

# X-Ray and X-Ray Spectra

Absorption of x-ray  
Medical Imaging

# How an X-ray Image is Made

- An X-ray image is a special kind of photograph that doesn't use visible light.
- Instead, it uses a high-energy form of radiation to capture the shadows cast by the bones and tissues inside your body.
- This allows us to see structures that are otherwise completely hidden from view.
- Imagine shining a very powerful flashlight through your hand. Your bones would block more light than your skin, casting a darker shadow.
- An X-ray works on a similar principle, but with a special kind of light that can pass through your skin.

# How an X-ray Image is Made

- This remarkable ability was discovered by accident in 1895 by German physicist Wilhelm Conrad Roentgen.
- While experimenting with high-energy cathode rays, he noticed the image of the bones of his hand fingers on the wall.
- He had discovered a new, invisible form of radiation and later famously imaged the left hand of his wife.
- Because it was completely unknown, he called it "X-radiation," with "X" standing for the unknown.
- To understand how we get from this invisible radiation to a clear image of a bone, we must first step inside the machine's core the X-ray tube to see how these special rays are born.

# How an X-ray Image is Made

- The first-ever medical radiograph was of his wife's hand, revealing the bones within.
- For the first time, an image of the inside of the human body was made public,
- Starting a revolution in medicine.
- Rontgen was awarded the first Nobel Prize in Physics in 1901 for this discovery.



# X-ray tube

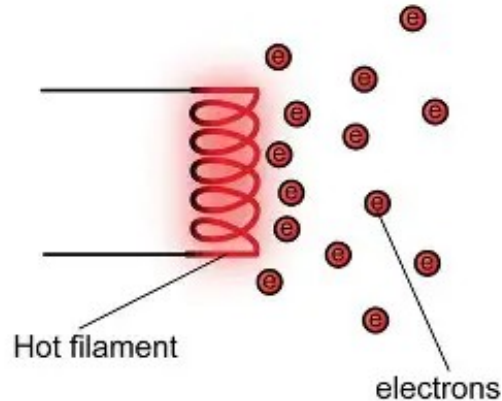
The heart of an X-ray machine is a component called the X-ray tube . It's a highly evacuated vacuum tube where a three-step process is followed to generate the X-ray beam.



# X-ray tube

**Step 1: Boil Off Electrons.** Inside the tube, a component called the cathode (the negative (-) electrode) contains a tiny filament, much like the one in an old-fashioned light bulb.

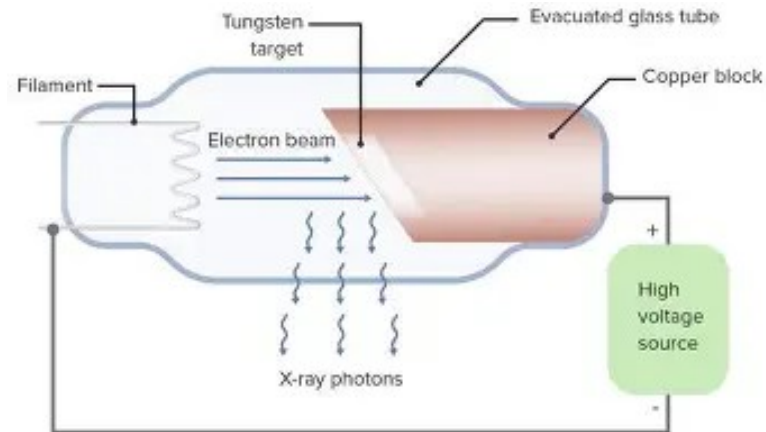
When an electric current heats this filament to an extreme temperature over  $2200^{\circ}\text{C}$  it begins to "boil off" a cloud of high-energy electrons. The scientific term for this process is thermionic emission .



# X-ray tube

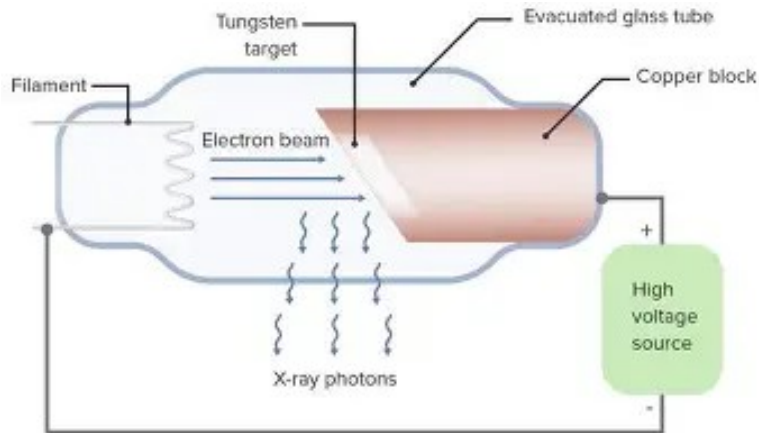
**Step 3:** The stream of high-speed electrons crashes into a small metal target on the anode (the positive (+) electrode). This sudden, violent deceleration converts the electrons' big kinetic energy into two other forms (Heat and X-ray).

- The useful X-rays produced this way are known as Bremsstrahlung , a German term for "braking radiation."
- The result of this collision is a remarkably inefficient but effective energy



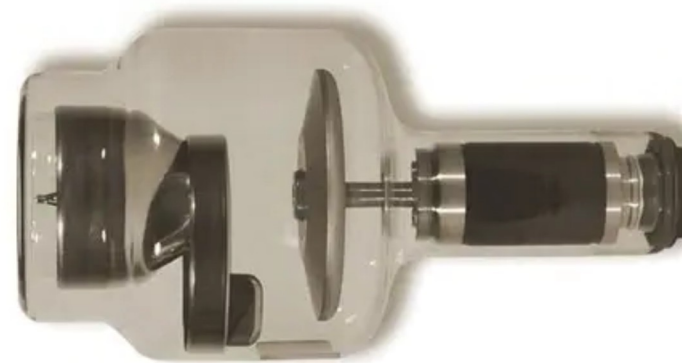
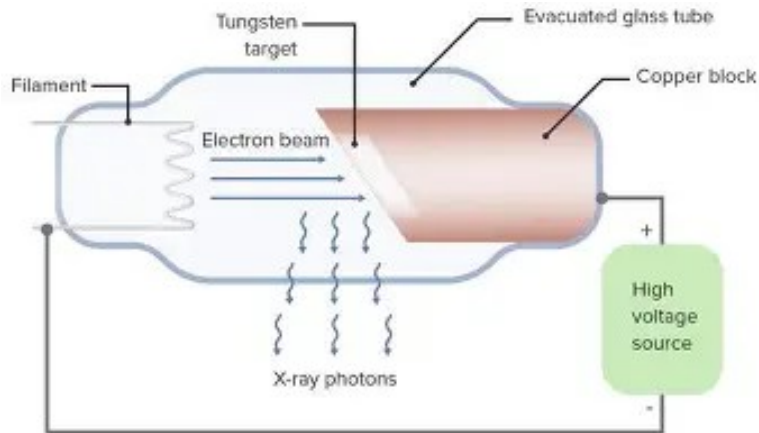
# X-ray tube

**Extreme Heat:** About 99.93% of the electrons' energy is wasted as heat. This is why the anode must be made of a material like tungsten, which is chosen for its unique combination of a high atomic number ( $Z=74$ ) for efficient X-ray production, a very high melting point, and excellent durability. To prevent the target from melting, most anodes are designed as a rotating disc to spread this intense heat load over a much larger area.



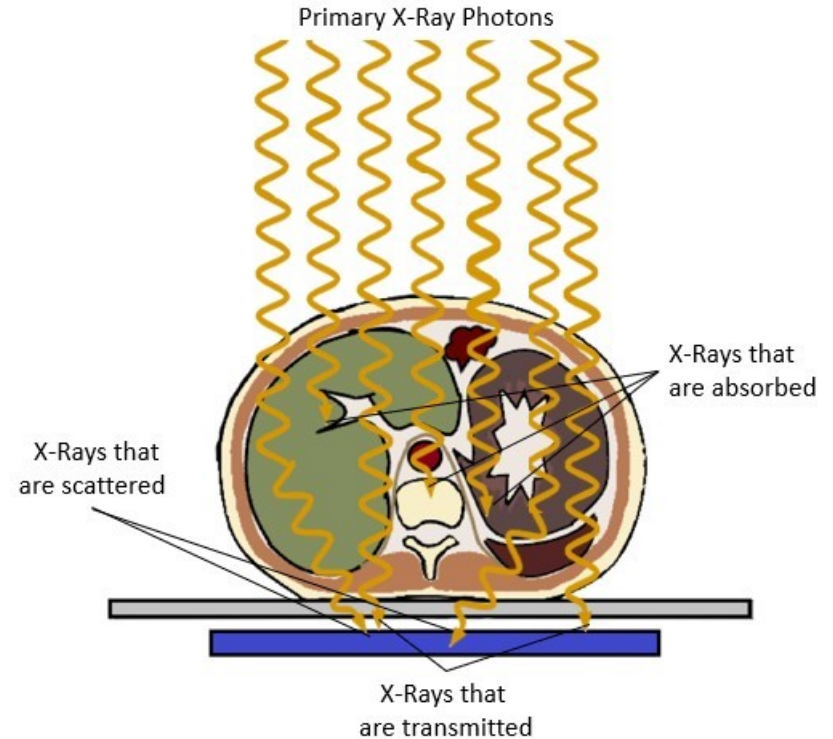
# X-ray tube

- **X-rays:** A tiny fraction about 0.07% of the energy is converted into useful X-ray photons. These photons exit the tube through a window and form the beam that will create the image.
- With our beam of X-rays now generated, the next stage of its journey is the most critical: the passage through the human body.



# X-ray photons passes through the body

- As the beam of X-ray photons passes through the body, it is weakened in a process called **attenuation** .
- The final X-ray image is only possible because different tissues in the body attenuate X-rays differently a crucial concept known as differential absorption.
- For diagnostic imaging, there are two primary ways X-rays interact with body tissues (Absorption and Scattering).



# X-ray photons passes through the body

**Absorption:** In this interaction, an incoming X-ray photon is completely stopped and absorbed by an atom in the tissue, transferring all of its energy.

Absorption is higher in bone.

It's scaling with the atomic number cubed ( $Z^3$ ). This exponential difference is the fundamental reason why bone (rich in high-Z calcium) appears so different from soft tissue.



# X-ray photons passes through the body

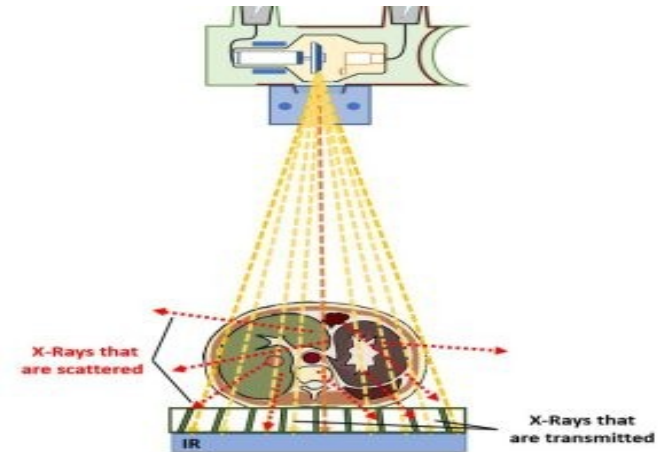
Scattering: creating a fog of useless radiation that we must actively fight to remove.

In this case, the X-ray photon doesn't get absorbed. Instead, it collides with an outer electron of an atom, loses some of its energy, and "bounces off" in a new direction.

This scattered radiation travels randomly and degrades the final image, making it appear blurry or foggy.

Specialized devices, called **anti-scatter grids**, are often placed between the patient and the detector precisely to block this unwanted scattered radiation.

This difference in absorption is what allows the X-ray machine to distinguish between bone, muscle, and air, ultimately creating the black, white, and gray image we recognize.



X-ray Image without Grid



X-ray Image with Grid

# X-ray photons passes through the body

The X-rays that manage to pass all the way through the body without being absorbed or scattered are the ones that reach the detector (such as X-ray film) and create the image.

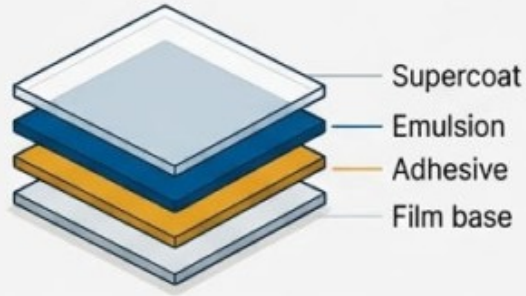
The final radiograph is a map of where these X-rays landed. The following table summarizes how different tissues interact with X-rays to produce the final image:|

Tissue Type	Density	X-ray Interaction	Appearance on Radiograph
Air (Lung)	Very low	Almost no absorption	Black
Fat	Low	Very little absorption	Dark Gray
Muscle and water	Higher	Some Absorption	Light Gray
Bone	Very high	High absorption	white



# Making the Invisible Visible: From Film to Digital Sensors

## Conventional Film-Screen Radiography



### Process

Transmitted X-rays strike an "intensifying screen," which emits visible light. This light exposes a silver halide emulsion on a film base. Chemical processing develops the latent image.

### Pros

Low initial cost.

### Cons

Requires chemical processing (darkroom), takes time, image cannot be enhanced, dose is higher.

## Digital Radiography (DR)



### Process

Transmitted X-rays strike a solid-state electronic sensor. The sensor converts the X-ray energy directly or indirectly into an electrical signal, which is digitized and sent to a computer.

### Pros

**Immediate Processing:** Image is available in seconds.

**Lower Dose:** Sensors are more efficient (up to 90% less radiation than some conventional systems).

**Image Enhancement:** Contrast and brightness can be digitally manipulated.

**Easy Storage & Sharing:** Digital files can be archived and transmitted electronically (PACS).

### Cons

Higher equipment cost.

# Enhancing Reality: When Anatomy Needs a Boost

## The Problem:

Soft tissue organs (like the GI tract or blood vessels) have very similar attenuation coefficients, resulting in poor image contrast. They are difficult to distinguish from surrounding tissues.

## The Solution:

**Contrast Agents:** Materials introduced into the body to enhance the contrast and resolution of internal structures.

### Positive Contrast Agents

**Principle:** Composed of high atomic number (high-Z) elements that are strong X-ray absorbers. They dramatically increase photoelectric absorption in the area they occupy.

#### Examples:

**Barium Sulfate (Z=56):** Given orally or rectally to visualize the GI tract. Appears bright white.

**Iodine (Z=53):** Injected to visualize blood vessels (angiography) or organs.

### Negative Contrast Agents

**Principle:** Low-density materials that are more radiolucent (transparent to X-rays) than surrounding tissue.

#### Examples:

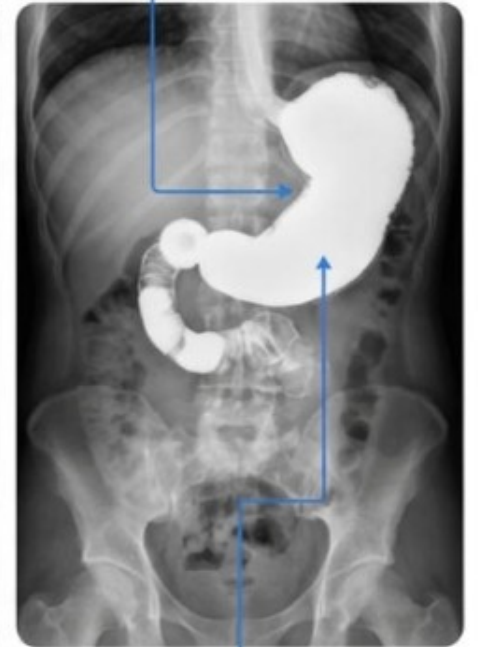
Air or carbon dioxide. Used in "double-contrast" studies with Barium to coat and distend the walls of the colon or stomach.

Standard Abdominal X-ray



Standard Abdominal X-ray

Upper GI Series with Barium



Upper GI Series with Barium

# Application Spotlight: Mammography

## Core Challenge

Detecting subtle differences (microcalcifications, small masses) in soft tissue, which has inherently low subject contrast.

## Technical Solutions & Key Features

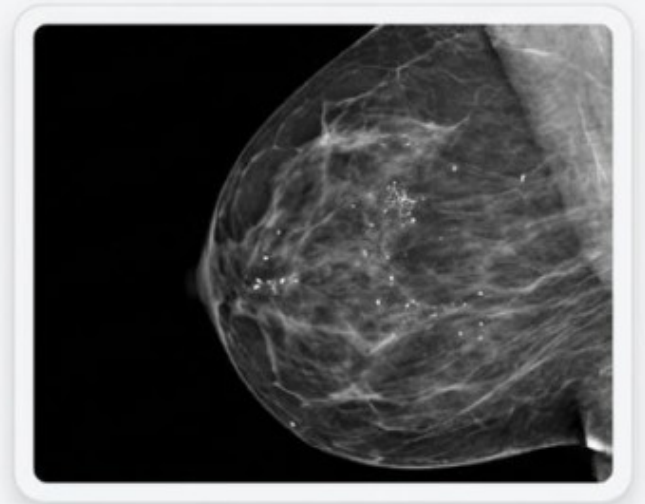
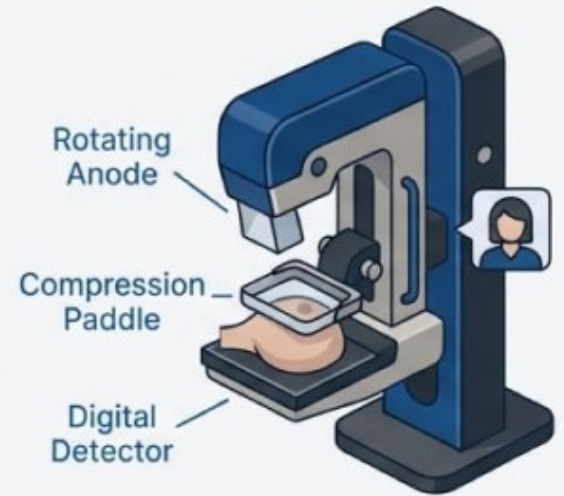
**Low Energy Beam:** Uses low kilovoltage (around 30 kVp) to maximize the photoelectric effect and enhance subtle contrast differences in soft tissue.

**Breast Compression:** The breast is compressed between two plates during imaging. **Why?** 1) Reduces tissue thickness for a more uniform exposure. 2) Spreads out tissue to prevent abnormalities from being hidden. 3) Reduces motion blur. 4) Decreases scattered radiation.

**Specialized Equipment:** Uses a dedicated machine with specific target materials (e.g., Molybdenum) and a specialized digital detector.

## Clinical Goal

Early detection of breast cancer when it is most treatable. Used for both **screening** (asymptomatic women) and **diagnostic** (women with symptoms) purposes.

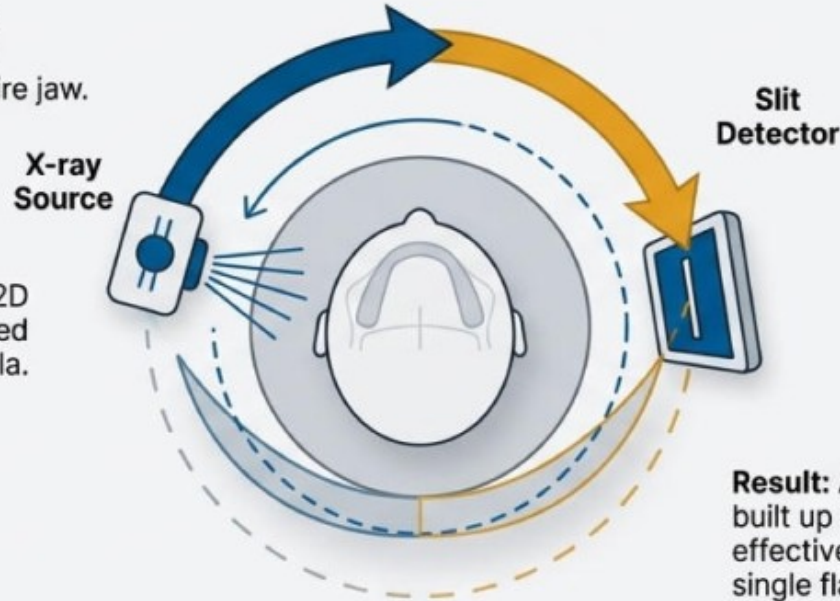


# Application Spotlight: Dental & Panoramic Radiography

## From Local to Global:

Dental imaging has evolved from small, conventional films for a single tooth to comprehensive digital views of the entire jaw.

**Challenge:** How to create a flat, 2D image of the entire curved structure of the mandible and maxilla.



**The Mechanism:** The patient remains still while a rotating arm moves the X-ray source and a narrow slit detector in a semi-circle around the patient's head.

**Result:** A continuous, panoramic image is built up slice-by-slice on the detector, effectively "unwrapping" the jaw into a single flat plane.

## Clinical Uses

- Diagnosis of impacted teeth, tumors, cysts, tooth positioning for orthodontics, and advanced periodontal disease.

## Radiation Safety



The radiation dosage of a full mouth dental X-ray series is very small, approximately 0.15 mSv, which is equivalent to a few days of natural background radiation exposure.