CHAPTER 11

DUAL NATURE OF MATTER

➢ Photons are packets of energy emitted by a source of radiation. They travel in a straight line with speed of light.

(a) Energy of photon $E = h\nu = \frac{hc}{\lambda}$, $h = 6.626 \times 10^{-34}$ Js $= 4.136 \times 10^{-5}$ evs.

(b) Rest mass of photon is zero.

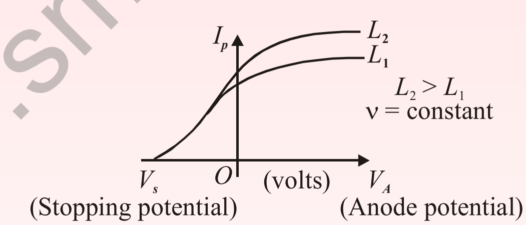
(c) Momentum of a photon $(p) = \frac{h}{\lambda} = mc = \frac{E}{C}$.

Photoelectric effect

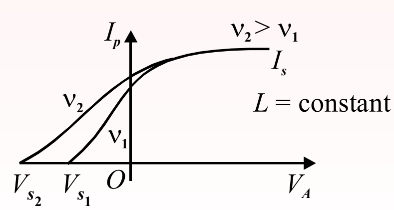
When light of sufficiently small wavelength is incident on a metal surface, electrons are ejected from its surface. This phenomenon is called **photoelectric effect**. Electrons so emitted are called photoelectrons.

(a) No emission occurs until the incident radiation have a frequency greater than a certain minimum called **threshold frequency** ν_0 irrespective of time of exposure and irrespective of intensity of incident radiations.

(b) The photocurrent increases on increasing the intensity.



(c) If frequency of incident radiations is greater than the threshold frequency ν_0 then stopping potential increases if frequency of incident radiation is increased.



(d) Work function:

Minimum energy given to electron to bring it out of the metal is called work function. $\phi = h\nu_0$

Stopping potential is that negative voltage given to anode with respect to cathode at which photocurrent becomes zero. $eV_s = (KE)_{max}$.

(e) Einstein's equation of Photoelectric effect:

According to Einstein a part of the energy of incident photon is used to eject electron out of the metal and the remaining energy of photon is converted in to the kinetic energy of electron. Therefore,

$$KE = hv - \phi_o \quad \text{or} \quad eV_s = hv - hv_o$$

Note:

(i) Maximum KE of ejected electrons is independent of intensity of light incident on metal surface.

(ii) Cesium has least ϕ which can further be decreased by oxide coating a substance.

(iii) The slope of stopping potential versus frequency is $\frac{h}{e}$ in photoelectric effect and slope of stopping potential versus $\frac{1}{\lambda}$ is $\frac{hc}{e}$.

(iv) Number of photons incident per second $= \frac{I_p}{e} = \frac{\text{Photo current}}{\text{Charge on an electron}}$, if efficiency of emission 100°C.

(v) Force exerted by photons $F = \frac{dp}{dt} = \frac{P}{C}$ for absorbing surface where C = speed of light. $F = \frac{2P}{C}$ for perfectly reflecting surface where, P is power and p is momentum.

(vi) Photo cells are of three types

(a) Photo emissive

(b) Photo conductive

(c) Photo voltaic or solar cells.

❖ **Matter waves:**

When a particle is in motion with momentum P, it is connected to a wave known as a matter wave or de Broglie wave. This wave has a wavelength λ, which is determined by the relationship

$\lambda = h / P$, where h represents Planck's constant.

Example 1: **Calculate the de-Broglie wavelength for electron and proton, if their speed is** 10^5 ms^{-1}**. Given, mass of an electron** $= 9.1\times10^{-31}\text{kg}$**, mass of proton** $= 1.67\times10^{-27}\text{kg}$ **and Planck's constant** $= 6.62\times10^{-34}$ **J s.**

Solution: Here, $h = 6.62\times10^{-34}\text{ Js}$

De-Broglie wavelength of electron

Here, $m_e = 9.1\times10^{-31}\text{kg};\ v_e = 10^5\text{ ms}^{-1}$

$$\lambda_e = \frac{h}{m_e v_e} = \frac{6.62\times10^{-34}}{9.1\times10^{-31}\times10^5} = 7.27\times10^{-9}\text{ m}$$

de-Broglie wavelength of proton

Here, $m_p = 1.67\times10^{-27}\text{kg};\ v_p = 10^5\text{ ms}^{-1}$

$$\lambda_p = \frac{h}{m_p v_p} = \frac{6.62\times10^{-34}}{1.67\times10^{-27}\times10^5} = 3.96\times10^{-12}\text{ m}$$

Example 2: **Find the de-Broglie wavelength associated with an electron moving with a velocity 0.5c and rest mass** $= 9.1\times10^{-31}\text{kg}$

Solution: Here, $m_o = 9.1\times10^{-31}kg;\quad h = 6.62\times10^{-34}\text{ Js}$

$v = 0.5c$ or $v/c = 0.5$

Since electron is moving at a speed comparable to the velocity of light,

$$\lambda = \frac{h}{mv} = \frac{h\sqrt{1-v^2/c^2}}{m_o v} = \frac{6.62\times10^{-34}\sqrt{1-(0.5)^2}}{9.1\times10^{-31}\times1.5\times10^8} = \frac{6.62\times10^{-34}\sqrt{1-0.25}}{9.1\times10^{-31}\times1.5\times10^8} = 4.2\times10^{-12}\text{ m}$$

Example 3: **Calculate the de-Broglie wavelength of an electron of energy 400 eV. Given planck's constant** $=6.6\times110^{-34}$ Js **, mass of electron** $=9.1\times10^{-31}$ kg ; $1\,eV=1.6\times10^{-19}$ J

Solution: Here, $h=6.6\times10^{-34}$ Js; $m=9.1\times10^{-31}$ kg

1eV $=1.6\times10^{-19}$ J

$E=400eV=400\times1.6\times10^{-19}=6.4\times10^{-174}$ J

If λ is de-Broglie wavelength of electron, then

$$\lambda=\frac{h}{\sqrt{2mE}}=\frac{6.6\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times6.4\times10^{-17}}}=\frac{6.6\times10^{-34}}{10.8\times10^{-24}}=0.61\times10^{-10}\,\text{m}\;=0.61\mathring{A}$$

Example 4: **Obtain the de-Broglie wavelength associated with thermal neutrons at room temperature (27°C). Hence, explain why a fast neutron beam needs to be thermalized with the environment, before it can be used for neutron diffraction experiments**.

Solution: Here, $T=27+273=300K$

Energy of neutron at temperature T, E $=\frac{3}{2}$kT

Taking $k=1.38\times10^{-23}$ J molecule^{-1} K^{-1}, we have

$E=\frac{3}{2}\times1.38\times10^{-23}\times300=6.21\times10^{-21}$ J

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

Taking mass of deuteron, $m=1.675\times10^{-27}$ kg ,

we have $\lambda=\frac{6.62\times10^{-34}}{\sqrt{2\times1.675\times10^{-27}\times6.21\times10^{-21}}}=\frac{6.62\times10^{-34}}{4.56\times10^{-24}}=1.452\times10^{-10}$ m

Example 5: **Work function of sodium is 2.3 eV. Does sodium show photoelectric emission for orange light? (λ = 6800Å). Given** $h=6.63\times10^{-34}$ Js.

Solution: Here $\phi_0=2.3\text{eV},\lambda=6800\text{Å}=6.8\times10^{-8}$ m

Energy of a photon or orange light is

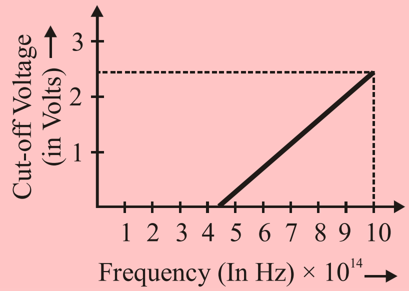
$$E=\frac{hc}{\lambda}=\frac{6.6\times10^{-34}\times3\times10^{8}\,\text{J}}{68\times10^{-8}}=\frac{6.6\times10^{-34}\times3\times10^{8}}{68\times10^{-8}\times1.6\times10^{-19}}\text{eV}=1.83\text{eV}.$$

As the energy of a photon of orange light is less than the work function of sodium, so sodium does not show photoelectric emission with orange light.

Example 6: **For photoelectric effect in sodium, the figure shows the plot of cut-off voltage versus frequency of incident radiation. Calculate:**

(i) the threshold frequency.

(ii) the work function for sodium.



Solution: (i) From the given graph, threshold frequency is $v_0 = 4.5 \times 10^{14}$ Hz

(ii) Work function of the metal is

$$\phi_0 = hv_0 = 6.6 \times 10^{-34} \times 4.5 \times 10^{14} = 2.97 \times 10^{-19}\,\text{J} = 1.86\text{eV}.$$

Example 7: **The emitter in a photoelectric tube has a threshold wavelength of 6000Å. Determine the wavelength of the light incident on the tube if the stopping potential for this light is 2.5V.**

Solution: The work function is $\phi_0 = h\nu_o = \frac{hc}{\lambda_o} = \frac{12.4 \times 10^3 \text{ eV.Å}}{6000 Å} = 2.07$ eV

Then photoelectric equation gives

$$eV_s = h\nu - \phi_0 = \frac{hc}{\lambda} - \phi_0 \quad \text{or} \quad 2.5 \text{ eV} = \frac{12.4 \times 10^3 \text{ eV.Å}}{\lambda} - 2.07 \text{ eV}$$

Solving, $\lambda =$ **2713 Å.**

Example 8: **If a light wave of wavelength 4950Å is viewed as a continuous flow of photons, what is the energy of each photon in eV? Given, Planck's constant $h = 6.6 \times 10^{-34}$ Js, $c = 3 \times 10^8 \text{ ms}^{-1}$.**

Solution: Here $\lambda = 4950 Å = 4950 \times 10^{-10}$ m; $h = 6.6 \times 10^{-34}$ Js; $c = 3 \times 10^8 \text{ ms}^{-1}$

Energy of photon, $$E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{4950 \times 10^{-10}} = 4.0 \times 10^{-19}\,\text{J} = \frac{4.0 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.5\,eV$$

Example 10: **Calculate the energy of a photon, whose (i) frequency is 1000 kHz (ii) wavelength is 5890Å. Also express the energy of the photon in eV in each case. Given, 1eV** $=1.6\times10^{-19}\,\text{J}$**,** $h=6.62\times10^{-34}\,\text{Js}$ **and** $c=3\times10^{8}\,\text{ms}^{-1}$

Solution: The energy of a photon is given by $E=hv=\dfrac{hc}{\lambda}$; where c is velocity of light.

Here, $h=6.62\times10^{-34}\,\text{Js};\ c=3\times10^{8}\ \text{ms}^{-1}$

$1\text{eV} =1.6\times10^{-19}\,\text{J}$

(i) When $v=1000\,kHz=10^{6}\,Hz$

$$E=hv=6.62\times10^{-34}\times10^{6}=6.62\times10^{-28}=\frac{6.62\times10^{-28}}{1.6\times10^{-19}}=4.14\times10^{-9}\,eV$$

(ii) When $v=5890\mathring{A}=5890\times10^{-10}\,m$

$$E=\frac{hc}{\lambda}=\frac{6.62\times10^{-34}\times3\times10^{8}}{5890\times10^{-10}}=3.37\times10^{-19}\,\text{J}\ =\frac{3.37\times10^{-19}}{1.6\times10^{-19}}=2.11\,eV$$

Example 11: **If radiation of wavelength 5000Å is incident on a surface of work function 1.2 eV, find the value of stopping potential.**

Solution: Here, work function, $\phi_o=1.2eV=1.2\times1.6\times10^{-19}=1.92\times10^{-19}\,\text{J}$

Wavelength of incident radiation, $\lambda=5000\mathring{A}=5000\times10^{-10}\,\text{m}$

If photoelectrons are emitted with maximum velocity $v_{\max'}$ then $\dfrac{1}{2}mv_{\max}^{2}=hv-\phi_o=\dfrac{hc}{\lambda}-\phi_o$

$$=\frac{6.62\times10^{-34}\times3\times10^{8}}{5000\times10^{-10}}-1.92\times10^{-19}\quad=3.97\times10^{-19}-1.92\times10^{-19}=2.05\times10^{-19}\,\text{J}$$

If e is the charge on electron and V_o is the stopping potential, then

$$eV=\frac{1}{2}mv^{2}=2.05\times10^{-19}\,\text{J}$$

or $$V_o=\frac{2.05\times10^{-19}}{e}=\frac{2.05\times10^{-19}}{1.6\times10^{-19}}=1.28V$$

Example 12: **A metal has a work function of 2.0 eV. It is illuminated by monochromatic light of wavelength 500 nm. Calculate: (i) the threshold wavelength (ii) the maximum energy of photoelectrons (iii) the stopping potential. Given, Planck's constant** $h = 6.6\times10^{-34}$ Js **charge on electron,** $e = 1.6\times10^{-19} C$ **and** $1eV = 1.6\times10^{-19}$ J

Solution: Here, $h = 6.6\times10^{-34}$ Js; $e = 1.6\times10^{-19} C$

$1eV = 1.6\times10^{-19}$ J

$\phi_o = 2.0eV = 2.0\times1.6\times10^{-19} = 3.2\times10^{-19}$ J

$\lambda = 500\,nm = 500\times10^{-9}$ m

(i) If λ_o is the threshold wavelength,

then $\phi_o = \dfrac{hc}{\lambda_o}$ or $\lambda_o = \dfrac{hc}{\phi_o} = \dfrac{6.6\times10^{-34}\times3\times10^{8}}{3.2\times10^{-19}} = 618.75\times10^{-9}\,\text{m} = 618.75\,\text{nm}$.

(ii) The maximum energy of photoelectrons, $\frac{1}{2}mv_{\max}^2 = hv - \omega = \dfrac{hc}{\lambda} - \omega$

$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{500\times100^{-9}} - 3.2\times10^{-19} = 3.96\times10^{-19} - 3.2\times10^{-19} = 0.76\times10^{-19}\,\text{J}$$

(iii) The stopping potential is given by

$$eV_s = \frac{1}{2}mv_{\max}^2 = 0.76\times10^{-19} \quad \text{or} \quad V_s = \frac{0.76\times10^{-19}}{e} = \frac{0.76\times10^{-19}}{1.6\times10^{-19}} = 0.475V$$

Example 13: **Monochromatic radiation of wavelength 640.2 nm (1nm =** 10^{-9} m **) from a lamp neon irradiates a photosensitive material made of cesium or tungsten. The stopping voltage is measured to be 0.54 V. The source is replaced by an iron source and its 427.2 nm line irradiates the same photocell. Predict the new stopping voltage.**

Solution: For neon lamp: $\lambda = 640.2\,\text{nm} = 640.2\times10^{-9}$ m, $V_s = 0.54$ volt

Now, $hv = hv_o + \frac{1}{2}mv_{\max}^2$ or $\dfrac{hc}{\lambda} = \phi_o + eV_o$

or $\phi = \dfrac{hc}{\lambda} - eV_s = \dfrac{6.62\times10^{-34}\times3\times10^{8}}{640.2\times10^{-9}} - 1.6\times10^{-19}\times0.54$

$= 3.102\times10^{-19} - 0.864\times10^{-19}\,\text{m} = 2.238\times10^{-19}$ J

For iron source: $\lambda = 427.2\,\text{nm} = 427.2\times10^{-9}$ m

$\phi_o = 2.238\times10^{-19}$ J

Again $\phi_o = \frac{hc}{\lambda} - eV_s$ or $eV_s = \frac{hc}{\lambda} - \phi_o$

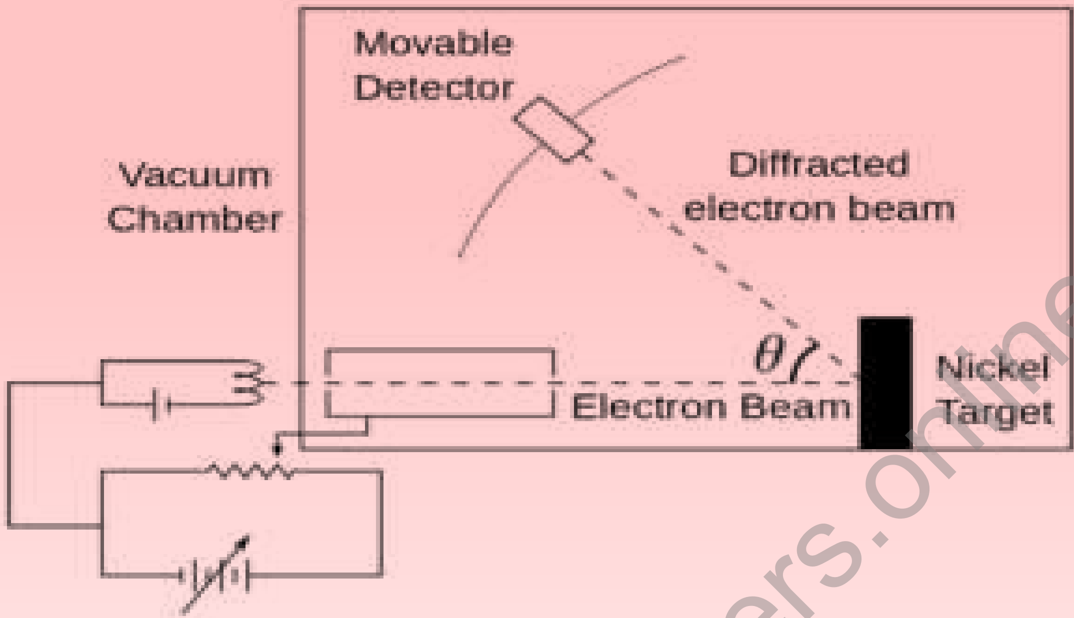
or $V_s = \frac{1}{e}\left(\frac{hc}{\lambda} - \phi_o\right) = \frac{1}{1.6\times10^{-19}} \times \left(\frac{6.62\times10^{-34}\times3\times10^{8}}{427.2\times10^{-9}} - 2.238\times10^{-19}\right)$

$$= \frac{1}{1.6\times10^{-19}}(4.649\times10^{-19} - 2.238\times10^{-19}) = \frac{2.411\times10^{-19}}{1.6\times10^{-19}} = 1.507\text{V}$$

Davisson and Germer Experiment

- The Davisson-Germer experiment is a landmark experiment in physics that provided experimental evidence for the wave-particle duality of matter, confirming Louis de Broglie's hypothesis that particles, such as electrons, can exhibit wave-like properties. In the experiment, a beam of electrons is directed at a crystalline nickel target. The scattered electrons are then detected and measured. The Davisson-Germer experiment played a crucial role in the development of quantum mechanics and our understanding of the wave-particle duality of matter.
- The experimental setup for the Davisson and Germer experiment is enclosed within a vacuum chamber. Thus, the deflection and scattering of electrons by the medium are prevented. The main parts of the experimental setup are as follows:

- **Electron gun**: An electron gun is a Tungsten filament that emits electrons via thermionic emission i.e., it emits electrons when heated to a particular temperature.
- **Electrostatic particle accelerator**: Two opposite charged plates (positive and negative plate) are used to accelerate the electrons at a known potential.
- **Collimator**: The accelerator is enclosed within a cylinder that has a narrow passage for the electrons along its axis. Its function is to render a narrow and straight (collimated) beam of electrons ready for acceleration.
- **Target**: The target is a Nickel crystal. The electron beam is fired normally on the Nickel crystal. The crystal is placed such that it can be rotated about a fixed axis.
- **Detector**: A detector is used to capture the scattered electrons from the Ni crystal. The detector can be moved in a semicircular arc as shown in the diagram above.



- In the Davisson and Germer experiment waves were used in place of electrons. These electrons formed a diffraction pattern. The dual nature of matter was thus verified. We can relate the de Broglie equation and the Bragg's law as shown below:
- From the de Broglie equation, we have:

$\lambda = h/p$

$= h/\sqrt{2mE}$

$= h/\sqrt{2meV}$ … (1)

where, m is the mass of an electron, e is the charge on an electron and h is the Plank's constant.

Therefore, for a given V, an electron will have a wavelength given by equation (1).

The following equation gives Bragg's Law:

$n\lambda = 2d \sin(90-\theta/2)$ … (2)

Since the value of d was already known from the X-ray diffraction experiments. Hence for various values of θ, we can find the wavelength of the waves producing a diffraction pattern from equation (2).

- The diffraction pattern observed in the experiment indicated that the electrons were behaving as waves and undergoing interference with each other as they interacted with the crystalline structure of the nickel target. The specific pattern of bright spots provided evidence for the wave-like nature of electrons and confirmed the wave-particle duality proposed by de Broglie.
- By studying the angles at which the diffraction patterns occurred, the researchers were able to determine the wavelength of the electron waves, which matched the predictions based on de Broglie's hypothesis. This observation confirmed the wave-like properties of electrons and established an important connection between particle behaviour and wave phenomena in the microscopic world.
- From the Davisson and Germer experiment, we get a value for the scattering angle θ and a corresponding value of the potential difference V at which the scattering of electrons is maximum. Thus, these two values from the data collected by Davisson and Germer, when used in equation (1) and (2) give the same values for λ. Therefore, this establishes the de Broglie's wave-particle duality and verifies his equation as shown below:

From (1), we have:

$$\lambda = h/\sqrt{2meV}$$

For V = 54 V, we have

$$\lambda = 12.27/\sqrt{54} = 0.167 \text{ nm} \ldots (3)$$

Now the value of 'd' from X-ray scattering is 0.092 nm.

Therefore, for V = 54 V, the angle of scattering is 500

- using this in equation (2),

we have:

$$n\lambda = 2\,(0.092 \text{ nm}) \sin(90-50/2)$$

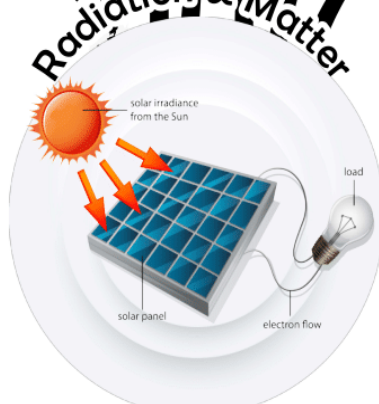
For n = 1, we have:

$$\lambda = 0.165 \text{ nm} \ldots (4)$$

Therefore, the experimental results are in a close agreement with the theoretical values got from the de Broglie equation.

The equations (3) and (4) verify the de Broglie equation.

Dual Nature of Radiation & Matter



Dual Nature of Radiation

- Light has both wave character as well as particle **nature**
- **Interference and diffraction can be explained by wave nature**
- When light **is**of sufficiently **small wavelength, it** behaves as particle.
- Light particles having definite energy and definite **linear momentum are called "photons"**
  Energy of each photon = $h\nu = hc/\lambda$
  Momentum of each photon = $h/\lambda = E/c$

Contribution

Einstein, after an average academic career put forward quantum theory of light in 1905 while working as a grade III technical officer in a patent office.

Matter waves

All matter can exhibit wave–like behaviour e.g., beam of electrons can be diffracted like a water wave

de-Broglie relation

$\lambda = h/p$

λ = wavelength associated with particle or de-Broglie wavelength

p = momentum

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2m\,K_{max}}}$$

Photoelectric Effect

- When light of sufficient small wavelength is incident on metal surface, electrons are ejected from the metal, the phenomenon is called photoelectric effect.
- Ejected electrons are called photoelectrons
- Minimum energy equal to work function (ϕ) must be given to an electron so as to bring it out of the metal

Einstein's Photoelectric equation

- If $\lambda = \lambda_0 = hc/\phi$
  $K_{max} = 0$, i.e.,
  Electron may just come out **onto the surface**
- If $\lambda > \lambda_0$
  i.e., $E < \phi$
  no electron will come out
- If $\lambda > \lambda_0$.
  Electrons come out with definite KE.
- λ_0 = depends on metal used

- $K_{max} = E - \phi = eV_0$
  $= \frac{hc}{\lambda} - \phi$, V_0 = stopping potential
  K_{max} = maximum kinetic energy of **ejected**electrons

Here, $\lambda_0 = hc/\phi$

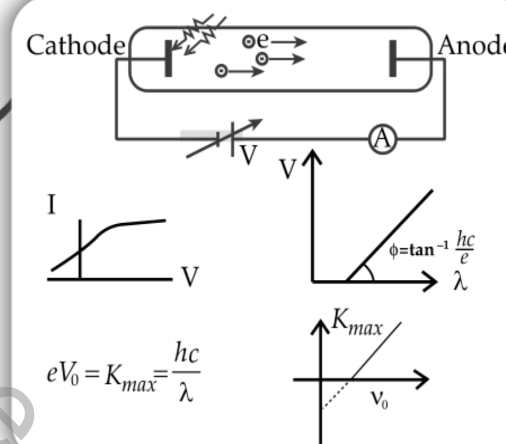
λ_0 = Threshold Wavelength

$\lambda_0 = c/\nu_0 = \phi/h$

ν_0 = Threshold frequency

$K_{max} = \lambda(\nu - \nu_0)$

Hertz and Lenard's Observation



$eV_0 = K_{max} = \frac{hc}{\lambda}$

Trace the Mind Map

- First Level
- Second Level
- Third Level

PRACTICE QUESTIONS

1. If the linear momentum of a particle is 1.2×10^4 kg-ms^{-1}, then what will be its de-Broglie wavelength? (Take $h = 6.6 \times 10^{-34}$ Js)
   a) 3×10^{-29}m b) 5.5×10^{-29}nm c) 6.4×10^{-29}m d) 6×10^{-29}nm

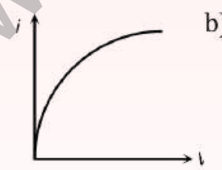
2. What is the maximum kinetic energy observed when two identical metal plates are subjected to the photoelectric effect, with plate A illuminated by light of wavelength λ A and plate B illuminated by light of wavelength λ_B (where $\lambda_A = 2\lambda_B$)?
   a) $2\ K_A = K_B$ b) $K_A < K_B/2$ c) $K_A = 2K_B$ d) $K_A = K_B/2$

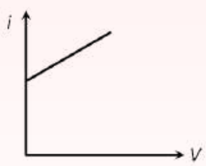
3. At a rate of 2.5 calories per cm^2 per minute, energy from the sun is received on Earth. Assuming the average wavelength of solar light is 5000 Å, how many photons are received on Earth per cm^2 per minute? (Given: Planck's constant, $h = 6.6 \times 10^{-34}$ Js, and 1 calorie = 4.2 J)
   a) 1.5×10^{13} b) 2.6×10^{13} c) 2.3×10^{19} d) 1.75×10^{19}

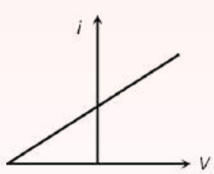
4. The de-Broglie wavelength is proportional to
   a) $\lambda \propto \frac{1}{v}$ b) $\lambda \propto \frac{1}{m}$ c) $\lambda \propto \frac{1}{p}$ d) $\lambda \propto p$

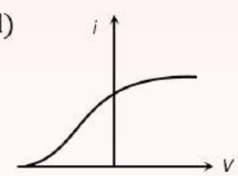
5. If a parallel beam of light, carrying 40 W of power, is incident normally on a plane surface that absorbs 30% of the light and reflects the remaining portion, what is the force exerted by the beam on the surface?
   a) 1.73×10^{-8}N b) 1.73×10^{-7}N c) 5.12×10^{-7}N d) 5.12×10^{-8}N

6. What is the relationship between (i) and potential difference (V) for a photoelectric cell?
   1.

a) 

b) 

c) 

d) 

7. The work function for metals A, B and C are respectively 1.94 eV, 2.0 eV and 4 eV. According to the Einstein's equation, the metals which will emit photo electrons for a radiation of wavelength 4000 Å is/are

a) None of these b) A only c) A and B only d) All the three metals

8. In the experimental setup of photoelectric effect, the metal surface is first illuminated with violet light and then with ultraviolet light and the stopping potential is determined in each case. The stopping potential will
   a) Be more with violet light
   b) Be more with ultraviolet light
   c) Be equal in both cases
   d) Depend upon the current
9. What is the mathematical equation of Bragg's law?

a) $2d \sin\theta = n\lambda$ b) $d \sin\theta = 2n\lambda$ c) $n \sin\theta = 2\lambda d$ d) None of these

10. The kinetic energy of an electron is 10 eV. Calculate the de-Broglie wavelength associated with it ($h = 6.6 \times 10^{-34} Js, m_e = 9.1 \times 10^{-31} kg$)
    a) 3.86 Å b) 10.9 Å c) 2.7 Å d) None of these

11. A photoelectric cell is illuminated by a point source of light 2m away. When the source is shifted to 4m then
    a) each emitted electron carries half the initial energy
    b) number of electrons emitted is a quarter of the initial number
    c) each emitted electron carries one quarter of the initial energy
    d) number of electrons emitted is half of the initial number

12. A tiny spherical oil drop carrying a net charge q is balanced in still air with vertical uniform electric field of strength $\frac{9\pi}{7} \times 10^5 Vm^{-1}$.When the field is switched off, the drop is observed to fall with terminal velocity $2.7 \times 10^{-3} ms^{-1}$. Given $g = 9.8 ms^{-2}$, viscosity of the air $=1.8 \times 10^{-5} Ns\ m^{-2}$ and the density of oil $= 900\ kg\ m^{-3}$, the magnitude of q is

a) 1.6×10^{-14} C b) 3.2×10^{-14} C c) 4.8×10^{-14} C d) 4.37×10^{-14} C

13. Velocity ratio of the two cathode rays 2:1. They are applied to the same electric field. What is the deflection ratio of the two cathode rays

a) 2 :1 b) 1 :4 c) 4 :1 d) 8 :1

14. A radio transmitter operates at a frequency of 440 kHz and a power of 10 kW. The number of photons emitted per second are

a) 3.44×10^{31} b) 1327×10^{34} c) 13.27×10^{34} d) 0.075×10^{-34}

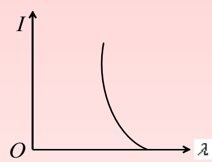
15. The de-Broglie wavelength of a proton (charge $=1.6\times 10^{-19}$ C, mass$=1.6 \times 10^{-27}$ kg) accelerated through a potential difference of 2kV is

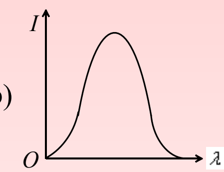
a) 600 Å b) 0.63×10^{-12} m c) 7 Å d) o.9 nm

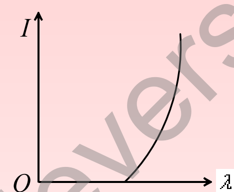
16. If the specific charge of a proton is 9.6×10^7 C/kg, what will be the specific charge of an alpha particle?

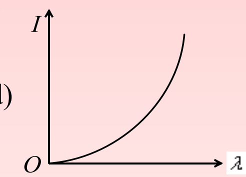
a) 9.6×10^{7} Ckg^{-1} b) 19.2×10^{7} Ckg^{-1} c) 4.8×10^{7} Ckg^{-1} d) 2.4×10^{7} Ckg^{-1}

17. If the anode voltage of a photocell is kept fixed and the wavelength λ of the incident light on the cathode is gradually changed, how does the plate current (I) of the photocell vary?

a) 

b) 

c) 

d) 

18. In Millikan's oil drop experiment, an oil drop of mass 8×10^{-6} kg is balanced by an electric field of 10^{6} Vm^{-1}. The charge in coulomb on the drop is (assuming $g = 10$ ms^{-2})

a) 16×10^{-11} b) 16×10^{-9} c) 8×10^{-11} d) 8×10^{-13}

19. How can the velocity of electrons emitted from the electron gun be increased in the Davisson and Germer experiment?

a) Decreasing the potential difference between the anode and filament
b) Increasing the potential difference between the anode and filament
c) Increasing the filament current
d) Decreasing the filament current

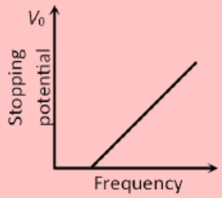
20. What is the cut-off wavelength of the X-rays generated when a beam of 32.0 keV electrons strikes a molybdenum target?

a) 38.8 pm b) 40.0 pm c) 15.95 pm d) 18.2 pm

21. The ratio of the de Broglie wavelengths of an electron of energy 20 eV to that of person of mass 33 kg travelling at a speed of 100 km/hr is of the order of

a) 10^{34} b) 10^{28} c) 10^{17} d) 10^{-10}

22. If the slope is 2.1×10^{-15}V-s, then value of $'h'$ should be



a) 6.6×10^{-31}J-s b) 3.36×10^{-34}J-s c) 9.1×10^{-31}J-s d) None of these

23. When a proton of mass M is accelerated through a potential difference V, similar to an electron of mass m accelerated through the same potential difference, what will be the de Broglie wavelength associated with the proton?

a) $\lambda\frac{m}{M}$ b) $\lambda\sqrt{\frac{m}{M}}$ c) $\lambda\frac{M}{m}$ d) $\lambda\sqrt{\frac{M}{m}}$

24. De-Broglie wavelength of a body of mass 2 kg moving with velocity of 1000 m/s is
a)3.32×10^{-27}Å b) 1.5×10^{7}Å c) 0.55×10^{-22}Å d) None of these

25. What will be detected by the detector when a stationary hydrogen atom in its ground state undergoes two consecutive inelastic collisions with photons of energies 10.2 eV and 15 eV, respectively, with a time interval of approximately microseconds between them?
a) 2 photons of energy 10.2 eV
b) 2 photons of energy of 1.4 eV
c) One photon of energy 10.2 eV and an electron of energy 1.4 eV
d) One photon of energy 10.2 eV and another photon of 1.4 eV

26. The momentum of a photon is 3×10^{-16} gm-cm/sec. Its energy is
a)0.61×10^{-26}erg b)2.0×10^{-26}erg c) 9×10^{-6}erg d) 6×10^{-8}erg

27. In a photo emissive cell with exciting wavelength λ, the fastest electron has speed v. If the exciting wavelength is changed to $\lambda/4$, the speed of the fastest emitted electron will be
a) $v(1/3)^{1/2}$ b) $v(4/1)^{1/2}$
c) Less than $v(1/3)^{1/2}$ d) Greater than $v(4)^{1/2}$

28. If a voltage applied to an X-ray tube is increased to 2 times the minimum wavelength (λ_{min}) of an X-ray continuous spectrum shifts by $\Delta\lambda = 13$ pm. The initial voltage applied to the tube is
a) ≈ 10 kV b) ≈ 16 kV c) ≈ 50 kV d) ≈ 75 kV

29. An important spectral emission line has a wavelength of 7cm. The corresponding photon energy is ($h = 6.62 \times 10^{-34}$ Js and $c = 3 \times 10^{8}$ ms^{-1})
a) 5.9×10^{-8} eV b) 5.9×10^{-4} eV c) 1.76×10^{-5} eV d) 11.8×10^{-6} eV

30. If light of wavelength λ strikes a photosensitive surface and electrons are ejected with kinetic energy E, what wavelength (λ') is required to increase the kinetic energy to 2E?

a) $\lambda' = \frac{\lambda}{2}$ b) $\lambda' = 2\lambda$ c) $\frac{\lambda}{2} < \lambda' < \lambda$ d) $\lambda' > \lambda$

31. An electron microscope is used to probe the atomic arrangement to a resolution of 2 Å. What should be the electric potential to which the electrons need to be accelerated

a) 2.5 V b) 37 V c) 2.5 kV d) 2 kV

32. Why are X-rays used in determining the molecular structure of crystalline materials?

a) Energy is high
b) It can penetrate the material
c) Its wavelength is comparable to interatomic distance
d) Its freqency is low

33. Given a uniform electric field of 1.6×10^5 V/m, an α-particle with a mass of 6.4×10^{-27} kg and a charge of 3.2×10^{-19} C starts from rest and travels a distance of 2×10^{-2} m. What will be the velocity of the α-particle at the end of its path?

a) $2\sqrt{3}\times10^5 \text{ms}^{-1}$ b) 8×10^5 ms^{-1} c) 16×10^5 ms^{-1} d) $4\sqrt{2}\times10^5$ ms^{-1}

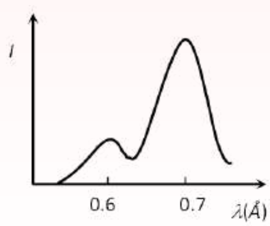
34. Among a photon, an electron, and a uranium nucleus, all having the same wavelength, which one possesses the highest energy?

a) Is the photon
b) Is the electron
c) Is the uranium nucleus
d) Depends upon the wavelength and the properties of the particle

35. In an experiment on photoelectric emission from a metallic surface, wavelength of incident light is 2.2×10^{-7}m and stopping potential is 2.2 V. The threshold frequency of the metal (in Hz) approximately (charge on electron $e = 1.6\times10^{-19}$ C, Planck's constant $h = 6.6\times10^{-34}$J-s)

a) 12×10^{15} b) 9.1×10^{15} c) 8.3×10^{14} d) 7.9×10^{13}

36. When electrons with an energy of 30 keV are incident on a molybdenum target, a graph is obtained showing the intensity of emitted X-rays plotted against their corresponding wavelengths. The graph exhibits two distinct peaks, with one peak corresponding to the Kα line and the other peak corresponding to the Kβ line.



a) First peak is of K_α line at 0.6 Å
b) Highest peak is of K_α line at 0.7 Å
c) If the energy of incident particles is increased, then the peaks will shift towards left
d) If the energy of incident particles is increased, then the peaks will shift towards right

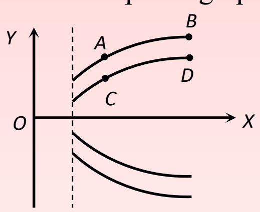
37. What is the estimated lower limit of the wavelength of X-rays emitted from an X-ray tube when a potential difference of V volts is applied?

a) $\frac{1227}{\sqrt{V}}$ Å b) $\frac{1240}{V}$ Å c) $\frac{2400}{V}$ Å d) $\frac{12400}{V}$ Å

38. Cathode rays of velocity 2×10^6 ms^{-1} describe an approximate circular path of radius 1 m in an electric field 150 Vcm^{-1}. If velocity of cathode rays is doubled. The value of electric field so that the rays describe the same circular path, will be

a) 2400 Vcm^{-1} b) 600 Vcm^{-1} c) 1200 Vcm^{-1} d) 12000 Vcm^{-1}

39. The figure displays the positions of four positive ions (A, B, C, D) on the Y-X curve in the Thomson spectrograph experiment.



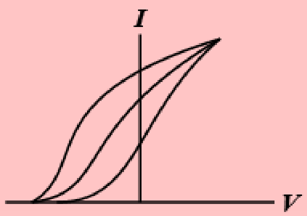
a) The specific charge of C and D are same b) The masses of A and D are same
c) The specific charges of B and C are same d) The velocities of C and D are same

40. The linear momentum of an electron, initially at rest, accelerated through a potential difference of 90 V is
a) 9.1×10^{-24} b) 6.5×10^{-24} c) 5.11×10^{-24} d) 1.6×10^{-24}

41. What is the relationship between the frequency (v) of a specific characteristic X-ray and the atomic number (Z) of the element, as stated by Moseley's law of X-rays?

a) $\sqrt{v} = kZ^2$ b) $\sqrt{v} = \frac{k}{Z^2}$ c) $v = kZ$ d) $\sqrt{v} = kZ$

42. Photoelectric effect experiments are performed using three different metal plates p, q and r having work functions are Q_p=2.0 eV, Q_q= 2.5 eV and Q_r=3.0 eV respectively. A light beam containing wavelength of 550 nm, 450 nm and 350 nm with equal intensities illuminates each of the plates. The correct **I–V** graph for the experiment is (take h_c=1240eVnm) a)



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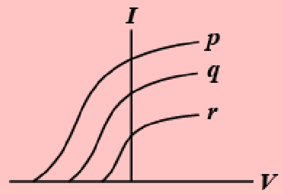
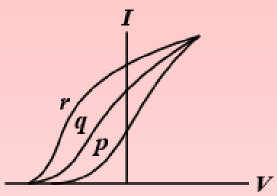
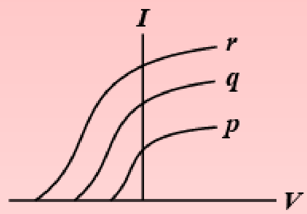


c)



d)



----------------------------ANSWER KEY---------------------------

1)	b	2)	b	3)	c	4)	c
5)	b	6)	d	7)	c	8)	b
9)	a	10)	a	11)	b	12)	d
13)	a	14)	a	15)	b	16)	c
17)	a	18)	c	19)	b	20)	a
21)	b	22)	b	23)	b	24)	a
25)	c	26)	c	27)	d	28)	b
29)	c	30)	c	31)	b	32)	c
33)	d	34)	a	35)	c	36)	b
37)	d	38)	b	39)	a	40)	c
41)	d	42)	a				

HINTS AND SOLUTIONS

1. (b)

Given, the linear momentum of particle (p)

$$= 1.2 \times 10^4 \text{kg} - \text{ms}^{-1}$$
$$h = 6.6 \times 10^{-34} \text{ JS}$$

The de-Broglie wavelength of particle

$$\lambda = \frac{h}{p}$$
$$\lambda = \frac{6.6\times10^{-34}}{1.2\times10^4}$$

Or $\lambda = 5.5 \times 10^{-38}$ m

Or $\lambda = 5.5 \times 10^{-29}$ mm

2. (b)

$K_A = \frac{hc}{\lambda_A} - \phi_0$ and $K_B = \frac{hc}{\lambda_B} - \phi_0$

$$\frac{K_A}{K_B} = \frac{\frac{hc}{2\lambda_B}}{\frac{hc}{\lambda_B}} < \frac{1}{2} \text{ or } K_A < K_B/2$$

3. (c)

Energy received from the sun =

$2.5 \text{ cal cm}^{-2}(\text{min })^{-1}$

$=10.4 \text{ J cm}^{-2} (\text{min })^{-1}$

Energy of 1 photon received from the sun

$$E = \frac{hc}{\lambda}$$
$$= \frac{6.6\times10^{-34}\times3\times10^8}{5000\times10^{-10}}$$
$$=3.96\times 10^{-19} \text{ J}$$

∴ Number of photons reaching the earth per cm^2 per minute will be

$$n = \frac{\text{energy received from sun}}{\text{energy of one photon}}$$
$$n = \frac{10.4}{3.96\times10^{-19}} = 2.62 \times 10^{19}$$

4. (c)

$$\lambda = \frac{h}{p} \Rightarrow \lambda \propto \frac{1}{p}$$

5. (b)

Momentum of incident light per second

$$p_1 = \frac{E}{c} = \frac{40}{3 \times 10^8} = 1.33 \times 10^{-7}$$

Momentum of reflected light per second

$$p_2 = \frac{30}{100} \times \frac{E}{c} = \frac{60}{3 \times 10^8} = 0.4 \times 10^{-7}$$

Force on the surface = change in momentum per second

$$= p_2 - (-p_1) = p_2 + p_1 = (1.33 + 0.4) \times 10^{-7} = 1.73 \times 10^{-7}\text{N}$$

6. (d)

In a photocell, when the anode is set to a specific negative potential (referred to as the stopping potential V_0), the photoelectric current ceases and becomes zero. However, as the potential difference between the cathode and anode increases, the current through the circuit begins to rise. After reaching a certain point, a constant current known as the saturation current flows through the circuit, regardless of any further increase in the potential difference.

7. (c)

Momentum $p = \frac{E}{c} \Rightarrow E^2 = p^2c^2$

$$= \frac{12375}{4000} = 3.09 \text{ eV}$$

Work functions of metal A and B are less than 3.09eV, so A and B will emit photo electrons

8. (b)

The stopping potential will be higher for the ultraviolet light compared to the violet light in the experimental setup of the photoelectric effect. This is because ultraviolet light has higher energy photons, which require a greater potential difference to stop the emitted photoelectrons.

9. (a)

10. (a)

$$\lambda = \frac{h}{\sqrt{2mE}}$$
$$= \frac{6.6 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 10 \times 1.6 \times 10^{-19}}}$$
$$= 3.86 \times 10^{-10}m = 3.86\text{Å}$$

11. (b)

Number of photoelectrons emitted per second is directly proportional to intensity of light

Intensity of light source is

$I \propto 1/d^2$

When distance is doubled, intensity becomes one-fourth

As number of photoelectrons ∝ intensity, so number of photoelectrons is quarter of the initial number.

12. (d)

$qE = mg$ ... (i)

$6\pi\eta\, rv = mg$

$\frac{4}{3}\pi r^3 \rho g = mg$ ... (ii)

∴ $r = \left(\frac{3mg}{4\pi\rho g}\right)^{1/3}$ ... (iii)

Substituting the value of r in Eq. (ii), we get

$$6\pi\eta v \left(\frac{3mg}{4\pi\rho g}\right)^{1/3} = mg$$

or $$(6\pi\eta v)^3 \left(\frac{3mg}{4\pi\rho g}\right) = (mg)^3$$

Again substituting $mg = qE$, we get

$$(qE)^2 = \left(\frac{3}{4\pi\rho g}\right)(6\pi\eta v)^3$$

Or $$qE = \left(\frac{3}{4\pi\rho g}\right)^{1/2} (6\pi\eta g)^{3/2}$$

∴ $$q = \frac{1}{E}\left(\frac{3}{4\pi\rho g}\right)^{\frac{1}{2}}(6\pi\eta v)^{3/2}$$

Substituting the values, we get

$$q = \frac{7}{9\pi \times 10^5}\sqrt{\frac{3}{4\pi \times 900 \times 9.8} \times 216\pi^3} \times \sqrt{(1.8 \times 10^{-5} \times 2.7 \times 10^{-3})^3} = 4.37 \times 10^{-14}\ \text{C}$$

13. (a)

$$\frac{u_1}{u_2} = \frac{2}{1}$$

Accelerations of cathode rays in electric field,

$\vec{a} = \frac{eE}{m}$

It is same for both the cathode rays

As displacement, $s = ut + \frac{1}{2}at^2$

So, for a given value of a and t, $s \times u$

$$\text{So, } \frac{s_1}{s_2} = \frac{u_1}{u_2} = \frac{2}{1}$$

14. (a)

Number of photons emitted per second

$$n = \frac{p}{hv} = \frac{10 \times 10^3}{6.6 \times 10^{-34} \times 440 \times 10^3} = 3.44 \times 10^{31}$$

15. (b)

According to de-Broglie hypothesis

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

$$\therefore \lambda = \frac{6.6 \times 10^{-34}}{\sqrt{2 \times (1.6 \times 10^{-27})(1.6 \times 10^{-19}) \times 2000}} = \frac{6.6 \times 10^{-34}}{7.16 \times 10^{-22}} = 0.63 \times 10^{-12}\ \text{m}$$

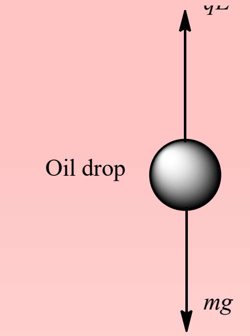
16. (c)

Reducing the pressure inside a tube from 1 cm to 10^ (-3) cm results in an increase in the mean free path of electrons in the discharge tube. This increased mean free path allows electrons to gain higher kinetic energy as they move towards the anode. The higher kinetic energy of the electrons leads to the ionization of atoms they encounter during their trajectory, causing an excitation phenomenon.

17. (a)

On increasing wavelength of light of the photoelectric current decreases and at a certain wavelength (cut off) above which photoelectric current stops

18. (c)



Solving for q, we get

$$q = \frac{mg}{E}$$

Given,

$m = 8 \times 10^{-6}$kg, $g = 10ms^{-2}$,
$E = 10^6 V\text{–}m^{-1}$

$\therefore \quad q = \frac{8\times10^6\times10}{10^6} = 8 \times 10^{-11}$ C

19. (b)

In the Davisson and Germer experiment, the velocity of electrons emitted from the electron gun can be increased by applying a higher accelerating voltage to the gun. By increasing the potential difference, or voltage, across the electron gun, the electrons can gain more kinetic energy, resulting in higher velocities. This increase in velocity allows the electrons to have sufficient energy to exhibit diffraction when they interact with the crystal lattice, as observed in the Davisson and Germer experiment.

20. (a)

The cut-off wavelength λ_{min} corresponds to an electron transferring (approximately) all of its energy to an X-ray photon, thus producing a photon with the greatest possible frequency and least possible wavelength.

From relation

$$\lambda_{\min} = \frac{hc}{K_o}$$
$$= \frac{(4.14\times10^{-15})(3\times10^8)}{32.0\times10^3}$$
$$= 3.88\times 10^{-11} \text{ m}$$
$$= 38.8\text{pm}$$

21. (b)

For an electron

Mass, $m_e = 9.11 \times 10^{-31} kg$

Kinetic energy, $K = 20eV = 20 \times 1.6 \times 10^{-19} J$

de Broglie wavelength, $\lambda_e = \frac{h}{\sqrt{2m_eK}}$ …(i)

For the person Mass, $m = 33\ kg$

Speed, $v = 100 kmhr^{-1} = 100 \times \frac{5}{18} ms^{-1}$

de Broglie wavelength, $\lambda = \frac{h}{mv}$ …(ii)

Diving (i) by (ii), we get

$$\frac{\lambda_e}{\lambda} = \frac{h}{\sqrt{2m_eK}} \times \frac{mv}{h} = \frac{mv}{\sqrt{2m_eK}}$$
$$= \frac{33 \times 100 \times \frac{5}{18}}{\sqrt{2 \times 9.11 \times 10^{-31} \times 20 \times 1.6 \times 10^{-19}}}$$
$$= 0.37 \times 10^{27}$$

22. (b)

Slope of $V_0 - v$ curve $= \frac{h}{e}$

$\Rightarrow h = \text{Slope } \times e$

$$= 1.6 \times 10^{-19} \times 2.1 \times 10^{-15}$$
$$= 3.36 \times 10^{-34} J\text{-}s$$

23. (b)

$$\lambda = \frac{h}{\sqrt{2mE}} \Rightarrow \lambda \propto \frac{1}{\sqrt{m}} \quad [E = \text{same}]$$

24. (a)

$$\lambda = \frac{h}{mv} = \frac{6.6\times10^{-34}}{2\times1000} = 3.3 \times 10^{-37} m = 3.3 \times 10^{-27} \text{Å}$$

25. (c)

Due to 10.2 eV photon one photon of energy 10.2 eV will be detected.
Due to 15 eV photon the electron will come out of the atom with energy $(15 - 13.6) = 1.4\ eV$

26. (c)

$p = \frac{E}{c} \Rightarrow E = p \times c = 3 \times 10^{-16} \times (3 \times 10^{10}) = 9 \times 10^{-6} erg$

27. (d)

$$h\nu - W_0 = \frac{1}{2}mv_{\max}^2 \Rightarrow \frac{hc}{\lambda} - \frac{hc}{\lambda_0} = \frac{1}{2}mv_{\max}^2$$

$$\Rightarrow hc\left(\frac{\lambda_0 - \lambda}{\lambda\lambda_0}\right) = \frac{1}{2}mv_{\max}^2 \Rightarrow v_{\max} = \sqrt{\frac{2hc}{m}\left(\frac{\lambda_0 - \lambda}{\lambda\lambda_0}\right)}$$

When wavelength is λ and velocity is v, then

$$v = \sqrt{\frac{2hc}{m}\left(\frac{\lambda_0 - \lambda}{\lambda\lambda_0}\right)} \quad \text{... (i)}$$

When wavelength is $\frac{\lambda}{4}$ and velocity is v' then

$$v' = \sqrt{\frac{2hc}{m}\left[\frac{\lambda_0 - (\lambda/4)}{(\lambda/4) \times \lambda_0}\right]} \quad \text{... (ii)}$$

Divide equation (ii) by (i), we get

$$\frac{v'}{v} = \sqrt{\frac{[\lambda_0 - (\lambda/4)]}{\frac{1}{4}\lambda\lambda_0} \times \frac{\lambda\lambda_0}{\lambda_0 - \lambda}}$$

$$v' = v\left(\frac{4}{1}\right)^{1/2}\sqrt{\frac{[\lambda_0 - (\lambda/4)]}{\lambda_0 - \lambda}}$$

$i.e. v' > v(4)^{1/2}$

28. (b)

$$\lambda_{\min} = \frac{hc}{eV} \Rightarrow \lambda_1 = \frac{hc}{eV_1} \text{ and } \lambda_2 = \frac{hc}{eV_2}$$

$$\therefore \Delta\lambda = \lambda_2 - \lambda_1 = \frac{hc}{e}\left[\frac{1}{V_2} - \frac{1}{V_1}\right].$$

Given $V_2 = 2\,V_1$

on solving we get $V_1 = 16000\ volt = 16\ kV$

29. (c)

$$E = h\nu/\lambda = \frac{hc}{e\lambda} \text{(In eV)}$$
$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 0.07}$$
$$= 1.76 \times 10^{-5}\text{eV}$$

30. (c)

$$E = \frac{hc}{\lambda} - W_0 \text{ and } 2E = \frac{hc}{\lambda'} - W_0$$

$$\Rightarrow \frac{\lambda'}{\lambda} = \frac{E + W_0}{2E + W_0} \Rightarrow \lambda' = \lambda\left(\frac{1 + W_0/E}{2 + W_0/E}\right)$$

Since $\frac{(1+W_0/E)}{(2+W_0/E)} > \frac{1}{2}$ so $\lambda' > \frac{\lambda}{2}$

31. (b)

Minimum wavelength = 2Å

$$\lambda = \frac{12.2\ \text{Å}}{\sqrt{V}} = 2\text{Å}$$

Acceleration potential = 37 V

32. (c)

Crystal structure is explored through the diffraction of waves having a wavelength comparable with the inter-atomic spacing (10^{-10}m) in crystals. Radiation of larger wavelength cannot resolve the details of structure, while radiation of much shorter wavelength is diffracted through small angles. Usually, diffraction of X-rays is employed in the study of crystal structure as X-rays have wavelength comparable to interatomic spacing.

33. (d)

Given, $m_\alpha = 6.4 \times 10^{-27}$kg

$q_\alpha = 3.2 \times 10^{-19}$ C, $E = 1.6 \times 10^5$ Vm^{-1}

Force on α-particle

$F = q_\alpha F = 3.2 \times 10^{-19} \times 1.6 \times 10^5$

$= 51.2 \times 10^{-15}$N

Now, acceleration of the particle

$$\alpha = \frac{F}{m_\alpha} = \frac{51.2 \times 10^{-15}}{6.4 \times 10^{-27}} = 0.8 \times 10^{13} \text{ ms}^{-2}$$

$\because$ Initial velocity, u = 0

$\therefore$ $v^2 = 2\alpha s$

$= 2 \times 8 \times 10^{12} \times 2 \times 10^{-2}$

$= 32 \times 10^{10}$

or

$v = 4\sqrt{2} \times 10^5$ms^{-1}

34. (a)

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mE}} \therefore E = \frac{h^2}{2m\lambda^2}$$

λ is same for all, so $E \propto \frac{1}{m}$. Hence energy will be maximum for particle with lesser mass

35. (c)

$eV_0 = hv - hv_0$

$\therefore$ Threshold frequency,

$$v_0 = v - \frac{eV_0}{h}$$

$$= \frac{c}{\lambda} - \frac{eV_0}{h}$$

$$\therefore = \frac{3\times10^8}{2.2\times10^{-7}} - \frac{1.6\times10^{-19}\times2.2}{6.6\times10^{-34}}$$

$= 8.3 \times 10^{14}\ Hz$

36. (b)

Peak of K_α in greater than peak of K_β line

37. (d)

$$\lambda_{\min} = \frac{hc}{eV} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19}V}$$

$$= \frac{12375}{V} \approx \frac{12400}{V} \text{ Å}$$

38. (b)

Cathode rays are composed of electrons, when they move in electric field a force

$F = eE$ ...(i)

Acts on them, this provides the necessary centripetal force to the particles

$F = \frac{mv^2}{r}$ ...(ii)

rom Eqs. (i) and (ii), we get

$$eE = \frac{mv^2}{r}$$

$\Rightarrow$ $r = \frac{mv^2}{eE} = \frac{m(2*10^6)^2}{e(300)}$ ...(iii)

When velocity is doubled same circular path is followed, hence radius is same

$r = \frac{m(4\times10^6)^2}{eE}$ ...(iv)

Equating Eqs. (iii) and (iv), we get

$$m \times \frac{(2*10^6)^2}{150e} = \frac{m\times(4\times10^6)^2}{eE}$$

$\Rightarrow$ $E = 150 \times 4 = 600$ V-cm^{-1}

39. (a)

All the positive ions of same specific charge moving with different velocity lie on the same parabola

40. (c)

de- Broglie wavelength of electron is given by

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

Substituting the value of E, we get

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

Here m=9.1×10^{-31} kg; $e = 1.6 \times 10^{-19}$C

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

we get $\lambda = \frac{12.27}{\sqrt{V}} \times 10^{-10} = \frac{12.27}{\sqrt{V}}$ Å

The de-Broglie wavelength of electrons, when accelerated through a potential difference of 90 V will be

$$\lambda = \frac{12.27}{\sqrt{90}} = 1.29\text{Å}$$

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

$\Rightarrow P = \frac{6.6\times10^{-34}}{1.29\times10^{-10}} = 5.11 \times 10^{-24}$ kg-ms^{-1}

41. (d)

According to Moseley's law, when $\sqrt{v}$ is plotted against Z, one gets a straight line. v is the frequency of the X-ray lines. $v \propto Z^2$ or $\sqrt{v} \propto Z$

42. (a)

On observing the graphs, it is very clear that nature of current in all the cases will be same. Maximum current will be registered in the case having the minimum work function. So, p will have highest current in any given voltage.