$

$$V_0 = \frac{h}{e}\nu - \frac{h}{e}\nu_0$$

$\frac{h}{e}$ is the slope of the graph between V_0 and ν

Photocell : is a device used to convert light energy to electrical energy. There are three types of photocells. Viz (i) photo emissive cell (ii) photo voltaic cell and (iii) photo conductive cell.

Photo emissive cell



It consists of a glass tube containing a cathode C and anode A. When light incident on C, photoelectrons are emitted and are collected by A producing a current in the circuit. The change in intensity of light produces corresponding change in photoelectric current in the circuit.

Photocells are used in burglar alarms, automatic switching arrangements, reproduction of sound in cinemas, automatic counting devices etc.

Particle nature of Radiation - According to Planck, light consists of tiny packets of energy called quanta or photons of energy value $h\nu$ and momentum $\frac{h}{\lambda}$. Momentum of photon $P = mc = \frac{h}{\lambda}$ or $\lambda = \frac{h}{mc}$

λ is the attribute of a wave while mc is an attribute of a particle. This shows the dual nature of radiation.

Wave nature of particle

From the particle nature of radiation, Louis de Broglie, argued that what is true for radiation must be true for particles also. ie, for a particle of mass m moving with a velocity v a wave must be associated with it. This wave is called de Broglie wave or matter wave. The wave length of de Broglie wave, $\lambda = \frac{h}{mv}$

de Broglie wavelength of an accelerated electron

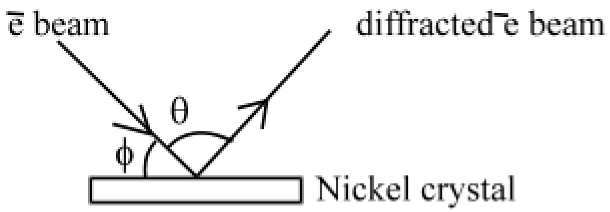
Velocity of electron accelerated through a p.d of V volts. $v = \sqrt{\frac{2eV}{m}}$

$\therefore$ de Broglie wavelength of the electrons $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2meV}} = \frac{12.27}{\sqrt{V}} A^o$

For V = 100 volts, $\lambda = 1.227 A^o$

This was verified by Davisson and Germer.

Davisson and Germer Experiment



Davisson and Germer allowed the electron beam accelerated through 54 volt to fall on a nickel crystal. They measured maximum intensity of diffracted electron beam at an angle $\theta = 50^\circ$. Then, the glancing angle $\phi = \frac{180 - \theta}{2} = 65^\circ$. Using this value in Bragg's equation for X-ray diffraction $2d\sin\phi = n\lambda$ (here $d = 0.91\,\overset{\circ}{A}$ for nickel and n = 1) they calculated λ as $1.65\,\overset{\circ}{A}$. This is in close agreement with the theoretical value $\lambda = \frac{h}{P} = \frac{12.27}{\sqrt{54}} \times 10^{-10} = 1.66\,\overset{\circ}{A}$.

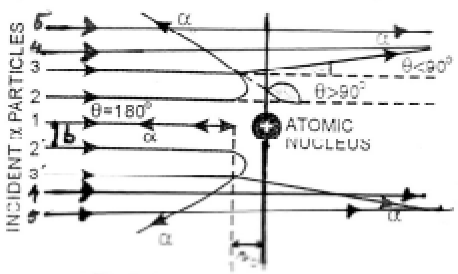
Teaching Points

1. Basic idea of electron emission
   i) Thermionic emission
   ii) Field emission
   iii) Photoelectric emission
   iv) Secondary emission
2. Photoelectric effect
   i) Basic idea
   ii) Experimental study
   iii) Effect of intensity of light on photocurrent
   iv) Effect of potential on photoelectric current
   v) Effect of frequency of incident radiation on stopping potential
3. Drawbacks of wave theory
4. Einstein's photo electric explanation
   $\Rightarrow$ Idea of quantum of energy
   $\Rightarrow$ Photoelectric equation
   $\Rightarrow$ Particle nature of radiation
5. Wave nature of Matter
   i) De Broglie wavelength
   ii) Relation between accelerating potential & de Broglie wavelength
   iii) Matter-wave picture & uncertainty principle

6. Davisson and Germer experiment

Atomic Structure and Spectrum

The first atom model was proposed by Thomson. The model failed to explain the origin of spectral lines from the atom and the large angle scattering of α-particles. Then Rutherford proposed another model of atom. According to Rutherford, the atom consists of a central core called atomic nucleus, where the mass and positive charge of the atom are concentrated and the electrons are moving round the nucleus in circular orbits. This model explained large angle scattering of α-particles. The distance of closest approach $r_0 = \frac{1}{4\pi\epsilon_0}\frac{Ze.2e}{\frac{1}{2}mv^2}$



Impact parameter b is given by b = $\frac{1}{4\pi\epsilon_0}\frac{Ze^2}{\frac{1}{2}mv^2}\cot(\theta/2)$

Number of atoms scatterd at an angle θ, $N_\theta = \frac{N_0 nt(2Ze^2)^2}{4(4\pi\epsilon_0)^2 r^2 (mv_0^2)^2}\cdot\frac{1}{\sin^4(\theta/2)}$ or, $N_\theta \alpha \frac{1}{\sin^4(\theta/2)}$

Rutherford measured the size of the nucleus as of the order 10^{-15} m (ie, fm) and atoms as of the order of 10^{-10}m (ie, A^0). But, the model failed to explain the origin of spectral lines from the atoms.

Bohr Atom Model

Bohr modified Rutherford atom model by introducing certain postulates.

1. Every atom consists of the central nucleus and the electrons are revolving round the nucleus in specified orbits. The centripetal force required for the motion is given by

$$\frac{mv^2}{r} = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r^2}$$

For hydrogen Z = 1; $\therefore \frac{mv^2}{r} = \frac{1}{4\pi\epsilon_r}\cdot\frac{e^2}{r^2}$........................(1)

2. The electrons can revolve only in orbits for which the angular momentum is an integral multiple of $\frac{h}{2\pi}$

ie; mvr = $n\frac{h}{2\pi}$..............................(2)

3. Electrons revolving in the orbit do not radiate energy.
4. Energy is radiated when the electrons jump from an outer orbit to inner orbit. The energy radiated is given by, $h\upsilon = E_2 - E_1$ ....(3)

Calculations for hydrogen atom Z = 1

Radius of the orbit r_n

Sq. eq (2) and devide by eq. (1) $r = r_n = \dfrac{\epsilon_0 h^2}{\pi me^2}.n^2$ ......(4)

or ; $r_n = 0.53\ n^2\ A^0$ ....(5)

Velocity of electon v_n

Dividing eqn. (1) by eq (2) $v = v_n = \dfrac{e^2}{2\epsilon_0 h}\dfrac{c}{c}.\dfrac{1}{n}$

or, $v_n = \dfrac{1}{137}\dfrac{c}{n}$ ....(6)

$\dfrac{e^2}{2\epsilon_0 hc} = \dfrac{1}{137} = \alpha$ is called fine structure constant.

Period of revolution of the electron T_n

Period $T_n = \dfrac{2\pi r_n}{v_n} \quad \infty\ n^3$ ....(7)

Energy of electron in the orbit E_n

KE = $\dfrac{1}{8\pi\epsilon_0}\dfrac{e^2}{r^2}$; $PE = -\dfrac{1}{4\pi\epsilon_0}\dfrac{e^2}{r^2}$

TE = KE + PE = E = $E_n = \dfrac{-1}{8\pi\epsilon_0}\dfrac{e^2}{r^2}$

Substituting for r, $E = E_n = \dfrac{-me^4}{8\epsilon_0^2 h^2}.\dfrac{1}{n^2}$ .... (8)

In terms of fine structure constant $E_n = -\dfrac{1}{2}mc^2\alpha^2.\dfrac{1}{n^2}$

In eV, $E_n = -13.6.\dfrac{1}{n^2}$ ....(9)

For n = 1 ie; ground state, $E_1 = -13.6eV,\ KE = 13.6eV,\ PE = -27.2\,eV$

Spectral lines

From eqn (3) $h\upsilon = E_{n_2} - E_{n_1}$

ie; $h\upsilon = h\frac{c}{\lambda} = \frac{1}{2}mc^2\alpha^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ or , $\frac{1}{\lambda} = \bar{\upsilon} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$........................(10)

λ is the wavelength, $\bar{\upsilon}$ wave number

R is Rydberg constant, R = $\frac{1}{2}mc^2\alpha^2 = 1.097 \times 10^7 m^{-1}$

For hydrogen like atoms

$r_n = \frac{1}{Z}.r_n$ of H, $\qquad V_n = Z \times V_n$ of H

$E_n = Z^2 \times E_n$ of H, $\qquad \frac{1}{\lambda} = Z^2 \times \frac{1}{\lambda}$ of H

Spectral series

1. For Lyman Series (U.V. rays) $n_1 = 1$, $n_2 = 2, 3, 4, 5$...............
2. For Balmer series (Visible rays) $n_1 = 2$, $n_2 = 3, 4, 5$,.................
3. For Paschen series (Infra red rays) $n_1 = 3$, $n_2 = 4, 5, 6$, ...
4. For Bracket series (Infra red rays) $n_1 = 4$, $n_2 = 5, 6, 7$, ...
5. For Pfund series (Far infrared rays) $n_1 = 5$, $n_2 = 6, 7, 8$, ...

Spectrum - Emission spectra and Absorption spectra

Emission spectra are of three types

1. Line spectrum : is obtained when substances in atomic state are excited.

   Eg : H spectrum, Hg spectrum, Sodium lamp
2. Band spectrum : is obtained when substance is in molecular state are excited.

   Eg : O_2, N_2, CO_2
3. Continuous spectrum : is obtained when matter in bulk is excited

   Eg : Carbon arc, copper arc, hot filament lamp.

Absorption spectra is obtained when a composite light is passing through a less intense medium and the transmitted light is examined through a spectro graph. If the medium is in atomic state, *absorption line spectrum* is obtained and if the medium is in molecular state *absorption band spectrum* is obtained.

ATOMIC NUCLEI

Atomic nucleus is the central part of every atom. Its size is of the order of 1 fm or 10^{-15} m. The mass of the nucleus is more than 99.9% of the mass of the atom and is expressed in atomic mass unit (a.m.u) or simply u.

1 amu = $\frac{1}{12}$ of mass of $_6C^{12}$ = 1.66×10^{-27} kg. When 1 a.m.u is fully converted into energy, the energy produced is 1.49×10^{-10} J.

$1 \text{ a.m.u.} = 931 \text{ MeV}$

The nucleus of an atom is represented by $_zX^A$ or ^A_ZX

Where Z is the atomic number ie, number of protons and A is the atomic mass number ie, total number of protons and neutrons

<u>Nuclear size</u> : The nucleus is assumed to be almost spherical. Its volume $\frac{4}{3}\pi R^3 \alpha A$

$\therefore R^3 \alpha A$ or, $R = R_0 A^{1/3}$; R_0 = 1.2 fm to 1.3 fm

Nuclear density : $\rho = \frac{\text{mass}}{\text{volume}} = \frac{\mu A}{\frac{4}{3}\pi R_0^3 A} = 2.29 \times 10^{17} \text{ kg/m}^3$

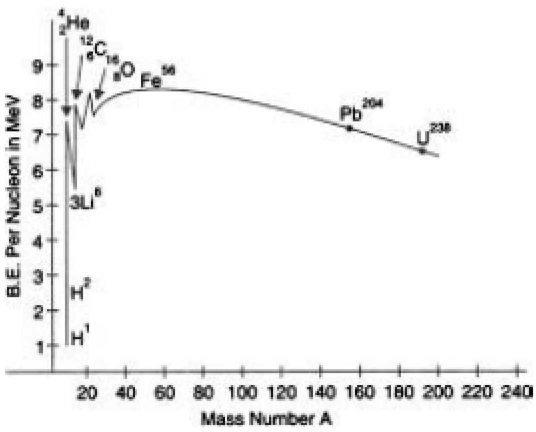
Conservation Laws : The sum of mass-energy, the momentum and the total charge are conserved before and after any nuclear interactions.

<u>Binding Energy and mass defect</u>

BE = mass defect x c^2

BE = $(Z m_p + (A - Z) m_n - M_N)c^2$

$M_N \rightarrow$ mass of nucleus



The importance of BE curve is that it led to the possibility of release of energy during nuclear fission and fusion.

<u>Nuclear forces :</u> Nuclear forces are the strongest attractive forces and are existing between nucleons - which are independent of charge, short range, non central, non-conservative and not obeying inverse square law. The nuclear forces are dependent on spin or angular momentum of nuclei. According to Yukawa, the exchange of π mesons is responsible for nuclear forces.

Natural Radio Activity

It is the spontaneous emission of certain active radiations from the nucleus of the atoms of certain elements. The emitted radiations contain α-particles, β-particles and γ-rays.

Decay Law - Rutherford and Soddy law.

Number of atoms disintegrated per second at any instant is directly proportional to the number of radio active atoms actually present in the sample at that instant.

ie; $\frac{dN}{dt} \alpha N$ or , $\frac{dN}{dt} = -\lambda N$

$\therefore$ Number of atoms left undecayed after t seconds N = $N_0 e^{-\lambda t}$

Half life period T is the time required to decay half the number of atoms initially present in the sample.

T = $\frac{0.693}{\lambda}$

Number of atoms left undecayed after n half life periods is, $N_n = N_0\left(\frac{1}{2}\right)^n = N_0\left(\frac{1}{2}\right)^{\frac{t}{T}}$

Mean life time τ

$$\tau = \frac{1}{\lambda} = \frac{T}{.693} = 1.44\ T$$

Activity A . The rate of disintegration is the activity A. Then, $A = \frac{dN}{dt} = \lambda N = \lambda N_0 e^{-\lambda t}$

Or, A = $A_0 e^{-\lambda t}$

Units of Radioactivity

1) Curie (Ci)

2) Becquerel (Bq) SI unit

3) Rutherford (Rd)

α *-decay:* Emission of an α-particle from the nucleus of an atom is α-decay. It is represented by ${}_ZX^A \rightarrow {}_{Z-2}Y^{A-4} + {}_2He^4 + Q$.

${}_ZX^A$ is parent nucleus ${}_{Z-2}Y^{A-4}$ is daughter nucleus Q is disintegration energy which remains as KEs of product particles.

β *-decay* means emission of an electron (β^-) or positron (β^+) from the nucleus. It is found that a (β^-)

emission is accompanied with the emission of an antineutrino $(\bar{\upsilon})$ and (β^+) emission is accompanied with emission of a neutrino (υ).

γ *-decay or emission*

After an α-decay or β-decay the daughter nucleus is usually in an excited state. It attains stability by the emission of one or more γ-ray photons.

Nuclear fission is the process of splitting the nucleus of a heavy atom in to two nuclei of nearly equal mass with release of large energy.

Eg : ${}_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{144} + {}_{36}Kr^{89} + 3{}_0n^1 + 200\ \text{MeV}$

The three neutrons released can produce further fission and the process is going on, resulting in chain reaction. An uncontrolled chain reaction results in explosion (atom bomb) and a controlled chain reaction gives controlled release of energy and is achieved in nuclear reactors. The main parts of a nuclear reactor are (1) nuclear fuel (U^{235} or Pu^{239}) (2) Moderators - (heavy water, parafin) and control rods (Boron, Cadmium)

Nuclear Fusion : is the fusion of two light nuclei into a single nucleus with release of large energy. This requires large KE and hence very high temperature of the order of 10^7 K. So, fusion process is taking place in the sun and the stars. Then, the process is also called thermonuclear process.

Teaching Points

I. Basic idea of atomic structure
   a) Plum pudding model
   b) α-particle scattering experiment and Rutherford's atom model
   c) Scattering angle
   d) Closest distance of approach
   e) Impact parameter

II. Rutherford's model of hydrogen atom
   a) Radius of orbit
   b) Orbital velocity
   c) Energy of atom

III. Draw back of Rutherford's model

IV. Bohr model
   a) Bohr hypothesis or Bohr postulates
   b) Bohr model of hydrogen atom
   c) Bohr model of hydrogen-like atom

V. Atomic spectra
   a. Emission spectrum
   b. Absorption spectrum

NUCLEI

I. Atomic mass and composition of nucleus
  a) Atomic mass unit
  b) Proton and neutron
  c) Atomic number, mass number, isotope, isobar, isotone

II. Size of nucleus
  a) Radius of a nucleus
  b) Nuclear density

III. Mass-Energy relation
  a) Einstein's relation
  b) Mass defect, Binding energy, Binding energy per nucleon
  c) Binding energy per nucleons and mass number curve
  d) Nuclear fission and nuclear fusion
  e) Packing fraction

IV. Nuclear forces
  a) Nuclear stability

V. Radioactivity
  a) Basic idea
  b) α-decay, β-decay, γ-decay
  c) Law of radioactive decay
  d) Half life, mean life
  f) Activity

VI. Nuclear fission and working of reactor

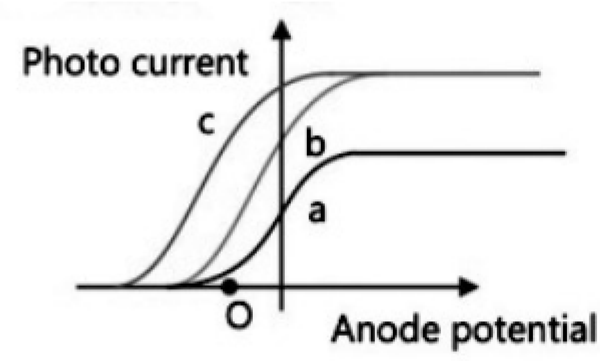
PART I - (JEEMAIN)

SECTION - I - Straight objective type questions

1. In a photoemissive cell with exciting wavelength λ, the fastest electron has a speed υ. If the exciting wavelength is changed to $\frac{3\lambda}{4}$, the speed of the fastest emitted electrons will be

1) $\upsilon\sqrt{\frac{3}{4}}$ 2) $\upsilon\sqrt{\frac{4}{3}}$ 3) less than $\upsilon\sqrt{\frac{4}{3}}$ 4) greater than $\upsilon\sqrt{\frac{4}{3}}$

2. The figure shows the variation of photocurrent with anode potential for a photo-sensitive surface for three different radiations. Let I_a, I_b and I_c, be the intensities and f_a, f_b and f_c be the frequencies for the curves a, b and c respectively



1) $f_a = f_b$ and $I_a \neq I_b$
2) $f_a = f_c$ and $I_a = I_c$
3) $f_a = f_b$ and $I_a = I_b$
4) $f_a \neq f_b$ and $I_a = I_b$

3. A proton, a deutron and an alpha particle are accelerated through potentials of V, 2V and 4V respectively. Their velocities will bear a ratio

1) 1 : 1: 1
2) $1:\sqrt{2}:1$
3) $\sqrt{2}:1:1$
4) $1:1:\sqrt{2}$

4. An electron of mass 'm' is moving with initial velocity $v_0\hat{i}$ in an electric field $\vec{E} = E_0\hat{i}$ (E_0 is positive). Which of the following is correct de Broglie wavelength at a given time t (λ_0 is initial de Broglie wavelength).

1) $\dfrac{\lambda_0}{\left(1+\dfrac{eE_0}{m\lambda_0}t\right)}$
2) $\dfrac{\lambda_0}{\left(1+\dfrac{eE_0}{mv_0}t\right)}$
3) $\dfrac{h}{\left(1+\dfrac{mv_0}{Ev_0}t\right)}$
4) $\dfrac{h}{\left(1+\dfrac{eE}{mv_0}t\right)}$

5. A particle A of mass m and initial velocity v collides with a particle B of mass $\dfrac{m}{2}$ which is at rest. The collision is head on and elastic. The ratio of the de Broglie wavelengths λ_A to λ_B after the collision is

1) $\dfrac{\lambda_A}{\lambda_B}=\dfrac{1}{3}$
2) $\dfrac{\lambda_A}{\lambda_B}=2$
3) $\dfrac{\lambda_A}{\lambda_B}=\dfrac{2}{3}$
4) $\dfrac{\lambda_A}{\lambda_B}=\dfrac{1}{2}$

6. In Rutherford's scattering experiment, if the number of α particles scattered at an angle of 90^0 is 55, then calculate the number of α particles scattered at an angle of 60^0

1) 120
2) 220
3) 320
4) 420

7. A small particle of mass *m* moves in such a way that the potential energy $U = -\frac{1}{2}mb^2r^2$, where b is a constant and r is the distance of the particle from the origin taken at the nucleus, Assuming Bohr model of quantization of angular momentum and circular orbits. Radius of the n^{th} allowed orbit is proportional to

1) n 2) $\sqrt{n}$ 3) n^2 4) n^3

8. A hydrogen atom emits a photon corresponding to an electron transition from n = 5 to n =1. The recoil speed of hydrogen atom is almost

1) 10^{-4} ms^{-1} 2) $2\times10^{-2}ms^{-1}$ 3) 4 ms^{-1} 4) $8\times10^{2}\,ms^{-1}$

9. The binding energy per nucleon of ${}_3Li^7$ and ${}_2He^4$ nuclei are 5.60 MeV and 7.06 MeV, respectively. In the nuclear reaction ${}_3Li^7 +{}_1H^1 \rightarrow {}_2He^+ + {}_2He^4 + Q$, the value of energy Q released is

1) 19.6 MeV 2) -2.4 MeV 3) 8.4 MeV 4) 17.3 MeV

10. One milligram of matter is converted into energy, the energy released will be

1) 90 J 2) $9\times10^3 J$ 3) $9\times10^5 J$ 4) $9\times10^{10} J$

SECTION - II
Numerical Type Questions

11. Calculate the nuclear radius of ${}^{125}Fe$ knowing that the nuclear radius of ${}^{27}Al$ is 3.6 fermi. (Answer in fermi)

12. The radionuclide ${}^{11}_{6}C$ decays by β^+ emission. Write symbolically this decay process.

Given that
$$m\left({}^{11}_{6}C\right) = 11.011434\,u$$
$$m\left({}^{11}_{6}B\right) = 11.009305\,u$$
$$m_e = 0.000548\,u,\ 1u = 931.5\,MrV/c^2$$
then Q value is nearly _____MeV.

13. An electron in a hydrogen atom undergoes a transition from an orbit with quantum number n_i to another with quantum number n_f. V_i and V_f are respectively the initial and final potential energies of the electron.

If $\frac{V_i}{V_f} = 6.25$, then the smallest possible n_f is:

PART - II (JEE ADVANCED)
SECTION - III (Only one option correct type)

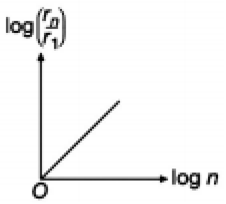
14. A metal plate is exposed to light with wavelength λ. It is observed that electrons are ejected from the surface of the plate. When a retarding uniform electric field E is imposed, no electric can move away from the plate farther than a certain distance d. Then the threshold wavelength λ_0 for the material of plate is (e is the electronic charge, h is Planck's constant and c is the speed of light)

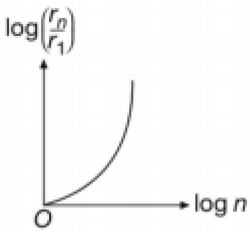
A) $\lambda_0 = \left(\frac{1}{\lambda} - \frac{hc}{eEd}\right)^{-1}$ B) $\lambda_0 = \left(\frac{1}{\lambda} - \frac{eEd}{hc}\right)^{-1}$ C) $\lambda_0 = \lambda - \frac{hc}{eEd}$ D) $\lambda_0 = \lambda - \frac{eEd}{hc}$

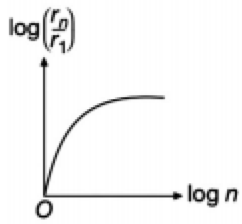
15. A charged particle q of mass m is projected along the y-axis at t= 0 from origin with a velocity v_0. If a uniform electric field E also exists along the x-acis, then the time at which de-Broglie wavelength of the particle becomes half of the initial value is

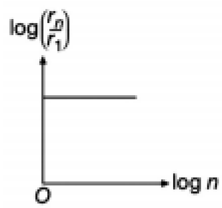
A) $\frac{mv_0}{qE}$ B) $2\left(\frac{mv_0}{qE}\right)$ C) $\sqrt{3}\left(\frac{mv_0}{qE}\right)$ D) $3\left(\frac{mv_0}{qE}\right)$

16. In hydrogen atom, the radius of n^{th} Bohr orbit is r_n. The hrapg between $\log\left(\frac{r_n}{r_1}\right)$ and log n will be

A) 

B) 

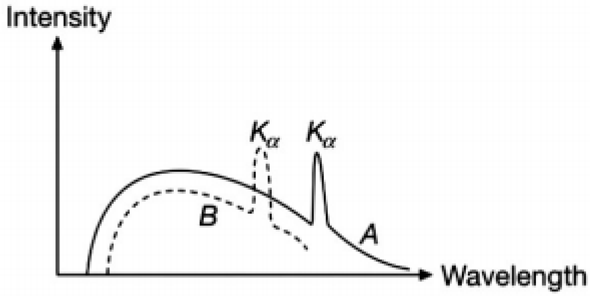
C) 

D) 

17. The ratio of the maximum wavelength of the Lyman series in hydrogen spectrum to the maximum wave length in the Paschen series is

A) $\frac{3}{105}$ B) $\frac{6}{15}$ C) $\frac{52}{7}$ D) $\frac{7}{108}$

18. The figure represents the observed intensity of X-rays emitted by two different tubes A and B as a function of wavelength λ. For the tube A, the potential difference betwenn the filament and target is V_A and atomic number of target is Z_A. For the tube B, corresponding potential difference is V_B and the atomic number is Z_B. The solid curve is for tube A and dotted curve for tube B, then



A) $Z_A > Z_B, V_A > V_B$ B) $Z_A = Z_B, V_A = V_B$ C) $Z_A < Z_B, V_A > V_B$ D) $Z_A < Z_B, V_A < V_B$

19. There are two ratio nuclei A and B out of which A is an alpha emitter and B is a beta emitter. Their disintegration constants are in the ratio of 1:2. The ratio of number of atoms of A and B at any time t so that probabilities of getting alpha and beta particles are same at that instant is

A) 1 : 2 B) 1 : e C) 2 : 1 D) e : 1

20. A nucleus X initially at rest, undergoes alpha decay according to the equation

$${}^{232}_{Z}X \rightarrow {}^{A}_{90}Y + \alpha$$

What fraction of the total energy released in the decay will be the kinetic energy of the alpha particle?

A) $\frac{90}{92}$ B) $\frac{228}{232}$ C) $\sqrt{\frac{228}{232}}$ D) $\frac{1}{2}$

21. The binding energy per nucleon of ${}_1H^2$ and ${}_2He^4$ are 1.1 eV and 7 MeV respectively. The energy released in the process ${}_1H^2 + {}_1H^2 = {}_2He^4$ is

A) 20.8 MeV B) 16.6 MeV C) 25.2 MeV D) 23.6 MeV

SECTION - IV (More than one correct answer)

22. Radiations of monochromatic waves of wavelength 400nm are made incident on the surface of metals Zn, Fe and Ni of work functions 3.4 eV, 4.8 eV and 5.9 eV respectively (take hc = 12400 eV $\mathring{A}$)

A) maximum KE associated with photoelectrons from the surface of any metal is 0.3eV

B) no photoelectrons are emitted from the surface of Ni

C) if the wavelength of source of radiation is doubled then KE of photoelectrons is also doubled

D) photoelectrons will be emitted from the surface of all the three metals if the wavelength of incident radiations is less than 200nm

23. The radius of the orbit of an electron in a Hydrogen like atom is 4.5 a_0, where a_0 is the Bohr radius. Its orbital angular momentum is $\frac{3h}{2\pi}$. It is given that *h* is Planck constant and R is Rydberg constant. The possible wavelength(s), when the atom de-excites, is (are)

A) $\frac{9}{32R}$ B) $\frac{9}{16R}$ C) $\frac{9}{5R}$ D) $\frac{4}{3R}$

24. A photon collides with a stationary hydrogen atom in ground state inelastically. Energy of the colliding photon is 10.2eV. After a time interval of the order of macro second another photon collides with same hydrogen atom inelastically with an energy of 15eV. What will be observed by the detector?

A) 2 photon of energy 10.2eV

B) 2 photon of energy 1.4 eV

C) One photon of energy 10.2eV and an electron of energy 1.4 eV

D) One photon of energy 10.2 eV and another photon of energy 1.4 eV

25. Consider two radioactive samples A and B. Their respective half lives are 1 hour and 2 hours. Initially their mass ratio is 3:4, initial activity of A a is 5 units. The ratio of their atomic masses is 6:7. After 8 hours

A) ratio of their masses is 3:64

B) ratio of their masses is 7:58

C) the activit of B is $\frac{5}{28}$ units

D) the activity of B $\frac{3}{14}$ units

26. Polonium ${}_{84}Po^{210}$ emits $\alpha-$ particles and is converted into ${}_{82}Pb^{206}$. This reaction is used for producing electric power in a space mission. Po^{210} has half life of 138.6 days. Assuming an efficiency of 10%. Select the correct statement(s)

Given : M (Po^{210}) = 209.98264 amu; $M(\alpha)=4.0026\,amu$ $M(Pb^{206})=205.97440\,amu$;

$1\,amu = 931\,MeV$ energy

A) 10g Po^{210} is required to produce 1.2×10^{7} Joule energy

B) Decay constant of Po^{210} is 0.005 day^{-1}

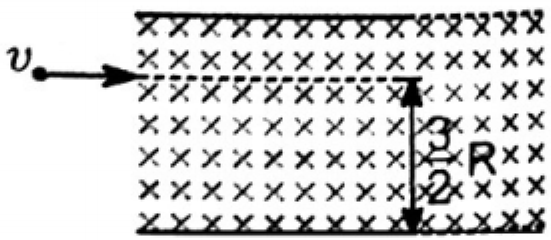
C) Q-value of $\alpha-$ decay process is $8.4\times10^{-13}\,J$

D) None of these is correct

SECTION - V (Numerical Type - Upto two decimal place)

27. An electron in an excited state of Li^{2+} ion has angular momentum $\frac{3h}{2\pi}$. The de-Broglie wavelength of the electron in this state is $p\pi a_0$ (where a_0 is the Bohr radius). The value of p is

28. Light from a discharge tube containing hydrogen atoms falls on a piece of sodium due to the transition of electron from 4^{th} orbit to 2^{nd} orbit. Work function of sodium is 1.83 eV. The fastest moving photoelectron is allowed to enter in a magnetic field, which is perpendicular to the direction of motion of phoroelectron as shown in figure. Find distance $(\text{in }\ \mu m)$ covered by the electron in the magnetic field. [B=1 Tesla, $\pi^2=10$, mass of electron $=9\times10^{-31}kg$] where R is the radius of the path that the most energetic electron takes in the presence of applied magnetic field.

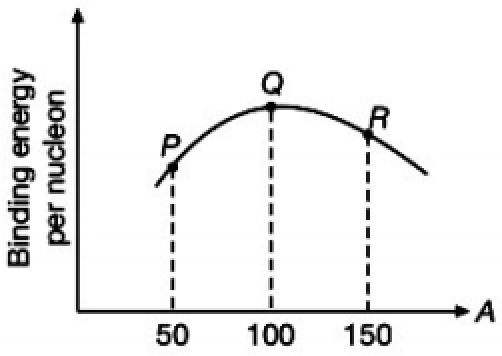


29. Nuclei A and B convert into a stable nucleus C. Nucleus A is converted into C by emitting 2 $\alpha-$ particles and $3\beta-$ particles. Nucleus B is converted into C by emitting one $\alpha-$ particles and $5-$ particles. At time t=0, nucleus of A are $4N_0$ and nuclei of B are N_0. Initially number of nuclei of C are zero. Half life of A (into conversion of C) is 1min and that of B is 2 min. Find the time (in minutes) at which rate of disintegration of A and B are equal

30. The radioactivity of a sample is R_1 at a time T_1 and R_2 at a time T_2. If the half-life of the specimen is T, the number of atoms that have disintegrated in the time $(T_2 - T_1)$ is equal to $\frac{n(R_1 - R_2)T}{\ln 4}$. Here n is some integral number. What is the value of n?

SECTION - VI (Matrix Matching)

31. Corresponding to the graph of binding energy per nucleon vs mass number (A) shown in figure, match the following two columns



Column -I	Column-II
A) $P+P \rightarrow Q$	p) Energy is released
B) $P+P+P \rightarrow R$	q) Energy is absorbed
C) $P+R \rightarrow 2Q$	r) No energy transfer will take place
D) $P+Q \rightarrow R$	s) Data insufficient