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DUAL NATURE OF MATTER AND RADIATION

Revision Module

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POINTS TO REMEMBER

1. Dual Nature of Radiations

It is well known that the phenomena of interference, diffraction and polarisation indicate that light has wave nature. But some phenomena like photoelectric effect, Compton effect, emission and absorption of radiation could not be explained by wave nature.

These were explained by particle (quantum) nature of light. Thus, light (radiation) has dual nature.

2. Quantum Nature of Light: Concept of a Photon

Some phenomena like photoelectric effect, Compton effect, Raman effect could not be explained by wave theory of light. Therefore, quantum theory of light was proposed by Einstein. According to quantum theory of light "light is propagated in bundles of small energy, each bundle being called a photon and possessing energy."

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

where ν is frequency, λ is wavelength of light and h is Planck's constant $= 6.63 \times 10^{-34}$ joule second and c = speed of light in vacuum $= 3 \times 10^8$ m/s.

Momentum of photon, $p = \frac{h\nu}{c} = \frac{h}{\lambda}$

Rest mass of photon = 0

Dynamic or kinetic mass of photon, $m = \frac{h\nu}{c^2} = \frac{h}{c\lambda}$

3. Photoelectric Effect

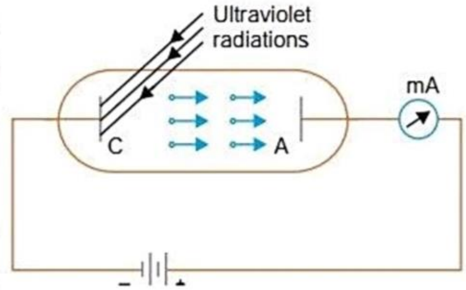
The phenomenon of emission of electrons from a metallic surface by the use of light (or radiant) energy is called *photoelectric effect*. The phenomenon was discovered by Lenard. For photoelectric emission, the metal used must have low work function, *e.g.*, alkali metals. *Caesium* is the best metal for photoelectric effect.

4. Hertz's Observations

The phenomenon of photoelectric effect was discovered by Heinrich Hertz in 1887. While performing an experiment for production of electromagnetic waves by means of spark discharge, Hertz observed that sparks occurred more rapidly in the air gap of his transmitter when ultraviolet radiations was directed at one of the metal plates. Hertz could not explain his observations.

5. Lenard's Observations

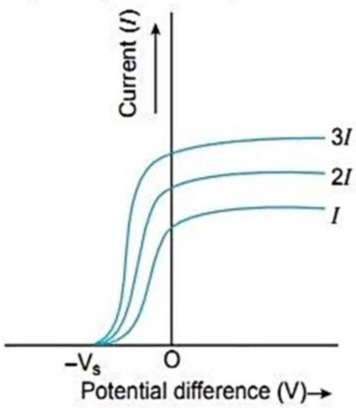
Phillip Lenard observed that when ultraviolet radiations were made incident on the emitter plate of an evacuated glass tube enclosing two metal plates (called electrodes), current flows in the circuit, but as soon as ultraviolet radiation falling on the emitter plate was stopped, the current flow stopped. These observations indicate that when ultraviolet radiations fall on the emitter (cathode) plate *C*, the electrons are ejected from it, which are attracted towards anode plate *A*. The electrons flow through the evacuated glass tube, complete the circuit and current begins to flow in the circuit.



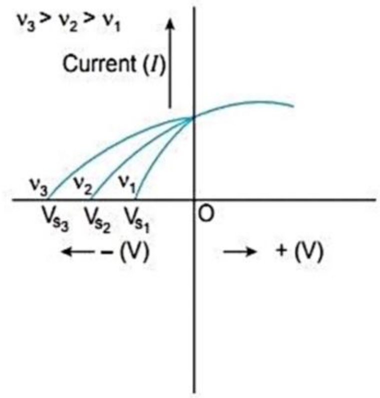
6. Characteristics of Photoelectric Effect

(*i*) **Effect of Intensity:** Intensity of light means the energy incident per unit area per second. For a given frequency, if intensity of incident light is increased, the photoelectric current increases and with decrease of intensity, the photoelectric current decreases; but the stopping potential remains the same.

Intensity of radiations can be increased/decreased by varying the distance between source and metal plate (or emitter).



(*a*)



(*b*)

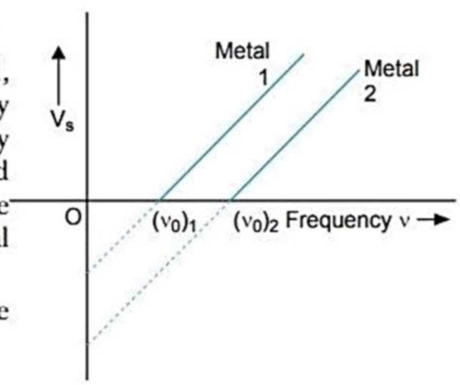
This means that the *intensity of incident light affects the photoelectric current but the maximum kinetic energy of photoelectrons remains unchanged as shown in fig (b).*

(*ii*) **Effect of Frequency:** When the intensity of incident light is kept fixed and frequency is increased, the photoelectric current remains the same; but the stopping potential increases.

If the frequency is decreased, the stopping potential decreases and at a particular frequency of incident light, the stopping potential becomes zero. This value of frequency of incident light for which the stopping potential is zero is called *threshold frequency* ν_0. If the frequency of incident light (ν) is less than the threshold frequency (ν_0) no photoelectric emission takes place.

Thus, *the increase of frequency increases the maximum kinetic energy of photoelectrons but the photoelectric current remain unchanged.*

(*iii*) **Effect of Photometal:** When frequency and intensity of incident light are kept fixed and photometal is changed, we observe that stopping potential (V_s) versus frequency (ν) graphs are parallel straight lines, cutting frequency axis at different points (Fig.). This shows that threshold frequencies are different for different metals, the slope (V_S / ν) for all the metals is same and hence a universal constant.



(*iv*) **Effect of Time:** There is no time lag between the incidence of light and the emission of photoelectrons.

7. Some Definitions

Work Function: The minimum energy required to free an electron from its metallic bonding is called work function. It is denoted by *W* or ϕ and is usually expressed in electron volt ($1 \text{ eV} = 1.6 \times 10^{-19}$ J).

Threshold Frequency: The minimum frequency of incident light which is just capable of ejecting electrons from a metal is called the threshold frequency. It is denoted by ν_0. It is different for different metal.

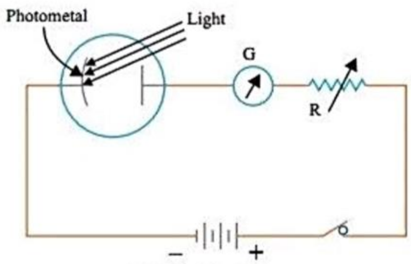
Stopping Potential: The minimum retarding potential applied to anode of a photoelectric tube which is just capable of stopping photoelectric current is called the stopping potential. It is denoted by V_0 (or V_S)

8. Einstein's Explanation of Photoelectric Effect: Einstein's Photoelectric Equation

Einstein extended Planck's quantum idea for light to explain photoelectric effect.

The assumptions of Einstein's theory are:

1. The photoelectric effect is the result of collision of a photon of incident light and an electron of photometal.
2. The electron of photometal is bound with the nucleus by coulomb attractive forces. The minimum energy required to free an electron from its bondage is called work function (W).
3. The incident photon interacts with a single electron and loses its energy in two parts:
   (*i*) in releasing the electron from its bondage, and
   (*ii*) in imparting kinetic energy to emitted electron.



Photoelectric cell

Accordingly, if $h\nu$ is the energy of incident photon, then from law of conservation of energy

$$h\nu = W + E_k$$

or maximum kinetic energy of photoelectrons, $E_k = \frac{1}{2}mv^2_{max} = h\nu - W$

where W is work function. This equation is referred as *Einstein's photoelectric equation* and explains all experimental results of photoelectric effect. If V_s is stopping potential, then

$$E_k = \frac{1}{2}mv^2_{max} = eV_S$$

Stopping potential, $V_s = \frac{h}{e}\nu - \frac{W}{e}$

The slope of E_k versus ν graph is h.

The slope of V_S versus ν graph is $\frac{h}{e}$.

9. Photocell

A photocell is a device which converts light energy into electrical energy. It is also called electric eye.

10. Matter Waves: Wave Nature of Particles

Light exhibits particle aspects in certain phenomena (*e.g.*, photoelectric effect, emission and absorption of radiation), while wave aspects in other phenomena (*e.g.*, interference, diffraction and polarisation). That is, light has dual nature. In analogy with dual nature of light, de Broglie thought in terms of dual nature of matter.

11. de Broglie Hypothesis

Louis de Broglie postulated that the **material particles** (*e.g.*, electrons, protons, α-particles, atoms, etc.) may exhibit wave aspect. Accordingly, *a moving material particle behaves as wave and the wavelength associated with material particle is*

$$\lambda = \frac{h}{p} = \frac{h}{mv}, \quad \text{where } p \text{ is momentum.}$$

If E_k is kinetic energy of moving material particle, then $p = \sqrt{2mE_k}$

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

i.e.,
$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE_k}}$$

The wave associated with material particle is called the ***de Broglie wave or matter wave***. The de Broglie hypothesis has been confirmed by diffraction experiments.

For charged particles associated through a potential of V volt,

$$E_k = qV$$

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

For electrons, $q = e = 1.6 \times 10^{-19}$ C, $m = 9 \times 10^{-31}$ kg

$$\lambda = \frac{12.27}{\sqrt{V}} \times 10^{-10}\text{m} = \frac{12.27}{\sqrt{V}}\text{Å} \quad \text{(Only for electrons)}$$

For electron orbiting in an atom, de Broglie wavelength is given as $\lambda = \frac{h}{p} = \frac{h}{mv}$

For neutral particles in thermal equilibrium at absolute temperature T, $E_k = kT$

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

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **A particle is dropped from a height H. The de Broglie wavelength of the particle as a function of height is proportional to** [*NCERT Exemplar*]
   (*a*) H (*b*) $H^{1/2}$
   (*c*) H^0 (*d*) $H^{-1/2}$
2. **The wavelength of a photon needed to remove a proton from a nucleus which is bound to the nucleus with 1 MeV energy is nearly** [*NCERT Exemplar*]
   (*a*) 1.2 nm (*b*) 1.2×10^{-3} nm
   (*c*) 1.2×10^{-6} nm (*d*) 1.2×10^{1} nm
3. **Consider a beam of electrons (each electron with energy E_0) incident on a metal surface kept in an evacuated chamber. Then** [*NCERT Exemplar*]
   (*a*) no electrons will be emitted as only photons can emit electrons.
   (*b*) electrons can be emitted but all with an energy, E_0.
   (*c*) electrons can be emitted with any energy, with a maximum of $E_0 - \phi$ (ϕ is the work function).
   (*d*) electrons can be emitted with any energy, with a maximum of E_0.
4. **The threshold wavelength for photoelectric emission from a material is 5200 Å. Photoelectrons will be emitted when this material is illuminated with monochromatic radiation from a:**
   (*a*) 50 watt infrared lamp
   (*b*) 1000 watt infrared lamp
   (*c*) 1 watt ultraviolet lamp
   (*d*) 1 watt infrared lamp
5. **A photoelectric cell is illuminated by a point source of light 1 m away. The plate emits electrons having stopping potential V. Then**
   (*a*) V decreases as distance increase
   (*b*) V increases as distance increase
   (*c*) V is independent of distance (r)
   (*d*) V becomes zero when distance increases or decreases

6. **In a photoelectric experiment, the stopping- potential for the incident light of wavelength 4000 Å is 2 volt. If the wavelength be changed to 3000 Å, the stopping-potential will be**
(*a*) 2 volt (*b*) less than 2 volt
(*c*) zero (*d*) more than 2 volt.

7. **The work-function for a metal is 3 eV. To emit a photoelectron of energy 2 eV from the surface of this metal, the wavelength of the incident light should be**
(*a*) 6187 Å (*b*) 4125 Å (*c*) 12375 Å (*d*) 2486 Å

8. **A photocell connected in an electrical circuit is placed at a distance '*d*' from a source of light. As a result, current *I* flows in the circuit. What will be the current in the circuit when the distance is reduced to '*d*/2'?** **[*CBSE 2020 (55/4/1)*]**
(*a*) I (*b*) $2I$ (*c*) $4I$ (*d*) $I/2$

9. **A graph is plotted between the stopping potential (on *y*-axis) and the frequency of incident radiation (on *x*-axis) for a metal. The product of the slope of the straight line obtained and the magnitude of charge on an electron is equal to** **[*CBSE 2023 (55/3/1)*]**
(*a*) h (*b*) $\frac{h}{c}$ (*c*) $\frac{2h}{c}$ (*d*) $\frac{h}{2c}$

10. **A proton, a neutron, an electron and an α-particle have same energy. Then their de Broglie wavelengths compare as** **[*NCERT Exemplar*]**
(*a*) $\lambda_p = \lambda_n > \lambda_e > \lambda_\alpha$ (*b*) $\lambda_\alpha < \lambda_p = \lambda_n > \lambda_e$
(*c*) $\lambda_e < \lambda_p = \lambda_n > \lambda_\alpha$ (*d*) $\lambda_e = \lambda_p = \lambda_n = \lambda_\alpha$

11. **Light of frequency 6.4×10^{14} Hz is incident on a metal of work function 2.14 eV. The maximum kinetic energy of the emitted electrons is about** **[*CBSE 2023 (55/3/1)*]**
(*a*) 0.25 eV (*b*) 0.51 eV (*c*) 1.02 eV (*d*) 0.10 eV

12. **Relativistic corrections become necessary when the expression for the kinetic energy $\frac{1}{2}mv^2$, becomes comparable with mc^2, where *m* is the mass of the particle. At what de Broglie wavelength will relativistic corrections become important for an electron?** **[*NCERT Exemplar*]**
(*a*) $\lambda = 10$ nm (*b*) $\lambda = 10^{-1}$ nm
(*c*) $\lambda = 10^{-4}$ nm (*d*) $\lambda = 10^{-6}$ nm

13. **Monochromatic light of wavelength 667 nm is produced by a helium neon laser. The power emitted is 9 mW. The number of photons arriving per second on the average at a target irradiated by this beam is**
(*a*) 3×10^{16} (*b*) 9×10^{15} (*c*) 3×10^{19} (*d*) 9×10^{17}

14. **Electrons used in an electron microscope are accelerated by a voltage of 25 kV. If the voltage is increased to 100 kV then the de Broglie wavelength associated with the electrons would**
(*a*) increase by 2 times (*b*) decrease by 2 times
(*c*) decrease by 4 times (*d*) increase by 4 times

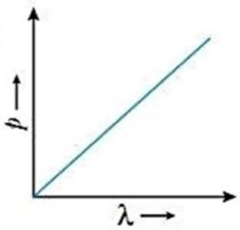
15. **An electron (mass *m*) with an initial velocity $\vec{v} = v_0\hat{i}$ is in an electric field $\vec{E} = E_0\hat{j}$. If $\lambda_0 = h/mv_0$, it's de Breoglie wavelength at time *t* is given by** **[*NCERT Exemplar*]**
(*a*) λ_0 (*b*) $\lambda_0\sqrt{1+\frac{e^2E_0^2t^2}{m^2v_0^2}}$ (*c*) $\frac{\lambda_0}{\sqrt{1+\frac{e^2E_0^2t^2}{m^2v_0^2}}}$ (*d*) $\frac{\lambda_0}{\left(1+\frac{e^2E_0^2t^2}{m^2v_0^2}\right)}$

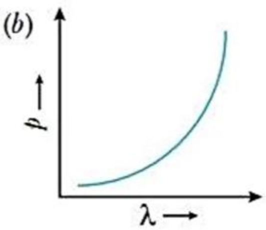
16. **Photons of energy 3.2 eV are incident on a photosensitive surface. If the stopping potential for the emitted electrons is 1.5 V, the work funtion for the surface is** **[*CBSE 2023 (55/4/1)*]**
(*a*) 1.5 eV (*b*) 1.7 eV (*c*) 3.2 eV (*d*) 4.7 eV

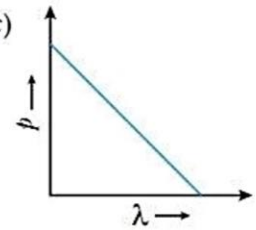
17. A particle of mass 1 mg has the same wavelength as an electron moving with a velocity of 3×10^6 ms^{-1}. The velocity of the particle is (mass of electron = 9.1×10^{-31} kg)

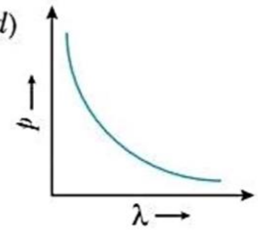
(*a*) 2.7×10^{-18} ms^{-1} (*b*) 9×10^{-2} ms^{-1} (*c*) 3×10^{-31} ms^{-1} (*d*) 2.7×10^{-21} ms^{-1}

18. Which of the following figures represent the variation of particle momentum and the associated de Broglie wavelength? [*CBSE 2020 (55/5/1)*]

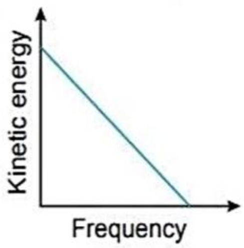
(*a*)


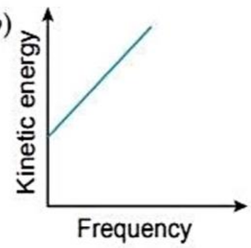
(*b*)


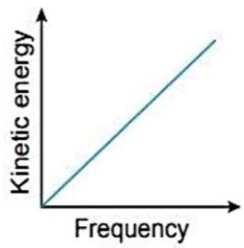
(*c*)


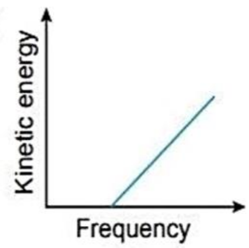
(*d*)


19. According to Einstein's photoelectric equation, the graph between the kinetic energy of photoelectrons ejected and the frequency of incident radiation is

(*a*)


(*b*)


(*c*)


(*d*)


20. The kinetic energy of a proton and that of an α-particle are 4 eV and 1 eV respectively. The ratio of the de Broglie wavelengths associated with them will be [*CBSE 2020 (55/4/1)*]

(*a*) 2:1 (*b*) 1:1
(*c*) 1:2 (*d*) 4:1

21. If photons of frequency ν are incident on the surfaces of two metals, *A* and *B* of threshold frequencies ν/2 and ν/3 respectively, the ratio of maximum kinetic energy of electrons emitted from *A* to that from *B* is [*CBSE 2020 (55/5/1)*]

(*a*) 2 : 3 (*b*) 3 : 4
(*c*) 1 : 3 (*d*) $\sqrt{3} : \sqrt{2}$

22. Sodium surface is illuminated by ultraviolet and visible radiation successively and the stopping potential is determined. This stopping potential is

(*a*) equal in both cases (*b*) more with ultraviolet light
(*c*) more with visible light (*d*) varies randomly

23. In a photoelectric experiment, the wavelength of the incident radiation is reduced from 6000 Å to 4000 Å, while the intensity of radiation remains the same; then

(*a*) the cut-off potential will decrease
(*b*) the cut-off potential will increase
(*c*) the photoelectric current will increase
(*d*) the kinetic energy of the emitted electrons will decrease

Answers

1. (*d*)	**2.** (*b*)	**3.** (*d*)	**4.** (*c*)	**5.** (*c*)	**6.** (*d*)	**7.** (*d*)
8. (*c*)	**9.** (*a*)	**10.** (*b*)	**11.** (*b*)	**12.** (*c*), (*d*)	**13.** (*a*)	**14.** (*b*)
15. (*c*)	**16.** (*b*)	**17.** (*a*)	**18.** (*d*)	**19.** (*d*)	**20.** (*b*)	**21.** (*b*)
22. (*b*)	**23.** (*b*)					

AS PER NEP — COMPETENCY-FOCUSED QUESTIONS

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) *Both A and R are true and R is the correct explanation of A.*

(b) *Both A and R are true but R is not the correct explanation of A.*

(c) *A is true but R is false.*

(d) *A is false and R is also false.*

1. **Assertion** (*A*) : Matter has wave-particle nature.
   Reason (*R*) : Light has dual nature.

2. **Assertion** (*A*) : In the process of photoelectric emission, all emitted electrons have the same kinetic energy.
   Reason (*R*) : According to Einstein's equation $E_k = h\nu + \phi_0$.

3. **Assertion** (*A*) : Photoelectric effect demonstrates the wave nature of light.
   Reason (*R*) : The number of photoelectrons is proportional to the velocity of incident light.

4. **Assertion** (*A*) : Photoelectric effect demonstrates the particle nature of light.
   Reason (*R*) : Photoelectric current is proportional to intensity of incident radiation for frequencies more than the threshold frequency. [*CBSE 2023 (55/1/1)*]

5. **Assertion** (*A*) : On increasing the intensity of light the photocurrent increases.
   Reason (*R*) : The photocurrent increases with increase of frequency of light.

6. **Assertion** (*A*) : Photoelectric process is instantaneous process.
   Reason (*R*) : When photons of energy ($h\nu$) greater than work function of metal (ϕ_0) are incident on a metal, the electrons from metal are emitted with no time lag.

7. **Assertion** (*A*) : Photoelectric effect demonstrates the wave nature of light. [*AIIMS 2018*]
   Reason (*R*) : The number of photoelectrons is proportional to the frequency of light.

8. **Assertion** (*A*) : If intensity of incident light is doubled, the kinetic energy of photoelectron is also doubled.
   Reason (*R*) : The kinetic energy of photoelectron is directly proportional to intensity of incident light.

9. **Assertion** (*A*) : An electron and a photon possessing same wavelength, will have the same momentum.
   Reason (*R*) : Momentum of both particle is same by de-Broglie hypothesis.

10. **Assertion** (*A*) : An electron microscope is based on de-Broglie hypothesis. [*AIIMS 2014*]
    Reason (*R*) : A beam of electrons behaves as a wave which can be converged by electric and magnetic lenses.

Answers

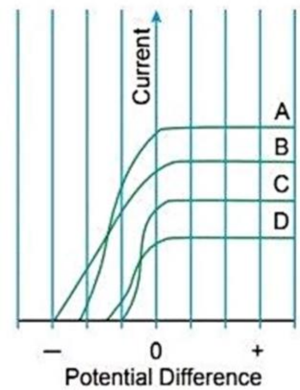
1. (*b*) **2.** (*d*) **3.** (*d*) **4.** (*b*) **5.** (*c*) **6.** (*a*) **7.** (*d*)
8. (*d*) **9.** (*a*) **10.** (*a*)

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Figure shows the variation of photoelectric current measured in a photo cell circuit as a function of the potential difference between the plates of the photo cell when light beams *A*, *B*, *C* and *D* of different wavelengths are incident on the photo cell. Examine the given figure and answer the following questions: **[*CBSE 2023 (55/2/1), Modified*]**



(*i*) Which light beam has the highest frequency?

(*a*) A (*b*) B
(*c*) C (*d*) D

(*ii*) Which light beam ejects photoelectrons will maximum momentum?

(*a*) D (*b*) C (*c*) B (*d*) A

(*iii*) Consider a beam of electrons (each electrons with energy E_0) incident on a metal surface kept in an evacuated chamber then

(*a*) electrons can be emitted with any energy, with a maximum of E_0
(*b*) electrons can be emitted with any energy, with a maximum of $E_0 - \phi$, (ϕ is the work function)
(*c*) electrons can be emitted but all with an energy, E_0
(*d*) no electrons will be emitted as only photons can emit electrons

(*iv*) The stopping potential of a photocell, in which electrons with a maximum kinetic energy of 6 eV are emitted will be

(*a*) –6V (*b*) 6V (*c*) 3V (*d*) –3V

OR

Sodium and copper have work functions 2.3 eV and 4.5 eV respectively. Then the ratio of their threshold wavelengths is nearest to

(*a*) 1 : 2 (*b*) 1 : 4 (*c*) 2 : 1 (*d*) 4 : 1

Explanations

(*i*) (*b*) The light beam *B*, because it requires maximum retarding potential to reduce the photoelectric current to zero.

(*ii*) (*c*) The light beam *B* ejects photoelectrons with maximum momentum, because highest frequency light beam ejects photoelectrons with highest kinetic energy and hence highest momentum.

(*iii*) (*d*) When a beam of electrons of energy E_0 of each electron is incident on a metal surface kept in vacuum, then due to elastic collision with electrons on surface, energy of incident electrons will be transferred to the emitted electrons. To emit the electrons below the surface, a part of E_0 of incident electrons is consumed against work function. So, energy of emitted electrons becomes less than E_0. So, the maximum energy of emitted electrons can be E_0.

(*iv*) (*a*) We have, $E_k = eV_0 \Rightarrow 6\text{ eV} = eV_0 \Rightarrow V_0 = 6\text{ V}$

The stopping potential V_0= 6 volt (Negative).

(c) $W_0 = h\upsilon_0 = \frac{hc}{\lambda_0} \Rightarrow \lambda_0 \propto \frac{1}{W_0}$

$$\Rightarrow \frac{\lambda_0(\text{Na})}{\lambda_0(\text{Cu})} = \frac{W_0(\text{Cu})}{W_0(\text{Na})} = \frac{4.5}{2.3} = 2$$

$$\therefore \lambda_0(\text{Na}) : \lambda_0(\text{Cu}) = 2:1$$

CONCEPTUAL QUESTIONS

Q. 1. Name the phenomenon which shows the quantum nature of electromagnetic radiation.
[CBSE (AI) 2017]

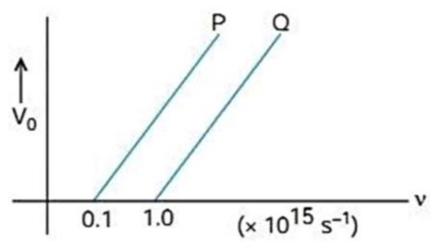
Ans. The quantum nature of electromagnetic radiation is shown by the phenomenon of photoelectric effect.
[Topper's Answer 2017]

Q. 2. Define intensity of radiation on the basis of photon picture of light. Write its SI unit.
[CBSE (AI) 2014; 2019 (55/1/1)]

Ans. The amount of light energy or photon energy incident per metre square per second is called intensity of radiation.

SI unit: $\frac{\text{W}}{\text{m}^2}$ or $\text{J/s} - \text{m}^2$

Q. 3. The figure shows the variation of stopping potential V_0 with the frequency ν of the incident radiations for two photosensitive metals P and Q. Which metal has smaller threshold wavelength? Justify your answer.
[CBSE 2019 (55/4/1)]



Ans. Since $\lambda_0 = \frac{c}{\nu_0}$, metal Q has smaller threshold wavelength.

Q. 4. Write the basic features of photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based. **[CBSE Delhi 2013]**

Ans. Features of the photons:

(i) Photons are particles of light having energy $E = h\nu$ and momentum $p = \frac{h}{\lambda}$, where h is Planck constant.

(ii) Photons travel with the speed of light in vacuum, independent of the frame of reference.

(iii) Intensity of light depends on the number of photons crossing unit area in a unit time.

Q. 5. Define the term 'stopping potential' in relation to photoelectric effect. **[CBSE (AI) 2011]**

Ans. The minimum retarding (negative) potential of anode of a photoelectric tube for which photoelectric current stops or becomes zero is called the stopping potential.

Q. 6. Define the term 'threshold frequency' in relations to photoelectric effects.
[CBSE (F) 2011, 2019 (55/1/1), 2020 (55/2/1)]

Ans. The minimum frequency that an incoming photon must contain so that it can just overcome the ~~to~~ work function and start photoelectric effect is called 'threshold frequency' in photoelectric emission.
[Topper's Answer 2020]

Q. 7. In photoelectric effect, why should the photoelectric current increase as the intensity of monochromatic radiation incident on a photosensitive surface is increased? Explain.

[CBSE (F) 2014]

Ans. The photoelectric current increases proportionally with the increase in intensity of incident radiation. Larger the intensity of incident radiation, larger is the number of incident photons and hence larger is the number of electrons ejected from the photosensitive surface.

Q. 8. State de Broglie hypothesis. *[CBSE Delhi 2012]*

Ans. According to hypothesis of de Broglie "The atomic particles of matter moving with a given velocity, can display the wave like properties."

i.e., $\lambda = \dfrac{h}{mv}$ (mathematically)

Q. 9. What is the wavelength of a photon of energy 3.3×10^{-19} J? *[CBSE 2020 (55/2/1)]*

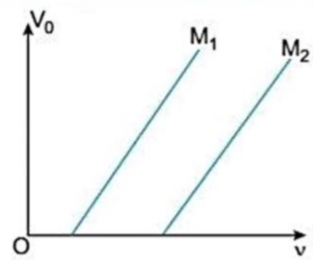
Ans. Wavelength, $\lambda = \dfrac{hc}{E}$. ∴ $\lambda = \dfrac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{3.3 \times 10^{-19}}$ m

$= \dfrac{19.89}{3.3} \times 10^{-7}$ m $\approx 6.03 \times 10^{-7}$ m.

∴ reqd. wavelength $= 6.03 \times 10^{-7}$ m.

[Topper's Answer 2020]

Q. 10. The variation of the stopping potential (V_o) withe the frequency (ν) of the light incident on two different photosensitive surfaces M_1 and M_2 is shown in the figure. Identify the surface which has greater value of the work function. *[CBSE 2020 (55/1/1)]*

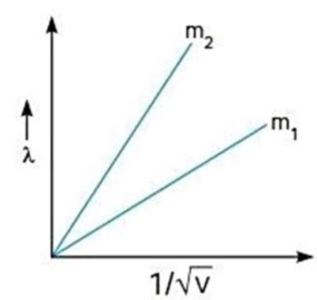


Ans. M_2 has greater value of work function due to higher value of threshold frequency.

Q. 11. Plot a graph showing variation of de Broglie wavelength λ versus $\dfrac{1}{\sqrt{V}}$, where V is accelerating potential for two particles A and B carrying same charge but of masses m_1, m_2 ($m_1 > m_2$). Which one of the two represents a particle of smaller mass and why? *[CBSE Delhi 2016] [HOTS]*

Ans. As, $\lambda = \dfrac{h}{\sqrt{2mqV}}$ or $\lambda = \left(\dfrac{h}{\sqrt{2q}} \cdot \dfrac{1}{\sqrt{m}}\right)\dfrac{1}{\sqrt{V}}$

or $\dfrac{\lambda}{\dfrac{1}{\sqrt{V}}} = \dfrac{h}{\sqrt{2q}} \cdot \dfrac{1}{\sqrt{m}}$



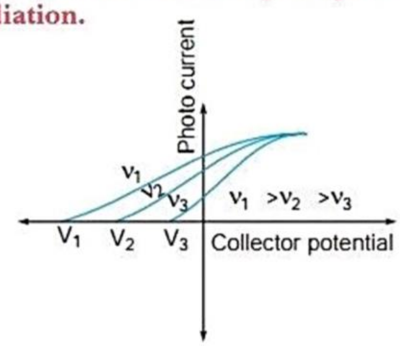
As the charge on two particles is same, we get

$$\text{Slope} \propto \frac{1}{\sqrt{m}}$$

Hence, particle with lower mass (m_2) will have greater slope.

Q. 12. Show the variation of photocurrent with collector plate potential for different frequencies but same intensity of incident radiation. *[CBSE (F) 2011] [HOTS]*

Ans.



Q. 13. **(a) Define the term 'intensity of radiation' in photon picture.**

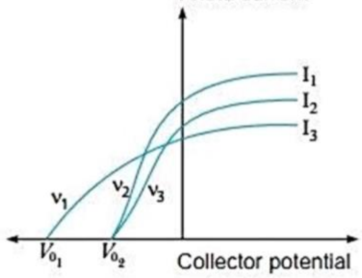
(b) Plot a graph showing the variation of photo current vs collector potential for three different intensities $I_1 > I_2 > I_3$, two of which (I_1 and I_2) have the same frequency ν and the third has frequency $\nu_1 > \nu$.

(c) Explain the nature of the curves on the basis of Einstein's equation.

[*CBSE South 2016*] [*HOTS*]

Ans. (a) The amount of light energy or photon energy incident per metre square per second is called intensity of radiation.

(b) $\nu_2 = \nu_3 = \nu$



(c) As per Einstein's equation,

(i) The stopping potential is same for I_1 and I_2 as they have the same frequency.

(ii) The saturation currents are as shown in figure because $I_1 > I_2 > I_3$.

Q. 14. **Two metals *A* and *B* have work functions 4 eV and 10 eV respectively. Which metal has the higher threshold wavelength?**

Ans. Work function $W = h\nu_0 = \dfrac{hc}{\lambda_0}$

$$\Rightarrow \quad \lambda_0 \propto \frac{1}{W}$$

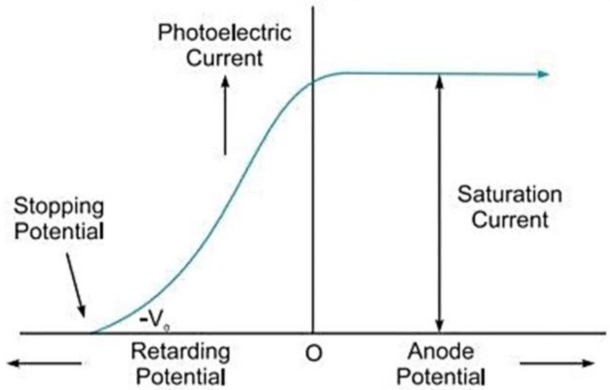
As $\quad W_A < W_B;\ (\lambda_0)_A > (\lambda_0)_B$

i.e., threshold wavelength of metal *A* is higher.

Q. 15. **(a) Draw a graph showing variation of photocurrent with anode potential for a particular intensity of incident radiation. Mark saturation current and stopping potential.**

(b) How much would 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?

Ans. (a)



Intercept of the graph with potential axis gives the stopping potential.

(b) We have, $h\nu_{in} = eV_O$

$$\Rightarrow \quad V_O = \frac{h(\nu_2 - \nu_1)}{e}$$

$$K_{max} = \frac{1}{2}mv^2_{max} = h\nu - h\nu_0$$

Characteristic properties of photons:

(*i*) Energy of photon is directly proportional to the frequency (or inversely proportional to the wavelength).

(*ii*) In photon-electron collision, total energy and momentum of the system of two constituents remains constant.

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

Q. 2. Write three characteristic features in photoelectric effect which cannot be explained on the basis of wave theory of light, but can be explained only using Einstein's equation.

[*CBSE Delhi 2016*]

Ans. The three characteristic features which cannot be explained by wave theory are:

(*i*) Kinetic energy of emitted electrons is found to be independent of the intensity of incident light.

(*ii*) There is no emission of electrons if frequency of incident light is below a certain frequency (threshold frequency).

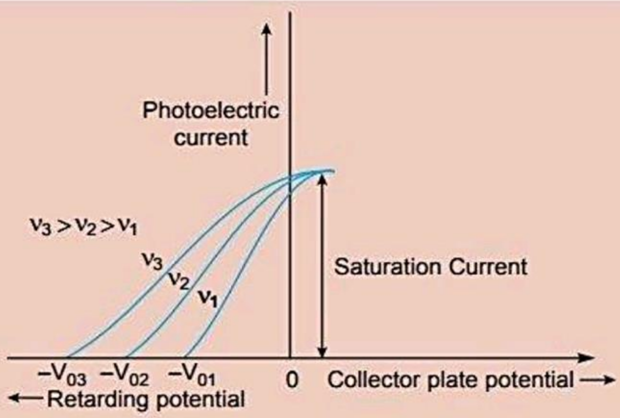
(*iii*) Photoelectric effect is an instantaneous process.

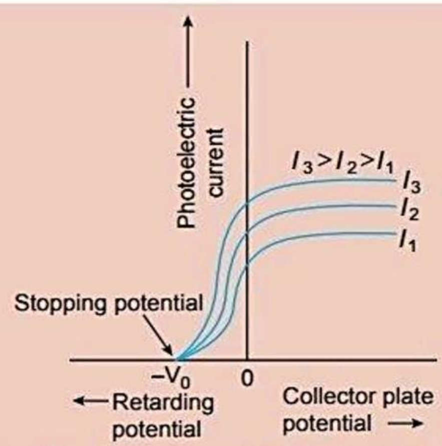
Q. 3. Plot suitable graphs to show the variation of photoelectric current with the collector plate potential for the incident radiation of [*CBSE 2022 (55/1/1), Term-2*]

(*i*) the same intensity but different frequencies ν_1, ν_2 and ν_3 ($\nu_1 < \nu_2 < \nu_3$)

(*ii*) the same frequency but different intensities I_1, I_2 and I_3 ($I_1 < I_2 < I_3$)

Ans. 1





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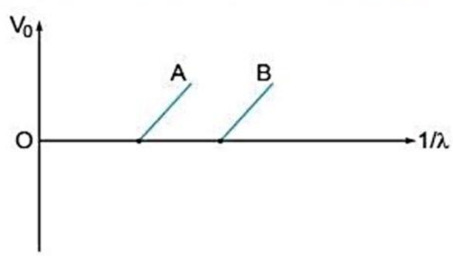
[*CBSE Marking Scheme 2022 (55/1/1), Term-2*]

Q. 4. Figure shows the stopping potential (V_0) for the photo electron versus ($1/\lambda$) graph, for two metals *A* and *B*, λ being the wavelength of incident light.



(*a*) How is the value of Planck's constant determined from the graph?

(*b*) If the distance between the light source and the surface of metal *A* is increased, how will the stopping potential for the electrons emitted from it be effected? Justify your answer.

[*CBSE 2020 (55/5/1)*]

Ans. According to Einstein's Photo-electric equation,

$$h\nu = \phi_0 + eV_s$$

$$\Rightarrow \quad eV_s = h\nu - \phi_0$$

$$\therefore \quad V_s = \frac{h\nu}{e} - \frac{\phi_o}{e}$$ ½

Since $\nu = c/\lambda$

$$\therefore V_s = \frac{h\nu}{e\lambda} - \frac{\phi_0}{e}$$

$$= \left(\frac{hc}{e}\right)\frac{1}{\lambda} + \left[\frac{-\phi_0}{e}\right]$$

Comparing with the equation of straight line $y = mx + c$

(*a*) The slope of the line $m = \frac{hc}{e}$. Hence, Planck's constant $h = \frac{me}{c}$ ½

(*b*) Stopping potential will remain same. ½

Justification

Variation of distance of light source from the metal surface will alter the intensity while the stopping potential however depends only on the frequency and not on the intensity of the incident light. ½

[*CBSE Marking Scheme 2022 (55/5/1)*]

Q. 5. Monochromatic light of frequency 6×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W. How many photons per second on an average are emitted by the source? **[*CBSE Guwahati 2015*]**

Ans. Power of radiation, $P = \frac{nh\nu}{t} = Nh\nu$, where N is number of photons per sec.

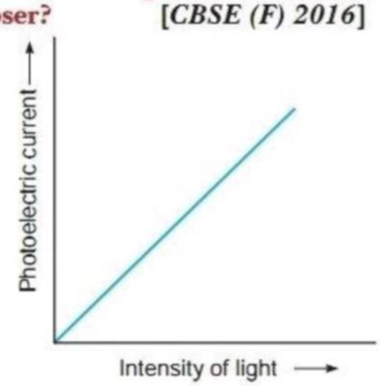
or $$N = \frac{P}{h\nu} = \frac{2.0 \times 10^{-3}}{6.63 \times 10^{-34} \times 6 \times 10^{14}}$$

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

Q. 6. Plot a graph showing the variation of photoelectric current with intensity of light. The work function for the following metals is given:

Na: 2.75 eV and Mo: 4.175 eV.

Which of these will not give photoelectron emission from a radiation of wavelength 3300 Å from a laser beam? What happens if the source of laser beam is brought closer? **[*CBSE (F) 2016*]**



Ans. Energy of photon $E = \frac{hc}{\lambda}$ joule

$$= \frac{hc}{e\lambda}\text{eV}$$

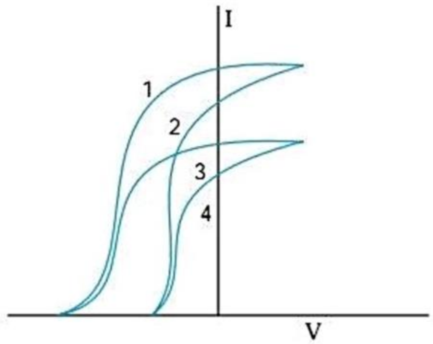
$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 3.3 \times 10^{-7}}\text{ eV} = \mathbf{3.76\ eV}$$

Since W_0 of Mo is greater than E, $\therefore$ Mo will not give photoemission.

There will be no effect of bringing source closer in the case of Mo.

In case of Na, photocurrent will increase.

Q. 7. The given graph shows 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 and explain using Einstein's photo electric equation for the pair of curves that correspond to (*i*) different materials but same intensity of incident radiation, (*ii*) different intensities but same materials. **[*CBSE East 2016*]**



Ans. (*i*) (*a*) 1 and 2 correspond to same intensity but different material.

(*b*) 3 and 4 correspond to same intensity but different material.

This is because the saturation currents are same and stopping potentials are different.

(*ii*) (*a*) 1 and 3 correspond to different intensity but same material.

(*b*) 2 and 4 correspond to different intensity but same material.

This is because the stopping potentials are same but saturation currents are different.

Q. 8. 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 cathode material. [*NCERT*]

Ans. Given $\lambda = 488 \text{ nm} = 488 \times 10^{-9}$ m, $V_0 = 0.38$ V,

Energy of incident photon, $E = \frac{hc}{\lambda}$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{488 \times 10^{-9}} = 4.08 \times 10^{-19} \text{ J}$$

$$= \frac{4.08 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.55 \text{ eV}$$

From Einstein's photoelectric equation, $\frac{hc}{\lambda} = \phi_0 + eV_0$

Work function, $\phi_0 = \frac{hc}{\lambda} - eV_0 = 2.55 \text{ eV} - 0.38 \text{ eV} = \mathbf{2.17 \text{ eV}}$

Q. 9. If the frequency of light incident on the cathode of a photo-cell is increased, how will the following be affected? Justify your answer.

(*i*) Energy of the photo electrons

(*ii*) Photo current [*CBSE 2020 (55/4/1)*]

Ans. (*i*) The energy of the emitted photoelectrons increases ½

As $E_k = h\nu - \phi_0$

As ν increases, E_k also increases. ½

(*ii*) Photo current will not be affected. ½

As, increase of ν E_k will increase but not the number of photoelectorns. ½

[Alternatively photocurrent depends upon intensity of light and not on frequency]

[*CBSE Marking Scheme 2020 (55/4/1)*]

Q. 10. An electromagnetic wave of wavelength λ_1 is incident on a photosensitive surface of negligible work function. If the photo-electrons emitted from this surface have the de Broglie wavelength prove that $\lambda = \left(\frac{2mc}{h}\right)\lambda_1^2$ [*CBSE Delhi 2008*]

Ans. Kinetic energy of electrons, E_k = energy of photon of EM wave

$$= \frac{hc}{\lambda} \quad ...(i)$$

de Broglie wavelength, $\lambda_1 = \frac{h}{\sqrt{2mE_k}}$ or $\lambda_1^2 = \frac{h^2}{2mE_k}$

Using (*i*), we get

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

Q. 11. The de Broglie wavelengths associated with an electron and a proton are equal. Prove that the kinetic energy of the electron is greater than that of the proton. [*CBSE 2020 (55/3/2)*]

Ans. As from de Broglie wavelength,

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE_k}}$$ ½ + ½

where E_k = kinetic energy

for equal λ,

$$E_k \propto \frac{1}{mass}$$

mass of electron < mass of proton ½

∴ Kinetic Energy of electron is more than kinetic energy of proton ½

[*CBSE Marking Scheme 2020 (55/3/2)*]

Q. 12. There are two sources of light, each emitting with a power 100 W. One emits *X*-rays of wavelength 1 nm and the other visible light at 500 nm. Find the ratio of number of photons of *X*-rays the photons of visible light of the given wavelength. [*NCERT Exemplar*]

Ans. Total E is constant.

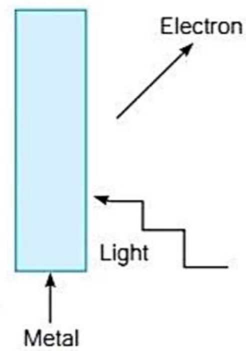
Let n_1 and n_2 be the number of photons of *X*-rays and visible region.

$$n_1E_1 = n_2E_2 \Rightarrow n_1\frac{hc}{\lambda_1} = n_2\frac{hc}{\lambda_2}$$

$$\therefore \frac{n_1}{n_2} = \frac{\lambda_1}{\lambda_2} = \mathbf{\frac{1}{500}}$$

Q. 13. Consider Fig. for photoemission.

How would you reconcile with momentum-conservation? No light (Photons) have momentum in a different direction than the emitted electrons. [*NCERT Exemplar*]



Ans. The momentum is transferred to the metal. At the microscopic level, atoms absorb the photon and its momentum is transferred mainly to the nucleus and electrons. The excited electron is emitted. Conservation of momentum needs to be accounted for the momentum transferred to the nucleus and electrons.

Q. 14. A photon and a proton have the same de Broglie wavelength λ. Prove that the energy of the photon is ($2m\lambda c/h$) times the kinetic energy of the proton. [*CBSE 2019 (55/2/1)*]

Ans. Energy of photon $E_P = \frac{hc}{\lambda}$ ...(*i*)

For proton $\lambda = \frac{h}{mv}$

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

Kinetic energy of proton, $E_k = \frac{1}{2}mv^2$

$$E_k = \frac{1}{2}\frac{h^2}{m\lambda^2}$$

From equation (*i*), we get,

$$E_P = \left(\frac{2m\lambda c}{h}\right)E_k$$

Q. 15. If light of wavelength 412.5 nm is incident on each of the metals given below, which ones will show photoelectric emission and why? [*CBSE 2018*]

Metal	Work Function (eV)
Na	1.92
K	2.15
Ca	3.20
Mo	4.17

Ans. The energy of the incident photon,

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

$$= \frac{6.63\times10^{-34}\times3\times10^{8}}{412.5\times10^{-9}}\text{ J}$$

$$= \frac{0.048\times10^{-17}}{1.6\times10^{-19}}\text{ eV } = \mathbf{3\ eV}$$

Metals having work function less than energy of the incident photon will show photoelectric effect. Hence, only Na and K will show photoelectric emission.

CONSTRUCTED RESPONSE QUESTIONS AS PER NEP

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. Explain briefly the reasons why wave theory of light is not able to explain the observed features of photo-electric effect. [*CBSE Delhi 2013; (AI) 2013; (F) 2010; 2019 (55/2/1)*]

Ans. The observed characteristics of photoelectric effect could not be explained on the basis of wave theory of light due to the following reasons.

(*i*) According to wave theory, the light propagates in the form of wavefronts and the energy is distributed uniformly over the wavefronts. With increase of intensity of light, the amplitude of waves and the energy stored by waves will increase. These waves will then, provide more energy to electrons of metal; consequently, the energy of electrons will increase.

Thus, ***according to wave theory, the kinetic energy of photoelectrons must depend on the intensity of incident light; but according to experimental observations, the kinetic energy of photoelectrons does not depend on the intensity of incident light.***

(*ii*) According to wave theory, the light of any frequency can emit electrons from metallic surface provided the intensity of light be sufficient to provide necessary energy for emission of electrons, but according to experimental observations, the light of frequency less than threshold frequency cannot emit electrons; whatever the intensity of incident light may be.

(*iii*) According to wave theory, the energy transferred by light waves will not go to a particular electron, but it will be distributed uniformly to all electrons present in the illuminated surface. Therefore, electrons will take some time to collect the necessary energy for their emission. The time for emission will be more for light of less intensity and vice versa. But experimental observations show that the emission of electrons take place instantaneously after the light is incident on the metal; whatever the intensity of light may be.

Q. 2. Write Einstein's photoelectric equation. State clearly the three salient features observed in photoelectric effect which can explain on the basis of this equation. [*CBSE 2023 (55/1/1)*]

The maximum kinetic energy of the photoelectrons gets doubled when the wavelength of light incident on the surface changes from λ_1 to λ_2. Derive the expressions for the threshold wavelength λ_0 and work function for the metal surface.

[*CBSE Delhi 2015; (AI) 2010; 2020 (55/2/1)*]

Ans. Einstein's photoelectric equation:

$$h\nu = h\nu_0 + eV_0$$

where ν = incident frequency, ν_0 = threshold frequency, V_0 = stopping potential

(*i*) Incident energy of photon is used in two ways (*a*) to liberate electron from the metal surface (*b*) rest of the energy appears as maximum energy of electron.

(*ii*) Only one electron can absorb energy of one photon. Hence increasing intensity increases the number of electrons hence current.

(*iii*) If incident energy is less than work function, no emission of electron will take place.

(*iv*) Increasing ν (incident frequency) will increase maximum kinetic energy of electrons but number of electrons emitted will remain same.

For wavelength λ_1,

$$\frac{hc}{\lambda_1} = \phi_0 + K = \phi_0 + eV_0 \quad \text{where } K = eV_0 \qquad ...(i)$$

For wavelength λ_2,

$$\frac{hc}{\lambda_2} = \phi_0 + 2eV_0 \qquad ...(ii)$$

From equation (*i*) and (*ii*), we get

$$\frac{hc}{\lambda_2} = \phi_0 + 2\left(\frac{hc}{\lambda_1} - \phi_0\right) = \phi_0 + \frac{2hc}{\lambda_1} - 2\phi_0$$

$$\Rightarrow \qquad \phi_0 = \frac{2hc}{\lambda_1} - \frac{hc}{\lambda_2}$$

For threshold wavelength λ_0 kinetic energy, $K = 0$, and work function $\phi_0 = \frac{hc}{\lambda_0}$

$$\therefore \qquad \frac{hc}{\lambda_0} = \frac{2hc}{\lambda_1} - \frac{hc}{\lambda_2}$$

$$\Rightarrow \qquad \frac{1}{\lambda_0} = \frac{2}{\lambda_1} - \frac{1}{\lambda_2} \Rightarrow \lambda_0 = \frac{\lambda_1\lambda_2}{2\lambda_2 - \lambda_1}$$

Work function, $\phi_0 = \dfrac{hc(2\lambda_2 - \lambda_1)}{\lambda_1\lambda_2}$

Q. 3. Using photon picture of light, show how Einstein's photoelectric equation can be established. Write two features of photoelectric effect which cannot be explained by wave theory.

[*CBSE (AI) 2017*]

Ans. In the photon picture, energy of the light is assumed to be in the form of photons each carrying energy.

When a photon of energy '$h\nu$' falls on a metal surface, the energy of the photon is absorbed by the electrons and is used in the following two ways:

(*i*) A part of energy is used to overcome the surface barrier and come out of the metal surface. This part of energy is known as a work function and is expressed as $\phi_0 = h\nu_0$.

(*ii*) The remaining part of energy is used in giving a velocity 'v' to the emitted photoelectron which is equal to the maximum kinetic energy of photo electrons $\left(\frac{1}{2}mv_{\max}^2\right)$.

(*iii*) According to the law of conservation of energy,

$$h\nu = \phi_0 + \frac{1}{2}mv_{\max}^2$$

$$\Rightarrow \quad h\nu = h\nu_0 + \frac{1}{2}mv_{\max}^2 \quad \Rightarrow \quad h\nu = h\nu_0 + KE_{\max}$$

$$\Rightarrow \quad KE_{\max} = h\nu - h\nu_0$$

$$\text{or} \quad KE_{\max} = h\nu - \phi_0$$

This equation is called Einstein photoelectric equation.

Features which cannot be explained by wave theory:

(*i*) The process of photoelectric emission is instantaneous in nature.

(*ii*) There exists a 'threshold frequency' for each photosensitive material.

(*iii*) Maximum kinetic energy of emitted electrons is independent of the intensity of incident light.

Q. 4. Calculate the wavelength of de Broglie waves associated with a proton having $\left(\frac{500}{1.673}\right)$ eV energy. How will the wavelength be affected for an alpha particle having the same energy.

[*CBSE 2023 (55/3/1)*]

Ans. From the de Broglie wave length,

$$\lambda_P = \frac{h}{p} = \frac{h}{\sqrt{2m_P KE}}$$

Given, KE of proton $= \left(\frac{500}{1.673}eV\right)$

$$= \frac{500}{1.673} \times 1.6 \times 10^{-19}\text{J}$$

$$= 4.78 \times 10^{-17}\text{J}$$

Wave length of proton, $\lambda_P = \dfrac{6.6 \times 10^{-34}}{\sqrt{2 \times 1.67 \times 10^{-27} \times 4.78 \times 10^{-17}}}$

$$= \frac{6.6 \times 10^{-34}}{4 \times 10^{-22}} = 1.65 \times 10^{-12}\text{m}$$

For α-particle, $\lambda_\alpha = \dfrac{h}{\sqrt{2m_\alpha KE}}$ [$K.E$ = constant (given)]

$$\Rightarrow \quad \frac{\lambda_P}{\lambda_\alpha} = \sqrt{\frac{m_\alpha}{m_P}} = \sqrt{\frac{4m_P}{m_P}} = 2$$

$$\therefore \quad \lambda_\alpha = \frac{1}{2}\lambda_P = \frac{1}{2} \times 1.65 \times 10^{-12} = 0.825 \times 10^{-12}\text{m}$$

Hence, wavelength for α–particle becomes half of proton's wavelength.

Q. 5. **The work function of a metal is 2.31 eV. Photoelectric emission occurs when light of frequency 6.4×10^{14} Hz is incident on the metal surface. Calculate : (*i*) the energy of the incident radiation, (*ii*) the maximum kinetic energy of the emitted electron and (*iii*) the stopping potential of the surface.** **[*CBSE 2022 (55/3/3), Term-2*]**

Ans.

Given frequency of light $= 6.4 \times 10^{14}$ Hz

Hence energy of incident radiation $= h\nu$

h → Planck's constant $= 6.63 \times 10^{-34}$ J-s

ν → frequency of incident light

$\Rightarrow$ Energy $= 6.63 \times 10^{-34} \times 6.4 \times 10^{14}$ J

$= \frac{6.63 \times 10^{-34} \times 6.4 \times 10^{14}}{1.6 \times 10^{-19}}$ eV [∵ 1 eV = 1.6×10^{-19} J]

$= \frac{26.52}{10} = 2.652$ eV

Ans: Thus energy of incident radiation = 2.652 eV

From photoelectric equation

$K_{max} = E - \phi$

K_{max} → maximum kinetic energy of electrons

E → energy of incident radiation (= 2.652 eV)

ϕ → Work function of metal (= 2.31 eV)

$\Rightarrow K_{max} = (2.652 - 2.31)$ eV

$\Rightarrow K_{max} = 0.342$ eV

Ans: Thus, maximum kinetic energy of emitted electrons is 0.342 eV

Stopping potential of surface $= \frac{K_{max}}{e}$ [e → charge of electron]

$= \frac{0.342 \text{ eV}}{e}$

$= 0.342$ V

Ans: Thus, stopping potential of the surface is 0.342 V

[*Topper's Answer 2022*]

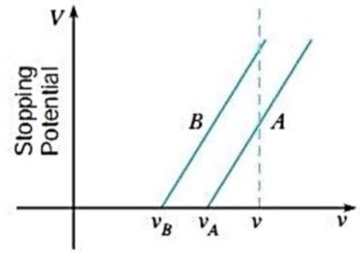
Q. 6. Sketch the graphs showing variation of stopping potential with frequency of incident radiations for two photosensitive materials *A* and *B* having threshold frequencies $\nu_A > \nu_B$.

(*i*) In which case is the stopping potential more and why?

(*ii*) Does the slope of the graph depend on the nature of the material used? Explain.

[*CBSE Central 2016*]

Ans. (*i*) From the graph for the same value of 'ν', stopping potential is more for material '*B*'.



From Einstein's photoelectric equation,

$$eV_0 = h\nu - h\nu_0$$

$$\Rightarrow \quad V_0 = \frac{h}{e}\nu - \frac{h}{e}\nu_0 = \frac{h}{e}(\nu - \nu_0)$$

$\therefore$ V_0 is higher for lower value of ν_0

(*ii*) No, as slope is given by $\frac{h}{e}$ which is a universal constant.

Q. 7. A beam of monochromatic radiation is incident on a photosensitive surface. Answer the following questions giving reasons:

(*i*) Do the emitted photoelectrons have the same kinetic energy?

(*ii*) Does the kinetic energy of the emitted electrons depend on the intensity of incident radiation?

(*iii*) On what factors does the number of emitted photoelectrons depend? [*CBSE (F) 2015*]

Ans. In photoelectric effect, an electron absorbs a quantum of energy $h\nu$ of radiation, which exceeds the work function, an electron is emitted with maximum kinetic energy,

$$K_{max} = h\nu - W$$

(*i*) No, all electrons are bound with different forces in different layers of the metal. So, more tightly bound electron will emerge with less kinetic energy. Hence, all electrons do not have same kinetic energy.

(*ii*) No, because an electron cannot emit out if quantum energy $h\nu$ is less than the work function of the metal. The *K.E.* depends on energy of each photon.

(*iii*) Number of emitted photoelectrons depends on the intensity of the radiations provided the quantum energy $h\nu$ is greater than the work function of the metal.

Q. 8. 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 photon is $\frac{2\lambda mc}{h}$ times the kinetic energy of electron, where *m*, *c*, *h* have their usual meanings. [*CBSE (F) 2016*]

Ans. Due to large mass of a football the de Broglie wavelength associated with a moving football is much smaller than its dimensions, so its wave nature is not visible.

de Broglie wavelength of electron $\lambda = \frac{h}{mv} \Rightarrow v = \frac{h}{m\lambda}$ ....(*i*)

energy of photon $E = \frac{hc}{\lambda}$ (because λ is same)

Ratio of energy of photon and kinetic energy of electrons

$$\frac{E}{E_k} = \frac{hc/\lambda}{\frac{1}{2}mv^2} = \frac{2hc}{\lambda mv^2}$$

Substituting value of v from (*i*), we get

$$\frac{E}{E_k} = \frac{2hc}{\lambda m (h/m\lambda)^2} = \frac{2\lambda mc}{h}$$

$\therefore$ Energy of photon $= \frac{2\lambda mc}{h} \times$ kinetic energy of electron

Q. 9. Find the ratio of the de Broglie wavelengths associated with an alpha particle and a proton, if both

(a) have the same speeds,

(b) have the same kinetic energy,

(c) are accelerated through the same potential difference. [*CBSE 2022 (55/2/1), Term-2*]

Ans. (a) As from de Broglie wave length,

$$\lambda = \frac{h}{p} \qquad [v = \text{Same}] \qquad \frac{1}{2}$$

$$\frac{\lambda_\alpha}{\lambda_\alpha} = \frac{h}{m_\alpha v_\alpha} \times \frac{m_p v_p}{h} = \frac{1}{4} \qquad \frac{1}{2}$$

(b) We know, $p = \sqrt{2m(K.E)}$ [$K.E$ = Same] ½

$$\frac{\lambda_\alpha}{\lambda_p} = \frac{h}{\sqrt{2m_\alpha (K.E.)_\alpha}} \times \frac{\sqrt{2m_p (K.E.)_p}}{h} = \sqrt{\frac{m_p}{m_\alpha}} = \frac{1}{2} \qquad \frac{1}{2}$$

(c) And $v = \sqrt{\frac{2qV}{m}}$ [V = Same] ½

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

$$= \frac{m_p}{m_\alpha}\sqrt{\frac{m_\alpha}{m_p}} \times \sqrt{\frac{q_p}{q_\alpha}} = \frac{1}{2\sqrt{2}} \qquad \frac{1}{2}$$

[*CBSE Marking Scheme 2022 (55/2/1), Term-2*]

Q. 10. 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 [*NCERT*]

(a) maximum kinetic energy of the emitted electrons?

(b) stopping potential and (c) maximum speed of emitted electrons?

Ans. Given $\phi_0 = 2.14$ eV, $\nu = 6\times10^{-14}$ Hz

(a) Maximum kinetic energy of emitted electron,

$$E_k = h\nu - \phi_0 = 6.63 \times 10^{-34} \times 6 \times 10^{14} - 2.14 \times 1.6 \times 10^{-19}$$

$$= 0.554 \times 10^{-19}\text{ J} = \frac{0.554 \times 10^{-19}}{1.6 \times 10^{-19}}\text{ eV} = \mathbf{0.34\ eV}$$

(b) Stopping potential V_0 is given by

$$E_k = eV_0 \Rightarrow V_0 = \frac{E_k}{e} = \frac{0.34\text{ eV}}{e} = \mathbf{0.34\ V}$$

(c) Maximum speed (v_{max}) of emitted electrons is given by

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

or

$$v_{max} = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 0.554 \times 10^{-19}}{9.1 \times 10^{-31}}} = \mathbf{3.48\times10^5\ m/s}$$

Q. 11. (a) Explain de Broglie argument to propose his hypothesis. Show that de Broglie wavelength of photon equals electromagnetic radiation.

(b) If deuterons and alpha particle are accelerated through same potential, find the ratio of the associated de Broglie wavelengths of two. [*CBSE Sample Paper 2021*]

Ans. (*a*) Light exhibits particle aspects in certain phenomena (*e.g.*, photoelectric effect, emission and absorption of radiation), while wave aspects in other phenomena (*e.g.*, interference, diffraction and polarisation). That is, light has dual nature. In analogy with dual nature of light, de Broglie thought in terms of dual nature of matter.

Louis de Broglie postulated that the **material particles** (*e.g.*, electrons, protons, α-particles, atoms, etc.) may exhibit wave aspect. Accordingly, a moving material particle behaves as wave and the wavelength associated with material particle is

$\lambda = \frac{h}{p}$, where p is momentum. ...(*i*)

Momentum of photon of frequency ν is given as $p = \frac{h\nu}{c}$

Equation (*i*) becomes

$$\lambda = \frac{h}{\frac{h\nu}{c}} = \frac{c}{\nu}$$

∴ The wavelength of photon is equal to the wavelength of electromagnetic wave.

(*b*) From de Broglie hypothesis, $\lambda = \frac{h}{\sqrt{2mK}} = \frac{h}{\sqrt{2meV}}$

$$\frac{\lambda_d}{\lambda_\alpha} = \frac{h}{h}\frac{\sqrt{2m_\alpha 2eV}}{\sqrt{2m_d eV}} = \frac{\sqrt{2\times m_\alpha}}{\sqrt{m_d}} = \frac{\sqrt{2\times 4m_p}}{\sqrt{2m_p}} = \frac{\sqrt{4}}{1} = \frac{2}{1}$$

∴ $\lambda_d : \lambda_\alpha$ **= 2 : 1**

Q 12. Determine the value of the de Broglie wavelength associated with the electron orbiting in the ground state of hydrogen atom (Given $E_n = -(13.6/n^2)$ eV and Bohr radius $r_0 = 0.53$ Å). How will the de Broglie wavelength change when it is in the first excited state? [*CBSE Bhubaneshwar 2015*]

Ans. In ground state, the kinetic energy of the electron is

$$K = -E = \frac{+13.6\text{ eV}}{1^2} = 13.6\times 1.6\times 10^{-19}\text{ J} = 2.18\times 10^{-18}\text{ J}$$

de Broglie wavelength, $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}}$

$$= \frac{6.63\times 10^{-34}}{\sqrt{2\times 9.1\times 10^{-31}\times 2.18\times 10^{-18}}}$$

$$= 0.33\times 10^{-9}\text{ m} = 0.33\text{ nm}$$

Kinetic energy in the first excited state (n=2)

$$K = -E = +\frac{13.6}{2^2}\text{ eV} = +3.4\text{ eV} = 3.4\times 1.6\times 10^{-19}\text{ J} = 0.54\times 10^{-18}\text{ J}$$

de Broglie wavelength, $\lambda' = \frac{h}{\sqrt{2mK}}$

$$= \frac{6.63\times 10^{-34}}{\sqrt{2\times 9.1\times 10^{-31}\times 0.544\times 10^{-18}}}$$

$= 2\times 0.33$ nm = **0.66 nm**

i.e., de Broglie wavelength will increase (or double).

Q. 13. Photoelectrons are emitted from a metal surface when illuminated with UV light of wavelength 330 nm. The minimum amount of energy required to emit the electrons from the surface is 3.5×10^{-19} J. Calculate : ***[CBSE 2022 (55/1/1), Term-2]***

(i) the energy of the incident radiation, and

(ii) the kinetic energy of the photoelectron.

Ans. (i) Energy of incident radiation,

$$E = h\nu = h\frac{c}{\lambda} \quad ½$$

$$= \frac{6.63\times10^{-34}\times3\times10^{8}}{330\times10^{-9}} \quad ½$$

$$= 6.027\times10^{-19}\text{ J} \quad ½$$

(ii) Kinetic energy of photoelectron,

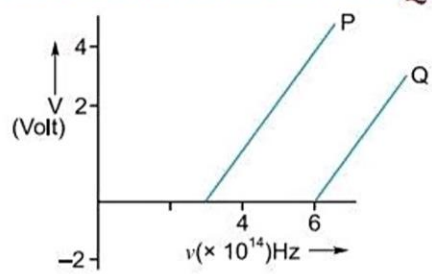
$$K.E. = E - \phi_0 \quad ½$$

$$= (6.027\times10^{-19} - 3.5\times10^{-19})\text{J} \quad ½$$

$$= 2.527\times10^{-19}\text{J} \quad ½$$

[CBSE Marking Scheme 2022 (55/1/1), Term-2]

Q. 14. In the study of a photoelectric effect the graph between the stopping potential *V* and frequency ν of the incident radiation on two different metals *P* and *Q* is shown below:



(i) Which one of the two metals has higher threshold frequency?

(ii) Determine the work function of the metal which has greater value.

(iii) Find the maximum kinetic energy of electron emitted by light of frequency 8×10^{14} Hz for this metal. ***[CBSE Delhi 2017]***

Ans. (i) Threshold frequency of *P* is 3×10^{14} Hz.

Threshold frequency of *Q* is 6×10^{14} Hz.

Clearly *Q* has higher threshold frequency.

(ii) Work function of metal *Q*, $\phi_0 = h\nu_0$

$$= (6.6\times10^{-34})\times6\times10^{14}\text{ J}$$

$$= \frac{39.6\times10^{-20}}{1.6\times10^{-19}}\text{eV} = \mathbf{2.5\ eV}$$

(iii) Maximum kinetic energy, $K_{max} = h\nu - h\nu_0$

$$= h(\nu - \nu_0)$$

$$= 6.6\times10^{-34}(8\times10^{14} - 6\times10^{14})$$

$$= 6.6\times10^{-34}\times2\times10^{14}\text{ J}$$

$$= \frac{6.6\times10^{-34}\times2\times10^{14}}{1.6\times10^{-19}}\text{eV}$$

$$\therefore \quad K_{max} = \mathbf{0.83\ eV}$$

Q. 15. Two monochromatic beams A and B of equal intensity I, hit a screen. The number of photons hitting the screen by beam A is twice that by beam B. Then what inference can you make about their frequencies? [*NCERT Exemplar*]

Ans. Let no. of photons falling per second of beam $A = n_A$

No. of photons falling per second of beam $B = n_B$

Energy of beam $A = h\nu_A$

Energy of beam $B = h\nu_B$

According to question, $I = n_A h\nu_A = n_B h\nu_B$

$$\frac{n_A}{n_B} = \frac{\nu_B}{\nu_A} \text{ or, } \frac{2n_B}{n_B} = \frac{\nu_B}{\nu_A} \Rightarrow \nu_B = 2\nu_A$$

The frequency of beam B is twice that of A.

Q. 16. A monochromatic light source of power 5 mW emits 8×10^{15} photons per second. This light ejects photo electrons from a metal surface. The stopping potential for this set up is 2V. Calculate the work function of the metal. [*CBSE Sample Paper 2016*]

Ans. Given, $P = 5\times10^{-3}$ W, $N = 8 \times 10^{15}$ photons per second

Energy of each photon,

$$E = \frac{P}{N} = \frac{5 \times 10^{-3}}{8 \times 10^{15}} = 6.25 \times 10^{-19}\text{J} = \frac{6.25 \times 10^{-19}}{1.6 \times 10^{-19}}\text{eV}$$

$$= 3.9 \text{ eV}$$

Work function, $W_0 = E - K.E_{max} = E - eV_0$ $\quad [\because K.E_{\max} = eV_0]$

$= (3.9 - 2)$ eV $=$ **1.9 eV**

Long Answer Questions

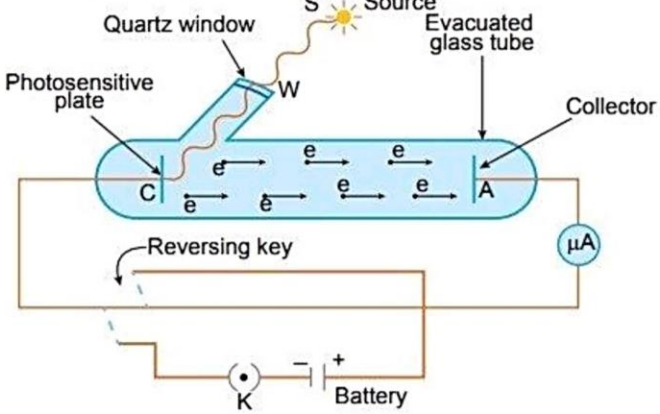
CONSTRUCTED RESPONSE QUESTIONS AS PER NEP

Each of the following questions are of 5 marks.

Q. 1. Describe an experimental arrangement to study photoelectric effect. Explain the effect of (*i*) intensity of light on photoelectric current, (*ii*) potential on photoelectric current and (*iii*) frequency of incident radiation on stopping potential.

Ans. **Experimental study of Photoelectric Effect:** The apparatus consist of an evacuated glass or quartz tube which encloses a photosensitive plate C (called emitter) and a metal plate A (called collector). A transparent window W is sealed on the glass tube which can be covered with a filter for a light of particular radiation. This will allow the light of particular wavelength to pass through it.

The plate A can be given a desired positive or negative potential with respect to plate C, using the arrangement as shown in figure.



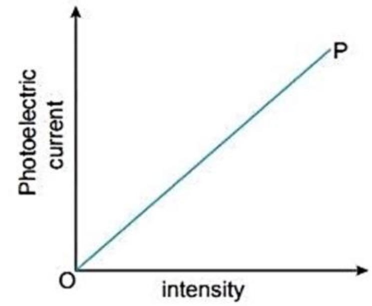
Working: When a monochromatic radiations of suitable frequency obtained from source S fall on the photosensitive plate C, the photoelectrons are emitted from C, which gets accelerated towards the plate A (collector) if it is kept at positive potential.

These electrons flow in the outer circuit resulting in the photoelectric current. Due to it, the microammeter shows a deflection. The reading of microammeter measures the photoelectric current.

This experimental arrangement can be used to study the variation of photoelectric current with the following quantities.

(*i*) **Effect of intensity of the incident radiation:** By varying the intensity of the incident radiations, keeping the frequency constant, it is found that the photoelectric current varies linearly with the intensity of the incident radiation.

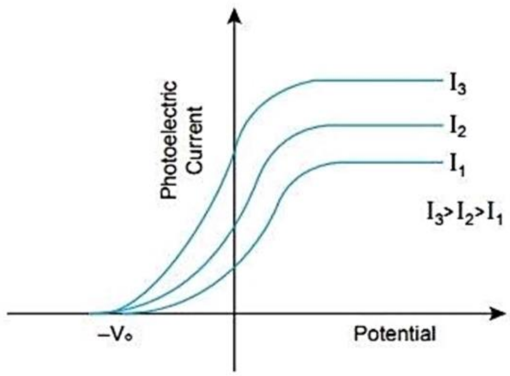
Also, the number of photoelectrons emitted per second is directly proportional to the intensity of the incident radiations.



(*ii*) **Effect of potential of plate A w.r.t place C:** It is found that the photoelectric current increases gradually with the increase in positive potential of plate A.

At one stage for a certain positive potential of plate A, the photoelectric current becomes maximum or saturates. After this if we increase the positive potential of plate A, there will be no increase in the photoelectric current.

This maximum value of current is called saturation current: The saturation current corresponds to the state when all the photoelectrons emitted from C reach the plate A.



Now apply a negative potential on plate A w.r.t. plate C. We will note that the photoelectric current decreases, because the photoelectrons emitted from C are repelled and only energetic photoelectrons are reaching the plate A.

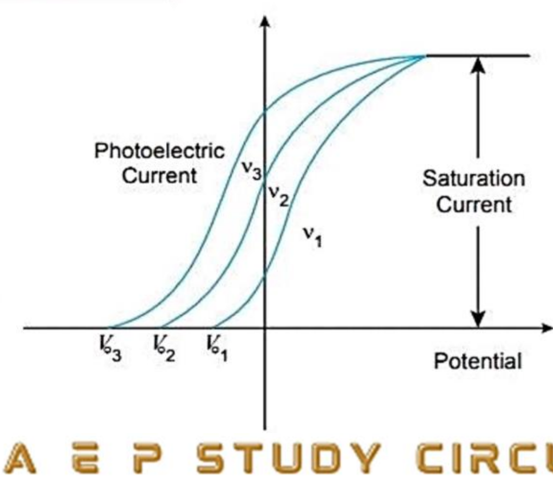
By increasing the negative potential of plate A, the photoelectric current decreases rapidly and becomes zero at a certain value of negative potential V_0 on plate A.

This maximum negative potential V_0, given to the plate A w.r.t. plate C at which the photoelectric current becomes zero is called stopping potential or cut off potential.

$$K_{max} = eV_0 = \frac{1}{2} m V_{max}^2$$

where e = charge on electron, m = mass of electrons, V_{max} = maximum velocity of emitted photoelectrons.

The value of stopping potential is independent of the intensity of the incident radiation. It means, the maximum kinetic energy of emitted photoelectrons depends on the radiation source and nature of material of plate C but is independent of the intensity of incident radiation.

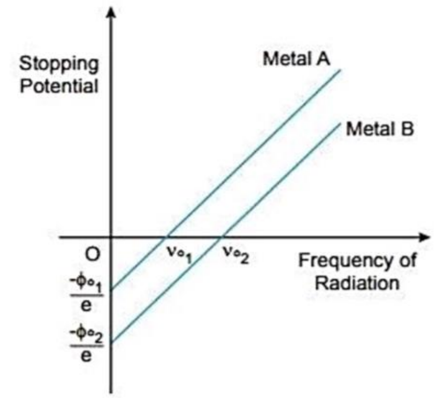


(*iii*) **Effect of frequency of the incident radiation:** When we take the radiations of different frequencies but of same intensity, then the value of stopping potential is different for radiation of different frequency.

The value of stopping potential is more negative for radiation of higher incident frequency. The value of saturation current depends on the intensity of incident radiation but is independent of the frequency of the incident radiation.

(*iv*) **Effect of frequency on stopping potential:** For a given photosensitive material, the stopping potential varies linearly with the frequency of the incident radiation.

For every photosensitive material, there is a certain minimum cut off frequency ν_0 (threshold frequency) for which the stopping potential is zero.



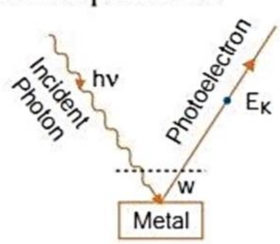
The intercept on the potential axis $= -\frac{\phi_0}{e} = -\frac{h\nu_0}{e}$.

Hence, work function $\phi_0 = e \times$ magnitude of intercept on the potential axis

Q. 2. Derive Einstein's photoelectric equation $\frac{1}{2}mv^2 = h\nu - h\nu_0$.

Ans. Einstein's Explanation of Photoelectric Effect: Einstein's Photoelectric Equation

Einstein explained photoelectric effect on the basis of quantum theory. The main points are



1. Light is propagated in the form of bundles of energy. Each bundle of energy is called a **quantum** or **photon** and has energy $h\nu$ where h = Planck's constant and ν = frequency of light.
2. The photoelectric effect is due to collision of a photon of incident light and a bound electron of the metallic cathode.
3. When a photon of incident light falls on the metallic surface, it is completely absorbed. Before being absorbed it penetrates through a distance of nearly 10^{-8} m (or 100 Å). The absorbed photon transfers its whole energy to a single electron. The energy of photon goes in two parts: a part of energy is used in releasing the electron from the metal surface (*i.e.*, in overcoming work function) and the remaining part appears in the form of kinetic energy of the same electron.

If ν be the frequency of incident light, the energy of photon $= h\nu$. If W be the work function of metal and E_K the maximum kinetic energy of photoelectron, then according to Einstein's explanation.

$$h\nu = W + E_K$$

or $$E_K = h\nu - W \quad \text{...}(i)$$

This is called **Einstein's photoelectric equation.**

If ν_0 be the threshold frequency, then if frequency of incident light is less then ν_0 no electron will be emitted and if the frequency of incident light be ν_0 then $E_K = 0$; so from equation (*i*)

$$0 = h\nu_0 - W \quad \text{or} \quad W = h\nu_0$$

If λ_0 be the threshold wavelength, then $\nu_0 = \frac{c}{\lambda_0}$,

where c is the speed of light in vacuum

$\therefore$ Work function $W = h\nu_0 = \frac{hc}{\lambda_0}$

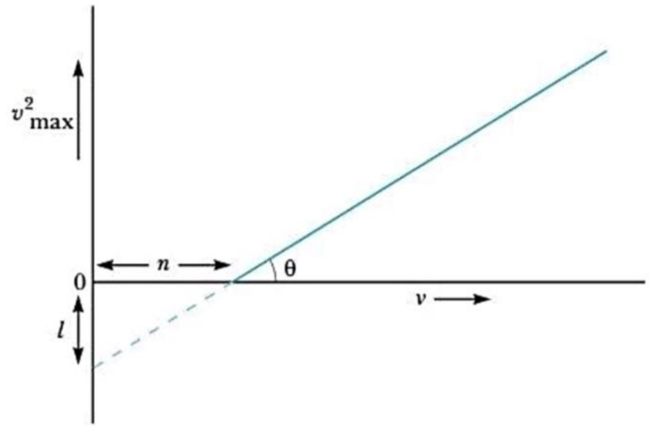
Substituting this value in equation (*i*), we get

$$E_K = h\nu - h\nu_0 \quad \Rightarrow \quad \frac{1}{2}mv^2 = h\nu - h\nu_0$$

This is another form of Einstein's photoelectric equation.

Q. 3. (*a*) **Give a brief description of the basic elementary process involved in the photoelectric emission in Einstein's picture.**

(*b*) **When a photosensitive material is irradiated with the light of frequency ν, the maximum speed of electrons is given by v_{max}. A plot of v^2_{max} is found to vary with frequency ν as shown in the figure.**



Use Einstein's photoelectric equation to find the expressions for

(*i*) **Planck's constant and**

(*ii*) **work function of the given photosensitive material, in terms of the parameters *l*, *n* and mass *m* of the electron.**

Ans. (*a*) Refer to Q. 2, Long Answer Questions.

(*b*) (*i*) v_1^2 and v_2^2 are the velocities of the emitted electrons for radiations of frequencies $\nu_1 > \nu$ and $\nu_2 > \nu$ respectively. So,

$$h\nu_1 = h\nu + \frac{1}{2}mv_1^2 \qquad \ldots(i)$$

and

$$h\nu_2 = h\nu + \frac{1}{2}mv_2^2 \qquad \ldots(ii)$$

From equation (*i*) and (*ii*), we get

$$h(\nu_2 - \nu_1) = \frac{1}{2}m(v_2^2 - v_1^2) \quad \Rightarrow \quad h = \frac{\frac{1}{2}m(v_2^2 - v_1^2)}{(\nu_2 - \nu_1)}$$

Slope of v^2_{max} vs frequency graph is

$$\tan\theta = \frac{v_2^2 - v_1^2}{(\nu_2 - \nu_1)}$$

$$\therefore \quad h = \frac{1}{2}m \cdot \tan\theta$$

From graph $\tan\theta = \frac{l}{n}$

So, $$h = \frac{1}{2}m\left(\frac{l}{n}\right) \qquad \ldots(iii)$$

(*ii*) From graph, the work function of the material is

$$W = hn \qquad \ldots(iv)$$

From equations (*iii*) and (*iv*), we get

$$W = \frac{1}{2}m\left(\frac{l}{n}\right) \times n = \frac{1}{2}ml$$

Questions for Practice

1. **Choosen and write the correct option in the following questions.**

   (*i*) Two particles A_1 and A_2 of masses m_1, m_2 ($m_1 > m_2$) have the same de Broglie wavelength. Then **[*NCERT Exemplar*]**

   (*a*) their momenta are the same

   (*b*) their energies are the same

   (*c*) energy of A_1 is less than the energy of A_2

   (*d*) energy of A_1 is more than the energy of A_2

   (*ii*) The threshold frequency for a photosensitive metal is 3.3×10^{14} Hz. If light of frequency 8.2×10^{14} Hz is incident on this metal, the cut-off voltage for the photoelectron emission is nearly

   (*a*) 1 V (*b*) 2 V

   (*c*) 3 V (*d*) 5 V

   (*iii*) When the light of frequency $2\nu_0$ (where ν_0 is threshold frequency), is incident on a metal plate, the maximum velocity of electrons emitted is v_1. When the frequency of the incident radiation is increased to $5\nu_0$, the maximum velocity of electrons emitted from the same plate is v_2. The ratio of v_1 to v_2 is

   (*a*) 1 : 2 (*b*) 1 : 4

   (*c*) 4 : 1 (*d*) 2 : 1

   (*iv*) Photoelectric effect supports

   (*a*) Newton's corpuscular nature of light

   (*b*) Huygen's wave theory of light

   (*c*) Maxwell's electromagnetic theory of light

   (*d*) Einstein's quantum theory of light

   (*v*) Which one of the following metals does not exhibit emission of electrons from its surface when irradiated by visible light? **[*CBSE 2023 (55/2/1)*]**

   (*a*) Rubidium (*b*) Sodium (*c*) Cadmium (*d*) Caesium

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

   (a) ***Both A and R are true and R is the correct explanation of A.***

   (b) ***Both A and R are true but R is not the correct explanation of A.***

   (c) ***A is true but R is false.***

   (d) ***A is false and R is also false.***

   Assertion (*A*) : On increasing the frequency of light, the photocurrent remains unchanged.

   Reason (*R*) : Photocurrent is independent of frequency but depends only on intensity of incident light.

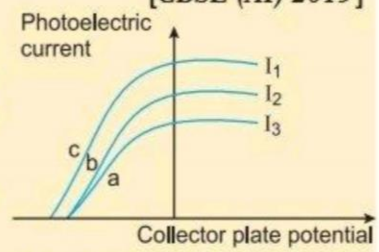
3. Plot a graph of the de Broglie wavelength associated with a proton versus its momentum.

4. In a photoelectric experiment, the potential required to stop the ejection of electrons from cathode is 4 V. What is the value of maximum kinetic energy of emitted photoelectrons? **[*CBSE Sample Paper 2021*]**

5. A proton and an electron have equal speeds. Find the ratio of de Broglie wavelengths associated with them. **[*CBSE 2020 (55/1/1)*]**

6. 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. **[CBSE (AI) 2013]**

7. The figure shows a plot of three curves *a, b, c* showing the variation of photocurrent verses collector plate potential for three different intensities I_1, I_2, and I_3 having frequencies ν_1, ν_2 and ν_3 respectively incident on a photosenitive surface.



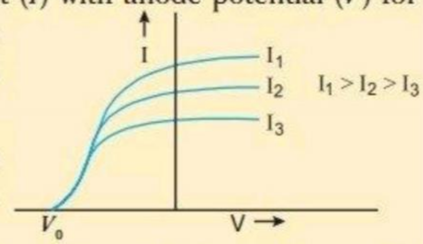
Point out the two curves for which the incident radiations have same frequency but different intensities. **[CBSE Delhi 2009]**

8. The stopping potential in an experiment on photoelectric effect is 1.5 V. What is the maximum kinetic energy of the photoelectrons emitted? **[CBSE (AI) 2009]**

9. The maximum kinetic energy of a photoelectron is 3 eV. What is its stopping potential? **[CBSE (AI) 2009]**

10. An electron and a proton have the same kinetic energy. Which one of the two has the larger de Broglie wavelength and why? **[CBSE (AI) 2012]**

11. (*a*) Draw a graph showing variation of photo-electric current (I) with anode potential (V) for different intensities of incident radiation. Name the characteristic of the incident radiation that is kept constant in this experiment.



(*b*) If the potential difference used to accelerate electrons is doubled, by what factor does the de Broglie wavelength associated with the electrons change? **[CBSE (F) 2009]**

12. Show on a graph the variation of the de Broglie wavelength (λ) associated with an electron, with the square root of accelerating potential (V). **[CBSE (F) 2012] [HOTS]**

13. What are matter waves? Find the ratio of de Broglie wavelengths associated with proton and alpha particles when both particles

(*a*) are accelerated through the same potential difference.

(*b*) have same velocity. **[CBSE 2020 (55/3/2)]**

14. Explain, how the process of emission of photoelectrons is different from the process of emission of β-particles. **[CBSE 2020 (55/1/3)]**

15. Light of wavelength 2500 Å falls on a metal surface of work function 3.5 eV. What is the kinetic energy (in eV) of (*i*) the fastest and (*ii*) the slowest electronic emitted from the surface?

If the same light falls on another surface of work function 5.5 eV, what will be the energy of emitted electrons?

16. In case of photo electric effect experiment, explain the following facts, giving reasons.

(*a*) The wave theory of light could not explain the existence of the threshold frequency.

(*b*) The photo electric current increases with increase of intensity of incident light. **[CBSE 2020 (55/5/2)]**

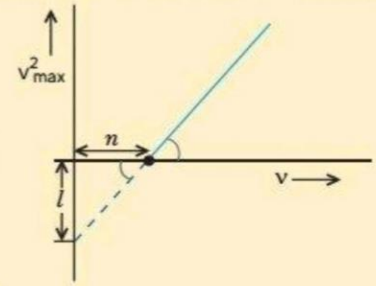
17. Explain how does (*i*) photoelectric current and (*ii*) kinetic energy of the photoelectrons emitted in a photocell vary if the frequency of incident radiation is doubled, but keeping the intensity same? Show the graphical variation in the above two cases. **[CBSE Sample Paper 2022, Term-2]**

18. Plot a graph showing variation of de Broglie wavelength (λ) associated with a charged particle of mass m, versus $1/\sqrt{V}$, where V is the potential difference through which the particle is accelerated. How does this graph give us the information regarding the magnitude of the charge of the particle?

(*b*) What will be the change in the energy of the emitted electrons if the intensity of light with same wavelength is doubled?

(*c*) If the same light falls on another surface of work function 6.5 eV, what will be the energy of emitted electrons? **[*CBSE Sample Paper 2022, Term-2*]**

20. When a given photosensitive material is irradiated with light of frequency ν, the maximum speed of the emitted photoelectrons equals v_{max}. The graph shown in the figure gives a plot of v^2_{max} varying with frequency ν.



Obtain an expression for

(*a*) Planck's constant, and

(*b*) The work function of the given photosensitive material in terms of the parameters '*l*', '*n*' and the mass '*m*' of the electron.

(*c*) How is threshold frequency determined from the plot?

21. An electron is accelerated from rest through a potential difference of 100 V. Find:

(*i*) the wavelength associated with

(*ii*) the momentum of and

(*iii*) the velocity required by, the electron. **[*CBSE 2022 (55/3/1) Term-2*]**

22. Light of same wavelength is incident on three photo-sensitive surfaces A, B and C. The following observations are recorded.

(*i*) From surface A, photo electrons are not emitted.

(*ii*) From surface B, photo electrons are just emitted.

(*iii*) From surface C, photo electrons with some kinetic energy are emitted. Compare the threshold frequencies of the three surfaces and justify your answer. **[*CBSE 2020 (55/4/1)*]**

23. How does Einstein's photoelectric equation explain the emission of electrons from a metal surface ? Explain briefly. **[*CBSE 2023 (55/1/1), Term-2*]**

Plot the variation of photo current with

(*a*) collector plate potential for different intensity of incident radiation, and

(*b*) intensity of incident radiation.

24. Find the (*a*) maximum frequency and (*b*) minimum wavelength of *X*-rays produced by 30 kV electrons. **[*NCERT*]**

25. An electron and a proton, each have de Broglie wavelength of 1.00 nm.

(*a*) Find the ratio of their momenta.

(*b*) Compare the kinetic energy of the proton with that of the electron.

[*NCERT*] [*CBSE (F) 2013*]

26. In an experiment of photoelectric effect, the slope of cut-off voltage versus frequency of incident light is found to be 4.12×10^{-15} Vs. Calculate the value of Planck's constant. **[*NCERT*]**

27. 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 photoelectric emission. **[*NCERT*]**

28. A proton and an electron have same velocity. Which one has greater de Broglie wavelength and why? **[*CBSE (AI) 2012*]**

29. 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. ***[CBSE North 2016, Delhi 2014]***

30. 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. ***[CBSE (AI) 2012]***

31. A proton and a deuteron are accelerated through the same accelerating potential. Which one of the two has

(*i*) greater value of de Broglie wavelength associated with it, and

(*ii*) less momentum?

Give reasons to justify your answer. ***[CBSE Delhi 2014]***

32. A proton and an α-particle have the same de Broglie wavelength. Determine the ratio of (*i*) their accelerating potentials (*ii*) their speeds. ***[CBSE Delhi 2015; 2019 (55/4/1)]***

33. (*a*) Define the term 'intensity of radiation' in terms of photon picture of light.

(*b*) Two monochromatic beams, one red and the other blue, have the same intensity. In which case (*i*) the number of photons per unit area per second is larger, (*ii*) the maximum kinetic energy of the photoelectrons is more? Justify your answer. ***[CBSE Patna 2015]***

34. Ultraviolet light of wavelength 2270 Å from 100 W mercury source irradiates a photo cell made of a given 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 ($\sim 10^5$ Wm^{-2}) red light of wavelength 6300 Å produced by a laser? ***[CBSE Bhubaneshwar 2015]***

Answers

1. (*i*) (*a*), (*c*) (*ii*) (*b*) (*iii*) (*a*) (*iv*) (*d*) (*v*) (*c*)

2. (*a*) **4.** 4 eV **5.** $5.45 \times 10^{-4} : 1$ **8.** 2.4×10^{-19} J

9. 3V **13.** (*a*) $2\sqrt{2} : 1$ (*b*) 4 : 1 **15.** (*i*) 1.47 eV (*ii*) 0

19. (*a*) 2.0 eV **24.** (*a*) 7.24×10^{18} Hz (*b*) 0.041 mm

25. (*a*) 1 : 1 (*b*) 5.4×10^{-4} **26.** 6.59×10^{-34} Js

32. (*i*) 8 : 1 (*ii*) 4 : 1 **34.** 4.2 eV