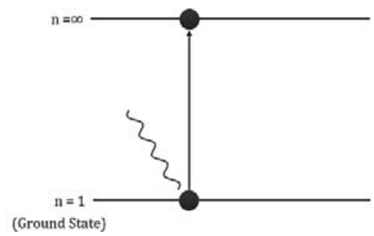
X-RAYS

Ionization Energy And Potential



Ionization energy is the minimum amount of energy needed to ionize an atom.

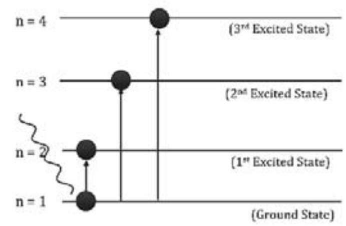
$E_{ionization} = E_{\infty} - E_n = -E_n$

Ionization potential refers to the potential difference necessary to accelerate an electron from rest to attain kinetic energy equivalent to the ionization energy.

$$V_{ionization} = \frac{E_{ionization}}{e}$$

For hydrogen atom, $V_{ionization} = \frac{13.6ev}{e} = 13.6V$

Excitation Energy And Potential



The energy necessary to transition an electron from the ground state to any other excited state is termed the excitation energy of that particular excited state.

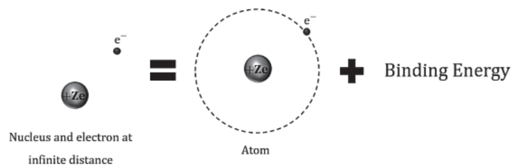
The potential difference needed to accelerate an electron from rest to obtain kinetic energy equivalent to the excitation energy of any state is referred to as the Excitation potential.

$$V_{Excitation} = \frac{E_{Excitation}}{e}$$

Binding Energy

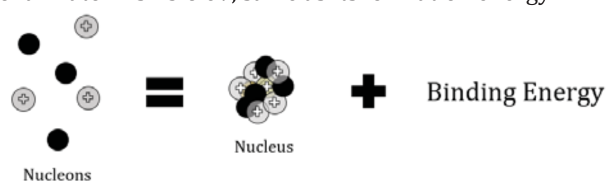
In light of the attractive force existing between the nucleus and the electron, they will endeavor to draw nearer to each other when left undisturbed, aiming to decrease their overall energy.

Therefore, when they are brought together to form an atom, the energy of the system decreases, and an amount of energy equivalent to the difference between the initial and final states of the system is liberated, known as the binding energy.



The energy released when the components of a system are brought together from infinity to form the system.

Binding Energy of a H-atom is 13.6 eV, same as its ionization energy.



Bohr's Atomic Model

Limitations OF Bohr Atomic Model

- The explanation for the atomic spectrum of atoms beyond hydrogen was unsuccessful.
- Even the spectral lines of hydrogen displayed deviations.
- It was arbitrarily assumed that electrons do not emit electromagnetic radiation in stationary orbits.
- The explanation for the relative intensities of the frequencies in the spectrum was lacking.

X- Rays - Types And Production Of X -Rays.

X-Ray Tube / Coolidge Tube

Discovered by W.C. Rontgen in 1895

X-rays are generated when high-energy (rapidly moving) electrons collide with a target, such as a metal object.

Glass Chamber: Nearly perfect vacuum state.

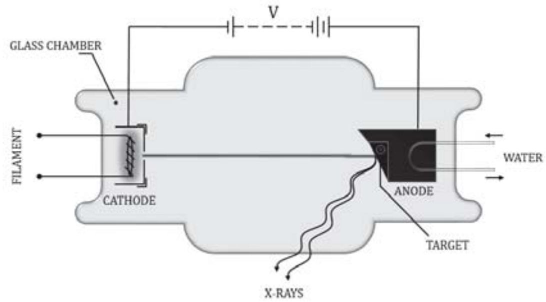
Filament: The filament is heated electrically and it emits electrons (thermionic emission).

Target: A metal with a high melting point like platinum or tungsten serves as a target

A high direct current voltage (V) of approximately 50 kilovolts is sustained between the filament and the target.

This elevated potential accelerates the emitted electrons, causing an electron beam of exceedingly high velocity to impinge upon the target, thereby generating X-rays.

The heat produced is dissipated by circulating water through the anode.



Continuous X-Rays

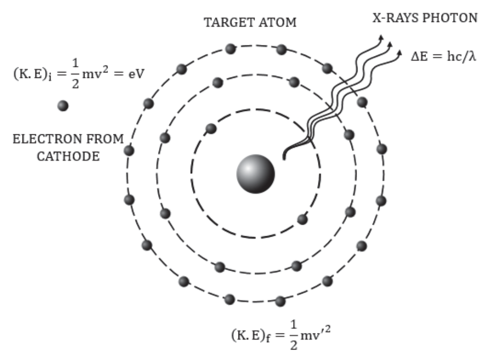
In an X-ray tube, a variety of photon energies are generated as a result of the deceleration of electrons when they approach an atomic nucleus closely. A spectrum of continuous wavelengths is observed.

Wavelength of the X-ray $\lambda = \frac{hc}{\Delta E}$

Since various electrons can lose varying amounts of energy upon colliding with the target atom, the value of ΔE will differ for each electron. This discrepancy can result in a range of values for ΔE.

$$0 < \Delta E < eV$$

Hence, a broad spectrum of X-ray wavelengths is obtained, leading to the continuum of the spectrum.



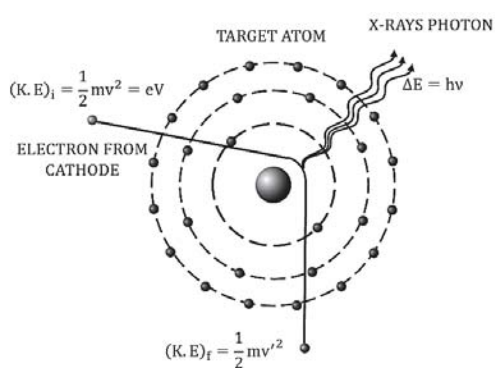
$$\Delta E = (K.E)_i - (K.E)_f$$

$$0 < \Delta E < eV$$

When $\Delta E = 0$ λ is very high.

When, $\Delta E = eV$ λ is very minimum.

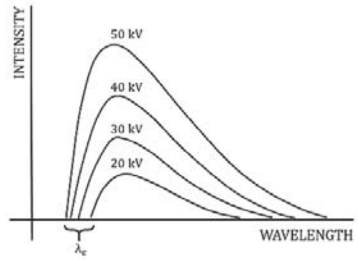
So wavelength of X – rays cannot be less then $\lambda_c = \frac{hc}{eV}$



This minimum wavelength is called Cut off or threshold wavelength.

Cutoff/Threshold Wavelength: $\lambda_c \approx \frac{12431}{V}$ Å

Does not depend on the metal.
The minimum wavelength threshold below which X-rays are not emitted.
It relies on the applied potential difference across the discharge tube.



Ex. An X-ray tube is operated at 20 KV and the current through the tube is 0.5 mA. Find:
(a) The number of electrons hitting the target per second.
(b) The energy falling on the target per second as the kinetic energy of the electrons.
(c) The cut-off wavelength of the X-rays emitted

Sol. (a) Current through the tube, $i = 0.5mA$
q_n 1 Secound, $q = 0 \cdot 5 \times 10^{-3}C$ (As current is the charge flowing per second)

No. of electron hitting the target per second.

$$n_e = 0 \cdot 5 \times 10^{-3}C$$
$$n = \frac{0{\cdot}5\times10^{-3}}{1{\cdot}6\times10^{-19}} =\cdot\ 31 \times 10^{-16}$$
$$= 3 \cdot 1 \times 10^{-15}$$
$$n = 3 \cdot 1 \times 10^{-15}$$

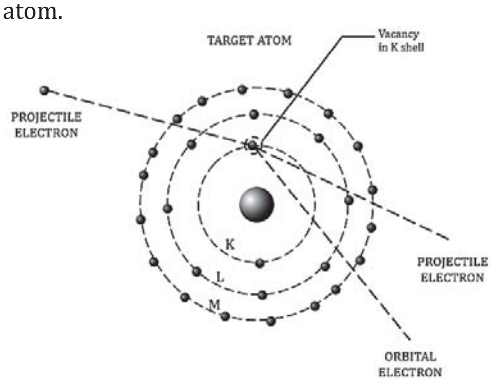
(b) K.E. of the electron hitting the target per second.

$$E = n_e v$$
$$\frac{i}{e} ev = ev \qquad \therefore n = \frac{i}{e}$$
$$0 \cdot 5 \times 10^{-3} \times 20 \times 10^{-3} = 10J/s$$

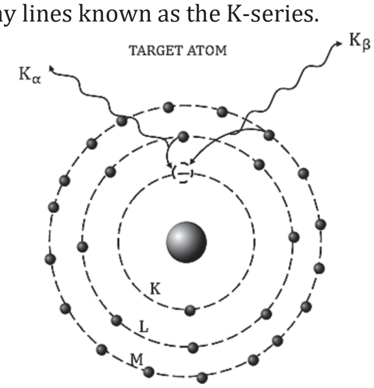
(c) Cut-off wavelength of the X – rays is given by,

$$\lambda = \frac{hc}{eV} = \frac{1240eV}{20000eV}$$
$$62 \times 10^{-3}nm = 0 \cdot 0.62nm$$

Characteristic X-rays are emitted exclusively when the incident electron displaces an orbital electron of the target atom.



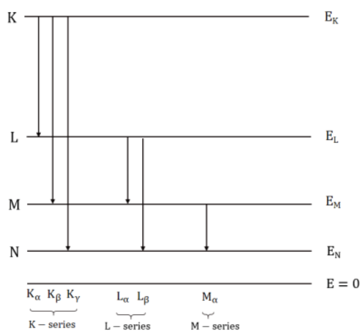
When a specific shell has an empty space, an electron from higher shells undergoes a quantum leap to occupy the vacancy. During the transition process, the electron emits energy with a frequency within the X-ray range. The movement of electrons from different outer shells to the innermost 'K' shell results in a set of X-ray lines known as the K-series.

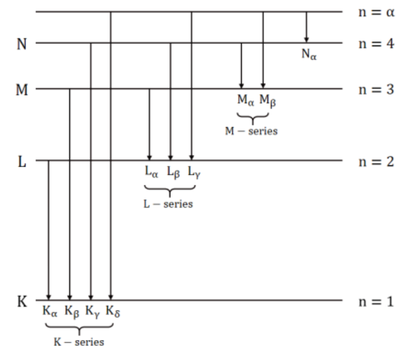


An atom with a vacant electron possesses greater energy compared to an atom with all its electrons intact.

The electron within the K-shell is bound more tightly to the nucleus than the electron within the L-shell. Consequently, it requires more energy to dislodge an electron from the K-shell compared to the L-shell. This is why an atom with a vacancy in the K-shell possesses higher energy than an atom with a vacancy in the L-shell.

When an electron from the L-shell occupies the vacancy in the K-shell, the energy of the atom decreases from E_K to E_L.

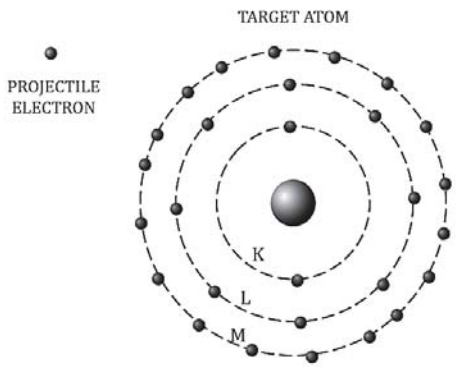


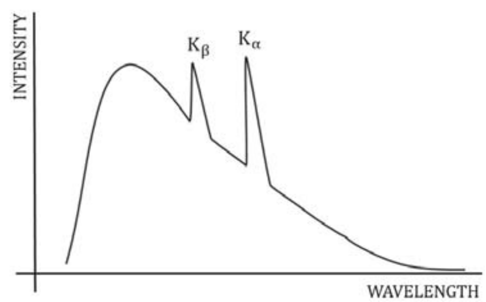


The distinct peaks observed in the graph are referred to as characteristic X-rays.

The characteristic lines are solely dependent on the target material and are not influenced by the accelerating voltage.

As cathode rays traverse the target, both types of X-rays (continuous and characteristic) are emitted.

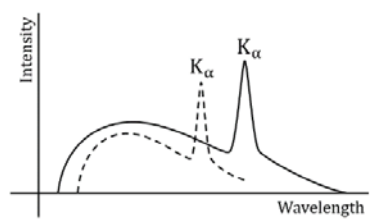




They earn the name "characteristic X-rays" due to their distinctive association with the element employed as the target anode.

The wavelengths within this group exhibit distinctive, discrete radiations emitted by the atoms of the target material.

Ex. Figure shows the intensity-wavelength relations of X-rays coming from two different Coolidge tubes. The solid curve represents the relation for the tube A in which the potential difference between the target and the filament is V_A and atomic number of the target material is Z_A. These quantities are V_B and Z_B for the other tube. Then,



(a) $V_A > V_B, Z_A > Z_B$ (b) $V_A > V_B, Z_A < Z_B$ (c) $V_A < V_B, Z_A > Z_B$ (d) $V_A < V_B, Z_A < Z_B$

Sol. From graph, cut off wavelength for atom A is lesser than that of atom B.

$$\lambda_A < \lambda_B$$

Cut off wavelength is inversely proportional to accelerating potential.

$$\lambda = \frac{hc}{eV} \therefore V_A > V_B$$

$$\lambda = \frac{hc}{\Delta E}$$

$$\lambda_A < \lambda_B [k_\alpha]$$

It means that to knock out an electron from K-shell, more energy is required in case of atom B. As this energy depends on the charge on nucleus i.e. Ze, the atomic no. of atom B should be greater than that of A.

$$Z_A < Z_B$$

Hence, option (b) is correct.

Soft And Hard X-Rays

Hard X-Rays

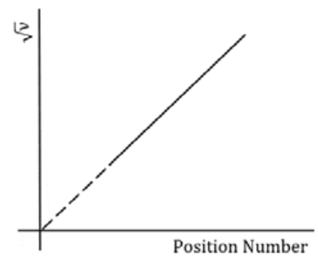
These X-rays correspond to short wavelengths.
They possess significant energy and therefore high penetration capabilities.

Soft X-Rays

These X-rays correspond to extended wavelengths.
They possess limited energy and therefore low penetration capabilities.

Moseley's Law And Bragg's Law.

Moseley's Law



Moseley's investigations into characteristic X-rays significantly contributed to the development of the concept of atomic number.
Moseley conducted measurements of characteristic X-ray frequencies for numerous elements and graphed the square root of frequency against the element's position number in the periodic table. $\sqrt{v} = a(Z - b)$
Where, a and b are positive constants.

Ex. Find the constants a and b in Moseley's equation $\sqrt{v} = a(Z - b)$ from the following data.

Element	Z	Wave length of K_α X – rays
Mo	42	71 pm
Co	27	178.5 pm

Sol. Moseley's equation can also be written as,

$$\sqrt{\frac{c}{\lambda}} = a(Z - b)$$

On substituting values of Z and λ for Mo and Co, we get,

$$\sqrt{\frac{c}{\lambda_1}} = a(42 - b) \quad \dots (1)$$

$$\sqrt{\frac{c}{\lambda_2}} = a(27 - b) \quad \dots (2)$$

Dividing $eq^n(1)$ and $eq^n(2)$ $\sqrt{\frac{\lambda_2}{\lambda_1}} = \frac{42-b}{27-b}$

On solving, we get, $b = 1.37$

$$a = 5 \times 10^7 (Hz)^{1/2}$$

$$a = 5 \times 10^7 (Hz)^{1/2} \text{ and } b = 1.37$$

Bragg's Law

X-rays are short-wavelength electromagnetic waves capable of diffraction by appropriate diffracting centers.
Path difference between the two rays, $2d\sin\theta$
For Constructive interference, $2d\sin\theta = n\lambda$
The analysis indicates that a robust reflected X-ray beam will occur exclusively if.

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

Where, n: an integer, d: interplanar spacing