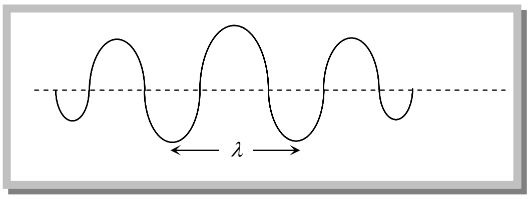
de-Broglie Waves or Matter Waves

The waves associated with the moving material particles are known as de-Broglie waves or matter waves. Matter waves propagate in the form of wave packet with group velocity.



(1) **de-Broglie wavelength :** The length of de-Broglie waves or matter waves is known as de-Broglie wavelength (λ).

$\lambda = \frac{h}{p} = \frac{h}{mv}$; where h = plank's constant, p = momentum of particle.

(i) If E is the kinetic energy of a particle (charge Q) of mass m then $\lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mQV}}$; V = potential difference through which charge particle is accelerated.

$$\lambda_{\text{electron}} = \frac{12.27}{\sqrt{V}}\mathring{A}, \qquad \lambda_{\text{photon}} = \frac{0.286}{\sqrt{V}}\mathring{A}, \qquad \lambda_{\alpha} = \frac{0.101}{\sqrt{V}}\mathring{A},$$

(ii) Energy of a particle due to it's thermal motion is $\frac{3}{2}kT$ (k = Boltzmann's constant) so $\lambda = \frac{h}{\sqrt{3mkT}}$.

(iii) de-Broglie wavelength associated with gas molecules is $\lambda = \frac{h}{m\,v_{rms}}$.

(iv) If m_o be the rest mass of the particle. Then $\lambda = \frac{h[1 - v^2/c^2]^{1/2}}{m_0 v}$; where v = speed of the particle.

(v) The de-Broglie wavelength associated with the orbital electron in the nth orbit of hydrogen atom is given by

$\lambda_n = \frac{12.27}{\sqrt{V}} = \frac{12.27}{\sqrt{13.6/n^2}} = 3.3(n)\mathring{A}.$

(2) **Characteristics of matter waves :**

(i) Matter waves are not electromagnetic in nature.

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

(iii) 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.

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

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

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

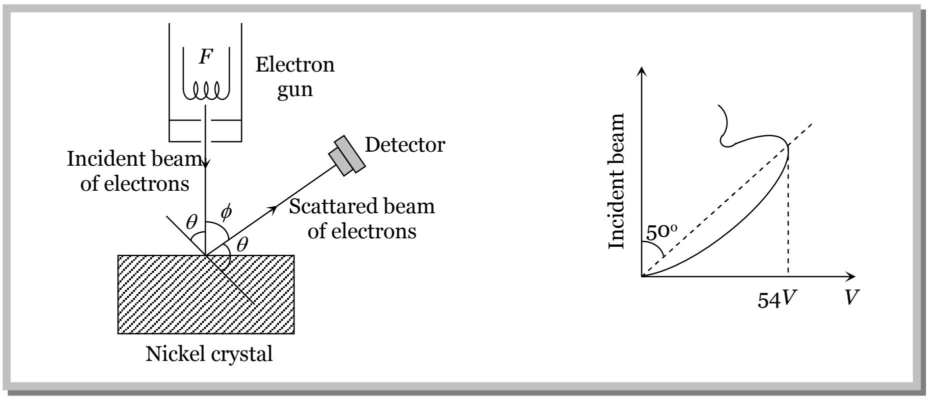
(vii) Matter waves can propagate in vacuum, hence they are not mechanical waves.

(viii) The number of de-Broglie waves associated with nth orbital electron is n.

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

(3) **Davission 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 the electron gun is made to fall on Nickel crystal cut along cubical axis at a particular angle. The scattered 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.



The intensity of scattered beam was maximum at an angle of 50°. Now $\theta + 50 + \theta = 180^\circ$ or $\theta = 65^\circ$. It means, at a glancing angle $\theta = 65^\circ$, the sharp maximum is obtained at an angle of 50°.

According to Bragg's equation $d \sin\theta = n\lambda$, if $\theta = 65^\circ$, $n = 1$ and $d = 0.91$ Å (for nickel), $\lambda = 1.65$ Å

According to de-Broglie hypothesis $\lambda = \frac{12.27}{\sqrt{V}} \mathring{A}$. If $V = 54$ *volt* then $\lambda = 1.67\,\mathring{A}$. This is the verification of de-Broglie hypothesis.

X–Rays

(1) **Nature of X-Rays**

(i) These rays are electromagnetic waves and their emission is in the form of photons.

(ii) They move with the velocity of light.

(iii) Their wavelength (of the order of $10^{-10} m$) is very small in between the wavelength of ultraviolet and γ-rays.

(iv) X-rays are of two types

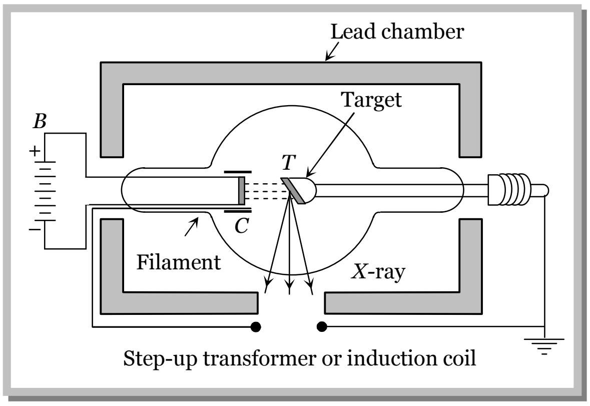
Hard X-rays	Soft X-rays
(a) Their penetrating power is high.	(a) Their penetrating power is low.
(b) wavelength range : $(0.1\,\mathring{A} - 4\mathring{A})$.	(b) wavelength range : $(4\,\mathring{A} - 100\,\mathring{A})$.
(c) Their frequency is high (10^{18} *Hz*).	(c) Their frequency is low (10^{16} *Hz*).
(d) Their energy is high.	(d) Their energy is low.

(v) These waves like light produce reflection, refraction, interference, polarisation and diffraction.

(vi) The hardness of X-rays depends on their wavelength or frequency.

(2) **Production of X-Rays**

(i) These rays were discovered by Rongten. These are also called Rongten rays.



(ii) The tube which is used in the production of X-rays is called Coolidge tube.

(iii) The pressure in the tube is maintained at 10^{-6} *mm Hg*.

(iv) Electrons are emitted from a filament by thermionic emission.

(v) The accelerated electrons are allowed to fall on a target inclined at an angle of 45°.

(vi) Atomic number of the target material is quite high. In general molybdenum material is used as target whose melting point is also high.

(vii) When electrons accelerated by a very high potential difference (10 *kV* to 80 *kV*) strike target, X-rays are emitted. In fact only 0.2% of the kinetic energy of electrons is utilized in producing X-rays and rest of the energy is dissipated as heat due to which the target gets heated.

(viii) The intensity of X-rays emitted depends upon the number of electrons striking the target or the current flowing through the filament but it does not depend upon the accelerating voltage.

(ix) The limiting wavelength or the frequency of X-rays depends upon the accelerating voltage. Lower is the potential difference, lower is the limiting frequency or higher is the limiting wavelength of X-rays emitted. Higher is the potential difference, higher is the limiting frequency or lower is the limiting wavelength of the X-rays emitted.

(x) The intensity and the penetrating power (energy) of X-rays produced by the Coolidge tube can be controlled independently. For increasing the intensity of X-rays the current flowing through the filament is increased, due to which the number of electrons emitted increases. The penetrating power (or energy) of the rays depends upon the potential difference between the cathode and the anode. Thus by varying this potential difference the penetrating power can be increased or decreased.

Note : ❑ Production of X-rays is the reverse of photo-electric effect.

(3) **Characteristics of X-Rays :**

(i) These are uncharged rays.

(ii) They are not deflected by electric and magnetic field.

(iii) Their limiting wavelength or frequency depends upon the potential difference.

(iv) They produce photoelectric and Compton effects.

(v) They ionize the gases.

(vi) They affect the photographic plates.

(vii) They produce deformation when they fall on living beings.

(viii) They damage cells of the living beings.

(ix) They can pass through thin sheets and flesh but can not pass through thick metal sheets and bones.

(x) When they are incident on a substance, they get absorbed. For the absorption by the substance, $\boldsymbol{I = I_0 e^{-\mu x}}$ where I_0 is the initial intensity I is the intensity of X-rays after traversing a distance x, μ is the absorption coefficient of the substance. Intensity of absorbed X-rays will be $I_0(1 - e^{-\mu x})$.

(xi) Half value thickness ($x_{1/2}$) : The thickness of material for which intensity of X-rays remains half $x_{1/2} = \frac{0.693}{\mu}$.

(xi) For X-rays lead is the best absorber.

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

(xiii) When X-rays are incident on a crystal, they are diffracted and this diffraction is explained according to Bragg equation $n\lambda = 2d \sin\theta$; where d is the distance between the lattice planes and θ is the angle between the incident beam and the plane of the crystal which is also called grazing angle.

(xiv) These can not be used in radar because they are not reflected by the target.

(xv) The penetrating power of X-rays depends upon the wavelength. Higher is the wavelength or lower is the frequency of the X-rays, lesser is the penetrating power. Lower is the wavelength or higher is the frequency of the X-rays, higher will be the penetrating power.

(xx)The energy of the X-rays depends upon the potential difference between the cathode and the target. Lower is the acceleration voltage, lower will be the energy or frequency of the X-rays produced and higher is the accelerating voltage, higher will be the energy or frequency of the X-rays produced.

(4) **X-ray spectra**

(i) Continuous X-ray spectrum : When the incident electrons peneterate the atom of the target and go past the nucleus, they are retarded, due to which the X-ray are emitted. The phenomenon is known as : Bremstrahlung. The spectrum of produced X-rays is called continuous spectrum.

The minimum wavelength of X-ray is given by $\lambda_{\min} = \frac{hc}{eV} = \frac{12375}{V} Å$ or $\lambda_{\min} \propto \frac{1}{V}$. Also $\nu_{\max} = \frac{eV}{h}$.

(ii) Characteristic X-ray spectrum : High energy electron peneterate target atom and knock out electron from the innermost orbit. When the electrons from the outer orbits jump to fill the vacancy so created, characteristic X-rays are produced. They depend on the atomic number of the target.

(a) The frequencies or the wavelength of characteristic X-rays do not depend on the applied potential difference.

(b) The characteristic X-rays for most of the elements consist of K and L series. They are produced due to the jumping of electrons to the K and L shells with principal quantum numbers 1 and 2 respectively.

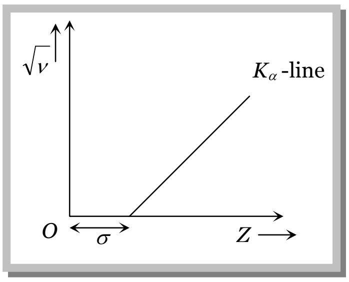
(c) The characteristic X-rays are called K_α when the electrons jumps from n = 2 to n = 1 orbit. They are called L_α when the electrons jump n = 3 to n = 2 orbit.

(d) Similarly transition from n = 3 to n = 1 gives K_β line and transition from n = 4 to n = 2 gives L_β line and so on.

(e) The wavelength of K_α line of the X-rays is given by $\frac{1}{\lambda} = R(Z-1)^2\left(\frac{1}{1^2}-\frac{1}{2^2}\right)$ and that of L_α lines is given by $\frac{1}{\lambda} = R(Z-7.4)^2\left(\frac{1}{2^2}-\frac{1}{3^2}\right)$

(5) **Moseley's law**

(1) Moseley studied the characteristic X-ray spectrum and gives a relation between the frequency of the spectral lines and the atomic number of the target. According to this law for particular line $\sqrt{\nu} \propto (Z-\sigma) \Rightarrow \sqrt{\nu} = a(Z-\sigma)$; here a and σ are constant, σ is screening constant.



For K_α - line $a = \sqrt{\frac{3}{4}Rc}$, where R = Rydberg constant, c = speed of light and b =1

(6) **Uses of X-Rays :** Some of the main uses are : Radiography, Radiotherapy, To detect cracks, flaws and air bubbles in the iron girders fitted in buildings and bridges, In the study of crystals and molecular structures *etc.*