13. *Light described at a place by the equation* $E = (100\ \text{V/m})\ [\sin(5 \times 10^{15}\ \text{s}^{-1})t + \sin(8 \times 10^{15}\ \text{s}^{-1})t]$ *falls on a metal surface having work function 2·0 eV. Calculate the maximum kinetic energy of the photoelectrons.*

Solution : The light contains two different frequencies. The one with larger frequency will cause photoelectrons with largest kinetic energy. This larger frequency is

$$\nu = \frac{\omega}{2\pi} = \frac{8 \times 10^{15}\ \text{s}^{-1}}{2\pi}$$

The maximum kinetic energy of the photoelectrons is

$$K_{max} = h\nu - \varphi$$

$$= (4{\cdot}14 \times 10^{-15}\ \text{eV-s}) \times \left(\frac{8 \times 10^{15}}{2\pi}\ \text{s}^{-1}\right) - 2{\cdot}0\ \text{eV}$$

$$= 5{\cdot}27\ \text{eV} - 2{\cdot}0\ \text{eV} = 3{\cdot}27\ \text{eV}.$$

QUESTIONS FOR SHORT ANSWER

1. Can we find the mass of a photon by the definition $p = mv$?
2. Is it always true that for two sources of equal intensity, the number of photons emitted in a given time are equal ?
3. What is the speed of a photon with respect to another photon if (a) the two photons are going in the same direction and (b) they are going in opposite directions ?
4. Can a photon be deflected by an electric field ? By a magnetic field ?
5. A hot body is placed in a closed room maintained at a lower temperature. Is the number of photons in the room increasing ?
6. Should the energy of a photon be called its kinetic energy or its internal energy ?
7. In an experiment on photoelectric effect, a photon is incident on an electron from one direction and the photoelectron is emitted almost in the opposite direction. Does this violate conservation of momentum ?
8. It is found that yellow light does not eject photoelectrons from a metal. Is it advisable to try with orange light ? With green light ?
9. It is found that photosynthesis starts in certain plants when exposed to the sunlight but it does not start if the plant is exposed only to infrared light. Explain.
10. The threshold wavelength of a metal is λ_0. Light of wavelength slightly less than λ_0 is incident on an insulated plate made of this metal. It is found that photoelectrons are emitted for sometime and after that the emission stops. Explain.
11. Is $p = E/c$ valid for electrons ?
12. Consider the de Broglie wavelength of an electron and a proton. Which wavelength is smaller if the two particles have (a) the same speed (b) the same momentum (c) the same energy ?
13. If an electron has a wavelength, does it also have a colour ?

OBJECTIVE I

1. Planck constant has the same dimensions as
   (a) force × time (b) force × distance
   (c) force × speed (d) force × distance × time.
2. Two photons having
   (a) equal wavelengths have equal linear momenta
   (b) equal energies have equal linear momenta
   (c) equal frequencies have equal linear momenta
   (d) equal linear momenta have equal wavelengths.
3. Let p and E denote the linear momentum and energy of a photon. If the wavelength is decreased,
   (a) both p and E increase
   (b) p increases and E decreases
   (c) p decreases and E increases
   (d) both p and E decrease.
4. Let n_r and n_b be respectively the number of photons emitted by a red bulb and a blue bulb of equal power in a given time.
   (a) $n_r = n_b$. (b) $n_r < n_b$. (c) $n_r > n_b$.
   (d) The information is insufficient to get a relation between n_r and n_b.
5. The equation $E = pc$ is valid
   (a) for an electron as well as for a photon
   (b) for an electron but not for a photon
   (c) for a photon but not for an electron
   (d) neither for an electron nor for a photon.
6. The work function of a metal is $h\nu_0$. Light of frequency ν falls on this metal. The photoelectric effect will take place only if
   (a) $\nu \geq \nu_0$ (b) $\nu > 2\nu_0$ (c) $\nu < \nu_0$ (d) $\nu < \nu_0/2$.
7. Light of wavelength λ falls on a metal having work function hc/λ_0. Photoelectric effect will take place only if
   (a) $\lambda \geq \lambda_0$ (b) $\lambda \geq 2\lambda_0$ (c) $\lambda < \lambda_0$ (d) $\lambda < \lambda_0/2$.

8. When stopping potential is applied in an experiment on photoelectric effect, no photocurrent is observed. This means that
(a) the emission of photoelectrons is stopped
(b) the photoelectrons are emitted but are reabsorbed by the emitter metal
(c) the photoelectrons are accumulated near the collector plate
(d) the photoelectrons are dispersed from the sides of the apparatus.

9. If the frequency of light in a photoelectric experiment is doubled, the stopping potential will
(a) be doubled (b) be halved
(c) become more than double
(d) become less than double.

10. The frequency and intensity of a light source are both doubled. Consider the following statements.
(A) The saturation photocurrent remains almost the same.
(B) The maximum kinetic energy of the photoelectrons is doubled.
(a) Both A and B are true. (b) A is true but B is false.
(c) A is false but B is true. (d) Both A and B are false.

11. A point source of light is used in a photoelectric effect. If the source is removed farther from the emitting metal, the stopping potential
(a) will increase (b) will decrease
(c) will remain constant
(d) will either increase or decrease.

12. A point source causes photoelectric effect from a small metal plate. Which of the following curves may represent the saturation photocurrent as a function of the distance between the source and the metal ?

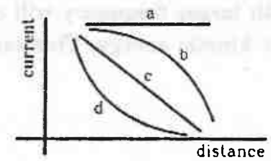


Figure 42-Q1

13. A nonmonochromatic light is used in an experiment on photoelectric effect. The stopping potential
(a) is related to the mean wavelength
(b) is related to the longest wavelength
(c) is related to the shortest wavelength
(d) is not related to the wavelength.

14. A proton and an electron are accelerated by the same potential difference. Let λ_e and λ_p denote the de Broglie wavelengths of the electron and the proton respectively.
(a) $\lambda_e = \lambda_p$. (b) $\lambda_e < \lambda_p$. (c) $\lambda_e > \lambda_p$.
(d) The relation between λ_e and λ_p depends on the accelerating potential difference.

OBJECTIVE II

1. When the intensity of a light source is increased,
(a) the number of photons emitted by the source in unit time increases
(b) the total energy of the photons emitted per unit time increases
(c) more energetic photons are emitted
(d) faster photons are emitted.

2. Photoelectric effect supports quantum nature of light because
(a) there is a minimum frequency below which no photoelectrons are emitted
(b) the maximum kinetic energy of photoelectrons 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.

3. A photon of energy $h\nu$ is absorbed by a free electron of a metal having work function $\varphi < h\nu$.
(a) The electron is sure to come out.
(b) The electron is sure to come out with a kinetic energy $h\nu - \varphi$.
(c) Either the electron does not come out or it comes out with a kinetic energy $h\nu - \varphi$.
(d) It may come out with a kinetic energy less than $h\nu - \varphi$.

4. If the wavelength of light in an experiment on photoelectric effect is doubled,
(a) the photoelectric emission will not take place
(b) the photoelectric emission may or may not take place
(c) the stopping potential will increase
(d) the stopping potential will decrease.

5. The photocurrent in an experiment on photoelectric effect increases if
(a) the intensity of the source is increased
(b) the exposure time is increased
(c) the intensity of the source is decreased
(d) the exposure time is decreased.

6. The collector plate in an experiment on photoelectric effect is kept vertically above the emitter plate. Light source is put on and a saturation photocurrent is recorded. An electric field is switched on which has a vertically downward direction.
(a) The photocurrent will increase.
(b) The kinetic energy of the electrons will increase.
(c) The stopping potential will decrease.
(d) The threshold wavelength will increase.

7. In which of the following situations the heavier of the two particles has smaller de Broglie wavelength ? The two particles
(a) move with the same speed
(b) move with the same linear momentum
(c) move with the same kinetic energy
(d) have fallen through the same height.

EXERCISES

Use $h = 6{\cdot}63 \times 10^{-34}$ J-s $= 4{\cdot}14 \times 10^{-15}$ eV-s, $c = 3 \times 10^{8}$ m/s and $m_e = 9{\cdot}1 \times 10^{-31}$ kg wherever needed.

1. Visible light has wavelengths in the range of 400 nm to 780 nm. Calculate the range of energy of the photons of visible light.
2. Calculate the momentum of a photon of light of wavelength 500 nm.
3. An atom absorbs a photon of wavelength 500 nm and emits another photon of wavelength 700 nm. Find the net energy absorbed by the atom in the process.
4. Calculate the number of photons emitted per second by a 10 W sodium vapour lamp. Assume that 60% of the consumed energy is converted into light. Wavelength of sodium light = 590 nm.
5. When the sun is directly overhead, the surface of the earth receives $1{\cdot}4 \times 10^{3}$ W/m^2 of sunlight. Assume that the light is monochromatic with average wavelength 500 nm and that no light is absorbed in between the sun and the earth's surface. The distance between the sun and the earth is $1{\cdot}5 \times 10^{11}$ m. (a) Calculate the number of photons falling per second on each square metre of earth's surface directly below the sun. (b) How many photons are there in each cubic metre near the earth's surface at any instant? (c) How many photons does the sun emit per second?
6. A parallel beam of monochromatic light of wavelength 663 nm is incident on a totally reflecting plane mirror. The angle of incidence is 60° and the number of photons striking the mirror per second is $1{\cdot}0 \times 10^{19}$. Calculate the force exerted by the light beam on the mirror.
7. A beam of white light is incident normally on a plane surface absorbing 70% of the light and reflecting the rest. If the incident beam carries 10 W of power, find the force exerted by it on the surface.
8. A totally reflecting, small plane mirror placed horizontally faces a parallel beam of light as shown in figure (42-E1). The mass of the mirror is 20 g. Assume that there is no absorption in the lens and that 30% of the light emitted by the source goes through the lens. Find the power of the source needed to support the weight of the mirror. Take $g = 10$ m/s^2.

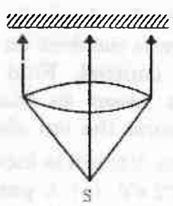


Figure 42-E1

9. A 100 W light bulb is placed at the centre of a spherical chamber of radius 20 cm. Assume that 60% of the energy supplied to the bulb is converted into light and that the surface of the chamber is perfectly absorbing. Find the pressure exerted by the light on the surface of the chamber.
10. A sphere of radius 1·00 cm is placed in the path of a parallel beam of light of large aperture. The intensity of the light is 0·50 W/cm^2. If the sphere completely absorbs the radiation falling on it, find the force exerted by the light beam on the sphere.
11. Consider the situation described in the previous problem. Show that the force on the sphere due to the light falling on it is the same even if the sphere is not perfectly absorbing.
12. Show that it is not possible for a photon to be completely absorbed by a free electron.
13. Two neutral particles are kept 1 m apart. Suppose by some mechanism some charge is transferred from one particle to the other and the electric potential energy lost is completely converted into a photon. Calculate the longest and the next smaller wavelength of the photon possible.
14. Find the maximum kinetic energy of the photoelectrons ejected when light of wavelength 350 nm is incident on a cesium surface. Work function of cesium = 1·9 eV.
15. The work function of a metal is $2{\cdot}5 \times 10^{-19}$ J. (a) Find the threshold frequency for photoelectric emission. (b) If the metal is exposed to a light beam of frequency $6{\cdot}0 \times 10^{14}$ Hz, what will be the stopping potential?
16. The work function of a photoelectric material is 4·0 eV. (a) What is the threshold wavelength? (b) Find the wavelength of light for which the stopping potential is 2·5 V.
17. Find the maximum magnitude of the linear momentum of a photoelectron emitted when light of wavelength 400 nm falls on a metal having work function 2·5 eV.
18. When a metal plate is exposed to a monochromatic beam of light of wavelength 400 nm, a negative potential of 1·1 V is needed to stop the photocurrent. Find the threshold wavelength for the metal.
19. In an experiment on photoelectric effect, the stopping potential is measured for monochromatic light beams corresponding to different wavelengths. The data collected are as follows:

wavelength (nm):	350	400	450	500	550
stopping potential(V):	1·45	1·00	0·66	0·38	0·16

Plot the stopping potential against inverse of wavelength ($1/\lambda$) on a graph paper and find (a) the Planck constant, (b) the work function of the emitter and (c) the threshold wavelength.

20. The electric field associated with a monochromatic beam becomes zero $1{\cdot}2 \times 10^{15}$ times per second. Find the maximum kinetic energy of the photoelectrons when this light falls on a metal surface whose work function is 2·0 eV.
21. The electric field associated with a light wave is given by
$$E = E_0 \sin[(1{\cdot}57 \times 10^{7}\ \text{m}^{-1})(x - ct)].$$
Find the stopping potential when this light is used in

an experiment on photoelectric effect with the emitter having work function 1·9 eV.

22. The electric field at a point associated with a light wave is $E = (100\ V/m) \sin[(3{\cdot}0 \times 10^{15}\ s^{-1})t] \sin[(6{\cdot}0 \times 10^{15}\ s^{-1})t]$. 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 ?

23. A monochromatic light source of intensity 5 mW emits 8×10^{15} photons per second. This light ejects photoelectrons from a metal surface. The stopping potential for this setup is 2·0 V. Calculate the work function of the metal.

24. Figure (42-E2) is the plot of the stopping potential versus the frequency of the light used in an experiment on photoelectric effect. Find (a) the ratio h/e and (b) the work function.

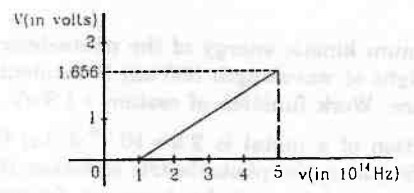


Figure 42-E2

25. A photographic film is coated with a silver bromide layer. When light falls on this film, silver bromide molecules dissociate and the film records the light there. A minimum of 0·6 eV is needed to dissociate a silver bromide molecule. Find the maximum wavelength of light that can be recorded by the film.

26. In an experiment on photoelectric effect, light of wavelength 400 nm 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 out of every 10^6 photons is able to eject a photoelectron, find the photocurrent in the circuit.

27. A silver ball of radius 4·8 cm is suspended by a thread in a vacuum chamber. Ultraviolet light of wavelength 200 nm is incident on the ball for some time during which a total light energy of $1{\cdot}0 \times 10^{-7}$ J falls on the surface. Assuming that on the average one photon out of every ten thousand is able to eject a photoelectron, find the electric potential at the surface of the ball assuming zero potential at infinity. What is the potential at the centre of the ball ?

28. In an experiment on photoelectric effect, the emitter and the collector plates are placed at a separation of 10 cm and are connected through an ammeter without any cell

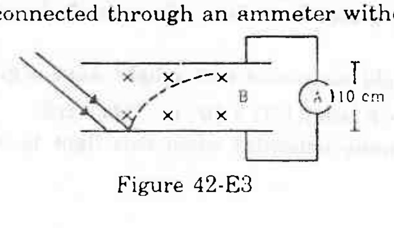


Figure 42-E3

(figure 42-E3). A magnetic field B exists parallel to the plates. The work function of the emitter is 2·39 eV and the light incident on it has wavelengths between 400 nm and 600 nm. Find the minimum value of B for which the current registered by the ammeter is zero. Neglect any effect of space charge.

29. In the arrangement shown in figure (42-E4), $y = 1{\cdot}0$ mm, $d = 0{\cdot}24$ mm and $D = 1{\cdot}2$ m. The work function of the material of the emitter is 2·2 eV. Find the stopping potential V needed to stop the photocurrent.

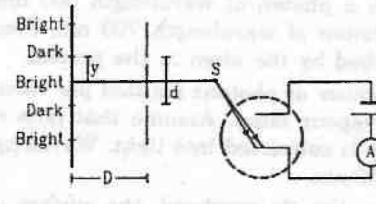


Figure 42-E4

30. In a photoelectric experiment, the collector plate is at 2·0 V with respect to the emitter plate made of copper ($\varphi = 4{\cdot}5$ eV). The emitter is illuminated by a source of monochromatic light of wavelength 200 nm. Find the minimum and maximum kinetic energy of the photoelectrons reaching the collector.

31. A small piece of cesium metal ($\varphi = 1{\cdot}9$ eV) is kept at a distance of 20 cm from a large metal plate having a charge density of $1{\cdot}0 \times 10^{-9}\ C/m^2$ on the surface facing the cesium piece. A monochromatic light of wavelength 400 nm is incident on the cesium piece. Find the minimum and the maximum kinetic energy of the photoelectrons reaching the large metal plate. Neglect any change in electric field due to the small piece of cesium present.

32. Consider the situation of the previous problem. Consider the fastest electron emitted parallel to the large metal plate. Find the displacement of this electron parallel to its initial velocity before it strikes the large metal plate.

33. A horizontal cesium plate ($\varphi = 1{\cdot}9$ eV) is moved vertically downward at a constant speed v in a room full of radiation of wavelength 250 nm and above. What should be the minimum value of v so that the vertically upward component of velocity is nonpositive for each photoelectron ?

34. A small metal plate (work function φ) is kept at a distance d from a singly ionized, fixed ion. A monochromatic light beam is incident on the metal plate and photoelectrons are emitted. Find the maximum wavelength of the light beam so that some of the photoelectrons may go round the ion along a circle.

35. A light beam of wavelength 400 nm is incident on a metal plate of work function 2·2 eV. (a) A particular electron absorbs a photon and makes two collisions before coming out of the metal. Assuming that 10% of the extra energy is lost to the metal in each collision, find the kinetic energy of this electron as it comes out of the metal. (b) Under the same assumptions, find the maximum number of collisions the electron can suffer before it becomes unable to come out of the metal.

□

ANSWERS

OBJECTIVE I

1. (d)	2. (d)	3. (a)	4. (c)	5. (c)	6. (a)
7. (c)	8. (b)	9. (c)	10. (b)	11. (c)	12. (d)
13. (c)	14. (c)				

OBJECTIVE II

1. (a), (b)	2. (a), (b), (c)	3. (d)
4. (b), (d)	5. (a)	6. (b)
7. (a), (c), (d)		

EXERCISES

1. 2.56×10^{-19} J to 5.00×10^{-19} J
2. 1.33×10^{-27} kg-m/s
3. 1.1×10^{-19} J
4. 1.77×10^{19}
5. (a) 3.5×10^{21} (b) 1.2×10^{13} (c) 9.9×10^{44}
6. 1.0×10^{-8} N
7. 4.3×10^{-8} N
8. 100 MW
9. 4.0×10^{-7} Pa
10. 5.2×10^{-9} N
13. 860 m, 215 m
14. 1.6 eV
15. (a) 3.8×10^{14} Hz (b) 0.91 V
16. (a) 310 nm (b) 190 nm
17. 4.2×10^{-25} kg-m/s
18. 620 nm
19. (a) 4.2×10^{-15} eV-s (b) 2.15 eV (c) 585 nm
20. 0.48 eV
21. 1.2 V
22. 3.93 eV
23. 1.9 eV
24. (a) 4.14×10^{-15} V-s (b) 0.414 eV
25. 2070 nm
26. 1.6 μA
27. 0.3 V in each case
28. 2.85×10^{-5} T
29. 0.9 V
30. 2.0 eV, 3.7 eV
31. 22.6 eV, 23.8 eV
32. 9.2 cm
33. 1.04×10^{6} m/s
34. $\dfrac{8\pi\varepsilon_0 dhc}{e^2 + 8\pi\varepsilon_0 \varphi d}$
35. (a) 0.31 eV (b) 4

PHOTO ELECTRIC EFFECT AND WAVE PARTICLE QUALITY
CHAPTER 42

1. λ_1 = 400 nm to λ_2 = 780 nm

$E = h\nu = \frac{hc}{\lambda}$ h = 6.63 × 10^{-34} j - s, c = 3 × 10^8 m/s, λ_1 = 400 nm, λ_2 = 780 nm

$E_1 = \frac{6.63\times10^{-34}\times3\times10^8}{400\times10^{-9}} = \frac{6.63\times3}{4}\times10^{-19} = 5\times10^{-19}$ J

$E_2 = \frac{6.63\times3}{7.8}\times10^{-19} = 2.55\times10^{-19}$ J

So, the range is 5 × 10^{-19} J to 2.55 × 10^{-19} J.

2. λ = h/p

$\Rightarrow$ P = h/λ = $\frac{6.63\times10^{-34}}{500\times10^{-9}}$ J-S = 1.326 × 10^{-27} = 1.33 × 10^{-27} kg – m/s.

3. λ_1 = 500 nm = 500 × 10^{-9}m, λ_2 = 700 nm = 700 × 10^{-9} m

$E_1 - E_2$ = Energy absorbed by the atom in the process. = hc [$1/\lambda_1 - 1/\lambda_2$]

$\Rightarrow$ 6.63 × 3[1/5 – 1/7] × 10^{-19} = 1.136 × 10^{-19} J

4. P = 10 W ∴ E in 1 sec = 10 J % used to convert into photon = 60%

∴Energy used = 6 J

Energy used to take out 1 photon = hc/λ = $\frac{6.63\times10^{-34}\times3\times10^8}{590\times10^{-9}} = \frac{6.633}{590}\times10^{-17}$

No. of photons used = $\frac{6}{\frac{6.63\times3}{590}\times10^{-17}} = \frac{6\times590}{6.63\times3}\times10^{17} = 176.9\times10^{17}$ = 1.77 × 10^{19}

5. a) Here intensity = I = 1.4 × 10^3 ω/m^2 Intensity, I = $\frac{\text{power}}{\text{area}}$ = 1.4 × 10^3 ω/m^2

Let no.of photons/sec emitted = n ∴ Power = Energy emitted/sec = nhc/λ = P

No.of photons/m^2 = nhc/λ = intensity

$n = \frac{\text{int ensity}\times\lambda}{hc} = \frac{1.9\times10^3\times5\times10^{-9}}{6.63\times10^{-34}\times3\times10^8} = 3.5\times10^{21}$

b) Consider no.of two parts at a distance r and r + dr from the source.

The time interval 'dt' in which the photon travel from one point to another = dv/e = dt.

In this time the total no.of photons emitted = N = n dt = $\left(\frac{p\lambda}{hc}\right)\frac{dr}{C}$

These points will be present between two spherical shells of radii 'r' and r+dr. It is the distance of the 1st point from the sources. No.of photons per volume in the shell

(r + r + dr) = $\frac{N}{2\pi r2dr} = \frac{P\lambda dr}{hc^2} = \frac{1}{4\pi r^2ch} = \frac{p\lambda}{4\pi hc^2r^2}$

In the case = 1.5 × 10^{11} m, λ = 500 nm, = 500 × 10^{-9} m

$\frac{P}{4\pi r^2} = 1.4\times10^3$, ∴ No.of photons/$m^3$ = $\frac{P}{4\pi r^2}\frac{\lambda}{hc^2}$

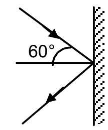
= 1.4 × 10^3 × $\frac{500\times10^{-9}}{6.63\times10^{-34}\times3\times10^8} = 1.2\times10^{13}$

c) No.of photons = (No.of photons/sec/m^2) × Area

= (3.5 × 10^{21}) × $4\pi r^2$

= 3.5 × 10^{21} × 4(3.14)(1.5 × 10^{11})^2 = 9.9 × 10^{44}.

6. $\lambda = 663 \times 10^{-9}$ m, $\theta = 60°$, n = 1×10^{19}, $\lambda = h/p$



$\Rightarrow P = p/\lambda = 10^{-27}$

Force exerted on the wall = n(mv cos θ –(–mv cos θ)) = 2n mv cos θ.

$= 2 \times 1 \times 10^{19} \times 10^{-27} \times ½ = 1 \times 10^{-8}$ N.

7. Power = 10 W P → Momentum

$\lambda = \frac{h}{p}$ or, $P = \frac{h}{\lambda}$ or, $\frac{P}{t} = \frac{h}{\lambda t}$

$E = \frac{hc}{\lambda}$ or, $\frac{E}{t} = \frac{hc}{\lambda t}$ = Power (W)

W = Pc/t or, P/t = W/c = force.

or Force = 7/10 (absorbed) + 2 × 3/10 (reflected)

$= \frac{7}{10} \times \frac{W}{C} + 2 \times \frac{3}{10} \times \frac{W}{C} \Rightarrow \frac{7}{10} \times \frac{10}{3 \times 10^8} + 2 \times \frac{3}{10} \times \frac{10}{3 \times 10^8}$

$= 13/3 \times 10^{-8} = 4.33 \times 10^{-8}$ N.

8. m = 20 g

The weight of the mirror is balanced. Thus force exerted by the photons is equal to weight

$P = \frac{h}{\lambda}$ $E = \frac{hc}{\lambda} = PC$

$\Rightarrow \frac{E}{t} = \frac{P}{t} C$

⇒ Rate of change of momentum = Power/C

30% of light passes through the lens.

Thus it exerts force. 70% is reflected.

∴ Force exerted = 2(rate of change of momentum)

= 2 × Power/C

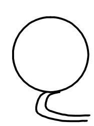
$$30\% \left(\frac{2 \times \text{Power}}{C} \right) = mg$$

$$\Rightarrow \text{Power} = \frac{20 \times 10^{-3} \times 10 \times 3 \times 10^8 \times 10}{2 \times 3} = 10 \text{ w} = 100 \text{ MW}.$$

9. Power = 100 W

Radius = 20 cm

60% is converted to light = 60 w



Now, Force $= \frac{\text{power}}{\text{velocity}} = \frac{60}{3 \times 10^8} = 2 \times 10^{-7}$ N.

Pressure $= \frac{\text{force}}{\text{area}} = \frac{2 \times 10^{-7}}{4 \times 3.14 \times (0.2)^2} = \frac{1}{8 \times 3.14} \times 10^{-5}$

$= 0.039 \times 10^{-5} = 3.9 \times 10^{-7} = 4 \times 10^{-7}$ N/m^2.

10. We know,

If a perfectly reflecting solid sphere of radius 'r' is kept in the path of a parallel beam of light of large aperture if intensity is I,

Force $= \frac{\pi r^2 I}{C}$

I = 0.5 W/m^2, r = 1 cm, C = 3×10^8 m/s

Force $= \frac{\pi \times (1)^2 \times 0.5}{3 \times 10^8} = \frac{3.14 \times 0.5}{3 \times 10^8}$

$= 0.523 \times 10^{-8} = 5.2 \times 10^{-9}$ N.

11. For a perfectly reflecting solid sphere of radius 'r' kept in the path of a parallel beam of light of large aperture with intensity 'I', force exerted = $\frac{\pi r^2 I}{C}$

12. If the i undergoes an elastic collision with a photon. Then applying energy conservation to this collision. We get, $hC/\lambda + m_0c^2 = mc^2$
and applying conservation of momentum $h/\lambda = mv$
Mass of e = m = $\frac{m_0}{\sqrt{1-v^2/c^2}}$
from above equation it can be easily shown that
V = C or V = 0
both of these results have no physical meaning hence it is not possible for a photon to be completely absorbed by a free electron.

13. r = 1 m
Energy = $\frac{kq^2}{R} = \frac{kq^2}{1}$
Now, $\frac{kq^2}{1} = \frac{hc}{\lambda}$ or $\lambda = \frac{hc}{kq^2}$
For max 'λ', 'q' should be min,
For minimum 'e' = 1.6×10^{-19} C
Max $\lambda = \frac{hc}{kq^2} = 0.863 \times 10^3 = 863$ m.
For next smaller wavelength = $\frac{6.63 \times 3 \times 10^{-34} \times 10^8}{9 \times 10^9 \times (1.6 \times 2)^2 \times 10^{-38}} = \frac{863}{4}$ = 215.74 m

14. λ = 350 nn = 350×10^{-9} m
ϕ = 1.9 eV
Max KE of electrons = $\frac{hC}{\lambda} - \phi = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{350 \times 10^{-9} \times 1.6 \times 10^{-19}} - 1.9$
= 1.65 ev = 1.6 ev.

15. $W_0 = 2.5 \times 10^{-19}$ J
a) We know $W_0 = h\nu_0$
$\nu_0 = \frac{W_0}{h} = \frac{2.5 \times 10^{-19}}{6.63 \times 10^{-34}}$ = 3.77×10^{14} Hz = 3.8×10^{14} Hz
b) $eV_0 = h\nu - W_0$
or, $V_0 = \frac{h\nu - W_0}{e} = \frac{6.63 \times 10^{-34} \times 6 \times 10^{14} - 2.5 \times 10^{-19}}{1.6 \times 10^{-19}}$ = 0.91 V

16. $\phi = 4$ eV $= 4 \times 1.6 \times 10^{-19}$ J
a) Threshold wavelength = λ
$\phi = hc/\lambda$
$\Rightarrow \lambda = \frac{hC}{\phi} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{4 \times 1.6 \times 10^{-19}} = \frac{6.63 \times 3}{6.4} \times \frac{10^{-27}}{10^{-9}} = 3.1 \times 10^{-7}\,\text{m}$ = 310 nm.
b) Stopping potential is 2.5 V
$E = \phi + eV$
$\Rightarrow hc/\lambda = 4 \times 1.6 \times 10^{-19} + 1.6 \times 10^{-19} \times 2.5$
$\Rightarrow \lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{\lambda \times 1.6 \times 10^{-19}}$ = 4 + 2.5
$\Rightarrow \frac{6.63 \times 3 \times 10^{-26}}{1.6 \times 10^{-19} \times 6.5}$ = 1.9125×10^{-7} = 190 nm.

17. Energy of photoelectron

$\Rightarrow$ ½ $mv^2 = \frac{hc}{\lambda} - hv_0 = \frac{4.14 \times 10^{-15} \times 3 \times 10^8}{4 \times 10^{-7}} - 2.5ev$ = 0.605 ev.

We know KE = $\frac{P^2}{2m} \Rightarrow P^2 = 2m \times KE$.

$P^2 = 2 \times 9.1 \times 10^{-31} \times 0.605 \times 1.6 \times 10^{-19}$

$P = 4.197 \times 10^{-25}$ kg – m/s

18. $\lambda = 400$ nm $= 400 \times 10^{-9}$ m

$V_0 = 1.1$ V

$\frac{hc}{\lambda} = \frac{hc}{\lambda_0} + ev_0$

$\Rightarrow \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{400 \times 10^{-9}} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{\lambda_0} + 1.6 \times 10^{-19} \times 1.1$

$\Rightarrow 4.97 = \frac{19.89 \times 10^{-26}}{\lambda_0} + 1.76$

$\Rightarrow \frac{19.89 \times 10^{-26}}{\lambda_0} = 4.97 - 17.6 = 3.21$

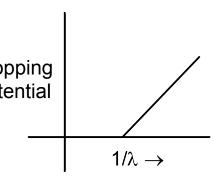
$\Rightarrow \lambda_0 = \frac{19.89 \times 10^{-26}}{3.21} = 6.196 \times 10^{-7}$ m = 620 nm.

19. a) When $\lambda = 350$, $V_s = 1.45$

and when $\lambda = 400$, $V_s = 1$

$\therefore \frac{hc}{350} = W + 1.45$ …(1)

and $\frac{hc}{400} = W + 1$ …(2)



Subtracting (2) from (1) and solving to get the value of h we get

$h = 4.2 \times 10^{-15}$ ev-sec

b) Now work function = $w = \frac{hc}{\lambda}$ = ev - s

$= \frac{1240}{350} - 1.45$ = 2.15 ev.

c) $w = \frac{hc}{\lambda} = \lambda_{\text{there cathod}} = \frac{hc}{w}$

$= \frac{1240}{2.15}$ = 576.8 nm.

20. The electric field becomes 0 1.2×10^{45} times per second.

$\therefore$ Frequency = $\frac{1.2 \times 10^{15}}{2} = 0.6 \times 10^{15}$

$h\nu = \phi_0 + kE$

$\Rightarrow h\nu - \phi_0 = KE$

$\Rightarrow KE = \frac{6.63 \times 10^{-34} \times 0.6 \times 10^{15}}{1.6 \times 10^{-19}} - 2$

= 0.482 ev = 0.48 ev.

21. $E = E_0 \sin[(1.57 \times 10^7 \text{ m}^{-1})(x - ct)]$

$W = 1.57 \times 10^7 \times C$

$\Rightarrow$ f = $\dfrac{1.57 \times 10^7 \times 3 \times 10^8}{2\pi}$ Hz $\qquad W_0$ = 1.9 ev

Now $eV_0 = h\nu - W_0$

$= 4.14 \times 10^{-15} \times \dfrac{1.57 \times 3 \times 10^{15}}{2\pi} - 1.9$ ev

= 3.105 – 1.9 = 1.205 ev

So, $V_0 = \dfrac{1.205 \times 1.6 \times 10^{-19}}{1.6 \times 10^{-19}}$ = 1.205 V.

22. E $= 100 \sin[(3 \times 10^{15}\ s^{-1})t] \sin[6 \times 10^{15}\ s^{-1})t]$

$= 100\ ½\ [\cos[(9 \times 10^{15}\ s^{-1})t] - \cos[3 \times 10^{15}\ s^{-1})t]$

The w are 9×10^{15} and 3×10^{15}

for largest K.E.

$f_{max} = \dfrac{w_{max}}{2\pi} = \dfrac{9 \times 10^{15}}{2\pi}$

$E - \phi_0$ = K.E.

$\Rightarrow hf - \phi_0$ = K.E.

$\Rightarrow \dfrac{6.63 \times 10^{-34} \times 9 \times 10^{15}}{2\pi \times 1.6 \times 10^{-19}} - 2 = KE$

$\Rightarrow$ KE = 3.938 ev = 3.93 ev.

23. $W_0 = hv - ev_0$

$= \dfrac{5 \times 10^{-3}}{8 \times 10^{15}} - 1.6 \times 10^{-19} \times 2$ (Given V_0 = 2V, No. of photons = 8×10^{15}, Power = 5 mW)

$= 6.25 \times 10^{-19} - 3.2 \times 10^{-19} = 3.05 \times 10^{-19}$ J

$= \dfrac{3.05 \times 10^{-19}}{1.6 \times 10^{-19}}$ = 1.906 eV.

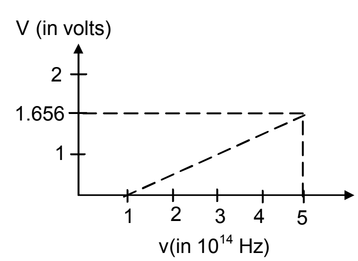
24. We have to take two cases :

Case I … v_0 = 1.656

$\nu = 5 \times 10^{14}$ Hz

Case II… v_0 = 0

$\nu = 1 \times 10^{14}$ Hz



We know ;

a) $ev_0 = h\nu - w_0$

$1.656e = h \times 5 \times 10^{14} - w_0$ …(1)

$0 = 5h \times 10^{14} - 5w_0$ …(2)

$1.656e = 4w_0$

$\Rightarrow w_0 = \dfrac{1.656}{4}$ ev = 0.414 ev

b) Putting value of w_0 in equation (2)

$\Rightarrow 5w_0 = 5h \times 10^{14}$

$\Rightarrow 5 \times 0.414 = 5 \times h \times 10^{14}$

$\Rightarrow h = 4.414 \times 10^{-15}$ ev-s

25. w_0 = 0.6 ev

For w_0 to be min 'λ' becomes maximum.

$w_0 = \dfrac{hc}{\lambda}$ or $\lambda = \dfrac{hc}{w_0} = \dfrac{6.63 \times 10^{-34} \times 3 \times 10^8}{0.6 \times 1.6 \times 10^{-19}}$

$= 20.71 \times 10^{-7}$ m = 2071 nm

26. λ = 400 nm, P = 5 w

E of 1 photon = $\frac{hc}{\lambda} = \left(\frac{1242}{400}\right)$ ev

No.of electrons = $\frac{5}{\text{Energy of 1 photon}} = \frac{5 \times 400}{1.6 \times 10^{-19} \times 1242}$

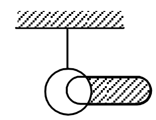
No.of electrons = 1 per 10^6 photon.

No.of photoelectrons emitted = $\frac{5 \times 400}{1.6 \times 1242 \times 10^{-19} \times 10^6}$

Photo electric current = $\frac{5 \times 400}{1.6 \times 1242 \times 10^6 \times 10^{-19}} \times 1.6 \times 10^{-19}$ = 1.6×10^{-6} A = 1.6 μA.

27. λ = 200 nm = 2×10^{-7} m

E of one photon = $\frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{2 \times 10^{-7}}$ = 9.945×10^{-19}



No.of photons = $\frac{1 \times 10^{-7}}{9.945 \times 10^{-19}}$ = 1×10^{11} no.s

Hence, No.of photo electrons = $\frac{1 \times 10^{11}}{10^4}$ = 1×10^7

Net amount of positive charge 'q' developed due to the outgoing electrons

= $1 \times 10^7 \times 1.6 \times 10^{-19} = 1.6 \times 10^{-12}$ C.

Now potential developed at the centre as well as at the surface due to these charger

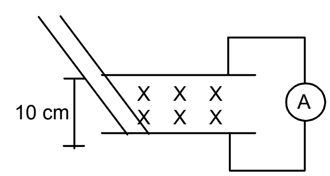
= $\frac{Kq}{r} = \frac{9 \times 10^9 \times 1.6 \times 10^{-12}}{4.8 \times 10^{-2}}$ = 3×10^{-1} V = 0.3 V.

28. ϕ_0 = 2.39 eV

λ_1 = 400 nm, λ_2 = 600 nm

for B to the minimum energy should be maximum

$\therefore$ λ should be minimum.



E = $\frac{hc}{\lambda} - \phi_0$ = 3.105 – 2.39 = 0.715 eV.

The presence of magnetic field will bend the beam there will be no current if the electron does not reach the other plates.

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

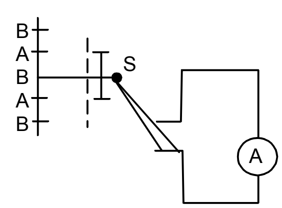
$\Rightarrow$ r = $\frac{\sqrt{2mE}}{qB}$

$\Rightarrow$ 0.1 = $\frac{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 0.715}}{1.6 \times 10^{-19} \times B}$

$\Rightarrow$ B = 2.85×10^{-5} T

29. Given : fringe width,

y = 1.0 mm $\times$ 2 = 2.0 mm, D = 0.24 mm, W_0 = 2.2 ev, D = 1.2 m



y = $\frac{\lambda D}{d}$

or, λ = $\frac{yd}{D} = \frac{2 \times 10^{-3} \times 0.24 \times 10^{-3}}{1.2}$ = 4×10^{-7} m

E = $\frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3 \times 10^8}{4 \times 10}$ = 3.105 ev

Stopping potential eV_0 = 3.105 – 2.2 = 0.905 V

30. ϕ = 4.5 eV, λ = 200 nm

Stopping potential or energy = E – ϕ = $\frac{WC}{\lambda} - \phi$

Minimum 1.7 V is necessary to stop the electron

The minimum K.E. = 2eV

[Since the electric potential of 2 V is reqd. to accelerate the electron to reach the plates]

the maximum K.E. = (2+1, 7)ev = 3.7 ev.

31. Given

$\sigma = 1 \times 10^{-9}$ cm^{-2}, W_0 (C_s) = 1.9 eV, d = 20 cm = 0.20 m, λ = 400 nm

we know $\rightarrow$ Electric potential due to a charged plate = V = E $\times$ d

Where E $\rightarrow$ elelctric field due to the charged plate = σ/E_0

d $\rightarrow$ Separation between the plates.

$$V = \frac{\sigma}{E_0} \times d = \frac{1 \times 10^{-9} \times 20}{8.85 \times 10^{-12} \times 100} = 22.598 \text{ V} = 22.6$$

$$V_0 e = h\nu - w_0 = \frac{hc}{\lambda} - w_0 = \frac{4.14 \times 10^{-15} \times 3 \times 10^8}{4 \times 10^{-7}} - 1.9$$

= 3.105 – 1.9 = 1.205 ev

or, V_0 = 1.205 V

As V_0 is much less than 'V'

Hence the minimum energy required to reach the charged plate must be = 22.6 eV

For maximum KE, the V must be an accelerating one.

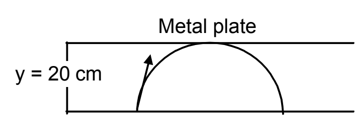
Hence max KE = V_0 + V = 1.205 + 22.6 = 23.8005 ev

32. Here electric field of metal plate = E = P/E_0

$$= \frac{1 \times 10^{-19}}{8.85 \times 10^{-12}} = 113 \text{ v/m}$$

accl. de = ϕ = qE / m

$$= \frac{1.6 \times 10^{-19} \times 113}{9.1 \times 10^{-31}} = 19.87 \times 10^{12}$$



$$t = \frac{\sqrt{2y}}{a} = \frac{\sqrt{2 \times 20 \times 10^{-2}}}{19.87 \times 10^{-31}} = 1.41 \times 10^{-7} \text{ sec}$$

$$\text{K.E.} = \frac{hc}{\lambda} - w = 1.2 \text{ eV}$$

= 1.2 $\times$ 1.6 $\times$ 10^{-19} J [because in previous problem i.e. in problem 31 : KE = 1.2 ev]

$$\therefore \; V = \frac{\sqrt{2KE}}{m} = \frac{\sqrt{2 \times 1.2 \times 1.6 \times 10^{-19}}}{4.1 \times 10^{-31}} = 0.665 \times 10^{-6}$$

$\therefore$ Horizontal displacement = $V_t \times t$

= 0.655 $\times$ 10^{-6} $\times$ 1.4 $\times$ 10^{-7} = 0.092 m = 9.2 cm.

33. When λ = 250 nm

$$\text{Energy of photon} = \frac{hc}{\lambda} = \frac{1240}{250} = 4.96 \text{ ev}$$

$$\therefore \; \text{K.E.} = \frac{hc}{\lambda} - w = 4.96 - 1.9 \text{ ev} = 3.06 \text{ ev.}$$

Velocity to be non positive for each photo electron

The minimum value of velocity of plate should be = velocity of photo electron

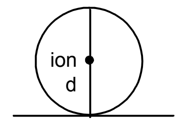
$\therefore$ Velocity of photo electron = $\sqrt{2KE/m}$

$= \sqrt{\dfrac{3.06}{9.1\times10^{-31}}} = \sqrt{\dfrac{3.06\times1.6\times10^{-19}}{9.1\times10^{-31}}} = 1.04 \times 10^6$ m/sec.

34. Work function = ϕ, distance = d

The particle will move in a circle

When the stopping potential is equal to the potential due to the singly charged ion at that point.



$eV_0 = \dfrac{hc}{\lambda} - \phi$

$\Rightarrow V_0 = \left(\dfrac{hc}{\lambda} - \phi\right)\dfrac{1}{e} \Rightarrow \dfrac{ke}{2d} = \left(\dfrac{hc}{\lambda} - \phi\right)\dfrac{1}{e}$

$\Rightarrow \dfrac{Ke^2}{2d} = \dfrac{hc}{\lambda} - \phi \Rightarrow \dfrac{hc}{\lambda} = \dfrac{Ke^2}{2d} + \phi = \dfrac{Ke^2 + 2d\phi}{2d}$

$\Rightarrow \lambda = \dfrac{hc\ 2d}{Ke^2 + 2d\phi} = \dfrac{2hcd}{\dfrac{1}{4\pi\varepsilon_0 e^2} + 2d\phi} = \dfrac{8\pi\varepsilon_0 hcd}{e^2 + 8\pi\varepsilon_0 d\phi}$.

35. a) When λ = 400 nm

Energy of photon = $\dfrac{hc}{\lambda} = \dfrac{1240}{400}$ = 3.1 eV

This energy given to electron

But for the first collision energy lost = 3.1 ev $\times$ 10% = 0.31 ev

for second collision energy lost = 3.1 ev $\times$ 10% = 0.31 ev

Total energy lost the two collision = 0.31 + 0.31 = 0.62 ev

K.E. of photon electron when it comes out of metal

= hc/λ – work function – Energy lost due to collision

= 3.1 ev – 2.2 – 0.62 = 0.31 ev

b) For the 3rd collision the energy lost = 0.31 ev

Which just equative the KE lost in the 3rd collision electron. It just comes out of the metal

Hence in the fourth collision electron becomes unable to come out of the metal

Hence maximum number of collision = 4.

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