DUAL NATURE OF LIGHT

7.1 QUANTUM THEORY

1. Photons

According to Planck's quantum theory of radiation, an electromagnetic wave travels in the form of discrete packets of energy called quanta. One quantum of light radiation is called a photon. The main features of photons are as follows:

(i) A photon travels with the speed of light.

(ii) The frequency of a photon does not changes as it travels from one medium to another.

(iii) The speed of photon changes as it travels through different media due to the change in its wavelength.

(iv) The rest mass of a photon is zero *i.e.*, a photon cannot exist at rest.

(v) Energy of a photon, $E = h\upsilon = \frac{hc}{\lambda}$.

(vi) Momentum of a photon, $p = mc = \frac{h\upsilon}{c} = \frac{h}{\lambda} = \frac{E}{c}$.

(vii) From Einstein's mass-energy relationship, the equivalent mass m of a photon is given by

$$E = mc^2 = h\upsilon \quad \text{or} \quad m = \frac{h\upsilon}{c^2} = \frac{E}{c^2}.$$

(viii) By increasing the intensity of light of given wavelength, there is only an increase in number of photons per second crossing a given area with each photon having the same energy. Thus photon energy is independent of intensity of radiation.

(ix) Photons are electrically neutral and are not deflected by electric and magnetic fields.

(x) In a photon-particle collision, the total energy and total momentum are conserved. However, the number of photons may not be conserved in a collision. The photons may be absorbed or a new photon may be created.

2. Electron Emission

We know that metals have free electrons responsible for their conductivity. However the free electrons can not normally escape out of metal surface. If an electron attempts to come out of the metal, the positive charge of the metal pulls the electrons back to the metal. Consequently, the electron can come out of the metal surface only if it has obtained sufficient energy to overcome the attractive pull.

The minimum energy required by an electron to escape from metal surface is called work function of the metal.

Work function energy is generally measured in eV (electron volts) and it is the energy gained by an electron when it has been accelerated by a potential difference of 1 volt.

So, 1 eV = 1.602×10^{-19} J

The work function energy can be supplied to the free electrons by any of the following physical processes.

(i) Thermionic emission : By suitably heating, sufficient thermal energy can be imparted to the free electrons to enable them to come out of the metal.

(ii) Field emission : By applying a very strong electric field (of the order of 10^8 V m^{-1}) to a metal, electrons can be pulled out of the metal, as in a spark plug.

(iii) Photoelectric emission : When light of suitable frequency illuminates a metal surface, electrons are emitted from the metal surface. These photo(light)-generated electrons are called photoelectrons.

Work function of some metals

Metal	Work function W_0(eV)	Metal	Work function W_0(eV)
Cs	2.14	Al	4.28
K	2.30	Hg	4.49
Na	2.75	Cu	4.65
Ca	3.20	Ag	4.70
Mo	4.17	Ni	5.15
Pb	4.25	Pt	5.65

7.2 PHOTOELECTRIC EFFECT

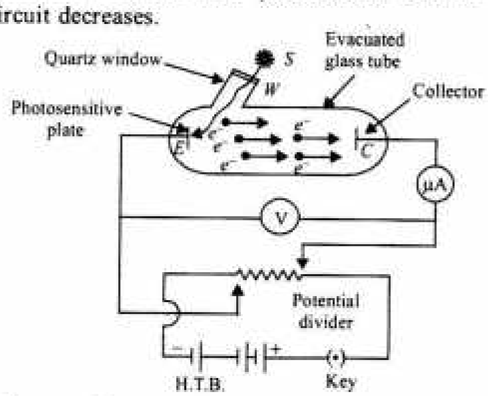
1. The phenomenon of emission of electrons from a metal surface, when electromagnetic radiations of sufficiently high frequency are incident on it, is called photoelectric effect. The photo (light)-generated electrons are called photoelectrons.

   Alkali metals like Li, Na, K, Cs show photoelectric effect with visible light. Metals like Zn, Cd, Mg respond to ultraviolet light.

2. To study photoelectric effect, an emitting electrode E of a photo sensitive material is kept at negative potential and

collecting electrode C is kept at positive potential in an evacuated tube. When light of sufficiently high frequency falls on emitting electrode, photoelectrons are emitted which travel directly to collecting electrode and hence an electric current called "photoelectric current" starts flowing in the circuit, which is directly proportional to the number of photoelectrons emitted by emitting electrode E.

3. When collecting electrode C is made negative with respect to emitting electrode E, an electric field is set up in direction of the motion of photo electrons, which apply retarding force on electrons. So now lesser electrons reach the collecting electrode and "photoelectric current" in the circuit decreases.



"The retarding potential V_0 at which no photo electron reaches the collecting electrode C and the photoelectric current in the circuit becomes zero is called "stopping potential".

4. At stopping potential V_0, work done by it is just equal to the maximum kinetic energy of the photoelectrons emitted *i.e.*,

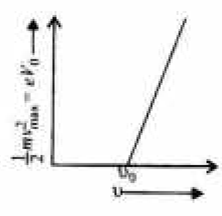
$$eV_0 = \frac{1}{2} mv_{max}^2$$

Thus, by measuring stopping potential V_0, maximum kinetic energy with which photoelectrons are emitted can be measured.

5. Lenard and Millikan gave the following laws on the basis of experiments on photoelectric effect, also known as "Laws of Photoelectric effect".

(i) "Emission of photoelectrons start as soon as light falls on metal surface *i.e.*, there is no time lag between incidence of light and emission of photoelectrons".

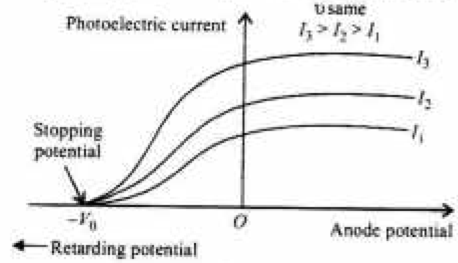
(ii) "The emission of photo-electrons takes place only when the frequency of the incident radiations is above a certain critical value called threshold frequency υ_0, which is characteristic of that metal emitting electrons".

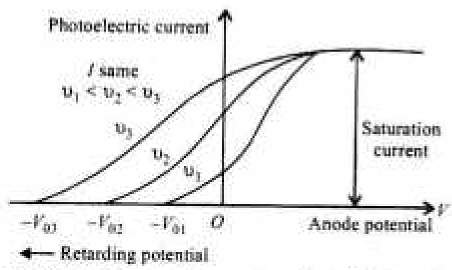


Above threshold frequency υ_0, maximum kinetic energy with which photoelectrons are emitted is directly proportional to frequency υ of incident radiation.

So the graph plotted between $(1/2)mv_{max}^2$ or eV_0 with frequency υ is a straight line for frequencies above threshold frequency υ_0 and is of slope equal to Planck's constant h. However, if graph is plotted between stopping potential V_0 and frequency υ, then it is also a straight line for frequencies above threshold frequency υ_0, but the slope of graph is then equal to h/e.

(iii) "The maximum kinetic energy with which a photoelectron is emitted from a metallic surface is independent of the intensity of light and depends only upon its frequency".





If radiations of same frequency υ but different intensities I_1 and I_2 are incident on metallic surface, then it is found that photoelectric current produced is different but stopping potential V_0 is same. As maximum kinetic energy with which photoelectrons are emitted is proportional to stopping potential V_0, so it follows that maximum kinetic energy with which photoelectrons are emitted is independent of intensity of incident light.

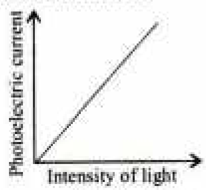
If radiations of same intensity I but different frequencies υ_1 and υ_2 are incident on metallic surface, then it is found that photoelectric current produced is same but the stopping potentials V_0 and V_0' are different at different frequencies. So it follows that maximum kinetic energy with which photoelectrons are emitted depends only upon the frequency of incident light.

(iv) "The number of photoelectrons emitted *i.e.*, photoelectric current, is independent of the frequency of the incident light and depends only upon its intensity".

This follows form the above two graphs.

Also, it is found that the photoelectric current increases with increase in accelerating forward (positive) potential, until a stage reaches at which, the photoelectric current becomes maxmimum called "Saturation Current" when all the photoelectrons emitted by the emitter electrode E reach the collecting electrode C. So if we now increase the accelerating potential of collecting electrode C [anode potential, the photoelectric current does not increase.

On keeping the frequency of incident radiation and the accelerating potential constant, it is found that the photoelectric current increases linearly with intensity of incident light as shown in graph. So it implies that the photoelectric current and hence the number of photoelectrons emitted per second is proportional to the intensity of incident radiation.



Failure of wave theory of light to explain Photoelectric effect

(i) According to wave theory, greater the intensity of radiation, greater are the amplitudes of electric and magnetic fields and hence greater is the energy density of the wave. So, the maximum kinetic energy of the photoelectron emitted must depend on intensity of incident light, however practically it does not happens. So independence of maximum kinetic energy of photoelectron emitted on intensity of incident light cannot be explained using wave theory of light.

(ii) Also, whatever the frequency of incident radiation may be, incident light of large intensity over a sufficient time must be able to impart enough energy to the electrons, so that they can get out of the metal surface. So, a threshold frequency must not exist.

(iii) Further, number of electrons absorb energy continuously over the entire wavefront of the radiation. So energy absorbed per unit time by an electron becomes very small. So, in that case electrons may take quite long time to come out of metallic surface on continuous exposure of light on the surface. However, practically we found that there is no time lag between incident of light and emission of photoelectron.

So, we conclude that wave nature of light cannot be used to explain photoelectric effect.

7.3 EINSTEINS EXPLANATION TO PHOTOELECTRIC EFFECT

1. Einstein's Photoelectric Equation

According to Einstein, when light is incident on metal surface, incident photons are absorbed completely by valence electrons of atoms of metal on its surface. Energy $h\upsilon$ of each photon is partially utilised by an electron to become free or to overcome its "work function W_0" and rest of the absorbed energy provides the maximum kinetic energy to the photoelectron during the emission. *i.e.*

$$h\upsilon = \frac{1}{2} m v_{max}^2 + W_0$$

"Work function W_0 is the minimum energy required by the valence electron of an atom on the surface of metal to become free or to become a photoelectron."

At threshold frequency υ_0, the energy of photon $h\upsilon_0$ of incident radiation is just sufficient enough to liberate the electron *i.e.* just equal to work function W_0 or

$$W_0 = h\upsilon_0 = h\frac{c}{\lambda_0}$$

where λ_0 is "Threshold wavelength" of incident radiation.

So, $h\upsilon = \frac{1}{2} m v_{max}^2 + h\upsilon_0$

or $\frac{1}{2} m v_{max}^2 = h(\upsilon - \upsilon_0)$

This is called "Einstein's photoelectric equation"

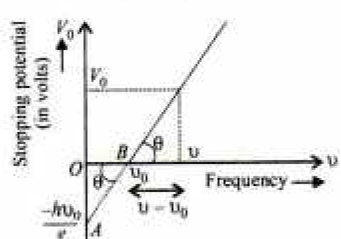
So at threshold frequency υ_0, kinetic energy of photoelectron emitted is zero.

2. Explanation to Laws of Photoelectric Effect

Using Einstein's photoelectric equation, we can explain laws of photoelectric effect as:

(i) As soon as an electron absorbs energy of photon, it sets itself free. So emission of photoelectrons start as soon as light falls on metal surface.

(ii) Below threshold frequency υ_0, energy of photon is less than work function of metal surface *i.e.* less than minimum amount of energy required to librate an electron. So emission of photoelectrons take place only when the frequency of incident radiation is above or equal to the threshold frequency υ_0. Further the slope of graph between stopping potential V_0 and frequency υ of incident radiation is



$$\tan\theta = \frac{V_0}{(\upsilon - \upsilon_0)} = \frac{eV_0}{e(\upsilon - \upsilon_0)}$$

$$= \frac{\frac{1}{2} m v_{max}^2}{e(\upsilon - \upsilon_0)} = \frac{h(\upsilon - \upsilon_0)}{e(\upsilon - \upsilon_0)} = \frac{h}{e}$$

However, the intercept of this curve on the potential axis is at $-OA = OB\tan\theta = \upsilon_0 \frac{h}{e}$

or $OA = -\frac{h\upsilon_0}{e}$

But if the graph is plotted between maximum kinetic energy $\frac{1}{2}mv_{max}^2 = eV_0$ of photoelectrons and frequency υ of incident radiations, then the slope of graph is equal to h, and intercept on the potential axis is at $-h\upsilon_0$.

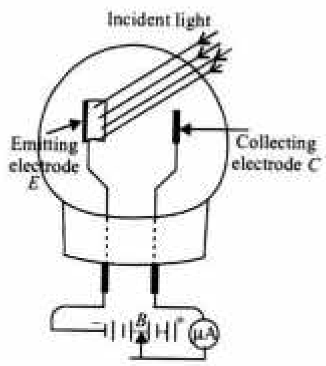
(iii) As energy of a photon depends on the frequency of light, so the maximum kinetic energy with which photoelectron is emitted depends only on the energy of photon or on the frequency of incident radiation.

(iv) As the number of photons in light depend on its intensity, and one photon liberates one photoelectron, so number of photoelectrons emitted depend only on the intensity of incident light.

3. Photoelectric Cell

A photoelectric cell is an arrangement which converts light energy into electrical energy. It works on the principle of photoelectric effect.

It consists of a semicylindrical photo-sensitive metal plate as emitting electrode E and a wire loop C as collecting electrode. It is connected to a high tension battery and a microammeter. When light of sufficiently high frequency falls on emitting electrode E, photoelectrons are emitted which when collected by collecting electrode C, a photoelectric current starts flowing in the circuit, which is proportional to the intensity of incident light.



A photo-cell converts a change in intensity of light into a change in photoelectric current. This current can be used to operate control systems and in light measuring devices.

A photo cell is used in

(i) burglar alarms

(ii) fire alarms

(iii) reproduction of sound in motion pictures

(iv) optical counters etc.

Light meters in photographic cameras make use of photo cells to measure the intensity of incident light. The photocells, inserted in the door light electric circuit, are used as automatic door opener. (A person approaching a doorway interrupts a light beam which is incident on photo cells. The change in photocurrent can be used to start a motor which opens the door or rings an alarm).

Photocells in counting device records every interruption of light beam caused by a person or object passing across the beam. In fire alarm, a number of photocells are installed at suitable places in a building. In the event of breaking out of fire, light radiations fall on the photocells. This completes the electric circuit through an electric bell or siren which starts operating.

7.4 DUAL NATURE OF RADIATION AND MATTER

1. In 1924, the French Physicist Louis Victor de Broglie put forward his hypothesis that moving particles of matter should display wave like properties under suitable conditions. He reasoned that nature was symmetrical and that the two basic physical entities - matter and energy, must have symmetrical character. In 1929, de Broglie was awarded the Nobel Prize. In physics for his discovery of wave nature of electron.

2. According to Louis de-Broglie, as the radiations exhibit dual nature *i.e.* wave as well as particle nature, similarly a wave is also associated with every moving particle. These waves are called "de-Broglie waves" or "matter waves".

   He proposed that the wavelength λ associated with a particle of momentum 'p' is

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

where m is the mass and v is the speed of particle. This relation is called "de-Broglie relation" and wavelength λ of matter wave is called de-Broglie wavelength.

From this equation, we draw following conclusions :

(i) Lighter the particle, greater is its de-Broglie wavelength. This is why wave character of sub-atomic particles is significant and measurable.

(ii) The faster the particle moves, the smaller is its de-Broglie wavelength.

(iii) The de-Broglie wavelength of a particle is independent of the charge or nature of the particle.

(iv) Matter waves are not electromagnetic in nature.

(v) Frequency of matter wave associated with particle of mass m moving with velocity v is

$$\upsilon = \frac{v}{\lambda} = v \times \frac{p}{h} = v \times \frac{mv}{h}$$

$$\text{or} \quad \upsilon = \frac{mv^2}{h}$$

3. For example the de-Broglie wavelength of a ball of mass 0.12 kg moving with a speed of 20 ms^{-1} can be calculated

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}\ \text{Js}}{0.12\ \text{kg} \times 20\ \text{m s}^{-1}} = 2.76 \times 10^{-34}\ \text{m}$$

   The wavelength is so small that it can not be measured. This is why the macroscopic objects do not show wave like properties. On the other hand the wave character of subatomic particles is significant and measurable.

4. De-Broglie wavelength of electron :

Energy of an electron of charge e accelerated by a potential of V volts is

$$\frac{1}{2}mv^2 = eV \quad \text{or} \quad v = \sqrt{\frac{2eV}{m}}$$

So, de-Broglie wavelength of an electron is then given by

$$\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{\frac{2eV}{m}}} \quad \text{or} \quad \lambda = \frac{h}{\sqrt{2meV}}$$

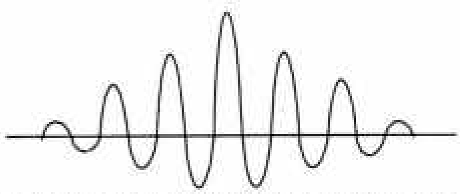
$$\text{or} \quad \lambda = \frac{12.27}{\sqrt{V}}\ \text{Å}$$

5. According to Heisenberg's uncertainity principle it is not possible to measure both the position and momentum of electron at the same time exactly.

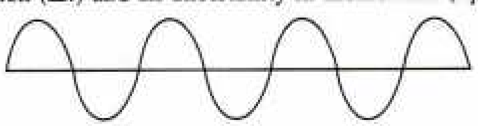
There is always some uncertainity (Δx) in the specification of position and some uncertainity (Δp) in the specification of momentum

$$\Delta x\, \Delta p = \frac{h}{2\pi}$$

In general, the matter wave associated with the electron is a wave packet extending over some finite region of space. So, Δx is finite, also the momentum of the electron have uncertainity Δp.



The wave packet description of an electron. The wave packet corresponds to a spread of wavelength around some central wavelength (and hence by de Broglie relation, a spread in momentum). Consequently, it is associated with an uncertainty in position (Δx) and an uncertainty in momentum (Δp).



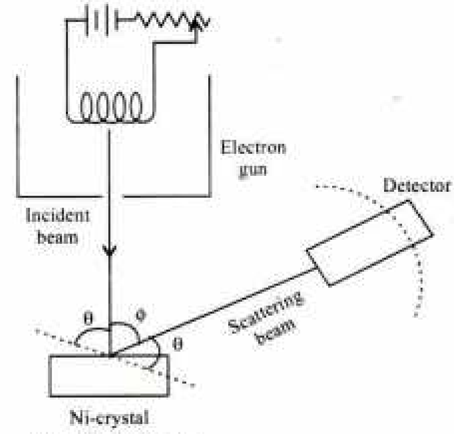
The matter wave corresponding to a definite momentum of an electron extends all over space. In this case,

$$\Delta p = 0 \text{ and } \Delta x \to \infty.$$

6. Davisson and Germer Experiment

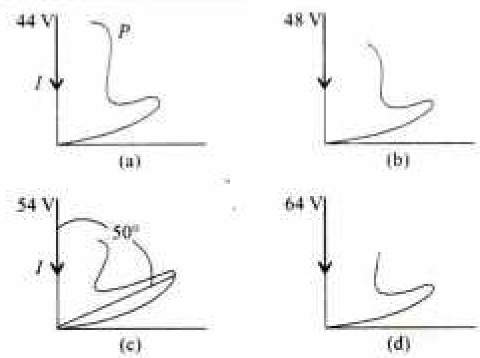
Davisson and Germer experiment proves the concept of wave nature of matter paricles. In a crystal lattice, the interatomic distance between the layers and de-Broglie wavelengths of an electron are nearly of same order. So diffraction of electron beam can be observed through crystals. This experiment uses an electron gun to produce fine beam of electrons which can be accelerated to any desired velocity by applying suitable voltage across the gun.

A fine beam of electrons is made to fall on the surface of nickel crystal. The electrons are scattered in all directions by the atoms of the crystal. The intensity of the electron beam, scattered in a given direction, is measured by the electron detector, which can be rotated, on a circular scale.



Experimental set up

For different values of scattering angles, intensity of scattered beam of electrons is measured.



When the graphs are drawn showing the variation of the intensity I of the scattered electrons with the angles of scattering ϕ at different accelerating voltages. It is found that intensity is different for different angles of scattering. Further, the maximum intensity is obtained due to constructive interference of electrons scattered from different layers of regularly spaced atoms of the crystals. It is found that angle θ between the scattered beam of electrons with the plane of atoms of crystal, when scattering angle $\phi = 50°$ is

$$\theta + \phi + \theta = 180°$$

$$2\theta = 180° - 50° \quad \text{or}\ \theta = 65°$$

Now, using Bragg's law, $\quad 2d \sin\theta = n\lambda$

but for first order diffraction, $\lambda = 2d \sin\theta$

where $d = 0.91°$ A is distance between two successive layers of atoms in Ni crystal

or $\quad \lambda = 2 \times 0.91 \sin 65° \quad$ or $\lambda = 1.66$ Å

This is the value of wavelength of electron as measured by Davisson and Germer experiment. However, the de-Broglie wavelength of an electron accelerated through potential difference $V = 54$ volts is

$$\lambda = \frac{12.27}{\sqrt{V}} = \frac{12.27}{\sqrt{54}} \quad \text{or} \quad \lambda = 1.65\ \text{Å}$$

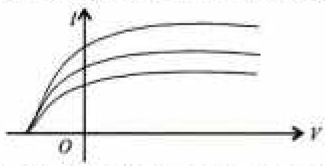
As the two results are same, so this experiment proves the wave nature of electron and hence of a particle in general.

VERY SHORT ANSWER TYPE QUESTION (1 MARK)

■ PHOTOELECTRIC EFFECT

1. What is the momentum of a photon of (i) frequency υ (ii) wavelength λ? *(Delhi 1987)*
2. What is the rest mass of a photon? *(Delhi 1990)*
3. Calculate the frequency associated with a photon of energy 3.3×10^{-20} J. ($h = 6.6 \times 10^{-34}$ Js) *(AI 1990)*
4. On what factor does the energy carried by a photon of light depend? *(PSB 1999)*
5. What is the energy of photon at the violet end of visible radiations of wavelength about 390 nm? ($h = 6.6 \times 10^{-34}$ Js)
6. The wavelength of electromagnetic radiation is doubled. What will happen to the energy of the photons? *(Delhi 1993)*
7. What is the energy associated in joules with a photon of wavelength 4000 Å? *(Delhi 1994)*
8. Mention one physical process for the release of electrons from the surface of metal. *(AI 1990)*
9. What is the effect on the velocity of the emitted photoelectrons if the wavelength of the incident light is decreased? *(Delhi 1992)*
10. If the intensity of incident radiation on a metal is doubled, what happens to the kinetic energy of electrons emitted? *(AI 1993)*
11. The wavelength of electromagnetic radiation is doubled. What will happen to the energy of the photons? *(Delhi 1993)*
12. The stopping potential in an experiment on photoelectric effect is 2 V. What is the maximum kinetic energy of the photoelectrons emitted? *(AI 2009)*
13. Light from bulb falls on a wooden table, but no photoelectrons are emitted. Why? *(AI 1997)*
14. If the maximum kinetic energy of electrons emitted in a photocell is 5 eV, what is the stopping potential? *(Delhi 2001)*
15. How does the maximum kinetic energy of electrons emitted vary with the works function of the metal? *(Delhi 2001)*
16. The frequency υ of incident radiation is greater than threshold frequency υ_0 in a photocell. How will the stopping potential vary if frequency υ is increased, keeping other factors constant. *(Delhi 2002)*
17. If the intensity of the incident radiation in a photocell is increased, how does the stopping potential vary? *(Delhi 2002)*
18. Two metals A and B have work functions 2 eV and 4 eV respectively. Which of the two metals has a smaller threshold wavelength? *(Delhi 1996, 2002)*
19. Two metals A and B have work functions 2 eV and 6 eV respectively. Which of the two metals have larger threshold frequency?
20. How does the photoelectric current in a photocell will change, if the frequency of incident light is doubled?
21. Give Einstein's photoelectric equation.
22. Ultraviolet radiations of different frequencies υ_1 and υ_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 electrons is same in both the cases. Which one of the two radiations will be of higher frequency? *(AI 2007)*
23. Does threshold frequency depends on intensity of light?
24. The maximum kinetic energy of photo electrons emitted from a surface, when photons of energy 6 eV fall on it is 4 eV. What is the stopping potential (in Volt) for the fastest photoelectrons?
25. What is the effect on the velocity of the photoelectrons, if the wavelength of the incident light is decreased?
26. A graph is plotted between the maximum K.E. of emitted photoelectrons and the frequency of incident radiations. Which physical constant can be determined from the slope of this graph? *(CBSE sample paper)*
27. In an experiment of photoelectric effect, the slope of the cut-off voltage versus frequency of incident light is found to be 4.12×10^{-15} Vs. Calculate the value of Planck's constant.
28. Does the 'stopping potential' in photoelectric emission depends upon
    (i) the intensity of the incident radiation in a photocell?
    (ii) the frequency of the incident radiation? *(Delhi 2005)*
29. Ultraviolet light is incident on two photosensitive materials having work functions W_1 and W_2 ($W_1 > W_2$). In which case will the kinetic energy of the emitted electrons be greater? Why? *(AI 2005)*

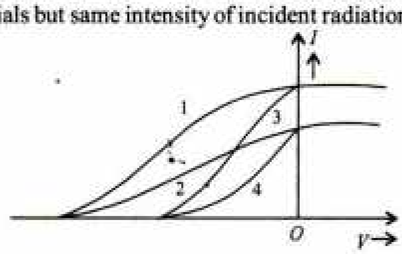
30. In an experiment on photoelectric effect, the following graphs were obtained between the photoelectric current (I) and the anode potential (V). Name the characteristic of the incident radiation that was kept constant in this experiment.



(AI 2005)

31. The photoelectric cut-off voltage in a certain experiment is 1.5 V. What is the maximum kinetic energy of photoelectrons emitted?

32. The given graphs show the variation of photo electric current (I) with the applied voltage (V) for two different materials and for two different intensities of the incident radiations. Identify the pairs of curves that correspond to different materials but same intensity of incident radiations.

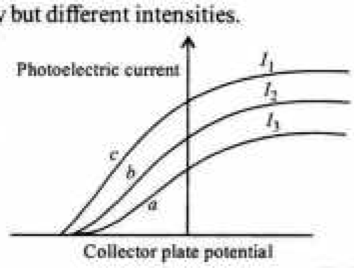


(CBSE sample paper 2007)

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

(AI 2009)

34. The figure shows a plot of three curves, *a, b, c* showing the variation of photocurrent vs collector plate potential for three different intensities I_1, I_2, and I_3 having frequencies υ_1, υ_2 and υ_3 respectively incident on a photosensitive surface.
Point out the two curves for which the incident radiations have same frequency but different intensities.



(Delhi 2009)

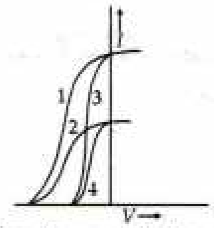
35. The maximum kinetic energy of a photoelectron is 3 eV. What is its stopping potential?

(Delhi 2009)

36. The stopping potential in an experiment on photoelectric effect is 2 V. What is the maximum kinetic energy of the photoelectrons emitted?

(Delhi 2009)

37. The given graph shows the variation of photo-electric current (I) versus applied voltage (V) for two different photosensitive materials and for two different intensities of the incident radiations.



Identify the pairs of curves that correspond to different materials but same intensity of incident radiation.

(Delhi 2013)

38. Define intensity of radiation on the basis of photon picture of light. Write its S.I. unit.

(AI 2014)

■ DUAL NATURE OF RADIATION AND MATTER

39. What is the de-Broglie wavelength of a 3 kg object moving with a speed of 2 ms^{-1}? *(AI 1992)*

40. What is the de-Broglie wavelength of a 2 kg object moving with a speed of 1 ms^{-1}? *(Delhi 1992)*

41. Obtain the energy in joules acquired by an electron beam when accelerated through a potential difference of 2000 V.

(AI 1994)

42. Name the experiment which establishes the wave nature of a particle. *(AI 2006C)*

43. Calculate the de-Broglie wavelength of the electrons accelerated through a potential difference of 10 KV.

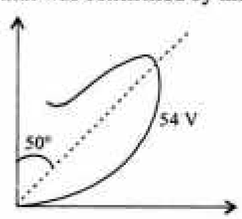
(Delhi 2007C)

44. Calculate the de-Broglie wavelength of an electron accelerated through a potential difference of 100 V. *(Foreign 2006)*

45. 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? *(AI 2006)*

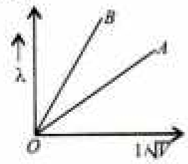
46. With what purpose was famous Davisson-Germer experiment with electrons performed ? *(Delhi 2006)*

47. Name the experiment for which the following graph, showing the variation of intensity of scattered electrons with the angle of scattering, was obtained. Also name the important hypothesis that was confirmed by this experiment.



(AI 2004C)

48. Two lines, A and B, in the plot given below show the variation of de Broglie wavelength, versus $1/\sqrt{V}$, where V is the accelerating potential difference, for two particles carrying the same charge. Which one of two represents a particle of smaller mass?



(AI 2008)

49. An electron and alpha particle have the same de-Broglie wavelength associated with them. How are their kinetic energies related to each other? *(Delhi 2008)*

50. An electron and alpha particle have the same kinetic energy. How are the de-Broglie wavelength associated with them related? *(Delhi 2008)*

51. An alpha particle and a proton are accelerated by the same accelerating potential. How are their de-Broglie wavelengths related? *(Foreign 2008)*

52. The de-Broglie wavelengths, associated with a proton and a neutron, are found to be equal. Which of the two has a higher value for kinetic energy?

(CBSE sample paper 2007)

53. Show graphically, the variation of the de-Broglie wavelength (λ) with the potential (V) through which an electron is accelerated from rest.

(AI 2011)

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

(AI 2012)

55. Write the expression for the de Broglie wavelength associated with a charged particle having charge q and mass m, when it is accelerated by a potential V.

(AI 2013)

SHORT ANSWER TYPE QUESTIONS (2 OR 3 MARKS)

■ PHOTOELECTRIC EFFECT

1. Calculate the photon energy in eV for radiation of wavelength 1 meter.

(Delhi 1993)

2. Light of wavelength 3500 Å is incident on two metals A and B. Which metal will yield photoelectrons if their work functions are 4.3 eV and 1.9 eV respectively?

(AI 1991)

3. Calculate kinetic energy of photoelectrons (in eV) emitted on shining light of wavelength 6.2×10^{-8} m on metal surface. The work function of metal is 0.1 eV. *(AI 1992)*

4. What is meant by the work function of a metal? Discuss, how the value of work function influences the kinetic energy of the electrons liberated by photoelectric emission.

(Delhi 1993C)

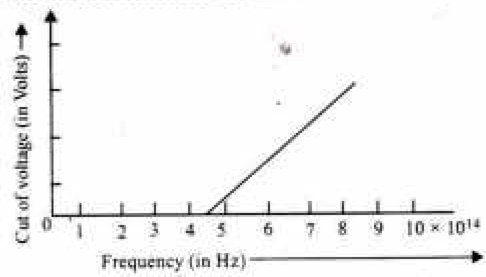
5. What is photoelectric effect? Explain the effect of increase of (i) frequency (ii) intensity of incident radiation on photoelectrons emitted by a photo tube. *(AI 1994)*

6. What is photoelectric effect? Why it cannot be explained on the basis of wave nature of light? *(Delhi 1994)*

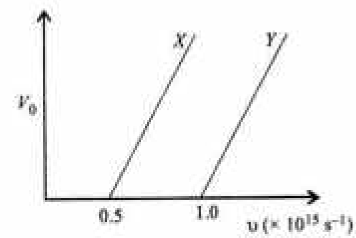
7. If a photoemission surface has a threshold frequency of 4.6×10^{14} Hz, calculate the energy of the photon in eV.

(Delhi 1994C)

8. For photoelectric effect in sodium, the figure shows the plot of cut off voltage versus frequency of incident radiation. Calculate
   (i) the threshold frequency
   (ii) the work function for sodium *(Delhi 1995)*



9. The following graph shows the variation of stopping potential V_0 with the frequency υ of the incident radiation for two photosensitive metals X and Y:

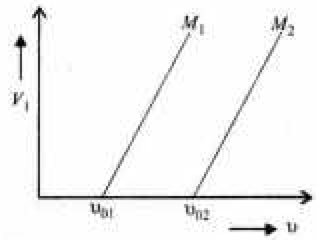


   (i) Which of the metals has larger threshold wavelength? Give reason.
   (ii) Explain, given reason, which metal gives out electrons, having largest kinetic energy, for the same wavelength of the incident radiation.
   (iii) If the distance between the light source and metal X is halved, how will the kinetic energy of electrons emitted from it change? Give reason.
   (iv) If the distance between the light source and metal Y is doubled, how will the stopping potential change?

(AI 2008)

10. The given graphs show the variation of the stopping potential V_s with the frequency (υ) of the incident radiations for two different photosensitive materials M_1 and M_2.
   (i) What are the values of work functions for M_1 and M_2?
   (ii) The values of the stopping potential for M_1 and M_2 for a frequency υ_3 (> V_{02}) of the incident radiations are V_1 and V_2

respectively. Show that the slope of the lines equals $\frac{V_1 - V_2}{\upsilon_{02} - \upsilon_{01}}$



(CBSE sample paper 2007)

11. Define the following terms for a given photosensitive surface.
(i) Threshold wavelength
(ii) Work function. *(Delhi 2007C)*

12. Write Einstein's photoelectric equation in terms of the stopping potential and the threshold frequency for a given photosensitive material. Draw a plot showing the variation of stopping potential vs the frequency of incident radiation. *(AI 2008C)*

13. Radiations of frequency 10^{15} Hz are incident on two photosensitive surfaces A and B. Following observations are recorded.
Surface A : No photo-emission takes place.
Surface B : Photo-emission takes place but photo-electrons have zero energy. Explain the above observations on the basis of Einstein's photoelectric equation. How will the observation with surface B change when the wavelength of incident radiation is decreased? *(Delhi 2007)*

14. Draw a graph to show the variation of stopping potential with frequency of radiations incident on a metal plate. How can the value of Planck's constant be determined from this graph. *(AI 1995)*
What information can be obtained from the value of the intercept on the potential axis? *(AI 2006)*

15. If we go on increasing the wavelength of light incident on a metal surface, what changes in the number of electrons and energy take place. *(Delhi 1995)*

16. Draw the graphs showing the variation of photoelectric current with anode potential of a photocell for (*i*) the same frequencies but different intensities $I_1 > I_2 > I_3$ of incident radiation, (*ii*) the same intensity but different frequencies $\upsilon_1 > \upsilon_2 > \upsilon_3$ of incident radiation. Explain why the saturation current is independent of the anode potential. *(AI 2006C)*

17. Radiations of frequency 10^{15} Hz is incident on two photosensitive surfaces P and Q. Following observations are recorded :
(i) Surface P : No photo emission occurs
(ii) Surface Q : Photoemission occurs but photoelectrons have zero kinetic energy.
Based on Einstein's photoelectric equation, explain the two observations. *(Delhi 1995C)*

18. Is photoelectric emission possible for all frequencies of e.m. waves? Give reason for your answer. *(Delhi 1996C)*

19. Draw a graph showing the variation of stopping potential with frequency of incident radiations in relation to photoelectric effect. Deduce an expression for the slope of this graph using Einstein's photoelectric equation. *(AI 1997)*

20. Obtain the expression for the maximum kinetic energy of the electrons emitted from a metal surface in terms of the frequency of the incident radiation and the threshold frequency. *(Delhi 1997C)*

21. Explain laws of photoelectric emission on the basis of Einstein's photoelectric equation.
Write one feature of the photoelectric effect which cannot be explained on the basis of wave theory of light. *(Foreign 2006)*

22. Define the terms 'threshold frequency' and 'stopping potential' for photoelectric effect. Show graphically how the stopping potential, for a given metal, varies with frequency of the incident radiations. Mark threshold frequency on this graph. *(AI 1998)*

23. If the frequency of incident light on a metal surface is doubled for the same intensity, what change would you observe in
(i) K.E. of photoelectrons emitted, (ii) photoelectric current and (iii) stopping potential?
Justify your answer in each case. *(AI 1998C, Delhi 1999)*

24. Two metals X and Y have work functions 2 eV and 5 eV respectively. Which metal will emit electrons, when it is irradiated with light of wavelength 400 nm and why? *(AI 1999)*

25. State the dependence of work function on the kinetic energy of electrons emitted in a photocell. If the intensity of incident radiation is doubled, what changes occur in the stopping potential and the photoelectric current? *(Delhi 2000)*

26. State how in a photocell the work function of the metal depends on the kinetic energy of the emitted electrons. If the frequency of the incident radiation is doubled, what changes occur in the (i) Stopping potential, and (ii) photoelectric current. *(Delhi 2000)*

27. What is meant by work function of a metal? How does the value of work function influence the kinetic energy of electrons, liberate during photoelectric emission. *(Delhi 2000C)*

28. In a plot of photoelectric current versus anode potential, how does
(i) the saturation current vary with anode potential for incident radiations of different frequencies but same intensity?

(ii) the stopping potential vary for incident radiations of different intensities but same frequency?

(iii) photoelectric current vary for different intensities but same frequency of incident radiations?

Justify your answer in each case. *(Delhi 2007)*

29. When a monochromatic yellow coloured light beam is incident on a given photosensitive surface, photo electrons are not ejected, while the same surface gives photoelectrons when exposed to green coloured monochromatic beam of light. What will happen if the same photosensitive surface is exposed to (i) violet and (ii) red coloured monochromatic beam of light. Justify your answer. *(AI 200C)*

30. What is photoelectric effect? Write Einstein's photoelectric equation and use it to explain

(i) independence of maximum energy of emitted photoelectrons from intensity of incident light.

(ii) existence of a threshold frequency for emission of photoelectrons. *(AI 2001C)*

31. A source of light is placed at a distance of 50 cm from the photocell and the cut-off potential is found to be V_0. If the distance between the light source and photocell is made 25 cm, what will be the new cut-off potential? Justify your answer. *(Delhi 2001C)*

32. For a photosensitive surface, threshold wavelength is λ_0. Does photoemission occur if the wavelength λ of the incident radiation is (i) more than λ_0 (ii) less than λ_0 ? Justify your answer. *(AI 2001C)*

33. Two metals X and Y when illuminated with appropriate radiations emits photoelectrons. The work function of X is higher than that of Y. Which metal will have higher value of threshold frequency and why? *(AI 2001C)*

34. A source of light of frequency $\upsilon > \upsilon_0$ is placed at 2 m from the cathode of a photo cell. The stopping potential is found to be V_0. If the distance of the light source is halved, state with reason what changes occur in (i) stopping potential, (ii) photoelectric current, and (iii) maximum velocity of photoelectrons emitted. *(Foreign 2001)*

35. The frequency υ of incident radiation is greater than threshold frequency υ_0 in a photocell. How will the stopping potential vary if frequency υ is increased, keeping other factors constant? *(Delhi 2002)*

36. Draw the graphs showing the variation of

(i) number of electrons emitted

(ii) kinetic energy of electrons emitted

(iii) stopping potential of a photocell, with change in frequency of light incident on it. *(Foreign 2002)*

37. The threshold frequency for a certain metal is 3.3×10^{14} Hz. If light of frequency 8.2×10^{14} Hz is incident on the metal, predict the cut-off voltage for the photoelectric emission.

38. Light of frequency 7.2×10^{14} Hz is incident on a metal surface. Electrons with a maximum speed of 6.0×10^5 ms^{-1} are ejected from the surface. What is the threshold frequency for photoemission of electrons?

39. The work function of lithium is 2.3 eV. What does it mean? What is the relation between the work function W and threshold wavelength λ of a metal? *(Delhi 2003)*

40. Explain the functioning of a photocell. Give its two uses. *(AI 1994C)*

41. Red light, however bright, cannot cause emission of electrons from a clean zinc surface. But even week ultraviolet radiations can do so. Why? Draw the variation of maximum kinetic energy of emitted electrons with the frequency of incident radiation on a photosensitive surface. On the graph drawn, what do the following indicate

(i) slope of the graph and

(ii) intercept on energy axis. *(AI 2003C)*

42. Define the term 'work function' of a metal. The threshold frequency of a metal is f_0. When the light of frequency $2f_0$ is incident on the metal plate, the maximum velocity of electrons emitted is v_1. When the frequency of the incident radiation is increased to $5f_0$, the maximum velocity of electrons emitted is v_2. Find the ratio of v_1 to v_2. *(Delhi 2004)*

43. The work function of caesium is 2.14 eV. Find (i) the threshold frequency for caesium, and (ii) the wavelength of incident light if the photo current is brought to zero by a stopping potential of 0.60 V. *(Foreign 2004)*

44. Ultraviolet light of wavelength 2271 Å from a 100 W mercury source irradiates a photocell made of molybdenum metal. If the stopping potential is 1.3 V, estimate the work function of the metal. How would the photocell respond to a high intensity (10^5 Wm^{-2}) red light of wavelength 6328 Å produced by He-Ne laser?

Plot a graph showing the variation of photoelectric current with anode potential for two light beams of same wavelength but different intensity. *(Delhi 2005)*

45. Monochromatic radiation of wavelength 640.2 nm from a neon lamp irradiates photosensitive material made of caesium on tungsten. The stopping voltage is measured to be 0.54 V. The source is replaced by an iron source and its 427.2 nm line irradiates the same photocell. Find the new stopping voltage.

46. The work function of caesium metal is 2.14 eV. When light of frequency 6×10^{14} Hz is incident on the metal surface, photoemission of electrons occurs. What is the

(a) maximum kinetic energy of the emitted electrons.

(b) stopping potential, and

(c) maximum speed of the emitted photoelectrons?

47. (a) Light of wavelength 488 nm is produced by an argon laser which is used in the photoelectric effect. When light from this spectral line is incident on the cathode, the stopping potential of photoelectrons is 0.38 V. Find the work function of the material from which the cathode is made.

(b) When light of frequency 2.4×10^{15} Hz, falls on a photosensitive surface, the retarding potential needed to completely stop the emitted photoelectron, is found to be 6.8 V. What is the work function (in eV) of the given photosensitive surface? *(AI 2007C)*

48. Name the device that converts changes in intensity of illumination into changes in electric current. Give three applications of this device. *(CBSE sample paper)*

49. The ground state energy of hydrogen atom is – 13.6 eV. The photon emitted during the transition of electron from $n = 3$ to $n = 1$ state, is incident on a photosensitive material of unknown work function. The photoelectrons are emitted from the materials with a maximum kinetic energy of 9 eV. Calculate the threshold wavelength of the material used.

(Foreign 2008)

50. The following table gives the values of work function for a few photo sensitive metals.
If each of these metals is exposed to radiations of wavelength 300 nm, which of them will not emit photoelectrons and why?

S. No.	Metal	Work Function (eV)
1.	Na	1.92
2.	K	2.15
3.	Mo	4.17

(CBSE sample paper 2007)

51. The work function, for a given photo sensitive surface, equals 2.5 eV. When light of frequency υ, falls on this surface, the emitted photoelectrons are completely stopped by applying a retarding potential of 4.1 V. What is the value of υ?

(AI 2007C)

52. By how much would the stopping potential for a given photosensitive surface go up if the frequency of the incident radiations were to be increased from 4×10^{15} Hz to 8×10^{15} Hz ?

53. 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.

(AI 2010)

54. 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.

(AI 2012)

55. Write Einstein's photoelectric equation and point out any two characteristic properties of photons on which this equation is based. Briefly explain the three observed features which can be explained by this equation.

(AI 2013)

56. (a) Why photoelectric effect cannot be explained on the basis of wave nature of light?

(b) Write the basic features of photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based.

(Delhi 2013)

57. An electron microscope uses electrons accelerated by a voltage of 50 kV. Determine the de-Broglie wavelength associated with the electrons. Taking other factors, such as numerical aperture etc. to be same, how does the resolving power of an electron microscope compare with that of an optical microscope which uses yellow light?

(AI 2014)

58. (i) Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W. Estimate the number of photons emitted per second on an average by the source.

(ii) Draw a plot showing the variation of photoelectric current versus the intensity of incident radiation on a given photosensitive surface.

(Delhi 2014)

59. (i) Monochromatic light of frequency 5.0×10^{14} Hz is produced by a laser. The power emitted is 3.0×10^{-3} W. Estimate the number of photons emitted per second on an average by the source.

(ii) Draw a plot showing the variation of photoelectric current versus the intensity of incident radiation on a given photosensitive surface.

(Delhi 2014)

■ DUAL NATURE OF MATTER AND RADIATION

60. Calculate the de-Broglie wavelength of a photon of momentum 2.55×10^{-22} kg ms^{-1}. *(Delhi 1991C)*

61. A photon and electron have got the same de-Broglie wavelength. Explain which has greater total energy.

(AI 1992C)

62. Show that the de-Broglie wavelength λ of electrons of energy E is given by the relation :

$$\lambda = \frac{h}{\sqrt{2mE}}$$ *(AI 1993)*

63. A proton, an electron and an α-particle have the same kinetic energy. Which of these particles has the largest de-Broglie wavelength? *(Delhi 2007)*

64. An electron and a proton each have a wavelength of 1.00 nm. Find
(a) their momenta
(b) the energy of the photon, and
(c) the kinetic energy of electron.

65. What is the
(a) momentum (b) speed, and
(c) de-Broglie wavelength of an electron with kinetic energy of 120 eV?

66. Calculate the
(a) momentum, and
(b) de-Broglie wavelength of the electrons accelerated through a potential difference of 81 V.

67. A particle is moving three times as fast as an electron. The ratio of the de-Broglie wavelength of the particle to that of the electron is 1.813×10^{-4}. Calculate the particle's mass and identify the particle.

68. Why are de-Broglie waves associated with a moving football not visible?
The wavelength λ of a photon and the de-Broglie wavelength of an electron have the same value. Show that the energy of the photon is $\frac{2\lambda mc}{h}$ times the kinetic energy of the electron, where m, c and h have their usual meanings.
(Delhi 2003)

69. Calculate the de-Broglie wavelength associated with an electron of energy 200 eV. What will be the change in this wavelength if the accelerating potential is increased to four times its earlier value? *(CBSE sample paper)*

70. Compare the energy of an electron of de-Broglie wavelength 1 Å with that of an X-ray photon of the same wavelength.
(CBSE sample paper)

71. A particle of mass M at rest decays into two particles of masses m_1 and m_2 having velocities v_1 and v_2 respectively. Find the ratio of de-Broglie wavelengths of the two particles.
(Foreign 2003)

72. An electron and a photon have the same kinetic energy. Which of the two has greater wavelength? Justify your answer.
Are matter waves electromagnetic? What is the momentum of a photon of frequency υ? *(Delhi 2003C)*

73. X-rays of wavelength λ fall on a photosensitive surface, emitting electrons. Assuming that the work function of the surface can be neglected, prove that the de-Broglie wavelength of electrons emitted will be $\sqrt{\frac{h\lambda}{2mc}}$
(AI 2004)

74. If the potential difference used to accelerate electrons is doubled, by what factor does that de-Broglie wavelength of the electron beam change? *(Foreign 2004)*

75. Mention the significance of Davisson Germer experiment. An α-particle and a proton are accelerated from rest through the same potential difference V. Find the ratio of de-Broglie wavelength associated with them. *(AI 2005)*

76. An electron, α-particle and a proton have the same de-Broglie wavelength. Which of these particles has (i) minimum kinetic energy (ii) maximum kinetic energy, and why? In what way has the wave nature of electron beam exploited in electron microscopes? *(Foreign 2007)*

77. For what kinetic energy of a proton, will be associated de-Broglie wavelength be 16.5 nm? *(AI 2008C)*

78. The wavelength of light from the spectral emission line of sodium is 589 nm. Find the kinetic energy at which
(a) an electron, and
(b) a neutron, would have the same de-Broglie wavelength.

79. An electron and a photon each have a wavelength of 1.00 nm. find
(a) their momenta,
(b) the energy of the photon, and
(c) the kinetic energy of electron.

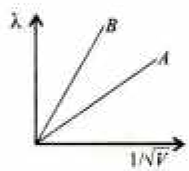
80. Find the de-Broglie wavelength of a neutron, in thermal equilibrium with matter, having an average kinetic energy of $(3/2)\,kT$ at 300 K.

81. What is the de-Broglie wavelength of a nitrogen-molecule in air at 300 K? Assume that the molecule is moving with root-mean-square speed of molecules at this temperature. (Atomic mass of nitrogen = 14.0076 u).

82. A nucleus of mass M initially at rest splits into two fragments of masses $M'/3$ and $2M'/3$ $(M > M')$. Find the ratio of de-Broglie wavelengths of the two fragments.
(CBSE sample paper)

83. Calculate the ratio of de-Broglie wavelengths associated with a deuteron moving with velocity $2v$ and an alpha particle moving with velocity v. *(CBSE sample paper)*

84. Obtain the expression for the wavelength of de-Broglie wave associated with an electron accelerated from rest through a potential difference V. The two lines A and B shown in the graph plot the de-Broglie wavelength (λ) as a function $1/\sqrt{V}$ (V is the accelerating potential) for two particles having the same charge. Which of the two represents the particle of heavier mass?



(Delhi 2004C)

85. Draw Schematic experimental arrangement used by Davisson and Germer to establish the wave nature of electrons. Describe briefly how the de-Broglie relation was experimentally verified in the case of electrons. *(AI 2007)*

Plot a graph showing variation in intensity of the diffracted beam with scattering angle θ for a typical accelerating voltage where the constructive interference in this experiment occurs. *(Foreign 2005)*

86. Draw a schematic diagram of the experimental arrangement used by Davisson and Germer to establish the wave nature of electrons. Express the de-Broglie wavelength λ associated with electron is terms of the accelerating voltage V.
An electron and a proton have the same kinetic energy. Which of the two will have larger wavelength and why? *(AI 2007)*

87. An electromagnetic wave of wavelength λ is incident on a photosensitive surface of negligible work function. If the photo-electrons emitted from this surface have the de-Broglie wavelength λ_1, prove that

$$\lambda = \left(\frac{2mc}{h}\right)\lambda_1^2$$ *(Delhi 2008)*

88. Calculate the de-Broglie wavelength of (i) an electron (in the hydrogen atom) moving with a speed of $\frac{1}{100}$ of the speed of light in vacuum and
(ii) a ball of radius 5 mm and mass 3×10^{-2} kg moving with a speed of 100 ms^{-1}. Hence show that the wave nature of matter is important at the atomic level but is not really relevant at the macroscopic level. *(CBSE sample paper 2007)*

89. A proton and an alpha particle are accelerated through the same potential. Which one of the two has (i) greater value of de-Broglie wavelength associated with it, and (ii) less kinetic energy? Justify your answers. *(Delhi 2009)*

90. An α-particle and a proton are accelerated from rest by the same potential. Find the ratio of their de Broglie wavelengths. *(AI 2010)*

91. An electron and a photon each have a wavelength 1.00 nm. Find
(i) their momenta,
(ii) the energy of the photon and
(iii) the kinetic energy of electron. *(AI 2011)*

92. A proton and a deuteron are accelerated through the same accelerating potential. Which one of the two has
(a) greater value of de-Broglie wavelength associated with it, and
(b) less momentum?
Give reasons to justify your answer. *(Delhi 2014)*

93. A proton and an alpha particle are accelerated through the same potential. Which one of the two has (i) greater value of de Broglie wavelength associated with it and (ii) less kinetic energy. Give reasons to justify your answer. *(Delhi 2014)*

94. A deutron and an alpha particle are accelerated with the same accelerating potential. Which one of the two has
(i) greater value of de-Broglie wavelength, associated with it and
(ii) less kinetic energy? Explain. *(Delhi 2014)*

LONG ANSWER TYPE QUESTIONS (5 MARKS)

1. What is photoelectric effect? Explain experimentally the variation of photoelectric current with
(i) intensity of light
(ii) the potential difference between the plates, and
(iii) the frequency of incident light and hence state the laws of photoelectric emission. *(Foreign 1999)*

2. How does (i) photoelectric current, (ii) kinetic energy of the photoelectrons emitted in a photocell vary if the intensity of the incident radiation is doubled? Light of wavelength 400 nm is incident on the cathode of photocell, the stopping potential recorded is 6 V. If the wavelength of incident light is increased to 600 nm, calculate the new stopping potential. *(AI 2000)*

3. Define the terms : (i) work function, (ii) threshold frequency and (iii) stopping potential, with reference to photoelectric effect.
Calculate the maximum kinetic energy of electrons emitted from a photo sensitive surface of work function 3.2 eV, for the incident radiation of wavelength 300 nm. *(AI 2002)*

4. What is photoelectric effect? Give any two practical applications of this effect. Write Einstein's photoelectric equation and use it to explain the
(i) independence of maximum energy of the emitted photoelectrons from intensity of incident light.
(ii) existence of threshold frequency for a given photosensitive surface. *(CBSE sample paper)*

5. A photon of wavelength 3310 Å falls on a photo cathode and an electron of energy 3×10^{-19} J is ejected. If the wavelength of the incident photon is changed to 5000 Å, the energy of the ejected electrons is 7.91×10^{-20} J. Calculate the value of Planck's constant and threshold wavelength of the photon. *(CBSE sample paper)*

6. On the basis of photon theory, obtain Einstein's photoelectric equation. Use this equation to show that there must exist a threshold frequency for each photosensitive surface.

Radiations of frequencies υ_1 and υ_2 are made to fall in turn, on a photosensitive surface. The stopping potentials required for stopping the most energetic emitted photo electrons in the two cases are V_1 and V_2 respectively. Obtain a formula for calculating Planck's constant and the threshold frequency in terms of these parameters. *(CBSE sample paper)*

7. Obtain the relationship between stopping potential and frequency of incident radiations for photo emission.
   X-rays of wavelength 0.82 Å fall on a metallic surface. Calculate the de-Broglie wavelength of the emitted photo electrons. Neglect the work function of the surface.
   (CBSE sample paper)

8. Derive the expression for the de-Broglie wavelength of an electron moving under a potential difference of V volts.
   Describe Davisson and Germer experiment to establish the wave nature of electrons. Draw a labelled diagram of the aparatus used. *(AI 2003)*

Hints and Solutions

VERY SHORT ANSWER TYPE QUESTIONS

1. $mv = \frac{h}{\lambda} = \frac{h\upsilon}{c}$

2. Zero

3. $h\upsilon = 3.3 \times 10^{-20}$ J or $\upsilon = \frac{3.3\times10^{-20}}{6.6\times10^{-34}} = 5 \times 10^{13}$ Hz

4. Frequency υ.

5. $E = h\upsilon = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{390\times10^{-9}} = 5.08\times10^{-19}$ J

6. $E \propto \frac{1}{\lambda}$, so when λ is doubled, energy of photons becomes halved.

7. $E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{4\times10^{-7}} = 4.95\times10^{-19}$ J

8. Photoelectric effect.

9. $\frac{1}{2}mv^2 = h\upsilon - W_0 = \frac{hc}{\lambda} - W_0$

So, if λ of incident light is decreased, energy $h\upsilon$ of photon increases and hence K.E. and velocity of photoelectron emitted also increases.

10. No effect.

11. $E = \frac{hc}{\lambda}$, so when λ is doubled, energy of photon gets halved.

12. $\frac{1}{2}mv_{max}^2 = eV_0 = 2$ eV

13. Because frequency of light is less than the threshold frequency of wooden table.

14. $\frac{1}{2}mv_{max}^2 = eV_0$ or $eV_0 = 5$ eV

So, $V_0 = 5$ V

15. $\frac{1}{2}mv_{max}^2 = h\upsilon - W_0$

So, larger the work function W_0 of a metal, smaller is the maximum K.E. with which photoelectrons are emitted with same incident light.

16. $\frac{1}{2}mv_{max}^2 = h(\upsilon - \upsilon_0)$

or $eV_0 = h(\upsilon - \upsilon_0)$

So, if frequency υ increased, then stopping potential V_0 also increases.

17. No effect

18. $W_0 = h\upsilon_0 = \frac{hc}{\lambda_0}$

So metal B of higher work function 4 eV has lower threshold wavelength λ_0.

19. $W_0 = h\upsilon_0$

So metal B of larger work function 6 eV has larger threshold frequency υ_0.

20. No effect

22. $\frac{1}{2}mv_{max}^2 = h\upsilon_1 - W_1 = h\upsilon_2 - W_2$

or $h(\upsilon_1 - \upsilon_2) = W_1 - W_2$

or $h(\upsilon_1 - \upsilon_2) =$ positive [$W_1 > W_2$]

or $\upsilon_1 - \upsilon_2 =$ positive

so $\upsilon_1 > \upsilon_2$

23. No

24. $\frac{1}{2}mv_{max}^2 = 4$ eV or $eV_0 = 4$ eV or $V_0 = 4$ volts

25. $\frac{1}{2}mv_{max}^2 = h\upsilon - W_0 = \frac{hc}{\lambda} - W_0$

So, if λ of incident light is decreased, energy $h\upsilon$ of photoelectrons increases and velocity of photoelectrons also increases.

26. Planck's constant h.

27. $\frac{h}{e} = 4.12\times10^{-15}$ or $h = 4.02\times10^{-15}e$

or $h = 4.12\times10^{-15}\times1.6\times10^{-19}$

or $h = 6.6\times10^{-34}$ Js

32. (1, 3) and (2, 4).

[As photoelectric saturation current for them is same, so incident radiations on them are of same intensity, however their stopping potential are different, so they correspond to different materials].

33. $KE_{max} = eV_0 = 1.5$ eV

34. a and b

35. $\frac{1}{2}mv_{max}^2 = 3$ eV

or $eV_0 = 3$ eV

or $V_0 = 3$ V.

36. $KE_{max} = eV_0 = e \times 2$ V

or $KE_{max} = 2$ eV

37. Since the value of stopping potential for the pair of curves (1 and 2) and (3 and 4) are the same hence curves 1 and 2 correspond to similar materials while curves 3 and 4 represent different materials.
The pairs of curves (1 and 3) and (2 and 4) correspond to different materials but same intensity of incident radiation as the saturation current depend upon intensity and not on material.

38. The amount of light energy/photon energy, incident per unit area per unit time is called intensity of radiation.
SI Unit : Wm^{-2} or $Jm^{-2}s^{-1}$

39. $\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{3 \times 2} = 1.1 \times 10^{-34}\,m$

40. $\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{2 \times 1} = 3.3 \times 10^{-34}\,m$

41. $\frac{1}{2}mv^2 = qV$

or $\frac{1}{2}mv^2 = 1\,e \times 2000\,V = 2000\,eV$

$= 2000 \times 1.6 \times 10^{-19}\,J$

$= 3.2 \times 10^{-16}\,J$

42. Davisson and Germer experiment.

43. $\lambda = \frac{12.27Å}{\sqrt{V}} = \frac{12.27Å}{\sqrt{10^4}} = 0.1227\,Å$

44. $\lambda = \frac{12.27\,Å}{\sqrt{100}} = 1.227Å$

45. $\frac{\lambda'}{\lambda} = \frac{12.27/\sqrt{4V}}{12.27/\sqrt{V}} = \sqrt{\frac{1}{4}} = \frac{1}{2}$

or $\lambda' = \frac{\lambda}{2}$

48. B represent a particle of smaller mass.

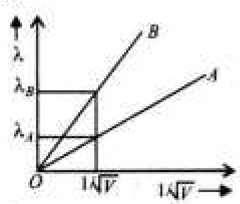
As, $\frac{\lambda_A}{\lambda_B} = \frac{h/\sqrt{2m_A qV}}{h/\sqrt{2m_B qV}}$

or $\frac{\lambda_A}{\lambda_B} = \sqrt{\frac{m_B}{m_A}}$

As $\lambda_A < \lambda_B$

or $\frac{\lambda_A}{\lambda_B} < 1$ or $\sqrt{\frac{m_B}{m_A}} < 1$

or $m_B < m_A$



49. $KE = \frac{p^2}{2m} = \frac{h^2}{2m\lambda^2}$ $\quad [\lambda = \frac{h}{p}$ or $p = \frac{h}{\lambda}]$

$\frac{KE_e}{KE_\alpha} = \frac{h^2/2m_e\lambda^2}{h^2/2m_\alpha\lambda^2} = \frac{m_\alpha}{m_e} > 1$

or $KE_e > KE_\alpha$

50. $\lambda^2 = \frac{h^2}{2mE}$ or $\lambda = \frac{h}{\sqrt{2mE}}$

$\frac{\lambda_e}{\lambda_\alpha} = \frac{h/\sqrt{2m_e E}}{h/\sqrt{2m_\alpha E}} = \sqrt{\frac{m_\alpha}{m_e}} > 1$

or $\lambda_e > \lambda_\alpha$

51. $\lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$ $\quad [\quad KE = qV]$

$\frac{\lambda_\alpha}{\lambda_p} = \frac{h/\sqrt{2m_\alpha qV}}{h/\sqrt{2m_p qV}} = \sqrt{\frac{m_p}{m_\alpha}} = \sqrt{\frac{m_p}{4m_p}}$

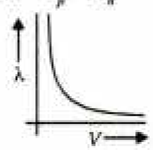
or $\frac{\lambda_\alpha}{\lambda_p} = \frac{1}{2} < 1$ or $\lambda_\alpha < \lambda_p$

52. $E = \frac{h^2}{2m\lambda^2}$

$\frac{E_p}{E_n} = \frac{h^2/2m_p\lambda^2}{h^2/2m_n\lambda^2} = \frac{m_n}{m_p} > 1$

or $E_p > E_n$

53.



54. We know the relation

$\lambda = \frac{h}{p}$,

kinetic energy, $K = \frac{p^2}{2m}$

Then, $\lambda = \frac{h}{\sqrt{2mK}}$

$K_p = K/e$

$m_p \gg m_e$

$\lambda_p \ll \lambda_e$

Hence for same kinetic energy wavelength associated with electron will be greater.

55. $\lambda = \frac{h}{\sqrt{2mqV}}$

SHORT ANSWER TYPE QUESTIONS

1. $E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1}J = \frac{19.8 \times 10^{-26}}{1.6 \times 10^{-19}}\,eV$

$= 1.24 \times 10^{-6}\,eV$

2. $h\upsilon = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{3.5 \times 10^{-7} \times 1.6 \times 10^{-19}} = 3.54\,\,eV$

Since metal B has work function W_0 of 1.9 eV, which is less than 3.54 eV, so metal B will yield photoelectrons.

3. $h\upsilon = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{6.2 \times 10^{-8} \times 1.6 \times 10^{-19}} = 19.96\,eV$

So, $(1/2)mv^2_{max} = h\upsilon - W_0 = 19.96 - 0.1 = 19.86\,eV$

5. (i) On increasing frequency υ of incident radiation, energy of photons increases and hence kinetic energy with which photoelectrons are emitted also increases.

(ii) On increasing intensity of incident radiation, number of photons in incident radiation and hence number of photoelectrons emitted also increases.

6. According to wave nature of light, a light wave cannot provide the sufficient amount of energy to liberate an electron from metallic surface, all it can do is make the atom vibrate about its mean position. Hence wave nature of light cannot explain photoelectric effect.

7. $E = h\upsilon = \dfrac{6.6\times10^{-34}\times4.6\times10^{14}}{1.6\times10^{-19}} = 1.9\text{ eV}$

8. (i) $\upsilon_0 = 4.5\times10^{14}$ Hz

(ii) $W_0 = h\upsilon_0$

$= \dfrac{6.6\times10^{-34}\times4.5\times10^{14}\text{ eV}}{1.6\times10^{-19}}\text{ eV} = 1.86\text{ eV}$

9. (i) For X, threshold frequency $\upsilon_x = 0.5\times10^{15}$ Hz

For Y, threshold frequency $\upsilon_y = 1.0\times10^{15}$ Hz

As $\upsilon_x < \upsilon_y$ or $\dfrac{c}{\lambda_x} < \dfrac{c}{\lambda_y}$

or $\lambda_y < \lambda_x$

So, metal X has largest threshold wavelength.

(ii) As $\dfrac{1}{2}mv_{max}^2 = h\upsilon - W_0 = \dfrac{hc}{\lambda} - h\upsilon_0$

For same wavelength of incident radiation, metal X gives out photoelectrons of larger kinetic energy, because it has smaller threshold frequency or smaller work function W_0.

(iii) If the distance between the light source and metal X is halved then the intensity of light falling on metal X will increase, however there will be no change in kinetic energy of electrons emitted, because it is independent of changes in intensity of incident radiations.

(iv) If the distance between light source and metal Y is doubled, then the intensity of light falling on metal Y will decrease, however there will be no change in kinetic energy of electrons emitted or no change in stopping potential V_0 as it is independent of changes in intensity of incident radiations.

10. (i) Work function for M_1 is $W_{01} = h\upsilon_{01}$

and for M_2 is $W_{02} = h\upsilon_{02}$

(ii) For metal M_1, $eV_1 = h\upsilon_3 - h\upsilon_{01}$

or $eV_1 + h\upsilon_{01} = h\upsilon_3$ ...(i)

For metal M_2, $eV_2 = h\upsilon_3 - h\upsilon_{01}$

or $eV_2 + h\upsilon_{02} = h\upsilon_3$ ... (ii)

By equations (i) and (ii)

$eV_1 + h\upsilon_{01} = eV_2 + h\upsilon_{03}$

or $e(V_1 - V_2) = h(\upsilon_{03} - \upsilon_{01})$

or $\dfrac{h}{e} = \dfrac{(V_1 - V_2)}{(\upsilon_{03} - \upsilon_{01})}$

or Slope $= \dfrac{V_1 - V_2}{\upsilon_{03} - \upsilon_{01}}$

13. By Einstein's photoelectric equation $\dfrac{1}{2}mv_{max}^2 = h\upsilon - W_0$

So, no emission of photo-electrons takes place at surface A, because the work function W_0 of surface A is more than the energy $h\upsilon$ of photons of incident radiations of frequency 10^{15} Hz.

However, for surface B, photo emission takes place but photoelectrons have zero energy,

So, $\dfrac{1}{2}mv_{max}^2 = 0$ or $h\upsilon - W_0 = 0$

$W_0 = h\upsilon$

or $hv_0 = h\upsilon$

or $\upsilon_0 = \upsilon = 10^{15}$ Hz

i.e. 10^{15} Hz is the threshold frequency for surface B.

If the wavelength of incident radiation is decreased, then the frequency and hence energy $h\upsilon$ of photons of incident radiations will increase, due to which photo electrons emitted will have same kinetic energy

(*i.e.* $\dfrac{1}{2}mv_{max}^2 > 0$)

15. $\dfrac{1}{2}mv_{max}^2 = h\upsilon - W_0 = \dfrac{hc}{\lambda} - W_0$

So, on increasing the wavelength of incident light, energy of photons decreases whereas the number of photoelectrons emitted remain same.

16. When all the photoelectrons emitted by emitting electrode E reach collecting electrode C, then photoelectric current in the circuit is maximum and constant called saturation current, which then becomes independent of the anode potential.

17. (i) For surface P, threshold frequency υ_0 is more than 10^{15} Hz. So, the energy of photon is less than work function W_0 of metal surface P and hence no photoemission occurs.

(ii) When kinetic energy of photoelectron is zero, then

$\dfrac{1}{2}mv_{max}^2 = 0$ or $h\upsilon - h\upsilon_0 = 0$

or $\upsilon = \upsilon_0$

i.e., for surface Q, 10^{15} Hz is the threshold frequency which is equal to the frequency of incident radiation and hence photoelectron emitted has no kinetic energy.

18. No, for photoelectric emission energy of photon must be greater than or equal to work function of metal surface. So photoelectric emission is possible only for frequencies larger than or equal to threshold frequency of metallic surface.

21. According to wave theory, greater the intensity of radiation greater are the amplitudes of electric and magnetic fields and

hence greater is the energy density of the wave. So the maximum kinetic energy of the photoelectron emitted must depend on intensity of incident light, however practically it does not happens. So, independence of maximum kinetic energy of photoelectron emitted on intensity cannot be explained using wave theory of light.

23. $\frac{1}{2}mv_{max}^2 = h\upsilon - W_0$ or $eV_0 = h\upsilon - W_0$

So, when frequency of incident light on a metal surface is doubled for same intensity, then

(i) K.E. of photoelectrons increases as it is proportional to frequency of incident radiation.

(ii) Photoelectric current remains same because the intensity remains same.

(iii) Stopping potential V_0 increases as K.E. of photoelectrons increases.

24. $h\upsilon = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^8}{400\times10^{-9}\times1.6\times10^{-19}} = 3.1$ eV

So metal X have work function 2 eV which is less than energy 3.1 eV of photon, so metal X will emit photoelectrons.

25. Work function W_0 is independent of kinetic energy of photoelectrons emitted. If intensity of incident radiation is doubled, then photoelectric current gets doubled but stopping potential remains same.

26. If frequency of incident radiation is doubled, then (i) stopping potential increases but (ii) photoelectric current remains same.

29. For given surface, frequency of green coloured beam is threshold frequency.

If the surface is exposed to (i) violet light of frequency more than that of green light or υ_0, photoelectrons are emitted. (ii) red light of frequency less than that of green light or υ_0, photoelectrons are not emitted.

31. Same. Because when distance is reduced between light source and photocell, intensity of incident light increases, although frequency remains the same. So maximum K.E. and hence cut-off potential remains same as it depends only on frequency of incident light.

32. $\upsilon = \frac{c}{\lambda}$

(i) If $\lambda > \lambda_0$, then $\upsilon < \upsilon_0$. So no photoemission will occur.

(ii) If $\lambda < \lambda_0$, then $\upsilon > \upsilon_0$. So photoemission will occur.

33. $W_0 = h\upsilon_0$

So metal X of larger work function W_0 has larger threshold frequency υ_0.

34. When distance is halved, intensity of incident light increases but frequency remains same.

(i) As stopping potential $V_0 = \frac{h}{e}(\upsilon - \upsilon_0)$, so it remains same.

(ii) As photoelectric current is proportional to intensity of incident light, so it increases.

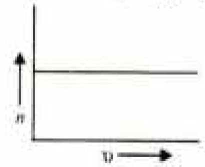
(iii) As $\frac{1}{2}mv_{max}^2 = h(\upsilon - \upsilon_0)$, so maximum velocity of photoelectrons emitted remains same.

35. $\frac{1}{2}mv_{max}^2 = h(\upsilon - \upsilon_0)$

or $eV_0 = h(\upsilon - \upsilon_0)$

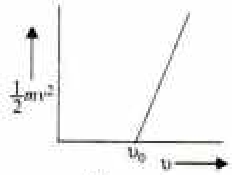
So, if υ increases, stopping potential V_0 also increases.

36. (i)

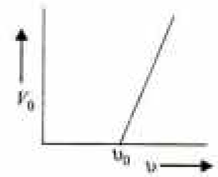


As number n of photoelectrons emitted is independent of frequency υ of incident light.

(ii)



(iii)



37. $\upsilon_0 = 3.3\times10^{14}$ Hz, $\upsilon = 8.2\times10^{14}$ Hz

$eV_0 = h(\upsilon - \upsilon_0)$

or $V_0 = \frac{6.6\times10^{-34}}{1.6\times10^{-19}}(8.2-3.3)\times10^{14}$

$V_0 = 2$ V

38. $\upsilon = 7.2\times10^{14}$ Hz, $v_{max} = 6.0\times10^5$ m s^{-1}

$\frac{1}{2}mv_{max}^2 = h(\upsilon - \upsilon_0)$

$\frac{1}{2}\times\frac{9.1\times10^{-31}\times(6\times10^5)^2}{6.6\times10^{-34}} = 7.2\times10^{14} - \upsilon_0$

$\upsilon_0 = 4.72\times10^{14}$ Hz

39. $W_0 = h\upsilon_0 = \frac{hc}{\lambda_0}$

42. $\frac{\frac{1}{2}mv_2^2}{\frac{1}{2}mv_1^2} = \frac{h[5f_0 - f_0]}{h[2f_0 - f_0]} = \frac{h\cdot4f_0}{h\cdot f_0} = \frac{4}{1}$ or $\frac{v_2^2}{v_1^2} = \frac{4}{1}$ or $v_2 = 2v_1$

43. (i) $W_0 = h\upsilon_0$ or $\upsilon_0 = \frac{W_0}{h} = \frac{2.14\times1.6\times10^{-19}}{6.6\times10^{-34}} = 5.2\times10^{14}$ Hz

(ii) $\frac{1}{2}mv_{max}^2 = eV_0 = e\times0.6$ V

$= 0.6$ eV $= 0.6\times1.6\times10^{-19}$ J $= 9.6\times10^{-20}$ J

$\frac{1}{2}mv_{max}^2 = \frac{hc}{\lambda} - W_0$ or $\frac{hc}{\lambda} = \frac{1}{2}mv_{max}^2 + W_0$

or $\lambda = \frac{hc}{\frac{1}{2}mv_{max}^2 + W_0} = \frac{6.6\times10^{-34}\times3\times10^8}{9.6\times10^{-20} + 34.24\times10^{-20}}$

or $\lambda = 4.5\times10^{-7}$ m

44. (i) $\lambda = 2271\times10^{-10}$ m

$\therefore\ h\upsilon = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{2271\times10^{-10}\times1.6\times10^{-19}}$

or $h\upsilon = 5.5$ eV

$$\frac{1}{2}mv_{max}^2 = eV_0 = e\times1.3\text{ V} = 1.3\text{ eV}$$

As $\frac{1}{2}mv_{max}^2 = h\upsilon - W_0$

or $W_0 = h\upsilon - \frac{1}{2}mv_{max}^2 = 5.5 - 1.3 = 4.2$ eV

(ii) Energy of photon of red light is

$$h\upsilon = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{6328\times10^{-10}\times1.6\times10^{-19}}\text{eV} = 1.96\text{ eV}$$

As ($h\upsilon$ =1.96 eV) < (W_0= 4.2 eV), so photocell will not respond to red light, however high its intensity may be.

45. $\frac{1}{2}mv_{max}^2 = eV_0 = \frac{hc}{\lambda} - W_0$ or $W_0 = \frac{hc}{\lambda} - eV_0$

$\therefore\ \frac{hc}{\lambda_1} - eV_1 = \frac{hc}{\lambda_2} - eV_2$ or $V_2 = \frac{hc}{e}(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}) + V_1$

or $V_2 = \frac{6.6\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times10^{-9}}[\frac{1}{427.2} - \frac{1}{640.2}] + 0.54$

or $V_2 = 12.375\times10^2[\frac{640.2-427.2}{427.2\times640.2}] + 0.54$

or $V_2 = 12.375\times10^2\times\frac{213}{427.2\times640.2} + 0.54$

or $V_2 = 1.5$ volts

46. (a) $\frac{1}{2}mv_{max}^2 = h\upsilon - W_0 = [\frac{6.6\times10^{-34}\times6\times10^{14}}{1.6\times10^{-19}} - 2.14]$ eV

or $\frac{1}{2}mv_{max}^2 = 0.34$ eV

(b) $eV_0 = \frac{1}{2}mv_{max}^2$ or $eV_0 = 0.34$ eV or $V_0 = 0.34$ V

(c) $\frac{1}{2}mv_{max}^2 = 0.34$ eV$= 0.34\times1.6\times10^{-19}$ J

$$v_{max}^2 = \frac{2\times0.34\times1.6\times10^{-19}}{9.1\times10^{-31}}$$

$v_{max} = 0.345\times10^6$ m/s = 345 km/s

47. (a) $\frac{1}{2}mv_{max}^2 = eV_0 = \frac{hc}{\lambda} - W_0$

or $W_0 = \frac{hc}{\lambda} - eV_0 = \frac{6.6\times10^{-34}\times3\times10^{8}}{488\times10^{-9}\times1.6\times10^{-19}}$ eV $-$ 0.38 eV

or $W_0 = (2.54 - 0.38)$ eV = 2.16 eV

(b) $\upsilon = 2.4\times10^{15}$ Hz, V_0= 6.8 V or eV_0 = 6.8 eV

As, $eV_0 = h\upsilon - W_0$

or $W_0 = h\upsilon - eV_0 = \frac{6.6\times10^{-34}\times2.4\times10^{15}\text{J}}{1.6\times10^{-19}}$eV $-$ 6.8 eV

or $W_0 = (9.9 - 6.8)$ eV = 3.1 eV

49. Energy of photon emitted during transition of electron in an atom is

$$h\upsilon = E_i - E_f = -\frac{13.6}{n_{i^2}} - \left(-\frac{13.6}{n_{f^2}}\right)$$

$$h\upsilon = \frac{-13.6}{3^2} + \frac{13.6}{1^2} = -1.51 + 13.6$$

or $h\upsilon = 12.09$ eV ......(i)

By Einstein's photoelectric equation

$\frac{1}{2}mv_{max}^2 = h\upsilon - W_0$

or $W_0 = h\upsilon - \frac{1}{2}mv_{max}^2 = 12.09 - 9$

or $\frac{hc}{\lambda_0} = 3.09\text{ eV} = 3.09\times1.6\times10^{-19}$ J

or $\lambda_0 = \frac{hc}{3.09\times1.6\times10^{-19}}$ or $\lambda_0 = \frac{6.6\times10^{-34}\times3\times10^{8}}{3.09\times1.6\times10^{-19}}$

or $\lambda_0 = 4\times10^{-7}$ m = 4000 Å

50. Energy of photon of radiation of wavelength 300 nm is

$$h\upsilon = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{300\times10^{-9}\text{ m}}\text{J}$$

or $h\upsilon = \frac{6.6\times10^{-19}}{1.6\times10^{-19}}$ eV = 4.125 eV

As, the work function W_0=4.17 eV of Mo is larger than the energy $h\upsilon$ = 4.125 eV of incident photon, so metal Mo will not emit photoelectrons.

51. $W_0 = 2.5\ eV$, $V_0 = 4.1$ V or eV_0=4.1 eV

As, $eV_0 = h\upsilon - W_0$

or $h\upsilon = eV_0 + W_0 = 4.1\ eV + 2.5\ eV$

or $h\upsilon = 6.6\ eV = 6.6\times1.6\times10^{-19}$ J

or $\upsilon = \frac{6.6\times1.6\times10^{-19}\text{ J}}{h}$

or $\upsilon = \frac{6.6\times1.6\times10^{-19}\text{ J}}{6.6\times10^{-34}\text{ J s}}$

or $\upsilon = 1.6\times10^{15}$ Hz

52. $eV_0 = h(\upsilon - \upsilon_0)$ or $V_0 = \frac{h}{e}(\upsilon - \upsilon_0)$

For incident lights of frequencies υ' and υ

$$V_0' - V_0 = \frac{h}{e}(\upsilon' - \upsilon_0 - \upsilon + \upsilon_0) = \frac{h}{e}(\upsilon' - \upsilon)$$

or $V_0' - V_0 = \frac{6.6\times10^{-34}}{1.6\times10^{-19}}(8-4)\times10^{15} = 16$ V

53. Einstein's photoelectric equation is given below.

$$h\upsilon = \frac{1}{2}mv_{max}^2 + W_0$$

where υ = frequency of incident radiation

$\frac{1}{2}mv_{max}^2$ = maximum kinetic energy of an electron emitted

W_0 = work function of the target metal

Three salient features observed are

(i) Below threshold frequency υ_0 corresponding to W_0, no emission of photoelectrons takes place.

(ii) As energy of a photon depends on the frequency of light, so the maximum kinetic energy with which photoelectron is emitted depends only on the energy of photon or on the frequency of incident radiation.

(ii) As the number of photons in light depend on its intensity, and one photon liberates one photoelectron, so number of photoelectrons emitted depend only on the intensity of incident light.

54. Cut-off Voltage : The minimum negative V_0 potential applied to the plate or anode, (A) for which the photoelectric current just becomes zero.

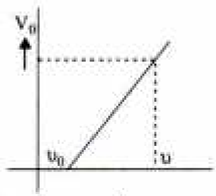
Threshold frequency : The minimum frequency of incident radiation which is required to have photo electrons emitted from a given metal surface.

As per Einstein's photoelectric equation

$eV_0 = h\upsilon - h\upsilon_0$, for $\upsilon > \upsilon_0$

$$V_0 = \frac{h}{e}(\upsilon - \upsilon_0)$$

Hence the intercept, on the y-axis, gives υ_0 (one can read V_0, for any υ, from the graph)



55. Einstein's photoelectric equation

$$K_{max} = \frac{1}{2}mv_{max}^2 = h\upsilon - h\upsilon_0$$

Characteristics properties : (Any two)

(i) In the interaction of photons with free electrons, the entire energy of photon is absorbed.

(ii) Energy of photon is directly proportional to frequency.

(iii) In photon electron collision, the total energy and momentum remain constant.

Three features: (Any three)

(i) There is no time lag between the incidence of radiation and emission of electrons from the surface.

(ii) The number of electrons emitted per second, *i.e.*, photoelectric current, is directly proportional to the intensity of the incident radiations.

(iii) There is a minimum frequency of the incident radiations below which emission of electrons cannot occur.

(iv) The maximum KE of electrons increases proportionally, with increase in the frequency of incident radiations.

57. $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$ or $\lambda = \frac{12.27}{\sqrt{V}}$ Å

$$\therefore \quad \lambda = \frac{6.63\times10^{-34}}{\sqrt{(2\times9.1\times10^{-31}\times1.6\times10^{-19}\times50\times10^{3})}}$$

$\lambda = 5.33 \times 10^{-12}$ m

The resolving power of an electron microscope is much better than that of optical microscope.

Resolving power of a microscope:

$$R.P. = \frac{2\mu\sin\theta}{\lambda}$$

This formula suggests that to improve resolution, we have to use shorter wavelength and media with large indices of refraction. For an electron microscope, μ is equal to 1 (vacuum).

For an electron microscope, the electrons are accelerated through a 60,000 V potential difference. Thus the wavelength of electrons is found to be 10^{-12} m.

As, λ is very small (approximately 10^{-5} times smaller) for electron microscope than an optical microscope which uses yellow light of wavelength (5700 Å to 5900 Å). Hence, the resolving power of an electron microscope is much greater than that of optical microscope.

58. (i) Given,

$\upsilon = 6.0 \times 10^{14}$ Hz

$P = 2.0 \times 10^{-3}$ W

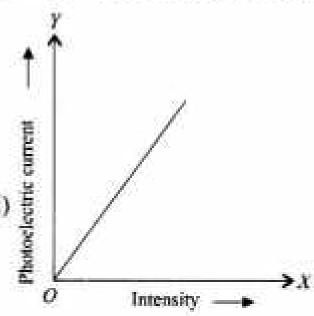
Let n is the number of photons emitted by the source per second.

$$n = \frac{P}{E} = \frac{P}{h\upsilon}$$

$$= \frac{2\times10^{-3}}{6.63\times10^{-34}\times(6.0\times10^{14})} = 0.0502 \times 10^{17}$$

$= 5 \times 10^{15}$ photons per second.

(ii)



60. $\lambda = \frac{h}{p} = \frac{6.6\times10^{-34}}{2.55\times10^{-22}} = 2.59\times10^{-12}$ m

61. $\lambda = \frac{h}{mv}$. Due to large mass m of football its de-Broglie wavelength is negligible.

Energy of photon $E_p = h\upsilon = \frac{hc}{\lambda}$

Energy of electron $E_e = \frac{1}{2}mv^2 = \frac{1}{2}m\left[\frac{h}{\lambda m}\right]^2$

$= \frac{h^2}{2\lambda^2 m}$

$\frac{E_p}{E_e} = \frac{hc/\lambda}{h^2/2\lambda^2 m} = \frac{2\lambda mc}{h}$

or $\frac{E_p}{E_e} > 1$ or $E_p > E_e$

i.e. photon has greater total energy.

62. $E = \frac{1}{2}mv^2$ or $v^2 = \frac{2E}{m}$

or $v = \sqrt{\frac{2E}{m}}$ or $mv = \sqrt{2mE}$

$\therefore$ de-Broglie wavelength $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$

63. As $\lambda = \frac{h}{mv}$

So, α-particles of largest mass has shortest de-Broglie wavelength.

64. (a) $mv = \frac{h}{\lambda} = \frac{6.6\times10^{-34}}{1\times10^{-9}} = 6.6\times10^{-25}$ kgm/s

(b) $E_p = h\upsilon = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^8}{1\times10^{-9}\times1.6\times10^{-19}} = 1.24$ keV

(c) $E_e = \frac{1}{2}mv^2 = \frac{h^2}{2m\lambda^2}$

$= \frac{(6.6\times10^{-34})^2}{2\times9\times10^{-31}\times(1\times10^{-9})^2\times1.6\times10^{-19}} = 1.5$ eV

65. (a) $mv = 9.1\times10^{-31}\times 6.5\times10^6 = 5.92\times10^{-24}$ kg m/s

(b) $\frac{1}{2}mv^2 = 120\times1.6\times10^{-19}$ J

$v^2 = \frac{2\times192\times10^{-19}}{9.1\times10^{-31}}$ or $v = 6.5\times10^6$ m/s

(c) $\lambda = \frac{h}{mv} = \frac{6.6\times10^{-34}}{5.92\times10^{-24}} = 1.12$ Å

66. (a) $mv = \frac{h}{\lambda} = \frac{6.6\times10^{-34}}{1.36\times10^{-10}} = 4.86\times10^{-24}$ kg m/s

(b) $\lambda = \frac{12.27Å}{\sqrt{V}} = \frac{12.27Å}{\sqrt{81}} = 1.36$ Å

67. $\frac{\lambda_p}{\lambda_e} = \frac{h/m_p v_p}{h/m_e v_e}$

or $1.813\times10^{-4} = \frac{m_e}{m_p}\times\frac{v_e}{3v_e}$

or $m_p = \frac{m_e}{1.813\times10^{-4}\times3}$

$m_p = \frac{9.1\times10^{-31}}{5.439\times10^{-4}}$

m_p=1.675×10^{-27} kg particle is neutron.

69. $E_e = \frac{h^2}{2m\lambda^2}$

or $\lambda^2 = \frac{(6.6\times10^{-34})^2}{2\times9.1\times10^{-31}\times200\times1.6\times10^{-19}}$

$\lambda = 0.87$ Å

As $\lambda = \frac{12.27Å}{\sqrt{V}}$, so if accelerating potential V is increased to four times, wavelength will become half of its initial value.

70. $\frac{E_e}{E_p} = \frac{h}{2\lambda mc} = \frac{6.6\times10^{-34}}{2\times10^{-19}\times9.1\times10^{-31}\times3\times10^8}$

or $\frac{E_e}{E_p} = \frac{1}{82.7}$

71. By law of conservation of momentum

$M\times0 = m_1v_1 + m_2v_2$ or $m_1v_1 = -m_2v_2$

or $m_1v_1 = m_2v_2$

$\therefore$ $\frac{\lambda_1}{\lambda_2} = \frac{h/m_1v_1}{h/m_2v_2} = \frac{1}{1}$

72. $\frac{1}{2}m_p v_p^2 = \frac{1}{2}m_e v_e^2$

or $\frac{v_p}{v_e} = \sqrt{\frac{m_e}{m_p}}$

$\frac{\lambda_e}{\lambda_p} = \frac{h/m_e v_e}{h/m_p v_p} = \frac{m_p v_p}{m_e v_e} = \frac{m_p}{m_e}\sqrt{\frac{m_e}{m_p}}$

or $\frac{\lambda_e}{\lambda_p} = \sqrt{\frac{m_p}{m_e}} > 1$ [$m_p > m_e$]

or $\lambda_e > \lambda_p$

i.e., electron has greater wavelength.

73. $\frac{1}{2}mv^2 = h\upsilon = \frac{hc}{\lambda}$

or $v^2 = \frac{2hc}{\lambda m}$ or $v = \sqrt{\frac{2hc}{\lambda m}}$

de-Broglie wavelength of electron is

$\lambda' = \frac{h}{mv} = \frac{h}{m}\sqrt{\frac{\lambda m}{2hc}}$

or $\lambda' = \sqrt{\frac{h^2}{m^2}\frac{\lambda m}{2hc}} = \sqrt{\frac{h\lambda}{2mc}}$

74. $\lambda = \frac{12.27}{\sqrt{V}}$ Å

So if V is doubled λ becomes $1/\sqrt{2}$ times.

75. $\frac{\frac{1}{2}m_\alpha v_\alpha^2}{\frac{1}{2}m_p v_p^2} = \frac{2eV}{eV}$ [$q_\alpha = 2e$ and $q_p = e$]

or $\frac{v_\alpha}{v_p} = \sqrt{\frac{2m_p}{m_\alpha}} = \sqrt{\frac{2m_p}{4m_p}} = \frac{1}{\sqrt{2}}$

$\frac{\lambda_\alpha}{\lambda_p} = \frac{h/m_\alpha v_\alpha}{h/m_p v_p} = \frac{m_p v_p}{m_\alpha v_\alpha}$

$\frac{\lambda_\alpha}{\lambda_p} = \frac{m_p}{4m_p}\sqrt{2} = \frac{\sqrt{2}}{4}$

76. By de-Broglie's equation $\lambda = \frac{h}{p}$ or $p = \frac{h}{\lambda}$

Now, KE of a particle of de-Broglie wavelength λ is

$E = \frac{p^2}{2m} = \frac{h^2}{2m\lambda^2}$

As, $m_e < m_p < m_\alpha$ and $E \propto \frac{1}{m}$

So, $E_e > E_p > E_\alpha$

(i) α-particle has minimum kinetic energy.

(ii) electron has maximum kinetic energy. An electron accelerated through a potential difference of 50 kV will have a de-Broglie wavelength of 0.0055 nm which is about 10^5 times smaller than that of visible light. This way wave nature of electron helps us to increase the resolving limit upto 0.0055 nm.

77. $E = \frac{h^2}{2m\lambda^2} = \frac{(6.6\times10^{-34})^2}{2\times1.67\times10^{-27}\times(16.5\times10^{-9})^2}$

or $E = 0.048\times10^{-23}\,J = \frac{4.8\times10^{-25}}{1.6\times10^{-19}}$ eV or $E = 3.0\times10^{-6}$ eV

78. (i) $\lambda_e = \frac{h}{m_e v_e}$ or $v_e = \frac{h}{m_e\lambda_e}$

$\therefore \frac{1}{2}m_e v_e^2 = \frac{1}{2}m_e\frac{h^2}{m_e^2\lambda_e^2} = \frac{h^2}{2m_e\lambda_e^2}$

$= \frac{(6.6\times10^{-34})^2}{2\times9.1\times10^{-31}\times(589\times10^{-9})^2}\,J = \frac{6.8\times10^{-25}}{1.6\times10^{-19}}$ eV

$\frac{1}{2}m_e v_e^2 = 4.25\ \mu$ eV

(ii) $\frac{1}{2}m_n v_n^2 = \frac{h^2}{2m_n\lambda_n^2} = \frac{(6.6\times10^{-34})^2}{2\times1.67\times10^{-27}\times(589\times10^{-9})^2}$ J

$= \frac{3.75\times10^{-29}}{1.6\times10^{-19}}$ eV $= 2.34\times10^{-10}$ eV $= 0.234$ n eV

79. (a) $\lambda_e = \frac{h}{m_e v_e}$ or $m_e v_e = \frac{h}{\lambda_e} = \frac{6.6\times10^{-34}}{1\times10^{-9}}$

or $m_e v_e = 6.6\times10^{-25}$ kg ms^{-1}

For photon also $p = h/\lambda = 6.6\times10^{-25}$ kg ms^{-1}

(b) Energy of photon, $E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^8}{1\times10^{-9}}$

or $E = 1.98\times10^{-16}$ J = 1.24 keV

(c) $v_e = \frac{h}{m_e\lambda_e}$

$\therefore$ Kinetic energy of electron is $E = \frac{1}{2}m_e v_e^2$

or $E = \frac{1}{2}m_e\frac{h^2}{m_e^2\lambda_e^2} = \frac{h^2}{m_2\lambda_e^2} = \frac{(6.6\times10^{-34})^2}{2\times9.1\times10^{-31}\times(1\times10^{-9})^2}$ J

or $E = \frac{2.4\times10^{-19}}{1.6\times10^{-19}} = 1.5$ eV

80. $\frac{1}{2}m_n v_n^2 = \frac{3}{2}kT$ or $v_n = \sqrt{\frac{3kT}{m_n}} = \sqrt{\frac{3\times1.38\times10^{-23}\times300}{1.67\times10^{-27}}}$

or $v_n = 2.73\times10^3$ m/s

$\therefore$ de-Broglie wavelength of neutron is

$\lambda_n = \frac{h}{m_n v_n} = \frac{6.6\times10^{-34}}{1.67\times10^{-27}\times2.73\times10^3} = 1.45\times10^{-10}$ m

or $\lambda_n = 0.145$ nm

81. $\frac{1}{2}m_N v_N^2 = \frac{3}{2}kT$ or $v_N = \sqrt{\frac{3kT}{m_N}} = \sqrt{\frac{3\times1.38\times10^{-23}\times300}{14.0076\times1.66\times10^{-27}}}$

or $v_N = 7.31\times10^2$ m/s

$\therefore \lambda_N = \frac{h}{m_N v_N} = \frac{6.6\times10^{-34}}{14.0076\times1.66\times10^{-27}\times7.3\times10^2}$

$= 0.039\times10^{-9}$ m = 0.039 nm

82. By principle of conservation of momentum

$M\times0 = \frac{M'}{3}v_1 + \frac{2M'}{3}v_2$

or $\frac{M'}{3}v_1 = \frac{2M'}{3}v_2$ [Magnitude only]

or $\frac{v_2}{v_1} = \frac{1}{2}$

Ratio of de-Broglie wavelengths is then given by

$\frac{\lambda_1}{\lambda_2} = \frac{h/m_1v_1}{h/m_2v_2} = \frac{m_2v_2}{m_1v_1}$

or $\frac{\lambda_1}{\lambda_2} = \frac{2M'/3}{M'/3}\times\frac{1}{2}$ or $\frac{\lambda_1}{\lambda_2} = 1$

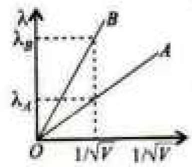
83. $m_d = 2m_p$ and $m_\alpha = 4m_p$

Also $v_d = 2v$ and $v_\alpha = v$

$\therefore$ Ratio of their de-Broglie wavelengths is

$\frac{\lambda_d}{\lambda_\alpha} = \frac{h/m_d v_d}{h/m_\alpha v_\alpha} = \frac{m_\alpha v_\alpha}{m_d v_d} = \frac{4m_p}{2m_p}\times\frac{v}{2v}$ or $\frac{\lambda_d}{\lambda_\alpha} = 1$

84. As $\lambda = \frac{12.27}{\sqrt{V}}$ Å,



So $\lambda \propto \frac{1}{\sqrt{V}}$

At same V, $\lambda_B > \lambda_A$

or $\frac{h}{m_B v_B} > \frac{h}{m_A v_A}$ or $m_A v_A > m_B v_B$

or $m_A\sqrt{\frac{2qV}{m_A}} > m_B\sqrt{\frac{2qV}{m_B}}$ or $\sqrt{m_A} > \sqrt{m_B}$

or $m_A > m_B$

So line A represents particle of heavier mass.

87. $W_0 = 0$, So by Einstein's photoelectric equation

$$\frac{1}{2}mv_{max}^2 = h\upsilon - W_0 = \frac{hc}{\lambda} - 0$$

or $\frac{p^2}{2m} = \frac{hc}{\lambda}$ $\quad [\ p = \frac{h}{\lambda_1}]$

or $\lambda = \left(\frac{2mc}{h}\right)\lambda_1^2$

88. (i) $v = \frac{1}{100}c = \frac{1}{100} \times 3\times10^8$ m/s $= 3\times10^6$ m/s

$$\lambda = \frac{h}{mv} = \frac{6{\cdot}6\times10^{-34}}{9{\cdot}1\times10^{-31}\times3\times10^6}$$

or $\lambda = 0.243\times10^{-9}$ m $= 2.43$ Å ...(1)

(ii) $\lambda' = \frac{h}{m'v'} = \frac{6.6\times10^{-34}}{3\times10^{-2}\times100}$

or $\lambda' = 2.2\times10^{-34}$ m ...(2)

From equations (1) and (2), we found that the de-Broglie wavelength of the ball is negligible as compared to that of the electron. So, wave nature of matter is important at the atomic level but is not really relevant at microscopic level.

89. As $m_\alpha = 4m_p$ and $q_\alpha = 2e$, $q_p = e$

As, both are accelerated through same electric potential, so

$$\frac{\frac{1}{2}m_p v_p^2}{\frac{1}{2}m_\alpha v_\alpha^2} = \frac{q_p V}{q_\alpha V}$$

or $\frac{m_p}{4m_p}\times\left(\frac{V_p}{V_\alpha}\right)^2 = \frac{e}{2e}$ or $\left(\frac{V_p}{V_\alpha}\right)^2 = \frac{4}{2} = 2$

or $\frac{V_p}{V_\alpha} = \sqrt{2}$ ...(i)

(i) $\frac{\lambda_p}{\lambda_\alpha} = \frac{h/m_p v_p}{h/m_\alpha v_\alpha} = \frac{m_\alpha v_\alpha}{m_p v_p} = \frac{4m_p}{m_p}\times\frac{1}{\sqrt{2}}$

or $\frac{\lambda_p}{\lambda_\alpha} = 2\sqrt{2} > 1$ or $\lambda_p > \lambda_\alpha$

So, proton has greater value of de-Broglie wavelength associated with it.

(ii) $\frac{\frac{1}{2}m_p v_p^2}{\frac{1}{2}m_\alpha v_\alpha^2} = \frac{q_p V}{q_\alpha V} = \frac{q_p}{q_\alpha} = \frac{e}{2e} = \frac{1}{2} < 1$

or $\frac{1}{2}m_p v_p^2 < \frac{1}{2}m_\alpha v_\alpha^2$

So, proton has less kinetic energy.

90. de Broglie wavelength $\lambda = \frac{h}{\sqrt{2mE}}$

$= \frac{h}{\sqrt{2mqV}}$ $\quad [\because$ kinetic energy $E = qV]$

$\therefore \frac{\lambda_\alpha}{\lambda_p} = \frac{h}{\sqrt{2m_\alpha q_\alpha V}} \times \frac{\sqrt{2m_p q_p V}}{h}$

$\Rightarrow \frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p q_p}{m_\alpha q_\alpha}} = \sqrt{\frac{m_p q_p}{(4m_p)(2q_p)}} = \sqrt{\frac{1}{8}} = \frac{1}{2\sqrt{2}}$

$\Rightarrow \lambda_\alpha : \lambda_p = 1 : 2\sqrt{2}$

91. (i) Momentum of photon

$p = \frac{h}{\lambda} = \frac{6.6\times10^{-34}}{1\times10^{-9}} = 6.6\times10^{-25}$ kg m s^{-1}

Momentum of electron

$p = \frac{6.6\times10^{-34}}{1\times10^{-9}} = 6.6\times10^{-25}$ kg m s^{-1}

(ii) Energy of photon

$E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^8}{1\times10^{-9}} = 1.98\times10^{-16}$ J

(iii) Kinetic energy of electron

$E_k = \frac{p^2}{2m} = \frac{(6.6\times10^{-25})^2}{2\times9.1\times10^{-31}} = 2.39\times10^{-19}$ J

92. For same accelerating potential, a proton and a deutron have same kinetic energy.

(a) de-Broglie wavelength is given by

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2\,mK}} = \frac{h}{\sqrt{2m(qV)}}$$

So, $\lambda \propto \frac{1}{\sqrt{m}}$

Mass of a deutron is more than that of a proton. So, proton will have greater value of de-Broglie wavelength.

(b) Momentum, $p = \sqrt{2\,mK}$

$p \propto \sqrt{m}$

Mass of a deutron is more than that of a proton. So, a proton has less momentum.

93. (i) de-Broglie wavelength with charged particle

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

de-Broglie wavelength of a particle depends upon its mass and charge for same accelerating potential, such that mass and charge of a proton are m_p and e respectively, and, mass and charge of an alpha particle are $4m_p$ and $2e$ respectively. where, e is the charge of an electron Thus, de-broglie wavelength associated with proton is $2\sqrt{2}$ times of the de-Broglie wavelength of alpha particle.

(ii) K.E. for same accelerating potential

Charge of an alpha particle is more as compared to a proton. So, it will have a greater value of K.E. Hence, proton will have lesser kinetic energy.

LONG ANSWER TYPE QUESTIONS

2. $\lambda_1 = 400\times10^{-9}\,\text{m}, V_0' = 6\text{V}, \lambda_2 = 600\times10^{-9}\,\text{m}$

$$eV_0' = h\upsilon_1 - W_0$$

or $W_0 = h\upsilon_1 - eV_0' = h\upsilon_2 - eV_0''$

$$\frac{h}{e}(\upsilon_1 - \upsilon_2) = V_0' - V_0''$$

$$\frac{hc}{e}\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right) = V_0' - V_0''$$

$$\frac{6.6\times10^{-34}\times3\times10^8}{1.6\times10^{-19}\times10^{-7}}\left[\frac{1}{4} - \frac{1}{6}\right] = 6 - V_0''$$

$$1 = 6 - V_0''$$

$$V_0'' = 5 \text{ volts}$$

3. $\frac{1}{2}mv_{max}^2 = \frac{hc}{\lambda} - W_0 = \frac{6.6\times10^{-34}\times3\times10^8}{300\times10^{-9}\times1.6\times10^{-19}} - 3.2$

$= 0.925\text{ eV} = 1.48\times10^{-19}\text{ J}$

5. $W_0 = \frac{hc}{\lambda_1} - KE_1 = \frac{hc}{\lambda_2} - KE_2$

$$hc\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right) = KE_1 - KE_2$$

$$\frac{h\times3\times10^8}{10^{-10}}\left[\frac{1}{3310} - \frac{1}{5000}\right] = (30 - 7.91)\times10^{-20}$$

$h = 7.21\times10^{-34}\text{ Js}$

$$W_0 = h\upsilon_0 = \frac{hc}{\lambda_1} - KE_1$$

$$\upsilon_0 = \frac{c}{\lambda} - \frac{KE}{h} = \frac{3\times10^8}{3310\times10^{-10}} - \frac{3\times10^{-19}}{6.6\times10^{-34}}$$

$\upsilon_0 = 4.52\times10^{14}\text{ Hz}$

$$\lambda_0 = \frac{c}{\upsilon_0} = \frac{3\times10^8}{4.52\times10^{14}\text{ Hz}} = 664\text{ nm}$$

6. $\frac{1}{2}mv_{max}^2 = h(\upsilon_1 - \upsilon_0)$ or $eV_1 - h\upsilon_1 = h\upsilon_0$

or $\upsilon_0 = \frac{eV_1 - h\upsilon_1}{h} = \frac{eV_2 - h\upsilon_2}{h}$ or $e(V_1 - V_2) = h(\upsilon_1 - \upsilon_2)$

or $h = \frac{e(V_1 - V_2)}{(\upsilon_1 - \upsilon_2)}$

$$\upsilon_0 = \frac{e}{h}V_1 - \upsilon_1 = \frac{eV_1(\upsilon_1 - \upsilon_2)}{e(V_1 - V_2)} - \upsilon_1$$

or $\upsilon_0 = \frac{\upsilon_1V_1 - \upsilon_2V_1 - \upsilon_1V_1 + \upsilon_1V_2}{V_1 - V_2}$

or $\upsilon_0 = \frac{\upsilon_1V_2 - \upsilon_2V_1}{V_1 - V_2}$

7. $\frac{1}{2}mv^2 = \frac{hc}{\lambda}$ or $v^2 = \frac{2hc}{\lambda m} = \frac{2\times6.6\times10^{-34}\times3\times10^8}{0.82\times10^{-10}\times9.1\times10^{-31}}$

or $v = 7.3\times10^7\text{ m/s}$

$$\lambda' = \frac{h}{mv} = \frac{6.6\times10^{-34}}{9.1\times10^{-31}\times7.3\times10^7} = 0.1\text{ Å}$$