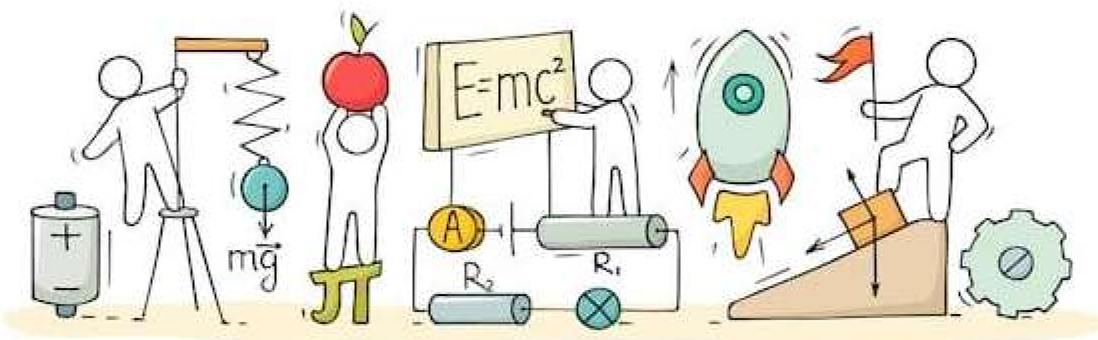
PHYSICS



DUAL NATURE OF RADIATION AND MATTER

Electron emission:

The phenomenon of emission of electrons from the surface of a metal. The minimum energy needed by an electron to come out from a metal surface is known as "work function" of the metal. It is denoted by Φ_0 or W_0 and measured in electron volt (eV).

Work function W = hv = $\frac{hc}{\lambda}$

The electron emission can be obtained from the following physical processes:

Thermionic emission: It is the phenomenon of emission of electrons from the metal surface when heated suitably.

Photoelectric emission: It is the phenomenon of emission of electrons from the surface of metal when light radiations of suitable frequency fall on it.

Field emission or cold cathode emission: It is the phenomenon of emission of electrons from the surface of a metal under the application of a strong electric field.

Photoelectric effect: It is the phenomenon of emission of electrons from the surface of metals when light radiations of suitable frequency fall on them.

Work Function:

To pull out electron from the surface of the metal, a certain minimum amount of energy is required. This minimum energy required by the electron is called the work function of the metal. Work function is generally denoted by 'w' and measured in eV (electron volt).

Threshold Frequency:

The minimum frequency of light which can emit photoelectrons from a material is called threshold frequency or cut-off frequency of that material.

Threshold Wavelength:

The maximum wavelength of light which can emit photoelectrons from a material is called threshold wavelength or cut-off wavelength of that material.

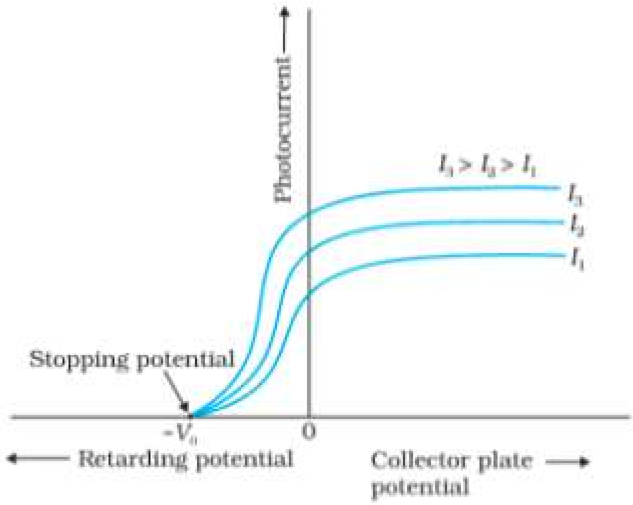
Electron Volt: One electron volt is the energy acquired by an electron, when it has been accelerated by 1-volt potential difference. (1 eV = 1.602 × 10–19 J).

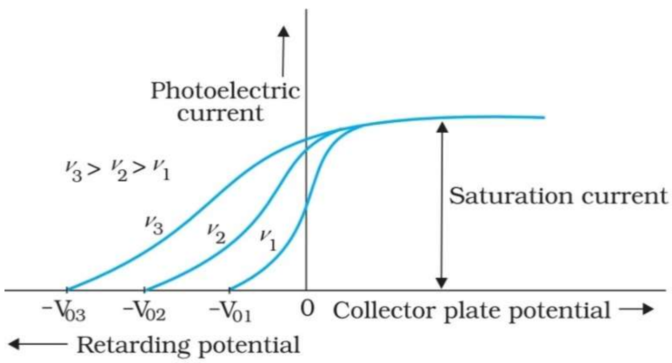
Photoelectric Effect:

The phenomenon of emission of photoelectron from the surface of metal, when a light beam of suitable frequency is incident on it, is called photoelectric effect. The emitted electrons are called photoelectrons and the current so produced is called photoelectric current.

Laws of Photoelectric Effect:

- For a given metal and a radiation of fixed frequency, the number of photoelectrons emitted is proportional to the intensity of incident radiation.
- For every metal, there is a certain minimum frequency below which no photoelectrons are emitted, howsoever high is the intensity of incident radiation. This frequency is called threshold frequency.
- For the radiation of frequency higher than the threshold frequency, the maximum kinetic energy of the photoelectrons is directly proportional to the frequency of incident radiation and is independent of the intensity of incident radiation.
- The photoelectric emission is an instantaneous process.





Hertz' Observation: The phenomenon of photo electric emission was discovered in 1887 by Heinrich Hertz during his electromagnetic wave experiment. In his experimental investigation on the production of electromagnetic waves by means of spark across the detector loop were enhanced when the emitter plate was illuminated by ultraviolet light from an arc lamp.

Lenard's Observation: Lenard observed that when ultraviolet radiation was allowed to fall on emitter plate of an evacuated glass tube enclosing two electrodes, current flows. As soon as, the ultraviolet radiations were stopped, the current flows also stopped.

These observations indicate that when ultraviolet radiations fall on the emitter plate, electrons are ejected from it which are attracted towards the positive plate by the electric field.

Cathode Rays:

Cathode rays are the stream of fast-moving electrons. These rays are produced in a discharge tube at a pressure below 0.01 rom of mercury.

Properties of Cathode Rays:

- Cathode rays are not electromagnetic rays.
- Cathode rays are deflected by electric field and magnetic field.
- Cathode rays produce heat in metals when they Fallon them.
- Cathode rays can pass through thin aluminium or gold foils without puncturing them.
- Cathode rays can produce physical and chemical change.
- Cathode ray travel in straight line with high velocity momentum and energy and cast shadow of objects placed in their path.
- On striking the target of high atomic weight and high melting point, they produce X-rays.
- Cathode rays produce fluorescence and phosphorescence in certain substance and hence affect photographic plate.

Positive Rays:

Positive rays were discovered by Goldstein. Positive rays are moving positive ions of gas filled in the discharge tube. The mass of these particles is nearly equal to the mass of the atoms of gas.

- These consist of fast moving positively charged particles.
- These rays are deflected in magnetic and electric fields.
- These rays travel in straight line.
- Speed of positive rays is less than that of cathode rays.
- These rays can produce fluorescence and phosphorescence.

Dual nature of radiation:

Wave theory of electromagnetic radiation explains the phenomenon of interference, diffraction, and polarization. On the other hand, photoelectric effect is supported by particle nature of light. Hence, we assume dual nature of light.

Einstein's Photoelectric Equation:

To explain photoelectric effect in 1905, Albert Einstein proposed completely different picture of electromagnetic radiation. In this picture radiation energy is built up of discrete units and photoelectric emission does not take place by continuous absorption of energy from radiation. These discrete units are called quanta of energy of radiation. Each quantum of energy is hv, where v is the frequency of light and h is Planck's constant.

In photoelectric effect, an electron absorbs a quantum of energy (hv) of radiation. If this absorbed energy exceeds the minimum energy (work function 'w' of the metal), the most loosely bound electron will emerge with maximum kinetic energy, more tightly bound electron will emerge with kinetic energies less than the maximum value.

Einstein's photoelectric equation

$$E_k = hv - \omega$$

$$E_k = hv - hv_0$$

$$E_k = h(v - v_0)$$

X-rays:

When cathode rays strike on a heavy metal of high melting point. then a very small fraction of its energy converts into a new type of waves, called X-rays.

Properties of X-rays:

- X-rays were discovered by Roentgen.
- X-rays are electromagnetic waves of wavelengths ranging from 0.1 A to 100 A and frequencies ranging from 1016 Hz to 1018 Hz.
- Soft X-rays have greater wavelength and lower frequency.
- Hard X-rays have lower wavelength and higher frequency.
- X-rays are produced by Coolidge tube.
- Molybdenum and tungsten provide suitable targets. These elements have large atomic number and high melting point for the purpose.
- The intensity of X – rays depend on the heating voltage or filament current.

Moseley's Law:

The frequency of X-ray is given by

$V = a (Z - b)^2$

where a and b are constants and Z is atomic number of element.

Frequency of X-rays

$$v \propto Z^2$$

Wave Nature of Matter:

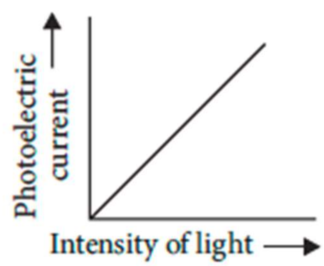
The wave nature of light shows up in the phenomena of interference, diffraction and polarization. De Broglie proposed that the wavelength λ associated with a particle of momentum p is given as.

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

Photocell:

- It is an arrangement which converts light energy into electric energy.
- It works on the principle of photoelectric effect.
- It is used in cinematography for the reproduction of sound.

Photoelectric current: Photoelectric current depends on the intensity of incident light and the potential difference applied between the two electrodes.



Particle Nature of Light:

Photoelectric effect thus gave evidence to the strange fact that light in interaction with matter behaved as if it was made of quanta or packets of energy, each of energy hv. A definite value of energy as well as momentum is associated with a particle. This particle was later named photon.

We can summaries the photon picture of electromagnetic radiation as follows:

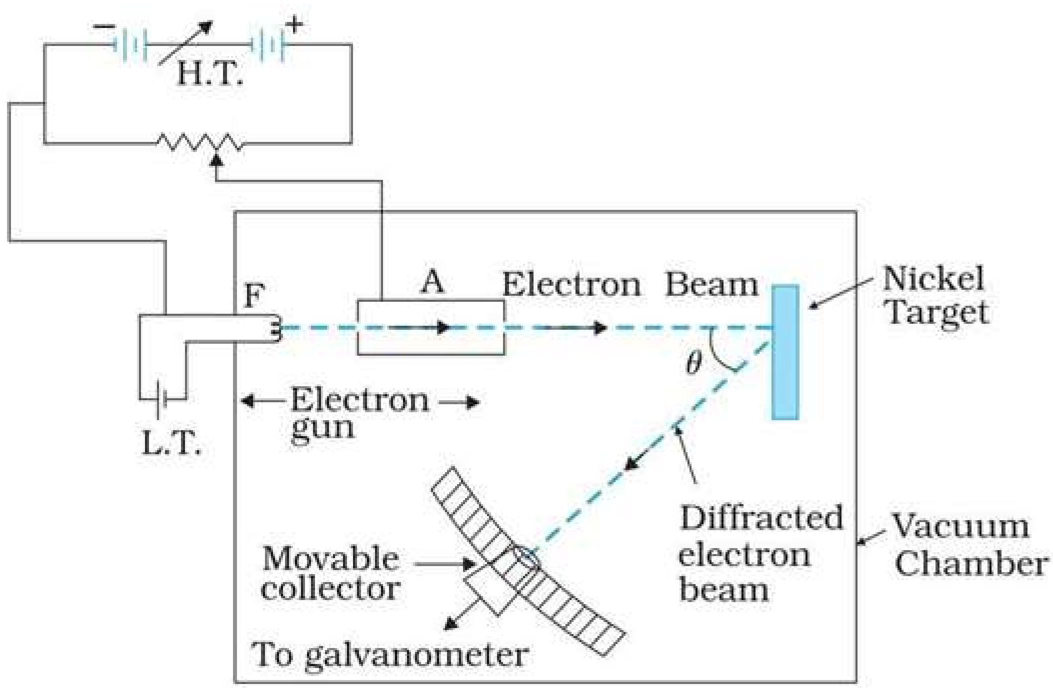
- In interaction of radiation with matter, radiation behaves as if it is made up of particles called photons.
- Each photon has energy E (= hv) and momentum $p\left(=\frac{hv}{c}\right)$, and speed c, the speed of light.

- All photons of light of a particular frequency ν, or wavelength #, have the same energy $E\left(= h\nu = \frac{hc}{\lambda}\right)$ and momentum $p\left(= \frac{h\nu}{c} = \frac{h}{\lambda}\right)$. Photons are electrically neutral and are not deflected by electric and magnetic fields.

- In a photon-particle collision (such as photon-electron collision), the total energy and total momentum are conserved.

Davisson and Germer Experiment:

The wave nature of electrons was first experimentally verified independently by C. J. Davisson and L. H. Germer in 1927 and by G. P. Thomson in 1928 while observing diffraction effects with beams of electrons scattered by crystals. The experimental arrangement is schematically shown in figure.



It has an electron gun made up of a tungsten filament F, heated by a low voltage battery and the filament is coated with barium oxide. Emitted electrons from filament are accelerated to a desired velocity by applying required potential/ voltage from a high-voltage power supply. C is a hollow metallic cylinder with a hole along the axis and is kept at negative potential to get a convergent beam of electrons emitted from filament. It acts as a cathode. A is a cylinder with fine hole along its axis acting as an anode.

The cathode and anode form an electron gun by which a fine beam of electrons can be obtained of different velocities by applying different accelerating potentials. N is a nickel crystal cut along cubical diagonal, D is an electron detector which can be rotated on a circular scale and is connected to a sensitive galvanometer which records the current.

Working: From electron gun a fine beam of accelerated electrons is made to fall normally on the surface of nickel crystal. The atoms of the crystal scatter the incident electrons in different directions. The detector detects the intensity of the electron beam scattered direction by rotating the electron detector on circular scale at different positions.

According to de Broglie hypothesis, the wavelength of the wave associated with electron is given by.

$$\lambda = \frac{12.27}{\sqrt{V}} A$$

MIND MAP : LEARNING MADE SIMPLE

CHAPTER - 11

Dual Nature of Radiation & Matter

Dual Nature of Radiation

- Light has both wave character as well as particle
- Interference explained by wave nature
- When light of sufficiently low wavelength, it behaves as a particle
- Light particle having definite energy and definite linear momentum called "photon" or Energy packets.

  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

All matter can exhibit wave–like behaviour e.g. beam of electrons can be diffracted like water wave

de - Broglie relation

$\lambda = h/p$

λ = wavelength associated with particle or de-Broglie wavelength

p = momentum

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2\,m\,K_{max}}}$$

Davisson–Germer Experiment

A beam of electrons emitted by electron gun is made to fall on nickel crystal cut along cubical axis at a particular angle .Scattered beam of electrons is received by detector.

Results : λ = de Broglie's wavelength

$= h/p$

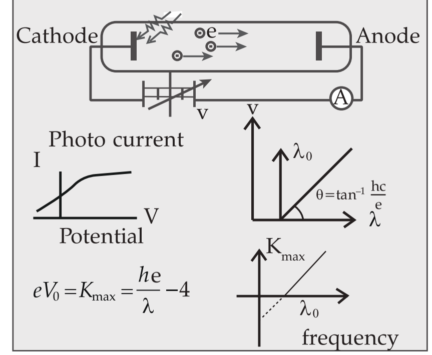
$= 1227/\sqrt{v}$ nm

$= 1227/\sqrt{54}$ nm

$= 0.167$ nm $= 1.67$ A°

This experiment verifies the wave nature of electrons & relation with de-Broglie wavelength.

Hertz and Lenard's Observation



$eV_0 = K_{max} = \frac{he}{\lambda} - 4$

Photoelectric Effect

- When light of sufficiently 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

Einstein's Photoelectric equation

- $K_{max} = E - \phi = eV_0$

  $= \frac{hc}{\lambda} - \phi$, V_0 = stopping potential

  K_{max} = maximum kinetic energy of elected electrons

Hore, $\lambda_0 = hc/\phi$

λ_0 = Threshold Wavelength

$\lambda_0 = c/\lambda_0 = \phi/h$

λ_0 = Threshold frequency

$K_{max} = \lambda(\nu - \nu_0)$

- If $\lambda = \lambda_0 = hc/\phi$

  $K_{max} = 0$, *i.e.*

  Electron may just come out.
- If $\lambda > \lambda_0$

  i.e. $E < \phi$

  no electron will come out
- If $\lambda \le \lambda_0$.

  Photoelectric effect takes place this λ_0
- λ_0 = depends on metal used

Important Questions

Multiple Choice questions-

Question 1. Photoelectrons are being obtained by irradiating zinc by a radiation of 3100 Å. In order to increase the kinetic energy of ejected photoelectrons.
(a) the intensity of radiation should be increased.
(b) the wave length of radiation should be increased.
(c) the wavelength of radiation should be decreased.
(d) both wavelength and intesity of radiation should be increased.

Question 2. The de-Broglie wavelength of an electron moving with a speed of 6.6×10^{15} ms^{-1} is nearly equal to
(a) 10^{-11}m
(b) 10^{-9} m
(c) 10^{-7} m
(d) 10^{-5} m

Question 3. An electron accelerated through a potential difference of V volt has a wavelength λ associated with it, Mass of proton is nearly 2000 times that of an electron. In order to have the same λ for proton, it must be accelerated through a potential difference (in volt) of:
(a) V
(b) $\sqrt{2000}$ V
(c) 2000V V
(d) $\frac{V}{2000}$

Question 4. An electron of mass m, when accelerated through a potential difference V, has de-Broglie wavelength λ. The de-Broglie wavelength associated with a proton of mass M and accelerated through the same potential difference will be
(a) $\lambda\sqrt{\frac{m}{M}}$
(b) $\lambda\frac{m}{M}$
(c) $\lambda\sqrt{\frac{M}{m}}$
(d) $\lambda\sqrt{\frac{m}{m}}$

Question 5. The energy E and momentum p of a photon is given by E = hν h and p = hλ. The velocity of photon will be:

(a) $\frac{E}{P}$

(b) $(\frac{E}{P})^2$

(c) $\sqrt{\frac{E}{P}}$

(d) $(EP)^3$

Question 6. Ultra-violet radiation of 6.2 eV falls on an aluminium surface having work-function 4.2 eV. The kinetic energy (in J) of the fastest electron emitted is nearly.

(a) 3×10^{-19}

(b) 3×10^{-15}

(c) 3×10^{-17}

(d) 3×10^{-21}

Question 7. For light of wavelength 5000 Å, the photon energy is nearly 2.5 eV. For X-rays of wavelength 1 Å, the photon energy will be close to:

(a) 2.5×5000 eV

(b) $2.5 \div 5000$ eV

(c) $2.5 \times (5000)^2$ eV

(d) $2.5 \div (5000)^2$ eV.

Question 8. A photocell is illuminated by a small bright source placed 1 metre away. When the same source of light is placed 2 m away, the electrons emitted per sec. (i.e. saturation current in the photo cell is) are

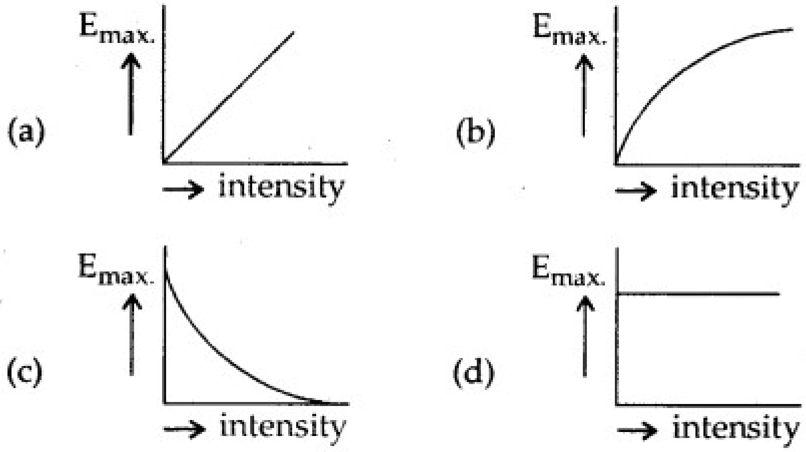
(a) $I \propto 2^2$

(b) $I \times \frac{1}{4}$

(c) $I \propto 4$

(d) $I \propto \frac{1}{2}$

Question 9. Which one of the following graph represent correctly the variation of maximum kinetic energy E_{max} with the intensity of incident radiations having a constant frequency.



Question 10. The best metal to be used for photoemission is:
(a) Potassium
(b) Lithium
(c) Sodium
(d) Cesium

Question 11. The threshold frequency for a certain metal is v_0. When light of frequency $v = 2v_0$ is incident on it, the maximum velocity of photo electrons is 4×10^6 ms^{-1}. If the frequency of incident radiation is increased to 5 v_0, then the maximum velocity of photo electrons (m/s) is:
(a) 8×10^5
(b) 2×10^6
(c) 2×10^7
(d) 8×10^6

Question 12. The frequency and the intensity of a beam of light falling on the surface of photoelectric material are increased by a factor of two. This will:
(a) increase the maximum K.E. of photo-electron as well as photoelectric current by a factor of two.
(b) increase maximum K.E. of photoelectrons and would increase the photo current by a factor of two.
(c) increase the maximum K.E. of photo electrons by a factor of two and will no affect photoelectric current.
(d) No effect on both maximum K.E. and photoelectric current.

Question 13. Which of the following is not the property of photons:
(a) charge
(b) rest mass
(c) energy
(d) momentum

Question 14. Dynamic mass of photon of wavelength k is:
(a) Zero
(b) $\frac{hc}{\lambda}$
(c) $\frac{h}{c\lambda}$
(d) $\frac{h}{2\lambda}$

Question 15. The time required in emitting photo electrons is:
(a) 10^{-8} s
(b) 10^{-4} s
(c) Zero
(d) 1 sec

Very Short :

1. Calculate the energy associated in eV with a photon of wavelength 4000A°

2. Mention one physical process for the release of electrons from the surface of a metal.

3. The maximum kinetic energy of photoelectron is 2.8 eV What is the value of stopping potential?

4. Calculate the threshold frequency of photon for photoelectric emission from a metal of work function 0.1eV

5. Ultraviolet light is incident on two photosensitive materials having work function Φ_1 and Φ_2 ($\Phi_1 > \Phi_2$). In which of the case will K.E. of emitted electrons be greater? Why?

6. Show graphically how the stopping potential for a given photosensitive surface varies with the frequency of incident radiations.

7. How does the stopping potential applied to a photocell change if the distance between the light source and the cathode of the cell is doubled?

8. On what factor does the retarding potential of a photocell depend?

9. Electron and proton are moving with same speed, which will have more wavelength?

10. If the maximum kinetic energy of electrons emitted by photocell is 4 eV, what is the stopping potential?

Short Questions :

1. An a-particle and a proton of the same kinetic energy are in turn allowed to pass through a

magnetic field B, acting normal to the direction of motion of the particles. Calculate the ratio of radii of the circular paths described by them. (CBSE Delhi 2019)

2. How will the photoelectric current change on decreasing the wavelength of incident radiation for a given photosensitive material?

3. Estimate the ratio of the wavelengths associated with the electron orbiting around the nucleus in the ground and first excited states of a hydrogen atom. (CBSE Delhi 2019C)

4. Show graphically how the stopping potential for a given photosensitive surface varies with the frequency of the incident radiation.

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

6. Plot a graph showing the variation of de Brogue wavelength (λ) associated with a charged particle of mass m, versus $\frac{1}{\sqrt{V}}$ where V is the potential difference through which the particle is accelerated. How does this graph give us information regarding the magnitude of the charge of the particle? (CBSE Dethi 2019)

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

8. Explain with the help of Einstein's photoelectric equation any two observed features in the photoelectric effect. cannot be explained by the wave theory. (CBSE Delhi 2019)

9. Why is the wave theory of electromagnetic radiation not able to explain the photoelectric effect? How does the photon picture resolve this problem? (CBSE Delhi 2019)

10. (a) Define the terms,

(i) threshold frequency and

(ii) stopping potential in the photoelectric effect.

(b) Plot a graph of photocurrent versus anode potential for radiation of frequency v and intensities I_1 and I_2. ($I_1 < I_2$). (CBSE Delhi 2019)

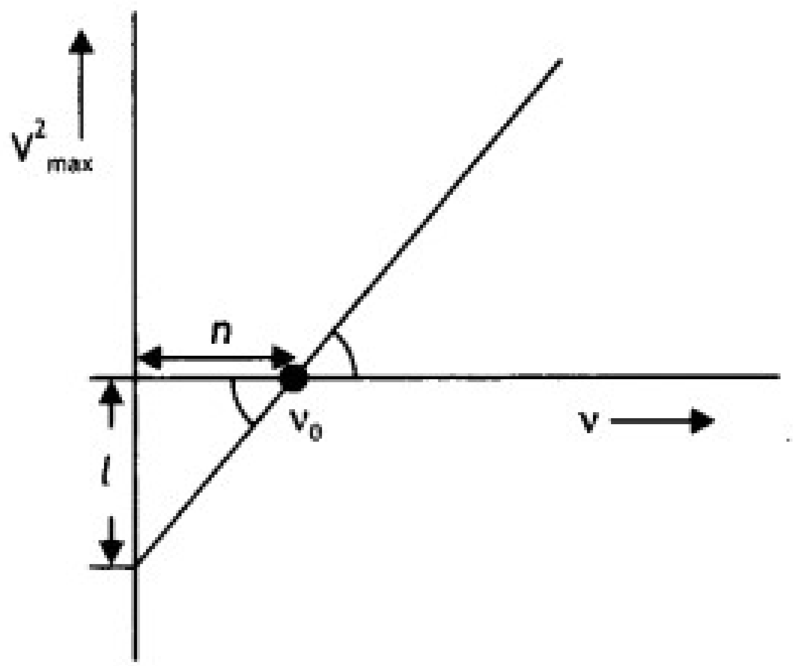
Long Answers Questions:

Question 1. What is the photoelectric effect? Write Einstein's photoelectric equation and use it to explain: (a) independence of maximum energy of emitted photoelectrons from the intensity of incident light and
(b) existence of a threshold frequency for the emission of photoelectrons.

Question 2. An electron of mass m and charge q is accelerated from rest through a potential difference of V. Obtain the expression for the de-Broglie wavelength associated with it. If electrons and protons are moving with the same kinetic energy, which one of them will have a larger de-Broglie wavelength associated with it? Give reason.

Question 3. Sketch the graphs showing the variation of stopping potential with the frequency of incident radiations for two photosensitive materials A and B having threshold frequencies $v_0 > v'_0$ respectively.
(a) Which of the two metals A or B has a higher work function?
(b) What information do you get from the slope of the graphs?
(c) What does the value of the intercept of graph 'A' on the potential axis represent?

Question 4. When a given photosensitive material is irradiated with light of frequency v, 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 v.

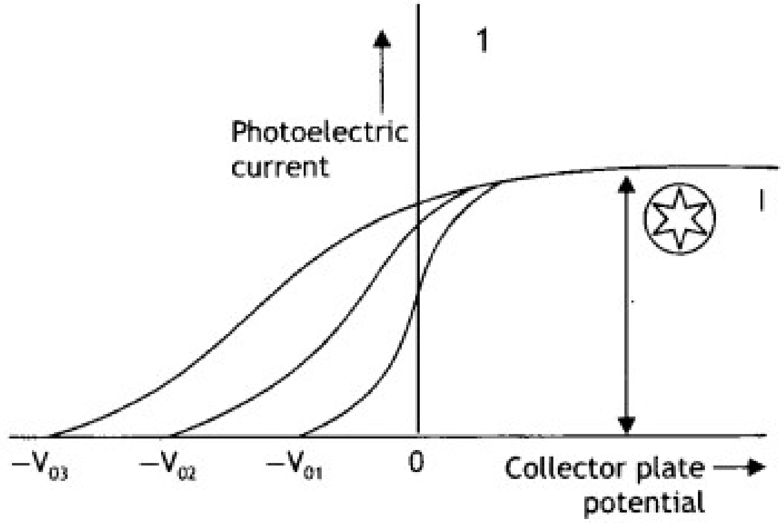


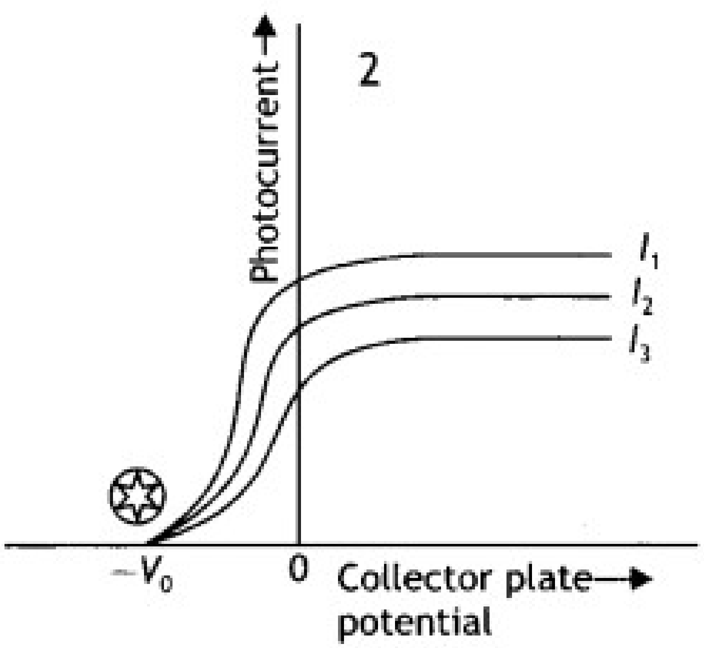
Obtain an expression for:
(a) Planck's constant, and
(b) The work function of the given photosensitive material in terms of the parameters T, 'n' and the mass 'm' of the electron.
(c) How is threshold frequency determined from the plot? (CBSE AI 2019)

Question 5. X-rays fall on a photosensitive surface to cause photoelectric emission. Assuming that the work function of the surface can be neglected, find the relation between the de-Broglie wavelength (λ) of the electrons emitted to the energy (E_v) of the incident photons. Draw the nature of the graph for λ as a function of E_v. (CBSE Delhi 2014C)

Question 6. Light of intensity 'I' and frequency 'v' is incident on a photosensitive surface and causes photoelectric emission. What will be the effect on anode current when:
(a) the intensity of light is gradually increased,
(b) the frequency of incident radiation is increased and
(c) the anode potential is increased?
In each case, all other factors remain the same. Explain giving justification in each case. (CBSE AI 2015)

Question 7. The graphs, drawn here, are for the phenomenon of the photoelectric effect.





(a) Identify which of the two characteristics (intensity/frequency) of incident light is being kept constant in each case.

(b) Name the quantity, corresponding to the ✡ mark, in each case.

(c) Justify the existence of a ‘threshold frequency’ for a given photosensitive surface. (CBSE Delhi 2016C)

Question 8. Draw a graph showing the variation of de-Broglie wavelength λ of a particle of charge q and mass, with the accelerating potential V. An alpha particle and a proton have the same de-Broglie wavelength equal to 1 Å. Explain with calculations, which of the two has more kinetic energy. (CBSE Delhi 2017C)

Assertion and Reason Questions-

1. For question two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions front the codes (a), (b), (c) and (d) as given below.

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): Photoelectric effect demonstrates the wave nature of light.

Reason (R): The number of photoelectrons is proportional to the frequency of light.

2. For question two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions front the codes (a), (b), (c) and (d) as given below.

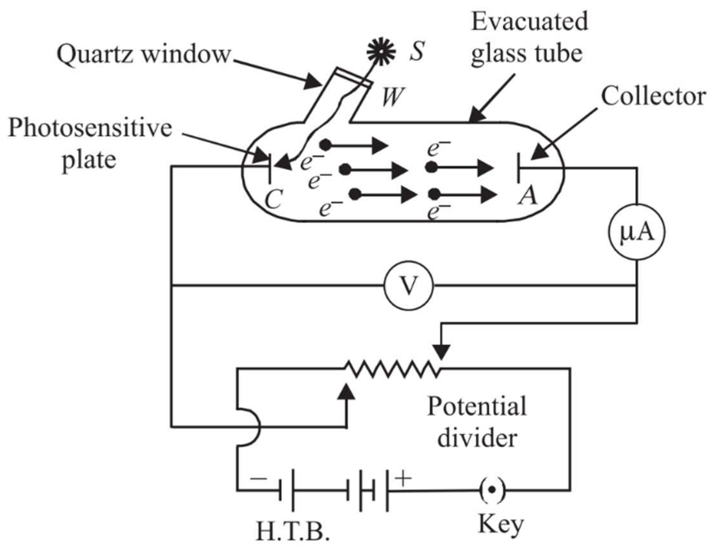
a) Both A and R are true and R is the correct explanation of A.
b) Both A and R are true but R is NOT the correct explanation of A.
c) A is true but R is false.
d) A is false and R is also false.

Assertion (A): On increasing the frequency of light, larger number of photoelectrons are emitted.

Reason (R): The number of electrons emitted is directly proportional to the intensity of incident light.

Case Study Questions-

1. To study photoelectric effect, an emitting electrode C of a photosensitive material is kept at negative potential and collecting electrode A is kept at positive potential in an evacuated tube. When light of sufficiently high frequency falls on emitting electrode, photoelectrons are emitted which travel directly to collecting electrode and hence an electric current called photoelectric current starts flowing in the circuit, which is directly proportional to the number of photoelectrons emitted by emitting electrode C.



While demonstrating the existence of electromagnetic waves, Hertz found that 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 ultraviolet light falling on the metal surface caused the emission of negatively charged particles, which are now known to be electrons, into the surrounding space and hence enhanced the high voltage sparks.

(i) Cathode rays were discovered by:

a) Maxwell Clerk James.
b) Heinrich Hertz.
c) William Crookes.
d) J. J. Thomson.

(ii) Cathode rays consists of:

a) Photons
b) Electrons
c) Pistons
d) αα-particles

(iii)Who discovered the charge on an electron for the frist time?

a) Millikan
b) Thomson
c) Kelvin
d) Coulomb

(iv)The dual nature of light is exhibited by:

a) Diffraction and photoelectric effect.
b) Photoelectric effect.
c) Refraction and interference.
d) Diffraction and reflection.

(v) In the phenomenon of electric discharge through gases at low pressure, the coloured glow in the tube appears as a result of:

a) Collisions between the charged particles emitted from the cathode and the atoms of the gas.
b) Collision between different electrons of the atoms of the gas.
c) Excitation of electrons in the atoms.
d) Collision between the atoms of the gas.

2. Photoelectric effect is the phenomenon of emission of electrons from a metal surface, when radiations of suitable frequency fall on them. The emitted electrons are called photoelectrons and the current so produced is called photoelectric current.

(i) With the increase of intensity of incident radiations on photoelectrons emitted by a photo tube, the number of photoelectrons emitted per unit time is:

a) Increases.
b) Decreases.
c) Remains same.
d) None of these.

(ii) It is observed that photoelectron emission stops at a certain time t after the light source is switched on. The stopping potential (V) can be represented as:

a) $2(KE_{max}/e)$
b) (KE_{max}/e)
c) $(KE_{max}/3e)$
d) $(KE_{max}/2e)$

(iii) A point source of light of power 3.2×10^{-3} W emits monoenergetic photons of energy 5.0eV and work function 3.0eV. The efficiency of photoelectron emission is 1 for every 10^6 ncident photons. Assume that photoelectrons are instantaneously swept away after emission. The maximum kinetic energy of photon is:

a) 4eV
b) 5eV
c) 2eV
d) Zero

(iv) Which of the following device is the application of Photoelectric effect?

a) Light emitting diode.
b) Diode.
c) Photocell.
d) Transistor.

(v) If the frequency of incident light falling on a photosensitive metal is doubled, the kinetic energy of the emitted photoelectron is:

a) Unchanged.
b) Halved.
c) Doubled.
d) More than twice its initial value.

Multiple Choice Question's Answers-

1. Answer: (c) the wavelength of radiation should be decreased.

2. Answer: (b) 10^{-9} m

3. Answer: (d) $\frac{V}{2000}$

4. Answer:

(a) $\lambda\sqrt{\frac{m}{M}}$

5. Answer: (a) $\frac{E}{P}$

6. Answer: (a) 3×10^{-19}

7. Answer: (a) 2.5×5000 eV

8. Answer: (b) $I \times \frac{1}{4}$

9. Answer: (d)

10. Answer: (d) Cesium

11. Answer: (d) 8×10^{6}

12. Answer: (b) increase maximum K.E. of photoelectrons and would increase the photo current by a factor of two.

13. Answer: (a) & (b)

14. Answer: (c) $\frac{h}{c\lambda}$

15. Answer: (c) Zero

Very Short Answers:

1. Ans: Given the wavelength of given photon is

$$\lambda = 4000\overset{o}{A} = 4 \times 10^{-7} m$$

Hence the energy associated is

$$E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{4000 \times 10^{-10}}$$

$$E = 4.95 \times 10^{-19} J$$

$$E = \frac{4.95 \times 10^{-19} J}{1.6 \times 10^{-19}} eV = 3.09 eV$$

2. Photoelectric emission.

The phenomenon in which the electrons from the surface of a metal are given energy in form of electromagnetic waves and they are ejected out, this phenomenon is called the photoelectric emission.

3. Given an electron that is moving with a kinetic energy. For it to be not ejected, it has to be held back using a stopping potential

$$V_0$$

. The relation between the two is:

$$KE = eV_o = 2.8eV$$

$$\Rightarrow V_o = 2.8V$$

4. Given is the work function

$$0.1\,eV$$

$$\phi_o = h\nu_0$$

$$\Rightarrow \nu_0 = \frac{\phi_o}{h} = \frac{0.1eV}{6.6\times10^{-34}Js}$$

$$\Rightarrow \nu_0 = \frac{0.1 \times 1.6 \times 10^{-19}J}{6.6 \times 10^{-34}Js} = 2.4 \times 10^{14}Hz$$

And hence the threshold frequency is $2.4 \times 10^{14}Hz$.

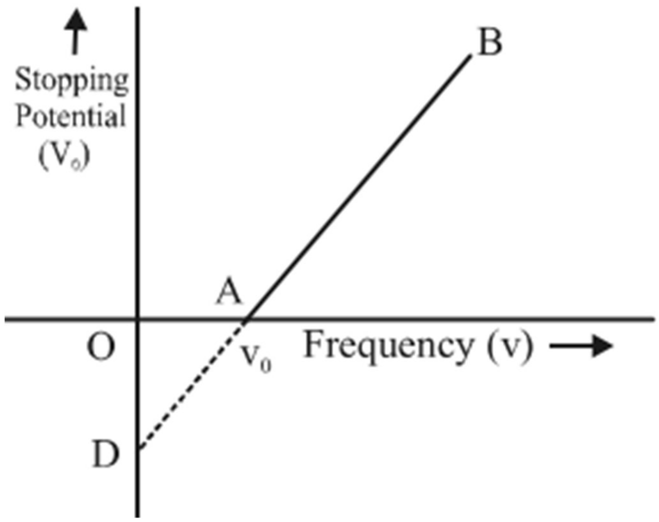
5. According to the energy balance equation of the photoelectric effect hv = Φ_o + K.E

   If $\Phi_1 > \Phi_2$ thus K.E. will be more for second surface whose work function is less.

6. Suppose

   ν_o is the threshold of frequency or cut off frequency;

   V_o is the corresponding stopping potential



7. Intensity of light drops quadratically with distance. However, the stopping potential does not depend on the intensity of the light. Hence it is independent of distance as well.

8. The retarding photocell depends upon the frequency of the incident light.

9. Since the wavelength is inversely proportional to the square root of the mass of the body, $\lambda \propto \frac{1}{\sqrt{m}}$. So, electrons being lighter will have more wavelengths.

10. The stopping potential is 4 V.

Short Answers :

1. Given $q_\alpha = 2e$, $q_p = e$, $K_\alpha = K_p$, $m\alpha = 4m_p$, $r_\alpha/r_p = ?$

   Using the expression

   $$r = \frac{\sqrt{2mK}}{qB} \text{ we have}$$

   $$\frac{r_\alpha}{r_p} = \left(\sqrt{\frac{m_\alpha}{m_p}} \times \frac{q_p}{q_\alpha}\right) = \sqrt{\frac{4m_p}{m_p}} \times \frac{e}{2e} = 1$$

2. Photoelectric current is independent of the wavelength of the incident radiation. Therefore there will be no change in the photoelectric current.

3. Since De Brogue's hypothesis is related to

   Bohr's atomic model as

$$n\lambda = 2\pi r$$

Since $r \propto n^2$

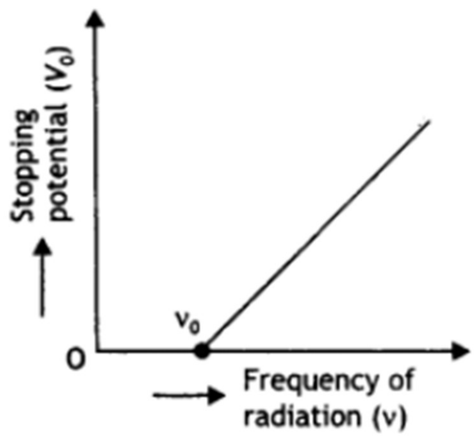
$\therefore \quad r = a_0 n^2$

$\therefore \quad n\lambda = 2\pi a_0 n^2$

$\therefore \quad \lambda = 2\pi a_0 n$

$$\frac{\lambda_1}{\lambda_2} = \frac{2\pi a_0 1}{2\pi a_0 2} = \frac{1}{2}$$

4. The required graph is as shown

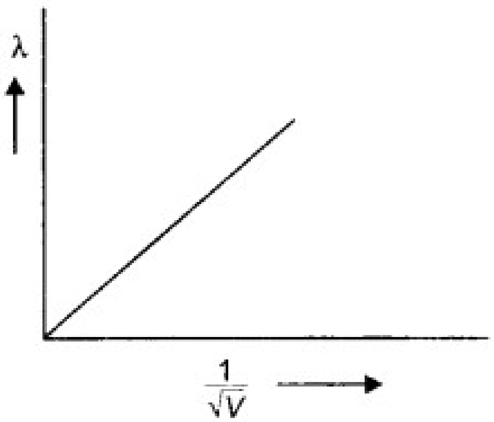


5. The de-BrogLie wavelength is inversely proportional to the square root of potential, therefore =

$\frac{\lambda_2}{\lambda_1} = \frac{\sqrt{V}}{\sqrt{4V}} = \frac{1}{2}$. Thus wavelength

wilt become half of its previous value.

6. The plot is as shown.



We know that $\lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$

Now $\frac{\lambda}{1/\sqrt{V}} = \frac{h}{\sqrt{2mq}}$ = slope of the graph

Or $q = \frac{h^2}{2m(\text{slope})^2}$

7. The energy possessed by X-rays of wavelength λ is given by E=hc / λ.

   Consider an electron of mass charge e to be accelerated the potential difference of V volts the velocity gained by it.

   Then kinetic energy of electron is

   $E = \frac{1}{2}mv^2 = eV$

   or

   $v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2E}{m}}$

   If λ is the de-Broglie wavelength associated with an electron, then

   $$\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{\frac{2ev}{m}}} = \frac{h}{\sqrt{2meV}} = \frac{h}{\sqrt{2mE}}$$

   Substituting for e, we have

   $$\lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mhc/\lambda}} = \sqrt{\frac{h\lambda}{2mc}}$$

8. According to Einstein's equation, we have

   $\frac{1}{2}mv_{\max}^2 = h(v - vo)$

   Two features

   (a) Maximum energy is directly proportional to the frequency

   (b) Existence of threshold frequency Explanation of two features:

   1. The energy of the photon is directly proportional to the frequency

2. No photoelectric emission is possible if $h\nu < h\nu_o$

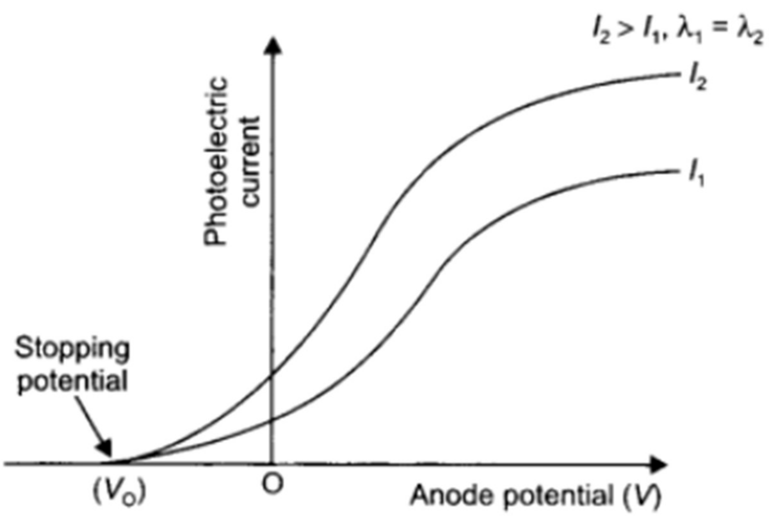
9. According to the wave theory, the more intense a beam, more is the kinetic energy it will impart to the photoelectron. This does not agree with the experimental observations (max K.E. of the emitted photoelectron is independent of intensity) on the photoelectric effect. Also according to the wave theory photoemission can occur at all frequencies.

The photon picture resolves this problem by saying that light in interaction with matter behaves as if it is made of quanta or packets of energy, each of energy $h\nu$. This picture enables us to get a correct explanation of all the observed experimental features of the photoelectric effect.

10. (a) Threshold frequency: It is the frequency of the incident radiation below which photoelectric effect does not take place.

Stopping potential: It is the minimum negative (retarding) potential, given to the anode (collector plate) for which the photocurrent stops or becomes zero.

(b) The plot is as shown.



Long Answers:

1. Answer: The election of photoelectrons from a metal surface when Light of suitable frequency is incident on it is catted photoelectric effect.

Einstein's equation of photoelectric effect is $\frac{1}{2}mv^2 = h\nu - \omega_0$

(a) In accordance with Einstein's equation, the kinetic energy of the photoelectrons is independent of the intensity of the incident radiation.

(b) In accordance with Einstein's equation, the kinetic energy will be positive and hence photoelectrons will be ejected if $v > v_0$. Thus below a certain frequency called threshold frequency, photoelectrons are not ejected from a metal surface (if $v < v_0$).

2. Answer: Consider an electron of mass m and charge e to be accelerated through a potential difference of V volts. Let v be the velocity gained by it. Then kinetic energy of the electron is

$$E = \frac{1}{2}mv^2 = eV$$

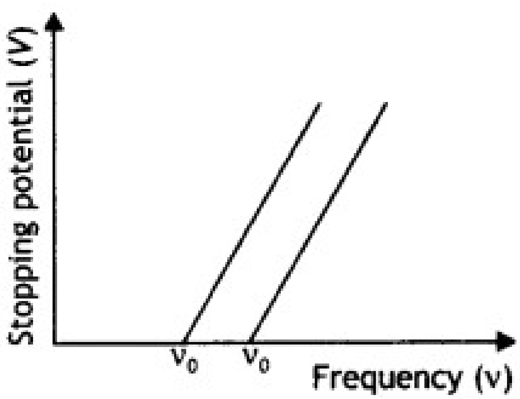
or $$v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2E}{m}}$$

If λ is the de-Broglie wavelength associated with an electron, then

$$\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{\frac{2ev}{m}}} = \frac{h}{\sqrt{2meV}} = \frac{h}{\sqrt{2mE}}$$

Since de-Broglie wavelength is inversely proportional to the square root of mass, the lesser the mass, the more is the de- Broglie wavelength. Since the mass of an electron is lesser than that of the proton, the electron has a greater de-Broglie wavelength than a proton.

3. Answer: The graphs are as shown below.



(a) The work function is directly proportional to the threshold frequency. The threshold frequency of metal A is greater than that of metal B; therefore A has a greater work function than B.
(b) The slope of the graphs gives the value of Planck’s constant.
(c) The intercept on the potential axis is negative ($-W_0/e$) w.r.t. stopping potential, i.e. Work function = e × magnitude of the intercept on the potential axis. We may infer it to give the voltage which, when applied with opposite polarity to the stopping voltage, will just pull out electrons from the metallic atom’s outermost orbit.

4. Answer: (a) By Einstein's photoelectric equation we have

$$K_{max} = \frac{1}{2}mv_{max}^2 = h\nu - \phi_o$$

$$\text{or } v_{max}^2 = \left(\frac{2h}{m}\right)\nu - \frac{2\phi_o}{m}$$

$$\text{Slope of the graph} = \frac{2h}{m} = \frac{l}{n}$$

(b)

The intercept on V^2_{max} axis is = $\frac{2\phi_o}{m}$ = l

Therefore, work function $\Phi_0 = \frac{ml}{2}$

(c) The threshold frequency is the intercept on the v axis i.e. $\nu_0 = n$

5. Answer:

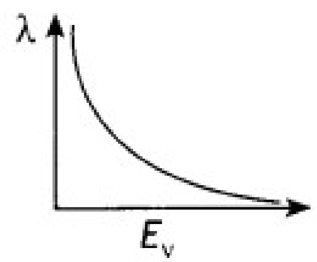
Consider an electron of mass m and charge e to be accelerated through a potential difference of V volt. Let v be the velocity gained by it. Then kinetic energy of the electron is

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

If λ is the de-Broglie wavelength associated with an electron, then

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mE_v}}$$

The nature of the graph is as shown.



6. Answer: (a) Anode current will increase with the increase of intensity as the more the intensity of light, the more is the number of photons and hence more number of photoelectrons are ejected.

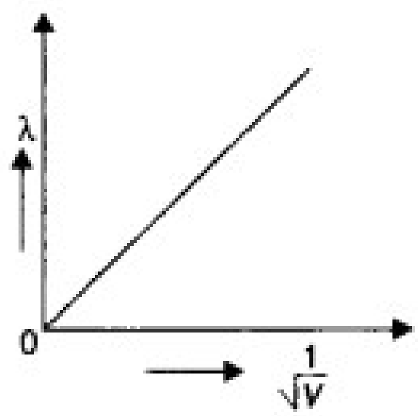
(b) No effect as the frequency of light affects the maximum K.E. of the emitted photoelectrons.
(c) Anode current will increase with anode potential as more anode potential will accelerate the more electrons till it attains a saturation value and gets them collected at the anode at a faster rate.

7. Answer: (a) Graph 1: Intensity, Graph 2: Frequency

(b) Graph 1: Saturation current, Graph 2: stopping potential

(c) The electrons require minimum energy to set themselves free. This is called the work function. As the energy of the photon depends upon its frequency, the photons must possess a minimum frequency so that their energy becomes equal to or greater than the work function. This is called threshold frequency and is given by $v_0 = \frac{\omega_0}{h}$

8. Answer: The graph is as shown.
The de-Broglie wavelength of a particle is given by the expression $\lambda = \frac{h}{\sqrt{2mqV}}$
Since the alpha particle and the proton have the same de- Broglie wavelength, we have



$$\frac{h}{\sqrt{2m_a E_\alpha}} = \frac{h}{\sqrt{2m_p E_p}}$$

Therefore proton has a greater value of de-Broglie wavelength.
Now kinetic energy is given by the expression

$$\frac{E_a}{E_p} = \frac{m_p}{m_\alpha} = \frac{m}{4m} = \frac{1}{4}$$

Thus proton has more kinetic energy.

Assertion and Reason Answers-

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

Explanation:

Photoelectric effect can be explained on the basis of quantum theory or particle nature of light where wave nature of light fails to explain the photoelectric effect. The number of photoelectrons is proportional to the intensity of incident light.

$\mathrm{I} = \mathrm{nh}v$ where n is the number of photons emitted/ absorbed per unit area per second. n and $\mathrm{h}v$ are independent factors.

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

Explanation:

The maximum kinetic energy of the photoelectrons varies linearly with the frequency of incident radiation, but is independent of its intensity. The number of photoelectrons emitted per second is directly proportional to the intensity of incident radiation.

Case Study Answers-

1. Answer :

(i) (c) William Crookes.

(ii) (b) Electrons

(iii)(a) Millikan

(iv)(a) Diffraction and photoelectric effect.

(v) (c) Excitation of electrons in the atoms.

Explanation:

In discharge tube, collision between charged particles emitted from cathode and atoms of the gas results to colorless glow in the tube.

2. Answer :

(i) (a) Increases.

Explanation:

With the increase of intensity of the incident radiation the number of photoelectrons emitted per unit time increases.

(ii) (b) (KE_{max}/e)

Explanation:

As $eV = KE_{max}$

$$\therefore V = \left(\frac{KE_{max}}{e}\right)$$

(iii) (c) 2eV

Explanation:

From Einstein's photoelectric equation,

$$KE_{max} = h\upsilon - \phi = (5-3) = 2eV$$

(iv) (c) Photocell.

Explanation:

A photocell is a technological application of the photoelectric effect.

(v) (d) More than twice its initial value.

Explanation:

According to Einstein's photoelectric equation, the kinetic energy of the emitted photoelectron is

$$K = h\upsilon - \phi_0$$

where υ is the frequency of incident radiation and ϕ_0 is a work function of the metal.

If the frequency of incident radiation is doubled, then

$$K' = 2h\upsilon - \phi_0 = 2(h\upsilon - \phi_0) + \phi_0$$

$$K' > 2K$$