UNIT-VII

DUAL NATURE OF RADIATION AND MATTER

FORMULA AT A GLANCE

Stopping potential vs Kinetic energy vs Energy of photon vs Work function vs Threshold frequency

$$\frac{1}{2}mv_{max}^2 = eV_0 = h\nu - \Phi_0 = h(\nu - \nu_0)$$

$V_0 \rightarrow$ Stopping potential

$v_{max} \rightarrow$ Maximum velocity

$h\nu \rightarrow$ Energy associated with photon

$\Phi_0 \rightarrow$ Work Function

$h\nu_0 \rightarrow$ Threshold frequency

Einstein's photoelectric equation

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

de-Broglie wavelength

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

For an electron

$$\lambda = \frac{h}{\sqrt{2meV}} = \frac{1.227}{\sqrt{V}}\ \text{nm}$$

For any particle

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

where, $E \rightarrow \frac{1}{2}mv^2$

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

$\rightarrow eV$

$\rightarrow \frac{3}{2}k_B T$

Heisenberg Uncertainty Principle

$$\Delta x \Delta p \geq \frac{h}{2\pi}$$

Maximum Velocity of Electron

$$v_{max} = \sqrt{\frac{2eV_0}{m}}$$

Relativistic energy of a particle

$$E = \sqrt{m_0^2c^4 + p^2c^2}$$

Velocity of electron having energy E

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

Energy of photon

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

Wave number, $\bar{\nu} = \frac{1}{\lambda}$

SYNOPSIS

Photon is packet of energy .a photon of frequency v posses energy h v. The rest mass of a photon is zero.

Work function of a metal. The minimum energy which must be supplied to the electron so that it can just come out of a metal surface is called the work function of the metal.

Photoelectric 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 emitted are called photoelectrons.

Threshold frequency. The minimum frequency (v_0) which the incident light must posses so as to eject photoelectrons from a metal surface is called threshold frequency of the metal.
Mathematically: work function ,$\omega = hv_0$
Cut off potential. It is that minimum value of the negative potential (v_0),which should be applied to the anode in a photo cell so that the photoelectric current becomes zero.
Mathematically: $e\ v_0 = \frac{1}{2}\ mv_{max}^2$, where v_{max} is the maximum velocity with which the photoelectrons are emitted.

Einstein's photoelectric equation. When light of frequency v is incident on a metal surface whose work function is ω(i.e. h v_0) then the maximum kinetic energy $\frac{1}{2}\ mv_{max}^2$ of the emitted photoelectrons is given by $hv = h\ v_0 + \frac{1}{2}\ mv_{max}^2$

Photoelectric cell. A photocell is an arrangement, which produces electric current, when light falls on its cathode.
If a source of light having power P, emits photons of frequency v, then the number of photons emitted per second $n = P/\ h\ v$

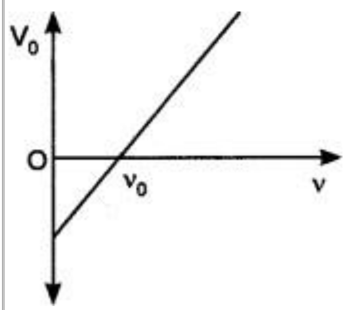
De-Broglie hypothesis. Both radiation and matter have ideal nature.
A particle of momentum ρ is associated with de-Broglie wave of wavelength, $\lambda = h/\ p = h/\ mv$
The above relation is called de-Broglie relation and the wavelength of the wave associated is called de-Broglie wavelength of the particle.

De- Broglie wavelength of electron. An electron of kinetic energy E possesses de Broglie wavelength

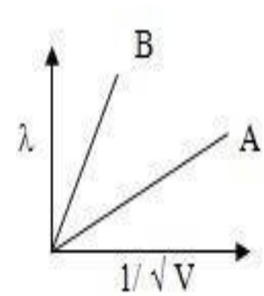
$\lambda = \frac{h}{\sqrt{2mE}}$ If electron is accelerated through a potential difference V, so as to acquire kinetic energy E (=eV), then **Error! Reference source not found.** = **Error! Reference source not found.**^{0}

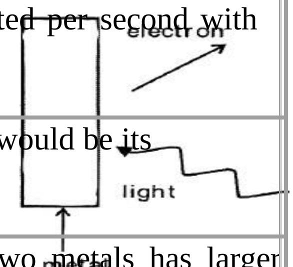
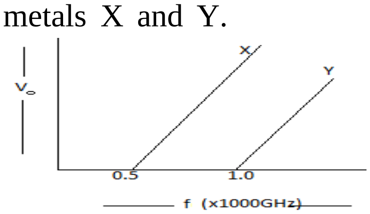
SL.NO:	Question Details	Marks
1.	When a metallic surface is illuminated with radiation of wavelength λ, the stopping potential is V. If the same surface is illuminated with radiation of wavelength 2 λ, the stopping potential is 4/V. The threshold wavelength for the metallic surface is a) 5/2 λ b) 3 λ c) 4 λ d) 5 λ	**1**
2.	Threshold wavelength for a metal having work function W0 is X. What is the threshold wavelength for the metal having work function 2W0? (a) 4λ (b) 2λ (c) λ/2 (d) λ/4	**1**
3.	The de Broglie wavelength of an electron accelerated to a potential of 400 V is approximately a) 0.03 nm b) 0.04 nm c) 0.12 nm d) 0.06 nm	**1**
4.	According to Einstein's photoelectric equation, the plot of the kinetic energy of the emitted photoelectrons from a metal Vs the frequency, of the incident radiation gives a straight line whose slope: a) depends on the nature of the metal used b) depends on the intensity of the radiation c) depends both on the intensity of the radiation and the metal used d) is the same for all metals and independent of the intensity of the radiation	**1**
5.	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 a) 1.2 nm b) 1.2×10^{-3} nm c) 1.2×10^{-6} nm d) 1.2×10^{1} nm	**1**
6.	Consider a beam of electrons (each electron with energy E_0) incident on a metal surface kept in an evacuated chamber. Then a) no electrons will be emitted as only photons can emit electrons. b) electrons can be emitted but all with an energy, E_0.	**1**

	c) electrons can be emitted with any energy, with a maximum of $E_0 - \varphi$ (φ is the workfunction). d) electrons can be emitted with any energy, with a maximum of E_0.	
7.	A proton, a neutron, an electron and an α-particle have same energy. Then their de Broglie wavelengths compare as 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) $\lambda_e = \lambda_p = \lambda_n = \lambda_\alpha$	**1**
8	Two particles A_1 sand A_2 of masses m1, m2 (m1 > m2) have the same de Brogliewavelength. Then a) their momenta are the same. b) their energies are the same. c) energy of A1 is more than the energy of A2. d) all of the above	**1**
9.	Accelerated electrons like waves performed a) Diffraction b) Movement c) absorbed potential energy d) all of these	**1**

10	The stopping potential V0 for photoelectric emission from a metal surface is plotted along y-axis and frequency v of incident light along x-axis. A straight line is obtained as shown. Planck's constant is given by  (a) slope of the line (b) product of the slope of the line and charge on electron (c) intercept along y-axis divided by charge on the electron (d) product of the intercept along x-axis and mass of the electron	**1**

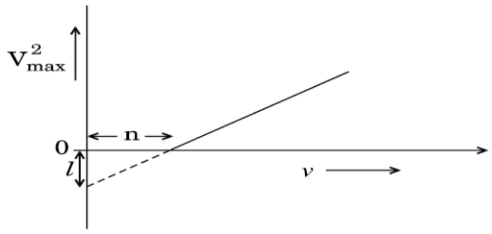
	ASSERTION & REASONING	
1.	Assertion : In photoelctric effect , on increasing the intensity of light , both the number of electrons emitted and kinetic energy of each of them get increased but photoelectric current remains unchanged. Reason : The photoelectric current depends only on wavelength of light .	**1**
2.	Assertion : Photoelectric effect demonstrates the wave nature of light. Reason: The number of photoelectrons is proportional to the frequency of light.	**1**
3.	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.	**1**
4.	Assertion : The de - Broglie wavelength of a molecule varies inversely as the square root of temperature. Reason : The root mean square velocity of the molecule depends on the temperature.	**1**
5.	Assertion : Photosensitivity of a metal is high if its work function is small. Reason : Work function $=hf_0$ where $f0$ is the threshold frequency.	**1**
	VERY SHORT ANSWER QUESTIONS	
1.	Two metals A and B have work functions 4 eV and 10 eV respectively. Which metal has A higher threshold wavelength?	**1**
2.	Ultraviolet light is incident on two photo sensitive materials having work functions W_1 and W_2 ($W_1 > W_2$). In which case will the kinetic energy of the emitted electrons be greater?	**1**

	Why?	
3.	If the intensity of incident radiation on a metal is doubled, what happens to the kinetic energy of electrons emitted?	**1**
4.	The two lines A and B shown in the graph plot the de-Broglie wavelength (□) as a function of $1/\sqrt{V}$ (V is the accelerating potential) for two particles having the same charge. Which of the two represents the particle of heavier mass? 	**1**
5.	The maximum kinetic energy of photoelectron is 2.8 eV. What is the value of stopping potential?	**1**
6.	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	**1**
7.	Electron and proton are moving with same speed, which will have more wavelength?	**1**
8.	Show graphically how the stopping potential for a given photosensitive surface varies with the frequency of incident radiations?	**1**
9.	What is the rest mass of a photon?	**1**
10.	How will the photoelectric current change on decreasing the wavelength of incident radiation for a given photosensitive material?	**1**
11.	Out of MW, UV rays and IR rays, which radiations will be the most effective for emission of electrons from a metallic surface?	**1**
	2 MARKER QUESTIONS	
12.	Red light however bright, cannot cause emission of electrons from a clean Zinc surface whereas even weak ultraviolet radiations can do so. Why?	**2**
13.	In a plot of photoelectric current versus anode potential, how does (i) The saturation current varies with anode potential for incident radiations of different frequencies but same intensity? (ii) The stopping potential vary for incident radiations of different intensities but same frequency? (iii) Photoelectric current varies for different intensities but same frequency of incident radiations? Justify your answer in each case.	**2**
14.	A proton and an α particle are accelerated through the same potential difference. Which one of the two has (i) greater de-Broglie wavelength, and (ii) less kinetic energy? Justify your answer	**2**

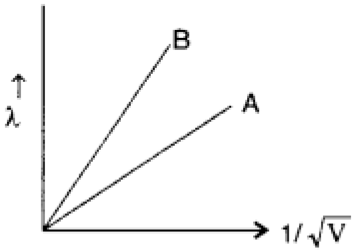
15.	Green light ejects photoelectrons from a given photosensitive surface whereas yellow light does not. What happen in case of violet and red light? Give reason for your answer.
16.	A metal has threshold wavelength of 6400 A°. Calculate (i) the threshold frequency (ii) work function of metal in eV.
17.	Calculate the threshold frequency of photon for photoelectric emission from a metal of work function 0.1eV?
18.	Ultraviolet light is incident on two photosensitive materials having work function $\varphi 1$ & $\varphi 2$ ($\varphi 1 > \varphi 2$). In which of the case will K.E. of emitted electrons be greater? Why?
19.	For a given K.E. which of the following has the smallest de-Broglie wavelength electron, proton, α- particle?
20.	Write briefly the underlying principle used in Davison-Germer experiment to verify wave nature of electrons experimentally. What is the de-Broglie wavelength of an electron withkinetic energy (K.E.) 120 eV ?
21.	Plot a graph showing variation of number of photoelectrons emitted per second with the intensity of the incident light.
22.	De-Broglie wavelength of a particle of kinetic energy k is λ. What would be its wavelengthif the kinetic energy were k/4? 
23.	The following graph shows the variation of stopping potential V_0 with the frequency f of the incident radiation for two photo sensitive metals X and Y.  1) Which of the two metals has larger threshold wavelength? Give reason. 2) Explain giving reason, which metal gives out electrons having larger kinetic energy, for the samewavelength of the incident radiation. 3) If the distance between the light source and the metal X is halved,how will the kinetic energy of the electrons emitted from it change? Give reason.

	3 MARKER QUESTIONS	
25.	The following table gives the values of work functions for a few sensitive metals. If each of these metals is exposed to radiations of wavelength 3300nm, which of these will not exit photoelectrons and why? S. No. | Metal | Work function(eV) 1 | Na | 1.92 2 | K | 2.15 3 | Mo | 4.17	**3**
26.	An electron has kinetic energy equal to 100eV. Calculate (1) momentum (2) speed (3) de Broglie wavelength of the electron.	**3**
27.	Define the term “work function” of a metal. Threshold frequency of a metal is □0. Whenthe light of frequency 2□0 is incident on the metal plate, the maximum velocity of electrons emitted is v_1. When the frequency of the incident radiation is increased to 5□□, the maximum velocity of electrons emitted is v_2. Find the ratio of v_1 to v_2.	**3**

28.	A nucleus of mass M, initially at rest splits into two fragments of masses M’/3 and 2M’/3 (M>M’). Find the ratio of de-Broglie wavelengths of two fragments.	**3**
29.	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.	**3**
30.	An electromagnetic wave of wavelength λ is incident on a photosensitive surface of negligible work function. If the photo electrons emitted from this surface have the de-Broglie wavelength λ_1 prove that $\lambda = \left(\frac{2mc}{h}\right)\lambda_1^2$.	**3**
31.	A photon and an electron have same De-Broglie wavelength, which one of these has a higher kinetic energy?	**3**
32.	When a photosensitive material is irradiated with the light of frequency *v*, the maximum speed of electrons is given by Vmax . A plot of 2max V is found to vary with frequency *v* as	**3**

	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 andmass m of the electron.	
	5 MARKER QUESTIONS	
33.	Why is de-Broglie wavelength associated with the moving football not visible? The wavelength of a photon and the de-Broglie wavelength of an electron have the same value. Show that energy of the photon is times the kinetic energy of the electron.	**5**
34.	a) Obtain the expression for the de-Broglie wavelength associated with an electronaccelerated from rest through a potential difference V_0. b) X-rays of wavelength λ fall on a photosensitive surface, emitting electrons. Assuming that the work function of the surface can be neglected, prove that the de-Broglie wavelength ofthe electrons emitted will be √hλ/2mC	**5**
35.	a) An electron of mass m is accelerated from rest through a potential difference V. Obtainthe expression for the de Broglie wavelength associated with the electron. b) If the electron and proton are moving with the same KE, which one of them will have alarge de Broglie wavelength associated with it? Give reason?	**5**
36.	(a) Is the de–Broglie wavelength of photon of an electromagnetic radiation equal to thewavelength of the radiation? (b) Are matter waves electromagnetic? Write de–Broglie wave equation. (c) What information is derived from electron diffraction experiments? (d) An electron, an alpha particle and a proton have the same kinetic energy. Which one ofthese particles has the largest de–Broglie wavelength?	**5**
37.	State the laws of photoelectric emission. Establish Einstein's photoelectric relation. Explainthe laws of photoelectric emission on the basis of this relation.	**5**
	CASE STUDY Initially, radiation was believed to have a wave nature. It was proven by Maxwell's equations and experiments conducted by Hertz. Around the same time, several different experiments hinted toward the possibility of light having a particle nature. William Crookes is credited with the discovery of cathode rays in 1870, which was a	

	huge milestone in establishing the particle nature of radiation. Radiation, thus, has a dual nature – both particle and wave. There are usually several questions asked in exams on this topic. Read on to find out more about the dual nature of radiation and matter.	
1	Define the phenomenon of photoelectric emission	1
2	Find the value of the stopping potential of an electron whose maximum kinetic energy is 5eV.	1
3	Two materials X and Y of different work functions (such that the work function of X is smaller than that of Y) were radiated with X-rays. In which case would the kinetic energy be higher? OR Two metals X and Y have a work function of 15 eV and 20 eV respectively. For which metal would the threshold wavelength be higher?	2
	CASE STUDY 2 The de Broglie equation is one of the equations that is commonly used to define the wave properties of matter. It basically describes the wave nature of the electron. Electromagnetic radiation, exhibit dual nature of a particle (having a momentum) and wave (expressed in frequency, wavelength). Microscopic particle-like electrons also proved to possess this dual nature property. Plank's quantum theory relates the energy of an electromagnetic wave to its wavelength or frequency. $E = h\nu = \frac{hc}{\lambda} \ldots\ldots.(1)$ Einstein related the energy of particle matter to its mass and velocity, as E = mc^2……..(2) As the smaller particle exhibits dual nature, and energy being the same, de Broglie equated both these relations for the particle moving with velocity 'v' as, $E = \frac{hc}{\lambda} = mv^2$: Then, $\frac{h}{\lambda} = mv$ or $\lambda = \frac{h}{mv} = \frac{h}{\text{momentum}}$: where 'h' is the Plank's constant. This equation relating the momentum of a particle with its wavelength is de Broglie equation and the wavelength calculated using this relation is de Broglie wavelength.	

1	Two lines, A and B, in the plot given below show the variation of de-Broglie wavelength, λ versus 1**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 ? (All India 2008)  	1
2	Show graphically, the variation of the de- Broglie wavelength (λ) with the potential (V) through which an electron is accelerated from rest.	1
3	State de-Broglie hypothesis OR A proton and an electron have same kinetic energy. Which one has greater de-Broglie wavelength and why?	2