Radiation Physics

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3rd Class

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Lecture 3: Production of X-Rays

2020/2021

Inverse Square Law for Radiation

- Any point source which spreads its influence equally in all directions without a limit to its range will obey the inverse square law.

The intensity of the influence at any given radius is the source strength divided by the area of the sphere.
Point sources of gravitational force, electric field, light, sound or radiation obey the inverse square law.
When light is emitted from a source such as the sun or a light bulb, the intensity decreases rapidly with the distance from the source. X-rays exhibit precisely the same property. The intensity of the radiation is inversely proportional to the square of the distance from a point source
As intensity is the power per unit area, Intensity = Power /Area

$$I = p/m^2$$

It naturally decreases with the square of the distance as the size of the radiative spherical wave front increases with distance. So, the luminous intensity on a spherical surface a distance from a source radiating a total power P is:

$$I = \frac{3}{4}\frac{\mathrm{p}}{\pi \mathrm{r}^2}$$

The luminous intensity is proportional to the inverse of distance:

$$I \propto \frac{1}{distance^2}$$

$$I \propto \frac{1}{r^2}$$

Supply of Electrons

There must be a supply of the electrons. Fortunately, they can be supplied by simply raising the temperature of a suitable material. It is necessary to sufficiently heat the proper material. As the temperature rises, the electrons become more and more agitated until finally they escape or “boil off” the material, surrounding it in the form of an electron cloud. This is known as thermionic emission.

In an X-ray tube the heated material is known as the filament. Just as in a light bulb the filament is heated by passing electrical current through it. This cloud of electrons simply hovers around and returns to the emitting substance unless some external action or force pulls it away (see figure 1).

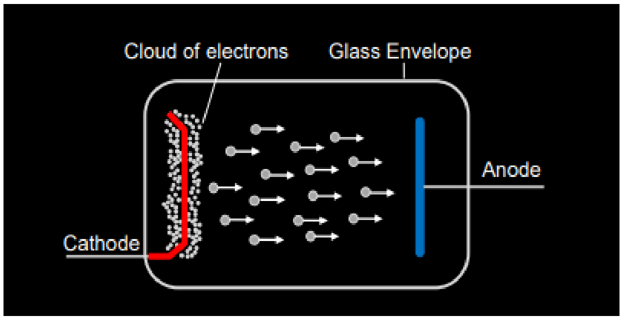

Figure 1: Electrons cloud surrounds the filament

Movement of the Electrons

Movement of the emitted electrons is the second step in producing X-rays. This movement is brought about by the repelling and attracting forces inherent in electrical charges.

The fundamental law of electrostatics states that like charges repel each other and unlike charges attract each other. Electrons are negative charges, thus repel each other. However, a stronger attracting force is needed to accelerate the electrons to a higher velocity. Therefore, a strong opposite (positive) charge is used to move the electrons from one point to another. It is important that this movement is conducted in a good vacuum; otherwise the electrons collide with air molecules and lose energy through ionization and scattering. In an X-ray tube the anode is given a positive charge with respect to the filament, which is part of the cathode.

Components of the X-ray Tube

An x-ray tube consists of two electrodes sealed into an evacuated glass envelope.
A negative electrode (cathode) which incorporates a fine tungsten coil or filament.
A positive electrode (anode) which incorporates a smooth flat metal target. usually of tungsten

The Cathode

The cathode assembly normally consists of two parts
(a) an electron source (emitter) and
(b) an auxiliary electrode surrounding it (see figure 2).
The electron emitter is usually a coiled wire filament 0.2–0.3 mm in diameter of reasonably high resistance. A metal is chosen for the cathode that will give a copious supply of electrons by thermionic emission at temperatures where there is very little evaporation of metal atoms into the vacuum (e.g. tungsten, melting point of 3370°C).

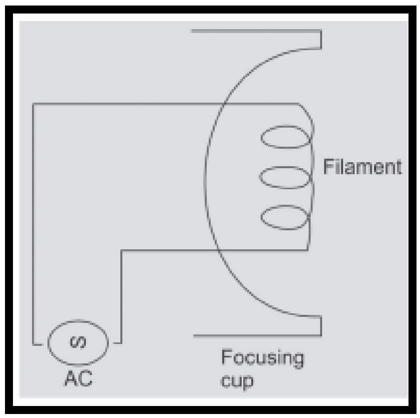

Figure 2: Cathode assembly

But because the filament gives off electrons in all directions, some means must be used to focus them on a target. A reflector or focusing cup within the cathode structure (figure 2), into which the filament is centered, serves to focus the electron beam.

The Anode Material

The material chosen for the anode should satisfy a number of requirements. It should have

1. A high conversion efficiency for electrons into X-rays. High atomic numbers are favoured since the X-ray intensity is proportional to Z. At 100 keV, lead (Z = 82) converts 1% of the energy into X-rays but aluminium (Z = 13) converts only about 0.1%.
2. A high melting point so that the large amount of heat released causes minimal damage to the anode.
3. A high conductivity so that the heat is removed rapidly.

4. A low vapour pressure, even at very high temperatures, so that atoms are not boiled off from the anode.

The tube current increases exponentially with increasing filament current and might, typically, rise by four orders of magnitude if the filament temperature increased from 2000 K to 3000 K .

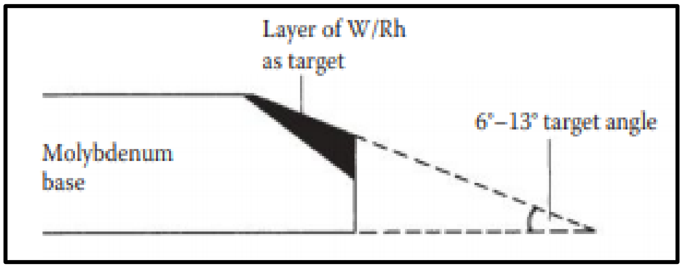

Figure 3: Detail of the target area on a modern rotating anode

In anode design as shown in figure 3, the anode surface is steeply angled to the electron beam.