Chapter
Dual Nature of Radiation and Matter

Topic-1: Matter Waves, Cathode and Positive Rays

1 MCQs with One Correct Answer

1. A proton has kinetic energy $E = 100$ keV which is equal to that of a photon. The wavelength of photon is λ_2 and that of proton is λ_1. The ratio of λ_2/λ_1 is proportional to **[2004S]**

(a) E^2 (b) $E^{1/2}$ (c) E^{-1} (d) $E^{-1/2}$

2. A particle of mass M at rest decays into two particles of masses m_1 and m_2, having non-zero velocities. The ratio of the de Broglie wavelengths of the particles, λ_1/λ_2, is **[1999S - 2 Marks]**

(a) m_1/m_2 (b) m_2/m_1

(c) 1.0 (d) $\sqrt{m_2}/\sqrt{m_1}$

2 Integer Value Answer

3. An α-particle and a proton are accelerated from rest by a potential difference of 100 V. After this, their de Broglie wavelengths are λ_α and λ_p respectively. The ratio $\frac{\lambda_p}{\lambda_\alpha}$, to the nearest integer, is **[2010]**

10 Subjective Problems

4. The potential energy of a particle of mass m is given by

$$V(x) = \begin{cases} E_0; & 0 \le x \le 1 \\ 0; & x > 1 \end{cases}$$

λ_1 and λ_2 are the de-Broglie wavelengths of the particle, when $0 \le x \le 1$ and $x > 1$ respectively. If the total energy of particle is $2E_0$, find λ_1/λ_2. **[2005-2 Marks]**

Topic-2: Photon, Photoelectric Effect X-rays and Davisson-Germer Experiment

1 MCQs with One Correct Answer

1. When light of a given wavelength is incident on a metallic surface, the minimum potential needed to stop the emitted photoelectrons is 6.0 V. This potential drops to 0.6 V if another source with wavelength four times that of the first one and intensity half of the first one is used. What are the wavelength of the first source and the work function of the metal, respectively? [Take $\frac{hc}{e} = 1.24 \times 10^{-6}\ JmC^{-1}$.] **[Adv. 2022]**

(a) 1.72×10^{-7} m, 1.20 eV (b) 1.72×10^{-7} m, 5.60 eV
(c) 3.78×10^{-7} m, 5.60 eV (d) 3.78×10^{-7} m, 1.20 eV

2. This equation has statement 1 and statement 2. Of the four choices given after the statements, choose the one that describes the two statements.

Statement 1: Davisson-Germer experiment established the wave nature of electrons.

Statement 2 : If electrons have wave nature, they can interfere and show diffraction. **[2012]**

(a) Statement 1 is false, Statement 2 is true.
(b) Statement 1 is true, Statement 2 is false
(c) Statement 1 is true, Statement 2 is true, Statement 2 is the correct explanation of statement 1
(d) Statement 1 is true, Statement 2 is true, Statement 2 is not the correct explanation of Statement 1

3. In a historical experiment to determine Planck's constant, a metal surface was irradiated with light of different wavelengths. The emitted photoelectron energies were measured by applying a stopping potential. The relevant data for the wavelength (λ) of incident light and the corresponding stopping potential (V_0) are given below :

λ (μm)	V_0 (Volt)
0.3	2.0
0.4	1.0
0.5	0.4

Given that $c = 3 \times 10^8 m s^{-1}$ and $e = 1.6 \times 10^{-19}$ C, Planck's constant (in units of J s) found from such an experiment is **[Adv. 2016]**

(a) 6.0×10^{-34} (b) 6.4×10^{-34}
(c) 6.6×10^{-34} (d) 6.8×10^{-34}

4. A metal surface is illuminated by light of two different wavelengths 248 nm and 310 nm. The maximum speeds of the photoelectrons corresponding to these wavelengths are u_1 and u_2, respectively. If the ratio $u_1 : u_2 = 2 : 1$ and $hc = 1240$ eV nm, the work function of the metal is nearly **[Adv. 2014]**

(a) 3.7 eV (b) 3.2 eV
(c) 2.8 eV (d) 2.5 eV

5. If λ_{Cu} is the wavelength of K_α X-ray line of copper (atomic number 29) and λ_{Mo} is the wavelength of the K_α X-ray line of molybdenum (atomic number 42), then the ratio $\lambda_{Cu}/\lambda_{Mo}$ is close to **[Adv. 2014]**

(a) 1.99 (b) 2.14 (c) 0.50 (d) 0.48

6. A pulse of light of duration 100 ns is absorbed completely by a small object initially at rest. Power of the pulse is 30 mW and the speed of light is 3×10^8 ms^{-1}. The final momentum of the object is **[Adv. 2013]**

(a) 0.3×10^{-17} kg ms^{-1} (b) 3.0×10^{-17} kg ms^{-1}
(c) 1.0×10^{-17} kg ms^{-1} (d) 9.0×10^{-17} kg ms^{-1}

7. Which one of the following statements is WRONG in the context of X-rays generated from a X-ray tube? **[2008]**

(a) Wavelength of characteristic X-rays decreases when the atomic number of the target increases.
(b) Cut-off wavelength of the continuous X-rays depends on the atomic number of the target
(c) Intensity of the characteristic X-rays depends on the electrical power given to the X-ray tube
(d) Cut-off wavelength of the continuous X-rays depends on the energy of the electrons in the X-ray tube

8. Electrons with de-Broglie wavelength λ fall on the target in an X-ray tube. The cut-off wavelength of the emitted X-rays is **[2007]**

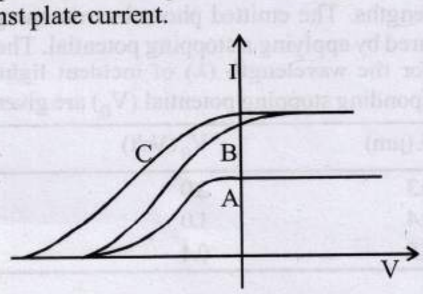
(a) $\lambda_0 = \dfrac{2mc\lambda^2}{h}$ (b) $\lambda_0 = \dfrac{2h}{mc}$

(c) $\lambda_0 = \dfrac{2m^2c^2\lambda^3}{h^2}$ (d) $\lambda_0 = \lambda$

9. K_α wavelength emitted by an atom of atomic number Z = 11 is λ. Find the atomic number for an atom that emits K_α radiation with wavelength 4λ. **[2005S]**

(a) Z = 6 (b) Z = 4 (c) Z = 11 (d) Z = 44

10. In a photoelectric experiment anode potential is plotted against plate current. **[2004S]**

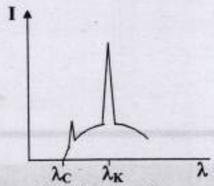


(a) A and B will have different intensities while B and C will have different frequencies
(b) B and C will have different intensities while A and C will have different frequencies
(c) A and B will have different intensities while A and C will have equal frequencies
(d) B and C will have equal intensities while A and B will have same frequencies

11. The potential difference applied to an X-ray tube is 5kV and the current through it is 3.2*mA*. Then the number of electrons striking the target per second is **[2002S]**

(a) 2×10^{16} (b) 5×10^6 (c) 1×10^{17} (d) 4×10^{15}

12. The intensity of X-rays from a Coolidge tube is plotted against wavelength λ as shown in the figure. The minimum wavelength found is λ_C and the wavelength of the K_α line is λ_K. As the accelerating voltage is increased **[2001S]**



(a) $\lambda_K - \lambda_C$ increases
(b) $\lambda_K - \lambda_C$ decreases
(c) λ_K increases
(d) λ_K decreases

13. Electrons with energy 80 keV are incident on the tungsten target of an X-ray tube. K-shell electrons of tungsten have 72.5 keV energy. X-rays emitted by the tube contain only **[2000S]**

(a) a continuous X-ray spectrum (Bremsstrahlung) with a minimum wavelength of 0.155Å
(b) a continuous X-ray spectrum (Bremsstrahlung) with all wavelengths
(c) the characteristic X-ray spectrum of tungsten
(d) a continuous X-ray spectrum (Bremsstrahlung) with a minimum wavelength of 0.155Å and the characteristic X-ray spectrum of tungsten.

14. The work function of a substance is 4.0 eV. The longest wavelength of light that can cause photoelectron emission from this substance is approximately **[1998S - 2 Marks]**

(a) 540 nm (b) 400 nm (c) 310 nm (d) 220 nm

15. X-rays are produced in an X-ray tube operating at a given accelerating voltage. The wavelength of the continuous X-rays has values from **[1998S - 2 Marks]**

(a) 0 to ∞
(b) λ_{min} to ∞ where $\lambda_{min} > 0$
(c) 0 to λ_{max} where $\lambda_{max} < \infty$
(d) λ_{min} to λ_{max} where $0 < \lambda_{min} < \lambda_{max} < \infty$

16. The maximum kinetic energy of photoelectrons emitted from a surface when photons of energy 6 eV fall on it is 4 eV. The stopping potential, in volt, is **[1997 - 1 Mark]**

(a) 2 (b) 4 (c) 6 (d) 10

17. An energy of 24.6 eV is required to remove one of the electrons from a neutral helium atom. The energy in (eV) required to remove both the electrons from a neutral helium atom is **[1995S]**

(a) 38.2 (b) 49.2 (c) 51.8 (d) 79.0

18. The X-ray beam coming from an X-ray tube will be **[1985 - 2 Marks]**

(a) monochromatic
(b) having all wavelengths smaller than a certain maximum wavelength

(c) having all wavelengths larger than a certain minimum wavelength

(d) having all wavelengths lying between a minimum and a maximum wavelength

19. The shortest wavelength of X-rays emitted from an X-ray tube depends on **[1982 - 3 Marks]**

(a) the current in the tube

(b) the voltage applied to the tube

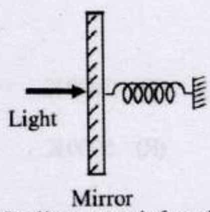
(c) the nature of the gas in tube

(d) the atomic number of the target material

2 Integer Value Answer

20. In a photoemission experiment, the maximum kinetic energies of photoelectrons from metals P, Q and R are E_P, E_Q and E_R, respectively, and they are related by $E_P = 2E_Q = 2E_R$. In this experiment, the same source of monochromatic light is used for metals P and Q while a different source of monochromatic light is used for the metal R. The work functions for metals P, Q and R are 4.0 eV, 4.5 eV and 5.5 eV, respectively. The energy of the incident photon used for metal R, in eV, is ______. **[Adv. 2021]**

21. A perfectly reflecting mirror of mass M mounted on a spring constitutes a spring-mass system of angular frequency such that $= 10^{24} m^{-2}$ with h as Planck's constant. N photons of wavelength $\lambda = 8\pi \times 10^{-6}$ m strike the mirror simultaneously at normal incidence such that the mirror gets displaced by 1μm. If the value of N is $x \times 10^{12}$, then the value of x is ______ [Consider the spring as massless] **[Adv. 2019]**



22. The work functions of Silver and Sodium are 4.6 and 2.3 eV, respectively. The ratio of the slope of the stopping potential versus frequency plot for Silver to that of Sodium is **[Adv. 2013-I]**

23. A silver sphere of radius 1 cm and work function 4.7 eV is suspended from an insulating thread in freespace. It is under continuous illumination of 200 nm wavelength light. As photoelectrons are emitted, the sphere gets charged and acquires a potential. The maximum number of photoelectrons emitted from the sphere is $A \times 10^z$ (where $1 < A < 10$). The value of 'z' is **[2011]**

3 Numeric / New Stem Based Questions

24. In a photoelectric experiment a parallel beam of monochromatic light with power of 200 W is incident on a perfectly absorbing cathode of work function 6.25 eV. The frequency of light is just above the threshold frequency so that the photoelectrons are emitted with negligible kinetic energy. Assume that the photoelectron emission efficiency is 100%. A potential difference of 500 V is applied between the cathode and the anode. All the emitted electrons are incident normally on the anode and are absorbed. The anode experiences a force $F = n \times 10^{-4}$ N due to the impact of the electrons. The value of n is ______. Mass of the electron $m_e = 9 \times 10^{-31}$ kg and $1.0\,eV = 1.6 \times 10^{-19}\,J$. **[Adv. 2018]**

4 Fill in the Blanks

25. The wavelength of K_α X-rays produced by an X-ray tube is 0.76Å. The atomic number of the anode material of the tube is..... **[1996 - 2 Marks]**

26. A potential difference of 20 kV is applied across an X-ray tube. The minimum wavelength of X-rays generated is...........Å. **[1996 - 2 Marks]**

27. In an X-ray tube, electrons accelerated through a potential difference of 15, 000 volts strike a copper target. The speed of the emitted X-ray inside the tube is .... m/s **[1992 - 1 Mark]**

28. The wavelength of the characteristic X-ray K_α line emitted by a hydrogen like element is 0.32 Å. The wavelength of the K_β line emitted by the same element will be .... **[1990 - 2 Marks]**

29. When the number of electrons striking the anode of an X-ray tube is increased, the .... of the emitted X-rays increases, while when the speeds of the electrons striking the anode are increased, the cut-off wavelength of the emitted X-rays......... **[1986 - 2 Marks]**

30. The maximum kinetic energy of electrons emitted in the photoelectric effect is linearly dependent on the ...... of the incident radiation. **[1984- 2 Marks]**

31. To produce characteristic X-rays using a Tungsten target in an X-ray generator, the accelerating voltage should be greater than ______ volts and the energy of the characteristic radiation is ______ eV. (The binding energy of the innermost electron in Tungsten is 40 keV). **[1983 - 2 Marks]**

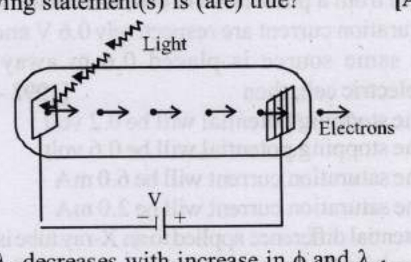
5 True / False

32. In a photoelectric emission process the maximum energy of the photo-electrons increases with increasing intensity of the incident light. **[1986 - 3 Marks]**

33. The kinetic energy of photoelectrons emitted by a photosensitive surface depends on the intensity of the incident radiation. **[1981-2 Marks]**

6 MCQs with One or More than One Correct Answer

34. Light of wavelength λ_{ph} falls on a cathode plate inside a vacuum tube as shown in the figure. The work function of the cathode surface is ϕ and the anode is a wire mesh of conducting material kept at a distance d from the cathode. A potential difference V is maintained between the electrodes. If the minimum de Broglie wavelength of the electrons passing through the anode is λ_e, which of the following statement(s) is (are) true? **[Adv. 2016]**



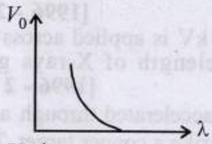
(a) λ_e decreases with increase in ϕ and λ_{ph}

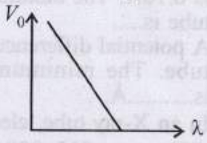
(b) λ_e is approximately halved, if d is doubled

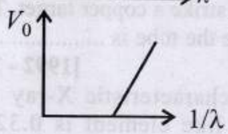
(c) For large potential difference ($V >> \phi/e$), λ_e is approximately halved if V is made four times

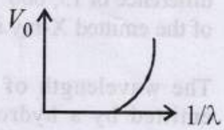
(d) λ_e increases at the same rate as λ_{ph} for $\lambda_{ph} < hc/\phi$

35. For photo-electric effect with incident photon wavelength λ, the stopping potential is V_0. Identify the correct variation(s) of V_0 with λ and $1/\lambda$. **[Adv. 2015]**

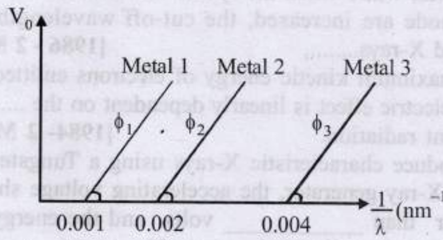
(a)


(b)


(c)


(d)


36. The graph between the stopping potential (V_0) and $\left(\frac{1}{\lambda}\right)$ is shown in the figure. ϕ_1, ϕ_2 and ϕ_3 are work functions, which of the following is/are correct **[2006 - 5M, –1]**



(a) $\phi_1 : \phi_2 : \phi_3 = 1:2:4$
(b) $\phi_1 : \phi_2 : \phi_3 = 4:2:1$
(c) $\tan\theta \propto \frac{hc}{e}$
(d) ultraviolet light can be used to emit photoelectrons from metal 2 and metal 3 only

37. When photons of energy 4.25 eV strike the surface of metal A, the ejected photoelectrons have maximum kinetic energy, T_A eV and de Broglie wavelength λ_A. The maximum kinetic energy of photoelectrons liberated from another metal B by photons of energy 4.70 eV is $T_B = (T_A - 1.50)$ eV. If the de Broglie wavelength of these photoelectrons is $\lambda_B = 2\lambda_A$, then **[1994 - 2 Marks]**
(a) The work function of A is 2.25 eV
(b) The work function of B is 4.20 eV
(c) T_A = 2.00 eV
(d) T_B = 2.75 eV

38. When a monochromatic point source of light is at a distance of 0.2 m from a photoelectric cell, the cut off voltage and the saturation current are respectively 0.6 V and 18.0 mA. If the same source is placed 0.6 m away from the photoelectric cell, then **[1992 - 2 Marks]**
(a) the stopping potential will be 0.2 volt
(b) the stopping potential will be 0.6 volt
(c) the saturation current will be 6.0 mA
(d) the saturation current will be 2.0 mA

39. The potential difference applied to an X-ray tube is increased. As a result, in the emitted radiation **[1988 - 2 Marks]**
(a) the intensity increases
(b) the minimum wavelength increases
(c) the intensity remain unchanged
(d) the minimum wavelength decreases

40. Photoelectric effect supports quantum nature of light because **[1987 - 2 Marks]**
(a) there is a minimum frequency of light below which no photoelectrons are emitted
(b) the maximum kinetic energy of photo electrons depends only on the frequency of light and not on its intensity
(c) even when the metal surface is faintly illuminated, the photoelectrons leave the surface immediately
(d) electric charge of the photoelectrons is quantized

41. The threshold wavelength for photoelectric emission from a material is 5200 Å. Photoelectrons will be emitted when this material is illuminated with monochromatic radiation from a **[1982 - 3 Marks]**
(a) 50 watt infrared lamp (b) 1-watt infra-red lamp
(c) 50 watt ultraviolet lamp (d) 1-watt ultraviolet lamp

7 Match the Following

42. Match the temperature of a black body given in List-I with an appropriate statement in List-II, and choose the correct option. **[Adv. 2023]**
[Given: Wien's constant as 2.9×10^{-3} m–K and $\frac{hc}{e} = 1.24 \times 10^{-6}$ V–m]

List-I		List-II	
(P)	2000 K	(1)	The radiation at peak wavelength can lead to emission of photoelectrons from a metal of work function 4 eV.
(Q)	3000 K	(2)	The radiation at peak wavelength is visible to human eye.
(R)	5000 K	(3)	The radiation at peak emission wavelength will result in the widest central maximum of a single slit diffraction.
(S)	10000 K	(4)	The power emitted per unit area is 1/16 of that emitted by a blackbody at temperature 6000 K.
		(5)	The radiation at peak emission wavelength can be used to image human bones.

(a) P → 3, Q → 5, R → 2, S → 3
(b) P → 3, Q → 2, R → 4, S → 1
(c) P → 3, Q → 4, R → 2, S → 1
(d) P → 1, Q → 2, R → 5, S → 3

9 Assertion and Reason Type Questions

43. **STATEMENT-1:** If the accelerating potential in an X-ray tube is increased, the wavelengths of the characteristic X-rays do not change.
STATEMENT-2: When an electron beam strikes the target in an X-ray tube, part of the kinetic energy is converted into X-ray energy. **[2007]**
(a) Statement-1 is True, Statement-2 is True; Statement-2 is a correct explanation for Statement-1
(b) Statement-1 is True, Statement-2 is True; Statement-2 is NOT a correct explanation for Statement-1
(c) Statement-1 is True, Statement-2 is False
(d) Statement-1 is False, Statement-2 is True

10 Subjective Problems

44. In a photoelectric experiment set up, photons of energy 5 eV falls on the cathode having work function 3 eV. (a) If the saturation current is $i_A = 4\mu A$ for intensity 10^{-5} W/m^2, then plot a graph between anode potential and current. (b) Also draw a graph for intensity of incident radiation 2×10^{-5} W/m^2. **[2003 - 2 Marks]**

45. Frequency of a photon emitted due to transition of electron of a certain element from L to K shell is found to be 4.2×10^{18} Hz. Using Moseley's law, find the atomic number of the element, given that the Rydberg's constant $R = 1.1 \times 10^7$ m^{-1}. **[2003 - 2 Marks]**

46. Two metallic plates A and B, each of area 5×10^{-4} m^2, are placed parallel to each other at a separation of 1 cm. Plate B carries a positive charge of 33.7×10^{-12} C. A monochromatic beam of light, with photons of energy 5 eV each, starts falling on plate A at $t = 0$ so that 10^{16} photons fall on it per square meter per second. Assume that one photoelectron is emitted for every 10^6 incident photons. Also assume that all the emitted photoelectrons are collected by plate B and the work function of plate A remains constant at the value 2eV. Determine **[2002 - 5 Marks]**
(a) the number of photoelectrons emitted up to $t = 10$ s,
(b) the magnitude of the electric field between the plates A and B at $t = 10$ s, and
(c) the kinetic energy of the most energetic photoelectron emitted at $t = 10$ s when it reaches plate B.
Neglect the time taken by the photoelectron to reach plate B. Take $\varepsilon_0 = 8.85 \times 10^{-12}$ C^2/N-m^2

47. Photoelectrons are emitted when 40 nm radiation is incident on a surface of work function 1.9 eV. These photoelectrons pass through a region containing α-particles. A maximum energy electron combines with an α-particle to form a He^+ ion, emitting a single photon in this process. He^+ ions thus formed are in their fourth excited state. Find the energies in eV of the photons, lying in the 2 to 4 eV range, that are likely to be emitted during and after the combination. [Take h = 4.14×10^{-15} eV.s.] **[1999 - 5 Marks]**

48. Assume that the de Broglie wave associated with an electron can form a standing wave between the atoms arranged in a one dimensional array with nodes at each of the atomic sites. It is found that one such standing wave is formed if the distance d between the atoms of the array is 2Å. A similar standing wave is again formed if d is increased to 2.5 Å but not for any intermediate value of d. Find the energy of the electrons in electron volts and the least value of d for which the standing wave of the type described above can form. **[1997 - 5 Marks]**

Topic-3: Miscellaneous (Mixed Concepts) Problems

2 Integer Value Answer

1. A proton is fired from very far away towards a nucleus with charge $Q = 120\,e$, where e is the electronic charge. It makes a closest approach of 10 fm to the nucleus. The de Broglie wavelength (in units of fm) of the proton at its start is: (take the proton mass, $m_p = (5/3) \times 10^{-27}$ kg; $h/e = 4.2 \times 10^{-15}$ J.s/C; $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9$ m/F; 1 fm $= 10^{-15}$ m **[2012]**

6 MCQs with One or More than One Correct Answer

2. The filament of a light bulb has surface area 64 mm^2. The filament can be considered as a black body at temperature 2500 K emitting radiation like a point source when viewed from far. At night the light bulb is observed from a distance of 100 m. Assume the pupil of the eyes of the observer to be circular with radius 3 mm. Then
(Take Stefan-Boltzmann constant $= 5.67 \times 10^{-8}$ Wm^{-2}K^{-4}, Wien's displacement constant $= 2.90 \times 10^{-3}$ m-K, Planck's constant $= 6.63 \times 10^{-34}$ Js, speed of light in vacuum $= 3.00 \times 10^8$ ms^{-1}) **[Adv 2016]**
(a) power radiated by the filament is in the range 642 W to 645 W
(b) radiated power entering into one eye of the observer is in the range 3.15×10^{-8} W to 3.25×10^{-8} W
(c) the wavelength corresponding to the maximum intensity of light is 1160 nm
(d) taking the average wavelength of emitted radiation to be 1740 nm, the total number of photons entering per second into one eye of the observer is in the range 2.75×10^{11} to 2.85×10^{11}

Answer Key

Topic-1 : Matter Waves, Cathode and Positive Rays

1. (d) 2. (c) 3. (3)

Topic-2 : Photon, Photoelectric Effect X-rays and Davisson-Germer Experiment

1. (a) 2. (a) 3. (b) 4. (a) 5. (b) 6. (b) 7. (b) 8. (a) 9. (a) 10. (d)
11. (a) 12. (a) 13. (d) 14. (c) 15. (b) 16. (b) 17. (d) 18. (c) 19. (b) 20. (6)
21. (1) 22. (1) 23. (7) 24. (24.00) 32. (False) 33. (False) 34. (c) 35. (a, c) 36. (a, c) 37. (a,b,c)
38. (b, d) 39. (c, d) 40. (a, b, c) 41. (c, d) 42. (c) 43. (b)

Topic-3 : Miscellaneous (Mixed Concepts) Problems

1. (7) 2. (b, c, d)

Hints & Solutions

Topic-1: Matter Waves, Cathode and Positive Rays

1. **(d)** For photon, $\lambda_2 = \frac{hc}{E}$ ...(i)

For proton, $\lambda_1 = \frac{h}{p} = \frac{h}{\sqrt{2mE}} \quad \because p = \sqrt{2mE}$ ...(ii)

$$\therefore \frac{\lambda_2}{\lambda_1} = \frac{hc}{E \times \frac{h}{\sqrt{2mE}}} \propto E^{-1/2}$$

2. **(c)** Applying conservation of linear momentum, $P_i = P_f$

$0 = m_1v_1 - m_2v_2 \Rightarrow m_1v_1 = m_2v_2$

de-Broglie wavelength $\lambda = \frac{h}{p}$

$$\therefore \frac{\lambda_1}{\lambda_2} = \frac{h/m_1v_1}{h/m_2v_2} = 1$$

$\because |M_1V_1| = |M_2V_2|$

3. **(3)** We know that, $\lambda = \frac{h}{\sqrt{2mqV}}$ or, $\lambda \propto \frac{1}{\sqrt{qm}}$

$$\therefore \frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha}{m_p q_p}} = \sqrt{\frac{4}{1} \times \frac{2}{1}} = \sqrt{8} \approx 3$$

4. de-Broglie wavelength $\lambda = \frac{h}{mv} \Rightarrow \lambda = \frac{h}{\sqrt{2mK}}$

when $0 \le x \le 1$
Potential energy E_0
and total energy $= 2E_0$ (given)
$\therefore$ Kinetic energy K.E. $= 2E_0 - E_0 = E_0$

$$\lambda_1 = \frac{h}{\sqrt{2mE_0}} \quad ...(i)$$

when $x > 1$
Potential energy $= 0$
and total energy $= 2E_0$ (given)
$\therefore$ Kinetic energy $= 2E_0$

$$\therefore \lambda_2 = \frac{h}{\sqrt{2m(2E_0)}} \quad ....(ii)$$

Dividing eq. (i) by (ii) $\frac{\lambda_1}{\lambda_2} = \sqrt{\frac{2E_0}{E_0}} \Rightarrow \frac{\lambda_1}{\lambda_2} = \sqrt{2}$

Topic-2: Photon, Photoelectric Effect X-rays and Davisson-Germer Experiment

1. **(a)** By Einstein Photoelectric equation

$$\frac{hC}{\lambda} - \phi = eV_{stopping}$$

For Ist source, $\frac{hC}{\lambda} - \phi = 6e$ ...(i)

For IInd source, $\frac{hC}{4\lambda} - \phi = 0.6e$ ...(ii)

Substracting (ii) from (i), we get

$$\frac{3}{4}\frac{hc}{\lambda} = 5.4e$$

$$\lambda = \frac{3}{4 \times 5.4} \times \frac{hc}{e} = \frac{3}{21.6} \times 1.24 \times 10^{-6} = 1.72 \times 10^{-7}\text{ m}$$

So, $\phi = \frac{hc}{\lambda} - 6e$ [from (i)]

$$\Rightarrow \phi(ev) = \frac{12400}{1720} - 6 = 1.2\text{ eV}$$

2. **(a)** Davisson Germer experiment showed that electron beams can undergo diffraction when passed through atomic crystal. This established wave nature of electron as waves can exhibit interference and diffraction.

3. **(b)** $\frac{hc}{e\lambda_1} - \frac{\phi}{e} = V_{0_1}$ and $\frac{hc}{e\lambda_2} - \frac{\phi}{e} = V_{0_2} \left(\because \frac{he}{\lambda} - \phi = eV_0\right)$

$$\therefore \frac{hc}{e}\left[\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right] = V_{0_1} - V_{0_2}$$

$$\therefore h = \frac{e(V_{0_1} - V_{0_2})\lambda_1\lambda_2}{(\lambda_2 - \lambda_1)c}$$

From the first two values given in data

$$h = \frac{1.6 \times 10^{-19}[2-1] \times 0.4 \times 0.3 \times 10^{-6}}{0.1 \times 3 \times 10^8}$$

$$h = 0.64 \times 10^{-33} = 6.4 \times 10^{-34}\text{ J-s}$$

Similarly if we calculate h for the last two values of data we get same values of $h = 6.4 \times 10^{-34}$ J-s

4. **(a)** Here, $\frac{hC}{\lambda_1} - \phi = \frac{1}{2}mu_1^2$ ...(i)

and $\frac{hC}{\lambda_2} - \phi = \frac{1}{2}mu_2^2$ ...(ii)

Dividing equations, (i) by (ii)

$$\frac{\frac{hC}{\lambda_1} - \phi}{\frac{hC}{\lambda_2} - \phi} = \frac{u_1^2}{u_2^2} \quad \therefore \frac{\frac{1240}{248} - \phi}{\frac{1240}{310} - \phi} = \frac{4}{1}$$

$$\therefore \frac{1240}{248} - \phi = \frac{4 \times 1240}{310} - 4\phi \quad \therefore \phi = 3.7\text{ eV}$$

Hence the work function of the metal is nearly, $\phi = 3.7\ eV$

5. **(b)** $\because \frac{1}{\lambda} = R(z - b^2)\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ For K-series, $b = 1$ and for k_α transition $n_f = 2$ to $n_i = 1$ $\therefore \frac{1}{\lambda} \propto (z-1)^2$

$$\because \frac{\lambda_{Cu}}{\lambda_{Mo}} = \frac{(Z_{Mo} - 1)^2}{(Z_{Cu} - 1)^2} = \left(\frac{42-1}{29-1}\right)^2 = \left(\frac{41}{28}\right)^2 = 2.14$$

6. **(b)** Final momentum,

$$p = \frac{E}{c} = \frac{P \times t}{c} = \frac{30 \times 10^{-3} \times 100 \times 10^{-9}}{3 \times 10^{8}}$$

$$= 1.0 \times 10^{-17} \text{ kg ms}^{-1}$$

7. **(b)** The wavelength of continuous X - rays is independent of the atomic number of target material. Wave length of ckaracteristic X-ray depends on atomic number of target material.

8. **(a)** The cut off wavelength of the emitted X-ray,

$$\lambda_0 = \frac{hc}{eV} \quad ...(i)$$

According to de Broglie equation

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$$

$$\text{or } \lambda^2 = \frac{h^2}{2meV} \Rightarrow V = \frac{h^2}{2me\lambda^2} \quad ..(ii)$$

From eq. (i) and (ii),

$$\lambda_0 = \frac{hc \times 2me\lambda^2}{eh^2} = \frac{2mc\lambda^2}{h}$$

9. **(a)** For $K_\alpha, \frac{1}{\lambda} \propto (Z-1)^2$

$$\therefore \frac{\lambda_2}{\lambda_1} = \frac{(Z_1-1)^2}{(Z_2-1)^2} \Rightarrow \frac{4\lambda}{\lambda} = \frac{(11-1)^2}{(Z_2-1)^2}$$

$$\Rightarrow Z_2 - 1 = \frac{10}{2} \quad \therefore Z_2 = 6$$

10. **(d)** Saturation current ∝ (intensity) and stopping potential increases with increase in frequency. From the graph it is clear that A and B have the same stopping potential and therefore, the same frequency. Also, B and C have the same intensity.

11. **(a)** As we know, $I = \frac{q}{t} = \frac{ne}{t}$

∴ No. of electrons striking the target per second

$$\frac{n}{t} = \frac{I}{e} = 2 \times 10^{16}$$

12. **(a)** In case of Coolidge tube $\lambda_{min} = \frac{hc}{eV} = \lambda_c$

Thus the minimum wavelength is inversely proportional to accelerating voltage. As V increases, λ_c decreases. λ_k is the wavelength of K_α line which is independent of accelerating voltage of bombarding electron. Since λ_k always refers to a photon wavelength of transition of e^- from the target element from 2 → 1. Therefore $\lambda_k - \lambda_c$ increases as accelerating voltage is increased.

13. **(d)** Minimum wave length of continuous X-ray spectrum

$$\lambda_{min} = \frac{hc}{E}$$

$$\therefore \lambda_{min} = \frac{12375}{80 \times 10^3} \text{Å} = 0.155\text{Å} \quad [\because E = 80 \text{ kev given}]$$

Energy of incident electrons is greater than the ionization energy of electrons in K-shell, the K-shell electrons will be knocked off. Hence, characteristic X-ray spectrum will be obtained.

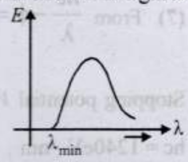
14. **(c)** $\lambda_{min} = \frac{hc}{\phi} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{4(1.6 \times 10^{-19})} = 310 \times 10^{-9}$m.

$= 310$ nm

15. **(b)** The continuous X-ray spectrum is shown in figure. All wavelengths > λ_{min} are found i.e., λ_{min} to ∝; $\lambda_{min} > 0$

where $\lambda_{min} = \frac{12400}{V \text{ (in volt)}}$ Å

Here V is the applied voltage.



16. **(b)** Stopping potential is the negative potential applied to stop the electrons having maximum kinetic energy.

∴ Stopping potential = 4 volt.

17. **(d)** According to question, 24.6 ev is required to remove one of the electrons from a neutral helium atom.

For helium ion, $Z = 2$ and for first orbit $n = 1$.

$$\therefore \quad E = \frac{-13.6 \times z^2}{n^2} = \frac{-13.6}{(1)^2} \times 2^2 = -54.4 \text{ eV}$$

∴ Energy required to remove this e^- = + 54.4 eV

∴ Total energy required = 54.4 + 24.6 = 79 eV

18. **(c)** Cut-off wave length, $\lambda_{min} = \frac{hc}{eV}$

19. **(b)** The wavelength of characteristic X-rays depends on the type of atoms of which the target material is made. It does not depend on the accelerating potential. Cut-off wavelength depends on the acceterating voltage.

When an electric beam strikes the target in an X-ray tube, part of the kinetic energy approximately (2%) is converted into X-ray energy.

20. **(6)** From photoelectric equation, $E = \phi_0 + K.E.\text{max}$

For metals P and Q

$E_1 = \phi_P + KE_P \Rightarrow E_1 - 4 = E_P$ and $E_1 - 4.5 = E_Q$

$E_P = 2E_Q$ (given)

∴ $E_1 - 4 = 2(E_1 - 4.5) \Rightarrow E_1 = 5\,eV$

$E_1 - 4 = E_P \Rightarrow 5 - 4 = E_P$

∴ $E_P = 1\,eV$ and $E_Q = E_R = 0.5\,eV$

For metal R, $E_2 - \phi_R = KE_R$

∴ $E_2 - 5.5 = 0.5$

∴ $E_2 = 0.5 + 5.5 = 6\,eV$

21. **(1)** From conservation of momentum principle, change in momentum of photon = change in momentum of mirror

2(NP) = MV_{max}

$$\Rightarrow 2\left[N\left(\frac{h}{\lambda}\right)\right] = MV_{max}$$

$$\therefore 2\frac{Nh}{\lambda} = M(A\Omega) \quad [\because V_{max} = A\Omega]$$

$$N = \left(\frac{M\Omega}{h}\right)\frac{A\lambda}{2} = \frac{10^{24}}{4\pi} \times \frac{10^{-6} \times 8\pi \times 10^{-6}}{2}$$

$$\left[\because \frac{m\Omega}{h} = \frac{10^{24}}{4\pi}; A = 1hm; \lambda = 8\pi \times 10^{-6}\right]$$

∴ N = 1 × 10^{12} = x × 10^{12} ∴ $x = 1$

22. **(1)** For photoelectric effect

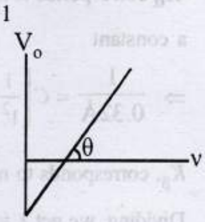
$h\nu - \phi = eV_0$

$$\Rightarrow \frac{h\nu}{e} - \frac{\phi_0}{e} = V_0$$

The slope of V_0 versus ν graph is a straight line with slope

$$\tan\theta = \frac{h}{e} = \text{constant}$$

∴ The ratio of two slopes will be 1.



23. **(7)** From $\frac{hc}{\lambda} - \phi = -eV_0$

Stopping potential $V_0 = \frac{1}{e}\left[\frac{hc}{\lambda} - \phi\right]$ where

hc = 1240eV –nm

$= \frac{1}{e}\left[\frac{1240}{200} - 4.7\right] = \frac{1}{e}[6.2 - 4.7] = \frac{1}{e} \times 1.5eV = 1.5V$

But $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r} = \frac{1}{4\pi\varepsilon_0}\frac{ne}{r}$ $\left(\begin{matrix} n = \text{no. of photo-} \\ \text{electrons emitted}\end{matrix}\right)$

$\Rightarrow n = \frac{Vr(4\pi\varepsilon_0)}{e} = \frac{1.5\times10^{-2}}{9\times10^9 \times 1.6\times10^{-19}}$

$\therefore n = 1.04 \times 10^7$

Comparing it with $A \times 10^z$ we get, $z = 7$

24. **(24.00)** Number of electrons emitted/s

$= \frac{200\ W}{6.25\times1.6\times10^{-19}\ J}$

Force, F = Rate of change of linear momentum = $N\sqrt{2mV}$

$= \frac{200}{6.25\times1.6\times10^{-19}} \times \sqrt{2\times9\times10^{-31}\times1.6\times10^{-19}\times500}$

$\Rightarrow F = 24 \times 10^{-4}$ N [$\because$ K = eV : e = 1.6 × 10^{-19} = V = 500]

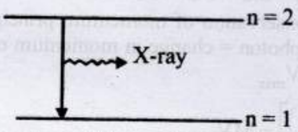
$\therefore n = 24.00$

25. $\frac{1}{\lambda} = R(Z-1)^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

For K_α, $n_2 = 2$ and $n_1 = 1$

$\therefore \frac{1}{0.76\times10^{-10}} = 1.097\,(Z-1)^2\left[\frac{1}{1^2} - \frac{1}{2^2}\right]$

$\Rightarrow z - 1 = 40 \quad \Rightarrow Z = 41$



The atomic number of the anode material of the tube is 41.

26. $\lambda_{min} = \frac{hc}{eV} = \frac{6.63\times10^{-34}\times3\times10^8}{1.6\times10^{-19}\times20\times10^3} = 0.62Å$

27. All electromagnetic waves propagate at 3 × 10^8 m/s in vacuum.
$\therefore$ Speed of X-rays is 3 × 10^8m/s in vacuum.

28. We know that

K_α corresponds to n = 2 to n = 1, $\frac{1}{\lambda} = C\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$, where C is a constant

$\Rightarrow \frac{1}{0.32Å} = C\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = \frac{3C}{4}$

K_β, corresponds to n = 3 to n = 1, $\frac{1}{\lambda} = C\left[\frac{1}{1^2} - \frac{1}{3^2}\right] = \frac{8C}{9}$

Dividing, we get λ = 0.27 Å.

29. More the number of electrons striking the anode, more number of photons of X-rays emitted. Hence more is the intensity of X-rays. When the speed of the striking electrons on anode is increased, the emitted X-rays have greater energy. And energy, $E = \frac{hc}{\lambda}$.
$\therefore$ when E increases then λ decreases.

30. According to Einstein's photoelectric equation
$(K.E.)_{max} = h\nu - h\nu_0$
$\therefore$ Maximum kinetic energy of electrons emitted in the photoelectric effect is linearly dependent on the frequency of incident radiation.

31. For characteristic X-rays

$\frac{1}{\lambda} = R_\alpha(Z-1)^2\left[1 - \frac{1}{n^2}\right] = \frac{E}{hc}$

$\therefore \frac{E_1}{hc} = R_\alpha(Z-1)^2\left[1 - \frac{1}{2^2}\right]$ .....(i)

As for minimum accelerating voltage, electron jumps from n = 1 to n = 2.

The binding energy of innermost electron in tungsten, E_2 = 40 keV

$\therefore \frac{E_2}{hc} = R_\alpha(Z-1)^2\left[1 - \frac{1}{\infty^2}\right]$ .....(ii)

Dividing eq. (i) by (ii)

$\frac{E_1}{E_2} = \frac{\left[1 - \frac{1}{2^2}\right]}{\left[1 - \frac{1}{\infty^2}\right]} \Rightarrow E_1 = \frac{3}{4}E_2 = \frac{3}{4}\times40{,}000\ \text{eV}$

$\therefore V_{min} = 30{,}000\ \text{eV} = 30\times10^3\,\text{V}$

32. **(False)**
According to Einstein's photoelectric equation, $(K.E.)_{max} = h\nu - h\nu_0 \Rightarrow (K.E.)_{max} \propto \nu$
Thus maximum kinetic energy is proportional to frequency and not intensity.

33. **(False)**
The kinetic energy of photo electrons emitted depends on frequency (ν) of incident radiation. For photoelectric effect
$h\nu - h\nu_0 = (K.E.)_{max}$
where h = Planck's constt.
ν_0 = Threshold frequency
$\Rightarrow (K.E.)_{max} \propto \nu$
K.E. does not depend on the intensity of incident radiation.

34. **(c)** de-Broglie wavelength passing through the anode,

$\lambda_e = \frac{h}{p} = \frac{h}{\sqrt{2m(K.E)}}$

When φ increases, K.E. decreases and therefore λ_e increases

When λ_{ph} increases, N_{ph} decreases, K.E decreases and therefore λe increases.

λe is independent of the distance d.

Also after reaching anode, $\frac{hc}{\lambda_{ph}} + eV - \phi = \frac{h^2}{2m\lambda_e^2}$

$\left[\lambda e = \frac{h}{\sqrt{2mk.E}}\right] \quad \therefore \frac{hc}{e\lambda_{ph}} + V - \frac{\phi}{e} = \frac{h^2}{2me\lambda_e^2}$ ...(i)

For $V >> \frac{\phi}{e}$, $\phi << eV$

Also $\frac{hc}{e\lambda_{Ph}} << V$. ∴ from eq (i). $\lambda_e \propto \frac{1}{\sqrt{V}}$

Hence, if V is made four times, λ_e is approximately half.

35. **(a, c)** We know that

$$\frac{hC}{\lambda} - \phi = eV_0 \Rightarrow \frac{hc}{e\lambda} - \frac{\phi}{e} = V_0 \Rightarrow \frac{he}{e}\left(\frac{1}{\lambda}\right) - \frac{\phi}{e} = V_0$$

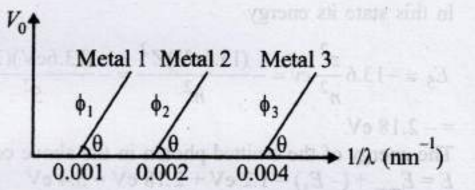
Therefore V_0 versus $\frac{1}{\lambda}$ graph is a straight line with negative slope $\left(\frac{hc}{e}\right)$ and positive intercept $\left(\frac{\phi}{e}\right)$.

For V_0 versus λ, we will get a hyperbola as λ decreases V_0 increases. And V_0 becomes zero when $\left(\frac{hc}{\lambda}\right) = \phi$ i.e., when $\lambda = \lambda_0$

36. **(a, c)** From $eV = \frac{hc}{\lambda} - \phi$ $V = \frac{hc}{e\lambda} - \frac{\phi}{e}$ At $V = 0$, $\phi_1 : \phi_2 : \phi_3$.

$$= \frac{hc}{\lambda_1} : \frac{hc}{\lambda_2} : \frac{hc}{\lambda_3}$$

$$= 0.001 : 0.002 : 0.004 = 1 : 2 : 4$$



By Einstein's photoelectric equation, $\frac{hc}{\lambda} - \phi = eV$

$$\Rightarrow V = \frac{hc}{e\lambda} - \frac{\phi}{e} \quad ...(i)$$

Comparing equation (i) by $y = mx + c$, we get the slope of the line

$$m = \frac{hc}{e} = \tan\theta$$

From the graph V_0 versus $\frac{1}{\lambda}$ it is clear that,

$$\frac{1}{\lambda_{0_1}} = 0.001(\text{nm})^{-1} \therefore \lambda_{0_1} = \frac{1}{0.001} = 1000\text{nm}$$

$$\frac{1}{\lambda_{0_2}} = 0.002(\text{nm})^{-1} \therefore \lambda_{0_2} = 500\text{nm and } \lambda_{0_3} = 250\text{nm}$$

Violet colour light has wavelength 400 nm.

Therefore, this light will be unable to show photoelectric effect on plate 3 can eject photoelectrons from metal–1 and metal–2.

37. **(a,b,c)** From Einstein's photoelectric equation, $K_{max} = E - W$

For metal *A*

$$4.25 = W_A + T_A \quad ...(i)$$

$$\text{Also } T_A = \frac{1}{2}mv_A^2 = \frac{1}{2}\frac{m^2v_A^2}{m} = \frac{p_A^2}{2m} = \frac{h^2}{2m\lambda_A^2} \quad ...(ii)$$

$$\left[\because \lambda = \frac{h}{p} \text{ and } P = mV\right]$$

For metal *B*

$$4.7 = (T_A - 1.5) + W_B \quad ...(iii)$$

$$\text{And } T_B = \frac{h^2}{2m\lambda_B^2} \quad ...(iv)$$

Dividing equation (iv) by (ii), $\frac{T_B}{T_A} = \frac{h^2}{2m\lambda_B^2} \times \frac{2m\lambda_A^2}{h^2} = \frac{\lambda_A^2}{\lambda_B^2}$

$$\Rightarrow \frac{T_A - 1.5}{T_A} = \frac{\lambda_A^2}{(2\lambda_A)^2} = \frac{\lambda_A^2}{4\lambda_A^2} = \frac{1}{4} \quad [\because \lambda_B = 2\lambda_A \text{ given}]$$

$\Rightarrow 4T_A - 6 = T_A \therefore T_A = 2$ eV

Putting this value of T_A in equation (i) and (ii) we get $W_A = 2.25$ eV and $W_B = 4.2$ eV

Also $T_B = T_A - 1.5 \Rightarrow T_B = 0.5$eV

38. **(b, d)** There is no change in stopping potential by increasing the distance of source from the cell as neither the energy of incident light nor the work function of metal wil change. The saturation current depends on the intensity *(D)* of incident light on the cathode of the photocell.

Intensity, $I \propto \frac{1}{r^2}$ and saturation current $\propto I$

$$\therefore \text{Saturation current} \propto \frac{1}{r^2} \therefore \frac{(\text{Saturation current})_{final}}{(\text{Saturation current})_{initial}} = \frac{r^2_{initial}}{r^2_{final}}$$

$$\therefore (\text{Saturation Current})_{final} = \frac{0.2 \times 0.2}{0.6 \times 0.6} \times 18 = 2\text{mA}$$

Hence the saturation current will be 2.0 *mA*

39. **(c, d)** When potential difference (V) applied to an X-ray tube is increased, the minimum wavelength $\lambda_{min} = \frac{12375}{V}$ will decrease.

Potential difference or voltage (V) does not change the intensity of emitted radiation.

40. **(a, b, c)**

41. **(c, d)** For ejection of electrons, the wavelength of the light should be less than threshold wavelength, 5200 Å, U.V light has less wavelength than 5200 Å.

42. **(c)** From Wien's displacement lens, $\lambda_m T = b$ (constant) and $b = 2.9 \times 10^{-3}$ mK

When T = 200 K (P), $\lambda_m = \frac{b}{T} = \frac{2.9 \times 10^{-3}}{2000}$

= 1450 nm (max)

When T = 3000 K (Q)

$$\lambda m = \frac{2.9 \times 10^{-3}}{3000} = 966.66 \text{ nm}$$

When T = 5000K (R)

$$\lambda_m = \frac{2.9 \times 10^{-3}}{5000} = 580\text{nm}$$

When T = 10000K (s)

(iii) $\lambda_m = \dfrac{2.9\times10^{-3}}{10000} = 290\text{nm min}$

(vi)...

For option (P) λ maximum and $\beta = \dfrac{\lambda D}{d}$

∴ widest central maximum

For option (Q) Power

$P_{3000} = \sigma A(3000)^4$

$P_{6000} = \sigma A(6000)^4$

$\dfrac{P_{3000}}{P_{6000}}\left(\dfrac{1}{2}\right)^4 = \dfrac{1}{16} \therefore P_{3000} = \dfrac{1}{16}P_{6000}$

For (R) Wavelength λ = 580 nm

Visible to human eyes

For (S) $\lambda = \dfrac{hc}{\phi} = \dfrac{1.24\times10^{-6}}{4} = 310\text{nm}$

290 nm < 310 nm so this radiation lead to emission of photo electrons from a metal of work function $\phi = 4$ ev.

For imaging human bones x–rays wavelength range 1–10 nm is used.

43. **(b) Note :** Shortest wavelength means highest frequency So highest energy.

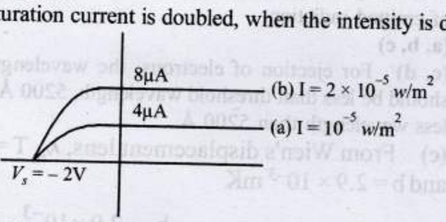
Shortest or cut-off wave length of X-rays emitted from an X-ray tube depends on the voltage applied to the tube.

Also, according to Moseley's law $\sqrt{v} = a(Z-b)$. Thus the frequency also depends on the atomic number.

44. (a) $eV_0 = hn - hn_0 = 5 - 3 = 2$ eV

∴ $V_0 = 2$ volt

(b) Saturation current is doubled, when the intensity is doubled



45. Energy released during transition from n_2 to n_1

$$\Delta E = h\nu = Rhc(Z-b)^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

For transition *L* shell → *K* shell

$b = 1, n_2 = 2, n_1 = 1 \therefore (Z-1)^2 Rhc\left[\dfrac{1}{1} - \dfrac{1}{4}\right] = h\nu$

Putting the value of $R = 1.1\times10^7\ \text{m}^{-1}$ and $c = 3\times10^8$ m/s, and solving we get $Z = 42$

46. (a) Number of electrons incident on the metal plate *A*
$= 10^{16}\times(5\times10^{-4})$

∴ Number of photoelectrons emitted from plate *A* in 10 s

$$n_e = \frac{(5\times10^4)\times10^{16}}{10^6}\times10 = 5\times10^7$$

(b) At $t = 10$ sec charge on plate *B*

$Q_b = 33.7\times10^{-12} - 5\times10^7\times1.6\times10^{-19} = 25.7\times10^{-12}\ C$

and $Q_a = 8\times10^{-12}\ C$

$$E = \frac{\sigma_B}{2\varepsilon_0} - \frac{\sigma_A}{2\varepsilon_0} = \frac{1}{2A\varepsilon_0}(Q_B - Q_A)$$

$$= \frac{17.7\times10^{-12}}{5\times10^{-4}\times8.85\times10^{-12}} = 2000\ N/C$$

(c) K.E. of most energetic particles = energy of photoelectrons due to light + due to work done by photoelectrons between the plates
$= (hn - f) + e(Ed) = 23$ eV

47. Given: Work function, $\phi = 1.9$ ev and $\lambda = 400$nm
$= 400\times10^{-9}$ m The energy of the incident photon is

$$E_1 = \frac{hc}{\lambda} = \frac{(4.14\times10^{-15}\text{eVs})(3\times10^8\text{m/s})}{(400\times10^{-9}\text{m})} = 3.1\text{eV}$$

The maximum kinetic energy of the emitted photelectrons

$E_{max} = E_1 - W = 3.1\text{ eV} - 1.9\text{ eV} = 1.2\text{eV}$

As per question,

$$\left(\begin{array}{l}\text{Emitted electrons of}\\ \text{maximum kinetic energy}\end{array}\right) + {}_2He^{2+} \longrightarrow \underset{\text{in 4th excited state}}{He^+} + 1\text{ photon}$$

The fourth excited state implies that the electron enters in the $n = 5$ state.

In this state its energy

$$E_5 = -13.6\frac{z^2}{n^2}ev = -\frac{(13.6\text{eV})Z^2}{n^2} = -\frac{(13.6\text{eV})(2)^2}{5^2}$$

$= -2.18$ eV.

The energy of the emitted photon in the above combination

$E = E_{max} + (-E_5) = 1.2\text{ eV} + 2.18\text{ eV} = 3.4\text{ eV}$

Similarly, energies in other states of He^+

$$E_4 = \frac{(-13.6\text{eV})(2^2)}{4^2} = -3.4\text{eV} \quad E_3 = \frac{(-13.6\text{eV})(2^2)}{3^2} = -6.04\text{eV}$$

$$E_2 = \frac{(-13.6\text{eV})(2^2)}{2^2} = -13.6\text{eV}$$

The possible transitions are

$n = 5 \rightarrow n = 4$

$\Delta E = E_5 - E_4 = [-2.18 - (-3.4)]$ eV = 1.28 eV

$n = 5 \rightarrow n = 3$

$\Delta E = E_5 - E_3 = [-2.18 - (-6.04)]$ eV = 3.84 eV

$n = 5 \rightarrow n = 2$

$\Delta E = E_5 - E_2 = [-2.18 - (-13.6)]$ eV = 11.4 eV

$n = 4 \rightarrow n = 3$

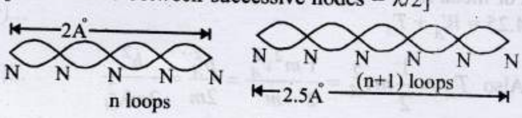
$\Delta E = E_4 - E_3 = [-3.4 - (-6.04)]$ eV = 2.64 eV

Hence, the photons that are likely to be emitted in the range of 2 eV to 4 eV are 3.4 eV during combination, 3.84 eV and 2.64 eV after combination.

48. Nodes are formed at each of the atomic sites,

$\therefore 2\text{Å} = n\left(\dfrac{\lambda}{2}\right)$ ...(i)

[∵ Distance between successive nodes = λ/2]



And $2.5\text{ Å} = (n+1)\dfrac{\lambda}{2}$ ...(ii)

From eq (ii) – (i) $0.5 = \frac{\lambda}{2} \therefore = 1\AA$

Now, de broglie wavelength

$$\lambda = \frac{h}{\sqrt{2mK}} \text{ or } K = \frac{h^2}{\lambda^2 .2m}$$

$$\therefore \quad K = \frac{(6.63\times10^{-34})^2}{(1\times10^{-10})^2\times2\times9.1\times10^{-31}\times1.6\times10^{-19}} \text{ eV}$$

$$= \frac{(6.63)^2}{8\times9.1\times1.6}\times10^2 \text{ eV} = 151 \text{ eV}$$

d will be minimum, when only one loop is formed $\therefore n = 1$

$$\therefore d_{min} = \frac{\lambda}{2} = \frac{1\text{Å}}{2} = 0.5\text{Å}$$

Topic-3: Miscellaneous (Mixed Concepts) Problems

1. (7) From energy conservation Loss in K.E. of proton = gain in potential energy of the proton – nucleus system

$$\frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r} \quad \therefore \frac{p^2}{2m} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r}$$

$$\therefore \frac{1}{2m}\left(\frac{h^2}{\lambda^2}\right) = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r} \quad \therefore \lambda = \sqrt{\frac{4\pi\epsilon_0 r . h^2}{q_1 q_2 (2m)}}$$

Putting the values of $4\pi\varepsilon_0$, r, h, q_1, q_2 and m we get, de-Broglie wavelength of proton, λ = 7fm

2. **(b, c, d)** According to question,
surface area of filament of light bulb, A = 64 mm^2
Temperature of filament, T = 2500 K
distance of bulb or source from observer, d = 100m
Radius of the pupil of the eyes of the observer, R_e = 3 mm = 3 × 10^{-3} m
(a) Power radiated by the filament P = σAeT^4
= 5.67 × 10^{-8} × 64 × 10^{-6} × 1 × $(2500)^4$ = 141.75 w
($\because$ e = 1 for black body)

Hence, option (a) is incorrect.
(b) Radiated power entering into one eye of the observer,

$$I = \frac{P}{4\pi d^2}\times(\pi R_e^2)$$

$$= \frac{141.75}{4\pi\times(100)^2}\times\pi\times(3\times10^{-3})^2 = 3.189375\times10^{-8} \text{ W}$$

Hence, option (b) is correct
(c) From wein's displacement law, λ_m T = b
or, λ_m × 2500 = 2.9 × 10^{-3}
or, λ_m = 1.16 × 10^{-6} = 1160 nm
Hence, option (c) is correct
(d) Total no. of photons entering per second into one eye of the observer $= \left(\frac{hc}{\lambda}\right)\times N_{photons} = I$

$$3.189375\times10^{-8} = \frac{6.63\times10^{-34}\times3\times10^{8}}{1740\times10^{-9}}\times N_{photons}$$

$\therefore N_{photons} = 2.79\times10^{11}$
Hence, option (d) is correct.