CHAPTER 11

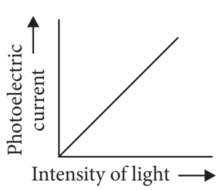
Dual Nature of Radiation and Matter

Recap Notes

- **Electron emission :** It is the phenomenon of emission of electrons from the surface of a metal. The minimum energy needed by an electron to come out from a metal surface is known as "work function" of the metal. It is denoted by ϕ_0 or W_0 and measured in electron volt (eV).

  Work function $W = h\upsilon_0 = \frac{hc}{\lambda_0}$

  The electron emission can be obtained from the following physical processes :
  - **Thermionic emission :** It is the phenomenon of emission of electrons from the metal surface when heated suitably.
  - **Photoelectric emission :** It is the phenomenon of emission of electrons from the surface of metal when light radiations of suitable frequency fall on it.
  - **Field emission or cold cathode emission:** It is the phenomenon of emission of electrons from the surface of a metal under the application of a strong electric field.
- **Photoelectric effect :** It is the phenomenon of emission of electrons from the surface of metals, when light radiations of suitable frequency fall on them.
  - **Photoelectric current :** Photoelectric current depends on the intensity of incident light and the potential difference applied between the two electrodes.

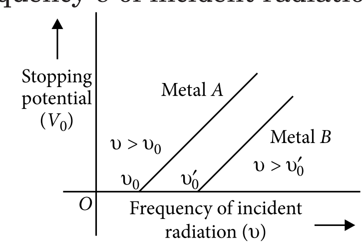


  - **Stopping potential :** The minimum negative potential given to anode plate w.r.t. to cathode plate at which the photoelectric current becomes zero is known as stopping potential or cut off potential. It is denoted by V_0. If e is the charge on the photoelectron, then

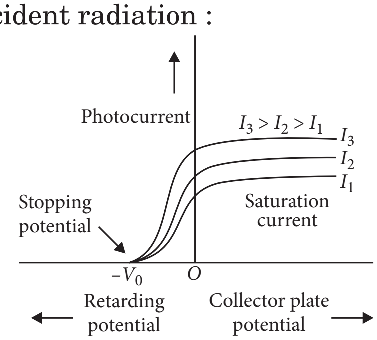
$$K_{max} = eV_0 = \frac{1}{2}mv_{max}^2$$

where m is the mass of photoelectron and v_{max} is the maximum velocity of emitted photoelectrons.

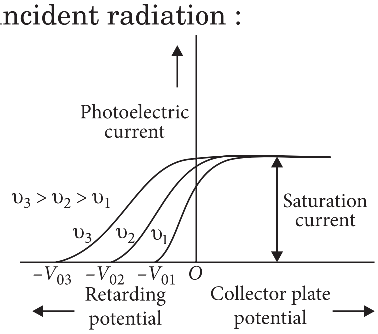
- Variation of stopping potential V_0 with frequency υ of incident radiation :



- Variation of photocurrent with collector plate potential for different intensity of incident radiation :



- Variation of photocurrent with collector plate potential for different frequencies of incident radiation :



- **Einstein's photoelectric equation :** If a light of frequency υ is incident on a photosensitive material having work function (ϕ_0), then maximum kinetic energy of the emitted electron is given as
$K_{max} = h\upsilon - \phi_0$
- For $\upsilon > \upsilon_0$
or $eV_0 = h\upsilon - \phi_0 = h\upsilon - h\upsilon_0$
or $eV_0 = K_{max} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$.
where υ_0 = threshold frequency
λ_0 = threshold wavelength
λ = incident wavelength
Einstein's photoelectric equation is in accordance with the law of conservation of energy.
- **Dual nature of radiation :** Wave theory of electromagnetic radiation explains the phenomenon of interference, diffraction and polarisation. On the other hand, photoelectric effect is supported by particle nature of light. Hence, we assume dual nature of light.
- **Photons :** These are the packets of energy (or energy particles) which are emitted by a source of radiation. The photons emitted from a source, travel through space with the same speed c (equal to the speed of light).
  - Energy of a photon $E = h\upsilon = \frac{hc}{\lambda}$
    where, υ = frequency, λ = wavelength
    h = Planck's constant, c = speed of the light
  - Momentum of photon is
    $p = \frac{E}{c} = \frac{h\upsilon}{c}$
  - The rest mass of photon is zero.
  - The moving mass m of photon is $m = \frac{E}{c^2} = \frac{h\upsilon}{c^2}$.
  - All photons of light of a particular frequency υ or wavelength λ have the same energy $E\left(= h\upsilon = \frac{hc}{\lambda}\right)$ and momentum $p\left(= \frac{h\upsilon}{c} = \frac{h}{\lambda}\right)$, whatever be the intensity of radiation.
  - Photon energy is independent of intensity of radiation.
  - Photons are not deflected by electric and magnetic fields.
  - In a photon-particle collision (such as photon-electron collision), the total energy and total momentum are conserved.
  - Number of photons emitted per second of frequency υ from a lamp of power P is
    $n = \frac{P}{h\upsilon} = \frac{P\lambda}{hc}$
- **de-Broglie waves (Matter waves) :** Radiation has dual nature, wave and particle. The nature of experiment determines whether a wave or a particle description is best suited for understanding the experimental result. Reasoning that radiation and matter should be symmetrical in nature, Louis Victor de Broglie attributed a wave like character to matter (material particles). The waves associated with the moving material particles are known as matter waves or de Broglie waves.
  - **de-Broglie wavelength :** The de Broglie wavelength associated with a moving particle is related to its momentum as
    de-Broglie wavelength, $\lambda = \frac{h}{p} = \frac{h}{mv}$
    where m is the mass of the particle, v is the velocity of the particle, p is the momentum of the particle.
    - de-Broglie wavelength is independent of the charge and nature of the material particle.
    - In terms of kinetic energy K, de Broglie wavelength is given by $\lambda = \frac{h}{\sqrt{2mK}}$.
    - If a particle of charge q is accelerated through a potential difference V, its de-Broglie wavelength is given by $\lambda = \frac{h}{\sqrt{2mqV}}$.

    For an electron, $\lambda = \left(\frac{150}{V}\right)^{1/2}$ Å.
    - For a gas molecule of mass m at temperature T kelvin, its de-Broglie wavelength is given by $\lambda = \frac{h}{\sqrt{3mkT}}$, where k is the Boltzmann constant.

Practice Time

OBJECTIVE TYPE QUESTIONS

Multiple Choice Questions (MCQs)

1. A particle is dropped from a height H. The de Broglie wavelength of the particle as a function of height is proportional to

(a) H (b) $H^{1/2}$ (c) H^0 (d) $H^{-1/2}$

2. The threshold frequency of a certain metal is 3.3×10^{14} Hz. If light of frequency 8.2×10^{24} Hz is incident on the metal, then the cut off voltage for photoelectric emission is (Given $h = 6.63 \times 10^{-34}$ J s)

(a) 2 V (b) 4 V (c) 6 V (d) 8 V

3. A proton and an α-particle are accelerated through the same potential difference. The ratio of de Broglie wavelength λ_p to that of λ_α is

(a) $\sqrt{2}:1$ (b) $\sqrt{4}:1$
(c) $\sqrt{6}:1$ (d) $\sqrt{8}:1$

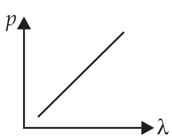
4. The de Broglie wavelength of a particle of kinetic energy K is λ. What will be the wavelength of the particle, if its kinetic energy is $\frac{K}{4}$?

(a) λ (b) 2λ (c) $\frac{\lambda}{2}$ (d) 4λ

5. When the velocity of an electron increases, its de Broglie wavelength

(a) increases (b) decreases
(c) remains same
(d) may increase or decrease

6. Which of the following figure represents the variation of particle momentum (p) and associated de Broglie wavelength (λ)?

(a)


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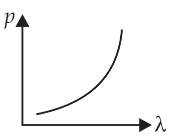

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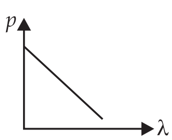

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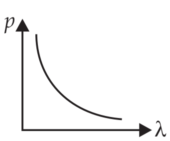


7. The de Broglie wavelength associated with a ball of mass 150 g travelling at 30 m s^{-1} is

(a) 1.47×10^{-34} m (b) 1.47×10^{-16} m
(c) 1.47×10^{-19} m (d) 1.47×10^{-31} m

8. The wavelength of matter wave is independent of

(a) mass (b) velocity
(c) momentum (d) charge

9. Photons absorbed in matter are converted to heat. A source emitting n photons per second of frequency υ is used to convert 1 kg of ice at 0°C to water at 0°C. Then, the time T taken for the conversion

(a) decreases with increasing n, with υ fixed.
(b) decreases with n fixed, υ increasing.
(c) remains constant with n and υ changing such that $n\upsilon$ = constant.
(d) All of these.

10. If alpha particle, proton and electron move with the same momentum, then their respective de Broglie wavelengths λ_α, λ_p, λ_e are related as

(a) $\lambda_\alpha = \lambda_p = \lambda_e$ (b) $\lambda_\alpha < \lambda_p < \lambda_e$
(c) $\lambda_\alpha > \lambda_p > \lambda_e$ (d) $\lambda_p > \lambda_e > \lambda_\alpha$

11. If the momentum of an electron is changed by p, then the de Broglie wavelength associated with it changes by 0.5%. The initial momentum of electron will be

(a) $200p$ (b) $400p$
(c) $\frac{p}{200}$ (d) $100p$

12. Who established that electric charge is quantised ?

(a) J.J. Thomson (b) William Crookes
(c) R.A Millikan (d) Wilhelm Rontgen

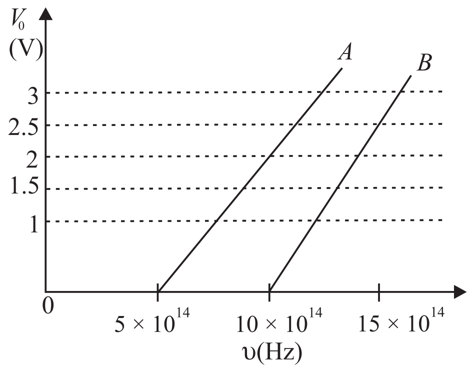
13. The phenomenon of photoelectric emission was discovered in 1887 by

(a) Albert Einstein (b) Heinrich Hertz
(c) Wilhelm Hallwachs (d) Philipp Lenard

14. The de Broglie wavelength of an electron in a metal at 27°C is
(Given $m_e = 9.1 \times 10^{-31}$ kg, $k_B = 1.38 \times 10^{-23}$ J K^{-1})

(a) 6.2×10^{-9} m (b) 6.2×10^{-10} m
(c) 6.2×10^{-8} m (d) 6.2×10^{-7} m

15. A student performs an experiment on photoelectric effect using two materials A and B. A plot of stopping potential (V_0) *vs* frequency (υ) (V_0) frequency is as shown in the figure.



The value of h obtained from the experiment for both A and B respectively is
(Given electric charge of an electron $= 1.6 \times 10^{-19}$ C)
(a) 3.2×10^{-34} J s, 4×10^{-34} J s
(b) 6.4×10^{-34} J s, 8×10^{-34} J s
(c) 1.2×10^{-34} J s, 3.2×10^{-34} J s
(d) 4.2×10^{-34} J s, 5×10^{-34} J s

16. The maximum frequency and minimum wavelength of X-rays produced by 30 kV electrons respectively is
(a) 7.24×10^{18} Hz, 0.041 nm
(b) 3.21×10^{18} Hz, 0.211 nm
(c) 5.32×10^{18} Hz, 0.001 nm
(d) 2.13×10^{18} Hz, 0.011 nm

17. The matter-wave picture of electromagnetic wave/radiation elegantly incorporated the
(a) Heinsenberg's uncertainty principle
(b) correspondence principle
(c) cosmic theory
(d) Hertz's observations

18. The minimum energy required for the electron emission from the metal surface can be supplied to the free electrons by which of the following physical processes?
(a) Thermionic emission
(b) Field emission
(c) Photoelectric emission
(d) All of these

19. Assume that a molecule is moving with the root mean square speed at temperature 300 K. The de Broglie wavelength of nitrogen molecule is (Atomic mass of nitrogen = 14.0076 u, $h = 6.63 \times 10^{-34}$ J s, $k_B = 1.38 \times 10^{-23}$ J K^{-1}, 1 u $= 1.66 \times 10^{-27}$ kg)
(a) 2.75×10^{-11} m (b) 2.75×10^{-12} m
(c) 3.24×10^{-11} m (d) 3.24×10^{-12} m

20. The photoelectric cut off voltage in a certain experiment is 1.5 V. The maximum kinetic energy of photoelectrons emitted is
(a) 2.4 eV (b) 1.5 eV
(c) 3.1 eV (d) 4.5 eV

21. Monochromatic light of frequency 6×10^{14} Hz is produced by a laser. The power emitted is 2×10^{-3} W. The number of photons emitted per second is (Given $h = 6.63 \times 10^{-34}$ J s)
(a) 2×10^{15} (b) 3×10^{15}
(c) 4×10^{15} (d) 5×10^{15}

22. 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^{-5} nm

23. In an accelerator experiment on high energy collisions of electrons with positrons, a certain event is interpreted as annihilation of an electron-positron pair of total energy 10.2×10^9 eV into two γ-rays of equal energy. The wavelength associated with each γ-ray is
(a) 3.21×10^{-18} m (b) 1.23×10^{-16} m
(c) 2.44×10^{-16} m (d) 4.21×10^{-14} m

24. A blue lamp mainly emits light of wavelength 4500 Å. The lamp is rated at 150 W and 8% of the energy is emitted as visible light. The number of photons emitted by the lamp per second is
(a) 3×10^{19} (b) 3×10^{24}
(c) 3×10^{20} (d) 3×10^{18}

25. A metallic surface is irradiated by a monochromatic light of frequency υ_1 and stopping potential is found to be V_1. If the light of frequency υ_2 irradiates the surface, the stopping potential will be
(a) $V_1 + \frac{h}{e}(\upsilon_1 + \upsilon_2)$ (b) $V_1 + \frac{h}{e}(\upsilon_2 - \upsilon_1)$
(c) $V_1 + \frac{e}{h}(\upsilon_2 - \upsilon_1)$ (d) $V_1 - \frac{h}{e}(\upsilon_1 + \upsilon_2)$

26. A particle of mass $4m$ at rest decays into two particles of masses m and $3m$ having non-zero velocities. The ratio of the de Broglie wavelengths of the particles 1 and 2 is

(a) $\frac{1}{2}$ (b) $\frac{1}{4}$ (c) 2 (d) 1

27. The photoelectric threshold frequency of a metal is υ. When light of frequency 4υ is incident on the metal, the maximum kinetic energy of the emitted photoelectron is

(a) $4h\upsilon$ (b) $3h\upsilon$ (c) $5h\upsilon$ (d) $\frac{5h\upsilon}{2}$

28. The de Broglie wavelength is given by

(a) $p = \frac{2\pi\hbar}{\lambda}$ (b) $p = \frac{\hbar}{2\lambda}$

(c) $p = \frac{2\pi}{\hbar\lambda}$ (d) $p = \frac{2\pi}{\lambda}$

29. The de Broglie wavelength of an electron with kinetic energy 120 eV is
(Given $h = 6.63 \times 10^{-34}$ J s, $m_e = 9 \times 10^{-31}$ kg, 1 eV $= 1.6 \times 10^{-19}$ J)

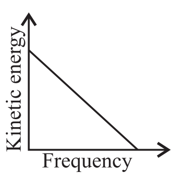
(a) 2.13 Å (b) 1.13 Å

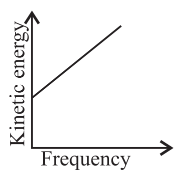
(c) 4.15 Å (d) 3.14 Å

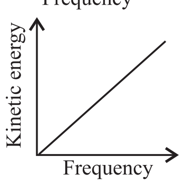
30. If h is Planck's constant, the momentum of a photon of wavelength 0.01 Å is

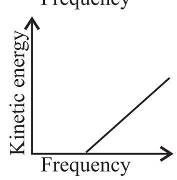
(a) $10^{-2}h$ (b) h (c) $10^{2}h$ (d) $10^{12}h$

31. According to Einstein's photoelectric equation, the graph between the kinetic energy of photoelectrons ejected and the frequency of incident radiation is

(a) 

(b) 

(c) 

(d) 

32. A photon of energy E ejects a photoelectron from a metal surface whose work function is ϕ_0. If this electron enters into a uniform magnetic field B in a direction perpendicular to the field and describes a circular path of radius r, then the radius r is (in the usual notation)

(a) $\sqrt{\frac{2m(E-\phi_0)}{eB}}$ (b) $\sqrt{2m(E-\phi_0)eB}$

(c) $\frac{\sqrt{2e(E-\phi_0)}}{mB}$ (d) $\frac{\sqrt{2m(E-\phi_0)}}{eB}$

33. An electron is moving with an initial velocity $\vec{v} = v_0\hat{i}$ and is in a magnetic field $\vec{B} = B_0\hat{j}$. Then its de Broglie wavelength

(a) remains constant (b) increases with time

(c) decreases with time

(d) increases and decreases periodically

34. The photoelectric threshold wavelength for silver is λ_0. The energy of the electron ejected from the surface of silver by an incident wavelength $\lambda(\lambda < \lambda_0)$ will be

(a) $hc(\lambda_0 - \lambda)$ (b) $\frac{hc}{\lambda_0 - \lambda}$

(c) $\frac{h}{c}\left(\frac{\lambda_0 - \lambda}{\lambda\lambda_0}\right)$ (d) $hc\left(\frac{\lambda_0 - \lambda}{\lambda\lambda_0}\right)$

35. Electrons with de Broglie wavelength λ fall on the target in an X ray tube. The cut off wavelength (λ_0)of the emitted X rays is

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

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

36. A and B are two metals with threshold frequencies 1.8×10^{14} Hz and 2.2×10^{14} Hz. Two identical photons of energy 0.825 eV each are incident on them. Then photoelectrons are emitted in
(Take $h = 6.6 \times 10^{-34}$ J s)

(a) B alone (b) A alone

(c) neither A nor B (d) both A and B

37. 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) 25% (b) 75% (c) 60% (d) 50%

38. The rest mass of photon is

(a) $\frac{h\upsilon}{c}$ (b) $\frac{h\upsilon}{c^2}$

(c) $\frac{h\upsilon}{\lambda}$ (d) zero

39. In photoelectric effect, the photoelectric current is independent of

(a) intensity of incident light

(b) potential difference applied between the two electrodes

(c) the nature of emitter material

(d) frequency of incident light

40. The work function for Al, K and Pt is 4.28 eV, 2.30 eV and 5.65 eV respectively. Their respective threshold frequencies would be

(a) Pt > Al > K (b) Al > Pt > K

(c) K > Al > Pt (d) Al > K > Pt

Case Based MCQs

Case I : Read the passage given below and answer the following questions from 41 to 44.

Photoelectric Effect

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

41. With the increase of intensity of incident radiations on photoelectrons emitted by a photo tube, the number of photoelectrons emitted per unit time is

(a) increases (b) decreases
(c) remains same (d) none of these

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

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

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

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

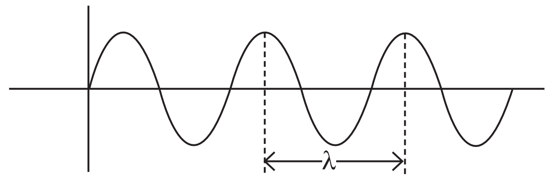
44. If the frequency of incident light falling on a photosensitive metal is doubled, the kinetic energy of the emitted photoelectron is

(a) unchanged
(b) halved
(c) doubled
(d) more than twice its initial value

Case II : Read the passage given below and answer the following questions from 45 to 47.

de-Broglie Wavelength

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



45. If a proton and an electron have the same de Broglie wavelength, then

(a) kinetic energy of electron < kinetic energy of proton
(b) kinetic energy of electron = kinetic energy of proton
(c) momentum of electron = momentum of proton
(d) momentum of electron < momentum of proton

46. Which of these particles having the same kinetic energy has the largest de Broglie wavelength?

(a) Electron
(b) Alpha particle
(c) Proton
(d) Neutron

47. Two particles A_1 and A_2 of masses m_1, m_2 ($m_1 > m_2$) have the same de Broglie wavelength. Then

(a) their momenta are the same.
(b) their energies are the same.
(c) momentum of A_1 is less than the momentum of A_2.
(d) energy of A_1 is more than the energy of A_2.

Case III : Read the passage given below and answer the following questions from 48 to 52.

Wave Theory of Light

According to wave theory, the light of any frequency can emit electrons from metallic surface provided the intensity of light be sufficient to provided necessary energy for emission of electrons, but according to experimental observations, the light of frequency less than threshold frequency can not emit electrons; whatever be the intensity of incident light. Einstein also proposed that electromagnetic radiation is quantised.

If photoelectrons are ejected from a surface when light of wavelength λ_1 = 550 nm is incident on it. The stopping potential for such electrons is V_s = 0.19 V. Suppose the radiation of wavelength λ_2 = 190 nm is incident on the surface.

48. Photoelectric effect supports quantum nature of light because

(A) there is a minimum frequency of light below which no photoelectrons are emitted.
(B) the maximum K.E. of photoelectric depends only on the frequency of light and not on its intensity.
(C) even when the metal surface is faintly illuminated, the photo electrons leave the surface immediately.
(D) electric charge of the photoelectrons is quantized.

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

49. In photoelectric effect, electrons are ejected from metals, if the incident light has a certain minimum

(a) wavelength (b) frequency
(c) amplitude (d) angle of incidence

50. Calculate the stopping potential V_{s_2} of surface.

(a) 4.47 (b) 3.16
(c) 2.76 (d) 5.28

51. Calculate the work function of the surface.

(a) 3.75 (b) 2.07
(c) 4.20 (d) 3.60

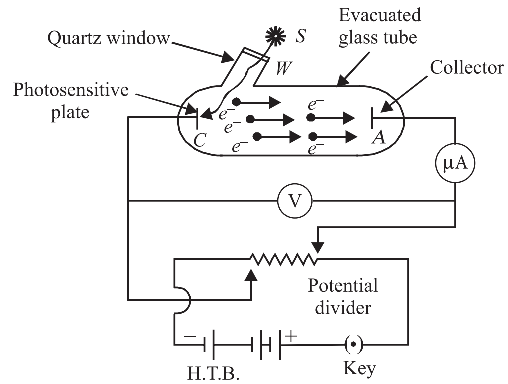
52. Calculate the threshold frequency for the surface.

(a) 500×10^{12} Hz (b) 480×10^{13} Hz
(c) 520×10^{11} Hz (d) 460×10^{13} Hz

Case IV : Read the passage given below and answer the following questions from 53 to 55.

Hertz Observations

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



While demonstrating the existence of electromagnetic waves, Hertz found that high voltage sparks passed across the metal electrodes of the detector loop more easily when the cathode was illuminated by ultraviolet light from an arc lamp. The ultraviolet light falling on the metal surface caused the emission of negatively charged particles, which are now known to be electrons, into the surrounding space and hence enhanced the high voltage sparks.

53. Cathode rays were discovered by

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

54. Cathode rays consists of

(a) photons (b) electrons
(c) pistons (d) α-particles.

55. Who discovered the charge on an electron for the frist time?

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

Assertion & Reasoning Based MCQs

For question numbers 56-60, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

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

56. Assertion (A) : Photoelectric effect demonstrates the wave nature of light. **Reason (R)** : The number of photoelectrons is proportional to the frequency of light.

57. Assertion (A) : The de-Broglie wavelength of particle having kinetic energy K is λ. If its kinetic energy becomes 4 K then its new wavelength would be $\lambda/2$.

Reason (R) : The de-Broglie wavelength λ is inversely proportional to square root of the kinetic energy.

58. Assertion (A) : There is a physical significance of matter waves.

Reason (R) : Both interference and diffraction occurs in it.

59. Assertion (A) : A photon has no rest mass, yet it carries definite momentum.

Reason (R) : Momentum of photon is due to its energy and hence its equivalent mass.

60. Assertion (A) : Photosensitivity of a metal is high if its work function is small.

Reason (R) : Work function = $h\upsilon_0$, where υ_0 is the threshold frequency.

SUBJECTIVE TYPE QUESTIONS

Very Short Answer Type Questions (VSA)

1. When a light of wavelength 400 nm falls on a metal of work function 2.5 eV, what will be the maximum magnitude of linear momentum of emitted photoelectron?

2. Do all the electrons that absorb a photon come out as photoelectron?

3. If light of wavelength 412.5 nm is incident on each of the metals given in table, which one will show photoelectric emission and why?

Metal	Work Function (eV)
Na	1.92
K	2.15
Ca	3.20
Mo	4.17

4. Define the term "Intensity" in photon picture of electromagnetic radiation.

5. The threshold wavelength for two photosensitive surfaces A and B are λ_1 and λ_2 respectively. What is the ratio of the work functions of the two surfaces?

6. There are materials which absorb photons of shorter wavelength and emit photons of longer wavelength. Can there be stable substances which absorb photons of larger wavelength and emit light of shorter wavelength.

7. Name the phenomenon which shows the quantum nature of electromagnetic radiation.

8. Write the relationship of de-Broglie wavelength λ associated with a particle of mass m in terms of its kinetic energy E.

9. (i) In the explanation of photoelectric effect, we assume one photon of frequency υ collides with an electron and transfers its energy. This leads to the equation for the maximum energy E_{max} of the emitted electron as

$E_{max} = h\upsilon - \phi_0$

where ϕ_0 is the work function of the metal. If an electron absorbs 2 photons (each of frequency υ) what will be the maximum energy for the emitted electron?

(ii) Why is this fact (two photon absorption) not taken into consideration in our discussion of the stopping potential?

10. A proton and an electron have same kinetic energy. Which one has greater de-Broglie wavelength and why?

Short Answer Type Questions (SA-I)

11. A metallic surface is irradiated with monochromatic light of variable wavelength. Above a wavelength of 5000 Å, no photoelectrons are emitted from the surface. With an unknown wavelength, stopping potential is 3 V. Find the unknown wavelength.

12. In an experiment on photoelectric effect, light of wavelength 800 nm (less than threshold wavelength) is incident on a cesium plate at the rate of 5.0 W. The potential of the collector plate is made sufficiently positive with respect to the emitter so that the current reaches its saturation value. Assuming that on the average one of every 10^6 photons is able to eject a photoelectron, find the photo current in the circuit.

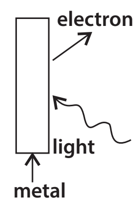
13. One milliwatt of light of wavelength λ = 4560 Å is incident on a cesium metal surface. Calculate the electron current liberated. Assume a quantum efficiency of η = 0.5%. [Work function for cesium = 1.89 eV]. Take hc = 12400 eV Å.

14. When light of wavelength l is incident on a metal surface, stopping potential is found to be x. When light of wavelength $n\lambda$ is incident on the same metal surface, stopping potential is found to be $\frac{x}{n+1}$ Find the threshold wavelength of the metal.

15. The magnetic field at a point associated with a light wave is $B = 2 \times 10^{-6}$ tesla $\sin[(3.0 \times 10^{15}\ s^{-1})t] \sin[(6.0 \times 10^{15}\ s^{-1})t]$. If this light falls on a metal surface having a work function of 2.0 eV, what will be the maximum kinetic energy of the photoelectrons?

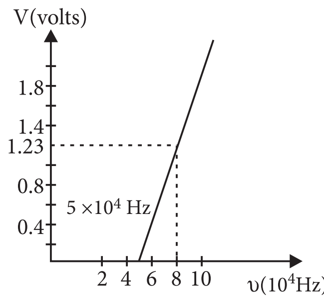
16. A light beam of wavelength 400 nm is incident on a metal plate of work function of 2.2 eV. An electron absorbs a photon and makes some collisions before coming out of the metal. Assuming that 10% of the instantaneous energy is lost to the metal in each collision.
(i) Find the kinetic energy of electron which makes two collisions as it comes out of the metal.
(ii) Under the same assumptions, find the minimum number of collisions the electron can suffer before it becomes unable to come out of metal.
(Use hc = 12400 eV Å)

17. Consider figure for photoemission. How would you reconcile with momentum-conservation? Note light (photons) have momentum in a different direction than the emitted electrons.



18. (a) Define the terms, (i) threshold frequency and (ii) stopping potential in photoelectric effect.
(b) Plot a graph of photocurrent versus anode potential for a radiation of frequency υ and intensities I_1 and I_2 ($I_1 < I_2$).

19. Using the graph shown in the figure for stopping potential versus the incident frequency of photons, calculate Planck's constant.



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

Short Answer Type Questions (SA-II)

21. In an experiment on photoelectric emission, following observations were made
1. Wavelength of the incident light = 2×10^{-7} m
2. Stopping potential = 3 V
Find
(i) kinetic energy of photoelectrons with maximum speed
(ii) work function and
(iii) threshold frequency (h = 6.62×10^{-34} J s).

22. A beam of light consists of four wavelengths 4000 Å, 4800 Å, 6000 Å and 7000 Å, each of intensity 1.5×10^{-3} Wm^{-2}. The beam falls normally on an area 10^{-4} m^2, of a clean metallic surface of work function 1.9 eV. Assuming no loss of light energy (*i.e.*, each capable photon emits one electron), calculate the number of photoelectrons liberated per second.

23. Two monochromatic beams A and B of equal intensity I, hit a screen. The number of photons hitting the screen by beam A is twice that by beam B. Then what inference can you make about their frequencies?

24. An electron and a photon each have a wavelength 1.00 nm. Find
(i) their momenta,
(ii) the energy of the photon and
(iii) the kinetic energy of electron.

25. (a) Ultraviolet light of wavelength 2271 Å from a 100 W mercury source is incident on a photocell made of molybdenum metal. If the stopping potential is 1.3 V, estimate the work function of the metal.

(b) How would the photocell respond to high intensity (10^5 W/m^2) red light of wavelength 6328 Å produced by a He – Ne laser?

26. Two particles A and B of de–Broglie wavelengths λ_1 and λ_2 combine to form a particle C. The process conserves momentum. Find the de–Broglie wavelength of the particle C. (The motion is one dimensional).

27. (a) An electron and a proton are accelerated through the same potential. Which one of the two has
(i) greater value of de-Broglie wavelength associated with it, and
(ii) lesser momentum?
Justify your answer in each case.
(b) How is the momentum of a particle related with its de-Broglie wavelength? Show the variation on a graph.

28. State three important properties of photons which describe the particle picture of electromagnetic radiation.

29. A neutron beam of energy E scatters from atoms on a surface with a spacing d = 0.1 nm. The first maximum of intensity in the reflected beam occurs at θ = 30 . What is the kinetic energy E of the beam in eV?

30. Assuming an electron is confined to a 1 nm wide region, find the uncertainty in momentum using Heisenberg Uncertainty principle. You can assume the uncertainty in position Δx as 1 nm. Assuming $p \simeq \Delta p$, find the energy of the electron in electron volts.

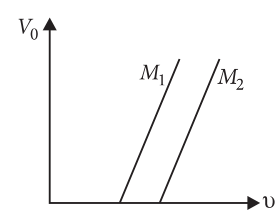
31. Consider a metal exposed to light of wavelength 600 nm. The maximum energy of the electron doubles when light of wavelength 400 nm is used. Find the work function in eV.

32. (a) State two important features of Einstein's photoelectric equation.
(b) Radiation of frequency 1015 Hz is incident on two photosensitive surfaces P and Q. There is no photoemission from surface P. Photoemission occurs from surface Q but photoelectrons have zero kinetic energy. Explain these observations and find the value of work function for surface Q.

Long Answer Type Questions (LA)

33. Consider a 20 W bulb emitting light of wavelength of 5000 Å and shining on a metal surface kept at a distance 2 m. Assume that the metal surface has work function of 2 eV and that each atom on the metal surface can be treated as a circular disk of radius 1.5 Å.
(i) Estimate no. of photons emitted by the bulb per second. [Assume no other losses]
(ii) Will there be photoelectric emission?
(iii) How much time would be required by the atomic disk to receive energy equal to work function (2 eV)?
(iv) How many photons would atomic disk receive within time duration calculated in (iii) above?
(v) Can you explain how photoelectric effect was observed instantaneously?

34. Figure shows a plot of stopping potential (V_0) with frequency (υ) of incident radiation for two photosensitive material M_1 and M_2. Explain
(i) why the slope of both the lines is same?
(ii) for which material emitted electrons have greater kinetic energy for the same frequency of incident radiation?



35. Explain how Einstein's photoelectric equation is used to describe photoelectric effect satisfactorily.

36. Consider a thin target (10^{-2} m square, 10^{-3} m thickness) of sodium, which produces a photocurrent of 100 μA when a light of intensity 100 W m^{-2} (λ = 660 nm) falls on it. Find the probability that a photoelectron is produced when a photon strikes a sodium atom. [Take density of Na = 0.97 kg m^{-3}].

37. A particle A with a mass m_A is moving with a velocity v and hits a particle B (mass m_B) at rest (one dimensional motion). Find the change in the de Broglie wavelength of the particle A. Treat the collision as elastic.

ANSWERS

OBJECTIVE TYPE QUESTIONS

1. (d) : Velocity acquired by a particle while falling from a height H is

$$v = \sqrt{2gH} \quad \text{...(i)}$$

As $\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{2gH}}$ (Using (i))

or $\lambda \propto \frac{1}{\sqrt{H}}$

2. (a) : Given threshold frequency, $\upsilon_0 = 3.3 \times 10^{14}$ Hz

Frequency of incident light, $\upsilon = 8.2 \times 10^{14}$ Hz

As $eV_0 = h(\upsilon - \upsilon_0)$ or $V_0 = \frac{h(\upsilon - \upsilon_0)}{e}$

$$= \frac{6.63 \times 10^{-34}(8.2 \times 10^{14} - 3.3 \times 10^{14})}{1.6 \times 10^{-19}} = 2 \text{ V}$$

3. (d) : As $\lambda = \frac{h}{\sqrt{2mqV}}$

$\therefore \lambda \propto \frac{1}{\sqrt{mq}} \quad \therefore \frac{\lambda_p}{\lambda_\alpha} = \frac{\sqrt{m_\alpha q_\alpha}}{\sqrt{m_p q_p}}$

$$= \frac{\sqrt{4m_p \times 2e}}{\sqrt{m_p \times e}} = \sqrt{8} \quad (\because m_\alpha = 4m_p, q_\alpha = 2q_p)$$

4. (b) : de Broglie wavelength, $\lambda = \frac{h}{\sqrt{2mK}}$ ...(i)

When the kinetic energy is $\frac{K}{4}$ then

$$\lambda' = \frac{h}{\sqrt{2m(K/4)}} = \frac{2h}{\sqrt{2mK}} = 2\lambda \quad \text{(Using (i))}$$

5. (b) : The de Broglie wavelength is given by

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

$$\lambda \propto \frac{1}{v}$$

So if the velocity of the electron increases, the de Broglie wavelength decreases.

6. (d) : de Broglie wavelength, $\lambda = \frac{h}{p}$

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

Hence, curve (d) is the correct option.

7. (a) : Mass of the ball, m = 150 g = 0.15 kg,

Speed of the ball, v = 30 m s^{-1}

Momentum, $p = mv = 0.15 \times 30 = 4.5$ kg m s^{-1}

de Broglie wavelength, $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{4.5} = 1.47 \times 10^{-34}$ m

8. (d)

9. (d) : Energy spent to convert ice into water

$= mL = (1000 \text{ g}) \times 80 \text{ cal g}^{-1} = 80000$ cal

Energy of photons used $= nT \times E = nT \times h\upsilon$

$\therefore nTh\upsilon = mL$ or $T = \frac{mL}{nh\upsilon}$

$\therefore T \propto 1/n$ when υ is constant, $T \propto 1/\upsilon$ when n fixed, $T \propto 1/n\upsilon$. Thus T is constant if $n\upsilon$ is constant. Thus options (a), (b) and (c) are correct.

10. (a) : de-Broglie wavelength, $\lambda = \frac{h}{p}$

where symbols have their usual meaning.

$\because p_\alpha = p_p = p_e$

$\therefore \lambda_\alpha = \lambda_p = \lambda_e$

11. (a) : de Broglie wavelength associated with an electron is

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

$$\therefore \frac{\Delta p}{p} = -\frac{\Delta\lambda}{\lambda} \Rightarrow \frac{p}{p_{\text{initial}}} = \frac{0.5}{100}$$

$p_{\text{initial}} = 200p$

12. (c) : Millikan's experiment established that electric charge is quantised.

13. (b) : The phenomenon of photoelectric emission was discovered by Heinrich Hertz in 1887.

14. (a) : Here, T = 27 + 273 = 300 K

For an electron in a metal, momentum $p = \sqrt{3mk_BT}$

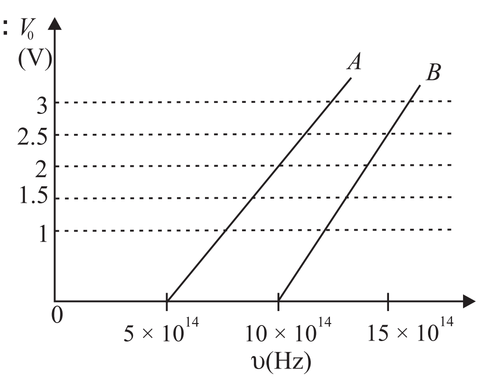
de Broglie wavelength of an electron is

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{3mk_BT}}$$

$$= \frac{6.63 \times 10^{-34}}{\sqrt{3 \times (9.1 \times 10^{-31}) \times (1.38 \times 10^{-23}) \times 300}}$$

$= 6.2 \times 10^{-9}$ m

15. (b) :



Since, $eV_0 = h\nu$

$\therefore$ slope of $\frac{h}{e}$ = slope of $\frac{v_0}{\nu}$

For metal A,

$$\text{Slope} = \frac{h}{e} = \frac{2-0}{(10-5)\times 10^{14}}$$

$$\text{or} \quad h = \frac{2\times e}{5\times 10^{14}} = \frac{2\times 1.6\times 10^{-19}}{5\times 10^{14}} = 6.4\times 10^{-34}\ \text{J s}$$

For metal B,

$$\text{Slope} = \frac{h}{e} = \frac{2.5-0}{(15-10)\times 10^{14}}$$

$$h = \frac{2.5\times e}{5\times 10^{14}} = \frac{2.5\times 1.6\times 10^{-19}}{5\times 10^{14}}$$

$= 8 \times 10^{-34}$ J s

16. (a) : Here, $V = 30$ kV, $h = 6.63 \times 10^{-34}$ J s

As $eV = h\upsilon_{max}$

$$\text{or} \quad \upsilon_{max} = \frac{eV}{h} = \frac{1.6\times 10^{-19}\times 3\times 10}{6.63\times 10^{-34}} = 7.24 \times 10^{18}\ \text{Hz}$$

$$\text{As} \quad eV = \frac{hc}{\lambda_{min}}$$

$$\text{or} \quad \lambda_{min} = \frac{hc}{eV} = \frac{6.63\times 10^{-34}\times 3\times 10^{8}}{1.6\times 10^{-19}\times 3\times 10^{4}} = 0.041\times 10^{-9}\ \text{m}$$

$= 0.041$ nm

17. (a) **18. (d)**

19. (a) : Mean kinetic energy of a molecule

$$= \frac{1}{2}mv_{rms}^2 = \frac{3}{2}k_BT$$

$$\therefore \quad v_{rms} = \sqrt{\frac{3k_BT}{m}}$$

Here, $m = 2 \times 14.0076 = 28.02$ u

$$\text{As} \quad \lambda = \frac{h}{mv_{rms}} = \frac{h}{\sqrt{3mk_BT}}$$

$$= \frac{6.63\times 10^{-34}}{\sqrt{3\times(28.02\times 1.66\times 10^{-27})\times 1.38\times 10^{-23}\times 300}}$$

$= 2.75 \times 10^{-11}$ m

20. (b) : Here, $V_0 = 1.5$ V,

Maximum kinetic energy = $eV_0 = 1.5$ eV

21. (d) : Here, $\upsilon = 6 \times 10^{14}$ Hz, $h = 6.63 \times 10^{-34}$ J s

As $E = h\upsilon = 6.63 \times 10^{-34} \times 6 \times 10^{14} = 3.98 \times 10^{-19}$ J

Number of photons emitted per second,

$$n = \frac{P}{E}$$

$$= \frac{2\times 10^{-3}}{3.98\times 10^{-19}} = 5\times 10^{15}\ \text{photons per second}$$

22. (b) : Here, $E = 1$ MeV $= 10^6$ eV, $h = 6.63 \times 10^{-34}$ J s, $c = 3 \times 10^8$ m s^{-1}

$$\text{or} \quad hc = \frac{6.63\times 10^{-34}\times 3\times 10^{8}}{1.6\times 10^{-19}} \approx 1240\ \text{eV nm}$$

$$\text{As} \quad E = \frac{hc}{\lambda}$$

$$\text{or} \quad \lambda = \frac{hc}{E} = \frac{1240\ \text{eV nm}}{10^6\ \text{eV}} = 1.24\times 10^{-3}\ \text{nm}$$

23. (c) : Here, total energy of 2 γ-rays $= 10.2 \times 10^9$ eV

$$\therefore \quad \text{Energy of each } \gamma\text{-rays} = \frac{1}{2} = (10.2\times 10^9\times 1.6\times 10^{-19})\ \text{J}$$

$= 8.16 \times 10^{-10}$ J

$$\text{As} \quad E = h\upsilon = \frac{hc}{\lambda}$$

$$\text{or} \quad \lambda = \frac{hc}{E} = \frac{6.63\times 10^{-34}\times 3\times 10^{8}}{8.16\times 10^{-10}} = 2.44 \times 10^{-16}\ \text{m}$$

24. (a) : Number of photons emitted per second $= \frac{8\%\text{ of } P}{E}$

$$= \frac{8P\lambda}{100hc} = \frac{8\times 150\times 4500\times 10^{-10}}{100\times 6.63\times 10^{-34}\times 3\times 10^{8}}$$

$= 3 \times 10^{19}$ photons per second

25. (b) : Maximum kinetic energy $K_{max} = \frac{1}{2}mv^2 = eV_o$

where V_o is the stopping potential.

According to Einstein's photoelectric equation

$h\upsilon_1 = \phi_0 + eV_1$ ... (i)

$h\upsilon_2 = \phi_0 + eV_2$ ... (ii)

$\therefore \quad h(\upsilon_1 - \upsilon_2) = e(V_1 - V_2)$

$$\frac{h}{e}(\upsilon_1 - \upsilon_2) = V_1 - V_2 \quad \text{or} \quad V_2 = V_1 + \frac{h}{e}(\upsilon_2 - \upsilon_1)$$

26. (d) : According to law of conservation of linear momentum, two particles will have equal and opposite momentum.

The de Broglie wavelength is given by

$$\lambda = \frac{h}{p} \qquad \therefore \quad \frac{\lambda_1}{\lambda_2} = 1$$

27. (b) : The maximum kinetic energy of the emitted electron is given by

$K_{max} = h\upsilon - \phi_0 = h(4\upsilon) - h(\upsilon) = 3h\upsilon$

28. (a) : de Broglie wavelength is given by

$\lambda = \dfrac{h}{p}$, where p is the momentum

or $p = \dfrac{h}{\lambda}$

Since, $\hbar = \dfrac{h}{2\pi}$ $\quad \therefore \quad p = \dfrac{2\pi\hbar}{\lambda}$

29. (b) : As $p = \sqrt{2mK}$

$= \sqrt{2 \times 9 \times 10^{-31} \times 120 \times 1.6 \times 10^{-19}}$

$= 5.88 \times 10^{-24}$ kg m s^{-1}

de Broglie wavelength,

$\lambda = \dfrac{h}{p} = \dfrac{6.63 \times 10^{-34}}{5.88 \times 10^{-24}} = 1.13 \times 10^{-10}$ m = 1.13 Å

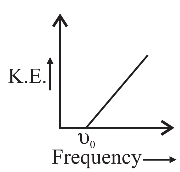
30. (d) : Momentum of photon, $p = \dfrac{E}{c} = \dfrac{h\upsilon}{c}$

where E is the energy of a photon and c is the velocity of light.

$\therefore \quad p = \dfrac{hc}{c\lambda} \qquad \left[\because \ \upsilon = \dfrac{c}{\lambda}\right]$

$= \dfrac{h}{\lambda} = \dfrac{h}{0.01 \times 10^{-10}} = 10^{12} h$

31. (d) : The maximum kinetic energy of photoelectron ejected is given by



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

$= h\upsilon - h\upsilon_0$

where work function depends on the type of material.

If the frequency of incident radiation is greater than υ_0 only then the ejection of photoelectrons start. After that as frequency increases kinetic energy also increases.

32. (d) : As the electron describes a circular path of radius r in the magnetic field, therefore

$\dfrac{mv^2}{r} = evB$

$r = \dfrac{mv}{eB} = \dfrac{p}{eB} = \dfrac{\sqrt{2mK}}{eB} \qquad \left(\text{As } K = \dfrac{p^2}{2m}\right)$

From Einstein's photoelectric equation

$K = E - \phi_0$

$\therefore \quad r = \dfrac{\sqrt{2m(E - \phi_0)}}{eB}$

33. (a) : Here, $\vec{v} = v_0 \hat{i}, \vec{B} = B_0 \hat{j}$

Force on moving electron due to magnetic field is

$\vec{F} = -e(\vec{v} \times \vec{B}) = -e(v_0 \hat{i} \times B_0 \hat{j}) = -ev_0 B_0 \hat{k}$

As this force is perpendicular to $\vec{v}$ and $\vec{B}$, so the magnitude of $\vec{v}$ will not change. *i.e* momentum (= mv) will remains constant in magnitude.

Therefore, de Broglie wavelength, $\lambda \left(= \dfrac{h}{mv}\right)$ remains constant.

34. (d) : According to Einstein's photoelectric equation

$$K = \frac{hc}{\lambda} - \frac{hc}{\lambda_0} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right) = hc\left(\frac{\lambda_0 - \lambda}{\lambda\lambda_0}\right)$$

35. (a) : Let K be the kinetic energy of the incident electron. Its linear momentum, $p = \sqrt{2mK}$

The de Broglie wavelength is related to the linear momentum as

$\lambda = \dfrac{h}{p} = \dfrac{h}{\sqrt{2mK}}$ or $K = \dfrac{h^2}{2m\lambda^2}$

The cut off wavelength of the emitted X rays is related to the kinetic energy of the incident electron as

$\dfrac{hc}{\lambda_0} = K = \dfrac{h^2}{2m\lambda^2}$ or $\lambda_0 = \dfrac{2mc\lambda^2}{h}$

36. (b) : $\phi_{0A} = \dfrac{h\upsilon_0}{e}$ eV

$= \dfrac{(6.6 \times 10^{-34}) \times (1.8 \times 10^{14})}{1.6 \times 10^{-19}}$ eV $= 0.74$ eV

$\phi_{0B} = \dfrac{(6.6 \times 10^{-34}) \times (2.2 \times 10^{14})}{1.6 \times 10^{-19}}$ eV $= 0.91$ eV

Since the incident energy 0.825 eV is greater than 0.74 eV and less than 0.91 eV, so photoelectrons are emitted from metal A only.

37. (b) : As $\lambda = \dfrac{h}{mv} = \dfrac{h}{\sqrt{2mK}}$ or $\lambda \propto \dfrac{1}{\sqrt{K}}$

$\therefore \quad \dfrac{\lambda'}{\lambda} = \sqrt{\dfrac{K}{K'}} = \sqrt{\dfrac{1}{16}} = \dfrac{1}{4}$

% change in de Broglie wavelength $= \left(\dfrac{\lambda - \lambda'}{\lambda}\right) \times 100$

$= \left(1 - \dfrac{\lambda'}{\lambda}\right) 100 = \left(1 - \dfrac{1}{4}\right) \times 100 = 75\%$

38. (d) : The rest mass of photon is zero.

39. (d) : Photoelectric current depends on

(i) the intensity of incident light.

(ii) the potential difference applied between the two electrodes.

(iii) the nature of the emitter material.

40. (a) : Work function, $\phi_0 = h\upsilon_0$
where υ_0 is the threshold frequency
So, $\phi_0 \propto \upsilon_0$
Hence Pt > Al > K

41. (a) : With the increase of intensity of the incident radiation the number of photoelectrons emitted per unit time increases.

42. (b) : As $eV = KE_{\max}$

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

43. (c) : From Einstein's photoelectric equation,
$KE_{\max} = h\upsilon - \phi = (5 - 3) = 2$ eV

44. (d) : According to Einstein's photoelectric equation, the kinetic energy of the emitted photoelectron is
$K = h\upsilon - \phi_0$ ... (i)
where υ is the frequency of incident radiation and ϕ_0 is a work function of the metal.
If the frequency of incident radiation is doubled, then
$K' = 2h\upsilon - \phi_0 = 2(h\upsilon - \phi_0) + \phi_0 = 2K + \phi_0$ (Using (i))
$K' > 2K$

45. (c) : de Broglie wavelength, $\lambda = \frac{h}{p}$
where p is the momentum of the particle
For electron, $\lambda_e = \frac{h}{p_e}$
For proton, $\lambda_p = \frac{h}{p_p}$
As $\lambda_e = \lambda_p \Rightarrow p_e = p_p$ (Given)
or Momentum of electron = Momentum of proton

46. (a) : As $\lambda = \frac{h}{\sqrt{2mK}}$ so $\lambda \propto \frac{1}{\sqrt{m}}$

Out of the given particles m is least for electron, therefore electron has the largest value of de Broglie wavelength.

47. (a) : As $\lambda = \frac{h}{p}$ or $p = \frac{h}{\lambda}$ or $p \propto \frac{1}{\lambda}$

$\therefore \quad \frac{p_1}{p_2} = \frac{\lambda_2}{\lambda_1} = \frac{\lambda}{\lambda} = 1$ or $p_1 = p_2$

Also $E = \frac{1}{2}\frac{p^2}{m} = \frac{1}{2m}\frac{h^2}{\lambda^2}$ $\left(\because p = \frac{h}{\lambda}\right)$

or $E \propto \frac{1}{m}$ $\quad \therefore \frac{E_1}{E_2} = \frac{m_2}{m_1} < 1$ or $E_1 < E_2$

48. (a) : The existence of the frequency and the instantaneous emission of photo electrons support the quantum nature of light.

49. (b) : For photoelectric emission, the incident light must have a certain minimum frequency, called threshold frequency.

50. (a) : From Einstein's relation
$eV_s = h\upsilon - W$
As work function is a constant for a surface.
$e(V_{s_2} - V_{s_1}) = h(\upsilon_2 - \upsilon_1)$

$V_{s_2} = V_{s_1} + \frac{h}{e}(\upsilon_2 - \upsilon_1)$

$= 0.19 + 1240\left(\frac{1}{190} - \frac{1}{550}\right) = 4.47$ V

51. (b) : $W = \frac{hc}{\lambda_1} - eV_{s_1} = \frac{1240}{550} - 0.19 = 2.07$ eV

52. (a) : $h\upsilon_c = W$

$\upsilon_c = \frac{W}{h} = \frac{(2.07)(1.602 \times 10^{-19})}{6.626 \times 10^{-34}} \approx 500 \times 10^{12}$ Hz

53. (c) **54. (b)**

55. (a)

56. (d) : Photoelectric effect can be explained on the basis of quantum theory or particle nature of light where wave nature of light fails to explain the photoelectric effect. The number of photoelectrons is proportional to the intensity of incident light.
$I = nh\upsilon$ where n is the number of photons emitted/absorbed per unit area per second. n and $h\upsilon$ are independent factors.

57. (a) **58. (a)**

59. (a) : Equivalent mass of photon (m) is given from equation

$E = mc^2 = h\upsilon \quad \therefore \; m = \frac{h\upsilon}{c^2}$

where E is energy, m is mass, c is speed of light, h is Planck's constant, υ is frequency.

$\therefore$ Momentum of photon $= \frac{h\upsilon}{c^2} \times c = \frac{h\upsilon}{c}$

60. (b) : Less work function means less energy is required for ejecting out the electrons.

SUBJECTIVE TYPE QUESTIONS

1. $K_{\max} = \frac{hc}{\lambda} - \phi$

$\frac{p^2}{2m} = \left(\frac{1.24 \times 10^4}{4000} - 2.5\right)\text{eV} = 0.6$ eV

$p = \sqrt{2 \times 9.1 \times 10^{-31} \times 0.6 \times 1.6 \times 10^{-19}} = 4.2 \times 10^{-25}$ kg m/s

2. Not all the electrons that absorb a photon come out as photoelectrons because most of electrons get scattered into the metal. Only those electrons come out as photoelectrons whose energy becomes greater than work function of metal.

3. Wavelength of incident light, λ = 412.5 nm

Energy of incident light, $E = \frac{hc}{\lambda} = \frac{1242\,\text{eV nm}}{412.5\,\text{nm}}$ = 3 eV

Metals Na and K will show photoelectric emission because their work functions are less than the energy of incident light.

4. The amount of light energy or photon energy, incident per unit area per unit time is called intensity of electromagnetic radiation.

5. Work function $= h\upsilon = \frac{hc}{\lambda}$

$\therefore$ The ratio, $\frac{\phi_A}{\phi_B} = \frac{hc}{\lambda_A} \times \frac{\lambda_B}{hc} = \frac{\lambda_2}{\lambda_1}$

6. In case of stable material, this is not possible because, to absorb a photon of larger wavelength and emit a photon of shorter wavelength, energy has to be supplied by the material.

7. Photoelectric effect shows the quantum nature of electromagnetic radiation.

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

9. Given, $E_{max} = h\upsilon - \phi_0$

As energy of 2 photons = $2h\upsilon$

$E'_{max} = 2h\upsilon - \phi_0$

As there is one to one interaction, probability of absorbing 2 photons by same electron is very low. Thus, emission of two photon absorption is negligible.

10. We know the relation, $\lambda = \frac{h}{p}$

kinetic energy, $K = \frac{p^2}{2m}$

Then, $\lambda = \frac{h}{\sqrt{2mK}}$

$K_p = K_e \Rightarrow \lambda \propto \frac{1}{\sqrt{m}}$

$\because$ $m_p >> m_e$ $\therefore$ $\lambda_p << \lambda_e$

Hence for same kinetic energy wavelength associated with electron will be greater.

11. According to question, λ_{th} = 5000 Å and V_s = 3V. Using equation of photoelectric equation,

$K_{max} = E - W$ $\quad$ $(K_{max} = eV_s)$

$\therefore$ $3\,\text{eV} = \frac{12400}{\lambda} - \frac{12400}{5000} = \frac{12400}{\lambda} - 2.48$ eV

or λ = 2262 Å

12. Number of photons falling in one second = $\frac{P}{E_\lambda} = \frac{P\lambda}{hc}$

where P is power of light and $E\lambda$ is energy of photon.

Number of photoelectron emitted per second = $\frac{P\lambda}{hc} \cdot \frac{1}{10^6}$

$\therefore$ Photocurrent = $\frac{P\lambda}{hc \times 10^6} \cdot e$

$= \frac{5 \times 800 \times 10^{-9} \times (1.6 \times 10^{-19})}{6.63 \times 10^{-34} \times 3 \times 10^8 \times 10^6} = 3.2\,\mu\text{A}$

13. Since $\frac{hc}{\lambda} = \frac{12400}{4560} = 2.7\text{ eV} > 1.89\text{ eV}$ so photocurrent will flow.

Number of photons incident per second

$= \frac{P(\text{Power})}{E_\lambda\,(\text{Energy of photon})} = \frac{P}{\frac{hc}{\lambda}} = \frac{P\lambda}{hc}$

Number of photoelectron emitted per second $= \frac{0.5}{100}\left(\frac{P\lambda}{hc}\right)$

Photocurrent = $\frac{0.5}{100}\left(\frac{P\lambda}{hc}\right)e = 1.84 \times 10^{-6}$ A.

14. Let λ_0 is the threshold wavelength, the work function is $\phi = \frac{hc}{\lambda_0}$

Now, by photoelectric equation, $eV_s = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$

$$ex = \frac{hc}{\lambda} - \frac{hc}{\lambda_0} \quad \text{...(i)}$$

$$\frac{ex}{n+1} = \frac{hc}{n\lambda} - \frac{hc}{\lambda_0} \quad \text{...(ii)}$$

From (i) and (ii), $\frac{hc}{\lambda} - \frac{hc}{\lambda_0} = (n+1)\frac{hc}{n\lambda} - (n+1)\frac{hc}{\lambda_0}$

or $\frac{nhc}{\lambda_0} = \frac{hc}{n\lambda} \Rightarrow \lambda_0 = n^2\lambda$

15. $B = 2 \times 10^{-6}$ tesla $\sin[(3.0 \times 10^{15}\,\text{s}^{-1})t]\sin[(6.0 \times 10^{15}\,\text{s}^{-1})t]$

$= 1 \times 10^{-6}$ tesla $[\cos\{(3.0 \times 10^{15}\,\text{s}^{-1})t\} - \cos\{(9.0 \times 10^{15}\,\text{s}^{-1})t\}]$

Maximum frequency of the wave = $\frac{9 \times 10^{15}}{2\pi}\,\text{s}^{-1}$

Maximum kinetic energy of the photoelectrons

$= \left(\frac{9 \times 10^{15}}{2\pi e}h - 2\right)\text{eV} = 3.93\,\text{eV}$

16. E_λ = Energy of the photon = $\frac{hc}{\lambda} = \frac{1.24 \times 10^4}{4000}$ eV = 3.1 eV

(i) K.E. of emitted e^- = (3.1 $(0.9)^2$ − 2.2) eV = 0.31 eV

(ii) For e^- not be able to come out, its energy should be less than 2.2 eV

i.e., (3.1) $(0.9)^n < 2.2$, $n > 4$

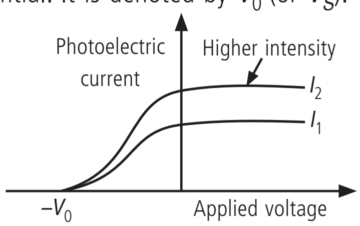
17. The momentum of incident photon is transferred to the metal during photoelectric emission at macroscopic level.

At microscopic level, atoms of metal absorb photons and momentum is transferred mainly to the nuclei and the electron. Excited electrons are emitted in the process and thus momentum is conserved.

18. (a) (i) Threshold Frequency : The minimum frequency of incident light which is just capable of ejecting electrons from a metal is called the threshold frequency. It is denoted by υ_0.

(ii) Stopping Potential : The minimum retarding potential applied to anode of a photoelectric tube which is just capable of stopping photoelectric current is called the stopping potential. It is denoted by V_0 (or V_S).

(b)



$$I = \frac{\varepsilon}{R + r}$$

19 Using Einstein's photoelectric equation,

$eV = h\upsilon - \phi$

on differentiation we get $e\Delta V = h\Delta\upsilon$

or $h = \dfrac{e\Delta V}{\Delta\upsilon} = \dfrac{1.6\times10^{-19}\times(1.23-0)}{(8-5)\times10^{14}} = 6.56\times10^{-34}$ J s

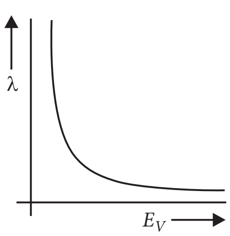
20. According to Einstein's photoelectric effect

$$E = W + \frac{1}{2}mv^2$$

Since work function of the surface is negligible, the above equation becomes

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

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



If λ is de-Broglie wavelength of the emitted electrons, then

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

21. (i) Since V_s = 3 V and $K_{max} = eV_s$, so K_{max} = 3 eV

(ii) $\lambda = 2 \times 10^{-7}$ m = 2000 Å and hc = 12400 eVÅ.

Energy of incident photon $= \dfrac{hc}{\lambda} = \dfrac{12400}{2000}$ eV = 6.20 eV

$W = E - K_{max}$ = 3.2 eV

(iii) $h\upsilon_{th} = W = 3.2 \times 1.6 \times 10^{-19}$ J

$$\upsilon_{th} = \frac{3.2\times1.6\times10^{-19}}{6.625\times10^{-34}} = 7.76\times10^{14} \text{ Hz}$$

22. $E_1 = \dfrac{12400}{4000} = 3.1$ eV, $E_2 = \dfrac{12400}{4800} = 2.58$ eV ,

$E_3 = \dfrac{12400}{6000} = 2.06$ eV and $E_4 = \dfrac{12400}{7000} = 1.77$ eV

Energy of photon (E_4) is less than work function. Therefore, light of wavelengths 4000 Å, 4800 Å,and 6000 Å can only emit photoelectrons.

$\therefore$ Number of photoelectrons emitted per second = Number of photons incident per second

$$= \frac{I_1A_1}{E_1} + \frac{I_2A_2}{E_2} + \frac{I_3A_3}{E_3} = IA\left(\frac{1}{E_1} + \frac{1}{E_2} + \frac{1}{E_3}\right)$$

$$= \frac{(1.5\times10^{-3})(10^{-4})}{1.6\times10^{-19}}\left(\frac{1}{3.1} + \frac{1}{2.58} + \frac{1}{2.05}\right) = 1.12 \times 10^{12}$$

23. Let n_1, n_2 be the number of photons hitting the screen per second by beam A and B respectively

Intensity of beam of photon, $I = nh\upsilon$

$\therefore \quad n_1\upsilon_1 = n_2\upsilon_2$

$$\frac{n_1}{n_2} = \frac{\upsilon_2}{\upsilon_1}$$

As $\dfrac{n_1}{n_2} = 2 \quad \therefore \quad \dfrac{\upsilon_2}{\upsilon_1} = 2$, $\upsilon_2 = 2\upsilon_1$

i.e, frequency of beam B is twice of that of beam A.

24. (i) Momentum of photon

$$p = \frac{h}{\lambda} = \frac{6.6\times10^{-34}}{1\times10^{-9}} = 6.6\times10^{-25} \text{ kg m s}^{-1}$$

Momentum of electron

$$p = \frac{6.6\times10^{-34}}{1\times10^{-9}} = 6.6\times10^{-25} \text{ kg m s}^{-1}$$

(ii) Energy of photon

$$E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^8}{1\times10^{-9}} = 1.98\times10^{-16} \text{ J}$$

(iii) Kinetic energy of electron

$$E_e = \frac{p^2}{2m} = \frac{(6.6\times10^{-25})^2}{2\times9.1\times10^{-31}} = 2.39 \times 10^{-19} \text{ J}$$

25. (a) From Einstein's equation

$h\upsilon = \phi_0 + K = \phi_0 + eV_s$

or $\phi_0 = h\upsilon - eV_s = \dfrac{hc}{\lambda} - eV_s$

(Equation is independent of the power of the source)

$$\phi_0 = \frac{6.6\times10^{-34}\times3\times10^8}{2271\times10^{-10}} - 1.3 \text{ eV}$$

$$=\left(\frac{6.6\times10^{-34}\times3\times10^{8}}{2271\times10^{-10}\times1.6\times10^{-19}}-1.3\right)\text{eV}$$

= 5.5 eV – 1.3 eV = 4.2 eV

(b) Threshold frequency $\upsilon_0=\frac{\phi_0}{h}$

$$=\frac{4.2\times1.6\times10^{-19}}{6.6\times10^{-34}}=1.0\times10^{15}\text{Hz}$$

and the frequency of red light from the source is 10^5 W/m^2.

$$\upsilon=\frac{c}{\lambda}=\frac{3\times10^{8}}{6328\times10^{-10}}=4.7\times10^{14}\text{ Hz}$$

Since frequency of red light is less than threshold frequency so photocell will not respond to red light, however high (10^5 W/m^2) be the intensity of light.

26. For one dimensional motion,

$$\vec{p_C}=\vec{p_A}+\vec{p_B}$$

If p_A, $p_B > 0$ or p_A, $p_B < 0$, *i.e.*, p_A and p_B are in same direction).

$p_C = p_A + p_B$

$$\frac{h}{\lambda_C}=\frac{h}{\lambda_A}+\frac{h}{\lambda_B}=h\left(\frac{\lambda_A+\lambda_B}{\lambda_A\lambda_B}\right)$$

$$\lambda_C=\frac{\lambda_A\lambda_B}{\lambda_A+\lambda_B}$$

If $p_A > 0$, $p_B < 0$ or $p_A < 0$, $p_B > 0$

(p_A and p_B are in opposite direction)

$p_C = |p_A - p_B|$

$$\frac{h}{\lambda_C}=\left|\frac{h}{\lambda_A}-\frac{h}{\lambda_B}\right|=\frac{h\,|\lambda_A-\lambda_B|}{\lambda_A\lambda_B}$$

$$\lambda_C=\frac{\lambda_A\lambda_B}{|\lambda_A-\lambda_B|}$$

27. For same accelerating potential, a proton and a deutron have same kinetic energy.

(a) de Broglie wavelength is given by

$$\lambda=\frac{h}{p}=\frac{h}{\sqrt{2\,mK}}=\frac{h}{\sqrt{2m(qV)}}$$

So, $\lambda\propto\frac{1}{\sqrt{m}}$

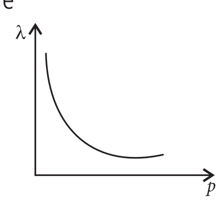
Mass of a deutron is more than that of a proton. So, proton will have greater value of de-Broglie wavelength.

(b) de-Broglie wavelength of a particle

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

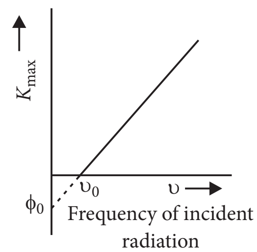
or $\lambda p=h=\text{constant}$

It shows a rectangular hyperbola.



28. Photons : According to Planck's quantum theory of radiation, an electromagnetic wave travels in the form of discrete packets of energy called quanta.

The main features of photons are as follows:



(i) In the interaction of photons with free electrons, the entire energy of photon is absorbed.

(ii) Energy of photon is directly proportional to frequency. Intensity of incident radiation depends on the number of photons falling per unit area per unit time for a given frequency.

(iii) In photon electron collision, the total energy and momentum remain constant.

Einstein's photoelectric equation is

$K_{max} = h\upsilon - \phi_0$

29. Given $\theta = 30°$, $d = 0.1$ nm, $n = 1$

According to Bragg's law,

$2d\sin\theta = n\lambda$

$2 \times 0.1 \times \sin 30° = 1 \times \lambda$

$\lambda = 0.1\text{ nm} = 1 \times 10^{-10}$ m.

As we know $\lambda=\frac{h}{\sqrt{2mE}}$

$$E=\frac{h^2}{2m\lambda^2}=\frac{(6.63\times10^{-34})^2}{2(1.67\times10^{-27})(1\times10^{-10})^2}\text{ J}$$

$$=\frac{(6.63\times10^{-34})^2}{2(1.67\times10^{-27})(1\times10^{-10})^2}\times\frac{1}{1.6\times10^{-19}}\text{ eV}$$

$= 8.2 \times 10^{-2}$ eV

30. Given, $\Delta x = 1\text{ nm} = 1 \times 10^{-9}$m, $\Delta p = ?$

$\Delta x\Delta p = \hbar$

$$\therefore\quad \Delta p=\frac{\hbar}{\Delta x}=\frac{h}{2\pi\Delta x}=\frac{6.62\times10^{-34}\text{ J s}}{2\times\left(\frac{22}{7}\right)\times10^{-9}\text{m}}\qquad\left(\because\ \hbar=\frac{h}{2\pi}\right)$$

$= 1.05 \times 10^{-25}$ kg m s^{-1}

Energy of electron,

$$E=\frac{p^2}{2m}\qquad\text{(Taking }\Delta p\approx p\text{)}$$

$$=\frac{(1.05\times10^{-25})^2}{2\times9.1\times10^{-31}}=0.06\times10^{-19}\text{ J}$$

$$=\frac{0.06\times10^{-19}}{1.6\times10^{-19}}=0.0375\text{ eV}=3.75\times10^{-2}\text{ eV}$$

31. Given, $\lambda = 600$ nm, $\lambda' = 400$ nm

$E'_{max} = 2E_{max}$, $\phi_0 = ?$

$$E_{max} = h\upsilon - \phi_0 = \frac{hc}{\lambda} - \phi_0 \quad \ldots(i)$$

$$2E_{max} = \frac{hc}{\lambda'} - \phi_0 \quad \ldots(ii)$$

Dividing (ii) by (i)

$$\frac{2E_{max}}{E_{max}} = \frac{hc/\lambda' - \phi_0}{hc/\lambda - \phi_0}$$

$$\Rightarrow \frac{2hc}{\lambda} - 2\phi_0 = \frac{hc}{\lambda'} - \phi_0 \Rightarrow hc\left(\frac{2}{\lambda} - \frac{1}{\lambda'}\right) = \phi_0$$

$$\therefore \quad \phi_0 = 1240\left(\frac{2}{600} - \frac{1}{400}\right) = 1.03 \text{ eV}$$

($\because$ $hc = 1240$ eV nm)

32. (a) Two features of Einstein's photoelectric equation:

(a) Below threshold frequency υ_0 corresponding to W_o, no emission of photoelectrons takes place.

(b) As the number of photons in light depend on its intensity, and one photon liberates one photo electron. So number of emitted photoelectrons depend only on the intensity of incident light for a given frequency.

(b) Below threshold frequency no emission takes place. As there is no photoemission from surface P *i.e.*, the frequency of incident radiation is less than the threshold frequency for surface P.

From surface Q photoemission is possible *i.e.*, the frequency of incident radiation is equal or greater than threshold frequency. As the kinetic energy of photo electrons is zero *i.e.*, the energy of incident radiation is just sufficient to pull out the electron from the surface Q.

Work function for surface Q, $W_Q = h\upsilon$.

As K.E. = 0 ; $\upsilon = \upsilon_0 = 10^{15}$ Hz

$W_Q = 6.6 \times 10^{-34} \times 10^{15} = 6.6 \times 10^{-19}$ J = 4.125 eV

33. Given $P = 20$ W, $\lambda = 5000$ Å $= 5 \times 10^{-7}$ m.

$d = 2$ m, $\phi_0 = 2$ eV, $r = 1.5$ Å $= 1.5 \times 10^{-10}$ m.

(i) Number of photons emitted by bulb per second is

$$n = \frac{P}{(hc/\lambda)} = \frac{P\lambda}{hc} = \frac{20 \times 5 \times 10^{-7}}{6.62 \times 10^{-34} \times 3 \times 10^8}$$

$$\approx 5 \times 10^{19} \text{ s}^{-1}$$

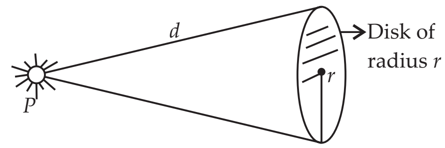
(ii) Energy of incident photon, $E = \dfrac{hc}{\lambda}$

$$= \frac{(6.62 \times 10^{-34})(3 \times 10^8)}{5 \times 10^{-7} \times 1.6 \times 10^{-19}} = 2.48 \text{ eV.}$$

As $E > \phi_0$ (2.48 eV > 2 eV)

hence photoelectric emission will take place.

(iii)



energy emitted by the bulb in time $\Delta t = P\Delta t$

energy falling on the disk *i.e.*,

$$E = \left(\frac{P\Delta t}{4\pi d^2}\right)(\pi r^2) = \left(\frac{Pr^2}{4d^2}\right)\Delta t$$

According to given condition, $E = \phi_0$

$$\therefore \quad \left(\frac{Pr^2}{4d^2}\right)\Delta t = \phi_0$$

$$\Delta t = \frac{4\phi_0 d^2}{Pr^2}$$

$$\Delta t = \frac{(4)(2 \times 1.6 \times 10^{-19})(2)^2}{(20)(1.5 \times 10^{-10})^2} = 11.4 \text{ s}$$

(iv) Number of photons received by atomic disk in time Δt is

$$N = n\left(\frac{\pi r^2}{4\pi d^2}\right) \times \Delta t = \frac{nr^2 \Delta t}{4d^2}$$

$$= \frac{5 \times 10^{19} \times (1.5 \times 10^{-10})^2 \times 11.4}{4(2)^2} = 0.8 \approx 1$$

(v) when $r = 1$ cm $= 1 \times 10^{-2}$ m

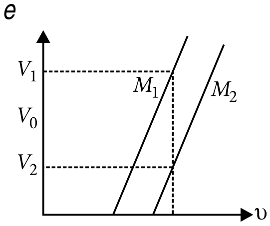
$$\Delta t = \frac{4\phi_0 d^2}{Pr^2}$$

$$\Delta t = \frac{4 \times 2 \times 1.6 \times 10^{-19} \times (2)^2}{20 \times (10^{-2})} = 2.56 \times 10^{-15} \text{ s}$$

Δt is exceedingly small, photo emission is instantaneous.

34. (i) Slope of line $= \dfrac{\Delta V}{\Delta \upsilon}$ $\quad [\because e\Delta V = h\Delta\upsilon]$

Slope of line $= \dfrac{h}{e}$



It is a constant quantity and does not depend on nature of metal surface.

(ii) Maximum kinetic energy of emitted photoelectron,

$KE = eV_0 = h\upsilon - h\upsilon_0$, ...(i)

For a given frequency $V_1 > V_2$ (from the graph)

So from equation (i),

$(KE)_1 > (KE)_2$

Since the metal M_1 has smaller threshold frequency *i.e.*, smaller work function. It emits electrons having a larger kinetic energy.

35. Einstein's photoelectric equation is given below.

$$h\upsilon = \frac{1}{2}mv_{max}^2 + W_0$$

where υ = frequency of incident radiation

$\frac{1}{2}mv_{max}^2$ = maximum kinetic energy of an emitted electron

W_0 = work function of the target metal

Three salient features observed are

(i) Below threshold frequency υ_0 corresponding to W_0, no emission of photoelectrons takes place.

(ii) As energy of a photon depends on the frequency of light, so the maximum kinetic energy with which photoelectron is emitted depends only on the energy of photon or on the frequency of incident radiation.

(iii) For a given frequency of incident radiation, intensity of light depends on the number of photons per unit area per unit time and one photon liberates one photoelectron, so number of photoelectrons emitted depend only on its intensity.

36. Given $d = 10^{-3}$ m, $I = 100 \times 10^{-6}$ A = 10^{-4} A

A = $(10^{-2}\text{ m})^2 = 10^{-4}\text{ m}^2$

Intensity, $I = 100\text{ W m}^{-2}$, $\lambda = 660\text{ nm} = 660 \times 10^{-9}$ m

Volume of 6.02×10^{26} sodium atoms

$$= \frac{23\,\text{kg}}{0.97\,\text{kg/m}^3} = 23.7\text{ m}^3$$

Volume of target = $(10^{-2})(10^{-2})(10^{-3}) = 10^{-7}\text{m}^3$

Number of sodium atoms in the target

$$= \frac{6.02\times10^{26}}{23.7}\times10^{-7} = 2.54\times10^{18}$$

Let n be the number of photons falling per second on the target.

Energy of each photon = $\frac{hc}{\lambda}$

Total energy falling per second on target

$$= \frac{nhc}{\lambda} = IA$$

$$\therefore \quad n = \frac{IA\lambda}{hc} = \frac{100\times10^{-4}\times660\times10^{-9}}{(6.62\times10^{-34})\times(3\times10^8)} = 3.3 \times 10^{16}$$

Number of electrons emitted per second by all the atoms in the target if one electron is emitted by each atom for one incident photon.

$$= (2.54 \times 10^{18})(3.3 \times 10^{16}) = 8.4 \times 10^{34}$$

Expected photocurrent

$$= (8.4 \times 10^{34})(1.6 \times 10^{-19}) = 1.34 \times 10^{16}\text{A}$$

Observed photocurrent = 100 μA

Probability of photo emission by single photon incident on a single atom

$$P = \frac{100\,\mu\text{A}}{1.34\times10^{16}\text{ A}} = 7.5\times10^{-21}$$

Thus the probability of emission by single photon on a single atom is very much less than 1, the probability of absorption of two photons by single atoms is negligible.

37. From the law of conservation of momentum,

$m_A v = m_A v_A + m_B v_B$

or $\quad m_A(v - v_A) = m_B v_B \qquad \text{...(i)}$

(as particle B is at rest, its initial velocity is zero and v_A and v_B are the velocities of particles A and B after collision)

Since the collision is elastic, kinetic energy is conserved during collision

$$\therefore \quad \frac{1}{2}m_A v^2 = \frac{1}{2}m_A v_A^2 + \frac{1}{2}m_B v_B^2$$

$$m_A(v^2 - v_A^2) = m_B v_B^2 \qquad \text{...(ii)}$$

Dividing eqn. (ii) by eqn. (i), we obtain

$$\frac{m_A(v^2 - v_A^2)}{m_A(v - v_A)} = \frac{m_B v_B^2}{m_B v_B}$$

or $\quad v + v_A = v_B \qquad \text{...(iii)}$

From eqns. (i) and (iii),

$m_A(v - v_A) = m_B(v + v_A)$

or $\quad (m_A - m_B)v = (m_A + m_B)v_A$

$$\text{or} \quad \frac{v}{v_A} = \left(\frac{m_A + m_B}{m_A - m_B}\right) \qquad \text{...(iv)}$$

Initial wavelength of the particle A, *i.e.*, $(\lambda_A)_i$

$$= \frac{h}{m_A v}$$

Final wavelength of the particle B, *i.e.*, $(\lambda_A)_f$

$$= \frac{h}{m_A v_A}$$

Change in wavelength,

$$\Delta\lambda = (\lambda_A)_f - (\lambda_A)_i = \frac{h}{m_A v_A} - \frac{h}{m_A v}$$

$$\text{or} \quad \Delta\lambda = \frac{h}{m_A v}\left[\frac{v}{v_A} - 1\right] \qquad \text{...(v)}$$

From eqns. (iv) and (v),

$$\Delta\lambda = \frac{h}{m_A v}\left[\left(\frac{m_A + m_B}{m_A - m_B}\right) - 1\right]$$

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