The method is illustrated in Figure-4. *C* is a cylindrical metallic chamber, usually of brass, 0.2 to 1 m long, with the open ends closed by two thin aluminium sheets W, W, known as the windows. X-radiations enter the cylinder through one of the windows and leave it by the other. The chamber is filled with air, ethyl bromide vapour etc. The X-ray beam ionises the gas or vapour inside the chamber. The positive ions are drawn to the tube wall which acts as the cathode and the negative ions move to the anode A, a metallic rod placed inside the chamber parallel to its axis but insulated from the wall. The anode A is connected to an electrometer M and a potential difference of several hundred volts is maintained between A and C. The electrometer M is capable of measuring very small ionisation current produced by X-radiation. The ion-current is found to be linearly related to the X-ray intensity, and thus gives the intensity of the beam.

A scintillation counter (detailed discussion of which is made in Chapter : Nuclear Radiation, Detectors) is especially suitable for measuring the intensity of X-rays from high voltage sources. The X-ray beam is allowed to penetrate a crystal or a liquid and is transformed into the visible fluorescent radiation. This radiation actuates a photomultiplier tube and the resulting photoelectric current is multiplied and measured. The intensity of X-rays is directly proportional to the photocurrent.

• Variation of X-ray intensity with wavelength

X-rays of different wavelengths are emitted from the X-rays tube and if the intensity is plotted against wavelength, then curves of the nature as shown in Figure-5 and Figure-6 are obtained. The different curves in each Figure corresponds to different voltages used. While Figure-5 gives I vs λ graph for a target material of high atomic number, e.g. tungsten ($Z = 74$), Figure-6 gives I-λ curve when a target material of low Z-value, e.g. Mo ($Z = 42$), is used.

The main features of the intensity distribution may be summed up as follows :

1. The intensity increases with increasing potential difference between the cathode and the anode.

2. For the same potential difference the curve, starting from the long wavelength side, attains a maximum and then falls rapidly to zero at the sharp cut-off wavelength λ_0 or λ_{min} which gets shifted to shorter wavelengths with increasing voltages.

3. For a given wavelength, the intensity is higher, higher the potential difference and as shown in Figure-5 I varies continuously with λ up to a voltage difference ~ 50 kV.

4. For the same p.d., the intensity increases with increase of the at. no. Z of the target.

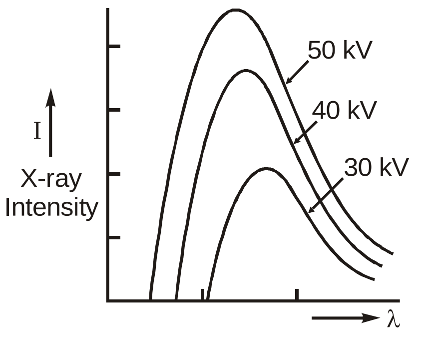

Fig.5-Intensity vs. wavelength curves (high Z-value)

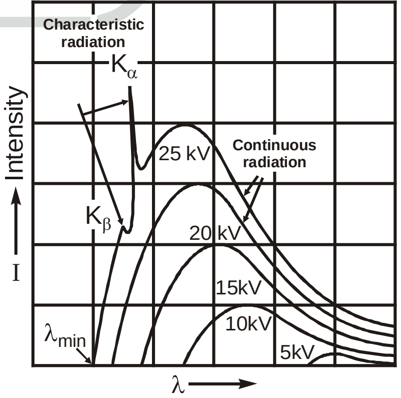

Fig.6-Intensity vs. wavelength curves (low Z-value)

5. At potentials ~ 25 kV or higher, several discrete peaks appear, superimposed on the continuous background, at specific wavelengths with target of $Z = 42$ (Figure-6). For target with still lower Z, e.g. Cu ($Z = 29$), the peaks begin to appear at still lower voltage ($V \geq 8$ kV), the peak wavelengths for Cu are however different from those of Mo. The heights of the peaks increase with increasing voltage.

6. The wavelengths of the peaks in the intensity distribution curve are characteristic of the target material and are independent of the applied voltage. These are called characteristic X-rays. Higher the Z, shorter is the wavelength of characteristic X-rays.

• Origin of continuous X-radiation

The origin of continuous X-radiation, the existence of minimum wavelength and the calculation of its magnitude can only, and easily, be understood from the quantum concept of radiation.

According to the quantum theory, each X-ray photon is produced as a result of particular collision of one electron. The photon of maximum energy is generated when the electron loses the whole of its energy in a single collision. The electrons are accelerated to an energy *Ve* by the accelerating voltages *V*. So the maximum energy of the photon is given by

$$E_m = h\nu_m = \frac{1}{2}mv^2 = eV \qquad \text{...(i)}$$

where ν_m is the maximum frequency of the photon.

But the maximum frequency ν_m corresponds to the minimum wavelength λ_0, given by

$$\lambda_0 = \frac{c}{\nu_m} = \frac{hc}{Ve} \qquad \text{...(ii)}$$

where *c* is the velocity of light in free space.

If *V* is measured in volt, we have $$\lambda_0 = \frac{12413}{V(\text{volt})} \mathring{A} \qquad \text{...(iii)}$$

So, if V = 10,000 volts, $\lambda_0 = 1.24\,\mathring{A}$; if $V = 50\,\text{kV}$, $\lambda_0 = 0.248\,\mathring{A}$, etc.

The magnitude of λ_0 can be measured accurately and the equation (ii) may be exploited to find the value of *h*, the Planck's constant. The value of *h* thus determined is in good agreement with those obtained from thermal radiation and photoelectric effect. Further, equation (iii) or (ii) shows that higher the *V*, lower is λ_0; this is also observed experimentally.

Events in which electron gives up the whole of its content are extremely rare and, in general, an electron produces several photons of wavelength $\lambda > \lambda_0$ in a succession of collisions. The electrons also cause some ionisation and much (sometimes 99%) of the kinetic energy gets converted into heat energy.

Note 1. The above mechanism of emission of electromagnetic radiation from an accelerated or decelerated electron is called bremsstrahlung process and the emitted radiation bremsstrahlung (brems = brake, strahlung = radiation, bremsstrahlung = brake-radiation i.e. radiation due to deceleration).

Note 2. X-rays are often classified on the basis of their penetrating power. Most penetrating radiation is called hard X-radiation, the least penetrating one the soft X-rays, the intermediate one the medium radiation.

11.9. Origin of characteristic X-ray lines

In addition to the smooth continuous spectrum just discussed there appear, as we have seen, some sharp, characteristic X-ray lines at sufficiently high voltages. The mechanism of their production is quite different and lies in the interior electronic structure of the atoms.

The wavelength of X-ray lines are usually of the order of few angstrom or even shorter, implying that their energies are ~ 10^4 eV or higher. Consequently, the atomic electrons whose transitions give rise to X-ray lines must have binding energies ~ 10^4 eV or higher. This is possible only if inner atomic orbits close to the nucleus house the electrons.

According to Bohr, an atom of an element of atomic number Z contains in its normal state Z electrons revolving round the nucleus in different shells. The innermost shell corresponds to the first quantum orbit $n = 1$ and is