CHAPTER

7

DUAL NATURE OF MATTER AND RADIATION

DUAL NATURE OF RADIATION

The phenomena such as interference, diffraction and polarisation in which interaction of radiation takes place with radiation itself. Such phenomenon can be explained on the basis of electromagnetic wave nature of radiation.

The phenomena such as rectilinear propagation reflection, refraction etc. which can be explained on the basis of either of the wave nature of the particle nature of radiation.

PHOTOELECTRIC EFFECT

The phenomenon of ejection of electrons from a metal surface, when light of sufficiently high frequency falls upon it, is called photoelectric effect. The electrons so emitted are called photoelectrons.

Threshold Frequency: The minimum frequency (ν_o) which the incident light must, posses so as to eject photoelectrons from a metal surface, is called threshold frequency of the metal. i.e., work function, W = $h\nu_o$.

Laws of Photoelectric Effect

(*i*) Photoelectric emission takes place from a metal surface, when the frequency of incident light is above its threshold frequency.

(*ii*) The photoelectric emission starts as soon as the light is incident on the metal surface.

(*iii*) The number of photoelectrons emitted is independent of the frequency of the incident light and depends only upon its intensity.

(*iv*) 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.

HERTZ AND LENARD'S OBSERVATIONS

Hertz Observations: Hertz studing experimentally, the production of electromagnetic waves by means of spark discharged, found that the high voltage sparks across the detector loop were enhanced, when emitter plate was illuminated by ultraviolet light from an arc lamp. If the suitable radiation fall on a metal surface, some electrons near the surface absorb enough energy from the incident radiations. So that the attraction of the positive ions in the material of the surface and escape to the surrounding space.

Lenard's Observations: These indicate that when ultraviolet radiations fall on emitter plate electrons are ejected from it which are attracted towards the other metal plate kept at positive potential. The flow of electrons through the evacuated glass tube results in the current flow in the external circuit. Thus, light falling on the surface of emitter causes current in the external circuit.

EINSTEIN'S PHOTOELECTRIC EQUATION

Einstein explained photoelectric equation on the basis of Max Planck's quantum theory of radiation.

A photon striking the metal surface transfer whole of its energy $h\nu$ to any one of the electrons present in the metal and its own existence is vanished. The energy supplied to the electrons is used in two ways—

1. A part of this energy is used in ejecting the electron from the metal surface (W), called work Function.

2. The rest of energy is given to the electron in the form of Kinetic energy, (E_K). Suppose the Kinetic energy of photoelectrons emitted from the metal surface is E_K, and W is the energy required to eject a photo electron from the metal surface, (W is the work function of the metal and is different for different metals), then we have—

$$h\nu = W + E_K$$

$$E_K = h\nu - W \quad ...(i)$$

where, $h\nu$ is the energy of incident photon.

If $h\nu < W$, then the photoelectrons will not be emitted, so if the light of frequency ν_0 (threshold frequency) is incident on the metal surface, then an amount of energy $h\nu_0$ of the photon of light will be spent in ejecting the electrons out of the metal *i.e.*,

$$W = h\nu_0$$

Putting this value of W in equation (*i*), we get

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

or,
$$\frac{1}{2}mv_{max}^2 = h(\nu - \nu_0) \quad ...(ii)$$

Where ν_{max} is the maximum velocity of emitted photoelectrons.

Electrons which get emitted may have belonged to the conduction shell or some shell below it. Naturally, conduction shell-electrons will need least energy to come out of the metal slab. Hence, the balance remainig energy for them will be more. Hence, the electrons coming out of the metal slab will have various kinetic energies or speeds. Out of these, we are concentrating on the electrons having the maximum speeds.

or,
$$\frac{1}{2}mv_{max}^2 = h\left(\frac{c}{\lambda} - \frac{c}{\lambda_0}\right) \quad ...(iii)$$

Equations (*i*), (*ii*) and (*iii*) represent Einstein's photoelectric equations.

The (negative) potential V_0 at which the current is just reduced to zero is called the 'Stopping Potential'. Since the energy of the fastest electrons is just balanced, when they fall through the stopping potential, we have,

$$\frac{1}{2}mv_{max}^2 = eV_0 \quad ...(iv)$$

where e is the electronic charge and V_0 is the stopping potential. Thus, the stopping potential multiplied by electronic charge gives the maximum kinetic energy of the photoelectrons.

Millikan plotted a graph between the stopping potential and the frequency of light over a wide range of frequencies and obtained a straight line. Parallel lines were obtained for other metallic surfaces.

Now, according to Einstein's equation, we have

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

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

$$\therefore \quad eV_0 = h(\nu - \nu_0)$$

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

Since h and e are constants and V_0 is constant for a given surface, this eq indicates that the graph between the kinetic energy, (eV_0) and the frequency of light v must be a straight line. This is actually the case, as found by Millikan. Hence Einstein's equation is verified. The slope of the curves determines Planck's Constant.

PARTICLE NATURE OF LIGHT (PHOTON)

A definite value of energy as well as momentum gives a strong indication that the light quantum is a particle, which was later named as photon. The particle like behaviour of light on the scattering of X-rays from electrons.

Energy of photon, $E = h\nu = \dfrac{hc}{\lambda}$

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

where h is Planck's constant.

MATTER WAVES-WAVE NATURE OF PARTICLE

Matter waves are associated with a moving particle. These waves are not electromagnetic waves in nature de-Broglie's concept of nature loves symmetry led to the discovery of matter of waves.

DE-BROGLIE WAVES RELATION

According to de-Broglie wave is associated with energy moving particle.

The quantum theory of radiation energy of the photon is given by

$$E = h\nu \quad ...(i)$$

Further the energy of relativistic particle is given by

$$E = \sqrt{m_0^2c^2 + p^2c^2} \quad [\because \text{Rest mass } m = 0]$$

$$\therefore \quad E = pc \quad ...(ii)$$

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

$$pc = h\nu \Rightarrow p = \frac{h\nu}{c} = \frac{h\nu}{c\lambda}$$

or $$p = \frac{h}{\lambda} \text{ or } \lambda = \frac{h}{p}$$

Hence, de-Broglie wavelength is given by, $\lambda = \frac{h}{mv}$.

This relation is called de-Broglie relation.

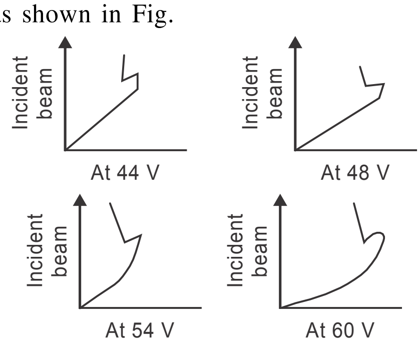
DAVISSON-GERMER EXPERIMENT

The wave nature of slow moving electrons has been established experimentally by Davisson and Germer in 1927. The electrons from hot tungsten cathode (C) are accelerated by the potential difference (V) between cathode (C) and anode (A). The fine beam of electron strike to the Ni crystal. By rotating the electron defector on circular scale at different positions, the intensity of scattered beam is measured for different values of scattering angled, the angle between the incident and the scattered electron beam.

The graph is plotted between angled and the intensity of scattered electron beam. Such graphs are plotted at different accelerating voltages. In each graph, the intensity of electron beam is in given curve point from the point O, direction is proportional to the distance, *i.e.*,

$$I \propto d$$

The experimental curves obtained by Davisson and Germen as shown in Fig.



From the above curve, we have

$$\theta = \frac{1}{2}(180° - \phi), \text{ For } \phi = 50°,$$

$$\theta = \frac{1}{2}(180° - 50°) = \frac{1}{2} \times 130° = 65°$$

From Bragg's law, for first order diffraction, $n = 1$

$$2d \sin \theta = 1 \times \lambda$$

For Ni crystal, distance between atomic planes

$$d = 0.91 \text{ Å}$$

$$\therefore \quad \lambda = 2 \times 0.91 \times \sin 65° = 1.66 \text{ Å}$$

From de-Broglie hypothesis, the wavelength associated with electron,

$$\lambda = \frac{12.27}{\sqrt{V}} = \frac{12.54}{\sqrt{54}} = 1.66 \text{ Å}$$

This verify the experiment at value determined by Davisson and Germer.

Max Planck's Quantum Theory of Radiation

In an attempt to explain the spectral distribution of energy in the spectrum of a black body, Max Planck, gave a revolutionary idea regarding the nature of light. His theory is known as Quantum theory of radiation. According to this theory, radiation consists of tiny packets of energy called photons or light quanta (each photon has a definite amount of energy by $h\nu$, 2 $h\nu$, 3 $h\nu$ ..... where h is plank's constant and ν is the frequency of radiation.

The rest mass of the photon is zero while the mass of moving photon is $\frac{h\nu}{c^2}$. The momentum of photon of wavelength λ is $\frac{h}{\lambda}$ and the momentum of photon of energy E is E/c).

EXERCISE

1. If a light wave of wavelength 4950 Å is viewed as a continous flow of photons, what is the energy of each photon in eV?

A. 1.2 eV B. 1.5 eV
C. 0.8 eV D. 2.5 eV

2. The radio transmitter operates on a wavelength of 1500 m at a power of 400 kilowatt. Then the frequency corresponding to this wavelength is

A. 500 kHz B. 200 kHz
C. 100 kHz D. 400 kHz

3. The work function of caesium is 2.14 eV. Find the threshold frequency for caesium, if the photocurrent is brought to zero by a stopping potential of 0.60 eV.

A. 1.25×10^{12} Hz B. 5.16×10^{14} Hz
C. 3.14×10^{16} Hz D. 1.0×10^{12} Hz

4. If a light of wavelength 4950 Å is viewed as a continous flow of photons, what is the energy of each photon in eV? (Given $h = 6.6 \times 10^{-34}$ Js, $c = 3 \times 10^8$ ms^{-1})

A. 1.2 eV B. 3.9 eV
C. 0.5 eV D. 2.5 eV

5. Light of two different frequencies whose photons have energies 1 and 2.5 eV respectively, successively illuminate a metal whose work function is 0.5 eV. The ratio of the maximum speeds of the emitted electrons will be

A. 1 : 5 B. 1 : 4
C. 1 : 2 D. 1 : 1

6. If the energy of a photon corresponding to a wave length of 6000 Å is 3.32×10^{-19} joule, the photon energy for a wavelength of 4000 Å will be

A. 1.11×10^{-19} joule B. 2.22×10^{-19} joule
C. 4.44×10^{-19} joule D. 4.98×10^{-19} joule

7. The mass of ${}_3Li^7$ nucleus is 0.042 amu less than the sum of masses of its nucleons. The binding energy per nucleon is

A. 3.358 Mev B. 5.586 MeV
C. 7.586 MeV D. 9.586 MeV

8. The work function of a photoelectric meterial is 3.32 eV. The threshold frequency will be equal to

A. 8×10^{14} Hz B. 8×10^{10} Hz
C. 5×10^{20} Hz D. 4×10^{14} Hz

9. An *x*-particle moves in a circular path of radius 0.83×10^{-12} m in the presence of magnetic field of 0.25 Wb/m^2. The de-Broglie wavelength associated with the particle will be.

A. 0.1 Å B. 10 Å
C. 0.01 Å D. 1 Å

10. The momentum of each photon in a given radiation is 3.3×10^{-29} kg metre/sec. The frequency of radiation is: Given $h = 6.6 \times 10^{-34}$ joule sec.

A. 3×10 Hz B. 6×10^{10} Hz
C. 7.5×10^{12} Hz D. 1.5×10^{13} Hz

11. The human eye can barely detect a yellow light (6000 Å) that delivers 1.7×10^{-18} watt to the retina. Nearly how many photons per second does the retina receive

A. 50 B. 5
C. 500 D. more than 5 million

12. A radio transmitter operates at a frequency of 880 kHz and a power of 10 kW. The number of photons emitted per second are

A. 1.71×10^{31} B. 1327×10^{34}
C. 13.27×10^{34} D. 0.75×10^{-34}

13. What is the energy of emitted photoelectrons, if light frequency 10^{16} Hz is incident on a Na-target? Work for function of Na = 2.5 eV

A. 38.875 eV B. 42.235 eV
C. 47.123 eV D. 51.234 eV

14. If the speed of photo electrons is 10^4 ms^{-1}, what should be the frequency of incident radiation on the potassium metal? (Work function potassium = 2.3 eV)

A. 5.56×10^{14} Hz B. 3.15×10^{12} Hz
C. 1.12×10^{16} Hz D. 2.14×10^{10} Hz

15. The distance between two plates of a cathode ray oscilloscope is 1 cm and potential difference between them is 1200 volt. If an electron of energy 2000 eV enters at right angles to the field, what will be its deflection if the plate be 1.5 cm long?

A. 0.03×10^{-2} m B. 0.43×10^{-2} m
C. 0.34×10^{-4} cm D. 0.34×10^{-2} m

16. In a Cathode ray tube, a potential difference of 3000 volts is maintained between the deflector plates whose separation is 2 cm. A magnetic field of 2.5×10^{-3} wbm^{-2} at right angles to the electric field gives no deflection of the electron beam which received an initial acceleration by a potential difference of 10,000 V. Calculate (e/M) of an electron

A. 1.5×10^{11} C/kg B. 2.8×10^{11} C/kg
C. 1.8×10^{11} C/kg D. 1.2×10^{11} C/kg

17. A drop of oil of radius 10^{-4} cm and carrying a charge *q* esu is moved vertically upward through air by an electric field of 1950 v/cm with a constant velocity of 0.035 cm/sec. If the viscosity of air is 180×10^{-6} cgs units. Calculate the charge *q* on the drop. Neglect density of air. Given the density of oil = 0.96 gm/cm^3 and g = 980 cm/sec^2

A. 23.43×10^{10} esu B. 24.34×10^{-10} esu
C. 34.24×10^{-10} esu D. 24.43×10^{-10} esu

18. How many photon per second does a one watt bulb emit if its efficiency is 10% and the wavelength of light emitted is 500 nm.

A. 2.53×10^{17} B. 2.35×10^{17}
C. 3.25×10^{17} D. 2.30×10^{17}

19. If the wavelength of light falling on a surface in increased from 3000 Å to 3040 Å then what will be the corresponding change in the stopping potential (Given that $hc = 12.4 \times 10^{-7}$ eV Å).

A. -5.5×10^{-12} V B. $+5.5 \times 10^{-12}$ V
C. -6.7×10^{-12} V D. $+6.7 \times 10^{-12}$ V

20. With what velocity must an electron travel so that its momentum is equal to that of a photon with a wavelength of 5200 Å?

A. 1200 m/s B. 1000 m/s
C. 1800 m/s D. 1400 m/s

21. If the wavelength of light incident on a photoelectric cell be reduced from 4000 Å to 3600 Å, then what will be the change in the cut off potential. (h = 6.6 × 10^{-34} J – s, C = 3.0 × 10^8 m/s, e = 1.6 × 10^{-19} C)

A. 0.42 volt B. 0.30 volt
C. 0.34 volt D. 0.43 volt

22. The kinetic energy of an electron gets tripled then the de-Broglie wavelength associated with it changes by a factor

A. $\frac{1}{\sqrt{3}}$ B. $\sqrt{3}$
C. $\frac{1}{3}$ D. 3

23. A particle of mass 1 mg has the some wavelength as an electron moving with a velocity of 3 × 10^6 m/sec. The velocity of the particle is

A. 2.7 × 10^{-18} m/sec B. 2.7 × 10^{-21} m/sec
C. 3 × 10^{-31} m/sec D. 9 × 10^{-2} m/sec

24. de-Broglic wavelength λ associated with an electron having kinetic energy E is given by the expression

A. $2\,mh\,\text{E}$ B. $\frac{2h}{m\text{E}}$
C. $\frac{h}{\sqrt{2m\text{E}}}$ D. $\frac{2\sqrt{2m\text{E}}}{h}$

25. Consider the metal exposed to light of wavelength 600 nm. The maximum energy of electron doubles, when light of wavelength 400 nm is used. Then, the value of work-function is

A. 0.50 eV B. 2.35 eV
C. 1.02 eV D. 2.45 eV

26. If an electron and a photon propagate in the form of waves having the same wavelength, it implies that they have the same

A. Energy
B. Momentum
C. Angular momentum
D. Velocity

27. The de-Broglie wavelength of particle moving with a velocity 2.25 × 10^8 m/sec is equal to the wavelength of proton. The ratio of kinetic energy of the particle to the energy of the photon is (velocity of light is 3 × 10^8 m/sec)

A. $\frac{7}{8}$ B. $\frac{1}{8}$
C. $\frac{5}{8}$ D. $\frac{3}{8}$

28. The kinetic energy of electron and proton is 10^{-32} J. Then, find the relation between their de-Broglie wavelengths is

A. $\lambda_p = \lambda_e$ B. $\lambda_p > \lambda_e$
C. $\lambda_p = 2\lambda_e$ D. $\lambda_p < \lambda_e$

29. A proton accelerated through a potential V has de-Broglie wavelength λ. Then, the de-Broglie wavelength of an α-particle, when accelerated through the same potential V is

A. $\frac{\lambda}{2}$ B. $\frac{\lambda}{\sqrt{2}}$
C. $\frac{\lambda}{2\sqrt{2}}$ D. $\frac{\lambda}{8}$

30. λ_e, λ_p and λ_α are the de-Broglie wavelengths of electron, proton and α-particle. If all are accelerated by same potential, then

A. $\lambda_e > \lambda_p < \lambda_\alpha$ B. $\lambda_e < \lambda_p < \lambda_\alpha$
C. $\lambda_e < \lambda_p < \lambda_\alpha$ D. $\lambda_e > \lambda_p > \lambda_\alpha$

31. When the momentum of proton in charged by an amount P_o, the corresponding change in the de-Broglie wavelength is found to be 0.25%. Then, the original momentum of the proton was

A. 400 p_o B. 4 p_o
C. p_o D. 100 p_o

32. The wavelength of photon is 1.4 Å. It collides with an electron at rest. Its wavelength after collision is 2.0 Å. Then, the energy of the scattered electron is:

A. 3.11 × 10^{-15} J B. 1.15 × 10^{-14} J
C. 4.26 × 10^{-16} J D. 0.12 × 10^{-16} J

33. A proton and α-particle are accelerated through a potential difference of 100 V, the ratio of the wavelength associated with the proton to associated with an α-partide is

A. $2\sqrt{2}:1$ B. 2 : 1
C. $\sqrt{2}:1$ D. $\frac{1}{2\sqrt{2}:1}$

34. The kinetic energy of an electron is 5 eV. Calculated the de-Broglie wavelength associated with it (h = 6.6 × 10^{-34} Js, m_e = 9.1 × 10^{-31} kg)

A. 2.71 Å B. 5.47 Å
C. 12.5 Å D. 9.23 Å

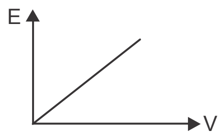
35. The de-Broglie wavelength of a proton (charge = 1.6 × 10^{-19}C mass = 1.6 × 10^{-27} kg) accelerated through a potential difference of 1 kV is

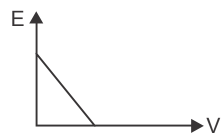
A. 7 Å B. 0.9 × 10^{-12} m
C. 0.9 nm D. 600 Å

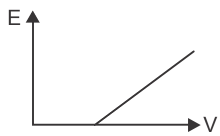
36. If the kinetic energy of the particle is increased by 16 times, the percentage change in the de-Broglie wavelength of the particle is

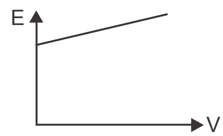
A. 60% B. 50%
C. 25% D. 75%

37. Maximum kinitic energy of photoelectron varies, with the frequency of the incident radiation of graph.

A. 

B. 

C. 

D. 

38. For a radiation of wavelength 3000 Å incident on a metal surface, maximum kinetic energy of emitted photoelectrons is 0.5 eV. If radiation of wavelength 2000 Å falls on the metal, then maximum kinetic energy of photoelectron will be
A. < 0.5 eV   B. = 0.5 eV
C. > 0.5 eV   D. Zero

39. In work function of a metal plate is negligible, then find the KE of the photoelectrons emitted, when radiations of 1000 Å are incident on the metal surface
A. 13.6 eV   B. 14.4 eV
C. 11.6 eV   D. 12.9 eV

40. If efficiency of a one watt bulb is 10% and it emits light of wavelength 500 nm, then number of photons emitted per second are about
A. 4.5×10^{19} B. 5.2×10^{19}
C. 2.5×10^{17} D. 3.1×10^{18}

41. The work function of caesium metal is 214 eV. When light of frequency 6×10^{14} Hz is incident on the metal surface, photoemission of electrons occurs. The maximum KE of the emitted electrons is
A. 0.34 eV   B. 0.64 eV
C. 0.11 eV   D. 0.26 eV

42. In an experiment of photoelectric effect, the slope of cut off voltage vs frequency of incident light is found to be 4.12×10^{-15} Vs. One value of Planck's constant is
A. 3.5×10^{-34} Js   B. 6.6×10^{-34} Js
C. 2.1×10^{-33} Js   D. 8.9×10^{-34} Js

43. The work function for a certain metal is 4.2 eV will this metal given photoelectric emission for incident radiation of wavelength 330 nm.
A. 1.246 eV   B. 2.567 eV
C. 3.767 eV   D. 4.1281 eV

44. The photoelectric cut off voltage in a certain experiment is 1.5 V. The maximum KE of photoelectric emitted is
A. 2.4×10^{-19} J   B. 1.5×10^{-19} J
C. 1.6×10^{-19} J   D. 0.6×10^{-19} J

45. Use Moseley's law with $b = 1$ to find the frequency of the K_α X-rays of La(X = 57), if the frequency of the K_α X-rays of Cu(z = 29) is known to be 1.88×10^{18} Hz
A. 7.52×10^{18}Hz   B. 8.75×10^{16}Hz
C. 12.34×10^{17}Hz   D. 4.05×10^{16}Hz

46. The wavelength of light incident on metal A is twice than that of falling on metal B. If maximum kinetic energy of photoelectrons emitted in two cases, is E_{kA} and E_{kB} respectively, then
A. $E_{kA} = E_{kB}/2$ B. $E_{kA} < E_{kB}/2$
C. $E_{kA} = E_{kB}$ D. $E_{ukA} = 2E_{kB}$

47. Light of wavelength 332 mm is incident on the metal surface of work function 1.07 eV. What will be the value of stopping potential required to stop emission of photoelectrons? ($h = 6.6 \times 10^{34}$Js)
A. 1.33 V   B. 4.66 V
C. 6.44 V   D. 2.66 V

48. A neutron beam of energy E scatters from atoms on a surface with a spacing $d = 0.1$ nm. The first maximum intensity in the reflected beam occurs at $\theta = 30°$. What is the kinetic energy E of the beam in eV?
A. 0.11 eV   B. 0.31 eV
C. 0.21 eV   D. 0.01 eV

49. Ultraviolet radiations of 6.2 eV fall on an aluminium surface, whose work function is 4.2 eV. KE of the fastest emitted electron will be
A. 3.2×10^{-17} J   B. 3.2×10^{-12} J
C. 3.2×10^{-21} J   D. 3.2×10^{-19} J

50. If the stopping potential for a photoelectrons is 39.9 V, then maximum velocity of photoelectron is
A. 3.75×10^{6} ms^{-1} B. -3×10^{8} ms^{-1}
C. 2.9×10^{7} ms^{-1} D. 4.8×10^{7} ms^{-1}

ANSWERS

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
D	B	D	B	C	D	B	A	C	D
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
B	A	C	A	D	C	B	A	A	D
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
C	C	A	C	C	B	D	D	C	D

31	32	33	34	35	36	37	38	39	40
A	C	A	B	B	D	C	C	D	C
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
A	B	C	A	A	B	D	C	D	A

EXPLANATORY ANSWERS

1. Energy of photon,

$$E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^8}{4950\times10^{-10}}$$

$$= 4.0 \times 10^{-19}\ \text{J}$$

$$= \frac{4.0\times10^{-19}}{1.6\times10^{-19}} = 2.5\ eV$$

2. Given, $\lambda = 1500$ m

As, $$v = \frac{c}{\lambda} = \frac{3\times10^8}{1500}$$

$$= 20000\ \text{Hz} = 200\ \text{kHz}.$$

3. For the minimum, cut off or threshold frequency. Energy $h\nu_0$ of incident photon = work function W_0

$$\therefore\ \nu_0 = \frac{W_0}{h} \Rightarrow \nu_0 = \frac{2.14\ \text{eV}}{6.6\times10^{-34}\ \text{Js}} = 5.16\times10^{14}\ \text{Hz}.$$

4. Given, $\lambda = 4950$ Å $= 4950 \times 10^{-10}$ m

Now, energy of each photon,

$$E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^8}{4950\times10^{-10}}$$

$$= 4.0 \times 10^{-19}\ \text{J}$$

$$= \frac{4.0\times10^{-19}}{1.6\times10^{-19}} eV = 2.5\ \text{eV}$$

5. E = Energy of incident photon

W_0 = Work function

$E - W_0$ = Available energy

$$\therefore\ E - W_0 = \frac{1}{2}mv^2$$

$$\therefore\ v = \sqrt{\frac{2(E - W_0)}{m}}$$

$$v \propto \sqrt{\text{available energy}}$$

$$\therefore\ \frac{v_1}{v_2} = \sqrt{\frac{1-0.5}{2.5-0.5}} = \sqrt{\frac{0.5}{2}} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

6. As, $E = hv = \frac{hc}{\lambda}$ and $E_1 = \frac{hc}{\lambda_1}$ and $E_2 = \frac{hc}{\lambda_2}$

$$\therefore\ \frac{E_1}{E_2} = \frac{\lambda_2}{\lambda_1} \Rightarrow E_2 = E_1\frac{\lambda_1}{\lambda_2}$$

$$= 3.32 \times 10^{-19} \times \frac{6000}{4000} = 4.98 \times 10^{-19}\ \text{J}.$$

7. We have, $$\frac{BE}{A} = \frac{\Delta m\times931}{A}$$

$$= \frac{0.042\times931}{7}$$

$$= 5.586\ \text{MeV}$$

8. As, $E = hv$

Since $E = 3.3\ \text{eV} = 3.3 \times 1.6 \times 10^{-19}$

$$\therefore\ v = \frac{3.3\times1.6\times10^{-19}}{6.6\times10^{-34}}\ \text{Hz}$$

$$= 8 \times 10^{14}\ \text{Hz}.$$

9. As, $$\lambda = \frac{h}{p} \Rightarrow \lambda = \frac{h}{mv}$$

$$\because\ r = \frac{mv}{qB}$$

$$\Rightarrow\ mv = qrB = 2e \times 0.83 \times 10^{-12} \times \frac{1}{4}$$

$$\therefore\ \lambda = \frac{6.6\times10^{-34}\times4}{2\times1.6\times10^{-19}\times0.83\times10^{-12}}$$

$$= 0.01\ \text{Å}$$

10. Momentum $= p = \frac{hv}{c}$

$$\therefore\ v = \frac{pc}{h} = \frac{3.3\times10^{-29}\times3\times10^8}{6.6\times10^{-34}}$$

$$= 1.5 \times 10^{13}\ \text{Hz}.$$

11. n = number of photons falling per second on retina

$$nhv = 1.7 \times 10^{-18}$$

or $$nh\frac{c}{\lambda} = 1.7 \times 10^{-18}$$

$$\therefore\ n = \frac{1.7\times10^{-18}\times\lambda}{hc}$$

$$= \frac{1.7\times10^{-18}\times6000\times10^{-10}}{6.6\times10^{-34}\times3\times10^8} = 5.15 \approx 5.$$

12. As, $nhv = P$, n = number of photons/sec

$$n \times 6.6 \times 10^{-34} \times 880 \times 10^3 = 10 \times 10^3$$

$$n = \frac{10\times10^3}{6.6\times10^{-34}\times880\times10^3} = 1.71 \times 10^{31}.$$

13. As, $\frac{1}{2}mv\max^2 = h\nu - W = \frac{6.6\times10^{-34}\times10^{16}}{1.6\times10^{-19}} - 2.5$

$= 41.375 - 2.5$

$= 38.875\ eV$

14. As, $h\nu = \frac{1}{2}mu^2 + W_0$

$= \frac{1}{2}\times9.1\times10^{-31} \times (10^4)^2 + 2.3 \times 1.6 \times 10^{-19}$

$= 4.55 \times 10^{-23} + 3.68 \times 10^{-19}$

$= 3.6795 \times 10^{-19}$ J

$\therefore \quad \nu = \frac{3.6795\times10^{-19}\,J}{h}$

$= \frac{3.6795\times10^{-19}}{6.6\times10^{-34}} = 5.56\times10^{14}\,Hz$

15. As, $E = \frac{V}{d} = \frac{1200\ V}{10^{-2}\,m} = 1.2 \times 10^5$ V/m

Kinetic energy of electron entering the field K = 2000 $eV = 3.2 \times 10^{-16}$

Deflection of electron in the field of length 1.5×10^{-2} is

$$y = \frac{eEl^2}{2mv^2} = \frac{eEl^2}{4K}$$

$$= \frac{1.6\times10^{-19}\times1.2\times10^5\times(1.5\times10^{-2})^2}{4(3.2\times10^{-16})}$$

$= 0.34 \times 10^{-2}$ m.

16. $Bev = eE$ or $V = \frac{E}{B} = \frac{V}{dB}$

$= \frac{3000}{2\times10^{-2}\times2.5\times10^{-3}} = 6.7 \times 10^7$ m/s

Now, $eV' = \frac{1}{2}mv^2$

or $v = \sqrt{\frac{2eV'}{m}} = \sqrt{\left(2\times\frac{e}{m}\times10000\right)}$

or $(6 \times 10^7)^2 = 2 \times \left(\frac{e}{m}\right)\times10{,}000$

$\therefore \quad \frac{e}{m} = 1.8 \times 10^{11}$ coulomb/kg.

17. As, $qE = 6\pi\eta rv + \left(\frac{4}{3}\right)\pi r^3\rho g$

$$q = \frac{6\pi\eta rv + (4\pi r^3\rho g/3)}{E}$$

$= [6 \times 3.14 \times (180 \times 10^{-6}) \times 10^{-4} \times .035 + (4/3) \times 3.14 \times (10^{-4})^3 \times 0.96 \times 980]/[1950/300]$

$= 24.34 \times 10^{-10}$ esu or stat coulomb

18. $\frac{hc}{\lambda}$ = energy of one photon for the light of wavelength λ.

n = number of photons emitted per sec.

$\frac{nhc}{\lambda}$ = energy emitted by bulb per sec.

Efficiency of the bulb is 10%

$\frac{nhc}{\lambda} = \frac{P}{10}$ or $n = \frac{P\lambda}{10\,hc}$ or

$$n = \frac{1\text{ watt}\times(500\times10^{-9}\,m)}{10\times(6.6\times10^{-34}\,J.s)\times(3\times10^8\,m.s^{-1})}$$

$= 2.53 \times 10^{17}$.

19. As, $eV_0 = \frac{hc}{\lambda} - W_0$

W_0 = work function of the metal over which light is incident

W = is a constant for a given metallic surface

$$edV_0 = \frac{hc\cdot d\lambda}{\lambda^2} = \frac{(12.4\times10^{-7}\,eV\text{Å})(40\text{Å})}{(3000\text{ Å})^2}$$

$\therefore \quad dv_0 = -5.5 \times 10^{12}$ eV

20. As $P = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{5200\times10^{-10}}$ kgm/sec.

Momentum of the electron $= mv$

$= 9.1 \times 10^{-31}\,v$

$9.1 \times 10^{-31} \times v = \frac{6.63\times10^{-34}}{5200\times10^{-10}}$

$\therefore \quad v = 1400$ m/s.

21. As, $eV_0 = \frac{hc}{\lambda} - w$ or $V_0 = \frac{hc}{e\lambda} - \frac{W}{e}$

$\Delta V_0 = (V_0)_2 - (V_0)_1$

$= \left(\frac{h_c}{e\lambda_2} - \frac{W}{e}\right) - \left(\frac{hc}{e\lambda_1} - \frac{W}{e}\right)$

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

$$= \frac{(6.6\times10^{-34})\times(3\times10^8)}{(1.6\times10^{-19})}\times\left[\frac{0.4\times10^{-7}}{4.0\times10^{-7}\times3.6\times10^{-7}}\right]$$

= 0.34 volt.

22. For an electron, the de-Broglie wavelength, $\lambda = \frac{h}{\sqrt{2\,mk}}$

where, h = Planck's constant,

m = mass of an electron

and k = kinetic energy of an electron

Since, h, m remain the same, then $\lambda \propto \frac{1}{\sqrt{k}}$

$$\Rightarrow \quad \frac{\lambda}{\lambda'} = \sqrt{\frac{k'}{k}} = \sqrt{\frac{3k}{k}} = \lambda' = \frac{\lambda}{3}.$$

23. The de-Broglie wavelength, $\lambda = \frac{h}{mv}$

As both particle electron having same wavelength Therefore, momentum will be equal

$$m_p v_p = m_e v_e \Rightarrow U_p = \frac{m_e v_e}{m_p}$$

$$= \frac{9.1 \times 10^{-31} \times 3 \times 10^6}{10^{-6}}$$

$$\Rightarrow \quad v_p = \frac{m_e v_e}{m_p}$$

$$\Rightarrow \quad v_p = 2.7 \times 10^{-18} \text{ m/sec.}$$

24. As, $E = \frac{1}{2}mv^2$ or $E = \frac{1}{2}\frac{(mv)^2}{m}$

$$\Rightarrow \quad mv = \sqrt{2mE}$$

$$\therefore \quad h = \frac{h}{m\nu} = \frac{h}{\sqrt{2mE}}.$$

25. Maximum energy = $h\nu - \phi$

$$\left(\frac{1230}{600} - \phi\right) = \frac{1}{2}\left(\frac{1230}{400} - \phi\right)$$

$$\therefore \quad \phi = \frac{1230}{1200} = 1.02 \text{ } eV.$$

26. When an electron and photon propagate in the form of the waves having the same wavelength, hence, they have same momentum. By de-Broglie equation

$$p \propto \frac{1}{\lambda}.$$

27. We have, $K_{electron} = \frac{1}{2}mv^2$ and $\lambda = \frac{h}{mu}$ ...(*i*)

$$\Rightarrow \quad K_{electron} = \frac{1}{2}\left(\frac{h}{\lambda\nu}\right)\nu^2 = \frac{\nu h}{2\lambda} \quad ...(ii)$$

$$K_{photon} = \frac{hc}{\lambda} \quad ...(iii)$$

Dividing equation from (*i*) & (*ii*), we get

$$\frac{K_{electron}}{K_{photon}} = \frac{\nu}{2c} = \frac{2 \times 25 \times 10^8}{2 \times 3 \times 10^8} = \frac{3}{8}.$$

28. As, $\lambda = \frac{h}{\sqrt{2mE}}$, $E = 10^{-32}$ J, which in constant for both particles, hence, $\lambda \propto \frac{1}{\sqrt{m}}$

$$m_p > m_e$$

$$\therefore \quad \lambda_p < \lambda_e.$$

29. As, $\lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}} \Rightarrow \lambda \propto \frac{1}{\sqrt{mq}}$

$$\Rightarrow \quad \frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p q_p}{m_\alpha q_\alpha}}$$

$$\therefore \quad q_\alpha = 2q_p,\ m_\alpha = 4mp,\ \lambda_p = \lambda$$

$$\lambda_a = \frac{\lambda}{2\sqrt{2}}.$$

30. As, $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}} \Rightarrow \lambda \propto \frac{1}{\sqrt{mE}}$

KE, gained by charged particle under potential V

$$E = qE$$

$$E_e = eV,\quad E_p = eV$$

$$E_\alpha = 2eV \Rightarrow E_e = E_p < E_\alpha$$

and $m_e < m_p < m_\alpha$

$$\Rightarrow \quad \lambda = \frac{h}{\sqrt{2m_e E_e}} > \frac{h}{\sqrt{2m_p E_p}} > \frac{h}{\sqrt{2m_\alpha E_\alpha}}$$

$$\lambda_e > \lambda_p > \lambda_\alpha.$$

31. As, $\lambda \propto \frac{1}{p} \Rightarrow \frac{\Delta p}{p} = -\frac{\Delta\lambda}{\lambda}$

$$\Rightarrow \left|\frac{\Delta p}{p}\right| = \left|\frac{\Delta\lambda}{\lambda}\right| \Rightarrow \frac{p_0}{p} = \frac{0.25}{100} = \frac{1}{400}$$

$$\Rightarrow \quad p = 400\ p_0.$$

32. As, $E = hc\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)$

$$= 6.63 \times 10^{-34} \times 3 \times 10^8 \left(\frac{1}{1.4 \times 10^{-10}} - \frac{1}{2 \times 10^{10}}\right)$$

$$= 4.26 \times 10^{-16} \text{ J}$$

33. As, $\lambda = \frac{h}{\sqrt{2mQV}} \Rightarrow \lambda \propto \frac{1}{\sqrt{mQ}}$

$$\Rightarrow \quad \frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha Q_\alpha}{m_p Q_p}} = \sqrt{\frac{4m_p \times 2Q_p}{m_p \times Q_p}} = 2\sqrt{2}.$$

34. As, $\lambda = \frac{h}{\sqrt{2mE}}$

$$= \frac{6.6 \times 10^{-34}}{\sqrt{2} \times 9.1 \times 10^{-31} \times 5 \times 1.6 \times 10^{-19}}$$

$$\lambda = 5.47 \text{ Å}.$$

35. As, $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$

$\Rightarrow \quad \lambda = \dfrac{6.6\times10^{-34}}{\sqrt{2\times(1.6\times10^{-27})\times(1.6\times10^{-19})\times100}}$

$\therefore \quad \lambda = 0.9 \times 10^{-12}$ m.

36. As, $\lambda = \dfrac{h}{\sqrt{2mk}} \Rightarrow \dfrac{\lambda_1}{\lambda_2} = \sqrt{\dfrac{k_2}{k_1}} = \sqrt{\dfrac{16k}{k}} = 4$

or $\dfrac{\lambda_1}{\lambda_2} = 4 \Rightarrow \lambda_2 = \dfrac{\lambda_1}{4} = \dfrac{100}{4} = 25$

$\therefore \quad \lambda_1 = 25 \times 4 = 100$

$\therefore$ Increase in percentage = 100 – 25 = 75%.

37. Some minimum frequency is required to eject the photoelectrons.

38. When wavelength of incident radiation is decreased, their frequency increases and hence, electron with more energy come out of the surface of the metal.

39. As $E = h\nu = \dfrac{hc}{\lambda}$

$$E = \frac{6.62\times10^{-34}\times3\times10^{8}}{1000\times10^{-10}\times1.6\times10^{-19}}\,eV$$

$\therefore \quad E = 12.41$ eV.

40. Let $\dfrac{hc}{\lambda}$ is energy emitted by bulb in 1 s

$\therefore \quad \dfrac{nhc}{\lambda} = \dfrac{p}{10}$ or $n = \dfrac{p\lambda}{10hc}$

$\therefore \quad n = 2.53 \times 10^{17}$.

41. Given, $W_0 = 2.14$ eV, $\nu = 6 \times 10^{14}$ Hz

As, $K_{max} = h\nu - W_0$

$= 6.63 \times 10^{-34} \times 6 \times 10^{14}$ J – 2.14 eV

$= \dfrac{6.63\times6\times10^{-20}}{1.6\times10^{-19}}$ eV – 2.14 eV

= 2.48 – 2.14 = 0.34 eV.

42. We have, $\dfrac{\Delta V}{\Delta\nu} = 4.12 \times 10^{-15}$ Vs

$e = 1.6 \times 10^{-19}$

$\therefore$ Planck's constant, $h = \dfrac{\Delta V}{\Delta \nu}\cdot e$

$= 4.12 \times 10^{-15} \times 1.6 \times 10^{-19}$

$= 6.592 \times 10^{-34}$ Js

$= 6.6 \times 10^{-34}$ Js.

43. Given, $W_0 = 4.2$ eV, $\lambda = 230$ nm $= 330 \times 10^{-9}$ m

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

$= \dfrac{6.63\times10^{-34}\times3\times10^{8}}{330\times10^{-9}}$ J

= 3.767 eV.

44. Given, $V_0 = 1.5$ V

As, $K_{max} = eV_0 = 1.5$ eV

$= 1.5 \times 1.6 \times 10^{-19}$ J

$= 2.4 \times 10^{-19}$ J

45. As, $\sqrt{f} = a(z - b)$

$$\frac{f_{La}}{f_{Cu}} = \left(\frac{z_{La}-1}{z_{Cu}-1}\right)^2$$

$$f_{La} = f_{Cu}\left(\frac{z_{La}-1}{z_{Cu}-1}\right)^2$$

$= 1.88 \times 10^{18}\left(\dfrac{57-1}{29-1}\right)^2$

$= 7.52 \times 10^{18}$ Hz.

46. As, $E_{kA} = \dfrac{hc}{\lambda} - W \Rightarrow \dfrac{hc}{\lambda} = E_{kA} + W$

$E_{kB} = \dfrac{hc}{\lambda/2} - W$

or $E_{kB} = \dfrac{2hc}{\lambda} - W = 2(E_{kA} + W) - W$

or $E_{kB} = \dfrac{E_{uB}}{2} - \dfrac{W}{2}$

or $E_{kB} < E_{uB}$.

47. As, $V_0 = \dfrac{hc}{e\lambda} - \dfrac{\phi_o}{e}$

$= \dfrac{6.6\times10^{-34}\times10^{8}}{1.6\times10^{-19}\times332\times10^{9}} - \dfrac{1.07\times1.6\times10^{-19}}{1.6\times10^{-19}}$

= 3.73 – 7.07 = 2.66 V.

48. As, $2d \sin\theta = \lambda = d = 10^{-10}$ m

$p = \dfrac{h}{10^{-10}} = \dfrac{6.6\times10^{-34}}{10^{-10}} = 6.6 \times 10^{-21}$ kg ms^{-1}

$\therefore \quad E = \dfrac{(6.6\times10^{-24})^2}{2\times(1.7\times10^{-27})}\times1.6\times10^{-19}$

$= \dfrac{6.6^2}{2\times1.7}\times1.6\times10^{-2}$ eV

$= 2.05 \times 10^{-2}$ eV = 0.21 eV.

49. As, $E_k = h_\nu - W = (6.2 - 4.2)$ eV = 2.0 eV

$= 2 \times 1.6 \times 10^{-19}$ J $= 3.2 \times 10^{-19}$ J

50. As, $eV_0 = \dfrac{1}{2}mv^2$

$\therefore \quad v^2 = \dfrac{2eV_0}{m}$ or $v = \sqrt{\dfrac{2eV}{m}}$

$\therefore \quad v = 3.75 \times 10^6$ ms^{-1}.