Types of X-rays

According to origin of X-ray, it is categorized into two types,

1. Continuous X-ray
2. Characteristic X-ray

1. Continuous X-ray When the electrons from the cathode are bombarded on the target, they enter into the interior of target atom, as a result of Coulomb attractive interaction between the nucleus of target atom and the electron. Consequently, the kinetic energy of electron goes on decreasing as a result of emission of X-rays of continuous wavelength(It is also called soft X-ray). For each anode potential, there is a minimum wavelength of X-ray denoted as λ_{min}.

Let us take an electron ejected from the cathode moving with the velocity v_1, enters into the interior of target atom. Due to Coulomb attraction , the electron's velocity decreases. Let it be v_2. Then,

$$\text{Loss of K.E} = \frac{1}{2}m_e(v_1^2 - v_2^2)$$

$$where\ m_e = mass\ of\ an\ e^-$$

The loss in K.E. appears in the form of X-ray of frequency ν,

$$\therefore \frac{1}{2}m_e(v_1^2 - v_2^2) = h\nu$$

If the moving electron is totally stopped by the attraction of target nucleus, then $v_2 = 0$. In this case, frequency of X-ray emitted should be maximum,

$$\Rightarrow \frac{1}{2}m_e(v_1^2 - 0) = h\nu_{max}$$

$$\Rightarrow \frac{1}{2}m_e v_1^2 = h\nu_{max}$$

If the accelerating potential applied across the cathode and anode be V, then energy acquired by an e^- is eV,

$$\Rightarrow \frac{1}{2}m_e(v_1^2) = eV$$

$$\boxed{\therefore eV = h\nu_{max}}$$

We have,

$$c = \lambda_{min}.\nu_{max}$$

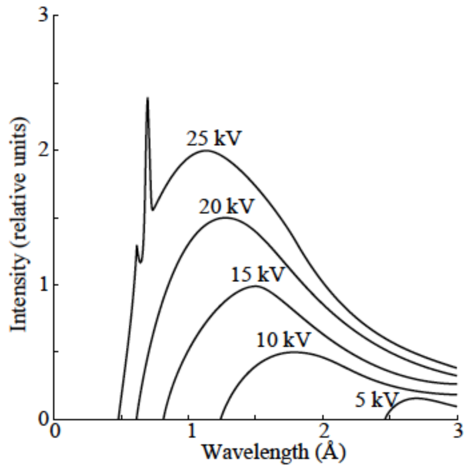
$$\lambda_{min} = \frac{c}{\nu_{max}}$$

$$\therefore \boxed{\lambda_{min} = \frac{hc}{eV}}$$

From above relation, it is obvious that, more the anode potential, shorter is the wavelength of X-ray produced.

When intensity of X-ray is plotted against the wavelength of X-ray for different anode potential, curves are obtained as shown in the figure.

The continuous curve is obtained for a particular anode potential, when intensity of X-ray is plotted against the wavelength. Such type of spectra is called continuous X-ray spectra. Following are the salient features of continuous X-ray spectra,



1. For each anode potential, there is a minimum value of wavelength of X-ray produced.
2. As the wavelength of X-ray increases, its intensity increases rapidly and reached to a maximum. On further increasing the wavelength, gradual decrease in intensity is observed, but intensity never becomes zero.
3. When the anode potential is increased, λ_{min} shifts towards the decreased wavelength side.
4. To a particular high anode potential instead of continuous curve, certain change in intensity is observed which is the characteristics spectra of X-ray.

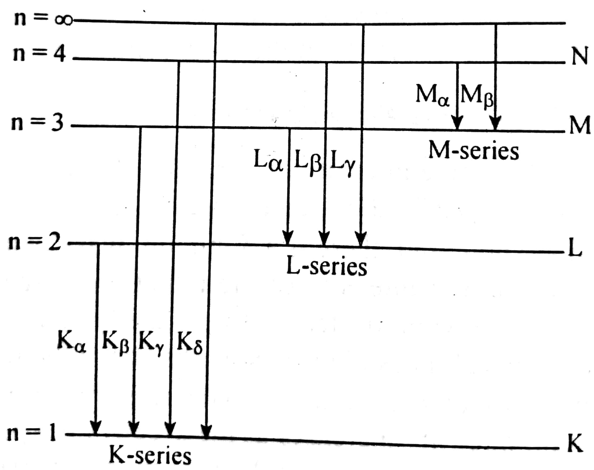
The origin of characteristic X-ray spectra depends on the nature of the target as well as corresponding anode potential.

2. Characteristic X-ray

It is characterized by a particular wavelength/frequency. It can be produced by the following two methods.

1. A fast moving electron ejected from the cathode enters into the interior of target atom and becomes able to knock interior electrons(k-electrons, L-electrons). The vacant position of the electron are filled up by outer electrons of higher energy. The difference in energy of the transition electron is emitted in the form of line X-ray which is also known as characteristic X-ray.
2. Instead of high energy electron, hard X-ray can also be used to dislodge the interior electron of target atom, The X-ray used for this purpose should be stronger than the X-ray to be produced. The vacant position of the electron can be fulfilled by outer electrons of the atom or free electron.

When innermost electron i.e. k-electron of the target atom is dislodged, transition of electron from any outer level or free e^-s to k-level occurs, resulting in spectra called k-series. The k-series is further categorized as k_α-line, k_β-line, k_γ-line etc. When transition of electron is from α orbit, it produces $k\alpha$ line and if from M level, the line produced is k_β line and so on. The transition between L and K level gives rise ti characteristic X-ray of least energy and hence low frequency. If the free electron get the chance to fill up the vacancy in K-orbit, the X-ray of highest possible frequency is produced.



Similarly, when L-electron is knocked out, L-series of X-ray line spectra are observed. In the same way $L\alpha$, $L\beta$, $L\gamma$ lines are observed. Likewise in heavier atom M and N series can also be observed.

Mosley performed several experiment regarding the characteristic X-ray spectra. He tried to correlate the frequency of spectral line with the atomic mass of the target atom. The plot of frequency against atomic mass didn't show uniformity in the chemical as well as physical properties of the elements and later he changed.

Moseley's Law

It states that,

" The square root of the frequency of each characteristic spectral lines of X-ray is directly proportional to the atomic number of the atom."

Let ν be the frequency of the line spectrum and Z be the atomic no. of the atom of the target. Then,

$$\nu \propto Z^2$$

$$\Rightarrow \nu = a(Z-\sigma)^2$$

where a and σ are constants depending on the type of spectral line and the nature of target atom. σ is taken as screening constant of the atom

The emission of characteristic line can be explained on the basis of Bohr's atomic theory, according to which the frequency is given by

$$\nu = Z^2 Rc\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$\Rightarrow \nu = (Z-\sigma)^2 Rc\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$\Rightarrow \boxed{\frac{1}{\lambda} = (Z-\sigma)^2 R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]} \tag{1}$$

The frequency and hence the wavelength of the line spectrum can be calculated with the help of relation (1).

In regards to K-series, if we consider the transition of electron from L-state to K-state, it gives rise to K_α line (L→K) i.e $n_1 = 1$ and $n_2 = 2$.

From (1),

$$\Rightarrow \frac{1}{\lambda} = R(Z-\sigma)^2\left[1 - \frac{1}{4}\right]$$

$$\Rightarrow \boxed{\frac{1}{\lambda} = \frac{3R(Z-\sigma)^2}{4}}$$

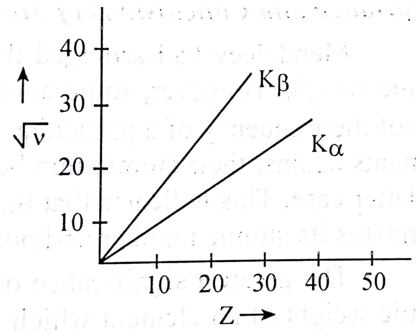
For K_β line (M→K), $n_1 = 1$ and $n_2 = 3$

$$\Rightarrow \frac{1}{\lambda} = R(Z-\sigma)^2\left[1 - \frac{1}{9}\right]$$

$$\Rightarrow \boxed{\frac{1}{\lambda} = \frac{8R(Z-\sigma)^2}{9}}$$

and so on.

The emission of characteristic line against the atomic number can be plotted as follows.



Importance of Moseley law

1. It is the atomic number and not the atomic weight of an element which determines its characteristic properties, both chemical and physical. This explained placing of argon before potassium in periodic table.
2. Mosely's work also helped to complete the periodic table by discovering new elements. For eg. Hafnium(72), Selenium(61)
3. It also helped to determine atomic number of rare earth element and hence, fixed their position in the periodic table.