

Fundamental of Radio Physics

X-Ray Production



جامعة ساوة

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المرحلة الثانية

X-ray production occurs when high-energy electrons interact with a target material, typically a metal like tungsten or molybdenum, inside an X-ray tube. The primary mechanisms responsible for X-ray production are Bremsstrahlung radiation and characteristic radiation.

Bremsstrahlung Radiation

Also known as "braking radiation," is produced when high-energy charged particles, typically electrons, are decelerated or deflected as they pass near the nucleus of an atom. The deceleration causes the electrons to lose energy, which is emitted in the form of X-ray photons.

Mechanism of Bremsstrahlung Radiation:

1. Electron Interaction with the Nucleus: When a fast-moving electron passes close to the positively charged nucleus of an atom, the strong electric field of the nucleus exerts a force on the electron. This causes the electron to change direction, decelerate, or "brake" (hence the name).

2. Energy Loss as X-rays: As the electron slows down, it loses kinetic energy. This lost energy is emitted as a photon, typically in the X-ray spectrum. The closer the electron comes to the nucleus, the more it is decelerated and the higher the energy of the emitted photon.

3. Continuous Spectrum: Bremsstrahlung produces a continuous spectrum of X-ray energies because the amount of energy an electron loses can vary depending on how close it comes to the nucleus and how much it decelerates. Therefore, the resulting X-rays have a wide range of energies, rather than discrete levels.

4. High-Energy Efficiency: Bremsstrahlung radiation becomes more significant at higher electron energies, such as those seen in X-ray tubes, linear accelerators, or synchrotron radiation facilities.

Factors Influencing Bremsstrahlung Radiation

- **Electron Energy:** Higher-energy electrons produce higher-energy (harder) X-rays.
- **Atomic Number of the Target Material (Z):** The efficiency of Bremsstrahlung radiation increases with the atomic number of the target material. Heavy elements like tungsten are commonly used because

they produce more intense X-rays.

- **Electron-Nucleus Distance:** The closer the electron passes to the nucleus, the stronger the deceleration and the higher the energy of the emitted X-ray photon.

Applications of Bremsstrahlung Radiation

- **Medical Imaging:** In X-ray tubes, most of the radiation is Bremsstrahlung, used for diagnostic imaging such as chest X-rays or CT scans.
- **Radiation Therapy:** In cancer treatment, high-energy X-rays are used to target and destroy cancerous tissues.
- **Material Analysis:** Bremsstrahlung X-rays can be used in X-ray fluorescence (XRF) analysis to investigate the composition of materials.
- **Synchrotron Sources:** In synchrotrons, charged particles emit Bremsstrahlung radiation as they are accelerated to relativistic speeds.

Characteristic Radiation

Is a type of X-ray radiation produced when an electron from an inner shell of an atom is ejected by an incoming high-energy particle, typically another electron. The vacancy in the inner shell is then filled by an electron from a higher energy level, and the energy difference between the two shells is released as an X-ray photon. The energy of this X-ray photon is specific to the atom's element, hence the term "characteristic."

Mechanism of Characteristic Radiation

1. **Electron Ejection:** When an incoming high-energy electron (or photon) strikes an atom in the target material, it may have enough energy to eject an electron from one of the inner electron shells (usually the K-shell). This creates a vacancy, leaving the atom in an excited, unstable state.
2. **Electron Transition:** To stabilize, an electron from a higher energy shell (like the L or M shell) falls into the lower-energy vacancy in the K-shell. As the electron moves from a higher to a lower energy level, it releases energy in the form of an X-ray photon.

3. Characteristic X-rays: The energy of the emitted X-ray photon is exactly equal to the difference in energy between the two electron shells. Since the energy levels of electrons are unique to each element, the emitted X-ray photons have a specific energy that is characteristic of the atom involved (hence "characteristic radiation"). For example, the energy difference between the K and L shells in tungsten produces X-rays with a well-defined energy of around 59 keV.

Applications of Characteristic Radiation

- 1. X-ray Tubes:** Characteristic X-rays are used in medical imaging and material analysis. In X-ray tubes, both characteristic and Bremsstrahlung radiation are produced when high-energy electrons strike the anode. The characteristic radiation is usually superimposed on the continuous Bremsstrahlung spectrum.
- 2. X-ray Fluorescence (XRF):** Characteristic radiation is essential in XRF, a non-destructive technique used to analyze the elemental composition of materials. By measuring the

energy of emitted X-rays, the presence of specific elements can be identified.

3. Crystallography: In X-ray crystallography, characteristic X-rays are used to study the atomic structure of crystals. The precise wavelength of the characteristic X-rays provides a suitable probe for diffraction experiments.

4. Auger Effect: In some cases, rather than emitting an X-ray, the energy from an inner-shell electron transition can cause the ejection of another electron. This is known as the Auger effect and competes with characteristic X-ray production in lower-Z elements.

Emission Spectrum

An emission spectrum refers to the range of wavelengths (or frequencies) of electromagnetic radiation emitted by an atom, molecule, or material when it transitions from a higher energy state to a lower energy state. Each element or molecule has a unique emission spectrum, making it a useful tool for identifying substances in fields like astronomy, spectroscopy, and materials science.

Types of Emission Spectra:

1. Continuous Spectrum:

- Produced by hot, dense objects like stars or incandescent solids (e.g., the filament in a light bulb).
- Contains all wavelengths of visible light without any gaps or lines, forming a smooth gradient from red to violet.
- **Example:** Sunlight or light from an incandescent bulb.

2. Line Spectrum (or Discrete Spectrum):

- Produced by gases or atoms in a low-density environment, such as in a gas discharge tube or excited atoms in a plasma.
- Consists of specific wavelengths of light, each corresponding to a unique energy transition within the atom.
- Appears as a series of bright lines on a dark background, with each line corresponding to a photon emitted at a specific wavelength.
- **Example:** The emission spectra of hydrogen, helium, or neon gas.

3. Band Spectrum:

- Produced by molecules rather than individual atoms.
- Consists of groups of closely spaced lines called "bands," corresponding to molecular transitions involving changes in vibrational or rotational energy states.
- **Example:** The emission spectrum of diatomic molecules like nitrogen (N_2) or oxygen (O_2).

Bremsstrahlung

Bremsstrahlung (from the German word for "braking radiation") is a type of radiation that occurs when charged particles, typically electrons, are decelerated or deflected as they pass through the electric field of a nucleus. This change in velocity results in the emission of electromagnetic radiation, often in the form of X-rays. It is one of the primary mechanisms of X-ray production in both medical and industrial applications.

Bremsstrahlung Process

1. High-Speed Electron Interaction:

- When a fast-moving electron comes close to a positively charged atomic nucleus, the electron experiences a strong Coulomb force due to the nucleus.

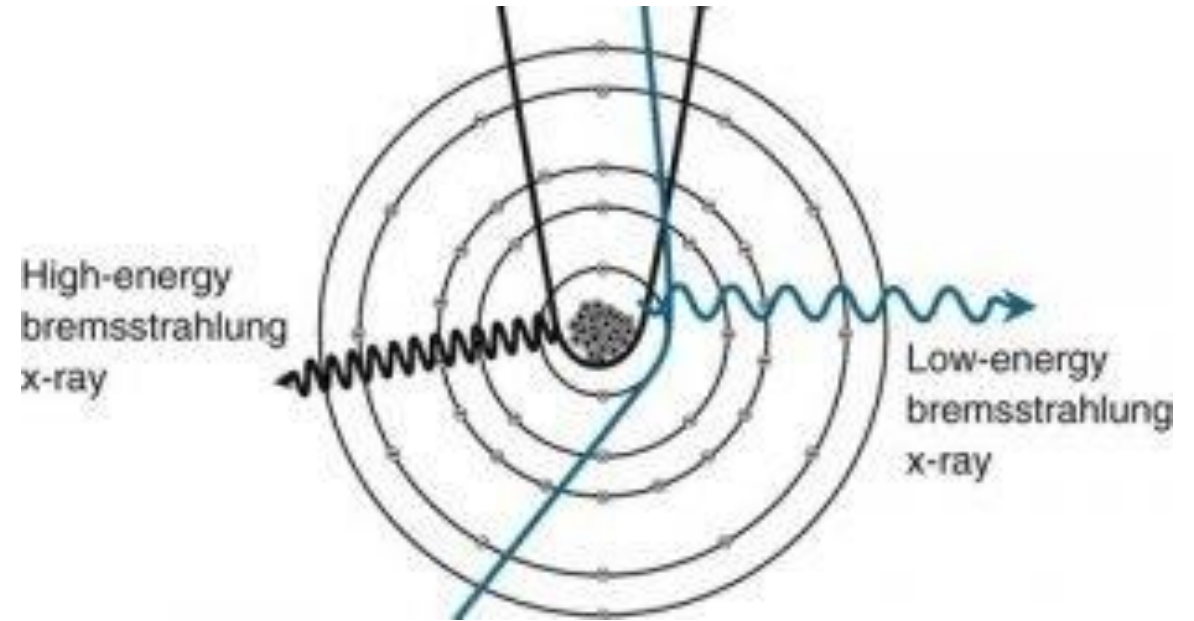
- This force causes the electron to slow down or change direction (decelerate), resulting in the loss of kinetic energy.

2. Emission of X-ray Photons:

- The energy lost by the electron during this deceleration is emitted as a photon, often in the X-ray range of the electromagnetic spectrum.
- The emitted photon can have any energy from near zero to the maximum energy of the incoming electron, depending on the degree of deceleration. This gives Bremsstrahlung radiation its characteristic continuous spectrum of photon energies.

3. Energy Distribution:

- Unlike characteristic radiation (which has discrete energy values), Bremsstrahlung produces a broad, continuous spectrum of X-rays.
- The energy of these X-rays depends on how close the electron comes to the nucleus and how much it slows down. The spectrum usually peaks at lower energies, with the intensity of radiation decreasing at higher energies.



Bremsstrahlung in Medical Imaging

1. X-ray Tube and Bremsstrahlung:

- In X-ray tubes, high-energy electrons are generated by the cathode and accelerated toward the anode (usually made of tungsten). When these electrons strike the anode, they interact with the nuclei of the target atoms, producing Bremsstrahlung radiation.
- Most of the X-rays used for diagnostic imaging come from Bremsstrahlung radiation, with a small contribution from characteristic X-rays.

2. Influence on Image Quality:

- The broad spectrum of Bremsstrahlung radiation allows for imaging tissues with different densities. Soft tissues, bones, and air-filled cavities absorb X-rays differently based on the energy of the photons, which creates contrast in medical images.
- Filters are often used to selectively remove low-energy X-rays from the Bremsstrahlung spectrum since they don't penetrate well and contribute more to patient dose than to image formation.

Bremsstrahlung and Radiation Dose

Bremsstrahlung radiation contributes significantly to the radiation dose that patients receive during X-ray imaging procedures. Managing this radiation is key to reducing unnecessary exposure while maintaining image quality.

1. Patient Exposure: Higher-energy Bremsstrahlung X-rays can penetrate deeper into the body, delivering dose to tissues beneath the skin. The total dose depends on factors like the energy of the incident electrons, the atomic number of the target material, and the distance between the source and the patient.

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2. Dose Optimization:

- In medical imaging, tube voltage (measured in kilovolt peak or kVp) controls the energy of the electrons and thus the energy of the Bremsstrahlung X-rays produced. Lower kVp settings result in softer X-rays, which are better for imaging soft tissues, but they also increase the dose absorbed by the patient. Higher kVp settings result in harder X-rays, which can penetrate more easily but may increase the total radiation dose.
- Proper filtration and collimation are used to reduce the patient's radiation dose by filtering out lower-energy X-rays that do not contribute to the image but increase the absorbed dose in tissues.



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