Solved Examples

JEE Main/Boards

Example 1: Calculate the energy of α-particle in the event of its head-on collision with gold nucleus if the closest distance of approach is 41.3 Fermi.

Sol: The kinetic energy of α-particle is converted into the electric potential energy at the distance of closest approach in the event of a head-on collision. The kinetic energy of alpha particle is thus $E = \frac{q_1 q_2}{4\pi\varepsilon_0 r}$

Given r_0 = 41.3 × 10^{-15} m, Z = 70, q_1= Ze= 79e and q_2 = 2e,

As $E = \frac{Ze(2e)}{4\pi\varepsilon_0 r} = \frac{9\times10^9 \times 79\times 2(1.6\times10^{-19})^2}{41.3\times10^{-15}}$

$= \frac{9\times79\times2\times1.6\times1.6\times10^{-14}}{41.3}$ J

$= 8.814\times10^{-13}$ J $= \frac{8.814\times10^{-13}}{1.6\times10^{-19}}$ eV = 5.51 MeV

Example 2: If the wavelength of the incident light is 5000 Å and the photoelectric work function of the metallic plate is 1.90 eV, find

(a) Energy of the photon in eV

(b) Kinetic energy of the photoelectrons emitted

(c) Stopping potential

Sol: The energy of photon is $E = h\nu = \frac{hc}{\lambda}$, where λ is the wavelength of the light. This photon knocks out photoelectron from the surface of metal with the maximum kinetic energy $E_{max} = h\nu - \phi_0 = eV$ where f_0 is the work function of metal and V is the stopping potential.

(a) Energy of the incident photon,

$E = h\nu = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^8}{5000\times10^{-10}}$

= 3.96 × 10^{-19} joule = 2.47 eV

(b) Kinetic energy of the photo-electrons emitted KE_{max}

$= \frac{1}{2}mv^2 = h\nu - \phi_0$ = (2.47 – 1.90) eV = 0.57 eV

(c) e V = KE_{max} Where V is stopping potential

$V = \frac{KE_{max}}{e} = \frac{0.57\times1.6\times10^{-19}}{1.6\times10^{-19}}$ = 0.57 V.

Example 3: Determine the de Broglie wavelength of an electron having kinetic energy of 500 eV?

Sol: The de-Broglie wavelength of electron moving with Kinetic energy K is given as $\lambda = \frac{h}{\sqrt{2mK}}$

Using $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mK}}$ we get

$$\lambda = \frac{6.6\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times500\times1.6\times10^{-19}}}$$

$\lambda = 0.5467\times10^{-10}$ m.

Example 4: If an X-ray tube produces a continuous spectrum of radiation with its short wavelength end 0.65Å, what is the maximum energy of a photon in the radiation?

Sol: The energy of radiation having wavelength λ is

$E = \frac{hc}{\lambda}$

Given λ_{min} = 0.65Å = 0.65×10^{-10} m,

h = 6.63×10^{-34} Js, c = $3\times10^8 ms^{-1}$

We know, maximum energy of X-ray photon is

$$E_{max} = h\nu_{max} = \frac{hc}{\lambda_{min}} = \frac{6.63\times10^{-34}\times3\times10^8}{0.65\times10^{-10}\times1.6\times10^{-19}}$$

$= 19.13\times10^3$ eV = 19.13 keV

Example 5: If ultra-violet light of $\lambda = 2600$ Å is incident on a silver surface with a threshold wavelength for photoelectric emission of $\lambda = 3800$ Å, calculate:

(i) Work function

(ii) Maximum kinetic energy of the emitted photoelectrons.

(iii) Maximum velocity of the photoelectrons.

Sol: The work function of metal is $\phi = h\nu_{th} = \frac{hc}{\lambda_{th}}$. The kinetic energy with which the photoelectron is ejected from the metal surface is $E = h\nu - \phi = \frac{1}{2}mv^2$

(i) $\phi = h\nu_{th} = \frac{hc}{\lambda_{th}} = \frac{6.63\times10^{-34}\times3\times10^{8}}{3800\times10^{-10}}$ J

$= 5.23\times10^{-19}$ J $= \frac{5.23\times10^{-19}}{1.6\times10^{-19}}$ eV = 3.27 eV

(ii) Incident wavelength $\lambda = 2600\,Å$

Then KE_{max} of emitted photoelectrons $= h\nu - \phi$;

here $h\nu = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{2600\times10^{-10}}$

$= 7.65\times10^{-19}\ J = \frac{7.65\times10^{-19}}{1.6\times10^{-19}} = 4.78$ eV

KE_{max} = (4.78 – 3.27) eV; = 1.51 eV

(iii) $V_{max} = \sqrt{\frac{KE_{max}\times2}{m}} = \sqrt{\frac{1.51\times1.6\times10^{-10}\times2}{9.1\times10^{-31}}}$ m/s.

$= 7.29\times10^{5}$ m / s

Example 6: The photocurrent generated when a surface is irradiated with light of wavelength 4950 Å, vanishes if a stopping potential greater than 0.6 V is applied across the photo tube. When a different source of light is used, it is found that the stopping potential has changed to 1.1 V. Determine the work function of the emitting surface and the wavelength of second source.

Sol: The maximum kinetic energy of emitted photoelectron is the product of stopping potential and electron charge, given by $KE_{max} = eV = h\nu - \phi$, where φ is the work function of the metal. For two different stopping potentials we have two different wavelengths of light used.

Let λ_1 = 4950Å, V_1 = 0.6 V

$KE_{max} = \frac{hc}{\lambda_1} - \phi;\ \because KE_{max} = eV_1 \Rightarrow \phi = \frac{hc}{\lambda_1} - eV_1 =$

$\frac{(6.6\times10^{-34})\times(3\times10^{8})}{4950\times10^{-10}\times1.6\times10^{-19}} - 0.6 = 1.9$ eV

(b) $\frac{hc}{\lambda_2} = \phi + eV_2$;

$\frac{hc}{\lambda_2} = 3.04\times10^{-19} + \left(1.6\times10^{-19}\times1.1\right) = 4.8\times10^{-19}$ J

$\therefore \lambda_2 = \frac{hc}{4.8\times10^{-19}} = \frac{(6.6\times10^{-34})\times(3\times10^{8})}{4.8\times10^{-19}}$

$\lambda_2 = 4.125\times10^{-7}$ m = 4125 Å

Example 7: A hydrogen-like atom (atomic number Z) in a higher excited state of quantum number n can make a transition to the first excited state by successively emitting two photons of energies 10.20 eV and 17.00 eV, respectively. On the other hand, the atom from the same excited state can make a transition to the second excited state by successively emitting two photon of energies 4.25 eV and 5.95 eV, respectively. What are the values of n and Z. (Ionization energy of hydrogen atom = 13.6 eV)?

Sol: For any hydrogen-like atom, the energy released in transition from a higher excited state to a lower excited state is $\Delta E = Z^2\times13.6\times\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$eV where n_f and n_i are principle quantum numbers of final (lower) and initial (higher) energy states respectively.

In first case, the excited atom makes a transition from n^{th} state to n = 2 state and two photons of energies 10.2 eV and 17.0 eV are emitted. Hence, if Z is the atomic number of H-like atom, then using

$\Delta E = Z^2\times13.6\times\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$eV;

$(10.2+17.0)\text{eV} = Z^2\times13.6\times\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$ ...(i)

In second case, the excited atom makes a transition from nth state to n = 3 state and two photons of energies 4.25 eV and 5.95 eV are emitted.

$(4.25+5.95)$ eV $= Z^2\times13.6\times\left[\frac{1}{3^2} - \frac{1}{n^2}\right]$ ...(ii)

Dividing equation (i) and (ii), we get

$\frac{27.2}{10.2} = \frac{9(n^2-4)}{4(n^2-9)}$ or $\frac{n^2-4}{n^2-9} = 1.185$ or $\frac{2n^2-13}{5}$

$= \frac{2.185}{0.185}$

or $n^2 = 36$ or n = 6

Putting in equation (i), we get

$27.2 = Z^2\times13.6\left(\frac{1}{4} - \frac{1}{36}\right)$ or $Z^2 = \frac{27.2}{13.6}\times\frac{9}{2} = 9$

or, Z = 3.

Example 8: In a hydrogen sample, if the atoms are excited to states with principal quantum number n, how many different wavelengths may be observed in the spectrum?

Sol: The hydrogen atom excited to the principal quantum number n will emit radiations as the electron hop back to lower energy states. Each transition to a lower energy state emits radiation of different wavelength. Thus, we get a radiation spectrum.

From the nth state, the atom may go to (n – 1)th state, ……, n = 2 state or n = 1 state. So there are (n – 1) possible transitions starting from the nth state. The atoms reaching (n – 1)th state may make (n – 2) different transitions to reach n = 1 state. In the same way, for other lower states, the total number of possible transitions is (n – 1) + (n – 2) + (n – 3) + …. 2+1

$= \frac{n(n-1)}{2}$.

Example 9: For a hydrogen-like, doubly ionized lithium atom with atomic number Z=3, determine the wavelength of the radiation required to excite the electron in Li^{2+} from the first to the third Bohr orbit. The ionization energy of hydrogen atom is 13.6 eV.

Sol: The energy required by the hydrogen-like atom for transition from ground state (n=1) to any of the excited states (nth orbit) is $\Delta E = 13.6Z^2(1-\frac{1}{n^2})$.

Wavelength of radiation having energy E is, $\lambda = \frac{hc}{E}$.

The energy of nth orbit of a hydrogen like atom is given as $E_n = -\frac{13.6}{n^2}$

Thus for Li^{2+} atom, as Z = 3, the electron energies for the first and third Bohr orbits are:

For n = 1, $E_1 = -\frac{13.6\times(3)^2}{1^2}$ eV = –122.4 eV

For n = 3, $E_3 = -\frac{13.6\times(3)^2}{(3)^2}$ eV = – 13.6 eV

Thus the energy required to transfer an electron from E_1 level to E_3 level is,

$E = E_1 - E_3 = -13.6 - (-122.4) = 108.8$eV

Therefore, the radiation needed to cause this transition should have photons of this energy.

hν = 108.8 eV. The wavelength of this radiation is $\frac{hc}{\lambda}$ = 108.8 eV or $\lambda = \frac{hc}{108.8\,eV}$

$= \frac{(6.63\times10^{-34})\times(3\times10^8)}{108.8\times1.6\times10^{-19}}m = 113.74\,Å.$

Example 10: For a hypothetical hydrogen-like atom, the wavelength in Å for the spectral lines for transitions from n = p to n = 1 are given by $\lambda = \frac{1500p^2}{p^2-1}$, where p = 2, 3, 4, ….

(i) Find the wavelength of the least energetic and the most energetic photons in this series.

(ii) Construct an energy level diagram for this element representing at least three energy levels.

(iii) Determine the ionization potential of this element?

Sol: If wavelength of spectral lines for transitions from n = p to n = 1 are given, then the energy of radiation for each transition is given as $E = \frac{hc}{\lambda} = \frac{hc}{1500}(1-\frac{1}{p^2})$. The least energy is obtained from transition from p = 2 to p = 1 and maximum energy is obtained from transition from p=∞ to p=1. The ionization corresponds to the maximum energy in the spectrum.

Given $\lambda = \frac{1500p^2}{p^2-1}$ and energy is E=$\frac{hc}{\lambda}$

Substituting for λ we get $E = \frac{hc}{1500}\left(1-\frac{1}{p^2}\right)\times10^{10}$ J

$= \frac{hc}{(1500)(1.6\times10^{-19})}\left(1-\frac{1}{p^2}\right)\times10^{10}$ eV

$= 8.28\left(1-\frac{1}{p^2}\right)$ eV.

Hence energy of nth state is given b $E_n = \frac{8.28}{n^2}$ eV

(i) Maximum energy is released for transition from p = ∞ to p = 1; hence wavelength of most energetic photon is 1500 Å.

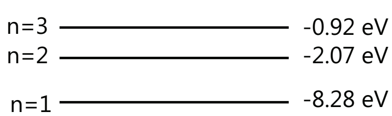
Least energy is released for transition from n = 2 to n = 1 transition. For p = 2 l = 2000Å

(ii) The energy level diagram is shown in the Fig. 24.60.

(iii) The ionization potential corresponds to energy required to liberate an electron from its ground state.

i.e., ionization energy = 8.28 eV

Hence, ionization potential = 8.28 V



Example 11: A single electron orbiting a stationary nucleus of charge +Ze, where Z is a constant and e is the magnitude of the electronic charge, requires 47.2 eV to excite the electron from the second Bohr orbit to the third Bohr orbit. Find

(i) The value of Z

(ii) Energy required to excite the electron from the third to the fourth Bohr orbit.

(iii) Wavelength of the electromagnetic radiation required to remove the electron from the first Bohr orbit to infinity.

(iv) Kinetic energy, potential energy, and angular momentum of the electron in the first Bohr orbit.

(v) The radius of the first Bohr orbit.

(The ionization energy of hydrogen atom = 13.6 eV. Bohr radius = 5.3×10^{11} m)

Sol: For a hydrogen-like atom, the total energy of electron in n^{th} orbit is $E=-\frac{13.6\times Z^2}{n^2}$ eV and radius of n^{th} orbit is

$$r_n=\frac{5.3\times10^{-11}n^2}{Z}$$

The kinetic energy in n^{th} orbit is equal to the magnitude of total energy in n^{th} orbit. The potential energy in n^{th} orbit is equal to twice the total energy in n^{th} orbit.

The energy required to excite the atom from n_1 state to n_2 state is $E=13.6Z^2\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)$ eV. To remove the electron from n = 1 state to infinity, $E=\frac{hc}{\lambda}=13.6\times Z^2$.

So $\lambda=\frac{hc}{13.6\times Z^2}$

This atom is hydrogen like

Z = atomic number of the nucleus

E_n = Energy of the electron in the nth orbit.

= $(Z)^2$ (energy of the electron in the nth orbit of the hydrogen atom) = $-(Z)^2\frac{13.6}{n^2}$ eV = $\frac{E_1}{n^2}$

Where E_1 = Energy of the electron in the 1st Bohr orbit of the given atom.

(i) Given $(Z^2)(13.6)\left(\frac{1}{2^2}-\frac{1}{3^2}\right)$ = 47.2 eV

$\Rightarrow$ Z = 5.

(ii) $E_1 = -(25)\frac{13.6}{1} = -340$ eV

$$E_4-E_3 = 13.6\ Z^2\left[\frac{1}{4^2}-\frac{1}{3^2}\right] = E_1\left[\frac{1}{3^2}-\frac{1}{4^2}\right]$$

$$= 340\left[\frac{1}{3^2}-\frac{1}{4}\right]\text{ eV} = 16.53\text{ eV}$$

(iii) Minimum energy required to remove electron from first orbit = 340 eV.

$$\Rightarrow \frac{hc}{\lambda} = 340\times1.6\times10^{-19}$$

$$\text{or }\lambda = \left[\frac{6.6\times10^{-34}\times3\times10^8}{340\times1.6\times10^{-19}}\right]\text{m} = 36.40\,\text{Å}$$

(iv) KE of the electron in the 1st orbit

$$KE_1 = -E_1 = 340\text{ eV};\ PE_1 = 2E_1 = -680\text{ eV}$$

Angular momentum of the electron in the 1st Bohr orbit

$$=\frac{h}{2\pi}=\frac{6.63\times10^{-34}}{2\pi} = 1.055\times10^{-34}\text{ kg m/s}$$

(v) Radius of the 1st Bohr orbit for the given atom

$$=\frac{\text{Bohr radius}}{Z}=\frac{5.3\times10^{-11}}{5} = 1.06\times10^{-11}\text{ m}$$

JEE Advanced/Boards

Example 1: If a hydrogen atom in its ground state is excited by means of a monochromatic radiation of wavelength 975 Å

(a) How many different lines are possible in the resulting spectrum?

(b) Calculate the longest wavelength amongst them.

The ionization energy for hydrogen atom is 13.6 eV.

Sol: First calculate the energy of the incident photon of given wavelength. From the formula $E=13.6\left(1-\frac{1}{n^2}\right)$ eV, find the value of n, i.e., the maximum excited state the hydrogen atom will reach after absorbing the photon of given wavelength. Longest wavelength in the resulting spectrum will correspond to transition from n^{th} orbit to $(n-1)^{th}$ orbit.

Energy of the ground state

(n = 1) = –(ionization energy) = –13.6 eV

The wavelength of the incident radiation

= λ = 975Å $\therefore$ Energy of the incident photon

$$=\frac{hc}{\lambda}=\frac{6.63\times10^{-34}\times3\times10^8}{975\times10^{-10}\times1.6\times10^{-19}} = 12.75\text{ eV}$$

Let electron be exerted to nth orbit

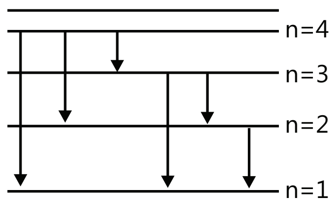
$$\Rightarrow 12.75 = 13.6\left(\frac{1}{1^2}-\frac{1}{n^2}\right) \Rightarrow n = 4$$

The quantum transitions to the less excited states give six possible lines as follows:

n = 4 : (4 → 3), (4 → 2), (4 → 1)

n = 3 : (3 → 2), (3 → 1); n = 2 : (2 → 1)

The longest wavelength emitted is for the transition (4 → 3) where energy difference is minimum



$$E_{min}\ (E_4 - E_3) = 13.6\left(\frac{1}{3^2}-\frac{1}{4^2}\right)$$

$$= 0.661\text{eV; Thus } \lambda_{max} = \frac{hc}{E_{min}}$$

$$= \frac{6.63\times10^{-34}\times3\times10^{8}}{0.661\times1.6\times10^{-19}} \approx 18807\text{Å}$$

Example 2: An X-ray tube operating at a potential difference of 40 kV produces heat at the rate of 720 W. Assuming 0.5% of the energy of the incident electrons is converted into X-rays, calculate

(a) The number of electrons per second striking the target.

(b) The velocity of the incident electrons.

Sol: When X-Rays are produced in an X-Ray tube, the power consumed is denoted by P = IV. Some of this power is wasted as heat and the rest is converted to X-Rays. The electron incident per second on target is n = I/e

As 0.5% of energy is converted into X-ray, therefore heat produced per second at the target is P = 0.995 VI

where, I is current inside tube

$$\Rightarrow I = \frac{P}{0.995V} = \frac{720}{0.995\times40\times10^{3}} = 0.018\text{Å}$$

Number of electrons per second incident of the target

$$n = \frac{I}{e} = \frac{0.018}{1.6\times10^{-19}} = 1.1\times10^{17}\ \text{electrons/s.}$$

(b) Kinetic energy of incident electron $\frac{1}{2}mv^2 = eV$

$$\text{Or } v = \sqrt{\frac{2eV}{m}}$$

$$= \sqrt{\frac{2\times1.6\times10^{-19}\times40\times10^{3}}{9.1\times10^{-31}}} = 1.19\times10^{8}\ m/s$$

Example 3: If one milliwatt of light of wavelength 4560 Å is incident on a cesium surface, calculate the photoelectric current liberated assuming a quantum efficiency of 0.5%.

Planck's constant h = 6.62×10^{-34} Js and velocity of light 3×10^{8} m/s.

Sol: The energy of one photon of light is $E=\frac{hc}{\lambda}$. The number of photons incident on the surface per second can be determined by dividing power by energy of one photon. The number of photons multiplied by quantum efficiency gives the number of photoelectrons emitted per second.

The energy of each photon of incident light

$$E = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3\times10^{8})}{4560\times10^{-10}} = 4.35\times10^{-19}\ J$$

Number of photons in one milliwatt source

$$= \frac{\text{Power of light}}{\text{Energy of one photon}}$$

$$= \frac{10^{-3}}{4.35\times10^{-19}} = 2.29\times10^{15}/s.$$

Number of electrons released = $2.29\times10^{15}\times\frac{0.5}{100}$

$= 1.14\times10^{13}/s$

∴ Photoelectric current

= Photo charge flowing per second

= Total electrons emitted per sec. × charge of one electron

$= (1.14\times10^{13})\times(1.6\times10^{-19}) = 1.824\ \mu A$

Example 4: Consider the following data: Incident beam: wavelength 3650 Å; intensity 10^{-8} W/m^2. Surface: Absorption coefficient 0.8; work function 1.6 eV.

Determine the time rate of number of electrons emitted per m^2, power absorbed per m^2, and the maximum kinetic energy of emitted photoelectrons.

Sol: The energy of one photon of light is $E = \frac{hc}{\lambda}$.

Number of photons incident on the surface per m^2 per second is the intensity divided by energy of one photon. Number of photons × absorption coefficient = the number of photons absorbed by the surface. The remaining number of photons is equal to the photoelectrons emitted per m^2 per second.

If N is the number of photons crossing per unit area per unit time,

Number of photons falling per second on unit area

$$= \frac{\text{Intensity}}{\text{Energy of one photon}} = \frac{I\lambda}{hc}$$

$$= \frac{10^{-8} \times 3650 \times 10^{-10}}{6.62 \times 10^{-34} \times 3 \times 10^{8}} = 18.35 \times 10^{9} \ / m^2 s$$

The number of photons absorbed N_{ab} by the surface per unit area per unit time

N_{ab} = absorption coefficient of surface × N

$= 0.8 \times 18.35 \times 10^{9} = 1.47 \times 10^{10} / m^2 s$

Now, assuming that each photon ejects one electron, the rate of electrons emitted per unit area is given by

$N - N_{ab} = 1.835 \times 10^{10} - 1.47 \times 10^{10} = 0.37 \times 10^{10} \ / m^2 - s$

Power absorbed/m^2

= Absorption coefficient × Intensity of light falling on surface= $0.8 \times 10^{-8} = 8 \times 10^{-9} \ W/m^2$. Maximum kinetic energy is of emitted photoelectron is given by

$$(K.E.)_{max} = \frac{hc}{\lambda} - \phi$$

$$= \frac{(6.62 \times 10^{-34})(3 \times 10^{8})}{3650 \times 10^{-10} \times 1.6 \times 10^{-19}} \text{ eV} - 1.6 \text{eV}$$

= 3.4 eV – 1.6 eV = 1.80 eV

Example 5: Consider two hydrogen-like atoms A and B of different masses but having equal number of protons and neutrons. The difference in the energies between the first Balmer lines emitted by A and B is 5.667 eV. When these atoms, moving with the same velocity, strike a heavy target elastically, the atom B imparts twice the momentum to the target than the atom A. Identify the atoms A and B.

Sol: The energy of hydrogen-like atom for n^{th} orbit is given by $E = -\frac{Z^2 \times 13.6}{n^2}$, where Z = atomic number. First line of Balmer series corresponds to transition from orbit n = 3 to orbit n = 2. Energy emitted is $\Delta E = Z^2 \times 13.6 \times \left(\frac{1}{4} - \frac{1}{9}\right)$. The momentum imparted to the heavy target during elastic collision is twice the momentum of the striking particle.

Suppose Z_A and Z_B are the atomic number and m_A and m_B are the mass numbers of hydrogen like atoms A and B, respectively.

$$E_n = -\frac{Z^2 Rhc}{n^2} = \frac{-Z^2 \times 13.6}{n^2} \text{ eV}$$

Energy emitted for first Balmer line of atom A

$$\Delta E_A = -Z_A^2 \times 13.6 \left(\frac{1}{2^2} - \frac{1}{3^2}\right) \text{eV}$$

Similarly, energy emitted for first Balmer line of atom B

$$\Delta E_B = -Z_B^2 \times 13.6 \times \left(\frac{1}{2^2} - \frac{1}{3^2}\right) \text{eV}$$

According to question, $\Delta E_A - \Delta E_B = 5.667$ eV

or 5.667 eV = $(Z_B^2 - Z_A^2) \times 13.6 \left(\frac{1}{2^2} - \frac{1}{3^2}\right)$ eV

$$\text{or } Z_B^2 - Z_A^2 = \frac{5.667 \times 36}{13.6 \times 5} = 3 \quad \text{... (i)}$$

Suppose you represent the initial velocity of each atom A and B as u.

Momentum imparted by A to target = $2m_A u$

Momentum imparted by B to target = $2m_B u$

Then according to questions,

$$2m_A u = 2m_B u \Rightarrow 2m_A = m_B \quad \text{... (ii)}$$

In case of both the atoms A and B, number of protons and neutrons is same separately, hence $m_B = 2Z_B$ and $m_A = 2Z_A$

Putting m_A and m_B in equation (ii)

$$2Z_B = 2(2Z_A) \text{ or } Z_B = 2Z_A \quad \text{... (iii)}$$

Solving (i) and (iii) $Z_A = 1$ and $Z_B = 2$

i.e., atom A contains 1 proton and 1 neutron, i.e., atom A is deuterium $({}_1H^2)$.

Similarly, atom B contains 2 protons and 2 neutrons, i.e., atom B is singly ionized Helium.

Example 6: A traveling hydrogen atom in the ground state makes a head-on inelastic collision with a stationary hydrogen atom in the ground state. After collision, they move together. What is the minimum velocity of the traveling hydrogen atom if one of the atoms is to gain the minimum excitation energy after the collisions?

Sol: Here we need to consider that the kinetic energy lost in the inelastic collision will be absorbed by one of the hydrogen atoms to reach to its next excited state. As both the hydrogen atoms are initially in ground state (n=1), the minimum energy absorbed will be equal to that required by one of the atoms to reach the first excited state (n=2). If the kinetic energy of the colliding hydrogen atom is less than this minimum energy, no energy will be absorbed, i.e. inelastic collision may not take place.

Let u be the velocity of the hydrogen atom before collision and v the velocity of the two atoms moving together after collision. By the principle of conservation of momentum, we have: Mu + M × 0 = 2Mv

or v = $\frac{u}{2}$. The loss in kinetic energy ΔE due to collision is given by $\Delta E = \frac{1}{2}Mu^2 - \frac{1}{2}(2M)v^2$

As v = $\frac{u}{2}$

we have $\Delta E = \frac{1}{2}Mu^2 - \frac{1}{2}(2M)\left(\frac{u}{2}\right)^2$

$= \frac{1}{2}Mu^2 - \frac{1}{4}Mu^2 = \frac{1}{4}Mu^2$

This loss in energy is due to the excitation of one of the hydrogen atoms. The ground state (n = 1) energy of a hydrogen atom is:

$E_1 = -13.6\,eV$

The energy of the first excited level (n = 2) is:

$E_2 = -3.4\,eV$

Thus the minimum energy required to excite a hydrogen atom from ground state to first excited state is: $E_2 - E_1$ = [– 3.4 – (–13.6)] eV = 10.2 eV = 10.2 × 1.6 × 10^{-19} J

= 16.32 × 10^{-19} J

As per problem, the loss in kinetic energy in collision is due to the energy used up in exciting one of the atoms. Thus. $\Delta E = E_2 - E_1$

Or $\frac{1}{4}Mu^2$ = 16.32 × 10^{-19}

Or $u^2 = \frac{4 \times 16.32 \times 10^{-19}}{M}$

The mass of the hydrogen atom is 1.0078 amu or 1.0078 × 1.66 × 10^{-27} kg

$$u^2 = \frac{4 \times 16.32 \times 10^{-19}}{1.0078 \times 1.66 \times 10^{-27}} = 39.02 \times 10^8$$

$\Rightarrow u = 6.246 \times 10^4 m/s$

Example 7: Assuming the potential energy between electron and proton at a distance r to be $U = \frac{ke^2}{3r^3}$, use Bohr's theory to obtain energy levels of such a hypothetical atom.

Sol: The negative of gradient of potential energy is equal to force on the electron. This force provides the necessary centripetal acceleration to the electron to move in a circular orbit around the proton. The magnitude of angular momentum of electron is quantized. The mass of the proton is very large as compared to the mass of electron, so it will not be accelerated due to the force exerted on it by the electron, hence it is assumed to be stationary.

As we know that negative of potential energy gradient is force for a conservative field.

$-\frac{dU}{dr}$ = F. It is given that U = $\frac{ke^2}{3r^3}$ ... (i)

Hence, force F = $-\frac{dU}{dr} = -\frac{d}{dr}\left(\frac{ke^2}{3r^3}\right) = \frac{ke^2}{r^4}$

According to Bohr's theory this force provides the necessary centripetal force for orbital motion.

$\frac{ke^2}{r^4} = \frac{mv^2}{r}$ ... (ii)

Also quantizing angular momentum,

mvr = $\frac{nh}{2\pi}$ ... (iii)

Hence, v = $\frac{nh}{2\pi mr}$ ... (iv)

Substituting this value in Eq.(ii), we get

$\frac{mn^2h^2}{4\pi^2m^2r^3} = \frac{ke^2}{r^4}$ or r = $\frac{4\pi^2me^2k}{n^2h^2}$

Substituting this value or r in Eq. (iv), we get

v = $\frac{n^3h^3}{8\pi^3km^2e^2}$

Total energy E = KE + PE

$= \frac{1}{2}mv^2 - \frac{ke^2}{3r^3}$

$$= \frac{m}{2}\left(\frac{n^3h^3}{8\pi^3 km^2e^2}\right)^2 - \frac{ke^2}{3}\left(\frac{n^2h^2}{4ke^2m\pi^2}\right)^3$$

$$= \frac{(n\hbar)^6}{6(ke^2)^2m^3} \text{ where } \left[\hbar = \frac{h}{2\pi}\right]$$

Example 8: When an electron in a tungsten (Z = 74) target drops from an M shell to a vacancy in the K shell, calculate the wavelength of the characteristic X-ray emitted there of.

Sol: In multi electron atoms, the nucleus is shielded from the outer most electron by the inner shell electron such that the outer most electron experience Z_{eff} charge from nucleus. The energy of this outermost electron in n^{th} shell is $E = -\frac{13.6 \times Z_{eff}^2}{n^2}$

Tungsten is a multi-electron atom. Due to the shielding of the nuclear charge by negative charge of the inner core electrons, each electron is subjected to an effective nuclear charge Z_{eff} which is different for different shells.

Thus, the energy of an electron in the nth level of a multi-electron atom is given by

$E_n = -\frac{13.6 Z_{eff}^2}{n^2}$ eV For an electron in the K shell (n = 1),

$Z_{eff} = (Z - 1)$

Thus, the energy of the electron in the K shell is:

$$E_K = -\frac{(74-1)^2 \times 13.6}{1^2} \approx -72500\,\text{eV}$$

For an electron in the M shell (n = 3), the nucleus is shielded by one electron of the n = 1 state and eight electrons of the n = 2 state, a total of nine electrons, so that $Z_{eff} = Z - 9$ Thus, the energy of an electron in the M shell is:

$$E_M = -\frac{(74-9)^2 \times 13.6}{3^2} \approx -6380 \text{ eV}$$

Therefore, the emitted X-ray photon has an energy given by Hv = $E_M - E_K$

=–6380 eV –(–72500eV) = 66100 eV

Or $\frac{hc}{\lambda}$ = 66100 × 1.6 × 10^{-19} J

$$\therefore \lambda = \frac{hc}{66100 \times 1.6 \times 10^{-19}} \text{ m}$$

$$= \frac{(6.63 \times 10^{-34}) \times (3 \times 10^8)}{66100 \times 1.6 \times 10^{-19}} \text{ m} = 0.0188 \times 10^{-9} \text{ m.}$$

Example 9: Assuming that the short series limit of the Balmer series for hydrogen is 3646 Å, calculate the atomic number of the element, given X-ray wavelength down to 1.0 A. Identify the element.

Sol: Balmer series spectra is obtained when an electron transitions from higher energy orbit to the second orbit (n =2). The wave number of radiation emitted is given as $\bar{\nu} = \frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$. The shortest wavelength will correspond to highest energy, i.e. n = ∞.

The short limit of the Balmer series is given by

$$\nu = \frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right) = \frac{R}{4}$$

$\therefore R = \frac{4}{\lambda} = \left(\frac{4}{3646}\right) \times 10^{10}\ \text{m}^{-1}$ Further the wavelengths of the k_a series are given by the relation

$$\nu = \frac{1}{\lambda} = R(Z-1)^2\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$$

The maximum wave number correspondence to $n = \infty$ and, therefore, we must have

$$\nu = \frac{1}{\lambda} = R(Z-1)^2$$

$$\text{Or } (Z-1)^2 = \frac{1}{R\lambda} = \frac{3646 \times 10^{-10}}{4 \times 1 \times 10^{-10}}$$

= 911.5 (Z – 1) = $\sqrt{911.5}$ ≅ 30.2

Or Z = 30.2 ≅ 31

Thus, the atomic number of the element concerned is 31.

The element having atomic number Z = 30 is Gallium.

JEE Main/Boards

Exercise 1

Q.1 Define the terms: (i) work function, (ii) threshold frequency and (iii) stopping potential, with reference to photoelectric effect.

Calculate the maximum Kinetic energy of electron emitted from a photosensitive surface of work function 3.2 eV, for the incident radiation of wavelength 300nm.

Q.2 Derive the expression for the de Broglie wavelength of an electron moving under a potential difference of V volt.

Describe Davisson and Germer experiment to establish the wave nature of electrons. Draw a labelled diagram of the apparatus used.

Q.3 Two metals A and B have work functions 2eV and 5eV respectively. Which metal has lower threshold wavelength?

Q.4 de-Broglie wavelength associated with an electron accelerated through a potential difference V is λ. What will be its wavelength when the accelerating potential is increased to 4 V?

Q.5 Sketch a graph between frequency of incident radiations and stopping potential for a given photosensitive material. What information can be obtained from the value of the intercept on the potential axis?

A source of light of frequency greater than the threshold frequency is placed at a distance of 1 m from the cathode of a photo-cell. The stopping potential is found to be V. If the distance of the light source from the cathode is reduced, explain giving reasons, what change will you observe in the

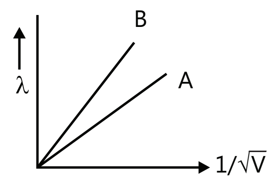
(i) Photoelectric current

(ii) Stopping potential

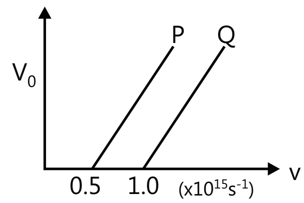
Q.6 Ultraviolet radiations of different frequencies v_1 and v_2 are incident on two photosensitive materials having work functions W_1 and W_2 $((W_1 > W_2)$ respectively. The Kinetic energy of the emitted electron is same in both cases. Which one of the two radiations will be of higher frequency?

Q.7 Draw a schematic diagram of the experimental arrangement used by Davisson and Germer to establish the wave nature of electrons. Explain briefly how the de-Broglie relation was experimentally verified in case of electrons.

Q.8 Two lines, A and B, in the plot given below show the variation of de-Broglie wavelength, λ, versus $\frac{1}{\sqrt{V}}$, where V is the accelerating potential difference. For two particles carrying the same charge, which one of the two represents a particle of smaller mass?



Q.9 The following graphs shows the variation of stopping potential V_0 with the frequency v of the incident radiation for two photosensitive metals P and Q:



(i) Explain which metal has smaller threshold wavelength.

(ii) Explain, giving reason, which metal emits photoelectron having smaller kinetic energy.

(iii) If the distance between the light source and metal P is doubled, how will the stopping potential change?

Q.10 The stopping potential in an experiment on photoelectric effect is 1.5V. What is the maximum kinetic energy of the photoelectrons emitted?

Q.11 An α -Particles and a proton are accelerated from rest by the same potential. Find the ratio of their de-Broglie wavelengths.

Q.12 Write Einstein's photoelectric equation. State clearly the three salient features observed in photoelectric effect, which can be explained on the basis of the above equation.

Q.13 Define the term 'stopping potential' in relation to photoelectric effect.

Q.14 Draw a plot showing the variation of photoelectric current with collector plate potential for two different frequencies, $v_1 > v_2$, of incident radiation having the same intensity. In which case will the stopping potential be higher? Justify your answer.

Q.15 A proton and an electron have same kinetic energy. Which one has greater de-Broglie wavelength and why?

Q.16 Define the terms (i) 'cut-off voltage' and (ii) 'threshold frequency' in relation to the phenomenon of photoelectric effect.

Using Einstein's photoelectric equation show how the cut-off voltage and threshold frequency for a given photosensitive material can be determined with the help of a suitable plot/graph.

Q.17 Derive the expression for the radius of the ground state orbit of hydrogen atom, using Bohr's postulates. Calculate the frequency of the photon, which can excite the electron to –3.4 eV from –13.6 eV.

Q.18 A stream of electrons travelling with speed 'v' m/s at right angles to a uniform electric field 'E', is deflected in a circular path of radius 'r'. Prove that $\frac{e}{m} = \frac{v^2}{rE}$.

Q.19 In a hydrogen atom, an electron of change 'e' revolves in a orbit of radius 'r' with a speed 'v'. Prove that the magnetic moment associated with the electron is given by $\frac{evr}{2}$.

Q.20 Draw a labeled diagram of experimental setup of Rutherford's alpha particle scattering experiment. Write two important inferences drawn from this experiment.

Q.21 The ground state energy of hydrogen atom is –13.6eV.

(i) What is the potential energy of an electron in the 3rd excited state?

(ii) If the electron jumps to the ground state from third excited state, calculate the wavelength of the photon emitted.

Q.22 Drawn a schematic arrangement of the Geiger–Marsden experiment. How did the scattering of α -particle by a thin foil of gold provide an important way to determine an upper limit on the size of the nucleus? Explain briefly.

Q.23 The ground state energy of hydrogen atom is –13.6eV. What are the kinetic and potential energies of electron in this state?

Q.24 In a Geiger-Marsden experiment, calculate the distance of closest approach to the nucleus of Z = 80, when an α -particle of 8 MeV energy impinges on it before it comes momentarily to rest and reverse its direction.

How will the distance of closest approach be affected when the kinetic energy of the α -particle is doubled?

Q.25 A photon and electron have got the same de-Broglie wavelength. Which has the greater total energy? Explain.

Q.26 If the intensity of incident radiation of a metal surface is doubled, what happens to the kinetic energy of the electrons emitted?

Q.27 The wavelength of a spectral line is 4000 Å. Calculate its frequency and energy. Given, $c = 3\times10^{8}\ ms^{-1}$ and $h = 6.6\times10^{-34}$ Js.

Q.28 Calculate the longest wavelength of the incident radiation, which will eject photoelectrons from a metal surface, whose work function is 3 eV.

Exercise 2

Single Correct Choice Type

Q.1 Let n_r and n_b be respectively the number of photons emitted by a red bulb and a blue bulb of equal power in a given time.

(A) $n_r = n_b$ (B) $n_r < n_b$

(C) $n_r > n_b$ (D) Data insufficient

Q.2 In a photo-emissive cell, with exciting wavelength λ, the maximum kinetic energy of electron is K. If the exciting wavelength is changed to $\frac{3\lambda}{4}$ the Kinetic energy of the fastest emitted electron will be:

(A) $\frac{3K}{4}$ (B) $\frac{4K}{3}$

(C) Less than $\frac{4K}{3}$ (D) Greater than $\frac{4K}{3}$

Q.3 If the frequency of light in a photoelectric experiment is doubled, the stopping potential will

(A) Be doubled

(B) Be halved

(C) Become more than doubled

(D) Become less than doubled

Q.4 The stopping potential for the photoelectron emitted from a metal surface of work function 1.7 eV is 10.4 V. Identify the energy levels corresponding to the transition in hydrogen atom which will result in emission of wavelength equal to that of incident radiation for the above photoelectric effect.

(A) n = 3 to 1 (B) n = 3 to 2

(C) n = 2 to 1 (D) n = 4 to 1

Q.5 Radiation of two photon energies twice and five times the work functions of metal are incident successively on the metal surface. The ratio of the maximum velocity of photoelectrons emitted is the two cases is

(A) 1 : 2 (B) 2 : 1 (C) 1 : 4 (D) 4 : 1

Q.6 Cut off potentials for a metal in photoelectric effect for light of wavelength λ_1, λ_2 and λ_3 is found to be V_1, V_2 and V_3 volts if V_1, V_2 and V_3 are in Arithmetic Progression and λ_1, λ_2 and λ_3 will be:

(A) Arithmetic Progression

(B) Geometric Progression

(C) Harmonic Progression

(D) None

Q.7 In a photoelectric experiment, the collector plate is at 2.0V with respect to the emitter plate made of copper ϕ=4.5eV). The emitter is illuminated by a source of monochromatic light of wavelength 200nm.

(A) The minimum kinetic energy of the photoelectrons reaching the collector is 0.

(B) The maximum kinetic energy of the photoelectrons reaching the collector is 3.7ev.

(C) If the polarity of the battery is reversed then answer to part A will be 0.

(D) If the polarity of the battery is reversed then answer to part B will be 1.7eV.

Q.8 By increasing the intensity of incident light keeping frequency ($v > v_0$) fixed, on the surface of metal

(A) Kinetic energy of the photoelectrons increase

(B) Number of emitted electrons increases

(C) Kinetic energy and number of electrons increase

(D) No effect

Q.9 A proton and an electron accelerated by same potential difference have de-Broglie wavelength λ_p and λ_e

(A) $\lambda_e = \lambda_p$ (B) $\lambda_e < \lambda_p$

(C) $\lambda_e > \lambda_p$ (D) None of these

Q.10 An electron with initial kinetic energy of 100eV is accelerated through a potential difference of 50V. Now the de-Broglie wavelength of electron becomes

(A) 1Å (B) $\sqrt{1.5}$ Å (C) $\sqrt{3}$ Å (D) 12.27Å

Q.11 If h is Planck's constant in SI system, the momentum of a photon of wavelength 0.01 Å is:

(A) 10^{-2} h (B) h (C) 10^2 h (D) 10^{12} h

Q.12 Let K_1 be the maximum kinetic energy of photoelectrons emitted by a light of wavelength λ_1 and K_2 corresponding to λ_2. If $\lambda_1 = 2\lambda_2$, then:

(A) $2K_1 = K_2$ (B) $K_1 = 2K_2$ (C) $K_1 < \frac{K_2}{2}$ (D) $K_1 > 2K_2$

Q.13 Imagine a Young's double slit interference experiment performed with waves associated with fast moving electrons produced from an electron gun. The distance between successive maxima will decrease maximum if

(A) The accelerating voltage in the electron gun is decreased

(B) The accelerating voltage is increased and the distance of the screen from the slits is decreased

(C) The distance of the screen from the slits is increased

(D) The distance between the slits is decreased.

Q.14 If the electron in a hydrogen atom was in the energy level with n = 3, how much energy in joule would be required to ionize the atom? (Ionization energy of H-atom is 2.18×10^{-18} J):

(A) 6.52×10^{-16} J (B) 2.86×10^{-10} J

(C) 2.42×10^{-19} J (D) 3.56×10^{-19} J

Q.15 In hydrogen and hydrogen like atoms, the ratio of difference of energies $E_{4n} - E_{2n}$ and $E_{2n} - E_n$ varies with its atomic number z and n as:

(A) $\frac{z^2}{n^2}$ (B) $\frac{z^4}{n^4}$ (C) $\frac{z}{n}$ (D) $z^0 n^0$

Q.16 In a hydrogen atom, the electron is in nth excited state. It may come down to second excited state by emitting ten different wavelengths. What is the value of n?

(A) 6 (B) 7 (C) 8 (D) 5

Q.17 Monochromatic radiation of wavelength λ is incident on a hydrogen sample in ground state. Hydrogen atoms absorb the light and subsequently emit radiations of ten different wavelengths. The value of λ is

(A) 95nm (B) 103nm (C) 73nm (D) 88nm

Q.18 In a sample of hydrogen like atoms all of which are in ground state, a photon beam containing photons of various energies is passed. In absorption spectrum, five dark lines are observed. The number of bright lines in the emission spectrum will be (Assume that all transitions take place)

(A) 5 (B) 10 (C) 15 (D) None of these

Q.19 When a hydrogen atom, initially at rest emits, a photon resulting in transition n = 5 $\rightarrow$ n = 1, its recoil speed is about

(A) 10^{-4} m/s (B) 2×10^{-2} m/s

(C) 4.2 m/s (D) 3.8×10^{-2} m/s

Q.20 The electron in a hydrogen atom makes a transition from an excited state to the ground state. Which of the following statement is true?

(A) Its kinetic energy increases and its potential and total energies decrease.

(B) Its kinetic energy decreases, potential energy increases and its total energy remains the same.

(C) Its kinetic, and total energies decrease and its potential energy increases.

(D) Its kinetic, potential and total energies decrease.

Q.21 The magnitude of angular momentum, orbit radius and frequency of revolution of electron in hydrogen atom corresponding to quantum number n are L, r and respectively. Then according to Bohr's theory of hydrogen atom,

(A) fr^2L is constant for all orbits

(B) frL is constant for all orbits

(C) f^2rL is constant for all orbits

(D) frL^2 is constant for all orbits

Q.22 Radius of the second Bohr orbit of singly ionized helium atom is

(A) 0.53 Å (B) 1.06 Å (C) 0.265 Å (D) 0.132 Å

Q.23 An electron in Bohr's hydrogen atom has an energy of –3.4 eV. The angular momentum of the electron is

(A) $\frac{h}{\pi}$ (B) $\frac{h}{2\pi}$

(C) $\frac{nh}{2\pi}$ (n is an integer) (D) $\frac{2h}{\pi}$

Q.24 An electron is in an excited state in hydrogen-like atom. It has a total energy of –3.4eV. If the kinetic energy of the electron is E and its de-Broglie wavelength is λ, then

(A) E = 6.8eV, $\lambda = 6.6 \times 10^{-10}$ m

(B) E = 3.4eV, $\lambda = 6.6 \times 10^{-10}$ m

(C) E = 3.4eV, $\lambda = 6.6 \times 10^{-11}$ m

(D) E = 6.8eV, $\lambda = 6.6 \times 10^{-11}$ m

Q.25 If radiation of all wavelengths from ultraviolet to infrared is passed through hydrogen a gas at room temperature, absorption lines will be observed in the:

(A) Lyman series (B) Balmer series

(C) Both (A) and (B) (D) Neither (A) nor (B)

Q.26 In the hydrogen atom, if the reference level of potential energy is assumed to be zero at the ground state level, choose the incorrect statement.

(A) The total energy of the shell increases with increase in the value of n.

(B) The total energy of the shell decrease with increase in the value of n.

(C) The difference in total energy of any two shells remains the same.

(D) The total energy at the ground state becomes 13.6 eV.

Q.27 Choose the correct statement(s) for hydrogen and deuterium atoms (considering motion of nucleus)

(A) The radius of first Bohr orbit of deuterium is less than that of hydrogen

(B) The speed of electron in the first Bohr orbit of deuterium is more than that of hydrogen.

(C) The wavelength of first Balmer line of deuterium is more than that of hydrogen

(D) The angular momentum of electron in the first Bohr orbit of deuterium is more than that of hydrogen.

Q.28 In a Coolidge tube experiment, the minimum wavelength of the continuous X-ray spectrum is equal to 66.3 pm, then

(A) Electron accelerate through a potential difference of 12.75 kV in the Coolidge tube

(B) Electrons accelerate through a potential difference of 18.75 kV in the Coolidge tube

(C) de-Broglie wavelength of the electrons reaching the anticathode is of the order of 10μm.

(D) de-Broglie wavelength of the electrons reaching the anticathode is 0.01Å.

Q.29 The potential difference applied to an X-ray tube is increased. As a result, in the emitted radiation:

(A) The intensity increases

(B) The minimum wave length increases

(C) The intensity decreases

(D) The minimum wave length decreases

Previous Years' Questions

Q.1 The shortest wavelength of X-rays emitted from an X-ray tube depends on ***(1982)***

(A) The current in the tube

(B) The voltage applied to the tube

(C) The nature of the gas in tube

(D) The atomic number of the target material

Q.2 Beta rays emitted by a radioactive material are ***(1983)***

(A) Electromagnetic radiations

(B) The electrons orbiting around the nucleus

(C) Charged particles emitted by the nucleus

(D) Neutral particles

Q.3 If elements with principal quantum number n > 4 were not allowed in nature, the number of possible elements would be ***(1983)***

(A) 60 (B) 32 (C) 4 (D) 64

Q.4 Consider the spectral line resulting from the transition n = 2 → n = 1 in the atoms and ions given below. The shortest wavelength is produced by ***(1983)***

(A) Hydrogen atom

(B) Deuterium atom

(C) Singly ionized helium

(D) Doubly ionized lithium

Q.5 Equation: $4{}_1^1H \longrightarrow {}_2^4He^{2+} + 2e^- + 26\text{ MeV}$

represents ***(1983)***

(A) β – decay (B) γ – decay

(C) Fusion (D) Fission

Q.6 For a given plate voltage, the plate current in a triode valve is maximum when the potential of ***(1985)***

(A) The grid is positive and plate is negative.

(B) The grid is zero and plate is positive.

(C) The grid is negative and plate is positive

(D) The grid is positive and plate is positive

Q.7 The X-ray beam coming from an X-ray tube will be ***(1985)***

(A) Monochromatic

(B) Having all wavelengths smaller than a certain maximum wavelength

(C) Having all wavelengths larger than a certain minimum wavelength

(D) Having all wavelengths lying between a minimum and a maximum wavelength

Q.8 **Statement-I:** If the accelerating potential in an X-ray tube is increased, the wavelengths of the characteristic X-rays do not change.

Statement-II: When an electron beam strikes the target in an X-ray tube, part of the kinetic energy is converted into X-ray energy. ***(2007)***

(A) If Statement-I is true, statement-II is true; statement-II is the correct explanation for statement-I.

(B) If Statement-I is true, statement-II is true; statement-II is not a correct explanation for statement-I.

(C) If statement-I is true; statement-II is false.

(D) If statement-I is false; statement-II is true.

Q.9 To produce characteristic X-rays using a tungsten target in an X-ray generator, the accelerating voltage should be greater than...... V and the energy of the characteristic radiation is .... eV. ***(1983)***

(The binding energy of the innermost electron in tungsten is 40 keV).

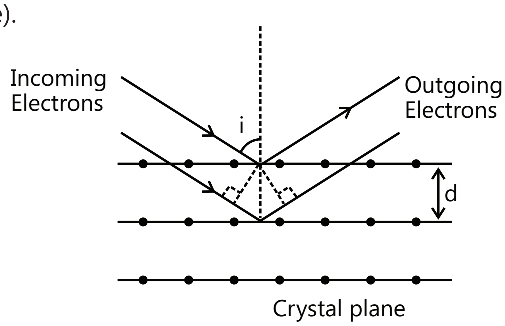
Q.10 The radioactive decay rate of a radioactive element is found to be 10^3 disintegration/second at a certain time. If the half-life of the element is one second, the decay rate after one second is .... and after three seconds is......... ***(1983)***

Q.11 The maximum kinetic energy of electrons emitted in the photoelectric effect is linearly dependent on the .... of the incident radiation. ***(1984)***

Q.12 In the uranium radioactive series the initial nucleus is ${}^{238}_{92}U$ and the final nucleus is ${}^{206}_{82}Pb$. When the uranium nucleus decays to lead, the number of α-particles emitted is .... and the number of β-particles emitted is......... ***(1985)***

Directions : Q.13, Q.14 and Q.15 are based on the following paragraph.

Wave property of electrons implies that they will show diffraction effects. Davisson and Germer demonstrated this by diffracting electrons from crystals. The law governing the diffraction from a crystal is obtained by requiring that electron waves reflected from the planes of atoms in a crystal interfere constructively (see in figure).



Q.13 Electrons accelerated by potential V are diffracted from a crystal. If d = 1Å and i = 30°, V should be about ($h = 6.6 \times 10^{-34}$ Js, $m_e = 9.1 \times 10^{-31}$ kg, $e = 1.6 \times 10^{-19}$ C) ***(2008)***

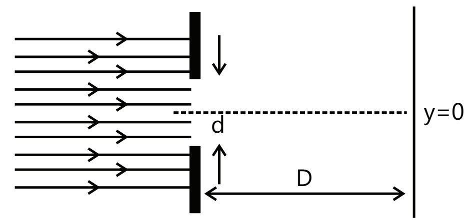
(A) 2000 V (B) 50 V (C) 500 V (D) 1000 V

Q.14 If a strong diffraction peak is observed when electrons are incident at an angle 'i' from the normal to the crystal planes with distance 'd' between them (see figure), de Broglie wavelength λ_{dB} of electrons can be calculated by the relationship (n is an integer) ***(2008)***

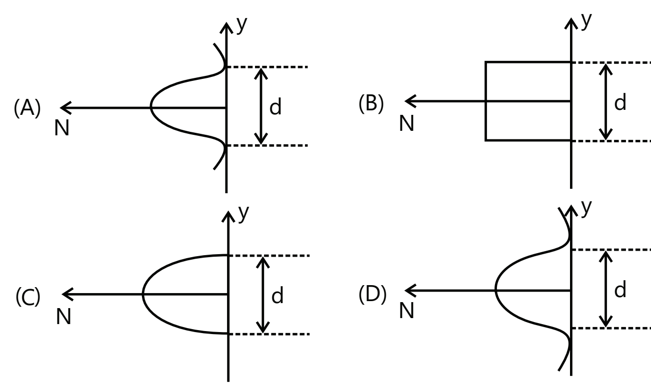
(A) $d \sin i = n\lambda_{dB}$ (B) $2d \cos i = n\lambda_{dB}$

(C) $2d \sin i = n\lambda_{dB}$ (D) $d \cos i = n\lambda_{dB}$

Q.15 In an experiment, electrons are made to pass through a narrow slit of width 'd' comparable to their de Broglie wavelength. They are detected on a screen at a distance 'D' from the slit (see figure). ***(2008)***



Which of the following graph can be expected to represent the number of electrons 'N' detected as a function of the detector position 'y'(y = 0 corresponds to the middle of the slit)?



Q.16 Two points P and Q are maintained at the potentials of 10V and -4V respectively. The work done in moving 100 electrons from P to Q is ***(2009)***

(A) -19×10^{-17} J (B) 9.60×10^{-17} J

(C) -2.24×10^{-16} J (D) 2.24×10^{-16} J

Q.17 The surface of a metal is illuminated with the light of 400 nm. The kinetic energy of the ejected photo electrons was found to be 1.68 eV. The work function of the metal is (hc = 1240 eV nm) ***(2009)***

(A) 3.09 eV (B) 1.41 eV

(C) 151 eV (D) 1.68 ev

Q.18 **Statement-I:** When ultraviolet light is incident on a photocell, its stopping potential is V_0 and the maximum kinetic energy of the photoelectrons is K_{max}. When the ultraviolet light is replaced by X-rays, both V_0 and K_{max} increase.

Statement-II: Photoelectrons are emitted with speeds ranging from zero to a maximum value because of the range of frequencies present in the incident light. ***(2010)***

(A) Statement-I is true, statement-II is true; statement-II is the correct explanation of statement-I.

(B) Statement-I is true, statement-II is true; statement-II is not the correct explanation of statement-I.

(C) Statement-I is false, statement-II is true.

(D) Statement-I is true, statement-II is false.

Q.19 If a source of power 4 kW produces 10^{20} photons/second, the radiation belong to a part of the spectrum called ***(2010)***

(A) X–rays (B) Ultraviolet rays

(C) Microwaves (D) γ – rays

Q.20 This question has Statement-I and Statement-II. Of the four choices given after the statements, choose the one that best describes the two statements.

Statement-I: A metallic surface is irradiated by a monochromatic light of frequency $v > v_0$ (the threshold frequency). The maximum kinetic energy and the stopping potential are K_{max} and V_0 respectively. If the frequency incident on the surface doubled, both the K_{max} and V_0 are also doubled ***(2011)***

Statement-II: The maximum kinetic energy and the stopping potential of photoelectrons emitted from a surface are linearly dependent on the frequency of incident light.

(A) Statement-I is true, statement-II is true; statement-II is the correct explanation of statement-I.

(B) Statement-I is true, statement-II is true; statement-II is not the correct explanation of statement-I.

(C) Statement-I is false, statement-II is true.

(D) Statement-I is true, statement-II is false.

Q.21 This question has statement-I and statement-II. Of the four choices given after the statements, choose the one that best describes the two statements

Statement-I: Davisson – germer experiment established the wave nature of electrons.

Statement-II: If electrons have wave nature, they can interfere and show diffraction. ***(2012)***

(A) Statement-I is false, statement-II is true

(B) Statement-I is true, statement-II is false

(C) Statement-I is true, statement-II is the correct explanation for statement-I

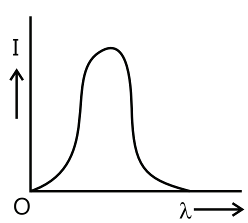
(D) Statement-I is true, statement-II is true, statement-II is not the correct explanation for statement-I.

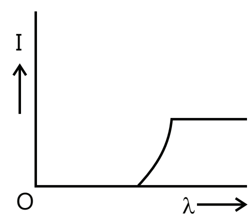
Q.22 A diatomic molecule is made of two masses m_1 and m_2 which are separated by a distance r. If we calculate its rotational energy by applying Bohr's rule of angular momentum quantization, its energy will be given by (n is an integer) ***(2012)***

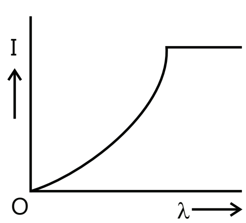
(A) $\frac{(m_1+m_2)^2n^2h^2}{2m_1^2m_2^2r^2}$ (B) $\frac{n^2h^2}{2(m_1+m_2)r^2}$

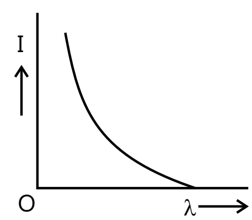
(C) $\frac{2n^2h^2}{(m_1+m_2)r^2}$ (D) $\frac{(m_1+m_2)n^2h^2}{2m_1m_2r^2}$

Q.23 The anode voltage of a photocellis kept fixed. The wavelength λ of the light falling on the cathode is gradually changed. The plate current I of the photocell varies as follows : ***(2013)***

(A)


(B)


(C)


(D)


Q.24 In a hydrogen like atom electron make transition from an energy level with quantum number n to another with quantum number (n – 1). If n>>1, the frequency of radiation emitted is proportional to : ***(2013)***

(A) $\frac{1}{n}$ (B) $\frac{1}{n^2}$ (C) $\frac{1}{n^{3/2}}$ (D) $\frac{1}{n^3}$

Q.25 The radiation corresponding to 3 → 2 transition of hydrogen atoms falls on a metal surface to produce photoelectrons. These electrons are made to enter a magnetic field of 3×10^{-4} T. If the radius of the largest circular path followed by these electrons is 10.0 mm, the work function of the metal is close to ***(2014)***

(A) 1.8 eV (B) 1.1 eV (C) 0.8 eV (D) 1.6 eV

Q.26 Hydrogen ($_1H^1$), Deuterium ($_1H^2$), singly ionised Helium ($_2He^4$)$^+$ and doubly ionised lithium ($_3Li^6$)$^{++}$ all have one electron around the nucleus. Consider an electron transition from n= 2 to n= 1. If the wave lengths of emitted radiation are λ_1, λ_2, λ_3 and λ_4 respectively then approximately which one of the following is correct? ***(2014)***

(A) $4\lambda_1 = 2\lambda_2 = 2\lambda_3 = \lambda_4$ (B) $\lambda_1 = 2\lambda_2 = 2\lambda_3 = \lambda_4$

(C) $\lambda_1 = \lambda_2 = 4\lambda_3 = 9\lambda_4$ (D) $\lambda_1 = 2\lambda_2 = 3\lambda_3 = 4\lambda_4$

Q.27 Match List-I (Fundamental Experiment) with List-II (its conclusion) and select the correct option from the choices given below the list : ***(2015)***

	List - I		List - II
(i)	Franck-Hertz experiment	(p)	Particle nature of light
(ii)	Photo-electric experiment	(q)	Discrete energy levels of atom
(iii)	Davison, Germer experiment	(r)	Wave nature of electron
		(s)	Structure of atom

(A) (i) → (p), (ii) → (s), (iii) → (r)

(B) (i) → (q), (ii) → (s), (iii) → (r)

(C) (i) → (q), (ii) → (p), (iii) → (r)

(D) (i) → (s), (ii) → (r), (iii) → (q)

Q.28 Radiation of wavelength λ, is incident on a photocell. The fastest emitted electron has speed v If the wavelength is changed to $\frac{3\lambda}{4}$, the speed of the fastest emitted electron will be : ***(2016)***

(A) $< v\left(\frac{4}{3}\right)^{\frac{1}{2}}$ (B) $= v\left(\frac{4}{3}\right)^{\frac{1}{2}}$

(C) $= v\left(\frac{3}{4}\right)^{\frac{1}{2}}$ (D) $> v\left(\frac{4}{3}\right)^{\frac{1}{2}}$

JEE Advanced/Boards

Exercise 1

Q.1 When a monochromatic point source of light is at a distance of 0.2 m from a photoelectric cell, the cut off voltage and the saturation current are respectively 0.6 V and 18.0 mA. If the same source is placed 0.6 m away from the photoelectric cell, then find

(a) The stopping potential

(b) The saturation current

Q.2 663 mW of light from of 540 nm source is incident on the surface of a metal. If only 1 of each 5 x 10^9 incidents photons is absorbed and causes an electron to be ejected from the surface, the total photocurrent in the circuit is _______.

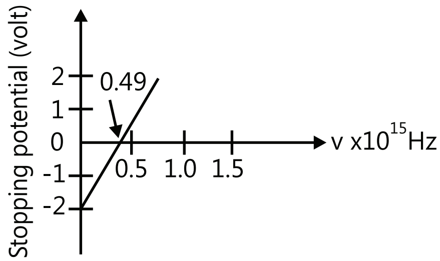
Q.3 Light of Wavelength 330 nm falling on a piece of metal ejects electrons with sufficient energy which requires voltage V_0 to prevent a electron from reading collector. In the same setup, light of wavelength 220 nm, ejects electron which require twice the voltage V_0 to stop them in reaching a collector. Find the numerical value of voltage V_0. (Take plank's constant, $h = 6.6\times10^{-34}$ J s and 1 eV = 1.6×10^{-19} J)

Q.4 A small 10W source of ultraviolet light of Wavelength 99 nm is held at a distance 0.1m from a metal surface. The radius of an atom of the metal is approximately 0.05 nm. Find

(i) The average number of photons striking an atom per second.

(ii) The number of photoelectrons emitted per unit area per second if the efficiency of liberation of photoelectrons is 1%.

Q.5 The surface of cesium is illuminated with monochromatic light of various wavelengths and the stopping potentials for the wavelengths are measured. The results of this experiment is plotted as shown in the figure. Estimate the value of work function of the cesium and Planck's constant.



Q.6 A small plate of a metal (work function = 1.17 eV) is placed at a distance of 2m from a monochromatic light source of wave length 4.8×10^{-7} m power 1.0 watt. The light falls normally on the plate. Find the number of photons striking the metal plate per square meter per second. If a constant uniform magnetic field of strength 10^{-4} tesla is applied parallel to the metal surface, find the radius of the largest circular path followed by the emitted photoelectrons.

Q.7 Electrons in hydrogen like atoms (Z = 3) make transition from the fifth to the fourth orbit & from the fourth to the third orbit. The resulting radiations are incident normally on a metal plate & eject photoelectrons. The stopping potential for the photoelectrons ejected by the shorter wavelength is 3.95 V. Calculate the work function of the metal, & the stopping potential for the photoelectrons ejected by the longer wavelength. (Rydberg constant = $1.094 \times 10^{7}\ m^{-1}$).

Q.8 A beam of light has three wavelength 4144 Å, 4972 Å & 6216Å with a total intensity of $3.6 \times 10^{-3}\ W.m^{-2}$ equally distributed amongst the three wavelengths. The beam falls normally on an area 1.0 cm^2 of a clean metallic surface of work function 2.3 eV. Assume that there is no loss of light by reflection and that each energetically capable photon ejects one electron. Calculate the number of photoelectrons liberated in time t = 2 s.

Q.9 A small 10 W source of ultraviolet light of wavelength 99nm is held at a distance 0.1 m from a metal surface. The radius of an atom of the metal is approximately 0.05 nm. Find:

(i) The number of photons striking an atom per seconds.

(ii) The number of photoelectrons emitted per seconds if the efficiency of liberation of photoelectrons is 1%.

Q.10 In a photoelectric effect set-up, a point source of light of power 3.2×10^{-3} W emits mono energetic photons of energy 5.0 eV. The source is located at a distance of 0.8 m from the center of a stationary metallic sphere of work function 3.0 eV & of radius 8.0×10^{-3}. The efficiency of photoelectrons emission is one for every 10^6 incident photons. Assume that the sphere is isolated and initially neutral, and that photoelectrons are instantly swept away after emission.

(a) Calculate the number of photoelectrons emitted per seconds.

(b) Find the ratio of the wavelength of incident light to the de-Broglie wave length of the fastest photoelectrons emitted.

(c) It is observed that the photoelectron emissions stops at a certain time t after the light source is switched on. Why?

(d) Evaluate the time t.

Q.11 When photons of energy 4.25eV strike the surface of a metal A, the ejected photoelectrons have maximum kinetic energy T_a eV and de Broglie wavelength λ_a. The maximum kinetic energy of photoelectrons liberated from another metal B by photons of energy 4.7eV is $T_b = (T_a - 1.5)$ eV. If the de Broglie wavelength of these photoelectrons is $\lambda_b = 2\lambda_a$, then find

(a) The work function of a

(b) The work function of b

(c) T_a and T_b

Q.12 An electron of mass "m" and charge "e" initially at rest gets accelerated by a constant electric field E. The rate of change of de Broglie wavelength of this electron at time t is..................

Q.13 A hydrogen atom in a state having a binding energy 0.85eV makes a transition to a state of excitation energy 10.2eV. The wave length of emitted photon is ....nm.

Q.14 A hydrogen atom is in 5^{th} excited state. When the electrons jump to ground state the velocity of recoiling hydrogen atom is ....m/s and the energy of the photon is ....eV.

Q.15 The ratio of series limited wavelength of Balmer series to wavelength of first line of

Paschen series is ....

Q.16 A neutron with kinetic energy 25 eV strikes a stationary deuteron. Find the de Broglie wavelengths of both particles in the frame of their center of mass.

Q.17 Assume that the de Broglie wave associated with an electron can form a standing wave between the atoms arranged in a one dimensional array with nodes at each of the atomic sites. It is found that one such standing wave is formed if the distance 'd' between the atoms of the array is 2 Å. A similar standing wave is again formed if 'd' is increased to 2.5 Å but not for any intermediate value of d. Find the energy of the electrons in electron volts and the least value of d for which the standing wave of the type described above can form.

Q.18 A stationary He^+ ion emitted a photon corresponding to the first line its Lyman series. That photon liberated a photoelectron from a stationary hydrogen atom in the ground state. Find the velocity of the photoelectron.

Q.19 A gas of identical hydrogen like atom has some atom in the lowest (ground) energy level A & some atoms in a particular upper (excited) energy level B & there are no atoms in any other energy level. The atoms of the gas make transition to a higher energy level by the absorbing monochromatic light of photon energy 2.7eV. Subsequently, the atom emit radiation of only six different photon energies. Some of the emitted photons have energy 2.7eV. Some have energy more and some have less than 2.7eV.

(i) Find the principle quantum of the initially excited level B.

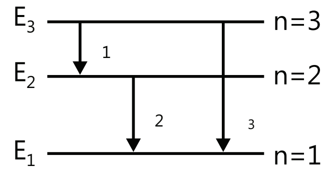
(ii) Find the ionization energy for the gas atoms.

(iii) Find the maximum and the minimum energies of the emitted photons.

Q.20 A hydrogen atom in ground state absorbs a photon of ultraviolet radiation of wavelength 50nm. Assuming that the entire photon energy is taken up by the electron, with what kinetic energy will the electron be ejected?

Q.21 An electron joins a helium nucleus to form a He^+ ion in ground state. The wavelength of the photon emitted in this process if the electron is assumed to have had no kinetic energy when it combines with nucleus is ________ nm.

Q.22 Three energy levels of an atom are shown in the figure. The wavelength corresponding to three possible transition are λ_1, λ_2 and λ_3. The value of λ_3 in terms of λ_1 and λ_2 is given by ______.



Q.23 Imagine an atom made up of a proton and a hypothetical particle of double the mass of an electron but having the same charge as the electron. Apply the Bohr atom model and consider a possible transition of this hypothetical particle to the first excited level. Find the longest wavelength photon that will be emitted λ (in terms of the Rydberg constant R.)

Q.24 In a hydrogen atom, the electron moves in an orbit of radius 0.5 Å making 10^{16} revolutions per second. The magnetic moment associated with the orbital motion of the electron is _________.

Q.25 A hydrogen like atom has its single electron orbiting around its stationary nucleus. The energy excite the electron from the second Bohr orbit to the third Bohr orbit is 47.2 eV. The atomic number of this nucleus is ______________.

Q.26 A single electron orbits a stationary nucleus of charge Ze where Z is a constant and e is the electronic charge. It requires 47.2eV to excite the electron from the 2^{nd} Bohr orbit to 3^{rd} Bohr orbit. Find

(i) The value of Z

(ii) Energy required to excite the electron from third to the fourth orbit

(iii) The wavelength of radiation required to remove the electron from the first orbit to

(iv) Infinity the Kinetic energy, potential energy and angular momentum in the first Bohr

(v) Orbit the radius of the first Bohr orbit.

Q.27 A hydrogen like atom (atomic number Z) is in higher excited state of quantum number n. This excited atom can make a transition to the first excited state by successive emitting two photons of energy 22.95eV and 5.15eV respectively. Alternatively, the atom from the same excited state can make transition to the second excited state by successive emitting two photons of energies 2.4eV and 8.7eV respectively. Find the value of n and Z.

Q.28 Find the binding energy of an electron in the ground state of a hydrogen like atom in whose spectrum the third of the corresponding Balmer series is equal to 108.5 nm.

Q.29 Which level of the doubly ionized lithium has the same energy as the ground state energy of the hydrogen atom? Find the ratio of the two radii of corresponding orbits.

Q.30 A 20 KeV energy electron is brought to rest in an X-ray tube, by undergoing two successive bremsstrahlung events, thus emitting two photons. The wavelength of the second photon is 130 x 10^{-12} m greater than the wavelength of the first emitted photon. Calculate the wavelength of the two photons.

Exercise 2

Single Correct Choice Type

Q.1 10^{-3} W of 5000 Å light is directed on a photoelectric cell. If the current in the cell is 0.16 μA, the percentage of incident photons which produce photoelectrons, is

(A) 0.4% (B) 0.04% (C) 20% (D) 10%

Q.2 Photons with energy 5eV are incident on a cathode C, on a photoelectric cell. The maximum energy of the emitted photoelectrons is 2 eV. When photons of energy 6 eV are incident on C, no photoelectrons will reach the anode A if the stopping potential of A relative to C is

(A) 3V (B) –3V (C) –1 V (D) 4 V

Q.3 In a hydrogen atom, the binding energy of the electron of the nth state is E_n, then the frequency of revolution of the electron in the nth orbit is:

(A) $\frac{2E_n}{nh}$ (B) $\frac{2E_n n}{h}$ (C) $\frac{E_n}{nh}$ (D) $\frac{E_n n}{h}$

Q.4 Difference between nth and $(n+1)^{th}$ Bohr's radius of 'H' atom is equal to it's $(n-1)^{th}$ Bohr's radius. The value of n is:

(A) 1 (B) 2 (C) 3 (D) 4

Q.5 Electron in a hydrogen atom is replaced by an identically charged particle muon with mass 207 times that of electron. Now the radius of K shell will be

(A) 2.56×10^{-3} Å (B) 109.7 Å

(C) 1.21×10^{-3} Å (D) 22174.4 Å

Q.6 An electrons collides with a fixed hydrogen atom in its ground state. Hydrogen atom gets excited and the colliding electron loses all its kinetic energy. Consequently the hydrogen atom may emit a photon corresponding to the largest wavelength of the Balmer series. The min. K.E. of colliding electron will be

(A) 10.2eV (B) 1.9 eV

(C) 12.1 eV (D) 13.6 eV

Q.7 A neutron collides head on with a stationary hydrogen atom in ground state

(A) If kinetic energy of the neutron is less than 13.6 eV, collision must be elastic.

(B) If kinetic energy of the neutron is less than 13.6 eV, collision may be inelastic.

(C) Inelastic collision takes place when initial kinetic energy of neutron is greater than 13.6 eV.

(D) Perfectly inelastic collision cannot take place.

Q.8 An electron in hydrogen atom first jumps from second excited state to first excited state and then, from first excited state to ground state. Let the ratio of wavelength, momentum and energy of photons in the two cases be x, y and z, then select the wrong answer(s):

(A) $z = \frac{1}{x}$ (B) $x = \frac{9}{4}$ (C) $y = \frac{5}{27}$ (D) $z = \frac{5}{27}$

Multiple Correct Choice Type

Q.9 In photoelectric effect, stopping potential depends on

(A) Frequency of the incident light

(B) Intensity of the incident light by varying source

(C) Emitter's properties

(D) Frequency and intensity of the incident light

Q.10 Two electrons are moving with the same speed v. One electron enters a region of uniform electric field while the other enters a region of uniform magnetic field, then after sometime if the de-Broglie wavelengths of the two are λ_1 and λ_2, then:

(A) $\lambda_1 = \lambda_2$ (B) $\lambda_1 > \lambda_2$

(C) $\lambda_1 < \lambda_2$ (D) $\lambda_1 > \lambda_2$ or $\lambda_1 < \lambda_2$

Q.11 A neutron collides head-on with a stationary hydrogen atom in ground state. Which of the following statements are correct (Assume that the hydrogen atom and neutron has same mass):

(A) If kinetic energy of the neutron is less than 20.4 eV collision must be elastic.

(B) If kinetic energy of the neutron is less than 20.4 eV collision may be inelastic.

(C) Inelastic collision may be take place only when initial kinetic energy of neutron is greater than 20.4 eV.

(D) Perfectly inelastic collision cannot take place.

Q.12 A free hydrogen atom in ground state is at rest. A neutron of kinetic energy 'K' collides with the hydrogen atom. After collision hydrogen atom emits two photons in succession one of which has energy 2.55 eV. (Assume that the hydrogen atom and neutron has same mass)

(A) Minimum value of 'K' is 25.5 eV.

(B) Minimum value of 'K' is 12.75 eV.

(C) The other photon has energy 10.2eV.

(D) The upper energy level is of excitation energy 12.75 eV.

Q.13 A particular hydrogen like atom has its ground state binding energy 122.4eV. It is in ground state. Then:

(A) Its atomic number is 3

(B) An electron of 90eV can excite it.

(C) An electron of kinetic energy nearly 91.8eV can be almost brought to rest by this atom.

(D) An electron of kinetic energy 2.6eV may emerge from the atom when electron of kinetic energy 125eV collides with this atom.

Q.14 A beam of ultraviolet light of all wavelengths pass through hydrogen gas at room temperature, in the x-direction. Assuming all photons emitted due to electron transition inside the gas emerge in the y-direction. Let A and B denote the lights emerging from the gas in the x and y directions respectively.

(A) Some of the incident wavelengths will be absent in A.

(B) Only those wavelengths will be present in B which are absent in A.

(C) B will contain some visible light.

(D) B will contain some infrared light.

Q.15 X-rays are produced by accelerating electrons across a given potential difference to strike a meta target of high atomic number. If the electrons have same speed when they strike the target, the X-ray spectrum will exhibit

(A) A minimum wavelength

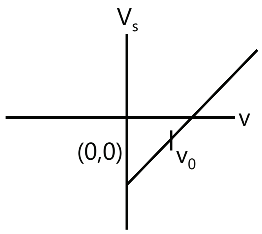
(B) A continuous spectrum

(C) Some discrete comparatively prominent wavelength

(D) Uniform density over the whole spectrum

Assertion Reasoning Type

Q.16 Statement-I: Figure shows graph of stopping potential and frequency of incident light in photoelectric effect. For values of frequency less than threshold frequency (v_0) stopping potential is negative.



Statement-II: Lower the value of frequency of incident light (for $v > v_0$) the lower is the maxima of kinetic energy of emitted photoelectrons.

(A) Statement-I is true, statement-II is true and statement-II is correct explanation for statement-I.

(B) Statement-I is true, statement-II is NOT the correct explanation for statement-I.

(C) Statement-I is true, statement-II is false.

(D) Statement-I is false, statement-II is true.

Q.17 Statement-I: Two photons having equal wavelengths have equal linear momenta.

Statement-II: When light shows its photons character, each photon has a linear momentum $\lambda = \frac{h}{p}$.

(A) Statement-I is true, statement-II is true and statement-II is correct explanation for statement-I.

(B) Statement-I is true, statement-II is NOT the correct explanation for statement-I.

(C) Statement-I is true, statement-II is false.

(D) Statement-I is false, statement-II is true.

Q.18 Statement-I: In the process of photoelectric emission, all the emitted photoelectrons have same K.E.

Statement-II: According to Einstein's photoelectric equation

$KE_{max} = hv - \phi$.

(A) Statement-I is True, statement-II is True, statement-II is a correct explanation for statement-I.

(B) Statement-I is True, statement-II is True, statement-II is NOT a correct explanation for statement-I.

(C) Statement-I is True, statement-II is False

(D) Statement-I is False, statement-II is True

Q.19 Statement-I: Work function of aluminum is 4.2 eV. If two photons each of energy 2.5 eV strikes on a piece of aluminum, the photoelectric emission does not occur.

Statement-II: In photoelectric effect a single photon interacts with a single electron and electron is emitted only if energy of each incident photon is greater than the work function.

(A) Statement-I is True, statement-II is True, statement-II is a correct explanation for statement-I.

(B) Statement-I is True, statement-II is True, statement-II is NOT a correct explanation for statement-I.

(C) Statement-I is True, statement-II is False

(D) Statement-I is False, statement-II is True

Q.20 Statement-I: An electron and a proton are accelerated through the same potential difference. The de-Broglie wavelength associated with the electron is longer.

Statement-II: de-Broglie wavelength associated with a moving particle is $\lambda = \frac{h}{p}$ where, p is the linear momentum and both have same K.E.

(A) Statement-I is True, statement-II is True, statement-II is a correct explanation for statement-I.

(B) Statement-I is True, statement-II is True, statement-II is NOT a correct explanation for statement-I.

(C) Statement-I is True, statement-II is False

(D) Statement-I is False, statement-II is True

Q.21 Statement-I: In a laboratory experiment, on emission from atomic hydrogen in a discharge tube, only a small number of lines are observed whereas a large number of lines are present in the hydrogen spectrum of a star.

Statement-II: The temperature of discharge tube is much smaller than that of the star.

(A) Statement-I is True, statement-II is True, statement-II is a correct explanation for statement-I.

(B) Statement-I is True, statement-II is True, statement-II is NOT a correct explanation for statement-I.

(C) Statement-I is True, statement-II is False

(D) Statement-I is False, statement-II is True

Previous Years' Questions

Q.1 A single electron orbits around a stationary nucleus of charge +Ze where Z is a constant and e is the magnitude of the electronic charge. It requires 47.2 eV to excite the electron from the second Bohr orbit to the third Bohr orbit. ***(1981)***

Find:

(a) The value of Z.

(b) The energy required to excite the electron from the third to the fourth Bohr orbit.

(c) The wavelength of the electromagnetic radiation required to remove the electron from the first Bohr orbit to infinity.

(d) The kinetic energy, potential energy and the angular momentum of the electron in the first Bohr orbit.

(e) The radius of the first Bohr orbit.

(The ionization energy of hydrogen atom = 13.6 eV, Bohr radius = 5.3×10^{-11}m, velocity of light = 3×10^{8}m / s. Planck's constant = 6.6×10^{-34} J s).

Q.2 Hydrogen atom in its ground state is excited by means of monochromatic radiation of wavelength 975° Å. How many different lines are possible in the resulting spectrum? Calculate the longest wavelength amongst them. You may assume the ionization energy for hydrogen atom as 13.6 eV. ***(1982)***

Q.3 How many electrons, protons and neutrons are there in a nucleus of atomic number 11 and mass number 24? ***(1982)***

(a) Number of electrons =

(b) Number of protons =

(c) Number of neutrons =

Q.4 A uranium nucleus (atomic number 92, mass number 238) emits an alpha particle and the resulting nucleus emits β -particle. What are the atomic number and mass number of the final nucleus? ***(1982)***

(a) Atomic number =

(b) Mass number =

Q.5 Ultraviolet light of wavelengths 800 Å and 700 Å when allowed to fall on hydrogen atoms in their ground state is found to liberate electrons with kinetic energy 1.8 eV and 4.0 eV respectively. Find the value of Planck's constant. ***(1983)***

Q.6 the ionization energy of a hydrogen like Bohr atom is 4 Rrydberg.

(a) What is the wavelength of the radiation emitted when the electron jumps from the first excited state to the ground state? ***(1984)***

(b) What is the radius of the first orbit for this atom?

Now, as $r \propto \frac{1}{Z}$ Radius of first orbit of this atom, $r_1 = \frac{r_{H_1}}{Z}$ $= \frac{0.529}{2}$ = 0.2645 Å

Q.7 A doubly ionized lithium atom is hydrogen-like with atomic number 3.

(a) Find the wavelength of the radiation required to excite the electron in Li^{2+} from the first to the third Bohr orbit. (Ionization energy of the hydrogen atom equals 13.6 eV.)

(b) How many spectral lines are observed in the emission spectrum of the above excited system? ***(1985)***

Q.8 There is a stream of neutrons with a kinetic energy of 0.0327 eV. If the half-life of neutrons is 700s, what fraction of neutrons will decay before they travel a distance of 10 m? ***(1986)***

Q.9 A particle of charge equal to that of an electron –e, and mass 208 times of the mass of the electron (called a mu-meson) moves in a circular orbit around a nucleus of charge +3e. (Take the mass of the nucleus to be infinite). Assuming that the Bohr model of the atom is applicable to this system. ***(1988)***

(a) Derive an expression for the radius of the n^{th} Bohr orbit.

(b) Find the value of n for which the radius of the orbit is approximately the same as that of the first Bohr orbit for the hydrogen atom.

(c) Find the wavelength of the radiation emitted when the mu-meson jumps from the third orbit to the first orbit. (Rydberg's constant = $1.097 \times 10^7\ m^{-1}$)

Paragraph 1: (Q.10–Q.12) In a mixture of $H-He^+$ gas (He^+ is single ionized He atom), H atoms and He^+ ions excited to their respective first excited states. Subsequently, H atoms transfer their total excitation energy of He^+ ions (by collisions). Assume that the Bohr model of atom is exactly valid.

Q.10 The quantum number n of the state finally populated in He^+ ions is ***(2008)***

(A) 2 (B) 3 (C) 4 (D) 4

Q.11 The wavelength of light emitted in the visible region by He^+ ions after collisions with H-atoms is ***(2008)***

(A) 6.5×10^{-7}m (B) 5.6×10^{-7}m

(C) 4.8×10^{-7}m (D) 4.0×10^{-7}m

Q.12 The ratio of the kinetic energy of the n = 2 electron for the H atom to that of He^+ ion is **(2008)**

(A) $\frac{1}{4}$ (B) $\frac{1}{2}$ (C) 1 (D) 2

Q.13 Some laws/processes are given in column I. Match these with the physical phenomena given in column II. ***(2006)***

Column I		Column II	
(A)	Nuclear fusion	(p)	Converts some matter into energy.
(B)	Nuclear fission	(q)	Generally possible for nuclei with low atomic number
(C)	β -decay	(r)	Generally possible for nuclei with higher atomic number
(D)	Exothermic nuclear reaction	(s)	Essentially proceeds by weak nuclear forces

Q.14 The threshold wavelength for photoelectric emission from a material is 5200 Å. Photoelectrons will be emitted when this material is illuminated with monochromatic radiation from a ***(1982)***

(A) 50W infrared lamp (B) 1 W infrared lamp

(C) 50W ultraviolet lamp (D) 1W ultraviolet lamp

Q.15 The allowed energy for the particle for a particular value of n is proportional to ***(2009)***

(A) a^{-2} (B) $a^{-3/2}$ (C) a^{-1} (D) a^2

Q.16 If the mass of the particle is m = 1.0×10^{-30} kg and a = 6.6 nm, the energy of the particle in its ground state is closest to ***(2009)***

(A) 0.8 MeV (B) 8 MeV (C) 80 MeV (D) 800 MeV

Q.17 The speed of the particle that can take discrete values is proportional to ***(2009)***

(A) $n^{-3/2}$ (B) n^{-1} (C) $n^{1/2}$ (D) n

Q.18 An α -particle and a proton are accelerated from rest by a potential difference of 100V. After this, their de-Broglie wavelength are λ_α and λ_p respectively. The ratio $\frac{\lambda_p}{\lambda_\alpha}$, to the nearest integer, is : ***(2010)***

Q.19 The wavelength of the first spectral line in the Balmer series of hydrogen atom is 6561 $\mathring{A}$. The wavelength of the second spectral line in the Balmer series of singly-ionized helium atom is ***(2010)***

(A) 1215 $\mathring{A}$ (B) 1640 $\mathring{A}$ (C) 2430 $\mathring{A}$ (D) 4687 $\mathring{A}$

Q.20 A proton is fired from very far away towards a nucleus with charge Q = 120 e, where e is the electronic charge. It makes a closest approach of 10 fm to the nucleus. The de Broglie wavelength (in units of fm) of the proton at its start is: (take the proton mass, mp = (5/3) × 10^{-27} kg; h/e = 4.2 × 10^{-15} J.s / C; $\frac{1}{4\pi\varepsilon_0}$ = 9 × 10^9 m/F; 1 fm = 10^{-15}) ***(2012)***

Q.21 A pulse of light of duration 100 ns is absorbed completely by a small object initially at rest. Power of the pulse is 30 mW and the speed of light is 3 × 10^8 m/s. The final momentum of the object is ***(2013)***

(A) 0.3 × 10^{-17} kg ms^{-1} (B) 1.0 × 10^{-17} kg ms^{-1}

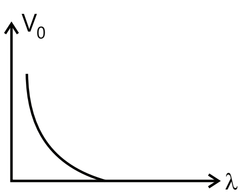
(C) 3.0 × 10^{-17} kg ms^{-1} (D) 9.0 × 10^{-17} kg ms^{-1}

Q.22 The work functions of Silver and Sodium are 4.6 and 2.3 eV, respectively. The ratio of the slope of the stopping potential versus frequency plot for Silver to that of Sodium is ***(2013)***

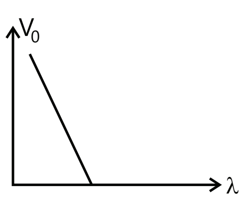
Q.23 Consider a hydrogen atom with its electron in the nth orbital. An electromagnetic radiation of wavelength 90 nm is used to ionize the atom. If the kinetic energy of the ejected electron is 10.4 eV, then the value of n is (hc = 1242 eV nm) ***(2015)***

Q.24 For photo-electric effect with incident photon wavelength λ, the stopping potential is V_o. Identify the correct variation(s) of V_0 with λ and $1/\lambda$. ***(2015)***

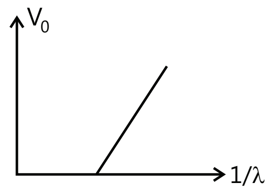
(A)



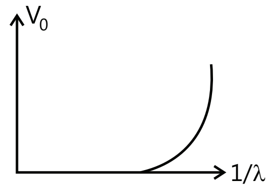
(B)



(C)



(D)



Q.25 In a historical experiment to determine Planck's constant, a metal surface was irradiated with light of different wavelengths. The emitted photoelectron energies were measured by applying a stopping potential. The relevant data for the wavelength (λ) of incident light and the corresponding stopping potential (V_0) are given below: ***(2016)***

$\lambda(\mu m)$	V_0 (Volt)
0.3	2.0
0.4	1.0
0.5	0.4

Given that c = 3 × 10^8 m s^{-1} and e = 1.6 × 10^{-19} C, Planck's constant (in units of J s) found from such an experiment is

(A) 6.0 × 10^{-34} (B) 6.4 × 10^{-34}

(C) 6.6 × 10^{-34} (D) 6.8 × 10^{-34}

Q.26 Highly excited states for hydrogen-like atoms (also called Rydberg states) with nuclear charge Ze are defined by their principal quantum number n, where n >> 1. Which of the following statement(s) is(are) true? ***(2016)***

(A) Relative change in the radii of two consecutive orbitals does not depend on Z

(B) Relative change in the radii of two consecutive orbitals varies as 1/n

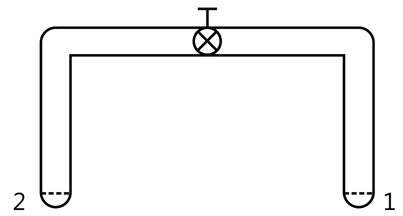
(C) Relative change in the energy of two consecutive orbitals varies as 1/n^3

(D) Relative change in the angular momenta of two consecutive orbitals varies as 1/n

Q.27 A hydrogen atom in its ground state is irradiated by light of wavelength 970A. Taking hc/e = 1.237 × 10^{-6} eVm and the ground state energy of hydrogen atom as –13.6 eV, the number of lines present in the emission spectrum is ***(2016)***

Q.28 A glass tube of uniform internal radius (r) has a valve separating the two identical ends. Initially, the valve is in a tightly closed position. End 1 has a hemispherical soap bubble of radius r. End 2 has sub-hemispherical soap bubble as shown in figure. Just after opening the valve, ***(2008)***

Figure:



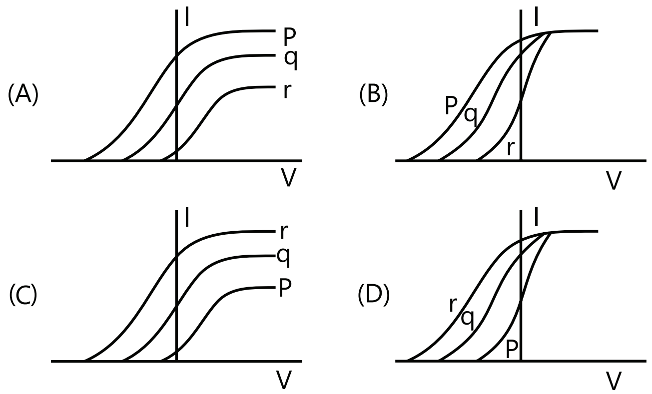
(A) Air from end 1 flows towards end 2. No change in the volume of the soap bubbles

(B) Air from end 1 flows towards end 2. Volume of the soap bubble at end 1 decreases

(C) No changes occurs

(D) Air from end 2 flows towards end 1. volume of the soap bubble at end 1 increases

Q.29 Photoelectric effect experiments are performed using three different metal plates p, q and r having work functions $\phi_p = 2.0$ eV, $\phi_q = 2.5$ eV and $\phi_r = 3.0$ eV, respectively. A light beam containing wavelengths of 550 nm, 450 nm and 350 nm with equal intensities illuminates each of the plates. The correct I-V graph for the experiment is (Take hc = 1240 eV nm) ***(2009)***



Paragraph for questions 30 to 32 ***(2010)***

The key feature of Bohr's theory of spectrum of hydrogen atom is the quantization of angular momentum when an electron is revolving around a proton. We will extend this to a general rotational motion to find quantized rotational energy of a diatomic molecule assuming it to be rigid. The rule to be applied is Bohr's quantization condition.

Q.30 A diatomic molecule has moment of inertia I. By Bohr's quantization condition its rotational energy in the n^{th} level (n = 0 is not allowed) is

(A) $\frac{1}{n^2}\left(\frac{h^2}{8\pi^2 I}\right)$ (B) $\frac{1}{n}\left(\frac{h^2}{8\pi^2 I}\right)$

(C) $n\left(\frac{h^2}{8\pi^2 I}\right)$ (D) $n^2\left(\frac{h^2}{8\pi^2 I}\right)$

Q.31 It is found that the excitation frequency from ground to the first excited state of rotation for the CO molecule is close to $\frac{4}{\pi}\times 10^{11}$ Hz. Then the moment of inertia of CO molecule about its centre of mass is close to (Take h = $2\pi\times 10^{-34}$ Js)

(A) 2.76×10^{-46} kg m^2 (B) 1.87×10^{-46} kg m^2

(C) 4.67×10^{-47} kg m^2 (D) 1.17×10^{-47} kg m^2

Q.32 In a CO molecule, the distance between C (mass = 12 a.m.u) and O (mass = 16 a.m.u.), where 1 a.m.u. = $\frac{5}{3}\times 10^{-27}$ kg, is close to

(A) 2.4×10^{-10} m (B) 1.9×10^{-10} m

(C) 1.3×10^{-10} m (D) 4.4×10^{-11} m

Q.33 A silver sphere of radius 1 cm and work function 4.7 eV is suspended from an insulating thread in free space. It is under continuous illumination of 200 nm wavelength light. As photoelectrons are emitted, the sphere gets charged and acquires a potential. The maximum number of photoelectrons emitted from the sphere is A $\times 10^z$ (where 1 < A < 10). The value of 'Z' is ***(2011)***

Q.34 Two bodies, each of mass M, are kept fixed with a separation 2L. A particle of mass m is projected from the midpoint of the line joining their centres, perpendicular to the line. The g ravitational constant is G. The correct statement(s) is (are) ***(2013)***

(A) The minimum initial velocity of the mass m to escape the gravitational field of the two bodies is $4\sqrt{\frac{GM}{L}}$

(B) The minimum initial velocity of the mass m to escape the gravitational field of the two bodies is $2\sqrt{\frac{GM}{L}}$

(C) The minimum initial velocity of the mass m to escape the gravitational field of the two bodies is $\sqrt{\frac{2GM}{L}}$

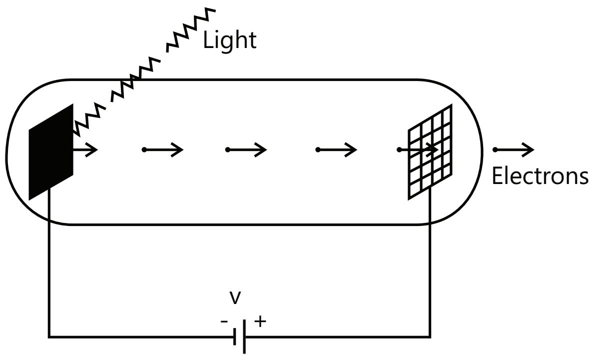
(D) The energy of the mass m remains constant.

Q.35 A metal surface is illuminated by light of two different wavelengths 248 nm and 310 nm. The maximum speeds of the photoelectrons corresponding to these wavelengths are u_1 and u_2, respectively. If the ratio $u_1 : u_2 = 2 : 1$and hc = 1240 eV nm, the work function of the metal is nearly ***(2014)***

(A) 3.7 eV (B) 3.2 eV

(C) 2.8 eV (D) 2.5 eV

Q.36 Light of wavelength λ_{ph} falls on a cathode plate inside a vacuum tube as shown in the figure. The work function of the cathode surface is ϕ and the anode is a wire mesh of conducting material kept at a distance d from the cathode. A potential difference V is maintained between the electrodes. If the minimum de Broglie wavelength of the electrons passing through the anode is λ_e, which of the following statement(s) is(are) true? ***(2016)***



(A) For large potential difference ($V >> \phi/e$), λ_e is approximately halved if V is made four times

(B) λ_e decreases with increase in ϕ and λ_{ph}

(C) λ_e increases at the same rate as λ_{ph} for $\lambda_{ph} < hc/\phi$

(D) λ_e is approximately halved, if d is doubled

PlancEssential Questions

JEE Main/Boards

Exercise 1

Q.10 Q.17 Q.23

Q.27 Q.28

Exercise 2

Q.2 Q.4 Q.7

JEE Advanced/Boards

Exercise 1

Q.4 Q.8 Q.10

Q.19 Q.22 Q.30

Exercise 2

Q.1 Q.6 Q.8

Q.12 Q.13 Q.14

Q.16

Previous Years' Questions

Q.10

Answer Key

JEE Main/Boards

Exercise 1

Q.1 (iii)1.49 × 10^{-19} J

Q.4 $\frac{\lambda}{2}$

Q.8 Line B represent a particle of smaller mass.

Q.9 (i) Metal Q, (ii) Metal P, (iii) Stopping potential remains unchanged.

Q.10. 1.5 eV

Q.11 $1:2\sqrt{2}$

Q.17 2.46×10^{15} Hz

Q.21 (i) –1.7 eV (ii) 972.54 Å

Q.23 +13.6 eV, –27.2 eV

Q.24 28.8 × 10^{-15} m

Q.27 7.5 × 10^{14} Hz, 3.094 eV

Q.28 4137.5 Å

Exercise 2

Single Correct Choice Type

Q.1 C	**Q.2** D	**Q.3** C	**Q.4** A	**Q.5** A	**Q.6** C
Q.7 B	**Q.8** B	**Q.9** C	**Q.10** A	**Q.11** D	**Q.12** C
Q.13 B	**Q.14** C	**Q.15** D	**Q.16** A	**Q.17** A	**Q.18** C
Q.19 C	**Q.20** A	**Q.21** B	**Q.22** B	**Q.23** A	**Q.24** B
Q.25 A	**Q.26** B	**Q.27** A	**Q.28** B	**Q.29** D	

Previous Years' Questions

Q.1 B	**Q.2** C	**Q.3** A	**Q.4** D	**Q.5** C	**Q.6** D
Q.7 C	**Q.8** B	**Q.9** 30×10^3V, 30×10^3eV		**Q.10** 500 dps, 125 dps	
Q.11 Frequency	**Q.12** 8, 6	**Q.13** B	**Q.14** B	**Q.15** D	**Q.16** D
Q.17 B	**Q.18** D	**Q.19** A	**Q.20** C	**Q.21** C	**Q.22** D
Q.23 D	**Q.24** D	**Q.25** B	**Q.26** C	**Q.27** C	**Q.28** D

JEE Advanced/Boards

Exercise 1

Q.1 (a) 0.6 V, (b) 2.0 mA

Q.2 5.76 × 10^{-11} A

Q.3 $\frac{15}{8}$V

Q.4 $\frac{5}{16}, \frac{10^{19}}{8\pi}$

Q.5 2eV, 6.53 × 10^{-34} J s

Q.6 4.8×10^{16}, 4.0 cm

Q.7 2 eV, 0.754 V

Q.8 1.1 × 10^{12}

Q.9 (i) $\frac{5}{16}$ photon/s, (ii) $\frac{5}{1600}$ electrons/s

Q.10 (a) 10^5 s^{-1} ; (b) 286.76 ; (d) 111.1s

Q.11 (a) 2.25 eV, (b) 4.2 eV, (c) 2.0 eV, 0.5 eV **Q.12** $-\frac{h}{eEt^2}$

Q.13 487 nm **Q.14** 4.26 m/s, 13.2 eV **Q.15** 7 : 36

Q.16 $\lambda_{deutron} = \lambda_{neutron} = 8.6$ pm **Q.17** KE $\cong$ 148.4 eV, d_{least} = 0.5 Å **Q.18** 3.1×10^6 m / s

Q.19 (i) 2 ; (ii) 23.04 × 10^{-19} J ; (iii) $4 \to 1$, $4 \to 3$ **Q.20** 11.24 eV

Q.21 22.8 nm **Q.22** $\frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2}$ **Q.23** $\frac{18}{5R}$

Q.24 1.257 × 10^{-23} Am^2 **Q.25** 5

Q.26 (i) Z = 5, (ii) E= 16.5 eV, (iii) λ=36.4 A, (iv) K.E = 340 eV, P.E = –680 eV, (v) Radius r = 0.1058 Å

Q.27 Z = 3, n = 7 **Q.28** 54.4 eV **Q.29** n = 3, 3 : 1

Q.30 $\lambda_1 = 0.871\,\mathring{A}$ and $\lambda_2 = 2.17\,\mathring{A}$

Exercise 2

Single Correct Choice Type

Q.1 B **Q.2** B **Q.3** A **Q.4** D **Q.5** A **Q.6** C

Q.7 A **Q.8** B

Multiple Correct Choice Type

Q.9 A, C **Q.10** A, D **Q.11** A,C **Q.12** A, C, D **Q.13** A, C, D

Q.14 A, C, D **Q.15** A, B, C

Assertion Reasoning Type

Q.16 D **Q.17** C **Q.18** D **Q.19** D **Q.20** A **Q.21** A

Previous Years' Questions

Q.1 (a) 5 (b) 16.53 eV (c) 36.4 Å (d) 340 eV, –680 eV, –340 eV, 1.05 × 10^{-34} $\frac{kgm^2}{s}$ (e) 1.06 × 10^{-11} m

Q.2 Six, 1.875 μm **Q.3** 0, 11, 13 **Q.4** (a) 91 (b) 234

Q.5 6.6 × 10^{-34} J s **Q.6** (a) 300 Å (b) 0.2645 Å **Q.7** (a) 113.74 Å (b) 3

Q.8 3.96 × 10^{-6} **Q.9** (a) $r_n = \frac{n^2 h^2 \varepsilon_0}{624\pi m_e e^2}$ (b) n = 25 (c) 0.546 $\mathring{A}$

Q.10 C **Q.11** C **Q.12** A **Q.13** $A \to p, q$; $B \to p, r$; $C \to p, s$; $D \to q$

Q.14 C,D **Q.15** A **Q.16** B **Q.17** D **Q.18** 3 **Q.19** A

Q.20 7 fm **Q.21** B **Q.22** 1 **Q.23** 2 **Q.24** A **Q.25** B

Q.26 A, B, D **Q.27** 6 **Q.28** B **Q.29** A **Q.30** D **Q.31** B

Q.32 C **Q.33** 7 **Q.34** B **Q.35** A **Q.36** A

Solutions

JEE Main/Boards

Exercise 1

Sol 1: (i) Work function – It is the minimum energy of incident photon below which no ejection of photoelectron from a metal surface will take place is known as work function or thresholds energy for that metal

$\phi = hV_0$

(ii) Threshold frequency – it is the minimum frequency of incident photon below which no ejection of photoelectron from a metal surface will take place is known as threshold frequency for that metal.

(iii) Stopping potential – The negative potential (V_0) applied to the anode at which the current gets reduced to zero is called stopping potential.

$KE_{max} = E - \phi$

$$E = \frac{12400}{3000} = 4.13 \text{ eV}$$

$KE_{max} = 4.13 - 3.2 = 0.93 \text{ eV} = 1.49 \times 10^{-19}$ J

Sol 2: KE = eV

$$\lambda_d = \frac{h}{p} = \frac{h}{\sqrt{2mKE}} = \frac{h}{\sqrt{2meV}}$$

$$= \frac{6.6\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.67\times10^{-19}\times V}} = \frac{12.27}{\sqrt{V}}\text{Å}$$

For Davisson and Germer's experiment, refer theory.

Sol 3: $\phi_A = 2 \text{ eV} = \dfrac{hc}{\lambda_A}$

$\phi_B = 5 \text{ eV} = \dfrac{hc}{\lambda_B}$

$\lambda_A > \lambda_B$

Sol 4: K.E. = eV

$$\lambda_1 = \frac{h}{\sqrt{2mKE_1}} = \frac{h}{\sqrt{2meV}} = \lambda$$

$$\lambda_2 = \frac{h}{\sqrt{2mKE_2}} = \frac{h}{\sqrt{2me\times4v}} = \frac{\lambda_1}{2} = \frac{\lambda}{2}$$

Sol 5: For graph, refer theory.

If the distance is reduced, intensity of light will increase and number of electrons will increase and current will increase. Stopping potential will not be affected by distance.

Sol 6: $h\nu_1 = W_1 + KE$

$h\nu_2 = W_2 + KE$

$W_1 > W_2$

$\Rightarrow \nu_1 > \nu_2$

Sol 7: Refer theory

Sol 8: $\lambda = \dfrac{h}{\sqrt{2meV}}$

Slope $= \dfrac{h}{\sqrt{2me}}$

Slope of B > Slope of A

$\Rightarrow m_B < m_A$

Sol 9: (i) Metal P has greater threshold wavelength because P has lower threshold frequency.

(ii) $KE_{max} = h\nu - h\nu_0$

Metal P emits electrons with less kinetic energy as P has less threshold frequency.

(iii) If distance is doubled, there is no change in stopping potential.

Sol 10: $KE_{max} = eV = 1.5$ eV

Sol 11: $\dfrac{\lambda_\alpha}{\lambda_p} = \dfrac{h}{\sqrt{2m_\alpha(KE)_\alpha}} \div \dfrac{h}{\sqrt{2m_p(KE)_p}}$

$$= \sqrt{\frac{m_p}{m_\alpha}\frac{(KE)_p}{(KE)_\alpha}} = \sqrt{\frac{1}{4}\cdot\frac{eV}{2eV}} = \frac{1}{2\sqrt{2}}$$

Sol 12: $h\nu = h\nu_0 + KE$

Refer theory

Sol 13: Refer theory

Sol 14: Refer theory for the graph

$h\nu_1 = h\nu_0 + eV;\ h\nu_2 = h\nu_0 + eV$

Stopping potential V is higher for ν_1 frequency by the above equations.

Sol 15: $\lambda_p = \frac{h}{\sqrt{2m_p(KE)}};\ \lambda_e = \frac{h}{\sqrt{2m_e(KE)}}$

$m_p > m_e$

$\lambda_p < \lambda_e$

Sol 16: (i) Cut-off voltage is the negative potential applied to the anode at which the current gets reduced to zero.

Refer theory for second part of question.

Sol 17: Refer theory

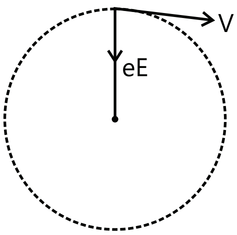
E = – 3.4 eV – (– 13.6 eV)

E = 10.2 eV

$h\nu = 10.2 \times 10^{-19} \times 1.6$ J

$\nu = 2.46 \times 10^{15}$ Hz

Sol 18: $eE = .\frac{mv^2}{r}.$



$\frac{e}{m} = \frac{v^2}{rE}$

Sol 19: Magnetic moment of a charged particle moving in a circle is given by

$\mu = IA$

I = charge flowing per sec $= \frac{e}{2\pi}\omega$

$\mu = \frac{e\omega}{2\pi} \times \pi r^2 = \frac{evr}{2}$

Sol 20: Refer theory

Sol 21: (i) PE = 2 T.E.

$PE = \frac{-13.6 \times 2}{16} = -0.85 \times 2 = -1.7$ eV

(ii) $E = 13.6\left[\frac{1}{1^2} - \frac{1}{4^2}\right] = \frac{15}{16} \times 13.6$ eV

E = 12.75 eV

$\lambda = \frac{12400}{12.75} = 972.54$ Å

Sol 22: Refer theory

Sol 23: T.E. = – 13.6 eV

KE = |T.E.| = 13.6 eV

P.E = 2T.E = – 13.6 × 2 = –27.2 eV

Sol 24: $8 \times 10^6 = \frac{K \times (2e)(80e)}{r}$

$r = \frac{9 \times 10^9 \times 160 \times 1.6 \times 10^{-19}}{8 \times 10^6} = 28.8 \times 10^{-15}$ m

If kinetic energy is doubled then closest distance will become half of the original.

Sol 25: $\lambda = \frac{h}{\sqrt{2m(KE)}}$

$\lambda_e = \frac{h}{\sqrt{2m_e(KE)_e}} = \frac{h}{\sqrt{2m_p(KE)_p}}$

$m_e(KE)_e = m_p(KE)_p$

$m_p > m_e$

$\Rightarrow (KE)_e > (KE)_p$

Sol 26: Kinetic energy = $h\nu - h\nu_0$

It is independent of the intensity of light.

Sol 27: $\nu = \frac{c}{\lambda} = \frac{3 \times 10^8}{4 \times 10^{-7}} = 0.75 \times 10^{15} = 7.5 \times 10^{14}$ Hz

Energy = $h\nu$

$= 6.6 \times 10^{-34} \times 7.5 \times 10^{14} = 49.5 \times 10^{-20}$ J= 3.094 eV

Sol 28: Longest wavelength ⇒ minimum frequency photon = ν_0

$\frac{12400}{3} = 4137.5$ Å

Exercise 2

Single Correct Choice Type

Sol 1: (C) Intensity of both bulb is same i.e. $I_1 = I_2$

E_r = Energy of red colour photon

E_b = Energy of blue colour photon

$E_b > E_r$

$n_r = \frac{I_1}{E_r}$

$n_b = \frac{I_2}{E_b}$

$\Rightarrow n_b < n_r$

Sol 2: (D) $\frac{hc}{\lambda} = \phi + K$ ... (i)

$\frac{4hc}{3\lambda} = \phi + K_2$ ... (ii)

By (i) and (ii)

$\frac{4}{3}[\phi + K] = \phi + K_2$

$\frac{4\phi}{3} + \frac{4k}{3} = \phi + K_2$

$K_2 = \frac{4K}{3} + \frac{\phi}{3}$

Sol 3: (C) $h\nu = \phi + KE$

KE = eV

V = stopping potential

$h\nu = \phi + eV$ ... (i)

$h2\nu = \phi + eV_2$ ... (ii)

By (i) and (ii)

$2(\phi + eV) = \phi + eV_2$

$\phi + 2eV = eV_2$

$V_2 = 2V + \frac{\phi}{e}$

Sol 4: (A) $E = \phi + KE$

KE = eV, where V is stopping potential

E = 1.7 eV + 10.4 eV

E = 12.1 eV

$12.1 = 13.6 \times (1)^2 \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

[As energy is greater than 12.1 eV so 1 state has to be ground state]

$12.1 = 13.6\left[\frac{1}{1^2} - \frac{1}{n_2^2}\right]$

$\frac{12.1}{13.6} = 1 - \frac{1}{n_2^2}$

$\frac{1}{n_2^2} = 1 - \frac{12.1}{13.6} = \frac{1.5}{13.6}$

$n_2^2 = \frac{13.6}{1.5}$

$n_2 = 3$

Sol 5: (A) $E_1 = 2\phi$

$E_2 = 5\phi$

$E_1 = \phi + KE_1$

$2\phi - \phi = KE_1$

$KE_1 = \phi = \frac{1}{2}mv_1^2$

$E_2 = \phi + KE_2$

$5\phi - \phi = KE_2$

$KE_2 = 4\phi = \frac{1}{2}mv_2^2$

$\frac{v_1}{v_2} = \frac{\sqrt{\frac{2\phi}{m}}}{\sqrt{\frac{8\phi}{m}}} = \frac{1}{2}$

Sol 6: (C) $\frac{hc}{\lambda_1} = \phi + KE_1$

$KE_1 = eV_1$

$\frac{hc}{\lambda_1} = \phi + eV_1 \Rightarrow V_1 = \left(\frac{hc}{\lambda_1} - \phi\right)\frac{1}{e}$

$\frac{hc}{\lambda_2} = \phi + eV_2 \Rightarrow V_2 = \left(\frac{hc}{\lambda_2} - \phi\right)\frac{1}{e}$

$\frac{hc}{\lambda_3} = \phi + eV_3 \Rightarrow V_3 = \left(\frac{hc}{\lambda_3} - \phi\right)\frac{1}{e}$

V_1 V_2 and V_3 are in A.P.

$\Rightarrow V_1 + V_3 = 2V_2$

$\left(\frac{hc}{\lambda_1} - \phi\right)\frac{1}{e} + \left(\frac{hc}{\lambda_3} - \phi\right)\frac{1}{e} = 2\left(\frac{hc}{\lambda_2} - \phi\right)\frac{1}{e}$

$$\frac{hc}{\lambda_1}+\frac{hc}{\lambda_3}=\frac{2hc}{\lambda_2}$$

$$\frac{1}{\lambda_1}+\frac{1}{\lambda_3}=\frac{2}{\lambda_2}$$

Sol 7: (B) ϕ = 4.5 eV

Wavelength of light = 2000Å

Energy of photon = $\frac{12400}{2000}=\frac{124}{20}=6.2\,\text{eV}$

K.E. of emitted electron = $h\nu - \phi$

= 6.2 – 4.5 = 1.7 eV

As electrons are further accelerated by 2V

so final kinetic energy = 1.7 eV + 2eV

= 3.7 eV

Sol 8: (B) $h\nu = h\nu_0 + KE$

Kinetic energy depends only on the energy of incident photon. Number of emitted electrons $\propto$ intensity of light.

Sol 9: (C) $\lambda_p = \frac{h}{p_p} = \frac{h}{\sqrt{2m_p(KE)_p}}$

$$\lambda_e = \frac{h}{p_e} = \frac{h}{\sqrt{2m_e(KE)_e}}$$

$m_p > m_e$

As proton and electron both are accelerated by same potential difference so $KE_p = KE_e$

$\lambda_p < \lambda_e$

Sol 10: (A) Initial KE is 100 eV

After accelerating through potential difference of 50 v final KE is 150 eV.

$$\lambda_d = \sqrt{\frac{150}{V}} = \sqrt{\frac{150}{150}} = 1\,\text{Å}$$

Sol 11: (D) $\lambda = \frac{h}{p}$; $p = \frac{h}{0.01\times10^{-10}} = 10^{12}h$

Sol 12: (C) $\frac{hc}{\lambda_1} = \phi + K_1$ ... (i)

$$\frac{hc}{\lambda_2} = \phi + K_2 \quad \text{... (ii)}$$

$$\lambda_2 = \frac{\lambda_1}{2}$$

$$\frac{2hc}{\lambda_1} = \phi + K_2$$

By (i) and (ii)

$2(\phi + K_1) = \phi + K_2 \Rightarrow \phi + 2K_1 = K_2$

$$K_1 = \frac{K_2}{2} - \frac{\phi}{2}$$

Sol 13: (B) Distance between two successive maxima in Young's double slit experiment is $\frac{\lambda D}{d}$

Distance will decrease if D will decreases.

Sol 14: (C)

Energy required = $\frac{2.18\times10^{-18}}{9}$ = 2.42×10^{-19} J

Sol 15: (D) In some Hydrogen like atom

$$E_{4n} - E_{2n} = \left(-\frac{13.6}{(4n)^2}+\frac{13.6}{(2n)^2}\right)Z^2$$

$$= \frac{13.6Z^2}{4n^2}\left[-\frac{1}{4}+1\right]$$

$$= \frac{3\times13.6Z^2}{16n^2}$$

$$E_{2n} - E_n = \left(-\frac{13.6}{(en)^2}+\frac{13.6}{n^2}\right)Z^2$$

$$= \frac{13.6z^2}{n^2}\left[-\frac{1}{4}+1\right] = \frac{3\times13.6Z^2}{4n^2}$$

Ratio = $\frac{E_{4n}-E_{2n}}{E_{2n}-E_n} = \frac{1}{4}$

Ratio is independent of Z and n.

Sol 16: (A)

n′ = n + 1

n′ = 3

No. of lines = $\frac{(n+1-3)\big((n+1-3)+1\big)}{2}$

$$= \frac{(n-2)(n-1)}{2} = 10$$

(n – 2) (n – 1) = 20,

n = 6

Sol 17: (A) Ten different wavelengths are emitted so

$\frac{n(n-1)}{2} = 10 \Rightarrow n\,(n-1) = 20$

$\Rightarrow n = 5$

Energy of incident radiation is $13.6\left[\frac{1}{1^2}-\frac{1}{5^2}\right]$

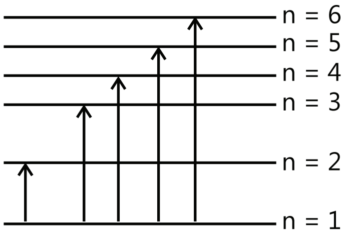
$= \frac{24}{25}\times 13.6 = 13.056$ eV

$\lambda = \frac{12400}{13.056} = 949.75$ Å

Sol 18: (C) Five dark line corresponds to transitions so highest state of electron is n = 6

So no of lines in emission spectrum = $\frac{n(n-1)}{2}$

$= \frac{6\times 5}{2} = 15$



Sol 19: (C) Energy of photon = $13.6\left(\frac{1}{1^2}-\frac{1}{25}\right)$

$= \frac{24}{25}\times 13.6$ eV

Momentum of photon

$= \frac{h}{\lambda} = \frac{h}{\frac{hc}{E}} = \frac{E}{c} = \frac{24}{25}\times\frac{13.6\times 1.6\times 10^{-19}}{3\times 10^{8}}$

By momentum conservation

$mv = 6.96 \times 10^{-27}$

$1.67 \times 10^{-27} \times v = 6.96 \times 10^{-27}$

v = 4.169 m/s

Sol 20: (A) Velocity $\propto \frac{1}{n}$

So kinetic energy will increase

P.E. = $\frac{-2\times 13.6\,Z^2}{n^2}$

So P.E. will decrease

T.E. = $\frac{-13.6\,Z^2}{n^2}$

T.E. will decrease with decrease in n.

Sol 21: (B) Angular momentum = $\frac{nh}{2\pi} = mvr$

$f \propto \frac{1}{n^3}$

$r \propto n^2$

$frL \propto \frac{1}{n^3}\times n^2 \times n = 1 \Rightarrow$ independent of n.

Sol 22: (B) $r = \frac{0.529n^2}{Z} = \frac{0.529\times 4}{2} = 1.058$ Å

Sol 23: (A) Energy $E_n = \frac{-13.6}{n^2} = -3.4$ (n = 2)

angular momentum = $\frac{nh}{2\pi} = \frac{2h}{2\pi} = \frac{h}{\pi}$

Sol 24: (B) $E_n = \frac{-13.6}{n^2} = -3.4 =$ T.E.

n = 2

Kinetic energy = |T.E.| = 3.4 eV

$\lambda = \frac{h}{\sqrt{2mKE}} = \frac{6.6\times 10^{-34}}{\sqrt{2\times 9.1\times 10^{-31}\times 3.4\times 1.6\times 10^{-19}}}$

$= \frac{6.6\times 10^{-34}}{9.9}\times 10^{25} = 6.6 \times 10^{-10}$ m

Sol 25: (A) Since some photons have energy greater than 13.6 eV so electrons in hydrogen atoms will come out of hydrogen atom. So only Lyman series absorbtion will be observed. Electron will not excite in other excited states as there are only few photons of required energy for the transition. So Balmer series will not be observed.

Sol 26: (B) Difference of energy between any shell is independent of the reference level.

T.E. = K.E. + P.E.

KE at ground state = 13.6 eV

So T.E. at ground state = 13.6 + 0 = 13.6 eV

Sol 27: (A) $r \propto \frac{1}{m}$

Mass of dueterium > mass of hydrogen

$\Rightarrow r_d < r_h$

Velocity is same for both.

Energy of dueterium > Energy of hydrogen

$\Rightarrow$ Wavelength of dueterium < wavelength of hydrogen

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

is independent of mass.

Sol 28: (B) $\lambda_{min} = \frac{hc}{eV} = \frac{12420}{V}$Å

$V = \frac{12420}{0.663} = 18.75 kV$

Sol 29: (D) $\lambda_{min} = \frac{12420}{V}$

If V increase λ_{min} will decrease.

Previous Years' Questions

Sol 1: (B) Shortest wavelength or cut-off wavelength depends only upon the voltage applied in the Coolidge tube.

Sol 2: (C) Beta particles are fast moving electrons which are emitted by the nucleus.

Sol 3: (A) The maximum number of electrons in an orbit are $2n^2$. If n > 4, is not allowed, then the number of maximum electrons that can be in first four orbit are:

$2(1)^2 + 2(2)^2 + 2(3)^2 + 2(4)^2$

$= 2 + 8 + 18 + 32 = 60$

Therefore, possible elements can be 60.

Sol 4: (D) Shortest wavelength will correspond to maximum energy. As value of atomic number (Z) increases, the magnitude of energy in different energy states gets increased. Value of Z is maximum for doubly ionized lithium atom (Z = 3) among the given elements. Hence, wavelength corresponding to this will be least.

Sol 5: (C) During fusion process two or more lighter nuclei combine to form a heavy nucleus.

Sol 6: (D) For a given plate voltage, the plate current in a triode valve is maximum when the potential of the grid is positive and plate is positive

Sol 7: (C) The X-ray beam coming from an X-ray tube will be having all wavelengths larger than a certain minimum wavelength

Sol 8: (B) Cut-off wavelength depends on the accelerating voltage, not the characteristic wavelengths. Further, approximately 2% kinetic energy of the electrons is utilized in producing X-rays. Rest 98% is lost in heat.

Sol 9: Minimum voltage required is corresponding to n = 1 to n = 2. Binding energy of the innermost electron is given as 40 keV i.e., ionization potential is 40 kV. Therefore,

$$V_{min} = \frac{40\times10^3\left(\frac{1}{1^2}-\frac{1}{2^2}\right)}{\left(\frac{1}{1^2}-\frac{1}{\infty}\right)} = 30\times10^3 V$$

The energy of the characteristic radiation will be $30\times10^3 eV$.

Sol 10: $R = R_0\left(\frac{1}{2}\right)^n$

Here R_0 = initial activity

= 1000 disintegration/s

and n = number of half-lives.

At t = 1 s, n = 1

$\therefore\ R = 10^3\left(\frac{1}{2}\right) =$ 500 disintegration/s

At t = 3 s, n = 3

$R = 10^3\left(\frac{1}{2}\right)^3$ = 125 disintegration/s

Sol 11: $K_{max} = h\nu - W$

Therefore, K_{max} is linearly dependent on frequency of incident radiation.

Sol 12: Number of α-particles emitted

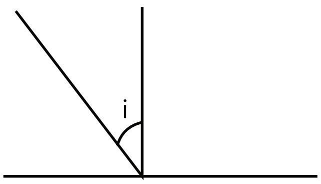
$n_1 = \frac{238-206}{4} = 8$

and number of β-particles emitted are say n_2, then

$92-8\times 2+n_2=82$

$\therefore\ n_2=6$

Sol 13: (B)



2d cos i = nλ

$2d\cos i=\dfrac{h}{\sqrt{2meV}}$

v = 50 volt

Sol 14: (B) 2d cos i = $n\lambda_{dB}$

Sol 15: (D) Diffraction pattern will be wider than the slit.

Sol 16: (D) W = QdV = $Q(V_q - V_P)$

$= -100\times(1.6\times10^{-19})\times(-4-10)$

$= +100\times1.6\times10^{-19}\times14 = +2.24\ 10^{-16}$ J.

Sol 17: (B)

$\frac{1}{2}mv^2=eV_o=1.68\text{ eV}\Rightarrow h\nu=\frac{hc}{\lambda}=\frac{1240\text{evnm}}{400\text{nm}}$

$=3.1\text{ eV}\Rightarrow 3.1\text{ eV}=W_o+1.6\text{ eV}$

$\therefore W_o = 1.42$ eV

Sol 18: (D) Since the frequency of ultraviolet light is less than the frequency of X–rays, the energy of each incident photon will be more for X–rays.

$K.E_{photoelectron} = hv-\phi$

Stopping potential is to stop the fastest photoelectron

$V_0=\frac{hv}{e}-\frac{\phi}{e}$

So, $K.E_{max}$ and V_0 both increases.

But K.E ranges from zero to $K.E_{max}$ because of loss of energy due to subsequent collisions before getting ejected and not due to range of frequencies in the incident light.

Sol 19: (A) 4 x 10^3 = 10^{20} x hf

$f=\frac{4\times10^3}{10^{20}\times6.023\times10^{-34}}$

f = 6.03 x 10^{16} Hz

The obtained frequency lies in the band of X–rays.

Sol 20: (C) $KE_{max}=h\upsilon-h\upsilon_0$

$h\upsilon-h\upsilon_0=e\times\Delta v$

$V_0=\frac{h\upsilon}{e}-\frac{h\upsilon_0}{e}$

'υ' is doubled

$KE_{max}=2h\upsilon-h\upsilon_0$

$V_0'=(\Delta V)'=\frac{2h\upsilon}{e}-\frac{h\upsilon_0}{e}$

$\frac{KE_{max}}{KE_{max}}$ may not be equal to 2

$\Rightarrow\frac{V_0'}{V_0}$ may not be equal to 2

Ke = max = $h\upsilon-h\upsilon_0$

$V=\frac{h\upsilon}{e}-\frac{h\upsilon_0}{e}$

Sol 21: (C) Davisson – Germer experiment showed that electron beams can undergo diffraction when passed through atomic crystals. This shows the wave nature of electrons as waves can exhibit interference and diffraction.

Sol 22: (D) $r_1=\frac{m_2f}{m_1+m_2};r_2=\frac{m_1r}{m_1+m_2}$

$(I_1+I_2)\omega=\frac{nh}{2\pi}=n\hbar$

$K.E.=\frac{1}{2}(I_2+I_2)\omega^2=\frac{(m_1+m_2)n^2h^2}{2m_1m_2r^2}$

Sol 23: (D) As λ is increased, there will be a value of λ above which photoelectrons will be cease to come out so photocurrent will become zero. Hence, (D) is correct answer .

Sol 24: (D) $\Delta E = h\nu$

$$\nu = \frac{\Delta E}{h} = k\left[\frac{1}{(n-1)^2} - \frac{1}{n^2}\right] = \frac{k2n}{n^2(n-1)^2}$$

$$\approx \frac{2k}{n^3} \propto \frac{1}{n^3}$$

Sol 25: (B) $r = \frac{m\upsilon}{qB}$

$$= \frac{\sqrt{2meV}}{eB}$$

$$= \frac{1}{B} = \sqrt{\frac{2m}{e}V} \Rightarrow V = \frac{B^2r^2e}{2m} = 0.8\text{ V}$$

For transition between 3 to 2,

$$E = 13.6\left(\frac{1}{4} - \frac{1}{9}\right) = \frac{13.6\times 5}{36} = 1.88\text{ eV}$$

Work function = 1.88 eV – 0.8 eV

= 1.08 eV = 1.1 eV

Sol 26: (C) $\frac{1}{\lambda} = RZ^2\left[\frac{1}{n_1^2} - \frac{1}{n^2}\right]$

$\Rightarrow \lambda \propto \frac{1}{Z^2}$ for given n_1 & n_2

$$\Rightarrow \lambda_1 = \lambda_2 = 4\lambda_3 = 9\lambda_4$$

Sol 27: (C) (i) Frants – Hertz Experiment is associated with Discrete energy levels of atom

(ii) Photo electric experiment is associated with particle nature of light.

(iii) Davison – Germer experiment is associated with wave nature of electron.

Sol 28: (D) $\frac{hc}{\lambda} = w + \frac{1}{2}mv^2$ ... (i)

$$\frac{hc}{\lambda'} = w + \frac{1}{2}m(v')^2$$

$$\frac{hc}{\left(\frac{3\lambda}{4}\right)} = w + \frac{1}{2}m(v')^2 \quad \text{... (ii)}$$

Equation $\left[(i)\times\frac{4}{3}\right] - (ii)$

$$\frac{4hc}{3\lambda} - \frac{4}{3}\frac{hc}{\lambda} = \frac{4}{3}w + \frac{4}{3}\left(\frac{1}{2}mv^2\right) - w - \frac{1}{2}m(v')^2$$

$$\Rightarrow \frac{4}{3}w + \frac{4}{3}\left(\frac{1}{2}mv^2\right) = w + \frac{1}{2}m(v')^2$$

$$\Rightarrow \frac{1}{2}m(v')^2 = \frac{w}{3} + \frac{4}{3}\frac{1}{2}mv^2$$

$$\Rightarrow \frac{1}{2}m(v')^2 > \frac{4}{3}\left(\frac{1}{2}mv^2\right)$$

$$\Rightarrow v' > \sqrt{\frac{4}{3}}v$$

JEE Advanced/Boards

Exercise 1

Sol 1: (a) Stopping potential is a property of material so it will remain same.

(b) Saturation current $\propto \frac{1}{r^2}$

r is thrice of initial distance so

Saturation current = $\frac{1}{9}\times 18\text{mA} = 2\text{mA}$

Sol 2: λ = 540 nm

Energy of photon $E = \frac{12400}{5400} = \frac{62}{27}\text{eV}$

Power = 663 mW

No. of photon per sec $= \frac{663\times 10^{-3}}{\frac{6.2}{27}\times 1.6\times 10^{-19}} = \frac{27\times 663}{62\times 1.6}\times 10^{16}$

No. of it e^- per sec $= \frac{27\times 663\times 10^{16}}{62\times 1.6\times 5\times 10^9}$

= 3.61×10^8 e^-/sec = $3.61 \times 10^8 \times 1.6 \times 10^{-19}$ A

= 5.776×10^{-11} A

Sol 3: λ = 330 nm

$h\nu_1 = h\nu_0 + KE$

$KE = eV_0$

$h\nu_1 = h\nu_0 + eV_0$

$h\nu_2 = h\nu_0 + 2eV_0$

$h(\nu_2 - \nu_1) = eV_0$

$$V_0 = \frac{h(\nu_2 - \nu_1)}{e} = \frac{E_2 - E_1}{e}$$

$E_2 = \frac{12400}{2200} eV$; $E_1 = \frac{12400}{3300} eV$

$E_2 = \frac{62}{11} eV$; $E_1 = \frac{41.3}{11} eV$

$V_0 = \frac{62 - 41.3}{11e} eV = 1.88$ V

Sol 4: $\lambda = 990$ Å

d = 0.1 m

r = 0.05 nm = 5×10^{-11} m

(i) Intensity of light = $\frac{10}{4\pi(0.1)^2} \times \pi(5\times10^{-11})^2$

$= 250 \times 25 \times 10^{-22}$

$= 6250 \times 10^{-22}$

$= 6.25 \times 10^{-19}$ J

Energy of photon = $\frac{12400}{990} = 12.52$ eV

$= 20 \times 10^{-19}$ J

Average no. of photon = $\frac{6.25\times10^{-19}}{20\times10^{-19}} = \frac{5}{16}$

(ii) No. of electron = $\frac{10}{4\pi(0.1)^2} \times \frac{1}{(20\times10^{-19}\text{ J})} \times \frac{1}{100}$

$= \frac{10\times10^{18}}{4\pi\times2} = \frac{5}{4\pi}\times10^{18} = \frac{10^{19}}{8\pi}$

Sol 5: $h\nu = h\nu_0 + KE$

$KE = eV_0$

$h\nu = h\nu_0 + eV_0$

$eV_0 = h\nu - h\nu_0$

$y = V_0$; $x = n$

$ey = hx - h\nu_0$

$y = \frac{hx}{e} - \frac{\phi}{e}$

Work function $\phi = 2$eV

Slope = $\frac{h}{e} = \frac{2}{0.49\times10^{15}}$

$h = \frac{2\times1.6\times10^{-19}}{0.49\times10^{15}} = 6.53 \times 10^{-34}$ J-s

Sol 6: $\phi = 1.17$ eV

d = 2m

$\lambda = 4.8 \times 10^{-7}$ m = 4800 Å

P = 1W

Intensity of light = $\frac{p}{4\pi d^2} = \frac{1}{4\pi\times4} = \frac{1}{16\pi}$

Energy of 1 photon = $\frac{12400}{4800} = 2.58$ eV

Number of photons striking per square meter per sec

$= \frac{1}{16\pi\times2.58\times1.6\times10^{-19}} = 4.81 \times 10^{16}$

$h\nu = h\nu_0 + KE$

$E = h\nu$

$E = h\nu_0$

$\frac{1}{2}mv^2 = h\nu - h\nu_0 = E - E_0$

$\frac{12400}{4800} - 1.17$

$\frac{1}{2}m_e v^2 = 2.58 - 1.17 = 1.41$ eV .... (i)

$v^2 = \frac{2.82\times1.6\times10^{-19}}{9.1\times10^{-31}}$

$v^2 = 0.495 \times 10^{12}$

$v = 7.04 \times 10^5$ m/s

Magnetic force = eVB = $\frac{mv^2}{R}$

By (i)

$mv^2 = 2.82$ eV

$eVB = \frac{2.82 eV}{R}$

$7.04 \times 10^5 \text{ m/s} \times 10^{-4} = \frac{2.82}{R}$

R = 4 cm

Sol 7: Z = 3

Energy of $E_1 = 13.6 \times 9 \left[\frac{1}{16} - \frac{1}{25}\right]$

$E_1 = 2.754$ eV

Energy $E_2 = 13.6 \times 9 \left[\frac{1}{9} - \frac{1}{16}\right]$

$E_2 = 5.95$ eV

$E_2 = \phi + KE_2$

$KE_2 = 3.95$ eV

$\phi = E_2 - KE_2$

$= 5.95 - 3.95$

$\phi = 2$ eV

$E_1 = \phi + KE_1$

$KE_1 = 2.754 - 2$

eV = 0.754 eV

V = 0.754 Volts

Sol 8: $\lambda_1 = 4144$ Å; $E_1 = \frac{12400}{4144}$ eV $= 2.99$ eV

$\lambda_2 = 4972$ Å; $E_2 = \frac{12400}{4972}$ eV $= 2.49$ eV

$\lambda_3 = 6216$ Å; $E_3 = \frac{12400}{6216}$ eV $= 1.99$ eV

$\phi = 2.3$ eV

Intensity $I_1 = I_2 = I_3 = \frac{3.6\times10^{-3}}{3}$ $Wm^{-2} \times 10^{-4}$

$= 1.2 \times 10^{-7}$ W

No electrons will be emitted by 6216 Å wavelength photons as $E_3 < \phi$.

No. of photons in light of wavelength λ_2 is

$\frac{1.2\times10^{-7}}{2.49\times1.6\times10^{-19}} = 3 \times 10^{11}$ photons / sec

No of photons in light wavelength λ_1 is

$\frac{1.2\times10^{-7}}{2.99\times1.6\times10^{-19}} = 2.5 \times 10^{11}$ photons / sec

No of electrons liberated in 2 seconds

$= 2\,(3 + 2.5) \times 10^{11}$

$= 11 \times 10^{11}$ electrons.

Sol 9: (i) Refer Sol 4 Exercise-I JEE Advanced

(ii) No. of photons $= \frac{5}{16}$ per second

No. of electrons $= \frac{5}{16} \times \frac{1}{100}$ per second

$= \frac{5}{1600}$ per second

Sol 10: $P = 3.2 \times 10^{-3}$ W

(a) Energy of photons = 5 eV;

$\therefore \lambda = \frac{12400}{5} = 2480$ Å

Distance = 0.8 m

$\phi = 3$ eV

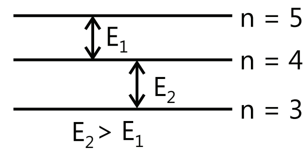
Radius $= 8 \times 10^{-3}$ m

Efficiency $= \frac{1}{10^6}$ electrons per photon

Power incident on atom

$$= \frac{3.2\times10^{-3}}{4\pi(0.8)^2}\times\pi(8\times10^{-3})^2$$

$$= \frac{10^{-3}}{0.8}\times0.8\times0.8\times10^{-4}$$



$= 0.8 \times 10^{-7} = 8 \times 10^{-8}$ W

No. of photons $= \frac{8\times10^{-8}}{5\times1.6\times10^{-19}}$

N = No. of electrons

$$= \frac{8\times10^{-8}}{10^6\times5\times1.6\times10^{-19}} = 10^5\ s^{-1}$$

(b) $\lambda_d = \frac{h}{mv}$

$KE = 2eV = \frac{p^2}{2m}$

$p^2 = 2 \times 1.6 \times 10^{-19} \times 2 \times 9.1 \times 10^{-31}$

$p^2 = 58.24 \times 10^{-50}$

$p = 7.63 \times 10^{-25}$

$$\lambda_d = \frac{6.6\times10^{-34}}{7.63\times10^{-25}} = 0.86\times10^{-9}$$

$$\frac{\lambda}{\lambda_d} = \frac{2480\times10^{-10}}{0.86\times10^{-9}} = \frac{248}{0.86} = 286.76$$

(c) After some time sphere gets positively charged and it will create electric field which will stop the further emission of electrons.

(d) KE = $h\nu - h\phi$ = 5 eV – 3 eV = 2 eV

K.E. = eV = 2 eV

V = 2 volts

Potential at the surface of sphere

$$= \frac{Kq}{r} = \frac{K(Nt)\times1.6\times10^{-19}}{8\times10^{-3}} = \frac{9\times10^{9}\times10^{5}t\times1.6\times10^{-19}}{8\times10^{-3}}$$

= 9 × 0.2 × 10^{-2} × t

2 = 1.8 × 10^{-2} × t

So time required $t = \frac{2}{1.8}\times100$ = 111.1 sec

Sol 11: For metal A

Energy of photons = 4.25 eV

Maximum $KE_A = T_a$

de Broglie wavelength = λ_a

For metal B

$KE_{B\,max} = T_b = T_a - 1.5$

Energy of photons = 4.7 eV

De-Broglie wavelength = $\lambda_b = 2\lambda_a$

$$KE = \frac{p^2}{2m} = \left(\frac{h}{\lambda_d}\right)^2\times\frac{1}{2m}$$

$$T_a = \left(\frac{h}{\lambda_a}\right)^2\times\frac{1}{2m}$$

$$T_b = \left(\frac{h}{2\lambda_a}\right)^2\times\frac{1}{2m}$$

$T_b = T_a - 1.5$

$$\left(\frac{h}{2\lambda_a}\right)^2\times\frac{1}{2m} - \frac{h^2}{\lambda_a^2}\times\frac{1}{2m} = -1.5$$

$$\left(\frac{h}{\lambda_a}\right)^2\times\frac{1}{2m}\times\frac{3}{4} = -1.5$$

$T_a \div 2 = 1$

T_a = 2 eV

T_b = 2 – 1.5 = 0.5 eV

From metal A

$E_A = \phi_A + T_a$

ϕ_A = 4.25 – 2 = 2.25 eV

For metal B

$E_B = \phi_B + T_b$

ϕ_B = 4.7 – 0.5 = 4.2 eV

Sol 12: Force on electron = eE

Acceleration = $\frac{eE}{m}$

Velocity = $\frac{eE}{m}t$; p = eEt

$$\lambda_d = \frac{h}{p}$$

$$\frac{d\lambda_d}{dt} = -\frac{h}{p^2}\frac{dp}{dt} = \frac{-heE}{(eEt)^2} = \frac{-heE}{e^2E^2t^2} = \frac{-h}{eEt^2}$$

Sol 13: B.E. = 0.85 eV = $\frac{13.6}{n^2}$

n = 4

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2}-\frac{1}{4^2}\right) = R\left(\frac{1}{4}-\frac{1}{16}\right)$$

$$\frac{1}{\lambda} = \frac{12R}{4\times16} = \frac{3R}{16} \Rightarrow \lambda = \frac{16R}{3} = 487\text{ nm}$$

Sol 14: 5th excited state

$\Rightarrow$ n = 6

m = mass of atom

v = velocity of atom

$$\frac{(mv^2)}{2m} + \frac{hc}{\lambda} = E_6 - E_0 = -\frac{13.6}{36} + 13.6$$

$$= \frac{35}{36}\times13.6$$

Momentum conservation, $\frac{h}{\lambda} = mv$

$$\frac{1}{2m}\left(\frac{h}{\lambda}\right)^2 + \frac{hc}{\lambda} = \frac{35}{36}\times13.6\times\left(10^{-19}\times1.6\right)J$$

$\Rightarrow \lambda$ = 939.4 Å

Energy = 13.2 eV

$v = \frac{h}{m\lambda} \Rightarrow v$ = 4.26 m/s

Sol 15: Energy of series limit of Balmer is $\frac{13.6}{4} = 3.4$

$$\lambda_B = \frac{hc}{3.4}$$

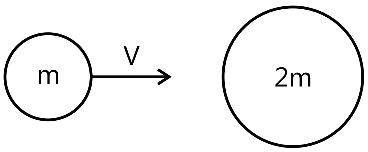
Energy of first line of Paschen is 13.6 $\left[\frac{1}{3^2}-\frac{1}{4^2}\right]$

$$\frac{hc}{\lambda_p}=\frac{13.6\times 7}{9\times 16} = 0.661$$

$$\lambda_P = \frac{hc}{0.661}$$

Ration $\frac{\lambda_B}{\lambda_P} = \frac{0.661}{3.4}=\frac{7}{36}$

Sol 16: 25 eV = $\frac{1}{2}m_n v^2$



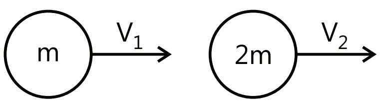
$v^2 = \frac{50\times 1.6\times 10^{-19}}{1.67\times 10^{-27}} = 47.9 \times 10^8$

V = 6.92 × 10^4 m/s

$V_{cm} = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2} = \frac{m\times V + 0}{3m} = \frac{V}{3}$

= 2.3 × 10^4 m/s

By momentum conservation



$mV = mV_1 + 2mV_2$

$V = V_1 + 2V_2$

By energy conservation

$$\frac{1}{2}mV^2 = \frac{1}{2}mV_1^2 + \frac{1}{2}2mV_2^2$$

$V^2 = V_1^2 + 2V_2^2 \Rightarrow V^2 = (V - 2V_2)^2 + 2V_2^2$

$V^2 = V^2 + 6V_2^2 - 4V_2V \Rightarrow 6V_2 = 4V$

$$V_2 = \frac{2V}{3}$$

$V_1 = V - 2V_2 = V - \frac{4V}{3} = -\frac{V}{3}$

Velocity of 1 w.r.t. C.M. is $V_{1cm} = \frac{-2V}{3} = -4.6 \times 10^4$ m/s

Velocity of 2 w.r.t. CM is $V_{2cm} = \frac{V}{3} = 2.3 \times 10^4$ m/s

$$\lambda_1 = \frac{h}{mv_{1cm}} = \frac{6.6\times 10^{-34}}{1.67\times 10^{-27}\times 4.6\times 10^4} = 8.6 \text{ pm}$$

$$\lambda_2 = \frac{h}{2mv_{2cm}} = \frac{6.6\times 10^{-34}}{2\times 1.67\times 10^{-27}\times 2.3\times 10^{-4}} = 8.6 \text{ pm}$$

Sol 17: $\frac{n\lambda}{2} = 2Å$

$\frac{(n+1)\lambda}{2} = 2.5Å \Rightarrow \frac{\lambda}{2} = 0.5Å$

$\Rightarrow \lambda = 1Å \Rightarrow \lambda = \frac{h}{p}$

$p = \frac{6.6\times 10^{-34}}{1\times 10^{-10}} = 6.6 \times 10^{-24}$

Energy = $\frac{p^2}{2m} = \frac{(6.6)^2\times 10^{-48}}{2\times 9.1\times 10^{-31}} = \frac{2.39\times 10^{-17}}{1.61\times 10^{-19}} = 148.4\text{eV}$

Sol 18: (D) Energy of photon from He^+

= 13.6 $Z^2 \left[\frac{1}{1^2}-\frac{1}{2^2}\right]$

= 13.6 × 4 × $\frac{3}{4}$ = 13.6 × 3 eV

Energy of photon from H = 13.6 eV

Energy of photoelectron = 13.6×3-13.6 = 13.6×2 eV

K.E. = $\frac{1}{2}mv^2 = 13.6 \times 2 \times 1.6 \times 10^{-19}$

$v^2 = \frac{4\times 13.6\times 1.6\times 10^{-19}}{9.1\times 10^{-31}} \Rightarrow v^2 = 9.56 \times 10^{12}$

v = 3.09 × 10^6 m/s

Sol 19: (i) $\frac{n(n-1)}{2} = 6$

$\Rightarrow n(n-1) = 12 \Rightarrow n = 4$

since emitted photons are of energy less, equal and more than 2.7 eV

So level B must be n = 2

(ii) 2.7 = 13.6 $Z^2 \left[\frac{1}{2^2}-\frac{1}{4^2}\right]$

$2.7 = \frac{13.6Z^2}{4}\left[\frac{3}{4}\right]$

Ionisation energy $\frac{2.7\times16}{3}$ = 14.4 eV = $14.4\times1.6\times10^{-19}$ J

= 23.04×10^{-19} J

(iii) Maximum energy= $13.6\ Z^2\left[\frac{1}{1^2}-\frac{1}{4^2}\right]$; $4 \to 1$

Minimum energy = $13.6\ Z^2\left[\frac{1}{3^2}-\frac{1}{4^2}\right]$; $4 \to 3$

Sol 20: λ = 500 Å

Energy = $\frac{12400}{500} = 24.8\text{eV}$

Energy required to take out electron from atom = 13.6 eV

KE = 24.8 – 13.6 = 11.2 eV

Sol 21: Energy of photon = $13.6\ Z^2$

= 13.6 × 4 = 54.4

Wavelength = $\frac{12400\,\text{eV}}{54.4\,\text{eV}}$ = 227.94 Å = 22.8 nm

Sol 22: $E_3 - E_2 + E_2 - E_1 = E_3 - E_1$

$$\frac{12400}{\lambda_1}+\frac{12400}{\lambda_2}=\frac{12400}{\lambda_3}$$

$$\frac{1}{\lambda_1}+\frac{1}{\lambda_2}=\frac{1}{\lambda_3} \Rightarrow \lambda_3=\frac{\lambda_1\lambda_2}{\lambda_1+\lambda_2}$$

Sol 23: Energy of new atom = 2 × energy of hydrogen atom

$$\frac{hc}{\lambda}=13.6\times2\left[\frac{1}{2^2}-\frac{1}{3^2}\right]$$

$$\frac{1}{\lambda}=2R\left[\frac{1}{2^2}-\frac{1}{3^2}\right] \Rightarrow \lambda=\frac{18}{5R}$$

Sol 24: r = 0.5 Å ; $\omega = 2\pi\times10^{16}\,\text{rad/sec}$.

Magnetic moment = $\frac{qVr}{2}$

$$=\frac{e\omega r^2}{2}=\frac{1.6\times10^{-19}\times2\pi\times10^{16}}{2}\times\frac{1}{4}\times10^{-20} = 0.4\times10^{-23}$$

= 1.25×10^{-23} Am^2

Sol 25: $47.2 = 13.6\ Z^2\left[\frac{1}{2^2}-\frac{1}{3^2}\right]$

$$47.2\times2=\frac{13.6\,Z^2\times5}{36}$$

$Z^2 = 25 \Rightarrow Z = 5$

Sol 26: $47.2 = 13.6\ Z^2\left[\frac{1}{2^2}-\frac{1}{3^2}\right]$

(i) Z = 5

(ii) E = $13.6\times25\left[\frac{1}{9}-\frac{1}{16}\right]$ = 16.5 eV

(iii) E = $13.6\times25\left[\frac{1}{1^2}-\frac{1}{\infty^2}\right]$

E = 13.6 × 25 eV

E = 340 eV

$\lambda=\frac{12400}{340}$ = 36.4 Å

(iv) KE = |T.E.|

KE = $13.6\ Z^2$ = 13.6 × 25 = 340 eV

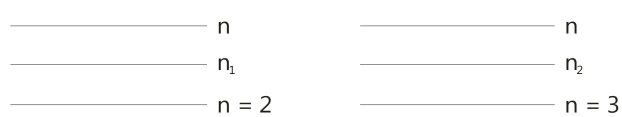
P.E. = – 2 |T.E.|

P.E. = – 2 × 340 = – 680 eV

(v) Angular momentum = mvr = $I\omega = n\frac{h}{2\pi}$

Radius = $\frac{0.529n^2}{z}$ = 0.1058 Å

Sol 27:



Energy gap between quantum states n and 2 is

22.95 + 5.15 = 28.1 eV

Energy gap between quantum state n and 3 is

2.4 + 8.7 = 11.1 eV

Energy gap between n = 2 and n = 3 is

28.1 – 11.1 = 17 eV

$$17 = 13.6\ Z^2\left[\frac{1}{2^2}-\frac{1}{3^2}\right]=\frac{13.6\,Z^2\times5}{36}$$

$Z^2 = 9 \Rightarrow Z = 3$

$$28.1 = 13.6\times9\left[\frac{1}{2^2}-\frac{1}{n^2}\right]$$

$$\frac{1}{4}-\frac{1}{n^2}=0.229 \Rightarrow \frac{1}{n^2}=0.25-0.229$$

$\Rightarrow n^2 = 48.96 \Rightarrow n = 7$

Sol 28: $E = 13.6\, Z^2 \left[\frac{1}{2^2} - \frac{1}{5^2}\right]$

$$\frac{12400}{1085} = 13.6 Z^2 \left[\frac{1}{2^2} - \frac{1}{5^2}\right]$$

$$\frac{12400}{1085} = 13.6 Z^2 \left[\frac{21}{100}\right]$$

$\Rightarrow Z^2 = 4 \Rightarrow Z = 2$

Binding energy = $13.6\, Z^2$ = $13.6 \times 4 = 54.4$ eV

Sol 29: Energy of n^{th} state of lithium ion = $\frac{-13.6 \times 3^2}{n^2}$

= – 13.6 eV (n = 3)

Radius = $\frac{0.529 n^2}{2}$

$$\frac{R_{Li^{2+}}}{R_H} = \frac{\frac{0.529 \times 9}{3}}{0.529} = 3$$

Sol 30: Total energy of the photons is 20 KeV

Let their wavelength be λ_1, λ_2 Å

$$\frac{12400}{\lambda_1} + \frac{12400}{\lambda_2} = 20000$$

$$\frac{1}{\lambda_1} + \frac{1}{\lambda_2} = 1.613 \qquad \text{... (i)}$$

$$\lambda_2 - \lambda_1 = 1.3 \qquad \text{... (ii)}$$

By (i) and (ii)

$$\frac{1}{\lambda_1} + \frac{1}{1.3 + \lambda_1} = 1.613$$

$$\frac{1.3 + 2\lambda_1}{\lambda_1 (1.3 + \lambda_1)} = 1.613$$

$1.3 + 2\lambda_1 = 1.613 \times 1.3\, \lambda_1 + 1.613\, \lambda_1^2$

$1.6\lambda_1^2 + 0.096\, \lambda_1 - 1.3 = 0$

$$\lambda_1 = \frac{-0.096 \pm \sqrt{(0.096)^2 + 4 \times 1.3 \times 1.6}}{3.2}$$

$\lambda_1 = 0.871$ Å

$\lambda_2 = 2.17$ Å

Exercise 2

Single Correct Choice Type

Sol 1: (B) No. of photons = $\frac{10^{-3}}{\text{Energy of 1 photon}}$

Energy of 1 photon = $\frac{12400}{5000}$ = 2.48 eV

n_p = No. of photons = $\frac{10^{-3}}{2.48 \times 1.6 \times 10^{-19}}$

= $0.25 \times 10^{16} = 2.5 \times 10^{15}$ photon

n_e = No. of electron = $\frac{0.16\, \mu A}{1.6 \times 10^{-19}}$ = $\frac{1.6 \times 10^{-7}}{1.6 \times 10^{-19}}$

= 10^{12} electron

Efficiency = $\frac{n_e}{n_p} \times 100$ = $\frac{10^{12}}{2.5 \times 10^{15}} \times 100$

$= \frac{1}{2.5 \times 10}$ = $\frac{4}{100}$ = 0.04%

Sol 2: (B) KE_{max} = 2eV

$E_1 = \phi + KE_{max\,1}$

$5eV = \phi + 2eV$

$\phi = 3eV$

$E_2 = \phi + KE_{max\,2}$; $KE_{max\,2} = eV_2$

$6\text{ eV} = 3\text{ eV} + eV_2 \Rightarrow 3\text{ eV} = eV_2$

$V_2 = 3V$

So stopping potential of A w.r.t. C is – 3V

Sol 3: (A) $E_n = \frac{2\pi^2 mk^2 Z^2 e^4}{n^2 h^2}$

Frequency $\nu = \frac{Z^2 . 4\pi^2 mk^2 e^4}{n^3 . h^3}$

$$\frac{\nu}{E_n} = \frac{Z^2 \times 4\pi^2 mk^2 e^4\ n^2 h^2}{n^2 h^3\ 2\pi^2 mk^2 Z^2 e^4} \Rightarrow \frac{\nu}{E_n} = \frac{2}{nh}$$

$$\Rightarrow \nu = \frac{2E_n}{nh}$$

Sol 4: (D) Bohr radius = $\frac{n^2}{Z} \times 0.529$

$r_{n+1} - r_n = [(n + 1)^2 - n^2]\, 0.529 = r_{n-1}$

$= (2n + 1)\, 0.529 = (n - 1)^2 \times 0.529$

$\Rightarrow (n - 1)^2 = 2n + 1$

$n^2 + 1 - 2n = 2n + 1 \Rightarrow n^2 = 4n$

$\Rightarrow n = 4$

Sol 5: (A) $r_n = \dfrac{n^2h^2e_0}{pme^2Z} = \dfrac{0.529n^2}{Z}$

n =1, Z = 1

For mean $r'_n = \dfrac{0.529n^2}{207Z} = 2.56 \times 10^{-3}\ \overset{o}{A}$

Sol 6: (C) Hydrogen emit a photon corresponding to the largest wavelength of the Balmer series. This implies electron was excited to n = 3

Energy required for transition $n = 1 \rightarrow 3$ is

$$13.6\left[\frac{1}{1^2} - \frac{1}{3^2}\right] = \frac{13.6 \times 8}{9} = 12.088\,\text{eV}$$

Minimum kinetic energy = 12.1 eV

Sol 7: (A) Refer Q-11 (in Exercise II JEE Advanced)

Sol 8: (B) $n = 3 \rightarrow 2;\ E_1 = 13.6\left[\frac{1}{4} - \frac{1}{9}\right] = \frac{5}{36} \times 13.6$

$n = 2 \rightarrow 1;\ E_2 = 13.6\left[1 - \frac{1}{4}\right] = \frac{3}{4} \times 13.6$

$$\lambda_1 = \frac{hc}{E_1};\quad \lambda_2 = \frac{hc}{E_2}$$

$$x = \frac{\lambda_1}{\lambda_2} = \frac{E_2}{E_1} = \frac{3}{4 \times 5} \times 36 = \frac{27}{5}$$

$$Z = \frac{E_1}{E_2} = \frac{5}{27}$$

$$y = \frac{p_1}{p_2} = \frac{h/\lambda_1}{h/\lambda_2} = \frac{\lambda_2}{\lambda_1} = \frac{5}{27}$$

Multiple Correct Choice Type

Sol 9: (A, C) Stopping potential $\propto$ kinetic energy

Kinetic energy depends on the frequency of light

$h\nu = h\nu_0 + KE$

Sol 10: (A, D) $\lambda_d = \dfrac{h}{p}$

de Broglie wavelength λ_1 will not change in magnetic field as in magnetic field kinetic energy does not change. Kinetic energy of electron in electric field may increase, remain same or decrease that's why λ_2 can increase or decrease.

$\lambda_1 > \lambda_2$ or $\lambda_2 < \lambda_1$ or $\lambda_1 = \lambda_2$

Sol 11: (A, C) Minimum energy required for transition to happen from ground state is 10.2 eV.

If the total loss in energy is less than 10.2 eV no transition will occur. Either there can be loss of energy greater than 10.2 eV or no loss in energy since the energy of neutron is 20.4 eV the maximum loss in energy due to inelasticity will be less then 10.2 eV. Therefore only option is no loss in energy which means elastic collision. So (A and C).

Sol 12: (A, C, D) Photon of energy 2.55 eV is emitted when transition is from n = 4 to n = 2

So other photon corresponds to $n = 2 \rightarrow n = 1$

Energy absorbed by hydrogen atom = 10.2 + 2.55 = 12.75 eV

Minimum Kinetic energy of photon is when collision is perfectly inelastic i.e. when K = 25.5 eV

Refer Q. 11

Sol 13: (A, C, D) $13.6\,Z^2 = 122.4$

Z = 3

For n = 1, $E_1 = -122.4$ eV

n = 2 $\quad E_2 = -30.6$ eV

$E_2 - E_1 = 91.8$ eV

If 125 eV energy electron collides with this atom then 122.4 eV will be used to take out the electron and kinetic energy of electron will be 125 – 122.4 = 2.6 eV

Sol 14: (A, C, D) Some incident wavelengths will be absent in A as some of them will be absorbed by the hydrogen atom. B will emit photons of Energy Corresponding to transitions in the hydrogen atom. This energy will lie in visible and infrared region.

Sol 15: (A, B, C) Having electrons of same speed won't matter because electrons get decelerated to different velocities (just like electrons with random velocities) giving photons of different wavelength. (Read theory).

Assertion Reasoning Type

Sol 16: (D) For frequency less than ν_o no electrons are emitted. so Statement-I is/false.

Sol 17: (C) Momentum of photon is $p = \frac{h}{\lambda}$

Sol 18: (D) All emitted electrons do not have same K.E.

There K.E. range from 0 to $(h\nu - \phi)$.

Sol 19: (D) If electron will not emit as only one single photon should have energy more than work function.

Sol 20: (A) $\lambda_e = \frac{h}{\sqrt{2m_e(KE)}}$; $\lambda_p = \frac{h}{\sqrt{2m_p(KE)}}$

$m_p > m_e$

$\Rightarrow \lambda_e > \lambda_p$

Sol 21: (A) By Boltzmann's law (randomization increases with temperature) electron's occupy more number of excited levels at higher temperature.

Previous Years' Questions

Sol 1: (a) Given $E_3 - E_2$ = 47.2 eV

Since $E_n \propto \frac{Z^2}{n^2}$ (for hydrogen like atoms)

$$\text{or}(-13.6)\left(\frac{Z^2}{9}\right) - \left[-(13.6)\left(\frac{Z^2}{4}\right)\right] = 47.2$$

Solving this equation, we get Z = 5

(b) Energy required to excite the electron from 3rd to 4th orbit:

$$E_{3-4} = E_4 - E_3$$

$$= (-13.6)\left(\frac{25}{16}\right) - \left[(-13.6)\left(\frac{25}{9}\right)\right] = 16.53\text{eV}$$

(c) Energy required to remove the electron from first orbit to infinity (or the ionization energy) will be:

E = (13.6) $(5)^2$ = 340 eV

The corresponding wavelength would be,

$$\lambda = \frac{hc}{E} = \frac{6.6\times10^{-34}\times3\times10^{8}}{340\times1.6\times10^{-19}}$$

$= 0.0364 \times 10^{-7}$ m = 36.4 Å

(d) In first orbit, total energy = –340eV

Kinetic energy = +340 eV

Potential energy = –2 × 340 eV = –680 eV

and angular momentum = $\frac{h}{2\pi}$

$$= \frac{6.6\times10^{-34}}{2\pi} = 1.05 \times 10^{-34}\ \text{kg–m}^2/\text{s}$$

(e) $r_n \propto \frac{n^2}{Z}$

Radius of first Bohr orbit

$$r_1 = \frac{r_1^H}{Z} = \frac{5.3\times10^{-11}}{5} = 1.06\times10^{-11}\text{m}$$

Sol 2: Energy corresponding to given wavelengths:

$$E(\text{in eV}) = \frac{12375}{\lambda(\text{in Å})} = \frac{12375}{975} = 12.69\text{eV}$$

Now, let the electron excites to nth energy state. Then, $E_n - E_1 = 12.69$

$$\text{or} \frac{(-13.6)}{(n^2)} - (-13.6) = 12.69$$

$\therefore n \approx 4$

i.e., electron excites to 4th energy state. Total number of lines in emission spectrum would be:

$$\frac{n(n-1)}{2} = \frac{4\times3}{2} = 6$$

Longest wavelength will correspond to the minimum energy and minimum energy is released in transition from n = 4 to n = 3.

$$E_{4-3} = E_4 - E_3 = \frac{-13.6}{(4)^2} - \frac{-13.6}{(3)^2} = 0.66\text{ eV}$$

$\therefore$ Longest wavelength will be,

$$\lambda_{max} = \frac{12375}{E(\text{in eV})} = \frac{12375}{0.66}\text{Å} = 1.875\times10^{-6}\text{m} = 1.875\ \mu\text{m}$$

Sol 3: Number of proton = atomic number = 11

Number of neutron = mass number – atomic number = 13

But note that in the nucleus number of electron will be zero.

Sol 4: ${}_{92}U^{238} \xrightarrow{\alpha-\text{decay}} {}_{90}X^{234} \xrightarrow{\beta-\text{decay}} {}_{91}Y^{234}$

During an α-decay atomic number decreases by 2 and mass number by 4. During a β-decay, atomic number increases by 1 while mass number remains unchanged.

Sol 5: When 800 Å wavelength falls on hydrogen atom (in ground state) 13.6 eV energy is used in liberating the electron. The rest goes to kinetic energy of electron.

Hence, K = E – 13.6 (in eV) or

$$(1.8\times1.6\times10^{-19}) = \frac{hc}{800\times10^{-10}} - 13.6\times1.6\times10^{-19} \quad \text{....(i)}$$

Similarly for the second wavelength:

$$(4.0\times1.6\times10^{-19}) = \frac{hc}{700\times10^{-10}} - 13.6\times1.6\times10^{-19} \quad \text{...(ii)}$$

Solving these two equations, we get

$$h \approx 6.6\times10^{-34}\text{ Js}$$

Sol 6: (a) 1 Rydberg = 2.2 × 10^{-18} J = Rhc

Ionisation energy is given as 4 Rydberg

$$= 8.8\times10^{-18}\text{ J} = \frac{8.8\times10^{-18}}{1.6\times10^{-19}} = 55\text{ eV}$$

$\therefore$ Energy in first orbit $E_1 = -55\,\text{eV}$

Energy of radiation emitted when electron jumps from first excited state (n = 2) to ground state (n = 1):

$$E_{21} = \frac{E_1}{(2)^2} - E_1 = -\frac{3}{4}E_1 = 41.25\,\text{eV}$$

$\therefore$ Wavelength of photon emitted in this transition would be,

$$\lambda = \frac{12375}{41.25} = 300\text{ Å}$$

(b) Let Z be the atomic number of given element. Then

$$E_1 = (-13.6)(Z^2) \text{ or } -55 = (-13.6)(Z^2) \text{ or } Z \approx 2$$

Now, as $r \propto \frac{1}{Z}$

Radius of first orbit of this atom,

$$r_1 = \frac{r_{H_1}}{Z} = \frac{0.529}{2} = 0.2645\text{ Å}$$

Sol 7: Given Z = 3 : $E_n \propto \frac{Z^2}{n^2}$

(a) To excite the atom from n = 1 to n = 3, energy of photon required is,

$$E_{1-3} = E_3 - E_1 = \frac{(-13.6)(3)^2}{(3)^2} - \left[\frac{(-13.6)(3)^2}{(1)^2}\right]$$

= 108.8 eV

Corresponding wavelength will be,

$$\lambda\text{ (in Å)} = \frac{12375}{E\text{(in eV)}} = \frac{12375}{108.8}$$

= 113.74 Å

(b) From n^{th} orbit total number of emission lines can be, $\frac{n(n-1)}{2}$.

$\therefore$ Number of emission lines = $\frac{3(3-1)}{2}$ = 3

Sol 8: Speed of neutrons = $\sqrt{\frac{2K}{m}}$

$$\left(\text{From } K = \frac{1}{2}mv^2\right)$$

$$\text{or } v = \sqrt{\frac{2\times0.0327\times1.6\times10^{-19}}{1.675\times10^{-27}}} \approx 2.5\times10^3\text{ m/s}$$

Time taken by the neutrons to travel a distance of 10 m:

$$t = \frac{d}{v} = \frac{10}{2.5\times10^3} = 4.0\times10^{-3}$$

Number of neutrons decayed after time t

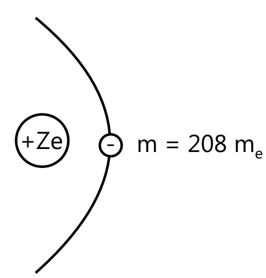
$$N = N_0(1-e^{-\lambda t})$$

$\therefore$ Fraction of neutrons that will decay in this time interval

$$= \frac{N}{N_0} = (1-e^{-\lambda t}) = 1 - e^{-\frac{\ln(2)}{700}\times4.0\times10^{-3}} = 3.96\times10^{-6}$$

Sol 9: If we assume that mass of nucleus >> mass of mu-meson, then nucleus will be assumed to be at rest, only mu-meson is revolving round it.

(a) In n^{th} orbit, the necessary centripetal force to the mu-meson will be provided by the electrostatic force between the nucleus and the mu-meson.



Hence, $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{r^2}$ ... (i)

Further, it is given that Bohr model is applicable to this system also. Hence,

Angular momentum in n^{th} orbit = $\frac{nh}{2\pi}$

or $mvr = n\frac{h}{2\pi}$ ... (ii)

We have two unknowns v and r (in n^{th} orbit). After solving these two equations, we get $r = \frac{n^2h^2\varepsilon_0}{Z\pi me^2}$

Substituting Z = 3 and m = 208 m_e, we get

$$r_n = \frac{n^2h^2\varepsilon_0}{624\pi m_e e^2}$$

(b) The radius of the first Bohr orbit for the hydrogen atom is: $\frac{h^2\varepsilon_0}{\pi m_e e^2}$

Equating this with the radius calculated in part (a), we

$$n^2 \approx 624 \text{ or } n \approx 25$$

(c) Kinetic energy of atom = $\frac{mv^2}{2} = \frac{Ze^2}{8\pi\varepsilon_0 r}$

and the potential energy = $-\frac{Ze^2}{4\pi\varepsilon_0 r}$

$\therefore$ Total energy $E_n = \frac{-Ze^2}{8\pi\varepsilon_0 r}$

Substituting value of r, calculate in part (a),

$$E_n = \frac{1872}{n^2}\left[-\frac{m_e e^4}{8\varepsilon_0^2 h^2}\right]$$

But $\left[-\frac{m_e e^4}{8\varepsilon_0^2 h^2}\right]$ is the ground state energy of hydrogen atom and hence is equal to – 13.6 eV.

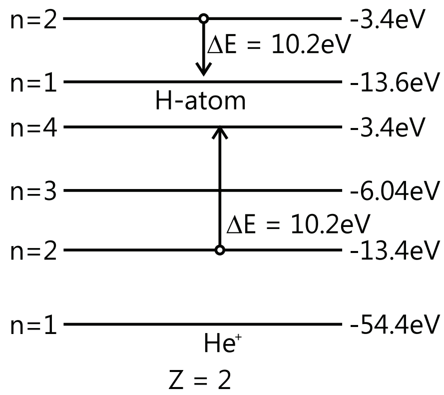
$$\therefore E_n = \frac{-1872}{n^2}(13.6)\text{ eV} = -\frac{25459.2}{n^2}\text{eV}$$

$$\therefore E_3 - E_1 = -25459.2\left[\frac{1}{9} - \frac{1}{1}\right] = 22630.4 \text{ eV}$$

$\therefore$ The corresponding wavelength,

$$\lambda(\text{In})\,\mathring{A} = \frac{12375}{22630.4} = 0.546\,\mathring{A}$$

Sol 10: (C)



Energy given by H-atom in transition from n = 2 to n = 1 is equal to energy taken by He^+ atom in transition from n = 2 to n = 4.

Sol 11: (C) Visible light lies in the range, λ_1 = 4000 Å to λ_2 = 7000 Å. Energy of photons corresponding to these wavelength (in eV) would be:

$$E_1 = \frac{12375}{4000} = 3.09 \text{ eV}$$

$$E_2 = \frac{12375}{7000} = 1.77 \text{ eV}$$

From energy level diagram of He^+ atom we can see that in transition from n = 4 to n = 3, energy of photon released will lie between E_1 and E_2.

$$\Delta E_{43} = -3.4 - (-6.04) = 2.64 \text{ eV}$$

Wavelength of photon corresponding to this energy,

$$\lambda = \frac{12375}{264}\text{ Å} = 4687.5 \text{ Å} = 4.68\times10^{-7} \text{ m}$$

Sol 12: (A) Kinetic energy $K \propto Z^2$

$$\therefore \frac{K_H}{K_{He^+}} = \left(\frac{1}{2}\right)^2 = \frac{1}{4}$$

Sol 13: A $\rightarrow$ p, q; B $\rightarrow$ p, r; C $\rightarrow$ p, s; D $\rightarrow$ q

Sol 14: (C, D) For photoemission to take place, wavelength of incident light should be less than the threshold wavelength. Wavelength of ultraviolet light < 5200Å while that of infrared radiation > 5200 Å.

Sol 15: (A) $a = \frac{n\lambda}{2} \Rightarrow \lambda = \frac{2a}{n}$

$$\lambda_{deBroglie} = \frac{h}{p}$$

$$\frac{2a}{n} = \frac{h}{p} \Rightarrow p = \frac{nh}{2a}$$

$$E = \frac{p^2}{2m} = \frac{n^2h^2}{8a^2m}$$

$$\Rightarrow E \propto 1/a^2$$

Sol 16: (B)

$$E = \frac{h^2}{8a^2m} = \frac{(6.6\times10^{-34})^2}{8\times(6.6\times10^{-9})^2\times10^{-30}\times1.6\times10^{-19}} = 8\text{ meV.}$$

Sol 17: (D) $mv = \frac{nh}{2a}$

$$v = \frac{nh}{2am} \;\Rightarrow\; v \propto n$$

Sol 18: $P_1 = \sqrt{2m(100\text{ eV})}$

$$\lambda_P = \frac{h}{\sqrt{2m(100\,eV)}} \Rightarrow \lambda_\alpha = \frac{h}{\sqrt{2(4m)(100\,eV)}}$$

$$\frac{\lambda_P}{\lambda_\alpha} = \sqrt{8}$$

$\Rightarrow$ The ratio $\frac{\lambda_P}{\lambda_\alpha}$ to the nearest integer, is equal to 3.

Sol 19: (A) $\frac{1}{6561} = R\left(\frac{1}{4}-\frac{1}{9}\right) = \frac{5R}{36}$

$$\frac{1}{\lambda} = 4R\left(\frac{1}{4}-\frac{1}{16}\right) = \frac{3R\times4}{16}$$

$$\lambda = 1215\,\mathring{A}$$

Sol 20: $0+\frac{1}{2}mv^2 = \frac{K(Q)e}{10\times10^{-15}} = \frac{K(120\,e)e}{10\times10^{-15}}$

$$\frac{1}{2}\times\frac{5}{3}\times10^{-27}v^2 = \frac{9\times10^9\times120\times(1.6\times10^{-19})^2}{10\times10^{-15}}$$

$$\Rightarrow v = \frac{9\times6\times10^9\times120\times2.56\times10^{-38}}{50\times10^{-42}}$$

$$\Rightarrow v = \sqrt{331.776\times10^{13}}$$

$$\lambda = \frac{h}{mv}$$

$$\lambda = \frac{4.2\times10^{-15}\times1.6\times10^{-19}}{\frac{5}{3}\times10^{-27}\times\sqrt{331.776\times10^{13}}} = \frac{4.2\times4.8\times10^{-34}}{57.6\times5\times10^{-21}} = 0.07\times10^{-13}$$

$$\lambda = 7\times10^{-15} = 7\text{ fm}$$

Sol 21: (B) $t = 100\times10^{-9}$ sec, $P = 30\times10^{-3}$ Watt, $C = C\times10^8$ m/s

$$\text{Momentum} = \frac{Pt}{C} = \frac{30\times10^{-3}\times100\times10^{-9}}{3\times10^8} = 1.0\times10^{-17}\text{ kg ms}^{-1}$$

Sol 22: Slope of graph is h/e = constant $\Rightarrow$ 1

Sol 23: $E_{photon} = E_{ionize\ atom} + E_{kinetic\ energy}$

$$\frac{1242}{90} = \frac{13.6}{n^2}+10.4$$

from this, n = 2

Sol 24: (A) For photoelectric emission

$$V_0 = \left(\frac{hc}{e}\right)\frac{1}{\lambda}-\frac{\phi}{e}$$

Sol 25:(B) $KE_{max} = \frac{hc}{\lambda}-\phi = eV_0$

$$\Rightarrow \frac{hc}{\lambda_1}-\frac{hc}{\lambda_2} = e(V_1-V_2)$$

$$\Rightarrow hc\left(\frac{1}{0.3}-\frac{1}{0.4}\right) = 1.6\times10^{-19}\times10^{-6}$$

$$\Rightarrow hc\left(\frac{0.1}{0.12}\right) = 1.6\times10^{-25}$$

$$\Rightarrow h = \frac{1.6\times10^{-25}\times1.2}{3\times10^8} = 0.64\times10^{-33} = 6.4\times10^{-34}$$

$$\Rightarrow hc\left(\frac{1}{0.4}-\frac{1}{0.5}\right) = (1.6\times10^{-19})\times0.6\times10^{-6}$$

$$\Rightarrow hc = (0.96\times10^{-25})\times\frac{0.20}{0.10}\times\frac{1}{3\times10^8}$$

$$\Rightarrow h = \frac{1.92}{3}\times10^{-33} = 6.4\times10^{-34}$$

Sol 26: (A), (B), (D) Orbital radius $r_{n} = n^2c$ [c = constant]

Angular momentum = nh = L

$$\frac{\Delta r}{r_n} = \frac{(n+1)^2 - n^2}{n^2} = \frac{2}{n} \text{ .....[B]; } \frac{\Delta L_n}{L_n} = \frac{1}{n} \text{ .... [D]}$$

(A) is correct since it will get cancelled in calculation of relative charge.

Sol 27: [6] Photon Energy

$$= \frac{hc}{\lambda} = \frac{1.237\times10^{-6}}{970\times10^{-10}} = \frac{1237}{970}\times10\text{eV}$$

Absorption of this photon changes the energy to = – 13.6 + 12.75 = – 0.85 eV

Number of possible transitions from the 4th quantum state = $^4C_2$ = 6

Sol 28: (B) P_1 = pressure just inside the bubble at the end 2 = $P_0 + \frac{4T}{R}$

P_2 = pressure just inside the bubble at the end 1 = $P_0 + \frac{4T}{r}$

R > r ⇒ $P_2 < P_1$ ⇒ Air will flow from end 1 to end 2

Sol 29: (A) $V_B = (1/e)[(hc/\lambda) - \phi]$

$V_P = (1/e)[(1240/550) - 2]\text{eV} = 0.2545$ V

$V_q = (1/e)[(1240/450) - 2.5]\text{eV} = 0.255$ V

$V_r = (1/e)[(1240/350) - 3]\text{eV} = 0.5428$ V

If n is the number of photons in unit time then $nhc/\lambda = I$

$\Rightarrow i_P : i_q : i_r = n_P : n_q : n_r = \lambda_P : \lambda_q : \lambda_r$

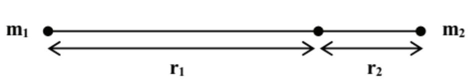
Sol 30: (D) $L = \frac{nh}{2\pi}$

$$\text{K.E.} = \frac{L^2}{2I} = \left(\frac{nh}{2\pi}\right)^2 \frac{1}{2I}$$

Sol 31: (B) $h\nu = k_{\cdot E_{n=2}} - kE_{n=1}$

$I = 1.87 \times 10^{-46}$ kg m^2

Sol 32: (C)



$$r_1 = \frac{m_2 d}{m_1 + m_2} \text{ and } r_2 = \frac{m_1 d}{m_1 + m_2}$$

$$I = m_1 r_1^2 + m_2 r_2^2$$

$\therefore$ d = 1.3 ×10^{-10} m.

Sol 33: (7) Stopping potential = $\frac{hc}{\lambda} - W$

= 6.2 eV −4.7 eV = 1.5 eV

$$V = \frac{Kq}{r} = 1.5$$

$$n = \frac{1.5\times10^{-2}}{9\times10^9\times1.6\times10^{-19}} = 1.05\times10^7$$

Z = 7

Sol 34: (B) $\frac{-2GMm}{L} + \frac{1}{2}mv^2 = 0$

$$\Rightarrow v = 2\sqrt{\frac{GM}{L}}$$

Note: The energy of mass 'm' means its kinetic energy (KE) only and not the potential energy of interaction between m and the two bodies (of mass M each) – which is the potential energy of the system.

Sol 35: (A) $\dfrac{\frac{hc}{\lambda_1} - \phi}{\frac{hc}{\lambda_2} - \phi} = \dfrac{u_1^2}{u_2^2}$

ϕ = 3.7 eV

Sol 36: (A) $K_{max} = \frac{hc}{\lambda_{ph}} - \phi + eV$ [K_{max} = maximum energy e$^-$ reaching the anode]

$$\Rightarrow \frac{h^2}{2m\lambda_e^2} = \left(\frac{hc}{\lambda_{ph}} - \phi\right) + eV \qquad \text{... (i)}$$

From Equation (i) (A) follows

if ϕ increases and λ_{ph} increases then $\left(\frac{hc}{\lambda_{ph}} - \phi\right)$ decreases

As a result λ_c increases λ_e is independent of 'd' and clearly λ_e and λ_{ph} do not increase at the same rate.