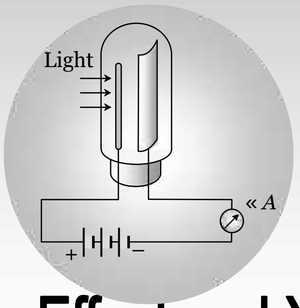


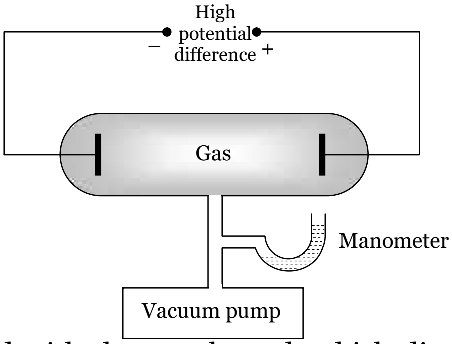
Electron, Photon, Photoelectric Effect and X-rays

Electric Discharge Through Gases

At normal atmospheric pressure, the gases are poor conductor of electricity. If we establish a potential difference (of the order of 30 *kV*) between two electrodes placed in air at a distance of few *cm* from each other, electric conduction starts in the form of sparks.

The passage of electric current through air is called electric discharge through the air.

The discharge of electricity through gases can be systematically studied with the help of discharge tube shown below



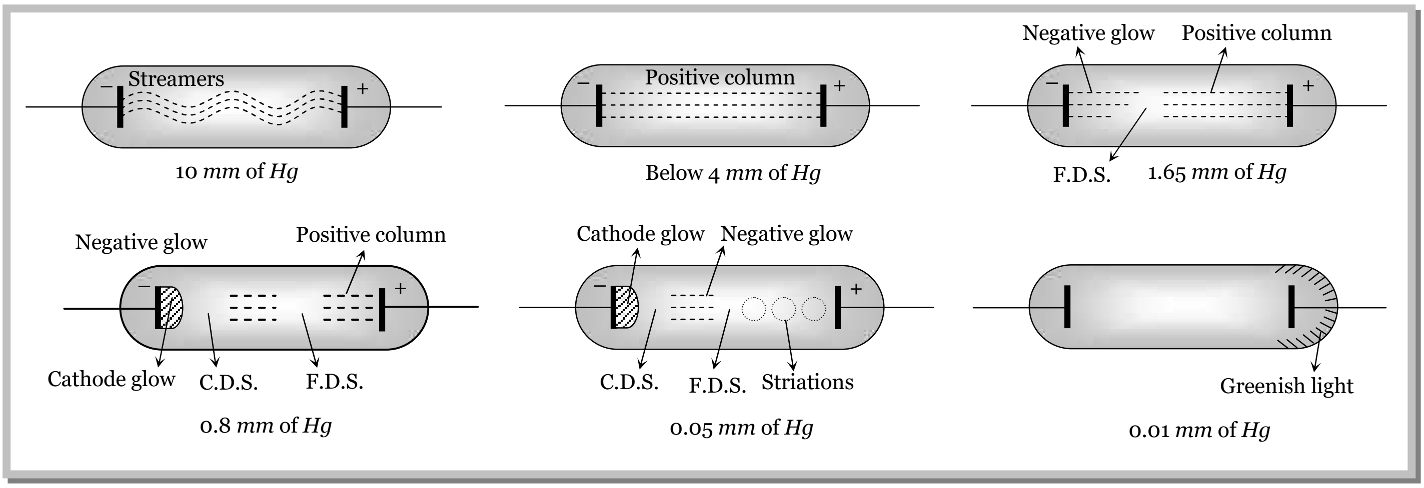
Length of discharge tube ≈ 30 to 40 *cm*

Diameter of the tube ≈ 4*cm*

The discharge tube is filled with the gas through which discharge is to be studied. The pressure of the enclosed gas can be reduced with the help of a vacuum pump and it's value is read by manometer.

Sequence of phenomenon

As the pressure inside the discharge tube is gradually reduced, the following is the sequence of phenomenon that are observed.



(1) At normal pressure no discharge takes place.

(2) At the pressure 10 *mm* of *Hg*, a zig-zag thin red spark runs from one electrode to other and cracking sound is heard.

(3) At the pressure 4 *mm.* of *Hg*, an illumination is observed at the electrodes and the rest of the tube appears dark. This type of discharge is called dark discharge.

(4) When the pressure falls below 4 *mm* of *Hg* then the whole tube is filled with bright light called positive column and colour of light depends upon the nature of gas in the tube as shown in the following table.

Gas	Colour
Air	Purple red
H_2	Blue
N_2	Red
Cl_2	Green
CO_2	Bluish white
Na	Yellow
Neon	Dark red

(5) At a pressure of 1.65 *mm* of *Hg* :

(i) Sky colour light is produced at the cathode it is called as negative glow.

(ii) Positive column shrinks towards the anode and the dark space between positive column and negative glow is called Faradays dark space (FDS)

(6) At a pressure of 0.8 *mm Hg* : At this pressure, negative glow is detached from the cathode and moves towards the anode. The dark space created between cathode and negative glow is called as Crook's dark space length of positive column further reduced. A glow appear at cathode called cathode glow.

(7) At a pressure of 0.05 *mm* of *Hg* : The positive column splits into dark and bright disc of light called striations.

(8) At the pressure of 0.01 or 10^{-2} *mm* of *Hg* some invisible particle move from cathode which on striking with the glass tube of the opposite side of cathode cause the tube to glow. These invisible rays emerging from cathode are called cathode rays.

(9) Finally when pressure drops to nearly 10^{-4} *mm* of *Hg*, there is no discharge in tube.

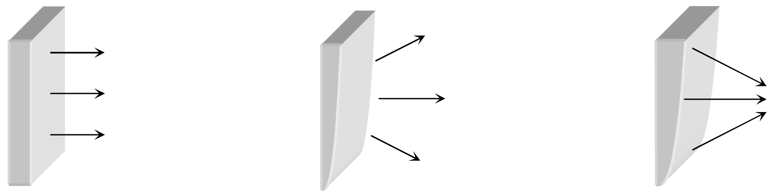
Cathode Rays

Cathode rays, discovered by sir Willium Crooke are the stream of electrons. They can be produced by using a discharge tube containing gas at a low pressure of the order of 10^{-2} *mm* of *Hg*. At this pressure the gas molecules ionise and the emitted electrons travel towards positive potential of anode. The positive ions hit the cathode to cause emission of electrons from cathode. These electrons also move towards anode. Thus the cathode rays in the discharge tube are the electrons produced due to ionisation of gas and that emitted by cathode due to collision of positive ions.

(1) **Properties of cathode rays**

(i) Cathode rays travel in straight lines (cast shadows of objects placed in their path)

(ii) Cathode rays emit normally from the cathode surface. Their direction is independent of the position of the anode.



(iii) Cathode rays exert mechanical force on the objects they strike.

(iv) Cathode rays produce heat when they strikes a material surface.

(v) Cathode rays produce fluorescence.

(vi) When cathode rays strike a solid object, specially a metal of high atomic weight and high melting point X-rays are emitted from the objects.

(vii) Cathode rays are deflected by an electric field and also by a magnetic field.

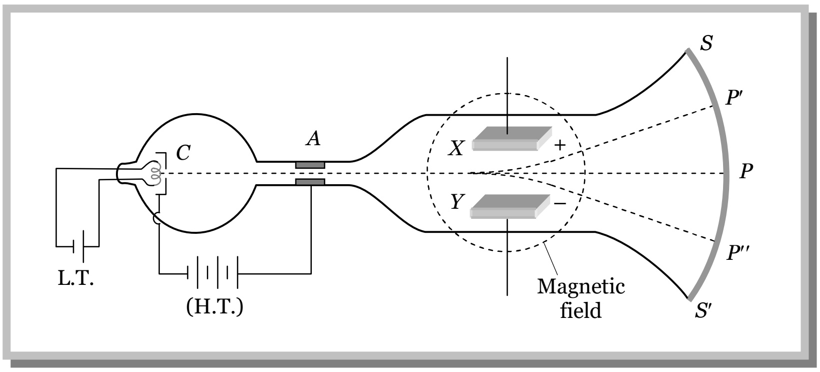
(viii) Cathode rays ionise the gases through which they are passed.

(ix) Cathode rays can penetrate through thin foils of metal.

(x) Cathode rays are found to have velocity ranging $\frac{1}{30}th$ to $\frac{1}{10}th$ of velocity of light.

(2) **J.J. Thomson's method to determine specific charge of electron**

It's working is based on the fact that if a beam of electron is subjected to the crossed electric field $\vec{E}$ and magnetic field $\vec{B}$, it experiences a force due to each field. In case the forces on the electrons in the electron beam due to these fields are equal and opposite, the beam remains undeflected.



C = Cathode, A = Anode, F = Filament, LT = Battery to heat the filament, V = potential difference to accelerate the electrons, SS' = ZnS coated screen, XY = metallic plates (Electric field produced between them)

(i) When no field is applied, the electron beam produces illuminations at point P.

(ii) In the presence of any field (electric and magnetic) electron beam deflected up or down (illumination at P' or P'')

(iii) If both the fields are applied simultaneously and adjusted such that electron beam passes undeflected and produces illumination at point P.

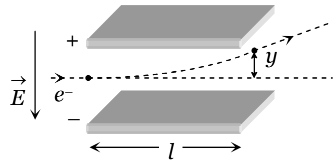
In this case; Electric force = Magnetic force $\Rightarrow eE = evB \Rightarrow v = \frac{E}{B}$; v = velocity of electron

As electron beam accelerated from cathode to anode its potential energy at the cathode appears as gain in the K.E. at the anode. If suppose V is the potential difference between cathode and anode then, potential energy = eV

And gain in kinetic energy at anode will be K.E. $= \frac{1}{2}mv^2$ i.e. $eV = \frac{1}{2}mv^2 \Rightarrow \frac{e}{m} = \frac{v^2}{2V} \Rightarrow \frac{e}{m} = \frac{E^2}{2VB^2}$

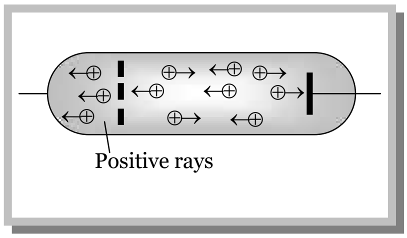
Thomson found, $\frac{e}{m} = 1.77 \times 10^{11}\ C/kg$.

Note : ❑ The deflection of an electron in a purely electric field is given by $y = \frac{1}{2}\left(\frac{eE}{m}\right).\frac{l^2}{v^2}$; where l length of each plate, y = deflection of electron in the field region, v = speed of the electron.



Positive Rays

Positive rays are sometimes known as the canal rays. These were discovered by Goldstein. If the cathode of a discharge tube has holes in it and the pressure of the gas is around 10^{-3} *mm* of *Hg* then faint luminous glow comes out from each hole on the backside of the cathode. It is said positive rays which are coming out from the holes.



(1) **Origin of positive rays**

When potential difference is applied across the electrodes, electrons are emitted from the cathode. As they move towards anode, they gain energy. These energetic electrons when collide with the atoms of the gas in the discharge tube, they ionize the atoms. The positive ions so formed at various places between cathode and anode, travel towards the cathode. Since during their motion, the positive ions when reach the cathode, some pass through the holes in the cathode. These streams are the positive rays.

(2) **Properties of positive rays**

(i) These are positive ions having same mass if the experimental gas does not have isotopes. However if the gas has isotopes then positive rays are group of positive ions having different masses.

(ii) They travels in straight lines and cast shadows of objects placed in their path. But the speed of the positive rays is much smaller than that of cathode rays.

(iii) They are deflected by electric and magnetic fields but the deflections are small as compared to that for cathode rays.

(iv) They show a spectrum of velocities. Different positive ions move with different velocities. Being heavy, their velocity is much less than that of cathode rays.

(v) q/m ratio of these rays depends on the nature of the gas in the tube (while in case of the cathode rays q/m is constant and doesn't depend on the gas in the tube). q/m for hydrogen is maximum.

(vi) They carry energy and momentum. The kinetic energy of positive rays is more than that of cathode rays.

(vii) The value of charge on positive rays is an integral multiple of electronic charge.

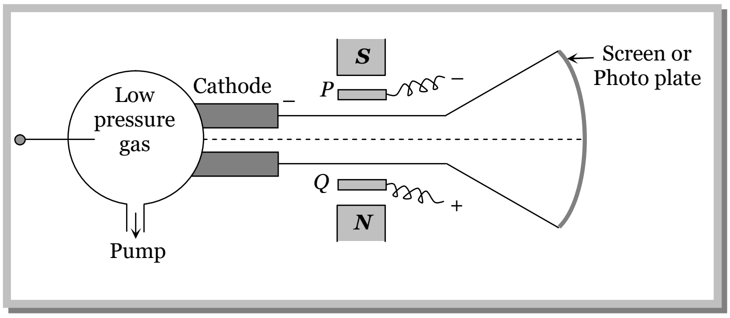
(viii) They cause ionisation (which is much more than that produced by cathode rays).

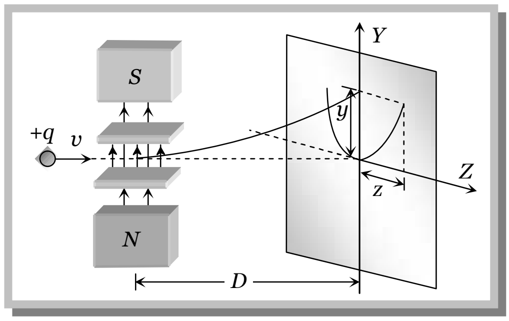
Mass Spectrograph

It is a device used to determine the mass or (q/m) of positive ions.

(1) **Thomson mass spectrograph**

It is used to measure atomic masses of various isotopes in gas. This is done by measuring q/m of singly ionised positive ions of the gas.





The positive ions are produced in the bulb at the left hand side. These ions are accelerated towards cathode. Some of the positive ions pass through the fine hole in the cathode. This fine ray of positive ions is subjected to electric field E and magnetic field B and then allowed to strike a fluorescent screen ($\vec{E} \parallel \vec{B}$ but $\vec{E}$ or $\vec{B} \perp \vec{v}$).

If the initial motion of the ions is in $+x$ direction and electric and magnetic fields are applied along $+y$ axis then force due to electric field is in the direction of y-axis and due to magnetic field it is along z-direction.

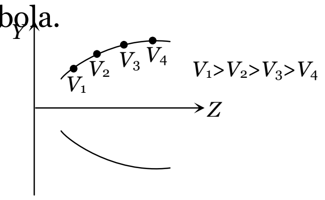
The deflection due to electric field alone $y = \dfrac{qELD}{mv^2}$ ....(i)

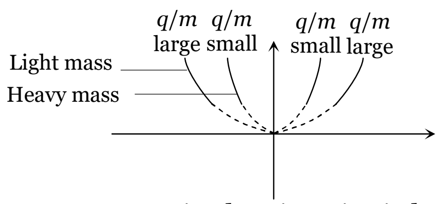
The deflection due to magnetic field alone $z = \dfrac{qBLD}{mv}$ ....(ii)

From equation (i) and (ii)

$z^2 = k\left(\dfrac{q}{m}\right)y$, where $k = \dfrac{B^2LD}{E}$; This is the equation of parabola. It means all the charged particles moving with different velocities but of same q/m value will strike the screen placed in yz plane on a parabolic track as shown in the above figure.

Note : ❑ All the positive ions of same. q/m moving with different velocity lie on the same parabola. Higher is the velocity lower is the value of y and z. The ions of different specific charge will lie on different parabola.





❑ The number of parabola tells the number of isotopes present in the given ionic beam.

(2) **Bainbridge mass spectrograph**

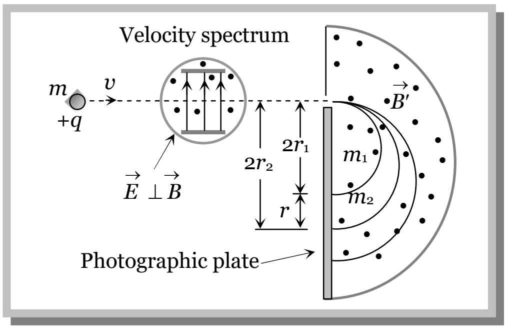
In Bainbridge mass spectrograph, field particles of same velocity are selected by using a velocity selector and then they are subjected to a uniform magnetic field perpendicular to the velocity of the particles. The particles corresponding to different isotopes follow different circular paths as shown in the figure.

(i) **Velocity selector :** The positive ions having a certain velocity v gets isolated from all other velocity particles. In this chamber the electric and magnetic fields are so balanced that the particle moves undeflected. For this the necessary condition is $v = \frac{E}{B}$.

(ii) **Analysing chamber :** In this chamber magnetic field B is applied perpendicular to the direction of motion of the particle. As a result the particles move along a circular path of radius

$$r = \frac{mE}{qBB'} \Rightarrow \frac{q}{m} = \frac{E}{BB'r} \text{ also } \frac{r_1}{r_2} = \frac{m_1}{m_2}$$

In this way the particles of different masses gets deflected on circles of different radii and reach on different points on the photo plate.



Note : ❑ Separation between two traces $= d = 2r_2 - 2r_1 \Rightarrow d = \frac{2v(m_2 - m_1)}{qB'}$.

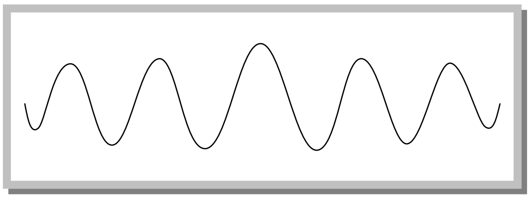
Matter waves (de-Broglie Waves)

According to de-Broglie a moving material particle sometimes acts as a wave and sometimes as a particle.

or

A wave is associated with moving material particle which control the particle in every respect.

The wave associated with moving particle is called matter wave or de-Broglie wave and it propagates in the form of wave packets with group velocity.



(1) **de-Broglie wavelength**

According to de-Broglie theory, the wavelength of de-Broglie wave is given by

$$a = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE}} \qquad \Rightarrow a \propto \frac{1}{p} \propto \frac{1}{v} \propto \frac{1}{\sqrt{E}}$$

Where h = Plank's constant, m = Mass of the particle, v = Speed of the particle, E = Energy of the particle.

The smallest wavelength whose measurement is possible is that of ¥ -rays.

The wavelength of matter waves associated with the microscopic particles like electron, proton, neutron, ~-particle *etc.* is of the order of 10^{-10} *m*.

(i) **de-Broglie wavelength associated with the charged particles.**

The energy of a charged particle accelerated through potential difference V is $E = \frac{1}{2}mv^2 = qV$

Hence de-Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$

$$\lambda_{electron} = \frac{12.27}{\sqrt{V}}\mathring{A}, \quad \lambda_{proton} = \frac{0.286}{\sqrt{V}}\mathring{A}, \quad \lambda_{deutron} = \frac{0.202 \times 10^{-10}}{\sqrt{V}}\mathring{A}, \quad \lambda_{\alpha-particle} = \frac{0.101}{\sqrt{V}}\mathring{A}$$

(ii) **de-Broglie wavelength associated with uncharged particles.**

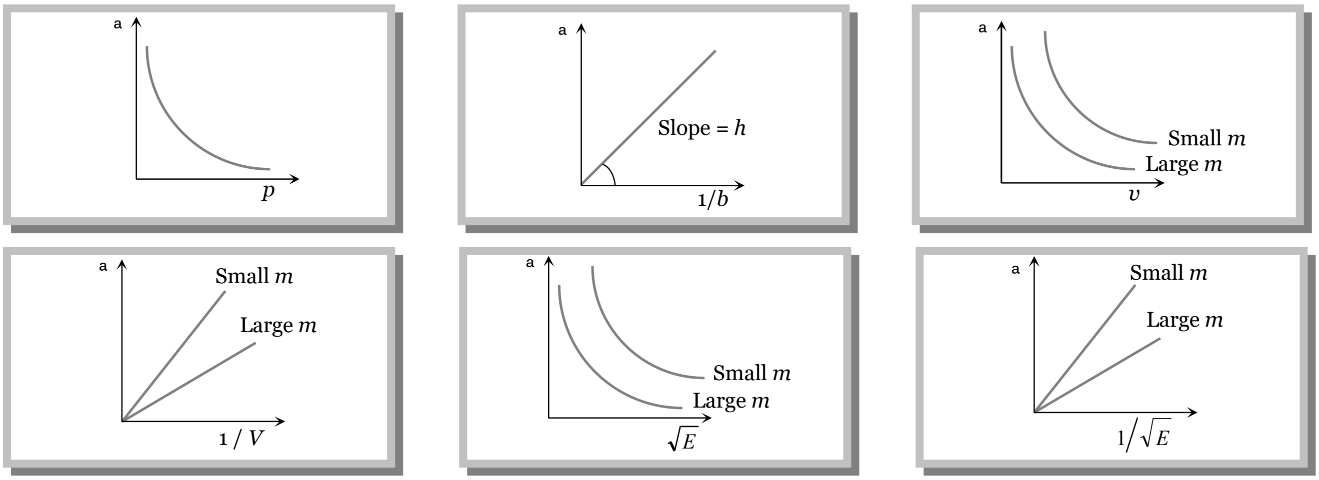
For *Neutron* *d*e-Broglie wavelength is given as $\lambda_{Neutron} = \frac{0.286 \times 10^{-10}}{\sqrt{E(\text{in } eV)}}m = \frac{0.286}{\sqrt{E(\text{in } eV)}}\mathring{A}$

Energy of thermal neutrons at ordinary temperature

$\because \; E = kT \Rightarrow \lambda = \frac{h}{\sqrt{2mkT}}$; where k = Boltzman's constant = 1.38×10^{-23} *Joules/kelvin* , T = Absolute temp.

So $\lambda_{\text{Thermal Neutron}} = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 1.07 \times 10^{-17} \times 1.38 \times 10^{-23}\, T}} = \frac{30.83}{\sqrt{T}}\mathring{A}$

(2) **Some graphs**



Note : ❑ A photon is not a material particle. It is a quanta of energy.

❑ When a particle exhibits wave nature, it is associated with a wave packet, rather then a wave.

(3) **Characteristics of matter waves**

(i) Matter wave represents the probability of finding a particle in space.

(ii) Matter waves are not electromagnetic in nature.

(iii) de-Brogile or matter wave is independent of the charge on the material particle. It means, matter wave of de-Broglie wave is associated with every moving particle (whether charged or uncharged).

(iv) Practical observation of matter waves is possible only when the de-Broglie wavelength is of the order of the size of the particles is nature.

(v) Electron microscope works on the basis of de-Broglie waves.

(vi) The electric charge has no effect on the matter waves or their wavelength.

(vii) The phase velocity of the matter waves can be greater than the speed of the light.

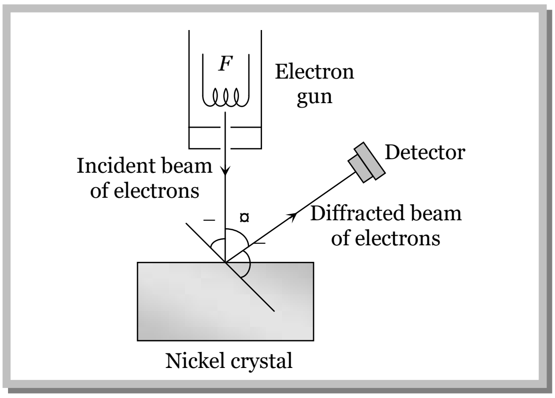
(viii) Matter waves can propagate in vacuum, hence they are not mechanical waves.

(ix) The number of de-Broglie waves associated with n^{th} orbital electron is n.

(x) Only those circular orbits around the nucleus are stable whose circumference is integral multiple of de-Broglie wavelength associated with the orbital electron.

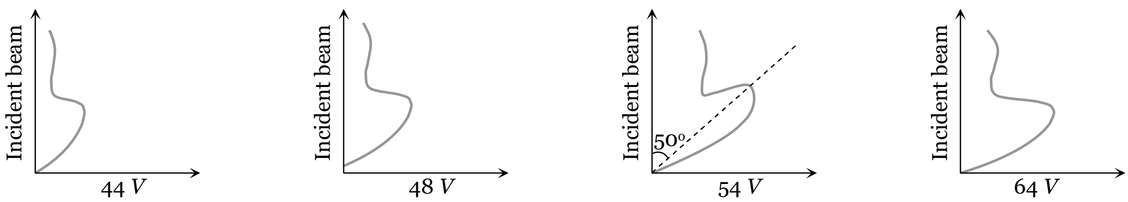
(4) **Davision and Germer experiment**

It is used to study the scattering of electron from a solid or to verify the wave nature of electron. A beam of electrons emitted by electron gun is made to fall on nickel crystal cut along cubical axis at a particular angle. *Ni* crystal behaves like a three dimensional diffraction grating and it diffracts the electron beam obtained from electron gun.



The diffracted beam of electrons is received by the detector which can be positioned at any angle by rotating it about the point of incidence. The energy of the incident beam of electrons can also be varied by changing the applied voltage to the electron gun.

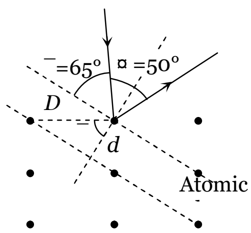
According to classical physics, the intensity of scattered beam of electrons at all scattering angle will be same but Davisson and Germer, found that the intensity of scattered beam of electrons was not the same but different at different angles of scattering.



Intensity is maximum at 54 *V* potential difference and 50° diffraction angle.

If the de-Broglie waves exist for electrons then these should be diffracted as *X*-rays. Using the Bragg's formula $2d\sin\theta = n\lambda$, we can determine the wavelength of these waves.

Where d = distance between diffracting planes, $\theta = \frac{(180 - \phi)}{2}$ = glancing angle for incident beam = Bragg's angle.



The distance between diffraction planes in *Ni*-crystal for this experiment is $d = 0.91 Å$ and the Bragg's angle = 65^o. This gives for $n = 1$, $\lambda = 2 \times 0.91 \times 10^{-10} \sin 65^o = 1.65\ Å$

Now the de-Broglie wavelength can also be determined by using the formula $\lambda = \frac{12.27}{\sqrt{V}} = \frac{12.27}{\sqrt{54}} = 1.67\ Å$.

Thus the de-Broglie hypothesis is verified.

Heisenberg Uncertainty Principle

According to Heisenberg's uncertainty principle, it is impossible to measure simultaneously both the position and the momentum of the particle.

Let Δx and Δp be the uncertainty in the simultaneous measurement of the position and momentum of the particle, then $\Delta x \Delta p = \hbar$; where $\hbar = \frac{h}{2\pi}$ and $h = 6.63 \times 10^{-34}$ *J-s* is the Planck's constant.

If $\Delta x = 0$ then $\Delta p = \infty$

and if $\Delta p = 0$ then $\Delta x = \infty$ *i.e.,* if we are able to measure the exact position of the particle (say an electron) then the uncertainty in the measurement of the linear momentum of the particle is infinite. Similarly, if we are able to measure the exact linear momentum of the particle *i.e.*, $\Delta p = 0$, then we can not measure the exact position of the particle at that time.

Photon

According to Eienstein's quantum theory light propagates in the bundles (packets or quanta) of energy, each bundle being called a photon and possessing energy.

(1) **Energy of photon**

Energy of each photon is given by $E = h\nu = \frac{hc}{\lambda}$; where c = Speed of light, h = Plank's constant = 6.6×10^{-34} *J-sec*, ν = Frequency in *Hz*, λ = Wavelength of light

Energy of photon in electron volt $E(eV) = \frac{hc}{e\lambda} = \frac{12375}{\lambda(Å)} \approx \frac{12400}{\lambda(Å)}$

(2) **Mass of photon**

Actually rest mass of the photon is zero. But it's effective mass is given as

$E = mc^2 = h\nu \Rightarrow m = \frac{E}{c^2} = \frac{h\nu}{c^2} = \frac{h}{c\lambda}$. This mass is also known as kinetic mass of the photon

(3) **Momentum of the photon**

Momentum $p = m \times c = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$

(4) **Number of emitted photons**

The number of photons emitted per second from a source of monochromatic radiation of wavelength a and power P is given as $(n) = \frac{P}{E} = \frac{P}{h¬} = \frac{Pa}{hc}$; where E = energy of each photon

(5) **Intensity of light (*I*)**

Energy crossing per unit area normally per second is called intensity or energy flux

i.e. $I = \frac{E}{At} = \frac{P}{A}$ $\left(\frac{E}{t} = P = \text{radiation power}\right)$

At a distance r from a point source of power P intensity is given by $I = \frac{P}{4®r^2} \Rightarrow I \propto \frac{1}{r^2}$

Concepts

- *Discovery of positive rays helps in discovering of isotopes.*
- *The de-Broglie wavelength of electrons in first Bohr orbit of an atom is equal to circumference of orbit.*
- *A particle having zero rest mass and non zero energy and momentum must travels with a speed equal to speed of light.*
- ***de-Broglie wave length associates with gas molecules** is given as* $a = \frac{h}{mv_{rms}} = \frac{h}{\sqrt{3\,mkT}}$ *(Energy of gas molecules at temperature T is* $E = \frac{3}{2}kT$ *)*

Example

***Example*: 1** The ratio of specific charge of an ~ -particle to that of a proton is

(a) 2 : 1 (b) 1 : 1 (c) 1 : 2 (d) 1 : 3

Solution : (c) Specific charge $= \frac{q}{m}$; Ratio $= \frac{(q/m)_{\sim}}{(q/m)_p} = \frac{q_{\sim}}{q_p} \times \frac{m_p}{m_{\sim}} = \frac{1}{2}$.

***Example*: 2** The speed of an electron having a wavelength of $10^{-10}\,m$ is

(a) $7.25 \times 10^6\, m/s$ (b) $6.26 \times 10^6\, m/s$ (c) $5.25 \times 10^6\, m/s$ (d) $4.24 \times 10^6\, m/s$

Solution : (a) By using $a_{electron} = \frac{h}{m_e v} \Rightarrow v = \frac{h}{m_e a_e} = \frac{6.6 \times 10^{-34}}{9.1 \times 10^{-31} \times 10^{-10}} = 7.25 \times 10^6\, m/s.$

***Example*: 3** In Thomson experiment of finding *e/m* for electrons, beam of electron is replaced by that of muons (particle with same charge as of electrons but mass 208 times that of electrons). No deflection condition in this case satisfied if

(a) *B* is increased 208 times (b) *E* is increased 208 times

(c) *B* is increased 14.4 times (d) None of these

Solution : (c) In the condition of no deflection $\frac{e}{m} = \frac{E^2}{2VB^2}$. If m is increased to 208 times then B should be increased by $\sqrt{208} = 14.4$ times.

Example: 4 In a Thomson set-up for the determination of *e/m,* electrons accelerated by 2.5 *kV* enter the region of crossed electric and magnetic fields of strengths $3.6\times10^{4}\ Vm^{-1}$ and $1.2\times10^{-3}\ T$ respectively and go through undeflected. The measured value of *e/m* of the electron is equal to

(a) $1.0\times10^{11}\ C\text{-}kg^{-1}$ (b) $1.76\times10^{11}\ C\text{-}kg^{-1}$ (c) $1.80\times10^{11}\ C\text{-}kg^{-1}$ (d) $1.85\times10^{11}\ C\text{-}kg^{-1}$

Solution : (c) By using $\frac{e}{m}=\frac{E^2}{2VB^2}\Rightarrow\frac{e}{m}=\frac{(3.6\times10^4)^2}{2\times2.5\times10^3\times(1.2\times10^{-3})^2}=1.8\times10^{11}\ C/kg.$

Example: 5 In Bainbridge mass spectrograph a potential difference of 1000 *V* is applied between two plates distant 1 *cm* apart and magnetic field in *B* = 1*T*. The velocity of undeflected positive ions in *m/s* from the velocity selector is

(a) $10^7\ m/s$ (b) $10^4\ m/s$ (c) $10^5\ m/s$ (d) $10^2\ m/s$

Solution : (c) By using $v=\frac{E}{B}$; where $E=\frac{V}{d}=\frac{1000}{1\times10^{-2}}=10^5\ V/m\ \Rightarrow v=\frac{10^5}{1}=10^5\ m/s$.

Example: 6 An electron and a photon have same wavelength. It *p* is the momentum of electron and *E* the energy of photon. The magnitude of *p/ E* in S.I. unit is

(a) 3.0×10^{8} (b) 3.33×10^{-9} (c) 9.1×10^{-31} (d) 6.64×10^{-34}

Solution : (b) $a=\frac{h}{p}$ (for electron) or $p=\frac{h}{a}$ and $E=\frac{hc}{a}$ (for photon)

$\therefore\ \frac{p}{E}=\frac{1}{c}=\frac{1}{3\times10^8\ m/s}=3.33\times10^{-9}\ s/m$

Example: 7 The energy of a photon is equal to the kinetic energy of a proton. The energy of the photon is *E*. Let a_1 be the de-Broglie wavelength of the proton and a_2 be the wavelength of the photon. The ratio a_1/a_2 is proportional to

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

Solution : (b) For photon $a_2=\frac{hc}{E}$ .... (i) and For proton $a_1=\frac{h}{\sqrt{2mE}}$ ....(ii)

Therefore $\frac{a_1}{a_2}=\frac{E^{1/2}}{\sqrt{2m}\ c}\Rightarrow\frac{a_1}{a_2}\propto E^{1/2}$.

Example: 8 The de-Broglie wavelength of an electron having 80*eV* of energy is nearly ($1eV=1.6\times10^{-19}J$, Mass of electron $9\times10^{-31}kg$ and Plank's constant 6.6×10^{-34} *J-sec*)

(a) 140 Å (b) 0.14 Å (c) 14 Å (d) 1.4 Å

Solution : (d) By using $a=\frac{h}{\sqrt{2mE}}=\frac{12.27}{\sqrt{V}}$. If energy is 80 *eV* then accelerating potential difference will be 80 *V*. So $a=\frac{12.27}{\sqrt{80}}=1.37\approx1.4$ Å.

Example: 9 The kinetic energy of electron and proton is $10^{-32}J$. Then the relation between their de-Broglie wavelengths is

(a) $a_p<a_e$ (b) $a_p>a_e$ (c) $a_p=a_e$ (d) $a_p=2a_e$

Solution : (a) By using $a=\frac{h}{\sqrt{2mE}}$ $E=10^{-32}J$ = Constant for both particles. Hence $a\propto\frac{1}{\sqrt{m}}$

Since $m_p>m_e$ so $a_p<a_e$.

***Example*: 10** The energy of a proton and an ~ particle is the same. Then the ratio of the de-Broglie wavelengths of the proton and the ~ is

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

Solution : (b) By using $ª = \frac{h}{\sqrt{2mE}} \Rightarrow ª \propto \frac{1}{\sqrt{m}}$ (E – same) $\Rightarrow \frac{ª_{proton}}{ª_{\sim-particle}} = \sqrt{\frac{m_{\sim}}{m_p}} = \frac{2}{1}$.

***Example*: 11** The de-Broglie wavelength of a particle accelerated with 150 *volt* potential is 10^{-10} *m*. If it is accelerated by 600 *volts* p.d., its wavelength will be

(a) 0.25 $Å$ (b) 0.5 $Å$ (c) 1.5 $Å$ (d) 2 $Å$

Solution : (b) By using $ª \propto \frac{1}{\sqrt{V}} \Rightarrow \frac{ª_1}{ª_2} = \sqrt{\frac{V_2}{V_1}} \Rightarrow \frac{10^{-10}}{ª_2} = \sqrt{\frac{600}{150}} = 2 \Rightarrow ª_2 = 0.5\,Å$.

***Example*: 12** The de-Broglie wavelength of an electron in an orbit of circumference $2®r$ is

(a) $2®r$ (b) $®r$ (c) $1/2®r$ (d) $1/4®r$

Solution : (a) According to Bohr's theory $mv\,r = n\frac{h}{2®} \Rightarrow 2®\,r = n\left(\frac{h}{mv}\right) = nª$

For $n = 1$ $ª = 2®r$

***Example*: 13** The number of photons of wavelength 540 *nm* emitted per second by an electric bulb of power 100*W* is (taking $h = 6 \times 10^{-34}$ *J-sec*)

(a) 100 (b) 1000 (c) 3×10^{20} (d) 3×10^{18}

Solution : (c) By using $n = \frac{Pª}{hc} = \frac{100 \times 540 \times 10^{-9}}{6.6 \times 10^{-34} \times 3 \times 10^{8}} = 3 \times 10^{20}$

***Example*: 14** A steel ball of mass 1*kg* is moving with a velocity 1 *m/s*. Then its de-Broglie waves length is equal to

(a) h (b) $h/2$ (c) Zero (d) $1/h$

Solution : (a) By using $ª = \frac{h}{mv} \Rightarrow ª = \frac{ª}{1 \times 1} = h.$

***Example*: 15** The de-Broglie wavelength associated with a hydrogen atom moving with a thermal velocity of 3 *km/s* will be

(a) 1 $Å$ (b) 0.66 $Å$ (c) 6.6 $Å$ (d) 66 $Å$

Solution : (b) By using $ª = \frac{h}{mv_{rms}} \Rightarrow ª = \frac{6.6 \times 10^{-34}}{2 \times 1.67 \times 10^{-27} \times 3 \times 10^{3}} = 0.66\,Å$

***Example*: 16** When the momentum of a proton is changed by an amount P_0, the corresponding change in the de-Broglie wavelength is found to be 0.25%. Then, the original momentum of the proton was

(a) p_0 (b) 100 p_0 (c) 400 p_0 (d) 4 p_0

Solution : (c) $ª \propto \frac{1}{p} \Rightarrow \frac{\Delta p}{p} = -\frac{\Delta ª}{ª} \Rightarrow \left|\frac{\Delta p}{p}\right| = \left|\frac{\Delta ª}{ª}\right| \Rightarrow \frac{p_0}{p} = \frac{0.25}{100} = \frac{1}{400} \Rightarrow p = 400\,p_0$.

***Example*: 17** If the electron has same momentum as that of a photon of wavelength 5200Å, then the velocity of electron in *m /sec* is given by

(a) 10^3 (b) 1.4×10^3 (c) 7×10^{-5} (d) 7.2×10^6

Solution : (b) $ª = \frac{h}{mv} \Rightarrow v = \frac{h}{mª} = \frac{6.6 \times 10^{-34}}{9.1 \times 10^{-31} \times 5200 \times 10^{-10}} \Rightarrow v = 1.4 \times 10^3$ *m/s*.

***Example*: 18** The de-Broglie wavelength of a neutron at 27°*C* is λ. What will be its wavelength at 927°*C*

(a) $\lambda / 2$ (b) $\lambda / 3$ (c) $\lambda / 4$ (d) $\lambda / 9$

Solution : (a) $\lambda_{neutron} \propto \frac{1}{\sqrt{T}} \Rightarrow \frac{\lambda_1}{\lambda_2} = \sqrt{\frac{T_2}{T_1}} \Rightarrow \frac{\lambda}{\lambda_2} = \sqrt{\frac{(273+927)}{(273+27)}} = \sqrt{\frac{1200}{300}} = 2 \Rightarrow \lambda_2 = \frac{\lambda}{2}.$

***Example*: 19** The de-Broglie wavelength of a vehicle is λ. Its load is changed such that its velocity and energy both are doubled. Its new wavelength will be

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

Solution : (a) $\lambda = \frac{h}{mv}$ and $E = \frac{1}{2}mv^2 \Rightarrow \lambda = \frac{hv}{2E}$ when v and E both are doubled, λ remains unchanged *i.e.* $\lambda' = \lambda$.

***Example*: 20** In Thomson mass spectrograph when only electric field of strength 20 *kV/m* is applied, then the displacement of the beam on the screen is 2 *cm*. If length of plates = 5 *cm*, distance from centre of plate to the screen = 20 *cm* and velocity of ions = 10^6 *m/s*, then *q/m* of the ions is

(a) 10^6 *C/kg* (b) 10^7 *C/Kg* (c) 10^8 *C/kg* (d) 10^{11} *C/kg*

Solution : (c) By using $y = \frac{qELD}{mv^2}$; where *y* = deflection on screen due to electric field only

$$\Rightarrow \frac{q}{m} = \frac{yv^2}{ELD} = \frac{2\times10^{-2}\times(10^6)^2}{20\times10^3\times5\times10^{-2}\times0.2} = 10^8\ C/kg.$$

***Example*: 21** The minimum intensity of light to be detected by human eye is $10^{-10}\ W/m^2$. The number of photons of wavelength $5.6\times10^{-7}m$ entering the eye, with pupil area $10^{-6}m^2$, per second for vision will be nearly

(a) 100 (b) 200 (c) 300 (d) 400

Solution : (c) By using $I = \frac{P}{A}$; where *P* = radiation power

$$\Rightarrow P = I \times A \Rightarrow \frac{nhc}{t\lambda} = IA \Rightarrow \frac{n}{t} = \frac{IA\lambda}{hc}$$

Hence number of photons entering per sec the eye $\left(\frac{n}{t}\right) = \frac{10^{-10}\times10^{-6}\times5.6\times10^{-7}}{6.6\times10^{-34}\times3\times10^8} = 300.$

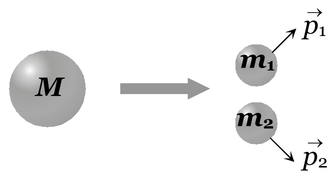
Tricky example: 1

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

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

Solution : (c) According to conservation of momentum *i.e.* $p_1 = p_2$

Hence from $\lambda = \dfrac{h}{p} \Rightarrow \dfrac{\lambda_1}{\lambda_2} = \dfrac{p_1}{p_2} = \dfrac{1}{1}$



Tricky example: 2

The curve drawn between velocity and frequency of photon in vacuum will be a

(a) Straight line parallel to frequency axis

(b) Straight line parallel to velocity axis

(c) Straight line passing through origin and making an angle of 45° with frequency axis

(d) Hyperbola

Solution : (a) Velocity of photon (*i.e.* light) doesn't depend upon frequency. Hence the graph between velocity of photon and frequency will be as follows.

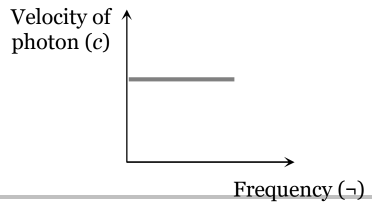


Photo-electric Effect

It is the phenomenon of emission of electrons from the surface of metals, when light radiations (Electromagnetic radiations) of suitable frequency fall on them. The emitted electrons are called photoelectrons and the current so produced is called photoelectric current.

This effect is based on the principle of conservation of energy.

(1) **Terms related to photoelectric effect**

(i) **Work function (or threshold energy) (W_0) :** The minimum energy of incident radiation, required to eject the electrons from metallic surface is defined as work function of that surface.

$$W_0 = h\nu_0 = \frac{hc}{\lambda_0} \text{ Joules}; \quad \nu_0 = \text{Threshold frequency}; \ \lambda_0 = \text{Threshold wavelength}$$

Work function in electron volt $W_0(eV) = \dfrac{hc}{e\lambda_0} = \dfrac{12375}{\lambda_0(\text{Å})}$

Note : ❑ By coating the metal surface with a layer of barium oxide or strontium oxide it's work function is lowered.

(ii) **Threshold frequency (ν_0) :** The minimum frequency of incident radiations required to eject the electron from metal surface is defined as threshold frequency.

If incident frequency $\nu < \nu_0 \Rightarrow$ No photoelectron emission

(iii) **Threshold wavelength (λ_0) :** The maximum wavelength of incident radiations required to eject the electrons from a metallic surface is defined as threshold wavelength.

If incident wavelength $\lambda > \lambda_0 \Rightarrow$ No photoelectron emission

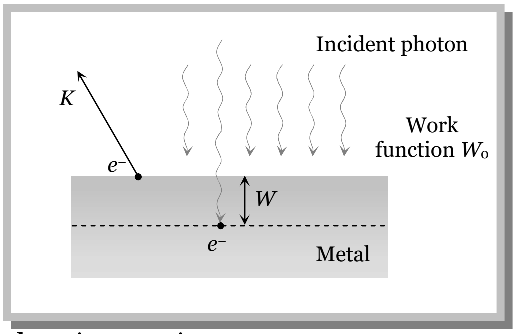
(2) **Einstein's photoelectric equation**

According to Einstein, photoelectric effect is the result of one to one inelastic collision between photon and electron in which photon is completely absorbed. So if an electron in a metal absorbs a photon of energy E $(= h\nu)$, it uses the energy in three following ways.

(i) Some energy (say W) is used in shifting the electron from interior to the surface of the metal.

(ii) Some energy (say W_0) is used in making the surface electron free from the metal.

(iii) Rest energy will appear as kinetic energy (K) of the emitted photoelectrons.



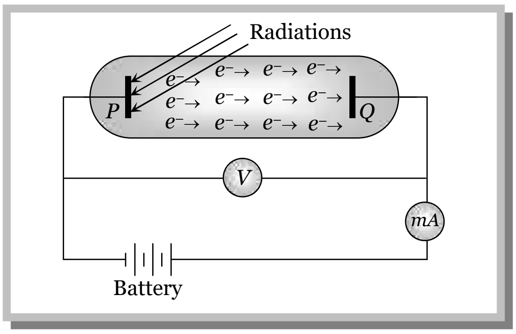
Hence $E = W + W_0 + K$

For the electrons emitting from surface $W = 0$ so kinetic energy of emitted electron will be max.

Hence $\boldsymbol{E = W_0 + K_{max}}$; This is the Einstein's photoelectric equation

(3) **Experimental arrangement to observe photoelectric effect**

When light radiations of suitable frequency (or suitable wavelength and suitable energy) falls on plate P, photoelectrons are emitted from P.



(i) If plate Q is at zero potential *w.r.t.* P, very small current flows in the circuit because of some electrons of high kinetic energy are reaching to plate Q, but this current has no practical utility.

(ii) If plate Q is kept at positive potential *w.r.t.* P current starts flowing through the circuit because more electrons are able to reach upto plate Q.

(iii) As the positive potential of plate Q increases, current through the circuit increases but after some time constant current flows through the circuit even positive potential of plate Q is still increasing, because at this condition all the electrons emitted from plate P are already reached up to plate Q. This constant current is called **saturation current.**

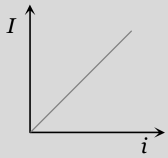
(iv) To increase the photoelectric current further we will have to increase the intensity of incident light.

Photoelectric current (i) depends upon

(a) Potential difference between electrodes (till saturation)

(b) Intensity of incident light (I)

(c) Nature of surface of metal



(v) To decrease the photoelectric current plate Q is maintained at negative potential *w.r.t.* P, as the anode Q is made more and more negative, fewer and fewer electrons will reach the cathode and the photoelectric current decreases.

(vi) At a particular negative potential of plate Q no electron will reach the plate Q and the current will become zero, this negative potential is called **stopping potential** denoted by V_0.

(vii) If we increase further the energy of incident light, kinetic energy of photoelectrons increases and more negative potential should be applied to stop the electrons to reach upto plate Q. Hence $eV_0 = K_{max}$.

Note : ❑ Stopping potential depends only upon frequency or wavelength or energy of incident radiation. It doesn't depend upon intensity of light.

We must remember that intensity of incident light radiation is inversely proportional to the square of distance between source of light and photosensitive plate P *i.e.*, $I \propto \frac{1}{d^2}$ so $I \propto i \propto \frac{1}{d^2}$)

Important formulae

$\Rightarrow h\nu = h\nu_0 + K_{\max}$

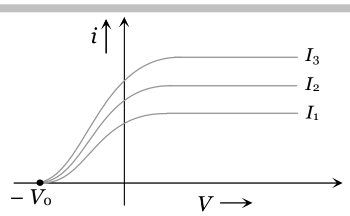
$\Rightarrow K_{\max} = eV_0 = h(\nu - \nu_0) \quad \Rightarrow \frac{1}{2} m v_{\max}^2 = h(\nu - \nu_0) \quad \Rightarrow v_{\max} = \sqrt{\frac{2h(\nu - \nu_0)}{m}}$

$\Rightarrow K_{\max} = \frac{1}{2} m v_{\max}^2 = eV_0 = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right) = hc\left(\frac{\lambda_0 - \lambda}{\lambda \lambda_0}\right) \Rightarrow v_{\max} = \sqrt{\frac{2hc}{m}\frac{(\lambda_0 - \lambda)}{\lambda \lambda_0}}$

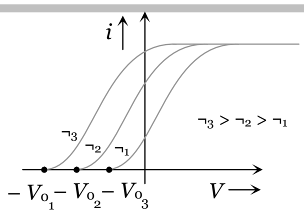
$\Rightarrow V_0 = \frac{h}{e}(\nu - \nu_0) = \frac{hc}{e}\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right) = 12375\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$

(4) **Different graphs**

(i) Graph between potential difference between the plates P and Q and photoelectric current

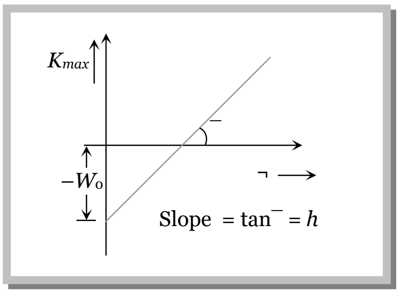


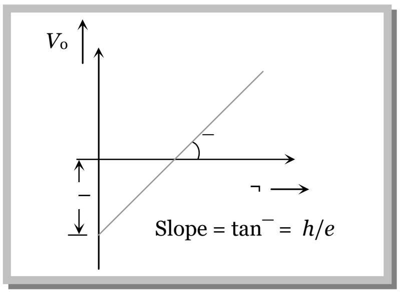
For different intensities of incident light



For different Frequencies of incident light

(ii) Graph between maximum kinetic energy / stopping potential of photoelectrons and frequency of incident light

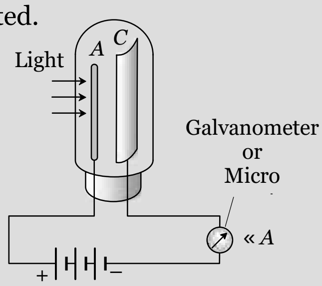
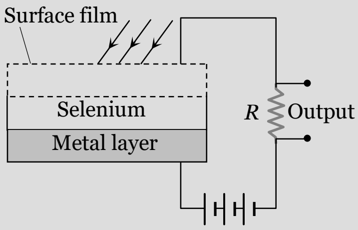
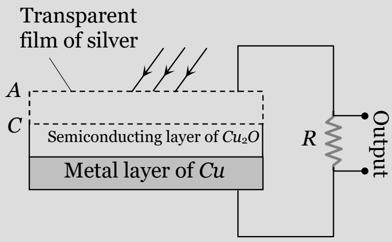




Photoelectric Cell

A device which converts light energy into electrical energy is called photoelectric cell. It is also known as photocell or electric eye.

Photoelectric cell are mainly of three types

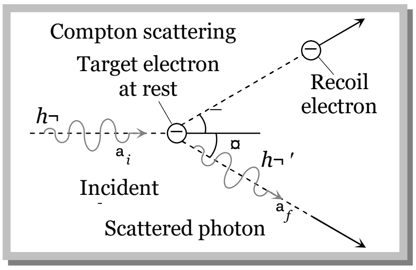
Photo-emissive cell	Photo-conductive cell	Photo-voltaic cell
It consists of an evacuated glass or quartz bulb containing anode A and cathode C. The cathode is semi-cylindrical metal on which a layer of photo-sensitive material is coated.	It is based on the principle that conductivity of a semiconductor increases with increase in the intensity of incident light.	It consists of a Cu plate coated with a thin layer of cuprous oxide (Cu_2O). On this plate is laid a semi transparent thin film of silver.
		
When light incident on the cathode, it emits photo-electrons which are attracted by the anode. The photoelectrons constitute a small current which flows through the external circuit.	In this, a thin layer of some semiconductor (as selenium) is placed below a transparent foil of some metal. This combination is fixed over an iron plate. When light is incident on the transparent foil, the electrical resistance of the semiconductor layer is reduced. Hence a current starts flowing in the battery circuit connected.	When light fall, the electrons emitted from the layer of Cu_2O and move towards the silver film. Then the silver film becomes negatively charged and copper plate becomes positively charged. A potential difference is set up between these two and current is set up in the external resistance.

Note : ❑ The photoelectric current can be increased by filling some inert gas like Argon into the bulb. The photoelectrons emitted by cathode ionise the gas by collision and hence the current is increased.

Compton effect

The scattering of a photon by an electron is called Compton effect. The energy and momentum is conserved. Scattered photon will have less energy (more wavelength) as compare to incident photon (less wavelength). The energy lost by the photon is taken by electron as kinetic energy.

The change in wavelength due to Compton effect is called Compton shift. Compton shift $a_f - a_i = \frac{h}{m_0 c}(1 - \cos ¯)$



Note : ❑ Compton effect shows that photon have momentum.

X-rays

X-rays was discovered by scientist Rontgen that's why they are also called Rontgen rays.

Rontgen discovered that when pressure inside a discharge tube kept 10^{-3} *mm* of *Hg* and potential difference is 25 *kV* then some unknown radiations (X-rays) are emitted by anode.

(1) **Production of X-rays**

There are three essential requirements for the production of X-rays

(i) A source of electron

(ii) An arrangement to accelerate the electrons

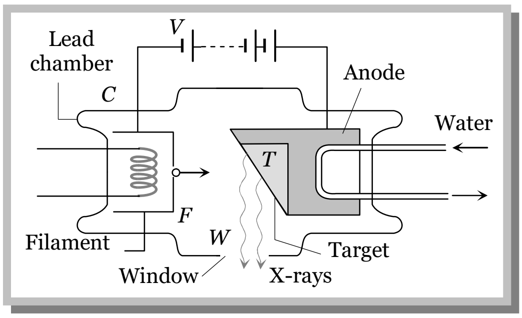
(iii) A target of suitable material of high atomic weight and high melting point on which these high speed electrons strike.

(2) **Coolidge X-ray tube**

It consists of a highly evacuated glass tube containing cathode and target. The cathode consist of a tungsten filament. The filament is coated with oxides of barium or strontium to have an emission of electrons even at low temperature. The filament is surrounded by a molybdenum cylinder kept at negative potential *w.r.t.* the target.

The target (it's material of high atomic weight, high melting point and high thermal conductivity) made of tungsten or molybdenum is embedded in a copper block.

The face of the target is set at 45° to the incident electron stream.



The filament is heated by passing the current through it. A high potential difference (≈ 10 *kV* to 80 *kV*) is applied between the target and cathode to accelerate the electrons which are emitted by filament. The stream of highly energetic electrons are focussed on the target.

Most of the energy of the electrons is converted into heat (above 98%) and only a fraction of the energy of the electrons (about 2%) is used to produce X-rays.

During the operation of the tube, a huge quantity of heat is produced in this target, this heat is conducted through the copper anode to the cooling fins from where it is dissipated by radiation and convection.

(i) **Control of intensity of X-rays** : Intensity implies the number of X-ray photons produced from the target. The intensity of X-rays emitted is directly proportional to the electrons emitted per second from the filament and this can be increased by increasing the filament current. So *intensity of X-rays* ó *Filament current*

(ii) **Control of quality or penetration power of *X*-rays :** Quality of X-rays implies the penetrating power of X-rays, which can be controlled by varying the potential difference between the cathode and the target.

For large potential difference, energy of bombarding electrons will be large and hence larger is the penetration power of X-rays.

Depending upon the penetration power, X-rays are of two types

Hard X-rays	Soft X-rays
More penetration power	Less penetration power
More frequency of the order of ≈ 10^{19} *Hz*	Less frequency of the order of ≈ 10^{16} *Hz*
Lesser wavelength range (0.1Å – 4Å)	More wavelength range (4Å – 100Å)

Note : ❑ Production of X-ray is the reverse phenomenon of photoelectric effect.

(3) **Properties of X-rays**

(i) X-rays are electromagnetic waves with wavelength range 0.1Å – 100Å.

(ii) The wavelength of X-rays is very small in comparison to the wavelength of light. Hence they carry much more energy (This is the only difference between X-rays and light)

(iii) X-rays are invisible.

(iv) They travel in a straight line with speed of light.

(v) X-rays are measured in Rontgen (measure of ionization power).

(vi) X-rays carry no charge so they are not deflected in magnetic field and electric field.

(vii) $a_{Gama\ rays} < a_{X\text{-}rays} < a_{UV\ rays}$

(viii) They used in the study of crystal structure.

(ix) They ionise the gases

(x) X-rays do not pass through heavy metals and bones.

(xi) They affect photographic plates.

(xii) Long exposure to X-rays is injurious for human body.

(xiii) Lead is the best absorber of X-rays.

(xiv) For X-ray photography of human body parts, $BaSO_4$ is the best absorber.

(xv) They produce photoelectric effect and Compton effect

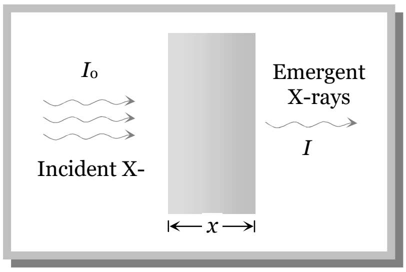
(xvi) X-rays are not emitted by hydrogen atom.

(xvii) These cannot be used in Radar because they are not reflected by the target.

(xviii) They show all the important properties of light rays like; reflection, refraction, interference, diffraction and polarization *etc.*

(4) **Absorption of X-rays**

X-rays are absorbed when they incident on substance.



Intensity of emergent *X*-rays $I = I_0 e^{-«x}$

So intensity of absorbed X-rays $I' = I_0 - I = I_0(1 - e^{-«x})$

where x = thickness of absorbing medium, « = absorption coefficient

Note : ❑ The thickness of medium at which intensity of emergent X-rays becomes half *i.e.* $I' = \frac{I_0}{2}$ is called half value thickness ($x_{1/2}$) and it is given as $x_{1/2} = \frac{0.693}{«}$.

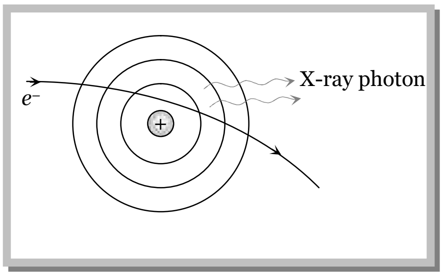
Classification of X-rays

In X-ray tube, when high speed electrons strikes the target, they penetrate the target. They loses their kinetic energy and comes to rest inside the metal. The electron before finally being stopped makes several collisions with the atoms in the target. At each collision one of the following two types of X-rays may get form.

(1) **Continuous X-rays**

As an electron passes close to the positive nucleus of atom, the electron is deflected from it's path as shown in figure. This results in deceleration of the electron. The loss in energy of the electron during deceleration is emitted in the form of X-rays.

The X-ray photons emitted so form the continuous X-ray spectrum.



Note : ❑ Continuos X-rays are produced due to the phenomenon called "Bremsstrahlung". It means slowing down or braking radiation.

Minimum wavelength

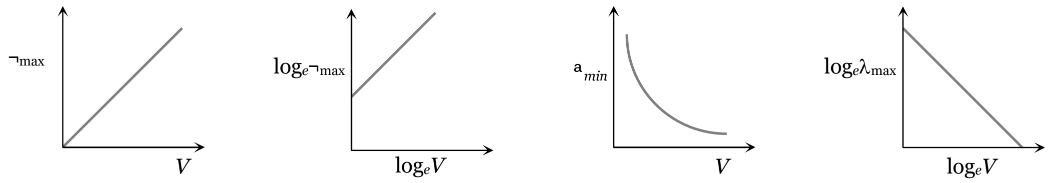
When the electron looses whole of it's energy in a single collision with the atom, an X-ray photon of maximum energy $h\nu_{max}$ is emitted *i.e.* $\frac{1}{2}mv^2 = eV = h\nu_{\max} = \frac{hc}{\lambda_{\min}}$

where v = velocity of electron before collision with target atom, V = potential difference through which electron is accelerated, c = speed of light = $3 \times 10^8\ m/s$

Maximum frequency of radiations (X-rays) $\quad \nu_{\max} = \frac{eV}{h}$

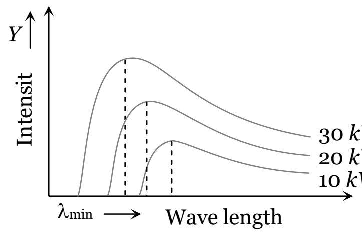
Minimum wave length = cut off wavelength of X-ray $\quad \lambda_{\min} = \frac{hc}{eV} = \frac{12375}{V}\ Å$

Note : ❑ Wavelength of continuous X-ray photon ranges from certain minimum (λ_{min}) to infinity.



Intensity wavelength graph

The continuous X-ray spectra consist of all the wavelengths over a given range. These wavelength are of different intensities. Following figure shows the intensity variation of different wavelengths for various accelerating voltages applied to X-ray tube.

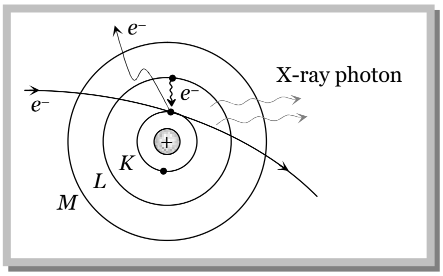


For each voltage, the intensity curve starts at a particular minimum wavelength (λ_{min}). Rises rapidly to a maximum and then drops gradually.

The wavelength at which the intensity is maximum depends on the accelerating voltage, being shorter for higher voltage and vice-versa.

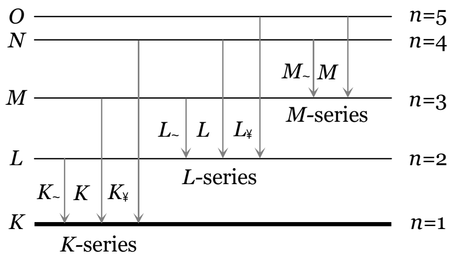
(2) **Characteristic X-rays**

Few of the fast moving electrons having high velocity penetrate the surface atoms of the target material and knock out the tightly bound electrons even from the inner most shells of the atom. Now when the electron is knocked out, a vacancy is created at that place. To fill this vacancy electrons from higher shells jump to fill the created vacancies, we know that when an electron jumps from a higher energy orbit E_1 to lower energy orbit E_2, it radiates energy ($E_1 - E_2$). Thus this energy difference is radiated in the form of X-rays of very small but definite wavelength which depends upon the target material. The X-ray spectrum consist of sharp lines and is called characteristic X-ray spectrum.



K, L, M, ... series

If the electron striking the target eject an electron from the *K*-shell of the atom, a vacancy is crated in the *K*-shell. Immediately an electron from one of the outer shell, say *L*-shell jumps to the *K*-shell, emitting an X-ray photon of energy equal to the energy difference between the two shells. Similarly, if an electron from the *M*-shell jumps to the *K*-shell, X-ray photon of higher energy is emitted. The X-ray photons emitted due to the jump of electron from the *L*, *M*, *N* shells to the K-shells gives $K_{\sim}$, K , $K_{¥}$ lines of the *K*-series of the spectrum.



If the electron striking the target ejects an electron from the *L*-shell of the target atom, an electron from the *M*, *N* ..... shells jumps to the *L*-shell so that X-rays photons of lesser energy are emitted. These photons form the lesser energy emission. These photons form the *L*-series of the spectrum. In a similar way the formation of *M* series, *N* series *etc*. may be explained.

Energy and wavelength of different lines

Series	Transition	Energy	Wavelength
$K_{\sim}$	$\underset{(2)}{L} \rightarrow \underset{(1)}{K}$	$E_L - E_K = h¬_{K\sim}$	$a_{K\sim} = \frac{hc}{E_L - E_K} = \frac{12375}{(E_L - E_K)eV}$ Å
K	$\underset{(3)}{M} \rightarrow \underset{(1)}{K}$	$E_M - E_K = h¬_K$	$a_K = \frac{hc}{E_M - E_K} = \frac{12375}{(E_M - E_K)eV}$ Å
$L_{\sim}$	$\underset{(3)}{M} \rightarrow \underset{(2)}{L}$	$E_M - E_L = h¬_{L\sim}$	$a_{L\sim} = \frac{hc}{E_M - E_L} = \frac{12375}{(E_M - E_L)eV}$ Å

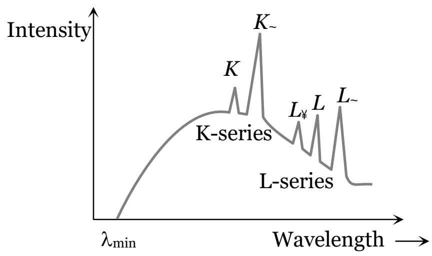
Note : ❑ The wavelength of characteristic X-ray doesn't depend on accelerating voltage. It depends on the atomic number (*Z*) of the target material.

❑ $a_{K\sim} < a_{L\sim} < a_{M\sim}$ and $¬_{K\sim} > ¬_{L\sim} > ¬_{M\sim}$

❑ $a_{K\sim} > a_{L} < a_{K¥}$

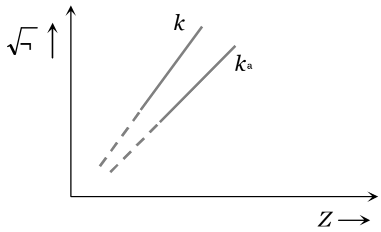
Intensity-wavelength graph

At certain sharply defined wavelengths, the intensity of X-rays is very large as marked $K_{\sim}$, K .... As shown in figure. These X-rays are known as characteristic X-rays. At other wavelengths the intensity varies gradually and these X-rays are called continuous X-rays.



Mosley's law

Mosley studied the characteristic X-ray spectrum of a number of heavy elements and concluded that the spectra of different elements are very similar and with increasing atomic number, the spectral lines merely shift towards higher frequencies.



He also gave the following relation $\sqrt{\nu} = a(Z - b)$

where ν = Frequency of emitted line, Z = Atomic number of target, a = Proportionality constant,

b = Screening constant.

Note : ❑ a and b doesn't depend on the nature of target. Different values of b are as follows

$b = 1$	for	K-series
$b = 7.4$	for	L-series
$b = 19.2$	for	M-series

❑ $(Z - b)$ is called effective atomic number.

More about Mosley's law

(i) It supported Bohr's theory

(ii) It experimentally determined the atomic number (Z) of elements.

(iii) This law established the importance of ordering of elements in periodic table by atomic number and not by atomic weight.

(iv) Gaps in Moseley's data for A = 43, 61, 72, 75 suggested existence of new elements which were later discovered.

(v) The atomic numbers of Cu, Ag and Pt were established to be 29, 47 and 78 respectively.

(vi) When a vacancy occurs in the K-shell, there is still one electron remaining in the K-shell. An electron in the L-shell will feel an effective charge of $(Z - 1)e$ due to $+Ze$ from the nucleus and $-e$ from the remaining K-shell electron, because L-shell orbit is well outside the K-shell orbit.

(vii) Wave length of characteristic spectrum $\frac{1}{\lambda} = R(Z-b)^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$ and energy of X-ray radiations.

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

(viii) If transition takes place from $n_2 = 2$ to $n_1 = 1$ (K_α - line)

(a) $a = \sqrt{\frac{3RC}{4}} = 2.47 \times 10^{15}\ Hz$

(b) $\nu_{K_\alpha} = RC(Z-1)^2\left(1 - \frac{1}{2^2}\right) = \frac{3RC}{4}(Z-1)^2 = 2.47 \times 10^{15}(Z-1)^2\ Hz$

(c) In general the wavelength of all the K-lines are given by $\frac{1}{\lambda_K} = R(Z-1)^2\left(1 - \frac{1}{n^2}\right)$ where n = 2, 3, 4, ...

While for K_α line $\lambda_{K_\alpha} = \frac{1216}{(Z-1)}\ Å$

(d) $E_{K\sim} = 10.2(Z-1)^2\, eV$

Uses of X-rays

(i) In study of crystal structure : Structure of DNA was also determined using X-ray diffraction.

(ii) In medical science.

(iii) In radiograph

(iv) In radio therapy

(v) In engineering

(vi) In laboratories

(vii) In detective department

(viii) In art the change occurring in old oil paintings can be examined by X-rays.

Concepts

- *Nearly all metals emits photoelectrons when exposed to UV light. But alkali metals like lithium, sodium, potassium, rubidium and cesium emit photoelectrons even when exposed to visible light.*
- *Oxide coated filament in vacuum tubes is used to emit electrons at relatively lower temperature.*
- *Conduction of electricity in gases at low pressure takes because colliding electrons acquire higher kinetic energy due to increase in mean free path.*
- *Kinetic energy of cathode rays depends on both voltage and work function of cathode.*
- *Photoelectric effect is due to the particle nature of light.*
- *Hydrogen atom does not emit X-rays because it's energy levels are too close to each other.*
- *The essential difference between X-rays and of ¥-rays is that, ¥-rays emits from nucleus while X-rays from outer part of atom.*
- *There is no time delay between emission of electron and incidence of photon i.e. the electrons are emitted out as soon as the light falls on metal surface.*
- *If light were wave (not photons) it will take about an year take about an year to eject a photoelectron out of the metal surface.*
- *Doze of X-ray are measured in terms of produced ions or free energy via ionisaiton.*
- *Safe doze for human body per week is one Rontgen (One Rontgon is the amount of X-rays which emits 2.5 ò 10^4 J free energy through ionization of 1 gm air at NTP*

Example

***Example*: 22** The work function of a substance is 4.0 *eV*. The longest wavelength of light that can cause photoelectron emission from this substance is approximately

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

Solution : (c) By using $a_0 = \frac{12375}{W_0(eV)} \Rightarrow a_0 = \frac{12375}{4} = 3093.7\,Å \simeq 310\ nm$

***Example*: 23** Photo-energy 6 *eV* are incident on a surface of work function 2.1 *eV*. What are the stopping potential

(a) – 5*V* (b) – 1.9 *V* (c) – 3.9 *V* (d) – 8.1 *V*

Solution : (c) By using Einstein's equation $E = W_0 + K_{max} \Rightarrow \quad 6 = 2.1 + K_{\max} \quad \Rightarrow K_{\max} = 3.9\,eV$

Also $V_0 = -\frac{K_{\max}}{e} = -3.9\,V$.

Example: 24 When radiation of wavelength λ is incident on a metallic surface the stopping potential is 4.8 *volts*. If the same surface is illuminated with radiation of double the wavelength, then the stopping potential becomes 1.6 *volts*. Then the threshold wavelength for the surface is

(a) 2λ (b) 4λ (c) 6λ (d) 8λ

Solution : (b) By using $V_0 = \frac{hc}{e}\left[\frac{1}{\lambda} - \frac{1}{\lambda_0}\right]$

$$4.8 = \frac{hc}{e}\left[\frac{1}{\lambda} - \frac{1}{\lambda_0}\right] \quad \text{...... (i)} \quad \text{and} \quad 1.6 = \frac{hc}{e}\left[\frac{1}{2\lambda} - \frac{1}{\lambda_0}\right] \quad \text{...... (ii)}$$

From equation (i) and (ii) $\lambda_0 = 4\lambda$.

Example: 25 When radiation is incident on a photoelectron emitter, the stopping potential is found to be 9 volts. If *e/m* for the electron is $1.8 \times 10^{11}\,Ckg^{-1}$ the maximum velocity of the ejected electrons is

(a) $6 \times 10^5\,ms^{-1}$ (b) $8 \times 10^5\,ms^{-1}$ (c) $1.8 \times 10^6\,ms^{-1}$ (d) $1.8 \times 10^5\,ms^{-1}$

Solution : (c) $\frac{1}{2} m v_{\max}^2 = eV_0 \Rightarrow v_{\max} = \sqrt{2\left(\frac{e}{m}\right).V_0} = \sqrt{2 \times 1.8 \times 10^{11} \times 9} = 1.8 \times 10^6\,m/s$.

Example: 26 The lowest frequency of light that will cause the emission of photoelectrons from the surface of a metal (for which work function is 1.65 *eV*) will be

(a) $4 \times 10^{10}\,Hz$ (b) $4 \times 10^{11}\,Hz$ (c) $4 \times 10^{14}\,Hz$ (d) $4 \times 10^{-10}\,Hz$

Solution : (c) Threshold wavelength $\lambda_0 = \frac{12375}{W_0(eV)} = \frac{12375}{1.65} = 7500\,Å$.

$\therefore$ so minimum frequency $\nu_0 = \frac{c}{\lambda_0} = \frac{3 \times 10^8}{7500 \times 10^{-10}} = 4 \times 10^{14}\,Hz$.

Example: 27 Light of two different frequencies whose photons have energies 1 *eV* and 2.5 *eV* respectively, successively illuminates a metal of work function 0.5 *eV*. The ratio of maximum kinetic energy of the emitted electron will be

(a) 1 : 5 (b) 1 : 4 (c) 1 : 2 (d) 1 : 1

Solution : (b) By using $K_{\max} = E - W_0 \Rightarrow \frac{(K_{\max})_1}{(K_{\max})_2} = \frac{1-0.5}{2.5-0.5} = \frac{0.5}{2} = \frac{1}{4}$.

Example: 28 Photoelectric emission is observed from a metallic surface for frequencies ν_1 and ν_2 of the incident light rays $(\nu_1 > \nu_2)$. If the maximum values of kinetic energy of the photoelectrons emitted in the two cases are in the ratio of 1 : *k*, then the threshold frequency of the metallic surface is

(a) $\frac{\nu_1 - \nu_2}{k-1}$ (b) $\frac{k\nu_1 - \nu_2}{k-1}$ (c) $\frac{k\nu_2 - \nu_1}{k-1}$ (d) $\frac{\nu_2 - \nu_1}{k-1}$

Solution : (b) By using $h\nu - h\nu_0 = k_{\max} \Rightarrow h(\nu_1 - \nu_0) = k_1$ and $h(\nu_1 - \nu_0) = k_2$

Hence $\frac{\nu_1 - \nu_0}{\nu_2 - \nu_0} = \frac{k_1}{k_2} = \frac{1}{k} \Rightarrow \nu_0 = \frac{k\nu_1 - \nu_2}{k-1}$

***Example*: 29** Light of frequency $8 \times 10^{15}\ Hz$ is incident on a substance of photoelectric work function 6.125 *eV*. The maximum kinetic energy of the emitted photoelectrons is

(a) 17 *eV* (b) 22 *eV* (c) 27 *eV* (d) 37 *eV*

Solution : (c) Energy of incident photon $E = h¬ = 6.6 \times 10^{-34} \times 8 \times 10^{15} = 5.28 \times 10^{-18}\ J = 33\ eV$.

From $E = W_0 + K_{max} \Rightarrow K_{max} = E - W_0 = 33 - 6.125 = 26.87\ eV \approx 27\ eV$.

***Example*: 30** A photo cell is receiving light from a source placed at a distance of 1 *m*. If the same source is to be placed at a distance of 2 *m*, then the ejected electron

(a) Moves with one-fourth energy as that of the initial energy

(b) Moves with one fourth of momentum as that of the initial momentum

(c) Will be half in number

(d) Will be one-fourth in number

Solution : (d) Number of photons $\propto$ Intensity $\propto \dfrac{1}{(\text{distance})^2}$

$$\Rightarrow \frac{N_1}{N_2} = \left(\frac{d_2}{d_1}\right)^2 \Rightarrow \frac{N_1}{N_2} - \left(\frac{2}{1}\right)^2 \Rightarrow N_2 = \frac{N_1}{4}.$$

***Example*: 31** When yellow light incident on a surface no electrons are emitted while green light can emit. If red light is incident on the surface then

(a) No electrons are emitted (b) Photons are emitted

(c) Electrons of higher energy are emitted (d) Electrons of lower energy are emitted

Solution : (a) $a_{Green} < a_{Yellow} < a_{Red}$

According to the question a_{Green} is the maximum wavelength for which photoelectric emission takes place. Hence no emission takes place with red light.

***Example*: 32** When a metal surface is illuminated by light of wavelengths 400 *nm* and 250 *nm* the maximum velocities of the photoelectrons ejected are *v* and 2*v* respectively. The work function of the metal is (*h* = Planck's constant, *c* = velocity of light in air)

(a) $2hc \times 10^6\ J$ (b) $1.5hc \times 10^6\ J$ (c) $hc \times 10^6\ J$ (d) $0.5hc \times 10^6\ J$

Solution : (a) By using $E = W_0 + K_{max} \Rightarrow \dfrac{hc}{a} = W_0 + \dfrac{1}{2}mv^2$

$$\frac{hc}{400 \times 10^{-9}} = W_0 + \frac{1}{2}mv^2 \quad ......(i) \quad \text{and} \quad \frac{hc}{250 \times 10^{-9}} = W_0 + \frac{1}{2}m(2v)^2 \quad ......(ii)$$

From equation (i) and (ii) $W_0 = 2hc \times 10^6\ J$.

***Example*: 33** The work functions of metals *A* and *B* are in the ratio 1 : 2. If light of frequencies *f* and 2*f* are incident on the surfaces of *A* and *B* respectively, the ratio of the maximum kinetic energies of photoelectrons emitted is (*f* is greater than threshold frequency of *A*, 2*f* is greater than threshold frequency of *B*)

(a) 1 : 1 (b) 1 : 2 (c) 1 : 3 (d) 1 : 4

Solution : (b) By using $E = W_0 + K_{max} \Rightarrow E_A = hf = W_A + K_A$ and $E_B = h(2f) = W_B + K_B$

So, $\dfrac{1}{2} = \dfrac{W_A + K_A}{W_B + K_B}$ ......(i) also it is given that $\dfrac{W_A}{W_B} = \dfrac{1}{2}$ ....(ii)

From equation (i) and (ii) we get $\frac{K_A}{K_B} = \frac{1}{2}$.

***Example*: 34** When a point source of monochromatic light is at a distance of 0.2*m* from a photoelectric cell, the cut-off voltage and the saturation current are 0.6 *volt* and 18 *mA* respectively. If the same source is placed 0.6 *m* away from the photoelectric cell, then

(a) The stopping potential will be 0.2 *V*
(b) The stopping potential will be 0.6 *V*
(c) The saturation current will be 6 *mA*
(d) The saturation current will be 18 *mA*

Solution : (b) Photoelectric current (*i*) ∝ Intensity ∝ $\frac{1}{(\text{distance})^2}$. If distance becomes 0.6 *m* (*i.e.* three times) so current becomes $\frac{1}{9}$ times *i.e.* 2*mA*.

Also stopping potential is independent of intensity *i.e.* it remains 0.6 *V*.

***Example*: 35** In a photoemissive cell with exciting wavelength λ, the fastest electron has speed *v*. If the exciting wavelength is changed to $3\lambda/4$, the speed of the fastest emitted electron will be

(a) $v(3/4)^{1/2}$
(b) $v(4/3)^{1/2}$
(c) Less then $v(4/3)^{1/2}$
(d) Greater then $v(4/3)^{1/2}$

Solution : (d) From $E = W_0 + \frac{1}{2}mv_{\max}^2 \Rightarrow v_{\max} = \sqrt{\frac{2E}{m} - \frac{2W_0}{m}}$ (where $E = \frac{hc}{\lambda}$)

If wavelength of incident light charges from λ to $\frac{3\lambda}{4}$ (decreases)

Let energy of incident light charges from *E* to E' and speed of fastest electron changes from *v* to v' then

$$v = \sqrt{\frac{2E}{m} - \frac{2W_0}{m}} \quad .....(i) \quad \text{and} \quad v' = \sqrt{\frac{2E'}{m} - \frac{2W_0}{m}} \quad ....(ii)$$

As $E \propto \frac{1}{\lambda} \Rightarrow E' = \frac{4}{3}E$ hence $v' = \sqrt{\frac{2\left(\frac{4}{3}E\right)}{m} - \frac{2W_0}{m}} \Rightarrow v' = \left(\frac{4}{3}\right)^{1/2}\sqrt{\frac{2E}{m} - \frac{2W_0}{m\left(\frac{4}{3}\right)^{1/2}}}$

$$\Rightarrow v' = \left(\frac{4}{3}\right)^{1/2} \quad X = \sqrt{\frac{2E}{m} - \frac{2W_0}{m\left(\frac{4}{3}\right)^{1/2}}} > v \quad \text{so } v' > \left(\frac{4}{3}\right)^{1/2} v.$$

***Example*: 36** The minimum wavelength of *X*-rays produced in a coolidge tube operated at potential difference of 40 *kV* is

(a) 0.31Å
(b) 3.1Å
(c) 31Å
(d) 311Å

Solution : (a) $\lambda_{\min} = \frac{12375}{40 \times 10^3} = 0.309\,Å \approx 0.31\,Å$

***Example*: 37** The *X*-ray wavelength of L_α line of platinum (Z = 78) is 1.30Å. The *X* –ray wavelength of L_α line of Molybdenum (Z = 42) is

(a) 5.41Å
(b) 4.20Å
(c) 2.70Å
(d) 1.35 Å

Solution : (a) The wave length of L_α line is given by $\frac{1}{\lambda} = R(z-7.4)^2\left(\frac{1}{2^2} - \frac{1}{3^2}\right) \Rightarrow \lambda \propto \frac{1}{(z-7.4)^2}$

$$\Rightarrow \frac{\lambda_1}{\lambda_2} = \frac{(z_2 - 7.4)^2}{(z_1 - 7.4)^2} \Rightarrow \frac{1.30}{\lambda_2} = \frac{(42 - 7.4)^2}{(78 - 7.4)^2} \Rightarrow \lambda_2 = 5.41\,Å.$$

***Example*: 38** The cut off wavelength of continuous X-ray from two coolidge tubes operating at 30 *kV* but using different target materials (molybdenum *Z*= 42 and tungsten *Z* = 74) are

(a) 1Å, 3Å (b) 0.3 Å, 0.2 Å (c) 0.414 Å, 0.8 Å (d) 0.414 Å, 0.414 Å

Solution : (d) Cut off wavelength of continuous X-rays depends solely on the voltage applied and does not depend on the material of the target. Hence the two tubes will have the same cut off wavelength.

$$Ve = h\nu = \frac{hc}{\lambda} \quad \text{or} \quad \lambda = \frac{hc}{Ve} = \frac{6.627 \times 10^{-34} \times 3 \times 10^{8}}{30 \times 10^{3} \times 1.6 \times 10^{-19}} m = 414 \times 10^{-10} m = 0.414\,Å.$$

Tricky example: 3

Two photons, each of energy 2.5*eV* are simultaneously incident on the metal surface. If the work function of the metal is 4.5 *eV*, then from the surface of metal

(a) Two electrons will be emitted (b) Not even a single electron will be emitted

(c) One electron will be emitted (d) More than two electrons will be emitted

Solution : (b) Photoelectric effect is the phenomenon of one to one elastic collision between incident photon and an electron. Here in this question one electron absorbs one photon and gets energy 2.5 *eV* which is lesser than 4.5 *eV*. Hence no photoelectron emission takes place.

Tricky example: 4

In X-ray tube when the accelerating voltage *V* is halved, the difference between the wavelength of K_α line and minimum wavelength of continuous *X*-ray spectrum

(a) Remains constant (b) Becomes more than two times

(c) Becomes half (d) Becomes less than two times

Solution : (c) $\Delta\lambda = \lambda_{K_\alpha} - \lambda_{\min}$ when *V* is halved $\lambda_{\min}$ becomes two times but λ_{K_a} remains the same.

$$\therefore \quad \Delta\lambda' = \lambda_{K_\alpha} - 2\lambda_{\min} = 2(\Delta\lambda) - \lambda_{K_a}$$

$$\therefore \quad \Delta\lambda' < 2(\Delta\lambda)$$

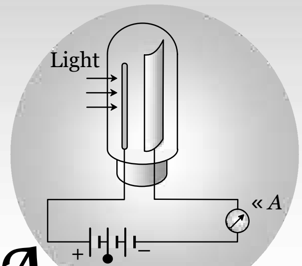
Tricky example: 5

Molybdenum emits K_α-photons of energy 18.5 *keV* and iron emits K_α photons of energy 34.7 *keV*. The times taken by a molybdenum K_α photon and an iron K_α photon to travel 300 *m* are

(a) (3 μ*s*, 15 μ*s*) (b) (15 μ*s*, 3μ*s*) (c) (1 μ*s*, 1 μ*s*) (d) (1 μ*s*, 5μ*s*)

Solution : (c) Photon have the same speed whatever be their energy, frequency, wavelength, and origin.

$$\therefore \text{time of travel of either photon} = \frac{300}{3 \times 10^{8}} = 10^{-6} s = 1\mu s$$



Assignment

Electron, cathode rays and positive rays

1. Order of e/m ratio of proton, ~ -particle and electron is

(a) $e > p > \sim$ (b) $p > \sim > e$ (c) $e > \sim > p$ (d) None of these

2. A cathode emits 1.8×10^{14} electrons per second, when heated. When 400V is applied to anode all the emitted electrons reach the anode. The charge on electron is $1.6 \times 10^{-19}\ C$. The maximum anode current is

(a) 2.7«A (b) 29«A (c) 72«A (d) 29 mA

3. An electron is accelerated through a pd of 45.5 *volt*. The velocity acquired by it is (in ms^{-1})......

(a) 4×10^6 (b) 4×10^4 (c) 10^6 (d) zero

4. The specific charge of an electron is

(a) 1.6×10^{-19} *coulomb* (b) 4.8×10^{-19} *stat coulomb* (c) 1.76×10^{11} *coulomb/kg* (d) 1.76×10^{-11} *coulomb/kg*

5. The colour of the positive column in a gas discharge tube depends on

(a) The type of glass used to construct the tube (b) The gas in the tube
(c) The applied voltage (d) The material of the cathode

6. Cathode rays are produced when the pressure is of the order of

(a) 2 *cm* of *Hg* (b) 0.1 *cm* of *Hg* (c) 0.01 *mm* of *Hg* (d) 1«m of *Hg*

7. Which of the following is not the property of a cathode ray

(a) It casts shadow (b) It produces heating effect
(c) It produces flurosence (d) It does not deflect in electric field

8. In Milikan's experiment, an oil drop having charge q gets stationary on applying a potential difference V in between two plates separated by a distance 'd'. The weight of the drop is

(a) qVd (b) $q\frac{d}{V}$ (c) $\frac{q}{Vd}$ (d) $q\frac{V}{d}$

9. In Thomson mass spectrograph $\vec{E} \perp \vec{B}$ then the velocity of electron beam will be

(a) $\left|\frac{\vec{E}}{\vec{B}}\right|$ (b) $\vec{E} \times \vec{B}$ (c) $\left|\frac{\vec{B}}{\vec{E}}\right|$ (d) $\frac{E^2}{B^2}$

10. Which is not true with respect to the cathode rays

(a) A stream of electrons (b) Charged particles
(c) Move with speed same as that of light (d) Can be deflected by magnetic fields

11. An electron is accelerated through a potential difference of 200 *volts*. If *e/m* for the electron be 1.6×10^{11} *coulomb/kg*. the velocity acquired by the electron will be

(a) $8 \times 10^6\ m/s$ (b) $8 \times 10^5\ m/s$ (c) $5.9 \times 10^6\ m/s$ (d) $5.9 \times 10^5\ m/s$

12. If the speed of electron is $5 \times 10^5\ m/s$. How long does one electron take to traverse 1m

(a) $1 \times 10^{6} s$ (b) $2 \times 10^{-6} s$ (c) $2 \times 10^{5} s$ (d) $1 \times 10^{5} s$

13. A metal plate gets heated, when cathode rays strike against, it due to

(a) Kinetic energy of cathode rays (b) Potential energy of cathode rays

(c) Linear velocity of cathode rays (d) Angular velocity of cathode rays

14. In Milikan's oil drop experiment, a charged drop falls with terminal velocity *V*. If an electric field *E* is applied in vertically upward direction then it starts moving in upward direction with terminal velocity 2*V*. If magnitude of electric field is decreased to $\frac{E}{2}$, then terminal velocity will become

(a) $\frac{V}{2}$ (b) V (c) $\frac{3V}{2}$ (d) 2*V*

15. The current conduction in a discharged tube is due to

(a) Electrons only (b) +*ve* ions and electrons

(c) – *ve* ions and electrons (d) + *ve* ions, – *ve* ions and electrons

16. Cathode rays and canal rays produced in a certain discharge tube are deflected in the same direction if

(a) A magnetic field is applied normally (b) An electric field is applied normally

(c) An electric field is applied tangentially (d) A magnetic field is applied tangentially

17. Cathode rays enter into a uniform magnetic field perpendicular to the direction of the field. In the magnetic field their path will be

(a) Straight line (b) Circle (c) Parabolic (d) Ellipse

18. Electric field and magnetic field in Thomson mass spectrograph are applied

(a) Simultaneously, perpendicular (b) Perpendicular but not simultaneously

(c) Parallel but not simultaneously (d) Parallel simultaneously

19. The discovery of positive rays helped in the discovery of

(a) Proton (b) Isotopes (c) Electron (d) ~ -particle

20. The ratio of momenta of an electron and ~ -particle which are accelerated from rest by a potential difference of 100 *V* is

(a) 1 (b) $\sqrt{\frac{2m_e}{m_{\sim}}}$ (c) $\sqrt{\frac{m_e}{m_{\sim}}}$ (d) $\sqrt{\frac{m_e}{2m_{\sim}}}$

21. In Millikan oil drop experiment, a charged drop of mass $1.8 \times 10^{-14} kg$ is stationary between its plates. The distance between its plates is 0.90 *cm* and potential difference is 2.0 *kilo volts*. The number of electrons on the drop is

(a) 500 (b) 50 (c) 5 (d) 0

22. The expected energy of the electrons at absolute zero is called

(a) Fermi energy (b) Emission energy (c) Work function (d) Potential energy

23. *K.E.* of emitted cathode rays is dependent on

(a) Only voltage (b) Only work function

(c) Both (a) and (b) (d) It does not depend upon any physical quantity

24. In a discharge tube at 0.02 *mm*, there is a formation of

(a) FDS (b) CDS (c) Both space (d) None of these

25. A narrow electron beam passes undeviated through an electric field $E = 3 \times 10^{4}\ volt/m$ and an overlapping magnetic field $B = 2 \times 10^{-3}\ Weber/m^{2}$. The electron motion, electric field and magnetic field are mutually perpendicular. The speed of the electrons is

(a) 60 *m/s* (b) $10.3 \times 10^{7} m/s$ (c) $1.5 \times 10^{7} m/s$ (d) $0.67 \times 10^{-7} m/s$

26. An oxide coated filament is useful in vacuum tubes because essentially

(a) It has high melting point
(b) It can withstand high temperatures
(c) It has good mechanical strength
(d) I can emit electrons at relatively lower temperatures

27. Gases begin to conduct electricity at low pressure because
(a) At low pressure, gases turn to plasma
(b) Colliding electrons can acquire higher kinetic energy due to increased mean free path leading to ionisation of atoms
(c) Atoms break up into electrons and protons
(d) The electrons in atoms can move freely at low pressure

28. When the speed of electrons increases, then the value of its specific charge
(a) Increases
(b) Decreases
(c) Remains unchanged
(d) Increases upto some velocity and then begins to decrease

29. Cathode rays moving with same velocity v describe an approximate cirular path of radius r metre in an electric field of strength x *volt/metre*. If the speed of the cathode rays is doubled to $2v$, the value of electric field needed so that the rays describe the same approximate circular path (*volt / metre*) is
(a) $2x$
(b) $3x$
(c) $4x$
(d) $6x$

30. Cathode rays are similar to visible light rays in that
(a) They both can be deflected by electric and magnetic fields
(b) They both have a definite magnitude of wavelength
(c) They both can ionise a gas through which they pass
(d) They both can expose a photographic plate

31. In Thomson's experiment if the value of q/m is the same for all positive ions striking the photographic plate, then the trace would be
(a) Straight line
(b) Parabolic
(c) Circular
(d) Elliptical

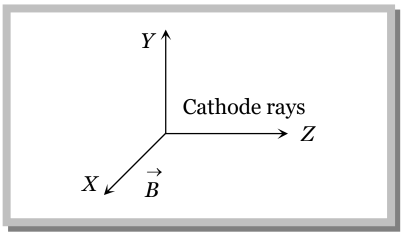
32. The cathode rays have particle nature because of the fact that
(a) They can propagate in vacuum
(b) They are deflected by electric and magnetic fields
(c) They produced fluorescence
(d) They cast shadows

33. When cathode rays (tube voltage ~ 10 kV) collide with the anode of high atomic weight then we get
(a) Positive rays
(b) X-rays
(c) Gamma rays
(d) Canal rays

34. To produce positive rays the pressure in a discharge tube should be
(a) Total vacuum
(b) 10^{-3} to 10^{-4} atmospheric pressure
(c) One atmospheric pressure
(d) 10^{-3} to 10^{-4} mm

35. Cathode-ray tube is a part of
(a) Compound microscope
(b) A radio receiver
(c) A television set
(d) A van de Graaf generator

36. In a region of space cathode rays move along +*ve* Z-axis and a uniform magnetic field is applied along X-axis. If cathode rays pass undeviated, the direction of electric field will be along



(a) – *ve* X-axis
(b) +ve Y-axis
(c) – ve Y-axis
(d) +ve Z-axis

37. A beam of electron whose kinetic energy is E emerges from a thin foil window at the end of an accelerator tube. There is a metal plate at a distance d from this window and at right angles to the direction of the emerging beam. The electron beam is prevented from hitting the plate P, if a magnetic field B is applied, which must be
(a) $B \geq \sqrt{\frac{2mE}{e^2d^2}}$, into the page
(b) $B \geq \sqrt{\frac{2mE}{e^2d^2}}$, out of the page
(c) $B \geq \sqrt{\frac{2mE}{ed}}$, into the page
(d) $B \geq \left(\frac{2mE}{ed}\right)$, out of the page

38. In Thomson's experiment for determining *e/m*, the potential difference between the cathode and the anode (in the accelerating column) is the same as that between the deflecting plates (in the region of crossed fields). If the potential difference is doubled, by what factor should the magnetic field be increased to ensure that the electron beam remains undeflected

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

39. In Thomson's experiment helium He^3 and He^4 exhibit parabolas. The equation of parabola for He^3 is $z^2 = 12Y$, then for He^4 the equation will be

(a) $Z^2 = 16Y$ (b) $Z^2 = 12Y$ (c) $Z^2 = 4Y$ (d) $Z^2 = 9Y$

Matter waves

40. An electron and a proton are accelerated through the same potential difference. The ratio of their De-Broglie wavelength will be

(a) $(m_p / m_e)^{1/2}$ (b) m_t / m_p (c) m_p / m_t (d) 1

41. An electron and proton have the same de-Broglie wavelength. Then the kinetic energy of the electron is

(a) Zero (b) Infinity

(c) Equal to the kinetic energy of the proton (d) Greater than the kinetic energy of the proton

42. For moving ball of cricket, the correct statement about de-Broglie wavelength is

(a) It is not applicable for such big particle (b) $\frac{h}{\sqrt{2mE}}$

(c) $\sqrt{\frac{h}{2mE}}$ (d) $\frac{h}{2mE}$

43. Photon and electron are given same energy $(10^{-20} J)$. Wavelength associated with photon and electron are a_{Ph} and a_{el} then correct statement will be

(a) $a_{Ph} > a_{el}$ (b) $a_{Ph} < a_{el}$ (c) $a_{Ph} = a_{el}$ (d) $\frac{a_{el}}{a_{Ph}} = C$

44. Wavelength associated with an electron of kinetic energy 54 *eV* is

(a) $1.66 \times 10^{-10} m$ (b) $2.6 \times 10^{-9} m$ (c) $3.5 \times 10^{-11} m$ (d) None of the above

45. The energy that should be added to an electron to reduce its de-Broglie wavelengths from $10^{-10} m$ to $0.5 \times 10^{-10} m$ will be

(a) Four times the initial energy (b) Thrice the initial energy

(c) Equal to the initial energy (d) Twice the initial energy

46. If the *K.E.* of an electron, a proton a neutron and an ~ -particle is identical, the maximum de-Broglie wavelength will be for

(a) Electron (b) Proton (c) ~ -particle (d) Neutron

47. Light of wavelength a strikes a photo-sensitive surface and electrons are ejected with kinetic energy *E*. If the kinetic energy is to be increased to 2*E,* the wavelength must be changed to a' where

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

48. The de-Brogile wavelength of electron is 10Å, then its velocity in *m/sec* will be

(a) 7.2×10^5 (b) 72×10^4 (c) 7.2×10^{-5} (d) 7.2×10^6

49. An electron of mass *m*, accelerated through a potential difference *V* has de-Brogile wavelength a. De-Broglie wavelength associated with a proton of mass *M* accelerated through same potential difference, will be

(a) $a\left(\frac{m}{M}\right)$ (b) $a\left(\frac{M}{m}\right)$ (c) $a\sqrt{\frac{m}{M}}$ (d) $a\sqrt{Mm}$

50. The accelerating voltage of an electron gun is 50,000 *volts*. de-Broglie wavelength of the electron will be

(a) 0.55Å (b) 0.055 Å (c) 0.077 Å (d) 0.095 Å

51. The wavelength of *x*-ray photon is 0.01 Å, then its momentum in *Kg m/s* is

(a) 6.63×10^{-22} (b) 6.63×10^{-24} (c) 6.63×10^{-46} (d) 6.63×10^{-32}

52. An proton moving with the velocity of $6.6 \times 10^{5}\ m/\sec$ has a de-Broglie wavelength given by

(a) 6×10^{-2} Å (b) 6×10^{-3} Å (c) 1 Å (d) 2 Å

53. A particle which has zero rest mass and non-zero energy and momentum must travel with a speed

(a) Equal to *c*, the speed of light in vacuum (b) Greater then *c*

(c) Less then *c* (d) Tending to infinity

54. The wavelengths of a photon, an electron and uranium atom are identical. Which of then will have highest energy

(a) Photon (b) Electron

(c) Uranium nucleus (d) Depends on wavelength and property of particles.

55. If E_1, E_2 and E_3 are the respective kinetic energies of an electron, an alpha particle and a proton each having the same De-Broglie wavelength then

(a) $E_1 > E_3 > E_2$ (b) $E_2 > E_3 > E_1$ (c) $E_1 > E_2 > E_3$ (d) $E_1 = E_2 = E_3$

56. Momentum of a photon of electro - magnetic radiation radiation is 3.3×10^{-29} *kg-m-s*$^{-1}$. Then frequency of related waves is

(a) $3.0 \times 10^{3}\ Hz$ (b) $6.0 \times 10^{2}\ Hz$ (c) $7.5 \times 10^{12}\ Hz$ (d) $1.5 \times 10^{13}\ Hz$

57. The energy of electron with de-Broglie wavelength of 10^{-10} *m*, is (in *eV*)

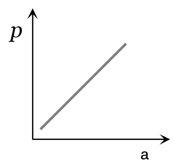
(a) 13.6 (b) 12.27 (c) 1.227 (d) 150.5

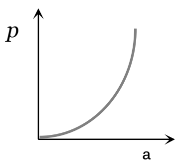
58. If there is an increase in linear dimensions of the object, the associated de-Broglie wavelength

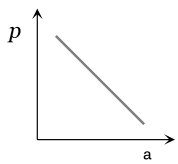
(a) Increases (b) Decreases

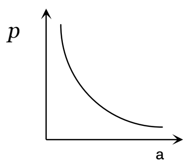
(c) Remains unchanged (d) Depends on the density of object

59. Which of the following figure represents the variation of particle momentum and the associated De-Broglie wavelength

(a) 

(b) 

(c) 

(d) 

60. On applying a potential difference of *V volt* on a proton, a wave of a wavelength is obtained. The voltage applied to an ~ -particle to produce the same wavelength will be (in *volts*)

(a) *V* (b) *V*/5 (c) *V*/8 (d) 2*V*

61. Matter waves are

(a) Electromagnetic waves (b) Longitudinal waves (c) Probability waves (d) Transverse waves

62. Two sand grains, one of diameter 0.5 *mm* and the other of diameter 1.0 *mm* are moving with the same momentum, then the de-Broglie wavelength of the first is

(a) Greater than that of the second (b) Less than that of the second

(c) Equal to that of the second (d) Double incomparison to that of the second

63. An atom when undergoing a transition from an excited state to the ground state emits a photon of wavelength 1Å. Then, the recoil energy of the atom will be (assume mass of the atom = 40 *amu*)

(a) $3.3 \times 10^{-20}\, J$ (b) $1.3 \times 10^{-20}\, J$ (c) $3.3 \times 10^{-22}\, J$ (d) $6.6 \times 10^{-24}\, J$

64. The electron micro-scope works on the principle of

(a) Particle theory (b) Matter wave concept (c) Uncertainty (d) All of the above

65. The de-Broglie wavelength of an electron moving in the n^{th} Bohr orbit of radius r Å will be

(a) nr Å (b) $\frac{r}{n}$ Å (c) $\frac{2®r}{n}$ Å (d) $2®n$ Å

66. If the energy of a particle is reduced to half then the percentage increase in the de-Broglie wavelength is about

(a) 41% (b) 50% (c) 29% (d) 100%

67. The velocity of an electron in the ground state of hydrogen atom is $2.2 \times 10^6\, m/s$. The De-Broglie wavelength associated with a muon in the ground state of a muonic hydrogen will be ($m_« = 207\, m_e$)

(a) 1.6 Å (b) 0.16 Å (c) 0.016 Å (d) 0.0016 Å

68. If the momentum of an electron is changed by Δp, then the de-Broglie wavelength associated with it changes by 0.50%. The initial momentum of the electron will be

(a) $\frac{\Delta p}{200}$ (b) $\frac{\Delta p}{199}$ (c) $199\, \Delta p$ (d) $400\, \Delta p$

69. An electron and a photon have same wavelength. It p is the momentum of electron and E the energy of photon. The magnitude of p/E in S.I. unit is

(a) 3.0×10^8 (b) 3.33×10^{-9} (c) 9.1×10^{-31} (d) 6.64×10^{-34}

Photon/Photoelectric effect

70. According to Einstein's photoelectric equation, the plot of the kinetic energy of the emitted photo electrons from a metal *Vs* the frequency, of the incident radiation gives a straight line whose slope

(a) Depends on the nature of the metal used

(b) Depends on the intensity of the radiation

(c) Depends both on the intensity of the radiation and the metal used

(d) Is the same for all metals and independent of the intensity of the radiation

71. The energy of incident photons corresponding to maximum wavelength of visible light is

(a) 3.2 *eV* (b) 7 *eV* (c) 1.55 *eV* (d) 1 *eV*

72. If the work function of potassium is 2*eV,* then its photoelectric threshold wavelength is

(a) 310 *nm* (b) 620 *nm* (c) 6200 *nm* (d) 3100 *nm*

73. Threshold wavelength for metal is 5200 Å. The photoelectrons will be ejected if it is irradiated by light from

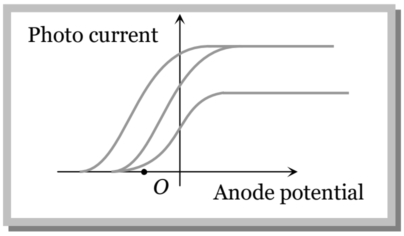
(a) 50 watt infrared lamp (b) 1 watt infrared lamp (c) 50 watt ultraviolet lamp (d) 0.5 watt infrared lamp

74. The dual nature of light is exhibited by

(a) Diffraction and photoelectric effect (b) Diffraction and reflection

(c) Refraction and interference (d) Photo electric effect

75. The figure shows the variation of photocurrent with anode potential for a photo-sensitive surface for three different radiations. Let I_a, I_b and I_c be the intensities and f_a, f_b and f_c be the frequencies for the curves *a*, *b* and *c* respectively.



(a) $f_a = f_b$ and $I_a \neq I_b$

(b) $f_a = f_c$ and $I_a = I_c$

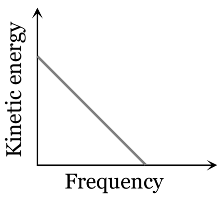
(c) $f_a = f_b$ and $I_a = I_b$

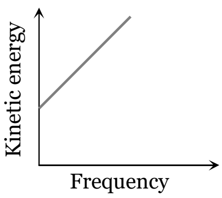
(d) $f_a = f_b$ and $I_b = I_c$

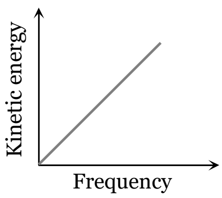
76. A photon of energy 4 *eV* is incident on a metal surface whose work function is 2 *eV*. The minimum reverse potential to be applied for stopping the emission of electrons is

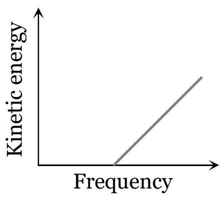
(a) 2 *V* (b) 4*V* (c) 6*V* (d) 8*V*

77. 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)


78. Consider the two following statements *A* and *B* and identify the correct choice given in the answers

(A) In photovoltaic cells the photoelectric current produced is not proportional to the intensity of incident light.

(B) In gas filled photoemissive cells the velocity of photoelectrons depends on the wavelength of the incident radiation

(a) Both *A* and *B* are true (b) Both *A* and *B* are false (c) *A* is true but *B* is false (d) *A* is false *B* is true

79. There are n_1 photons of frequency $¥_1$ in a beam of light. In an equally energetic beam, there are n_2 photons of frequency $¥_2$. Then the correct relation is

(a) $\frac{n_1}{n_2} = 1$ (b) $\frac{n_1}{n_2} = \frac{¥_1}{¥_2}$ (c) $\frac{n_1}{n_2} = \frac{¥_2}{¥_1}$ (d) $\frac{n_1}{n_2} = \frac{¥_1^2}{¥_2^2}$

80. Two identical photo-cathodes receive light of frequencies f_1 and f_2. If the velocities of the photo electrons (of mass *m*) coming out are respectively v_1 and v_2, then

(a) $v_1 - v_2 = \left[\frac{2h}{m}(f_1 - f_2)\right]^{1/2}$ (b) $v_1^2 - v_2^2 = \frac{2h}{m}(f_1 - f_2)$ (c) $v_1 + v_2 = \left[\frac{2h}{m}(f_1 + f_2)\right]^{1/2}$ (d) None of these

81. The frequency and work function of an incident photon are ¬ and $¤_0$. If $¬_0$ is the threshold frequency then necessary condition for the emission of photo electron is

(a) $¬ < ¬_0$ (b) $¬ = \frac{¬_0}{2}$ (c) $¬ \geq ¬_0$ (d) None of these

82. Light of frequency ¬ is incident on a substance of threshold frequency $¬_0 (¬_0 < ¬)$. The energy of the emitted photoelectron will be

(a) $h(¬ - ¬_0)$ (b) $h/¬$ (c) $he(¬ - ¬_0)$ (d) $h/¬_o$

83. In a photoelectric effect experiment the slope of the graph between the stopping potential and the incident frequency will be

(a) 1 (b) 0.5 (c) 10^{-15} (d) 10^{-34}

84. Ultraviolet radiation of 6.2 *eV* falls on an aluminium surface (work function 4.2 *eV*). The kinetic energy in joules of the fastest electron emitted is approximately

(a) 3.2×10^{-21} (b) 3.2×10^{-19} (c) 3.2×10^{-17} (d) 3.2×10^{-15}

85. In photoelectric emission the number of electrons ejected per second

(a) Is proportional to the intensity of light
(b) Is proportional to the wavelength of light
(c) Is proportional to the frequency of light
(d) Is proportional to the work function of metal

86. When ultraviolet rays are incident on metal plate, then photoelectric effect does not occurs. It occurs by the incidence of

(a) *X*-rays
(b) Radio wave
(c) Infrared rays
(d) Green house effect

87. The threshold wavelength for photoelectric effect of a metal is 6500Å. The work function of the metal is approximately

(a) 2 *eV*
(b) 1 *eV*
(c) 0.1 *eV*
(d) 3 *eV*

88. Which of the following statements is correct

(a) The stopping potential increases with increasing intensity of incident light
(b) The photocurrent increases with increasing intensity of light
(c) The photocurrent is proportional to applied voltage
(d) The current in a photocell increases with increasing frequency of light

89. A caesium photocell with a steady potential difference of 60 *V* across is illuminated by a bright point source of light 50 *cm* away. When the same light is placed 1 *m* away the photoelectrons emitted from the cell

(a) Are one quarter as numerous
(b) Are half as numerous
(c) Each carry one quarter of their previous momentum
(d) Each carry one quarter of their previous energy

90. A radio transmitter radiates 1 *kW* power at a wavelength 198.6 *m*. How many photons does it emit per second

(a) 10^{10}
(b) 10^{20}
(c) 10^{30}
(d) 10^{40}

91. Photon of 5.5 *eV* energy fall on the surface of the metal emitting photoelectrons of maximum kinetic energy 4.0 *eV*. The stopping voltage required for these electrons are

(a) 5.5 *V*
(b) 1.5 *V*
(c) 9.5 *V*
(d) 4.0 *V*

92. Energy of photon whose frequency is $10^{12}\ MHz$ will be

(a) $4.14 \times 10^{3}\ keV$
(b) $4.14 \times 10^{2}\ eV$
(c) $4.14 \times 10^{3}\ MeV$
(d) $4.14 \times 10^{3}\ eV$

93. If a photon has velocity *c* and frequency ν, then which of following represents its wavelength

(a) $\frac{hc}{E}$
(b) $\frac{h\nu}{c}$
(c) $\frac{h\nu}{c^2}$
(d) $h\nu$

94. Light of frequency $4\nu_0$ is incident on the metal of the threshold frequency ν_0. The maximum kinetic energy of the emitted photoelectrons is

(a) $3h\nu_0$
(b) $2h\nu_0$
(c) $\frac{3}{2}h\nu_0$
(d) $\frac{1}{2}h\nu_0$

95. When a metallic surface is illuminated by a monochromatic light of wavelength λ, then the potential difference required to stop the ejection of electrons is $3V_0$. When the same surface is illuminated by the light of wavelength 2λ, then the potential difference required to stop the ejection of electrons is V_0. Then for photoelectric effect, the threshold wavelength for the metal surface will be

(a) 6λ
(b) $\frac{4\lambda}{3}$
(c) 4λ
(d) 8λ

96. According to photon theory of light which of the following physical quantities associated with a photon do not / does not change as it collides with an electron in vacuum

(a) Energy and momentum
(b) Speed and momentum
(c) Speed only
(d) Energy only

97. Which of the following is incorrect statement regarding photon

(a) Photon exerts no pressure
(b) Photon energy is *hv*
(c) Photon rest mass is zero
(d) None of these

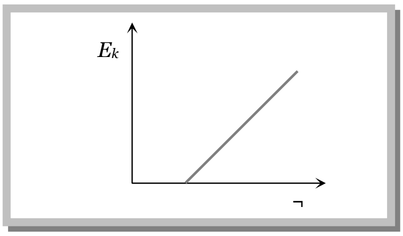
98. Light of frequency ν is incident on a certain photoelectric substance with threshold frequency ν_0. The work function for the substance is

(a) $h\nu$
(b) $h\nu_0$
(c) $h(\nu - \nu_0)$
(d) $h(\nu + \nu_0)$

99. Photons of energy 6 *eV* are incident on a metal surface whose work function is 4 *eV*. The minimum kinetic energy of the emitted photoelectrons will be

(a) 0 eV (b) 1 eV (c) 2 eV (d) 10 eV

100. For the photoelectric effect, the maximum kinetic energy E_k of the emitted photoelectrons is plotted against the frequency ¬ of the incident photons as shown in the figure. The slope of the curve gives



(a) Charge of the electron

(b) Work function of the metal

(c) Planck's constant

(d) Ratio of the Planck's constant to electronic charge

101. If intensity of incident light is increased in PEE then which of the following is true

(a) Maximum *K. E.* of ejected electron will increase

(b) Work function will remain unchanged

(c) Stopping potential will decrease

(d) Maximum *K.E.* of ejected electron will decrease

102. Consider the following statements

Assertion (*A*) : The number of electrons emitted in the photoelectric effect depend upon the intensity of incident photon.

Reason (*R*) : The ejection of electrons from a metallic surface is not possible until frequency of incident photons is not more than threshold frequency. Of these statements

(a) Both *A* and *B* are true and the *R* is a correct explanation of the *A*

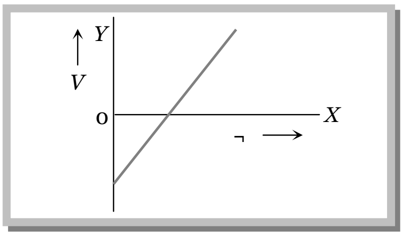
(b) Both *A* and *R* are true but the *R* is not a correct explanation of the *A*

(c) *A* is true but the *R* is false

(d) Both *A* and *R* are false

(e) *A* is false but the *R* is true

103. The stopping potential *V* for photoelectric emission from a metal surface is plotted along *Y*-axis and frequency ¬ of incident light along *X*-axis. A straight line is obtained as shown. Planck's constant is given by



(a) Slope of the line

(b) Product of slope on the line and charge on the electron

(c) Product of intercept along *Y*-axis and mass of the electron

(d) Product of Slope and mass of electron

104. Which of the following shows particle nature of light

(a) Refraction (b) Interference (c) Polarization (d) Photoelectric effect

105. With the increase in the no. of incident photons

(a) Photoelectric current increases

(b) Kinetic energy of photoelectrons increases

(c) Photoelectric current decreases

(d) Kinetic energy of photoelectrons decreases

106. The frequency of a photon having energy 100 eV is $(h = 6.610^{-34}\ J - \text{sec})$

(a) $2.42 \times 10^{26}\ Hz$ (b) $2.42 \times 10^{16}\ Hz$ (c) $2.42 \times 10^{12}\ Hz$ (d) $2.42 \times 10^{9}\ Hz$

107. Consider the following statements

Assertion (*A*) : Photo emission from a photosensitive surface is possible only if the incident radiation has a frequency above threshold frequency.

Reason (*R*) : Unless $h¬ > W$, the work function (*W*) of photo-sensitive surface, no photo emission is possible.

Of these statements

(a) Both *A* and *B* are true and the *R* is a correct explanation of the *A*

(b) Both *A* and *R* are true but the *R* is not a correct explanation of the *A*

(c) *A* is true but the *R* is false

(d) Both *A* and *R* are false

(e) *A* is false but the *R* is true

108. Which light when falling on a metal will emit photo electrons

(a) Ultra-violet radiation (b) Infrared radiation (c) Radiowaves (d) Microwaves

109. Two radiation containing photons of energy twice and five times the work function of a metal are incident successively on the metal surface. The ratio of the maximum velocities of the emitted electrons in the two cases will be

(a) 1 : 4 (b) 1 : 3 (c) 1 : 1 (d) 1 : 2

110. If a photo cell is used for light of wavelength 4000 Å and if *Na* and *Cu* are used as cathode whose work function are 2*eV* and 4*eV* respectively then which will be better for cathode

(a) *Na* (b) *Cu* (c) Both (d) None of these

111. Energy required to remove an electron from an aluminium surface is 4.2 *eV*. If light of wavelength 2000Å falls on the surface, the velocity of fastest electron ejected from the surface is

(a) $2.5 \times 10^{7}\, m/s$ (b) $8.4 \times 10^{5}\, m/s$ (c) $6.7 \times 10^{6}\, m/s$ (d) $8.4 \times 10^{4}\, m/s$

112. If in a photoelectric experiment, the wavelength of incident radiation is reduced from 6000 Å to 4000 Å, then

(a) Stopping potential will decrease (b) Stopping potential will increase

(c) Kinetic energy of emitted electrons will decrease (d) The value of work function will decrease

113. The maximum velocity of an electron emitted by light of wavelength ª incident on the surface of a metal of work function ¤ , is where *h* = Planck's constant, *m* = mass of electron and *c* = speed of light

(a) $\left[\frac{2(hc + ª¤)}{mª}\right]^{1/2}$ (b) $\frac{2(hc - ª¤)}{m}$ (c) $\left[\frac{2(hc - ª¤)}{mª}\right]^{1/2}$ (d) $\left[\frac{2(hª - ¤)}{m}\right]^{1/2}$

114. Light of wavelength 5000Å falls on a sensitive plate with photoelectric work function of 1.9 *eV*. The kinetic energy of the photoelectron emitted will be

(a) 0.58 *eV* (b) 2.48 *eV* (c) 1.24 *eV* (d) 1.16 *eV*

115. If mean wavelength of light radiated by 100 *W* lamp is 5000 *Å*, then number of photons radiated per second are

(a) 3×10^{23} (b) 2.5×10^{22} (c) 2.5×10^{20} (d) 5×10^{17}

116. When an inert gas is filled in the place vacuum in a photocell, then

(a) Photoelectric current is decreased

(b) Photoelectric current is increased

(c) Photoelectric current remains the same

(d) Decrease or increase in photoelectric current does no depend upon the gas filled

117. Energy conversion in a photoelectric cell takes place from

(a) Chemical to electrical (b) Magnetic to electrical (c) Optical to electrical (d) Mechanical to electrical

118. When light of wavelength is 2537Å made incident on the copper surface, then the stopping potential is 0.24 *volt*. The threshold frequency of copper

(a) $1.124 \times 10^{15}\, Hz$ (b) $1.414 \times 10^{14}\, Hz$ (c) $2.248 \times 10^{15}\, Hz$ (d) None of the above

119. An image of the sun is formed by a lens of focal length of 30 *cm* on the metal surface of a photoelectric cell and a photoelectric current *i* is produced. The lens forming the image is then replaced by another of the same diameter but of focal length 15 *cm*. The photoelectric current in this case is

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

120. Work function of a metal is 2.1 *eV*. Which of the waves of the following wavelengths will be able to emit photoelectrons from its surface

(a) 4000 Å, 7500 Å (b) 5500 Å, 6000 Å (c) 4000 Å, 6000 Å (d) None of these

121. Stopping potential for photoelectrons

(a) Does not depend on the frequency of the incident light

(b) Does not depend upon the nature of the cathode material

(c) Depends on both the frequency of the incident light and nature of the cathode material

(d) Depends upon the intensity of the incident light

122. 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 then double

123. Two identical metal plates show photoelectric effect. Light of wavelength a_A falls on plate *A* and a_B falls on plate *B*. $a_A = 2a_B$. The maximum *K.E.* of the photoelectron is K_A and K_B respectively. Which one of the following statements is true

(a) $2K_A = K_B$ (b) $K_A = 2K_B$ (c) $K_A < K_B / 2$ (d) $K_A > 2K_B$

124. When light of wavelength 300 *nm* (nanometer) falls on a photoelectric emitter, photoelctrons are liberated. For another emitter, however light of 600 *nm* wavelength is sufficient for creating photoemission. What is the ratio of the work functions of the two emitters

(a) 1 : 2 *(b) 2 : 1* *(c) 4 : 1* *(d) 1 : 4*

125. The kinetic energy of most energetic electrons emitted from a metallic surface is doubled when the wavelength a of the incident radiation is changed from 400 *nm* to 310 *nm*. The work function of the metal is

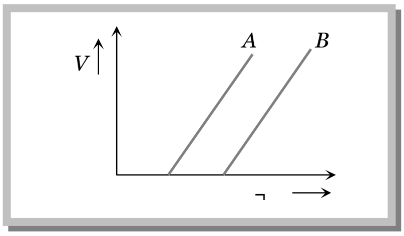
(a) 0.9 *eV* (b) 1.7 *eV* (c) 2.2 *eV* (d) 3.1 *eV*

126. Photo cell is a device to

(a) Store photons (b) Measure light intensity

(c) Convert photon energy into mechanical energy (d) Store electrical energy for replacing storage batteries

127. The stopping potential as a function of the frequency of the incident radiation is plotted for two different photoelectric surfaces *A* and *B*. The graphs show that work function of *A* is



(a) Greater than that of *B*

(b) Smaller than that of *B*

(c) Equal to that of *B*

(d) No inference can be drawn about their work functions from the given graphs

128. The *UV* photon is incident on a metal of photoelectric work function 2 *eV* and produces a photoelectron of energy 2 *eV*. The wavelength associated with the photon is

(a) 3100 Å (b) 6200 Å (c) 9300 Å (d) 4900 Å

129. Photoelectric work function of a metal is 1 *eV*. Light of wavelength 3000 Å falls on it. The photoelectrons come out with velocity

(a) $10\ ms^{-1}$ (b) $10^3\ ms^{-1}$ (c) $10^4\ ms^{-1}$ (d) $10^6\ ms^{-1}$

130. Threshold frequency for a metal is $10^{15}\ Hz$, when the light of 4000 Å wavelength incident on it, then choose the correct statement

(a) Photoelectric effect will not happen (b) Photoelectrons will be emitted with zero velocity

(c) Photoelectrons will be emitted with the velocity of 10^3 *m/sec.* (d) Photoelectrons will be emitted with the velocity of 10^5 *m/sec.*

131. The work function for tungsten and sodium are 4.5 *eV* and 2.3 *eV* respectively. If the threshold wavelength ª for sodium is 5460 Å, the value of ª for tungsten is

(a) 5893 Å (b) 10683 Å (c) 2791 Å (d) 528 Å

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

(a) 1.72×10^{31} (b) 1327×10^{34} (c) 13.27×10^{34} (d) 0.075×10^{-34}

133. *A* and *B* are two light sources. Intensity of source *A* is more than that of *B* and frequency of source *B* is more than that of *A*. The current obtained for the photocell is

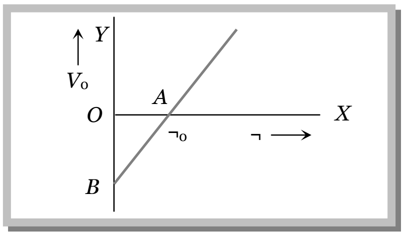
(a) More for source *A* (b) More for source *B* (c) Same for both the sources (d) Nothing can be said

134. Which of the following statement is not related to photon

(a) Its energy does not depends on frequency (b) Its energy depends on frequency

(c) It moves always with the velocity of light (d) Its wave is electromagnetic

135. In an experiment on photoelectric effect the frequency *f* of the incident light is plotted against the stopping potential V_0. The work function of the photoelectric surface is given by (*e* is electronic charge)



(a) *OB* $\times e$ in *eV*

(b) *OB* in *volt*

(c) *OA* in *eV*

(d) The slope of the line *AB*

136. When the photons of energy *h*¬ fall on a photo-sensitive surface (work function *h*¬o) electrons are emitted from the metallic surface. This is known as photoelectric effect. The electron coming out of the surface have a kinetic energy. Then it is possible to state that

(a) All ejected electrons have the same *K.E.* equal to $h¬ - h¬_0$

(b) The ejected electrons have a distribution of kinetic energy, the most energetic one have kinetic energy equal to $h¬ - h¬_0$

(c) The most energetic ejected electrons have kinetic energy equal to *h*¬

(d) The kinetic energy of the most energetic ejected electrons is $h¬_0$

137. Monochromatic light, incident on a metal surface emits photoelectrons whose energies range from zero to 2.5 *eV*. What will be the minimum energy of incident photon if the energy required to release the tightly bound electron is 4.2*eV*

(a) 1.6 *eV* (b) 1.6 eV to 6.8 *eV* (c) 6.8 *eV* (d) > 6.8 *eV*

138. The eye can detect 5×10^4 Photons/ m^2 – sec of green light (ª $= 5000$ Å), while ear can detect 10^{-13} watt/m^2. As a power electron, which is more sensitive and by what factor

(a) Eye is more sensitive and by a factor of 5.00 (b) Ear is more sensitive by a factor of 5.00

(c) Both are equally sensitive (d) Eye is more sensitive by a factor of 10^{-1}

139. When light of intensity 1 W/m^2 and wave length 5×10^{-7} *m* is incident on a surface, it is completely absorbed by the surface. If 100 photons emit one electron and area of the surface is $1 cm^2$, then the photoelectric current will be

(a) 2 *mA* (b) 0.4 «*A* (c) 4.0 *mA* (d) 4 «*A*

X-rays

140. The X-ray can not be diffracted by means of an ordinary grating due to

(a) Large wavelength (b) High speed (c) Short wavelength (d) All of these

141. *X*-ray will travel minimum distance in

(a) Air (b) Iron (c) Wood (d) Water

142. The minimum wavelength of *X*-ray emitted by *X*-rays tube is 0.4125 Å. The accelerating voltage is

(a) 30 kV (b) 50 kV (c) 80 kV (d) 60 kV

143. Characteristic *X*-rays are produced due to

(a) Transfer of momentum in collision of electrons with target atoms

(b) Transition of electrons from higher to lower electronic orbits in an atom

(c) Heating of the target

(d) Transfer of energy in collision of electrons with atoms in the target

144. *X*-rays when incident on a metal

(a) Exert a force on it (b) Transfer energy to it (c) Transfer pressure to it (d) All of the above

145. The minimum wavelength of X-rays produced by electrons accelerated by a potential difference of *V volts* is equal to

(a) $\frac{eV}{hc}$ (b) $\frac{eh}{cV}$ (c) $\frac{hc}{eV}$ (d) $\frac{cV}{eh}$

146. An X-ray machine is working at a high voltage. The spectrum of the X-rays emitted will

(a) Be a single wavelength (b) Extend from 0 to ∞ wavelength

(c) Extend from a minimum to ∞ wavelength (d) Extend from 0 to a maximum wavelength

147. What is the difference between soft and hard *X*-rays

(a) Velocity (b) Intensity (c) Frequency (d) Polarization

148. *X*-rays are produced due to

(a) Break up of molecules (b) Change in atomic energy level

(c) Change in nuclear energy level (d) Radioactive disintegration

149. The essential distinction between *X*-rays and ¥-rays is that

(a) ¥ -rays have smaller wavelength than X-rays

(b) ¥ -rays emanate from nucleus while X-rays emanate from outer part of the atom

(c) ¥ -rays have grater ionizing power than X-rays

(d) ¥ -rays are more penetrating than X-rays

150. *X*-ray beam can be deflected by

(a) Magnetic field (b) Electric field (c) Both (a) and (b) (d) None of these

151. For the production of characteristic $K_{¥}$, *X*-ray, the electron transition is

(a) $n = 2$ to $n = 1$ (b) $n = 3$ to $n = 2$ (c) $n = 3$ to $n = 1$ (d) $n = 4$ to $n = 1$

152. When *X* rays pass through a strong uniform magnetic field, then they

(a) Do not get deflected at all (b) Get deflected in the direction of the field

(c) Get deflected in the direction opposite to the field (d) Get deflected in the direction perpendicular to the field

153. If the potential difference applied across *X*-ray tube is *V* volts, then approximately minimum wavelength of the emitted *X*-rays will be

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

154. If V be the accelerating voltage, then the maximum frequency of continuous X-rays is given by

(a) $\frac{eh}{V}$ (b) $\frac{hV}{e}$ (c) $\frac{eV}{h}$ (d) $\frac{h}{eV}$

155. A metal block is exposed to beams of X-ray of different wavelength X-rays of which wavelength penetrate most

(a) 2Å (b) 4Å (c) 6Å (d) 8Å

156. An X-ray tube operates on 30 kV. What is the minimum wavelength emitted ? ($h = 6.6 \times 10^{-34}$ Js, $e = 1.6 \times 10^{-19}$ *coulomb*, $c = 3 \times 10^{8}$ ms^{-1})

(a) 0.133 Å (b) 0.4 Å (c) 1.2 Å (d) 6.6 Å

157. Bragg's law for X-rays is

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

158. Intensity of X-rays depends upon the number of

(a) Electrons (b) Protons (c) Neutrons (d) Positrons

159. In an X-ray tube electrons bombarding the target produce X-rays of minimum wavelength 1 Å. What must be the energy of bombarding electrons

(a) 13375 eV (b) 12375 eV (c) 14375 eV (d) 15375 eV

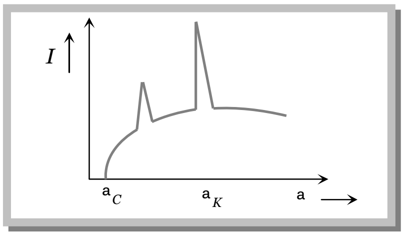
160. For production of characteristic K X-rays, the electron transition is

(a) $n = 2$ to $n = 1$ (b) $n = 3$ to $n = 2$ (c) $n = 3$ to $n = 1$ (d) $n = 4$ to $n = 2$

161. Penetrating power of X-rays does not depend on

(a) Wavelength (b) Energy (c) Potential difference (d) Current in the filament

162. The intensity of X-rays from a coolidge tube is plotted against wavelength as shown in the figure. The minimum wavelength found is λ_c and the wavelength of the K_α line is λ_k. As the accelerating voltage is increased



(a) $(\lambda_K - \lambda_C)$ increases

(b) $(\lambda_K - \lambda_C)$ decreases

(c) λ_K increases

(d) λ_K decreases

163. Penetrating power of X-rays can be increased by

(a) Increasing the potential difference between anode and cathode

(b) Decreasing the potential difference between anode and cathode

(c) Increasing the cathode filament current

(d) Decreasing the cathode filament current

164. In an X-ray tube the intensity of the emitted X-ray beam is increased by

(a) Increasing the filament current (b) Decreasing the filament current

(c) Increasing the target potential (d) Decreasing the target potential

165. X-rays are

(a) Stream of electrons (b) Stream of positively charged particles

(c) Electromagnetic radiations (d) Stream of uncharged particles

166. For the structural analysis of crystals, X-rays are used because

(a) X-rays have wavelength of the order of interatomic spacing (b) X-rays are highly penetrating radiations

(c) Wavelength of X-rays is of the order of nuclear size (d) X-rays are coherent radiations

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

(a) A continuous X-ray spectrum (Bremsstrahlung) with a minimum wavelength of ~ 0.155Å

(b) A continuous X-ray spectrum (Bremsstrahlung] with all wavelengths

(c) The characteristic X-rays spectrum of tungsten

(d) A continuous X-ray spectrum (Bremsstrahlung) with a minimum wavelength of ~ 0.155Å and the characteristic *X*-ray spectrum of tungsten

168. The wavelength of most energetic X-rays emitted when a metal target is bombarded by 40 *keV* electrons, is approximately

($h = 6.62 \times 10^{-34}$ *J-sec*; $1eV = 1.6 \times 10^{-19} J$; $c = 3 \times 10^8\ m/s$)

(a) 300 Å (b) 10 Å (c) 4 Å (d) 0.31 Å

169. Consider the following two statements *A* and *B* and identify the correct choice in the given answer

A : The characteristic *X*-ray spectrum depends on the nature of the material of the target.

B : The short wavelength limit of continuous X-ray spectrum varies inversely with the potential difference applied to the *X*-rays tube

(a) *A* is true and *B* is false (b) *A* is false and *B* is true (c) Both *A* and *B* are true (d) Both *A* and *B* are false

170. The energy of an *X* ray photon of wavelength 1.65 Å is ($h = 6.6 \times 10^{-34}$ *J-sec*, $c = 3 \times 10^8\ ms^{-1}$, $1eV = 1.6 \times 10^{-19} J$)

(a) 3.5 *keV* (b) 5.5 *keV* (c) 7.5 *keV* (d) 9.5 *keV*

171. The X-ray beam coming from an X-ray tube will be

(a) Monochromatic

(b) Having all wavelengths smaller than a certain maximum wavelength

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

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

172. Molybdenum is used as a target element for production of X-rays because it is

(a) A heavy element and can easily absorb high velocity electrons (b) A heavy element with a high melting point

(c) An element having high thermal conductivity (d) Heavy and can easily deflect electrons

173. K_a characteristic X-ray refers to the transition

(a) $n = 2$ to $n = 1$ (b) $n = 3$ to $n = 2$ (c) $n = 3$ to $n = 1$ (d) $n = 4$ to $n = 2$

174. What *kV* potential is to be applied on X-ray tube so that minimum wavelength of emitted X-rays may be 1Å ($h = 6.625 \times 10^{-34}$ *J-sec*)

(a) 12.42 *kV* (b) 12.84 *kV* (c) 11.98 *kV* (d) 10.78 *kV*

175. X-rays are not obtainable from *H*-atom because

(a) It is a gas (b) It is very light

(c) The difference in energy levels of *H*-atom is very small (d) The difference in energy levels of *H*-atoms is very large

176. Energy of *X*-rays is about

(a) 8 *eV* (b) 80 *eV* (c) 800 *eV* (d) 8000 *eV*

177. The continuous X-rays spectrum produced by an X-ray machine at constant voltage has

(a) A maximum wavelength (b) A minimum wavelength (c) A single wavelength (d) A minimum frequency

178. X-ray beam of intensity I_0 passes through an absorption plate of thickness *d*. If absorption coefficient of material of plate is «, the correct statement regarding the transmitted intensity *I* of *X*-ray is

(a) $I = I_0(1 - e^{-«d})$ (b) $I = I_0 e^{-«d}$ (c) $I = I_0(1 - e^{-«/d})$ (d) $I = I_0 e^{-«/d}$

179. X-rays are produced in X-ray tube operating at a given accelerating voltage. The wavelength of the continuous X-rays has values from

(a) 0 to ∞ (b) $^a{}_{min}$ to ∞, where $^a{}_{min} > 0$

(c) 0 to λ_{max}, where $\lambda_{max} < \infty$ (d) λ_{min} to λ_{max}, where $0 < \lambda_{min} < \lambda_{max} < \infty$

180. The emission of K_a X-rays from tungsten is at a wavelength of 0.021*nm*. The energy difference between the *K* and *L* energy levels will be approximately

(a) 0.51 *MeV* (b) 1.2 *MeV* (c) 59 *KeV* (d) 13.6 *eV*

181. Compton effect shows that

(a) *X*-rays are waves (b) *X*-rays have high energy (c) *X*-rays can penetrate matter (d) Photons have momentum

182. The wavelength of K_α X-rays produced by an X-ray tube is 0.76*Å*. The atomic number of the anode material of the tube is

(a) 20 (b) 60 (c) 40 (d) 80

183. X-ray astronomy

(a) Orbiting the earth because X-rays are almost completely absorbed by the atmosphere

(b) Is very much possible through the use of appropriate telescopes kept on the earth because the atmosphere is almost completely transparant to X-rays

(c) Is possible both with satellites and on the earth because the atmosphere does not affect X-rays at all

(d) Is not possible at all because X-rays have a very short wavelength

184. An X-ray tube with a copper target emits *Cu* K_α line of wavelength 1.50 Å. What should be the minimum voltage through which electrons are to be accelerated to produce this wavelength of *X* rays ($h = 6.63 \times 10^{-34}$ *J-sec*, $c = 3 \times 10^8$ *m/s*)

(a) 8280 *V* (b) 828 *V* (c) 82800 *V* (d) 8.28 *V*

185. An X-ray tube is operating at 50 *kV* and 20 *mA*. The target material of the tube has a mass of 1.0 *kg* and specific heat 495 Jkg^{-1} ^oC. One percent of the supplied electric power is converted into X-rays and the entire remaining energy goes into heating the target. Then

(1) A suitable target material must have a high melting temperature

(2) A suitable target material must have low thermal conductivity

(3) The average rate of rise of temperature of target would be $2^oC/s$

(4) The minimum wavelength of the X-rays emitted is about 0.25×10^{10} *m*

(a) 1, 3, 4 (b) 1, 2, 3 (c) 2, 3, 4 (d) None of these

186. In X-ray spectrum wavelength λ of line K_α depends on atomic number *Z* as

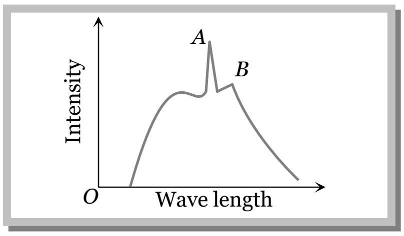
(a) $\lambda \propto Z^2$ (b) $\lambda \propto (Z-1)^2$ (c) $\lambda \propto \frac{1}{(Z-1)}$ (d) $\lambda \propto \frac{1}{(Z-1)^2}$

187. The energy of a photon of characteristic X-ray from a Coolidge tube comes from

(a) The kinetic energy of the striking electron (b) The kinetic energy of the free electrons of the target

(c) The kinetic energy of the ions of the target (d) An electronic transition of the target atom

188. The figure represents the observed intensity of X-rays emitted by an X-ray tube as a function of wavelength. The sharp peaks *A* and *B* denote



(a) Band spectrum

(b) Continuous spectrum

(c) Characteristic radiations

(d) White radiations

189. When a beam of accelerated electron hits a target a continuous X-ray spectrum is emitted from the target. Which of the following wavelength is absent in the X-ray spectrum. If the X-ray in operating at 40,000 volts

(a) 0.25 Å (b) 0.5 Å (c) 1.5 Å (d) 1.0 Å

190. Absorption of X-ray is maximum in which of the following different sheets

(a) Copper (b) Gold (c) Beryllium (d) Lead

191. Which of the following is accompanied by the characteristic X-ray emission

(a) α-particle emission (b) Electron emission (c) Positron emission (d) K-electron capture

192. A potential difference of 42,000 *volts* is used in an X-ray tube to accelerate electrons. The maximum frequency of the X-radiations produced is ($1\ eV = 1.6 \times 10^{-19}\ J$ and $h = 6.63 \times 10^{-34}\ J\text{-}sec$)

(a) $10^{19}\ Hz$ (b) $10^{18}\ Hz$ (c) $10^{16}\ Hz$ (d) $10^{20}\ Hz$

193. A direct X-ray photograph of the intestines is not generally taken by the radiologists because

(a) Intestines would burst on exposure to X-rays

(b) The X-rays would not pass thrugh the intestines

(c) The X-rays will pass through the intestines without causing a good shadow for any useful diagnosis

(d) A very small exposure of X-rays causes cancer in the intestines

194. If λ_1 and λ_2 are the wavelengths of characteristic X-rays and gamma rays respectively, then the relation between them is

(a) $\lambda_1 = \frac{1}{\lambda_2}$ (b) $\lambda_1 = \lambda_2$ (c) $\lambda_1 > \lambda_2$ (d) $\lambda_1 < \lambda_2$

195. The binding energy of the innermost electron in tungsten is 40 *keV*. To produce characteristic X-rays using a tungsten target in an X-ray tube the potential difference *V* between the cathode and the anticathode should be

(a) $V < 40\ kV$ (b) $V \le 40\ kV$ (c) $V > 40\ kV$ (d) $V > / < 40\ kV$

196. The wavelength of K_α-line in copper is 1.54 Å. The ionisatin energy of *K* electron in copper in *Joule* is

(a) 11.2×10^{-27} (b) 12.9×10^{-16} (c) 1.7×10^{-15} (d) 10×10^{-16}

197. The characteristic X-ray radiation is emitted when

(a) The electrons are accelerated to a fixed energy

(b) The source of electrons emits a monenergetic beam

(c) The bombarding electrons knock out electrons from the inner shell of the target atoms and one of the outer electrons falls into this vacancy

(d) The valence electrons in the target atom are removed as a result of the collision

198. In radio-theraphy, X-rays are used to

(a) Detect bone fractures (b) Treat cancer by controlled exposure

(c) Detect heart diseases (d) Detect fault in radio receiving circuits

199. In obtaining an X-ray photograph of our hand, we use the principle of

(a) Shadow photography (b) Image formation by an optical system

(c) Photoelectric effect (d) Positive rays

200. X-rays are not used for radar purpose because

(a) They are not reflected by the target (b) They are not electromagnetic waves

(c) They are completely absorbed by the air (d) They sometimes damage the target

201. The wavelength of K_α line for an element of atomic number 43 is λ. Then the wavelength of K_α line for an element of atomic number 29 is

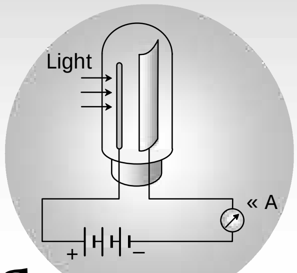
(a) $\frac{43}{29}\lambda$ (b) $\frac{42}{28}\lambda$ (c) $\frac{9}{4}\lambda$ (d) $\frac{4}{9}\lambda$

202. Let λ_α, λ_β and λ'_α denote the wavelengths of the X-rays of the K_α, K_β and L_α lines in the characteristic X-rays for a metal

(a) $\lambda'_\alpha > \lambda'_\alpha > \lambda_\beta$ (b) $\lambda'_\alpha > \lambda_\beta > \lambda_\alpha$ (c) $\frac{1}{\lambda_\beta} = \frac{1}{\lambda_\alpha} + \frac{1}{\lambda'_\alpha}$ (d) $\frac{1}{\lambda_\alpha} + \frac{1}{\lambda_\beta} = \frac{1}{\lambda'_\alpha}$

203. In a Coolidge tube, the potential difference across the tube is 20 *kV*, and 10 *mA* current flows through the voltage supply. Only 0.5% of the energy carried by the electrons striking the target is converted into X-rays. The X-ray beam carries a power of

(a) 0.1 *W* (b) 1 *W* (c) 2 *W* (d) 10 *W*



Answer Sheet

Assignments

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
a	b	a	c	b	c	d	d	a	c	a	b	a	c	d	a	b	d	b	d
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
c	a	c	b	c	d	b	b	c	d	b	b	b	d	c	c	b	a	d	a
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
d	b	a	a	a	a	c	a	c	b	a	a	a	d	a	d	d	c	d	c
61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
c	c	c	b	c	a	c	c	b	d	c	b	c	a	a	a	d	d	c	b
81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
c	a	c	b	a	a	a	b	a	c	b	d	a	a	c	b	a	b	a	c
101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
b	b	b	d	a	b	a	a	d	a	b	b	c	a	c	b	c	a	b	d
121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140
c	c	c	b	c	b	b	a	d	a	c	a	a	a	a	b	c	a	b	c
141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160
b	a	a	d	c	c	c	b	b	d	d	a	d	c	a	b	b	a	b	c
161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180
d	a	a	a	c	a	d	d	c	c	c	b	a	a	c	d	b	b	b	c
181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
d	c	a	a	a	d	d	c	a	d	d	a	c	c	c	c	c	b	a	a
201	202	203																	
c	c	b																	