Production of X-rays

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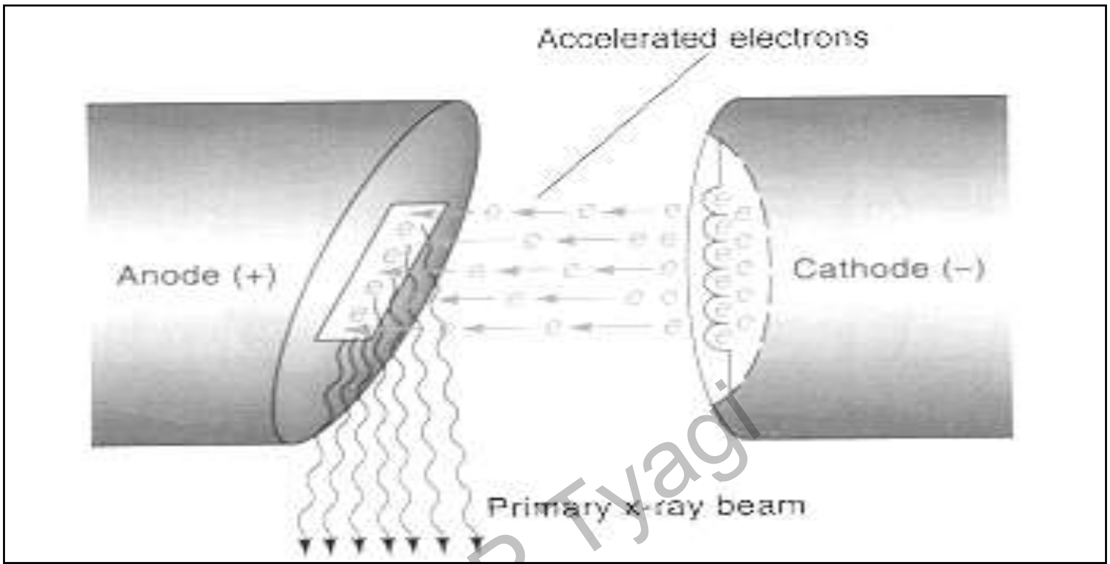
An x-ray tube has filament (made of tungsten) that provide the source of electrons. It also has a positively charged anode (made of tungsten) or target in which interaction take place to produce x-rays. The tube must be completely evacuated for electron to flow freely from cathode to anode.



When filament is heated the thermal energy overcomes the binding energy of the electron in the outer orbit of the atoms, and an electron cloud will form around the filament. This process is called ***thermo ionic emission***.

- ★ The heat of filament is dependent on the current beam passed through it. This current is controlled on the x-ray machine by the ***milliamperage (ma)*** control dial. The more is the ma, the more electrons will be available to interact with the target.
- ★ Another way to control the number of electrons is to increase the time for which machine is operated. This is controlled by another knob on the control dial which select the ***time (S).***

In order for interactions to take place with the target atoms, these electrons must flow towards anode (target) at very high speed. This speed is generated by applying high ***potential difference (kvp)*** between the cathode and anode. As soon as it is applied the stream of electron rush towards anode; this stream is called tube current (cathode rays). If a machine is operated at 70 kvp, each electron arrives at the target with the maximum energy of 70 KeV, the electron with such a high energy interact with the target in the following manners-

1. Collisional interaction: This is of two types

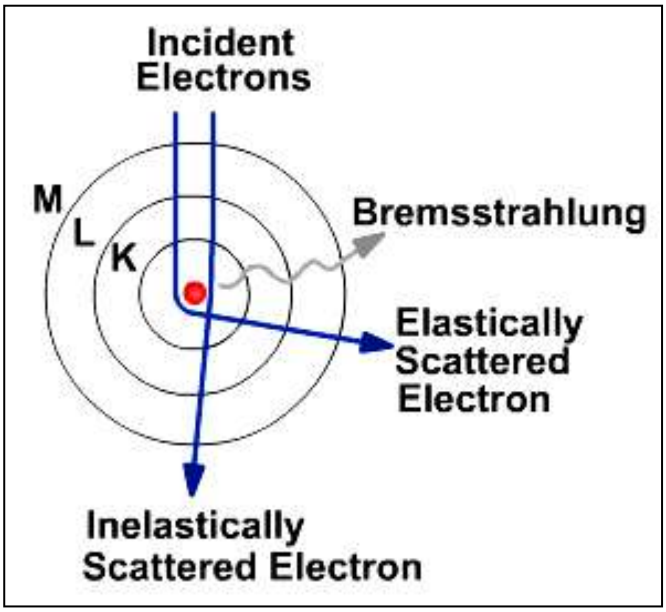
(i) An incoming electron may excite and outer orbital electron of the target atom by transferring its some or all energy while passing very near to orbit. Therefore the outer electron moves slightly away from the nucleus transiently and its return to original orbit occurs with the release of energy as heat due to infrared radiations or heat waves.

(ii) The incoming electrons may also release one or more electron from an outer orbit of target atoms causing ionization as described above. The ejected and incoming electrons further undergo additional interaction with target atoms till they lose all their energies. The total energy loss is given of as heat. Normally 99% of kinetic energy of electron is transformed into thermal energy due to collisional interaction. (The other one percent is eradiated as x-rays by following interactions).

2. Radiative interaction:

(a) General or Bremsstrahlung radiations (White radiations) (*Bremsstrahlung(Gr) - Break*):

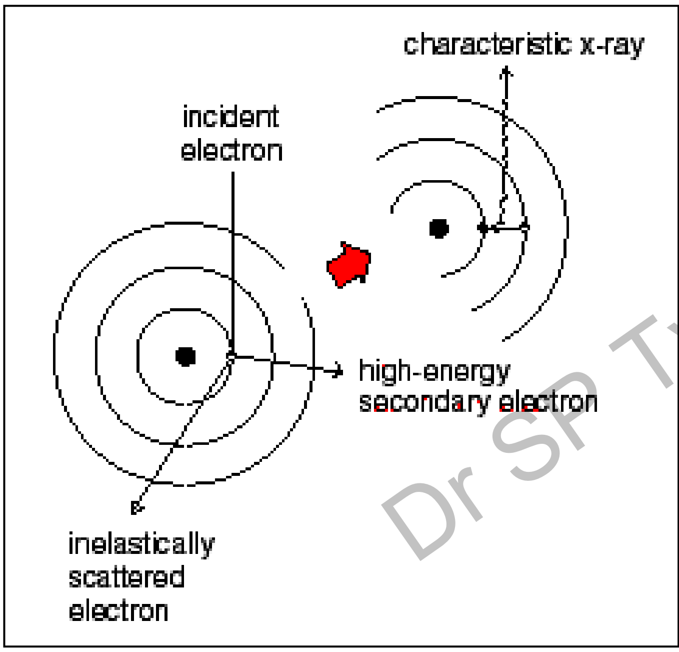
If a projectile electron completely avoids the orbital electron on passing through a tungsten atom of the target (anode), it may come sufficiently near the nucleus of the atom to come under its influence (Electrostatic attraction). The electron thus get slow down and is deflected from its original course. In this process electron loses some or all of its kinetic energy depending on its deflection. This loss of energy is emitted in the form of an x-ray photon. The x-ray produced in this form is called General or Bremsstrahlung radiations.



The electron may get deflected from 0-90^{o}; if it gets a deflection of 90^{o} (the probability of which is very small), almost all of its kinetic energy is lost and x-ray photon of high energy (equivalent to the kinetic energy of the incoming electron) will be formed. It means that an electron may loose all, none or an intermediate level of its kinetic energy in Bremsstrahlung interaction. Therefore x-ray produced will be of heterogeneous/ polyenergetic nature.

(b) Characteristic radiations/Line radiations:

If the energy of the incoming electron exceeds the binding energy of any one of inner shell electron of target atom, the electron is ejected out of the atom. (Now again both, the original and ejected electrons may travel away from the atom or/and participate in the other collisions). The vacancy created in the electron shell will be immediately filled up by an electron cascading from an adjacent lower energy shell (Outer shell) and the difference in the binding energies of these two shells will be released as an x-ray photon. The vacancy created in outer shell due to cascading of one its electron, will further be filled by electrons from further outer shells. This will again release an x-ray photon. This shifting of electron continues until the stable energy state reached.



The probability of production of characteristic x-ray is much lower than that of Bremsstrahlung. Therefore they do not contribute to the spectrum of x-ray used for diagnostic radiology.

Example: the binding energy of K, L, M shells of Tungsten atom is 70, 11 and 2 KeV respectively. If the incoming projectile electron removes a K shell electron the X photon will be released having energy of 70-11 = 59 KeV. If an electron cascade from M shell, another X ray photon of 9 KeV will be released. When L shell electron come to fill up the vacancy in the M shell.

Therefore the energy of the x-ray produced will be dependent upon the binding energy of the shell from which it arises, hence it is called characteristic x-ray as it is clear from the example that though the characteristic x-ray are produced by K, L, M, N and O shells of Tungsten atoms but x-rays produced by the K and L shell are the only one useful for diagnostic purposes (Rest are of extremely low energy).

Composition of x-ray at different KVP settings:

Tube Voltage (kvp)	Percentage of characteristic x-rays	Percentage of Bremsstrahlung x-rays
80	10	90
100	19	81
120	24	76
150	28	72

Types and applications of x-rays:

Type	Approximate kvp range	Application
Diffraction	< 10 kvp	Structural and molecular analysis.
Grenz rays	10-18 kvp	Dermatology
Superficial	50-100 kvp	Therapy of Superficial tissue
Diagnostic	30-150 kvp	Imaging of anatomical structures
Ortho Voltage	200-300 kvp	Therapy of deep line tissue
Super Voltage	300-1000 kvp	-do-
Mega Voltage	> 1 Mv	Checking integrity of welded material