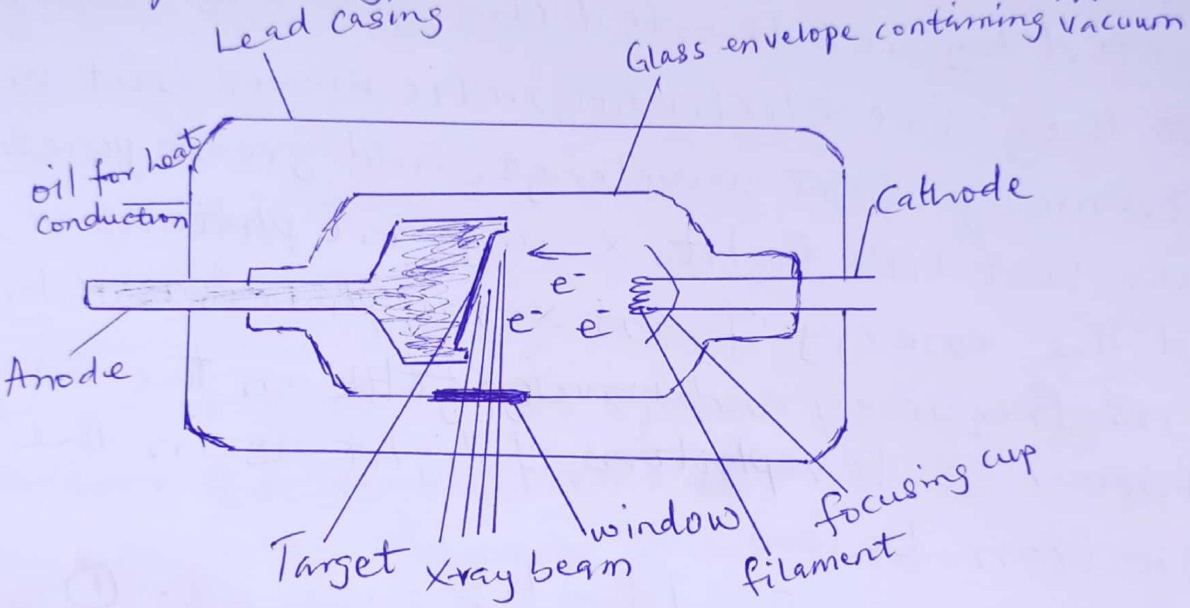
X-RAY PRODUCTION

In 1805, a German physicist Wilhelm Roentgen discovered x-rays. These rays were produced in high-voltage electric discharge tube. They are rapidly moving electrons that have been accelerated through a potential difference (pd) of the order of 10^3 to 10^6 V strikes a metal target. Because x-rays are emitted by accelerated charges. It is evident that they are electromagnetic waves but with extremely short wavelength and great penetrating power. Just like light, x-rays are photons or quanta, and the energy of an x-ray photon is related to its frequency and wavelength in the same manner as for photons of light as in the equation below

$$E = hf = \frac{hc}{\lambda} \quad \ldots \ldots \quad (1)$$

X-ray emission is the inverse of the photoelectric effect. Photoelectric effect involves transformation of energy of a photon into the kinetic energy of an electron while in x-ray production, there is transformation of the kinetic energy of the electron into the energy of a photon. In x-ray production, work function of the target and the initial kinetic energy of the ejected electrons are usually neglected because they are very small compared to other energies.

Two processes are involved in x-ray emission. First is that some electrons are slowed down or stopped by the target and part of all their kinetic energy is converted to a continuous spectrum of photons, including x-rays. This process is called bremsstrahlung. Classical physics was unable to explain this phenomenon, but with quantum physics, it is easy to explain why the emitted x-rays have maximum frequency f_{max} and a corresponding minimum wavelength λ_{min}.



An electron with charge $-e$ gains kinetic energy eV when accelerated through a potential increase V, photon with highest frequency and shortest wavelength (most energetic photon) is produced when all the electron's kinetic energy goes to produce one photon. That is

$$eV = hf_{max} = \frac{hc}{\lambda_{min}} \quad \ldots\ldots \quad (2)$$

NB: f_{max} and λ_{min} does not depend on the target material.

The second process gives peaks in the x-ray spectrum at xteristic frequencies and wavelength that do depend on the target material.

other electrons, if they have enough kinetic energy can transfer that energy partly or completely to individual atoms within the target. These atoms are left in excited levels; when they decay back to their ground levels, they may emit x-ray photons. Since each element has a unique set of atomic energy levels, each also has a xteristic x-ray spectrum. The energy levels associated with x-rays are rather different in character from those associated with visible spectra. They involve vacacies in the inner electron configurations of complex atoms. The energy differences between these levels can be hundreds or thousands of electron volts, rather than a few electron volts as is typical for optical spectra.

However, the target material may be filament which produces a beam of electron when it is hot. A low voltage heats the filament, which also controls the intensity of the X-ray produced. The high voltage applied between the filament and the mode accelerates the electron beam towards the tungsten target. When the electron beam strikes the tungsten target, their kinetic energy is changed to heat energy and x-rays. Less than 1% of the kinetic energy of the electron beam is converted to x-ray: the rest are transformed to heat energy. Heat produced because of the collission of the electrons with the target is removed by circulating coolant. This prevents the target from melting. Tungsten is embedded on the copper anode to conduct heat away from the tungsten target. The choice of tungsten as the target is because it has high melting point, therefore can withstand high temperature.

INTENSITY OF X-RAYS

The quantity of x-ray produced is referred to as its intensity. The intensity of an x-ray is high if the number of electrons hitting the target is increased. The number of electrons striking the target is given by:

$n = I/e$ (I = Current, e = electronic charge, n = number of electrons striking the target per second)

It is increased by

* increasing the filament current. Higher filament current makes the filament hotter and therefore more electrons are emitted
* Using target material with high proton (atomic) number.

QUALITY OF X-RAYS

The quality of an x-ray is measured by its ability to penetrate materials. It depends on the wavelength of the x-ray produced. The shorter the wavelength of an x-ray, the higher it penetrates materials and the better the quality. X-rays with high penetrating power (short wavelength) are called hard x-rays. Soft x-rays have low penetrating power or longer wavelengths. High quality x-rays are produced by increasing the voltage applied between the target and the filament.

PROPERTIES/Xteristics of X-rays

1. X-rays travel in straight lines
2. X-rays are not deflected by electric and magnetic fields
3. X-rays can be diffracted like other waves
4. X-rays affects photographic film
5. X-rays produces fluorescence in many materials
6. They ionize gases making them to conduct electricity and discharge electroscope
7. They can produce photoemission
8. X-rays penetrates many substances, which are opaque to light but are absorbed by bone, lead and other materials with high density.

USES OF X-RAYS

1. Industrial and scientific applications
   (i) X-rays are used to reveal covered paintings
   (ii) X-rays diffraction are used to find the structure of complex organic molecules
   (iii) X-rays are used to reveal things hidden from the ordinary eye. They reveal broken bones, bullets and other dense objects hidden in the body.
   (iv) X-ray photographs diffracted by crystals gives information on how the atoms of different crystals are arranged
2. Medical applications of X-rays;
   (i) X-ray photographs can reveal obstruction in digestive tract and internal growths.
   (ii) Hard X-rays given in a right dose is used to kill cancerous cells and malignant

growth in the body.

(6)

(3) X-rays are used to reveal things hidden from the ordinary eye. They reveal broken bones, bullets and other dense objects hidden in the body.

WORKED EXAMPLES.

* An x-ray tube operatrating at 100KV is used to produce X-ray itself. Calculate the
(i) maximum kinetic energy of the X-ray
(ii) Wavelength of the X-ray produced.
($h = 6.6\times10^{-34}Js$; $e = 1.6\times10^{-19}C$, $c = 3.0\times10^{8}ms^{-1}$)

Solution

(i) $Max.\ K.E = \frac{1}{2}mv^2 = eV = 1.6\times10^{-19}\times100{,}000 = 1.6\times10^{-}$

(ii) $\lambda = \frac{hc}{E_k} = \frac{6.6\times10^{-34}\times3.0\times10^{8}}{1.6\times10^{-14}} = 1.24\times10^{-11}m$

* Calc. the minimum voltage applied between the filament and the target of an X-ray tube to produce X-rays of wavelength $5.0\times10^{-11}m$

Solution

Minimum $K.E = \frac{1}{2}mv^2 = eV = hf$

$\therefore eV = \frac{hc}{\lambda}$; $f = c/\lambda$

$\therefore 1.6\times10^{-19}\times V = \frac{6.6\times10^{-34}\times3.0\times10^{8}}{5.0\times10^{-11}}$

$V = \frac{3.96\times10^{-15}}{1.6\times10^{-19}} = 2.475\times10^{4}V$

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