UNIT VII-DUAL NATURE OF RADIATION AND MATTER
CH–11: DUAL NATURE OF RADIATION AND MATTER

GIST OF CHAPTER

Dual nature of radiation, Photoelectric effect, Hertz and Lenard's observations; Einstein's photoelectric equation-particle nature of light. Experimental study of photoelectric effect, Matter waves-wave nature of particles, de-Broglie relation.

DEFINITION & CONCEPTS: -

Free electrons: - In metals, the electrons in the outer shell of the atoms are loosely bound. They move about freely throughout the lattice of positive ions. Such loosely bound electrons are called free electrons.

Work function of a metal. The minimum energy, which must be supplied to the electron so thatit can just come out of a metal surface, is called the work function of the metal. It is denoted by W_0.

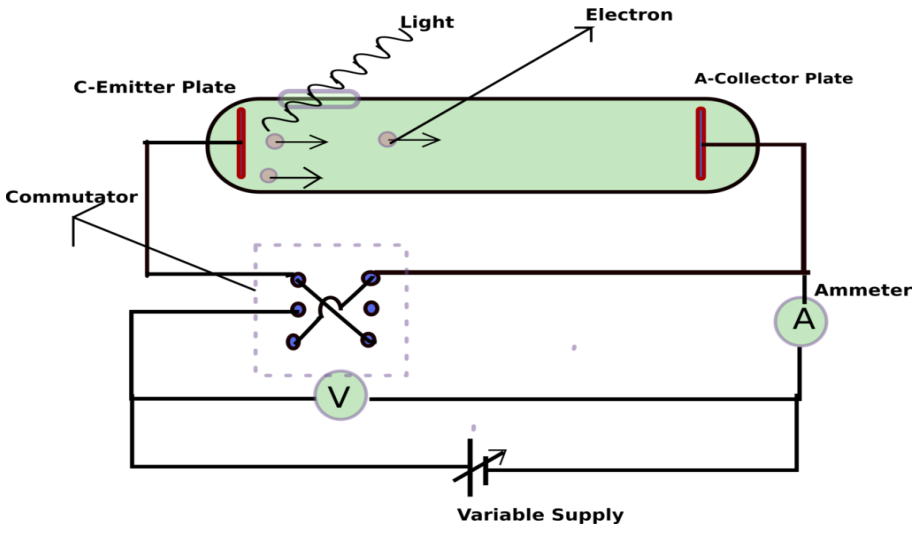
Work function depends on (i) nature of the metal (ii) the conditions of its surface.

Electron emission: - The phenomenon of ejecting out the electron from metal surface is called electron emission.

PHOTOELECTRIC EMISSION/ EFFECT: -.

The phenomenon of ejection of electrons from a metal surface, when light of sufficiently high frequency falls on it, is known as photoelectric effect.

The electrons so emitted are called **photoelectrons**



Hertz's observation: -While demonstrating the existence of electromagnetic waves, Hertz foundthat high voltage sparks passed across the metal electrodes of the detector loop more easily when the cathode was illuminated by ultraviolet light from an arc lamp. The uv light falling on metal surface caused the emission of negatively charged particles (electrons) into surrounding space and enhance the high voltage sparks**.**

Hallwachs and Lenard Observation: - It was observed that if the frequency of incident light is lessthan certain minimum value (Threshold frequency) emission of photo electrons do not takes place.

Threshold frequency. The minimum frequency (ν_0), which the incident light must possess so asto eject photoelectrons from a metal surface, is called threshold frequency of the metal.

Mathematically- Work function W = hν_0

Laws of photoelectric effect.

1. Photoelectric emission takes place from a metal surface, when the frequency of incident lightis above its threshold frequency.

2. The photoelectric emission starts as soon as the light is incident on the metal surface.

3. The maximum kinetic energy with which an electron is emitted from a metal surface is independent of the intensity of light and depends upon its frequency.

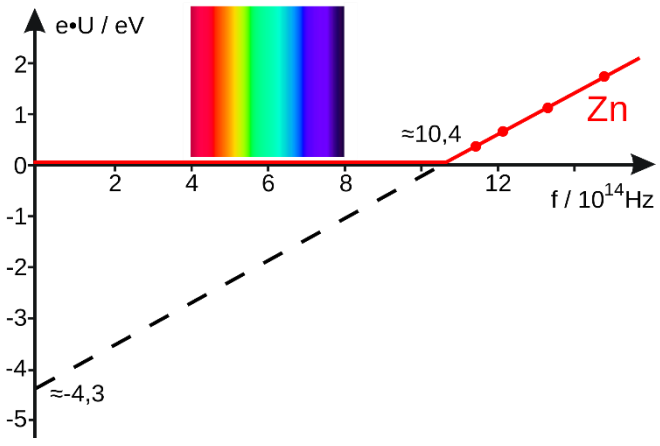
4. The number of photoelectrons emitted is independent of the frequency of the incident lightand depends only upon its intensity.

The Effect of Intensity:-

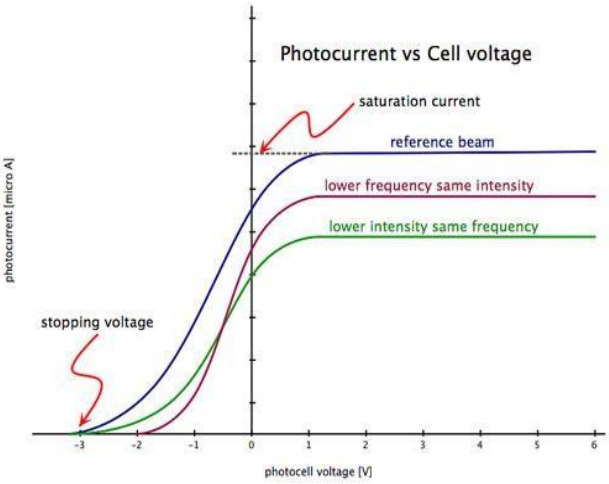
The number of electrons emitted per second is observed to be directly proportional to the intensity oflight.

This happens above the threshold frequency. Below this threshold frequency there is no photocurrent at all, howsoever high the intensityof light is.

The graph between the photoelectric current straight line when the frequency of light used isvalue.



The Effect of the Potential:-



The photoelectric current increases with increase in accelerating (positive) potential of collectorplate. For a certain positive potential of plate A, the photoelectric current becomes maximum and constant or saturates. *This maximum value of the photoelectric current is called* ***saturation current***.

Saturation current corresponds to the case when all the photoelectrons emitted by the emitter plateC reach the collector plate A.

Saturation current **increases with increase in intensity** of incident radiation. The photoelectric current **decreases with negative potential** of collector plate.

STOPPING POTENTIAL (V_0):-

At certain negative potential of the collector plate the photocurrent becomes zero. This negative potential is called **STOPPING POTENTIAL (**V_0).

The stopping potential is measure of maximum kinetic energy of photoelectron.

$$1/2\ mv^2_{max} = eV_o$$

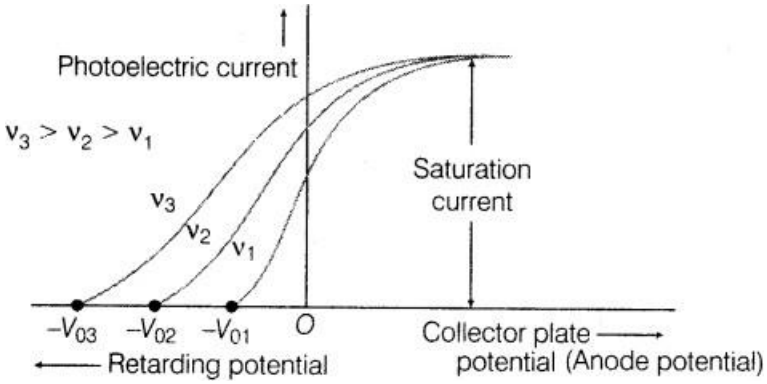
Where v_{max} is the maximum velocity with which the photoelectrons are emitted

Effect of intensity of incident radiation on stopping potential

- Stopping potential **does not change** on changing the intensity of incident radiation.
- The maximum kinetic energy of photoelectron **thus does not depend on intensity of incident radiation.**

EFFECT OF FREQUENCY:

- Saturation Photocurrent **does not change** on changing frequency of incident radiation.
- The rate of emission of photoelectron does not depend on frequency of incident radiation.

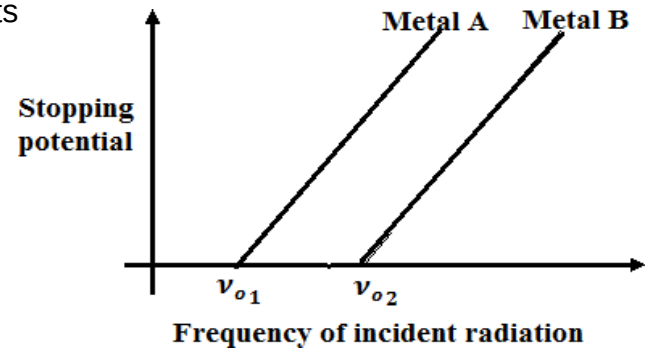


Effect of frequency on stopping potential

- Stopping potential increases on increasing frequency of incident radiation. maximumkinetic energy of photoelectron thus depends on frequency of incident radiation

Graph between stopping potential and frequency

- Graph between stopping potential and frequency of incident radiation is always a straightline.
- Slope of this graph is constant and its value *is* $\frac{h}{e}$.
- Thus **maximum kinetic energy ofphotoelectron** vary linearly with frequency of incident radiation.
- There exists a certain minimum cut-off frequency v_o for which the stopping potential is zero.



EINSTEIN'S PHOTOELECTRIC THEORY

Electromagnetic Radiation energy is built up of discrete units PHOTONS – the so called quantaof energy of radiation

In interaction of Electromagnetic Radiation with matter, radiation behaves as if it is made up ofparticles called photons.

Photo electric emission: Each Photon of incident radiation interacts with a single electron and ifenergy of photon (hv) is equal to or greater than work function, the electron is emitted.

When light of frequency v is incident on a metal surface, whose work function is W then themaximum kinetic energy of the emitted photoelectrons is given by

$$h\nu = \frac{1}{2} m v^2_{max} + \phi_o \qquad \Rightarrow \qquad \frac{1}{2} m v^2_{max} = h(\nu - \nu_o)$$

This is called **EINSTEIN'S PHOTOELECTRIC EQUATION**. It can explain the laws of photoelectric emission.

Properties of Photon:-

(i) In interaction of radiation with matter, radiation behaves as if it is made of particles like photons.

(ii) Each photon has energy (E= $h\nu$) and momentum (p=$h\nu$/c)

(iii) All photons of a particular frequency ν or wavelength have same energy (E= $h\nu$=h c/ λ)and same momentum (p=$h\nu$/c= h/ λ) irrespective of intensity of radiations.

(iv) Velocity of photon in different media is different due to change in its wave length.

(v) Rest mass of photon is zero.

(vi) During collision of photon and electron energy and momentum are conserved.

If stopping potential is V_o then, $Max.\ KE\ of\ photo\ electron = e\ V_o$

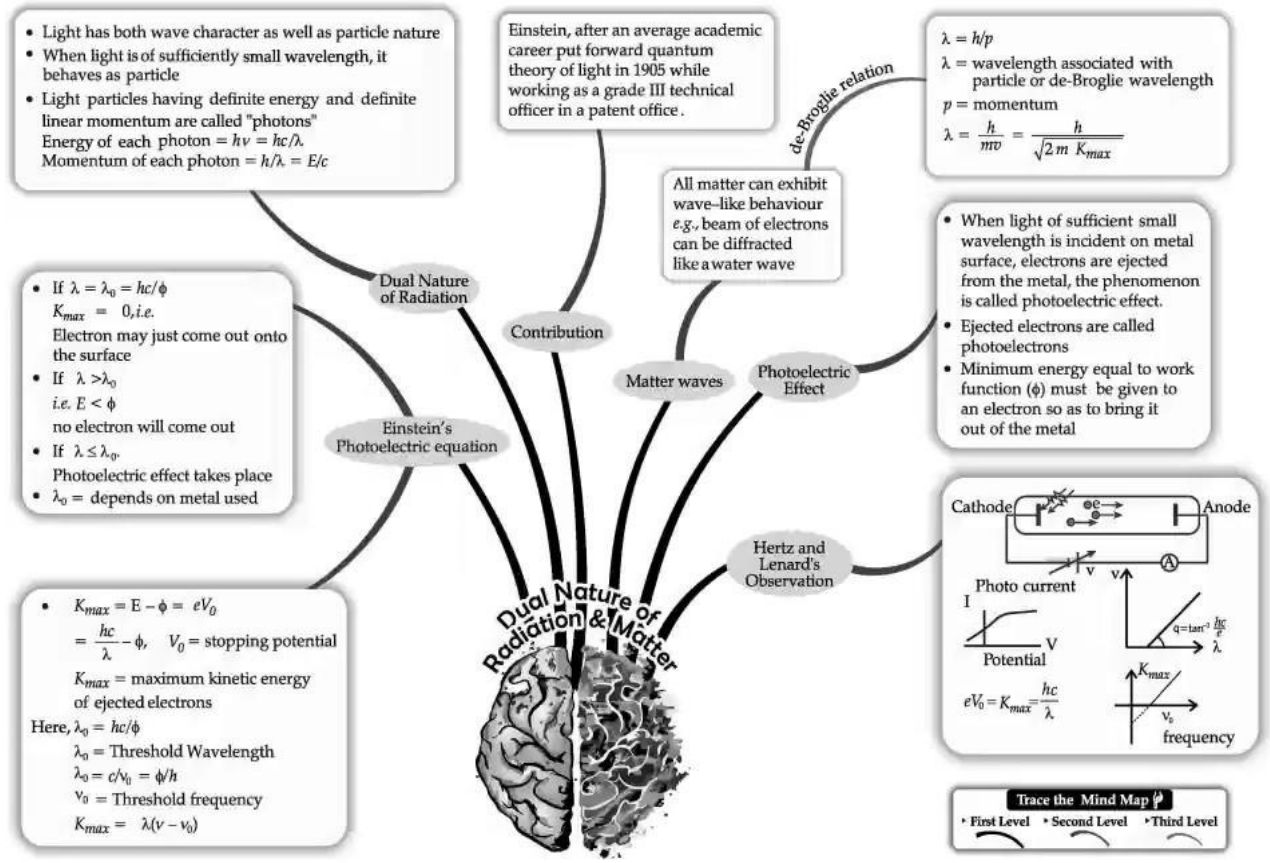
$$\Rightarrow e\ V_o = h\nu - \phi_o = h(\nu - \nu_o)$$

This explains why the $V_o$versus ν curve is a straight line with slope = (h/e), independent ofthe nature of the material.

DE-BROGLIE HYPOTHESIS.

Both radiation and matter have dual nature. A moving particle of momentum p is associated witha wave called de-Broglie wave of wavelength.

MIND MAP


Dual Nature of Radiation & Matter
Dual Nature of Radiation
Light has both wave character as well as particle nature
When light is of sufficiently small wavelength, it behaves as particle
Light particles having definite energy and definite linear momentum are called "photons"
Energy of each photon = $h\nu = hc/\lambda$
Momentum of each photon = $h/\lambda = E/c$
Contribution
Einstein, after an average academic career put forward quantum theory of light in 1905 while working as a grade III technical officer in a patent office.
Matter waves
de-Broglie relation
All matter can exhibit wave–like behaviour e.g., beam of electrons can be diffracted like a water wave
$\lambda = h/p$
λ = wavelength associated with particle or de-Broglie wavelength
p = momentum
$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2m\ K_{max}}}$
Photoelectric Effect
When light of sufficient small wavelength is incident on metal surface, electrons are ejected from the metal, the phenomenon is called photoelectric effect.
Ejected electrons are called photoelectrons
Minimum energy equal to work function (ϕ) must be given to an electron so as to bring it out of the metal
Hertz and Lenard's Observation
Cathode
Anode
Photo current
I
V
Potential
$q=\tan^{-1}\frac{hc}{e}$
λ
K_{max}
$eV_0 = K_{max} = \frac{hc}{\lambda}$
ν_0
frequency
Einstein's Photoelectric equation
If $\lambda = \lambda_0 = hc/\phi$
$K_{max} = 0$, i.e.
Electron may just come out onto the surface
If $\lambda > \lambda_0$
i.e. $E < \phi$
no electron will come out
If $\lambda \leq \lambda_0$.
Photoelectric effect takes place
λ_0 = depends on metal used
$K_{max} = E - \phi = eV_0$
$= \frac{hc}{\lambda} - \phi$, V_0 = stopping potential
K_{max} = maximum kinetic energy of ejected electrons
Here, $\lambda_0 = hc/\phi$
λ_0 = Threshold Wavelength
$\lambda_0 = c/\nu_0 = \phi/h$
ν_0 = Threshold frequency
$K_{max} = \lambda(\nu - \nu_0)$
Trace the Mind Map
First Level
Second Level
Third Level

List of Formula

1. Energy of a photon $E = h\upsilon = \frac{hc}{\lambda}$
2. Number of photon emitted per second $N = \frac{P}{E}$
3. Momentum of photon $P = mc = \frac{h}{c} = \frac{h}{\lambda} = \frac{E}{c}$
4. Equivalent mass of photon $m = \frac{h}{c2} = \frac{E}{c2} = \frac{h}{c\lambda}$
5. Work function $W_0 = h\upsilon_0 = \frac{hc}{\lambda 0} =$
6. Kinetic energy of photoelectron is given by Einstein's photoelectric equation: $K_{max} = \frac{1}{2}mV^2 = h\upsilon - W_0 = h(\upsilon - \upsilon_0) = h\left(\frac{c}{\lambda} - \frac{c}{\lambda 0}\right)$
7. If V_0 is the stopping potential, the maximum kinetic energy of the ejected photoelectron, $K = \frac{1}{2}mv_{max}^2 = eV_0$
8. Kinetic energy of De-Broglie Waves $K = \frac{1}{2}mv2 = P^2/2m$
9. Momentum of De-Broglie Waves $P = \sqrt{2mK}$
10. Wavelength of De-Broglie Waves $\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{(2mK)}}$
11. De –Broglie Wavelength of an electron beam accelerated through a potential difference of V volts is $\lambda = \frac{h}{\sqrt{(2meV)}} = \frac{1.23}{\sqrt{V}}\text{ nm} = \frac{12.27}{\sqrt{V}}\text{ A}^0$
12. De –Broglie Wavelength associated with gas molecules of mass m at temperature T kelvin is $\lambda = \frac{h}{\sqrt{(2mKT)}}$ K = Boltzmann constant
13. The value of hc = 12400eV A^0
14. The Value of $\frac{hc}{e} = 1240 \text{ X } 10^{-9}$ eV m

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MULTIPLE CHOICE QUESTIONS

LEVEL 1

1. **The minimum energy required to remove an electron is called**

a. Stopping potential b. Kinetic energy c.Work function d.None of these

2. In which of the following, emission of electrons does not take place?
   a. Thermionic emission b. X-rays emission c. Photoelectric emission d.Secondary emission
3. Which of the following when falls on a metal will emit photo electrons?
   a. UV radiations b. Infrared radiation c. Radio waves d. Microwaves
4. Which of the following metals is not sensitive to visible light?
   a. Cesium b. Sodium c. Rubidium d. Cadmium
5. Photons are deflected by
   a. electric field only b. magnetic field only c. electromagnetic field d.None of these
6. The emission of electrons does not occur in which of the following?

   a. Photoelectric Emission b. Thermionic Emission c, Secondary Emission d. X-Ray Emission
7. What happens to the kinetic energy of the emitted electrons when the light is incident on a metal surface?

   a. It varies with the frequency of light
   b. It varies with the light intensity
   c. It varies with the speed of light
   d. It varies irregularly
8. A photoelectric cell is a device which
   a. Converts light energy into electricity
   b. Converts electricity into light energy
   c. Stores Light energy
   d. Stores Electricity
9. What does a cathode ray consist of?

   a. Electrons b. Protons c. Photons d. Alpha particles
10. Who gave the theory of quantization of electric charge?

    a. J.J Thomason b. William Crookes c. R.A Millikan d. Wilhelm Hallwachs
11. Which of the following metals is not sensitive to visible light?

    a. Rubidium b. Sodium c. Caesium d. Cadmium
12. Which of the following does the wave theory of light not explain?

    a. Diffraction b. Photocurrent c. Polarization d. Interference

13. Photons are deflected by

a. Magnetic field only b. Electric field only c. Electromagnetic field d. None of the above

14. The photoelectric effect is based on the law of conservation of

a. Energy b. Momentum c. Mass d. Angular momentum

15. Photon does not possess

a. Energy b. Momentum c. Rest Mass d. Frequency

16. The momentum of a photon of wavelength λ is

a. hλ b. h/λ c. λ/h d. h/c λ

17. Maximum KE of photo electrons is 4 e V Then the stopping potential is

a. 4 V b. 1.6 V c. 4 J d. 4 e V

18. The slope of stopping potential vs frequency of the incident light graph is

a. e/h b. h/e c. h/c d. c/h.

19. Photoelectric effect shows

a. wave like behavior of light
b. particle like behavior of light
c. both wavelike and particle like behavior
d. neither wave like nor particle like behavior of light.

20. An electron and a proton have the same de Broglie wave length. Which of them have greater velocity?

a. Electron b. proton. c. both a and b d. none of the above.

LEVEL 2

1. Photoelectric emission from a given surface of metal can take place when the value of a physical quantity is less than the energy of incident photon. The physical quantity is

a. threshold frequency b. work function of surface c. threshold wavelength

d. stopping potential

2. The photoelectric work function for a metal surface is 4.14eV. The cut-off wavelength for this is

a. 4125 A˚ b. 2062.5A˚ c. 3000A˚ d. 6000A˚

3. 1eV is energy acquired by an electron when it is accelerated through potential difference of –

a. 1 V b. 2 V c. 3 V d. 4 V.

4. An electron, an alpha particle, a deutron and a proton have the same KE. which one has shortest de Broglie wavelength?

a. α particle b. electron c. proton d. deutron.

5. Photons of energies 1eV and 2eV are successively incident on a metallic surface of work function 0.5eV. The ratio of kinetic energy of most energetic photoelectrons in the two cases will be

a. 1:2 b.1:1 c. 1:3 d.1:4.

6. When a metallic surface is illuminated with radiation of wavelength λ, the stopping

potential is V. If the same surface is illuminated with radiation of wavelength 2λ, the stopping potential is V/4. The threshold wavelength for the metallic surface is

a. 4λ b. 5λ c. 5/2λ d. 3λ.

7. In an electron microscope, the electrons are accelerated by a voltage of 14 kV. If the voltage is changed to 224 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.

8. A particle of mass 3×10^{-6} g has the same wavelength as an electron moving with a velocity 6×10^{6} m s−1. The velocity of the particle is

a. 1.82×10^{-18} m s−1 b. 9×10^{-2} m s−1 c. 3×10^{-31}m s−1 d. 1.82×10^{-15} m s−1

9. If a light of wavelength 330 nm is incident on a metal with work function 3.55 eV, the electrons are emitted. Then the wavelength of the emitted electron is (Take h = 6.6×10^{-34} Js)

a. $< 2.75\times10^{-9}$ m b. $\geq 2.75\times10^{-9}$ m c. $\leq 2.75\times10^{-12}$ m d. $< 2.5\times10^{-10}$ m

10. A photoelectric surface is illuminated successively by monochromatic light of wavelength λ and λ/2. If the maximum kinetic energy of the emitted photoelectrons in the second case is 3 times that in the first case, the work function at the surface of material is

a) hc/λ b) 2hc/ λ c) hc/3λ d) hc/2λ

LEVEL 3

1. In photoelectric emission, a radiation whose frequency is 4 times threshold frequency of a certain metal is incident on the metal. Then the maximum possible velocity of the emitted electron will be

a) $\sqrt{\frac{hv_0}{m}}$

b) $\sqrt{\frac{6hv_0}{m}}$

c) $2\sqrt{\frac{hv_0}{m}}$

d) $\sqrt{\frac{hv_0}{2m}}$

2. Two radiations with photon energies 0.9 eV and 3.3 eV respectively are falling on a metallic surface successively. If the work function of the metal is 0.6 eV, then the ratio of maximum speeds of emitted electrons will be

a) 1:4 b) 1:3 c) 1:1 d) 1:9

3. A light source of wavelength 520 nm emits 1.04×10^{15} photons per second while the second source of 460 *nm* produces 1.38×10^{15} photons per second. Then the ratio of power of second source to that of first source is

a) 1.00 b) 1.02 c) 1.5 d) 0.98

4. The mean wavelength of light from sun is taken to be 550 nm and its mean power is 3.8×10^{26}W. The number of photons received by the human eye per second on the average from sunlight is of the order of

a) 10^{45} b) 10^{42} c) 10^{54} d) 10^{51}

5. The work functions for metals A, B and C are 1.92 eV, 2.0 eV and 5.0 eV respectively. The metals which will emit photoelectrons for a radiation of wavelength 4100 Å is/are

a) A only b) both A and B c) all these metals d) none

6. Light of frequency 1.9 times the threshold frequency is incident on a photosensitive material. If the frequency is halved and intensity is doubled, the photocurrent becomes

a. Doubled b) quadrupled c) halved d) zero

7. For a metal having a work function W_0, the threshold wavelength is λ. What is the threshold wavelength for the metal having work function $2W_0$?

a. λ/4 b)λ/2 c)2λ d) 4λ

8. Radiation of frequency v is incident on a photosensitive metal. When the frequency of the incident radiation is doubled, what is the maximum kinetic energy of the photoelectrons?

a. 4E b) 2E c) E + hv d) E – hv

9. By what factor will the de Broglie wavelength change if the K.E if the free electron is doubled?

a. ½ b) 1/√2 c) 2 d) 2

10. In photoelectric effect what determines the maximum velocity of the electron reacting with the collector?

a. Frequency of incident radiation alone
b. The potential difference between the emitter and the collector
c. The work function of metal
d. All of these

ASSERTION- REASON

Directions: In each of the following questions, a statement of Assertion is given followed by a corresponding statement of Reason just below it. Of the statements, mark the correct answer as:

(A)If both assertion and reason are true and reason is the correct explanation of assertion

(B)If both assertion and reason are true but reason is not the correct explanation of assertion

(C)If assertion is true and reason is false

(D)If both assertion and reason are false.

LEVEL 1

1. **Assertion:** A photon has no rest mass, yet it carries definite momentum.
Reason: Momentum of photon is due to its energy and hence its equivalent mass.
(a) A (b) B (c) C (d) D

2. **Assertion:** Photoelectric effect demonstrates the wave nature of light.
Reason. The number of photoelectrons is proportional to the frequency of light.
(a) A (b) B (c) C (d) D

3. **Assertion:** When light of certain wavelength falls on a metal surface it ejects electron.
Reason: Light has wave nature.
(a) A (b) B (c) C (d) D

4. **Assertion:** As work function of a material increases by some mechanism, it requires greater energy to excite the electrons from its surface.
Reason: A plot of stopping potential (V) versus frequency (v) for different materials, has greater slope for metals with greater work functions
(a) A (b) B (c) C (d) D

5. **Assertion:** Light of frequency 1.5 times the threshold frequency is incident on photosensitive material. If the frequency is halved and intensity is doubled the photo current remains unchanged.
Reason: The photo electric current varies directly with the intensity of light and frequency of light.
(a) A (b) B (c) C (d) D

LEVEL 2

6. **Assertion:** The de-Broglie wavelength of a neutron when its kinetic energy is k is λ. Its wavelength is 2 λ when its kinetic energy is 4k.
Reason: The de - Broglie wavelength λ is proportional to square root of the kinetic energy.
(a) A (b) B (c) C (d) D

7. **Assertion:** In process of photoelectric emission, all emitted electrons do not have same kinetic energy.
Reason: If radiation falling on photosensitive surface of a metal consists of different wavelength then energy acquired by electrons absorbing photons of different wavelengths shall be different.
(a) A (b) B (c) C (d) D

8. **Assertion:** Though light of a single frequency (monochromatic) is incident on a metal, the energies of emitted photoelectrons are different.
Reason: The energy of electrons emitted from inside the metal surface, is lost in collision with the other atoms in the metal.
(a) A (b) B (c) C (d) D

9. **Assertion:** The photoelectrons produced by a monochromatic light beam incident on a metal surface have a spread in their kinetic energies.
Reason: The work function of the metal is its characteristics property.
(a) A (b) B (c) C (d) D

10. **Assertion:** Photoelectric saturation current increases with the increase in frequency of incident light.
Reason: Energy of incident photons increases with increase in frequency and as a result photoelectric current increase. (a) A (b) B (c) C (d) D

LEVEL 3

11. **Assertion:** Photosensitivity of a metal is high if its work function is small. **Reason:** Work function = hf_0 where f_0 is the threshold frequency.

12. **Assertion:** In an experiment on photoelectric effect, a photon is incident on an electron from one direction and the photoelectron is emitted almost in the opposite direction. It violates the principle of conservation of linear momentum. **Reason:** It does not violate the principle of conservation of linear momentum.

13. **Assertion:** Two sources of equal intensity always emit equal number of photons in any time interval.

Reason: Two sources of equal intensity may emit equal number of photons in any time interval.

14. **Assertion:** Two photons of equal wavelength must have equal linear momentum. **Reason:** Two photons of equal linear momentum will have equal wavelength.

15. **Assertion:** The kinetic energy of photoelectrons emitted from metal surface does not depend on the intensity of incident photon. **Reason:** The ejection of electrons from metallic surface is not possible with frequency of incident photons below the threshold frequency.

2 MARKS QUESTIONS

LEVEL 1

1. If the wavelength of an electromagnetic radiation is doubled what will happen to the energy of photons?
2. Two metals A and B have work functions 4 eV and 10 eV, respectively. Which metal has higher threshold wavelength?
3. A proton and an electron have same kinetic energy. Which one has greater de-Broglie wavelength and why?
4. Two lines, A and B, in the plot given below show the variation of de-Broglie wavelength, λ 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?
5. An alpha particle and a proton are accelerated through same potential difference. Find the ratio ($v_α/v_p$) of velocities acquired by two particles.
6. What is the effect of wavelength of incident photons on velocity of photoelectrons? A beam of monochromatic radiation is incident on a photosensitive surface. Do the emitted photoelectrons have the same kinetic energy? Explain.

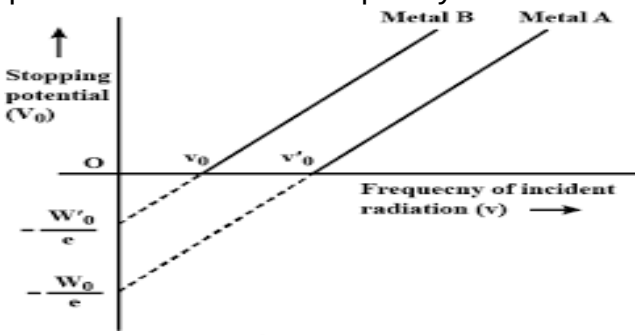
LEVEL 2

1. Electrons are emitted from a photosensitive surface when it is illuminated by green light but electron emission does not take place by yellow light. Will the electrons be emitted when the surface is illuminated by (i) red light, (ii) blue light?
2. A proton, a neutron, an electron and α particle have same energy. Then their de-Broglie wavelengths compare as?
3. Why do we not observe the phenomenon of photoelectric effect with non-metal?

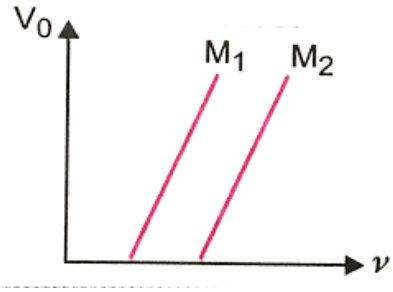
4. Work function of sodium is 2.3eV. Does sodium show photo electric emission for light of wavelength 6800A˚
5. Do all the electrons that absorb a photon come out as photoelectrons?

LEVEL 3

1.The graph shows variation of stopping potential Vo verses frequency of incident radiation ϑ for two photosensitive metals A and B. (i) Which of the two metals has higher threshold frequency and why? (ii) What does intercept on –ve y axis represent?



2.The variation of the stopping potential (v0) with the frequency (v) of the light incident on two different photosensitive surfaces M1 and M2 is shown in the figure. Identify the surface which has greater value of the work function.



3.Show that the wavelength of electromagnetic radiation is equal to the de-Broglie wavelength of its quantum.

3 MARKS QUESTIONS

LEVEL 1

1. In photoelectric effect, why should the photoelectric current increase as the intensity of monochromatic radiation incident on a photosensitive surface is increased? Explain.
2. Light of wavelength 3500 Å is incident on two metals A and B. Which metal will yield more photoelectrons if their work functions are 5 eV and 2 eV respectively?
3. Plot a graph showing the variation of photo current vs collector potential for three different intensities I1 > I2 > I3, two of which (I1 and I2) have the same frequency v and the third has frequency v1 > v.
4. Show the variation of photocurrent with collector plate potential for different frequencies but same intensity of incident radiation.
5. 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.

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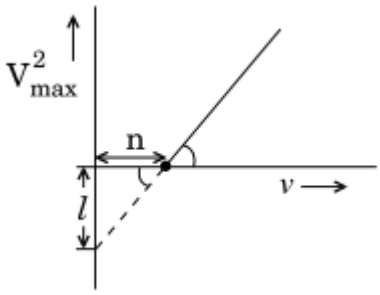
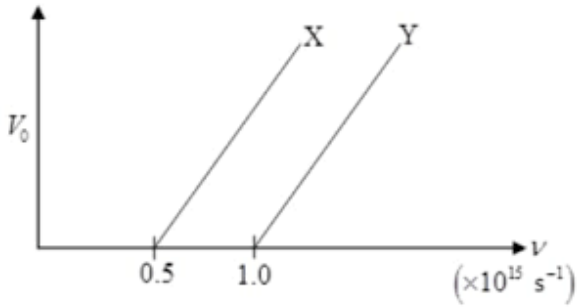
LEVEL 2

1. When a given photo-sensitive material is irradiated with light of frequency ν, and maximum speed of the emitted photoelectrons equals v_{max}. The square of v_{max} 2 is observed to vary with v, as per the graph shown in fig. Obtain expression for (i) Planck's constant and (ii) the work function of the given photo sensitive material, in terms of the parameter l, n and the mass m of the electrons. (iii) How is threshold frequency determined from the graph?



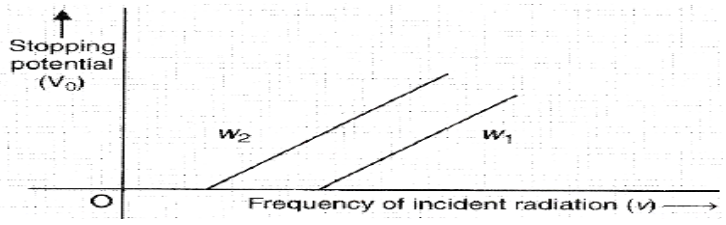
2. A beam of monochromatic radiation is incident on a photosensitive Surface. Answer the following questions giving reasons. i) Do the emitted photoelectrons have the same kinetic energy? ii) Does the kinetic energy of the emitted electrons depend on the intensity of incident radiation? iii) On what factors does the number of emitted photoelectrons depend?
3. The following graph shows the variation of stopping potential V_0 with the frequency v of the incident radiation for two photosensitive metals X and Y. i) which of the metals has larger threshold wavelength? Give reason. ii) Explain, giving reason, which metal gives out electrons, having larger 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.



LEVEL 3

1. 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.

2. Plot a graph showing the variation of stopping potential with the frequency of incident radiation for two different photosensitive materials having work functions W1 and W2 (W1>W2). On what factors does the (i) slope and (ii) intercept of the lines depend?



3. Figure shows a plot of $1/\sqrt{V}$, where V is the accelerating potential, Vs. The de Broglie wavelength λ in the case of two particles having same charge 'q' but different masses m1 and m2. Which line (A or B) represents a particle of larger mass?

5 MARKS QUESTIONS

LEVEL 1

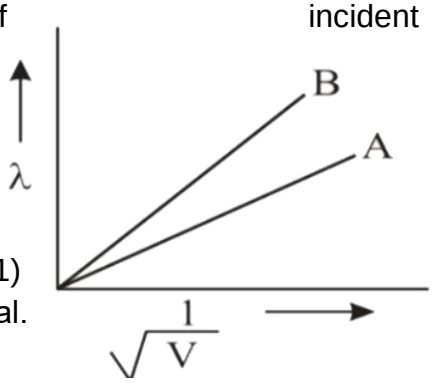
1. Draw properly labelled graphs to show the following concerning photo electric emission:

(i) Variation of photo electric current with the intensity of incident radiation.

(ii) Variation of photo electric current with accelerating and stopping potential.

(iii) Variation of stopping potential with frequency of incident radiation.

From the graph how the following can be determined. 1) Plank's constant. 2) The work function of the material. Obtain Einstein s photo- electric equation.



LEVEL 2

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

LEVEL 3

3. Two monochromatic radiations of frequencies v^1 and v^2 ($V^1 > v^2$) and having the same intensity are, in turn, incident on a photosensitive surface to cause photoelectric emission. Explain, giving reason, in which case (i) a greater number of electrons will be emitted and (ii) maximum kinetic energy of the emitted photoelectrons will be more.

NUMERICALS

LEVEL 1

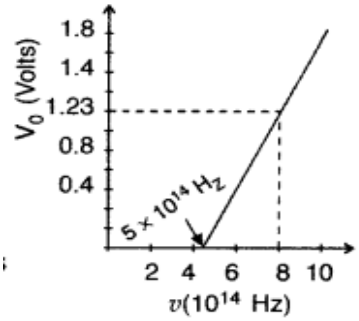
1. What is the momentum of a photon of energy 1 MeV?
2. The de-Broglie wavelength associated with an electron accelerated through a potential difference V is λ. What will be its wavelength when the accelerating potential is increased to 4V?
3. An electron is accelerated through a potential difference of 100 volt. What is the de-Broglie wavelength associated with it? To which part of the electromagnetic spectrum does this value of wavelength correspond?
4. The maximum kinetic energy of a photoelectron is 3 eV. What is its stopping potential?

LEVEL 2

5. Monochromatic light of frequency $6x10^{14}$ Hz is produced by a laser. The power emitted is $2x10^{3}$ W i) what is the energy of photon in the light? ii) How many photons per second on the average are emitted by the source?
6. In an experiment on photoelectric emission, following observations were made 1) Wavelength of the incident light = 2×10^{-7}m 2) Stopping potential = 3V Find (i) kinetic energy of photoelectrons with maximum speed (ii) work function.
7. The work function of Cesium metal is 2.14eV. When light of frequency 6×10^{14}Hz is incident on the metal surface photoemission of electrons occurs. a. What is the maximum kinetic energy of the emitted photoelectrons b. stopping potential c. maximum speed of the emitted photoelectrons?

LEVEL 3

8. Light of wavelength 2000 A^0 falls on an aluminum surface. In aluminum 4.2 eV are required to remove an electron. What is the kinetic energy of (a) fastest (b) the slowest photoelectron?
9. Using the graph shown in the figure for stopping potential v/s the incident frequency of photons, calculate Planck's constant.
10. The Kinetic Energy (K.E.), of a beam of electrons, accelerated through a potential V, equals the energy of a photon of wavelength 5460 nm. Find the de Broglie wavelength associated with this beam of electrons



CASE BASED QUESTIONS

1) According to de-Broglie a moving material particle sometimes acts as a wave and sometimes as a particle or a wave is associated with moving material particle which controls the particle in every respect. The wave associated with moving material particle is called matter wave or de-Broglie wave whose wavelength called de-Broglie wavelength, is given by $\lambda = h/mv$

i) If the momentum of a particle is doubled, then its de-Broglie wavelength will
a. remains unchanged b. become four times c. become two times
d. become half

ii) If an electron and proton are propagating in the form of waves having the same λ , it implies that they have the same
a. Energy b. Momentum c. Velocity d. angular momentum

iii) Velocity of a body of mass m, having de-Broglie wavelength λ , is given by relation
a. $v = \lambda h/m$ b. $v = \lambda m/h$ c. $v = \lambda/hm$ d. $v = h/\lambda m$

iv) Moving with the same velocity, which of the following has the longest de Broglie wavelength?
a. β -particle b. α -particle c. proton d. neutron.

COMPETENCY BASED QUESTIONS

1. According to wave theory of light, 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 be the intensity of incident light. Einstein also proposed that electromagnetic radiation is quantized. If photoelectrons are ejected from a surface when light of wavelength λ1 = 550 nm is incident on it. The stopping potential for such electrons is Vs =0.19. If photoelectrons are ejected from a surface when light of wavelength λ1 = 550 nm is incident on it. The stopping potential for such electrons is Vs =0.19. Suppose the radiation of wavelength λ2 = 190 nm is incident on the surface.

   i) Photoelectric effect supports quantum nature of light because
   a. there is a minimum frequency of light below which no photoelectrons are emitted.
   b. the maximum K.E. of photoelectric depends only on the frequency of light and not on its intensity
   c. even when the metal surface is faintly illuminated, the photo electrons leave the surface immediately.
   d. electric charge of the photoelectrons is quantized.

   ii) Calculate the stopping potential Vs2 of surface.
   a. 4.47 b. 3.16 c. 2.76 d. 5.28

   iii) Calculate the work function of the surface
   a. 3.75 b. 2.07 c. 4.20 d. 3.60

   iv) Calculate the threshold frequency for the surface
   a. 500 x 10^{12} Hz b. 480 x 10^{13} Hz c. 520 x 10^{11} Hz d. 460 x 10^{13} Hz

2. Observations in Photoelectric Effect
   1. For each metal there is a characteristic minimum frequency below which photoelectric effect is not observed. This is called threshold frequency. If frequency of light is less than the threshold frequency, there is no ejection of electrons no matter how long it falls on surface or how high is its intensity.
   2. The kinetic Energy of electrons emitted is directly proportional to frequency of striking photons & independent of their intensity.
   3. The no. of electrons that are ejected per second from metal surface depends upon intensity of striking radiations and doesn't depend upon their frequency.
   4. If frequency of incident light is more than threshold frequency, then the excess energy is imparted to electrons in the form of kinetic energy.

   i) Electrons are emitted with zero velocities from metal surface when exposed to radiation of wavelength 6800A°. Calculate (v0 = photon's frequency & W0 = work function)?
   a. 3.21x 10^{12} /sec & 9.7 x 10^{-19} J
   b. 4,14x 10^{14} /sec & 2.92 x 10^{-19} J

c. 7.76 x 10^{14} /sec & 9.7 x 10^{-19} J
d. 4.14 x 10^{-14} /sec & 2.922 x 10^{-19} J

ii) A proton of wavelength 400 nm strikes metal surface. The electrons are ejected with velocity 5.85 × 10^{5} m/s. Calculate min. energy required to remove electron from metal surface. (Mass of electron = 9.1 × 10^{-31} kg)
a. 29.43 ×10^{-20} J b. 34.50 ×10^{20} J c. 29.43 ×10^{20} J d. 34.50 ×10^{-20} J
iii) Einstein could explain photoelectric effect using Plank's Quantum theory as follows: -
a. Greater he frequency of incident light, greater the kinetic energy of e –
b. Greater the intensity of light more the no. of electrons ejected.
c. Both are correct
d. Only b is correct

iv) Who discovered the Photoelectric effect?
a. Hertz. b. Einstein. c. Max Planck d. de-Broglie

CCT BASED QUESTIONS

1. Lenard observed that when ultraviolet radiations were allowed to fall on the emitter plate of an evacuated glass tube, enclosing two electrodes (metal plates), and current started flowing in the circuit connecting the plates. As soon as the ultraviolet radiations were stopped, the current flow also stopped. These observations proved that it was ultraviolet radiations, falling on the emitter plate, that ejected some charged particles from the emitter and the positive plate attracted them.

i) Alkali metals like Li, Na, K and Cs show photo electric effect with visible light but metals like Zn, Cd and Mg respond to ultraviolet light. Why?
a. Frequency of visible light is more than that for ultraviolet light
b. Frequency of visible light is less than that for ultraviolet light
c. Frequency of visible light is same for ultraviolet light
d. Stopping potential for visible light is more than that for ultraviolet light

ii) Why do we not observe the phenomenon of photoelectric effect with non-metals?
a. For non-metals the work function is high
b. Work function is low
c. Work function can't be calculated
d. For non-metals, threshold frequency is low.
iii) What is the effect of increase in intensity on photoelectric current?
a. Photoelectric current increases b. Decreases c. No change.
d. Varies with the square of intensity

iv) How does the $K.E_{max}$ of the electrons emitted vary with the work function of metal?
a. It doesn't depend on work function
b. It decreases as the work function increases
c. It increases as the work function increases
d. Its value is doubled with the work function.

SELF ASSESEMENT

TOPIC: DUAL NATURE OF RADIATON & MATTER

Marks: 25 **Time: 40Min.**

General Instructions:

(a) All questions are compulsory

(b) There are 25 questions in total. Q. 1 to 6 carries1 mark each. Q. 7 to 8 carry 2 marks each, Q. 9 to 10 carry 3 mark each, Q. 11 carry 4 mark and Q. 12 carry 5 marks.

1. An electron, an alpha particle, a deuteron and a proton have the same KE. Which one has shortest de Broglie wavelength?
   a. α particle b. electron c. proton d. deuteron.
2. Photons of energies 1eV and 2eV are successively incident on a metallic surface of work function 0.5eV. The ratio of kinetic energy of most energetic photoelectrons in the two cases will be
   a. 1:2 b.1:1 c. 1:3 d.1:4
3. When a metallic surface is illuminated with radiation of wavelength λ, the stopping potential is V. If the same surface is illuminated with radiation of wavelength 2λ, the stopping potential is V/4. The threshold wavelength for the metallic surface is
   a.4λ b. 5λ c. 5/2λ d. 3λ
4. In an electron microscope, the electrons are accelerated by a voltage of 14 kV. If the voltage is changed to 224 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

Directions: In each of the following questions, a statement of Assertion (A) is given followed by a corresponding statement of Reason (R) just below it. Of the statements, mark the correct answer as:

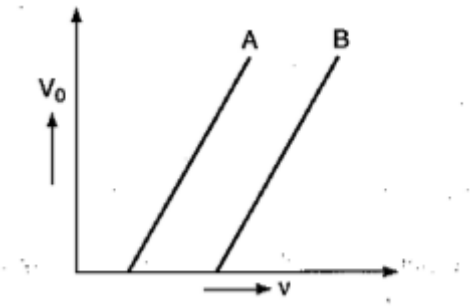
(A)If both assertion and reason are true and reason is the correct explanation of assertion (B)If both assertion and reason are true but reason is not the correct explanation of assertion (C)If assertion is true and reason is false

(D)If both assertion and reason are false.

5. **Assertion:** Two photons of equal wavelength must have equal linear momentum.
   Reason: Two photons of equal linear momentum will have equal wavelength.
   (a) A (b) B (c) C (d) D
6. **Assertion:** The kinetic energy of photoelectrons emitted from metal surface does not depend on the intensity of incident photon.
   Reason: The ejection of electrons from metallic surface is not possible with frequency of incident photons below the threshold frequency.

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

7. The energy required to remove electron from sodium is 2.3 eV. Does sodium show photoelectric effect for orange light of wavelength 6800A^o?
8. The given graphs show the variation of the stopping potential V_0 with the frequency v of the incident radiations for two different photosensitive materials A and B. Which one of the two has higher value of work function? Justify your answer.



9. 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 (b) less momentum? Give reasons to justify your answer.
10. The work function for certain metal is 1.8 eV. (a) What is the stopping potential for electrons ejected from metal, when light of 4000A^o shines on the metal? (b) What is the maximum speed of the ejected electrons?
11. According to de-Broglie a moving material particle sometimes acts as a wave and sometimes as a particle or a wave is associated with moving material particle which controls the particle in every respect. The wave associated with moving material particle is called matter wave or de-Broglie wave whose wavelength called de-Broglie wavelength, is given by $\lambda = h/mv$

    i) The dual nature of light is exhibited by

    a. diffraction and photo electric effect b. photoelectric effect c. refraction and interference d. diffraction and reflection

    ii) If the momentum of a particle is doubled, then its de-Broglie wavelength will

    a. remains unchanged b. become four times c. become two times d. become half

    iii) If an electron and proton are propagating in the form of waves having the same λ, it implies that they have the same

    a. Energy b. Momentum c. Velocity d. angular momentum

    iv) Velocity of a body of mass m, having de-Broglie wavelength λ, is given by relation

    a. $v = \lambda h/m$ b. $v = \lambda m/h$ c. $v = \lambda/hm$ d. $v = h/\lambda m$
12. a) What is photo electric effect? State the characteristics of photoelectric effect.

    b) Explain effect of following terms on the photo electric current.

    i) Intensity of light

    ii) Frequency of light

    iii) Potential difference between anode and cathode. **OR**

    a) Derive the expression for the de Broglie wavelength of an electron moving under a potential difference of V volts.

    b) A deuteron and an alpha particle are accelerated through the same accelerating potential. Which one of the two has-

    (I) greater value of de Broglie wavelength (II)Less kinetic energy? Explain.

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