INTRODUCTION AND OVERVIEW (x-ray production)

Dr. Mahmoud S Dahoud

Fundamental of Radio Physics
Fall semester
Week 1
Date: Oct 5th 2025

Outline

X-Ray production

- Characteristic radiation
- Bremsstrahlung radiation

Emission spectrum

Bremsstrahlun

- Importance in Imaging and Dose

Influnce of Electron Energy

Objectives

The student should be able to do the followings;

- Define x-ray tube
- Compare between the two type of x-rays
- Explain the emission spectrum.
- Evaluate the importance of Bremsstrahlung radiation in imaging and dose
- Demonstrate the influence of electron energy.

.

X-Ray

X-rays are basically the same thing as visible light rays. Both are wavelike forms of **electromagnetic energy** carried by photons.

The difference between x-rays and visible light rays is the **energy level** of the individual photons. This is also expressed as the **wavelength** of the rays.

Conventional x-ray Tubes

Figure 5-1 shows the main components of a modern x-ray tube. A heated filament releases electrons that are accelerated across a high voltage onto a target. The stream of accelerated electrons is referred to as the *tube current*. X rays are produced as the electrons interact in the target. The x rays emerge from the target in all directions but are restricted by collimators to form a useful beam of x rays. A vacuum is maintained inside the glass envelope of the x-ray tube to prevent the electrons from interacting with gas molecules.

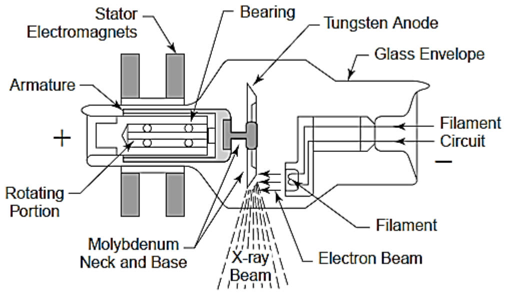

FIGURE 5-1
Simplified x-ray tube with a rotating anode and a heated filament.

ELECTRON SOURCE

- A metal with a high melting point is required for the filament of an x-ray tube. Tungsten filaments (melting point of tungsten 3370°C) are used in most x-ray tubes. A current of a few amperes heats the filament, and electrons are liberated at a rate that increases with the filament current. The filament is mounted within a negatively charged focusing cup. Collectively, these elements are termed the *cathode assembly.*

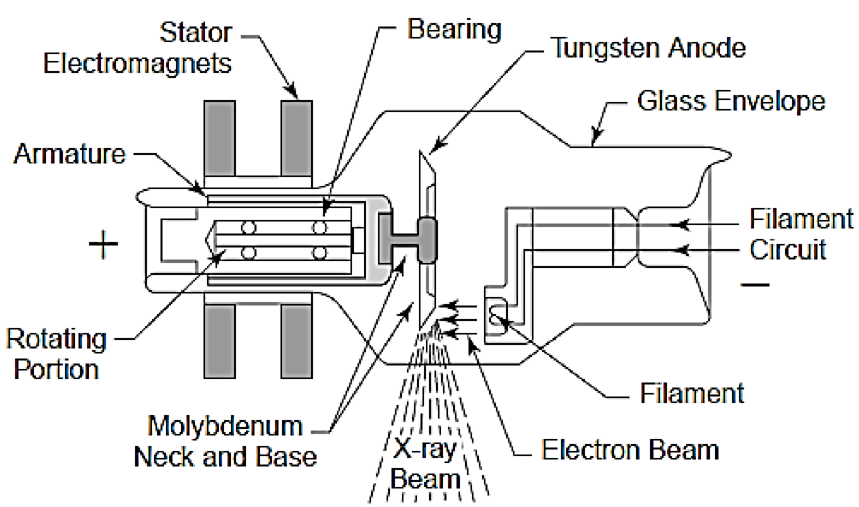

FIGURE 5-1
Simplified x-ray tube with a rotating anode and a heated filament.

EMISSION SPECTRA

- The useful beam of an x-ray tube is composed of photons with an energy distribution that depends on four factors:
- Bremsstrahlung x rays are produced with a range of energies even if electrons of a single energy bombard the target.
- X rays released as characteristic radiation have energies independent of that of the bombarding electrons so long as the energy of the bombarding electrons exceeds the threshold energy for characteristic x ray emission.
- The energy of the bombarding electrons varies with tube voltage, which fluctuates rapidly in some x-ray tubes.

Characteristic radiation

- X-ray production is a very inefficient process, even in targets with high atomic number. For x-ray tubes operated at conventional voltages, less than 1% of the energy deposited in the target appears as x radiation. Almost all of the energy delivered by impinging electrons is degraded to heat within the target. The characteristic radiation produced by a target is governed by the binding energies of the K, L, and M shells of the target atoms. Theoretically, any shell could contribute to characteristic radiation. In practice, however, transitions of electrons among shells beyond the M shell produce only low-energy x rays, ultraviolet light and visible light. Low-energy x rays are removed by inherent filtration and do not become part of the useful beam. The characteristic peak for a particular shell occurs only when the tube voltage exceeds the binding energy of that shell. Binding energies in tungsten and molybdenum are shown in Table 5-2.

TABLE 5-2 Electron Shell Binding Energies (keV)

Shell	*Molybdenum ($Z = 42$)*	*Tungsten ($Z = 74$)*
K	20	69
L	2.9, 2.6, 2.5[a]	12, 11, 10
M	0.50, 0.41, 0.39, 0.23, 0.22	2.8, 2.6, 2.3, 1.9, 1.8

Characteristic radiation

The characteristic radiation produced by an x-ray target is usually dominated by one or two peaks with specific energies slightly less than the binding energy of the K-shell electrons. The most likely transition involves an L-shell electron dropping to the K shell to fill a vacancy in that shell. This transition yields a photon of energy equal to the difference in electron binding energies of the K and L shells. A characteristic photon with an energy equal to the binding energy of the K shell alone is produced only when a free electron from outside the atom fills the vacancy. The probability of such an occurrence is vanishingly small.

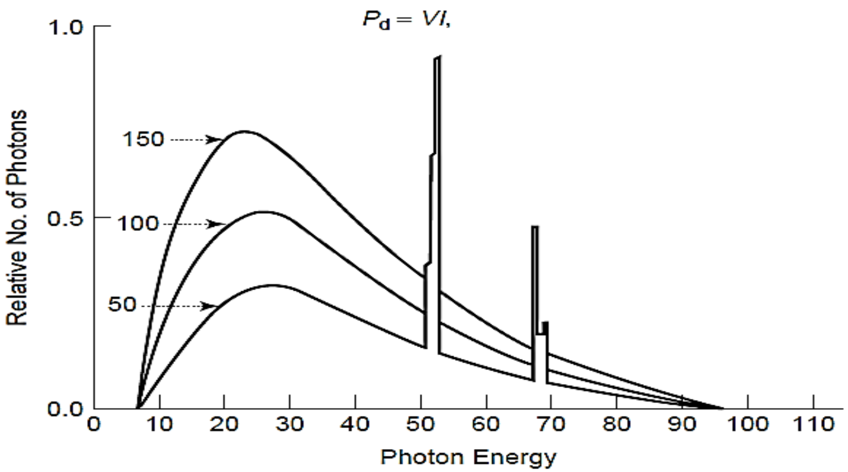

FIGURE 5-7
X-ray emission spectra for a 100-kVp tungsten target x-ray tube operated at 50, 100, and 150 mA. kVp and exposure time are the same for the three spectra.

Bremsstrahlung Radiation

bremsstrahlung, (German: “braking radiation”), electromagnetic radiation produced by a sudden slowing down or deflection of charged particles (especially electrons) passing through matter in the vicinity of the strong electric fields of atomic nuclei. Bremsstrahlung, for example, accounts for continuous X-ray spectra—*i.e.*, that component of X rays the energy of which covers a whole range from a maximum value downward through lower values. In generating bremsstrahlung, some electrons beamed at a metal target in an X-ray tube are brought to rest by one head-on collision with a nucleus and thereby have all their energy of motion converted at once into radiation of maximum energy. Other electrons from the same incident beam come to rest after being deflected many times by the positively charged nuclei. Each deflection gives rise to a pulse of electromagnetic energy, or photon, of less than maximum energy.

Video

Comparison

Characteristic radiation	**Bremsstrahlung**
Only accounts for small percentage of x-ray photons produced	Accounts for 80% of photons in x-ray beam
Bombarding electron interacts with inner shell electron	Bombarding electron interacts with whole atom
Radiation released due to electron dropping down into lower energy state	Radiation released due to diversion of bombarding electron as a result of the atomic pull
Radiation released is of a specific energy	Radiation released is of a large range of energies
X-ray photon energy depends on element of target atoms not tube voltage	X-ray photon energy depends on tube voltage

Importance in imaging and dose

During interaction of an electron with a target nucleus, a bremsstrahlung photon may emerge with energy equal to the total kinetic energy of the bombarding electron. Such a bremsstrahlung photon would have the maximum energy of all photons produced at a given tube voltage.

Most of the X-ray beam consists of bremsstrahlung interactions in the diagnostic range of 30 to 150 kVp. When the applied voltage is less than 70kVp, bremsstrahlung interactions account for ~100% of the X-ray beam. If the applied voltage is more than 70 kVp, the bremsstrahlung interactions accounts for ~85% of the X-ray beam. Most of the X-rays produced are of low energy because electron beams have higher chances of striking outer zones of the target atom that produces low energy photons than inner zones of the target atom that produces high energy photons.

The **efficiency of X-ray production** is governed by major factors such as kVp, current, exposure time, atomic number of the anode material, and beam filtration.

influence of x ray on dose and imaging

When radiation passes through the body, some of it is absorbed. The x-rays that are not absorbed are used to create the image. The amount the patient absorbs contributes to the patient's radiation dose. Radiation that passes through the body does not contribute to this dose. When x-rays interact with the human body during an x-ray exposure, they form an image that is highly dependent on the type of interactions of matter and x-rays. Diagnostic x-ray interactions are dominated by two different physical interactions – the photoelectric effect and Compton scatter. Higher electron energy increases the maximum energy of the produced X-rays, resulting in a spectrum of X-rays with higher average energy and greater intensity. This occurs because the higher kinetic energy of the incident electrons can be converted into higher-energy bremsstrahlung X-rays or lead to the ionization of inner-shell electrons, producing characteristic X-rays at higher, discrete energy levels

References

- Al-Qurashi M., and Qasim H., . (2015). *Radiation Physics and its Applications in Diagnostic Radiological techniques.* Medical technical University, Iraq
- Hendee W., and Ritenour E.,. (2002). *Medical Imaging Physics*. Willy-Liss,Inc