Production of X-Rays

X-rays were discovered by Roentgen in 1895 while studying cathode rays (stream of electrons) in a gas discharge tube. He observed that another type of radiation was produced (presumably by the interaction of electrons with the glass walls of the tube) which could be detected outside the tube. This radiation could penetrate opaque not transparent. not reflecting substances, produce fluorescence, blacken a photographic plate, and ionize a gas. He named the new radiation x-rays.

Following this historic discovery, the nature of x-rays was extensively studied and many other properties were unraveled. Our understanding of their nature was greatly enhanced when they were classified as one form of electromagnetic radiation (Section 1.9).

3.1 THE X-RAY TUBE

Figure 3.1 is a schematic representation of a conventional x-ray tube. The tube consists of a glass envelope which has been evacuated to high vacuum. At one end is a cathode (negative electrode) and at the other an anode (positive electrode), both hermetically sealed in the tube. The cathode is a tungsten filament which when heated emits electrons, a phenomenon known as *thermionic emission*. The anode consists of a thick copper rod at the end of which is placed a small piece of tungsten target. When a high voltage is applied between the anode and the cathode, the electrons emitted from the filament are accelerated toward the anode and achieve high velocities before striking the target. The x-rays are produced by the sudden deflection or acceleration of the electron caused by the attractive force of the tungsten nucleus. The physics of x-ray production will be discussed later in Section 3.4. The x-ray beam emerges through a thin glass window in the tube envelope. In some tubes, thin beryllium windows are used to reduce inherent filtration of the x-ray beam.

A. The Anode

The choice of tungsten as the target material in conventional x-ray tubes is based on the criteria that the target must have high atomic number and high melting point. As will be discussed in Section 3.4, the efficiency of x-ray production depends on the atomic number and for that reason tungsten with $Z = 74$ is a good target material. In addition, tungsten, which has a melting point of 3370°C, is the element of choice for withstanding intense heat produced in the target by the electronic bombardment.

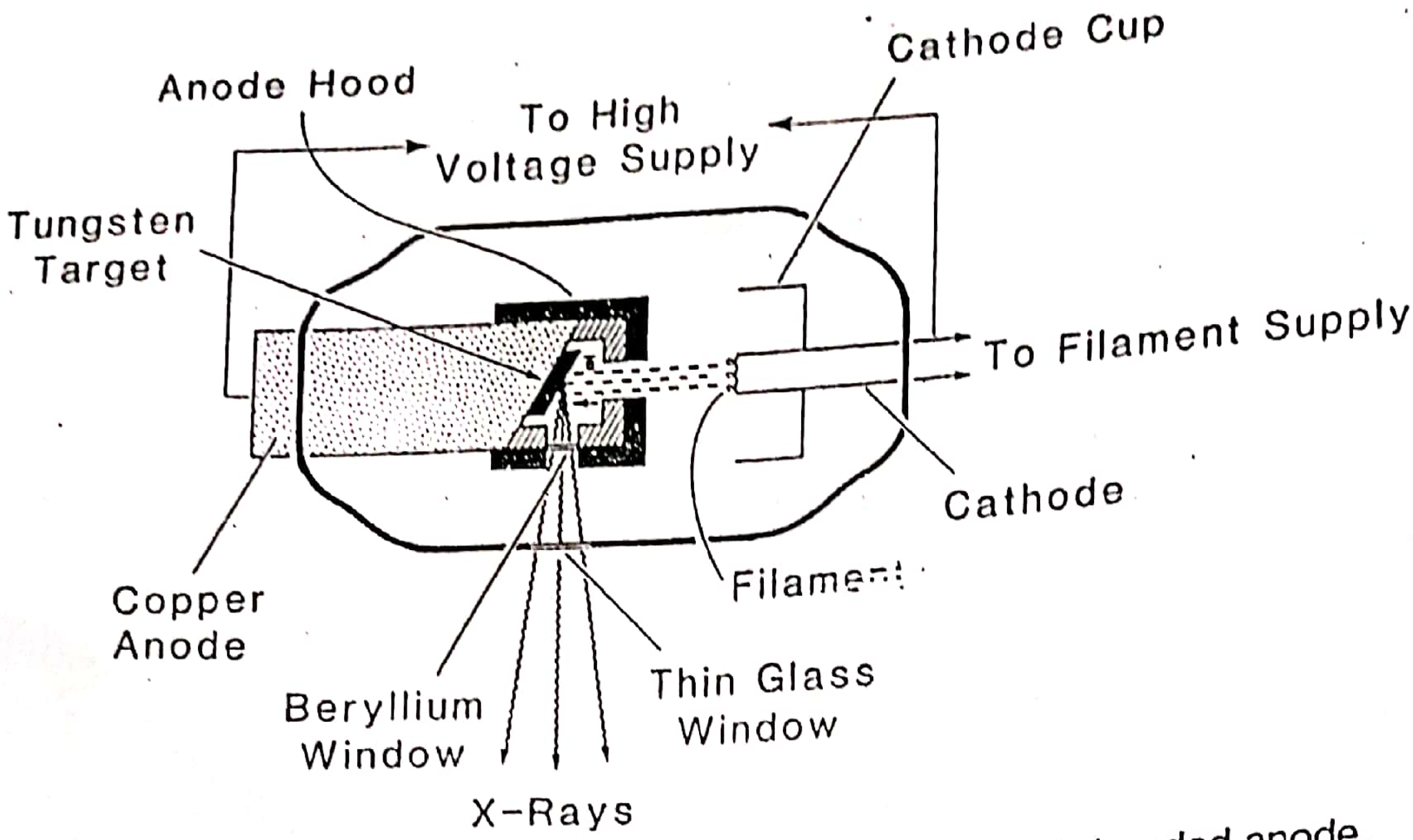

Figure 3.1. Schematic diagram of a therapy x-ray tube with hooded anode.

Removal of heat:-

Efficient removal of heat from the target is an important requirement for the anode design. This has been achieved in some tubes by conduction of heat through a thick copper anode to the outside of the tube where it is cooled by oil, water, or air. Rotating anodes have also been used in diagnostic x-rays in order to reduce the temperature of the target at any one spot. The heat generated in the rotating anode is radiated to the oil reservoir surrounding the tube. It should be mentioned that the function of the oil bath surrounding an x-ray tube is to insulate the tube housing from high voltage applied to the tube as well as absorb heat from the anode.

Some stationary anodes are *hooded* (covered) by a copper and tungsten shield to prevent stray electrons from striking the walls or other non-target components of the tube. These are secondary electrons produced from the target when it is being bombarded by the primary electron beam. Whereas, copper in the hood absorbs the secondary electrons, the tungsten shield surrounding the copper shield absorbs the unwanted x-rays produced in the copper.

An important requirement of the anode design is the optimum size of the target area from which the x-rays are emitted. This area which is called the *focal spot* should be as small as possible for producing sharp radiographic images. However, smaller focal spots generate more heat per unit area of target, and therefore limit currents and exposure. In therapy tubes, relatively larger focal spots are acceptable since the radiographic image quality is not the overriding concern.

The apparent size of the focal spot can be reduced by the principle of *line-focus*, illustrated in Fig. 3.2. The target is mounted on a steeply inclined surface of the anode. The apparent side a is equal to $A \sin \theta$, where A is the side of the actual focal spot at an angle θ with respect to the electron beam. Since the other side of the actual focal spot is perpendicular to the electron, its apparent