Chapter -2 *X-Ray Spectrum*

The radiation-electron interaction that gives rise to an absorption process occurs mainly with atomic electrons, i.e with bound electrons in general. In this section, we address the elementary interaction of X-rays with free electrons.

After completing this chapter , one can able to know

Continuous and characteristic X-ray
The frequency of X-ray and
X-ray spectroscopy and Mosley's

X-ray spectrum

X-rays, also known as **X-radiation**, refers to electromagnetic radiation (no rest mass, no charge) of high energies. The x-rays are produced in a Coolidge tube when a high energy electron interacts with a heavy metal like copper or gallium target. X-rays are high-energy **photons** with short wavelengths and thus, very high frequency.

When the beam hits the atom, the electrons in the inner shell, called the s-shell, get jostled, and sometimes flung out of their orbit. Without that electron, or electrons, the atom becomes unstable, and so for the atom to "relax" or go back to equilibrium, Gaffney said, an electron in the so-called 1p shell drops in to fill the gap. That results emission of high-energy **photons** in the form of X-ray.

"The problem with that is the fluorescence [or X-ray light given off] goes in all directions," Gaffney told Live Science. "They aren't directional and not focusable. It's not a very easy way to make a high-energy, bright source of X-rays."

Control of Intensity and Quality

Modern X-ray, the tube has the advantage of independent control of intensity and quality.

1. Control of intensity:

   The intensity of X-rays depends upon the number of electrons emitted from the filament. This depends upon the electric current flowing through the filament. So by controlling the current with the help of rheostat, we can control the intensity of X-rays. Hence, the intensity of the X-ray can be changed by adjusting the filament current.

2. Control of quality

   If V be the potential difference applied across the two electrodes, then the kinetic energy acquired by the electron is given by

$$eV = \tfrac{1}{2} mV^2$$

where m, e and v be the mass, charge and velocity of the electron. Therefore, the quality of X-rays depends upon their energy which, in turn, depends upon the kinetic energy of the incident electrons. The kinetic energy of the incident electrons depends upon the potential difference between the anode and the cathode. Hence, quality of X-rays can be adjusted by changing the potential difference across the tube. X-rays of low frequency having low penetrating power are called soft X-rays whereas; X-rays of high frequency having high penetrating power are called hard X-rays.

Frequency and Wavelength of X-rays Produced

When the whole kinetic energy of an electron is converted into the energy of the X-rays produced, then, X-ray of maximum frequency is obtained. Therefore, if υ_{max} is the maximum frequency of the emitted X-rays, then we have,

$$eV = \tfrac{1}{2} mV^2 = h\upsilon_{\max}$$ where, *h* is a Planck's constant.

$$\upsilon_{\max} = \frac{eV}{h}$$

If c is the velocity of light in vacuum and $\lambda_{\min}$ is the minimum possible wavelength of the rays produced, then.

$$\lambda_{\min} = \frac{c}{\upsilon_{\max}} = \frac{hc}{eV}$$

Nature of X-rays

X-rays is an E-M waves similar to light waves, but of much shorter wavelength about 0.1 A^0 i.e 10^{-11} m or 0.01 nm (to $10A^0$). However, the wavelength of visible light is nearly, 10^3 times more than the wavelength of X-rays. The wavelength of the visible light ranges from 4000 A^0 to $8000A^0$. Since wavelength is inversely proportional to frequency, therefore the frequency of X-rays is nearly, 10^3 of visible light. Again, since, the energy of the photon is directly proportional to frequency, therefore, x-ray photons are much stronger than the photons of visible light.

Continuous and Characteristic X-Ray Spectra

The spectrum from an X-ray tube contains two distinct parts:

(i) Continuous X-ray spectra

It consists of radiations of all possible wavelengths, from a certain lower limit to higher values continuously, as in the case of visible light.

Origin - Continuous X-ray spectra

X-rays are produced, when high velocity electrons strike the target material of high atomic number. It has also been mentioned in the production of X-rays, that most of the energy of the electrons goes into the heating of the target material.

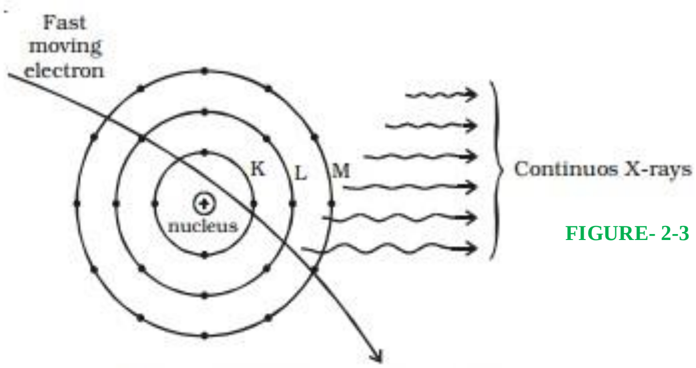

FIGURE- 2-3

Fig Origin of continuous X – rays

A few fast moving electrons penetrate deep into the interior of the atoms of the target material and are attracted towards the target nuclei by Coulomb's force. Due to that force, the electrons get deflected from their original path. As a result of this, the electrons are decelerated and hence, energy of the electron decreases continuously. This loss of energy during retardation is given off in the form of X-rays (or bremsstrahlung) of continuously varying wavelength as shown in figure 2.3. The X - rays consist of continuous range of frequencies up to a maximum frequency $\upsilon_{\max}$ or minimum wave length $\lambda_{\min}$. This is called as continuous X - rays.

When an electron loses its entire energy in a single Coulomb's interaction, then X-rays of minimum wavelength (cut-off wavelength) are emitted. The minimum wave length depends on the anode voltage. If *V* is the potential difference between the anode and the cathode,

$$eV = \tfrac{1}{2} mV^2 = h\upsilon_{\max}$$ where *h* is a Planck's constant.

$$\upsilon_{\max} = \frac{eV}{h}$$

If c is the velocity of light in vacuum and $\lambda_{\min}$ is the minimum possible wavelength of the rays produced, then.

$$\lambda_{\min} = \frac{c}{\upsilon_{\max}} = \frac{hc}{eV}$$

where h is Planck's constant, c is the velocity of light and e, the charge of the electron. Substituting the known values in the above equation,

$$\lambda_{\min} = \frac{12400}{V} \text{ A}^0$$

For the given operating voltage, the minimum wave length is same for all metals.

(ii) Characteristic or Discrete X-ray spectra

It consists of definite, well defined wavelengths superimposed on the continuous spectrum. These spectral lines generally occur in the form of small groups and are characteristic of the material of the target.

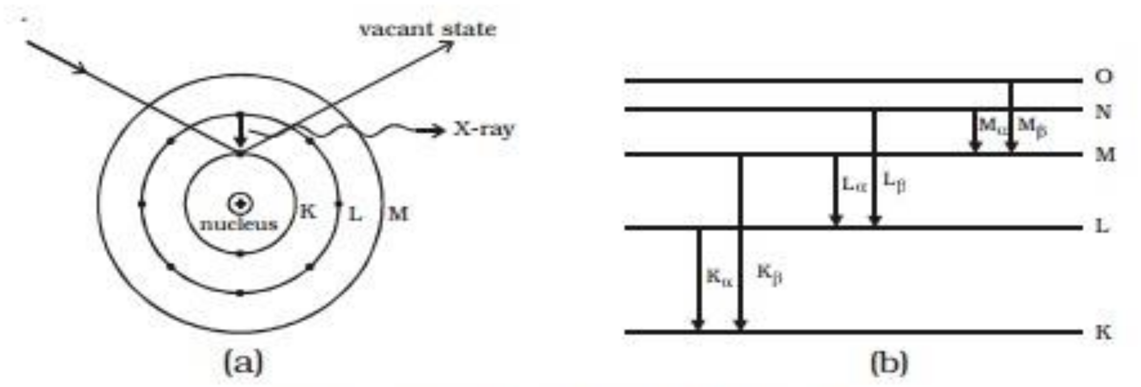

FIGURE- 2-4 *Characteristic X–ray spectra*

Origin - Characteristic X-ray spectra

Few of the fast moving electrons having velocity of about (1/10)th of the velocity of light may penetrate the surface atoms of the target materials and knock out the tightly bound electrons even from the inner most shells (like K, L, M shells) of the atom. Since the process leaves a **vacancy** in the electron energy level from which the electron came, the outer electrons of the atom **cascade down** to fill the lower atomic levels, and one or more **discrete** or **characteristic X-rays** are usually emitted. As a result, sharp intensity peaks appear in the spectrum at wavelengths that are a characteristic of the material from which the anode target is made. The frequencies of the characteristic X-rays can be predicted from the Bohr model.

Figure 2-4 shows the case, when the fast moving electrons knock off one electron from K, L and M Shells and the vacancy is filled by the nearby electron from the higher energy shell. During this transition, the energy difference is radiated in the form of X-rays of very small wave length.

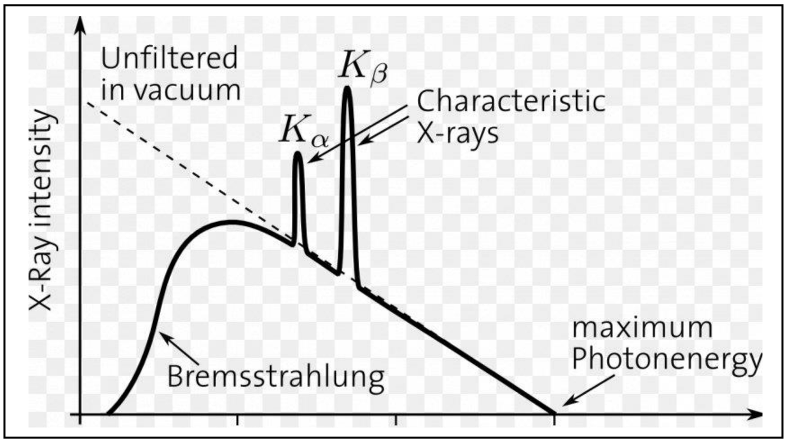

FIGURE- 2-5

For example, when fast moving electron hits an electron of K shell, characteristic X-rays emit that correspond to $K_{\alpha,}$ and K_{β} line of the K series. The frequencies ν_1, and ν_2 of those lines are given respectively by the relations $(E_L - E_K) = h\nu_1$ and $(E_M - E_K) = h\nu_2$ when electron from L shell jumps to the K shell and from M shell to the K shell. In this way, spectrum of different series K, L, M, etc have been produced. The frequency of radiation depends upon the target material. The X-ray spectrum consists of sharp lines superimposed on bremsstrahlung (continuous spectrum). This discrete sharp peak is known as characteristic spectra that depend upon the characteristic of target material. The X-ray spectrums are the variation of X-rays intensity with wavelength shown in figure 2.5.

X-ray spectroscopy and Mosley's Law

X-Ray Spectroscopy and Moseley's Law X-ray spectroscopy is used to study inner shell phenomena of atoms, states of highly ionized atoms produced by accelerators or to determine material properties. There are two principal methods: Using a semiconductor detector or a Bragg-type spectrometer.

Moseley's law states that the square root of the frequency of the emitted x-ray is proportional to the atomic number of the target .

$$\sqrt{\nu} = a\,(Z - b)$$

Where, a and b are constants called proportionality and screening (or shielding) constants.

For K series, the value of a is $\sqrt{\boxed{3Rc/4}}$ and that of b is 1. Here R is Rydberg's constant and c is speed of light (as in Bohr's model).

Importance of Moseley's law:

- Using this law Moseley arranged K and Ar, Ni and CO in a proper way in Mendeleev's periodic table.
- This law was held to the discovery of many new elements like Tc (43), Pr (61), Rh (45).
- The atomic number of rare earth have been determined by this law.