Terminology

- Current: measured in milliAmperes – mA
- Voltage: measured in kiloVoltage – kV
  (note that we use voltage as peak value / max. voltage supplied – kVp)
- Time: measured in milliSeconds – s
- Integrated exposure – product of mA and s: mAs
- Distances:
  - Source to object distance (SOD)
  - Source to image distance (SID)
  - Object to image distance (OID)

Cathode: negative electrode

Electron source - also called “filament”
Filament of Tungsten: Two sizes in most tubes: small and large

Advantages of Tungsten (W):
- High atomic number (74)
- High melting point (3370 °C)
- Good absorber and dissipater of heat
- Easily available; economical.
- Tungsten target (ANODE) bonded to a large copper block for better thermal distribution

Anode

- Positive electrode at a high potential difference.
- Small tungsten plate (target) embedded in a large block of copper.
- Major source of heat production
- Stationary OR Rotating anodes
Anode:

Stationary anode:
- Tungsten: 2-3 mm thick embedded in Cu; dimensions 1 x 1 cm.

Rotating anode:
- More heat tolerant;
- Lesser cooling time; less damage to anode
- Speed: 3600 – 10,000 rpm.

Electrons accelerated from CATHODE to ANODE by high voltage (potential difference).
Electrons strike ANODE suddenly decelerated energy lost is converted to x-rays.

Methods of heat dissipation
- To prevent binding of moving parts, disruption of target surface: roughening, pitting, cracking etc.
- Dry lubricants such as graphite provide for lubrication
- Heat dissipated by the following mechanisms:
  - Radiation through vacuum;
  - Convection through surrounding oil and tube housing;
  - Conduction through solid tube parts

Energy split-up:
- 99% converted to heat; only 1% to x-rays

Glass Enclosure
Purpose: provides a vacuum.
Overview of generator assembly

**X-ray Production Source Components**

- Step-up transformer: increases voltage between electrodes
- Step-down transformer: reduces voltage – used for heating the filament, for instance
- Change in voltage achieved at expense of current

**Transformers**

- Most units are AC powered.
- Need rectifiers (reverses –ve current flow)
- Without rectifiers, production efficiency suffers due to change in direction of current
- DC is more production-efficient but expensive

**Machine Schematic**

**Power Supply**
Types of power supply

Alternating current (AC): electrons flow in both directions; no constancy of current/voltage; changes direction frequently – expressed in cycles.

Relatively inefficient x-ray production.

Direct Current (DC): electrons flow in one direction only; current & voltage remain constant; most efficient for x-ray production; expensive.

Rectification

Full wave rectification

- Negative half of AC cycle is suppressed and reversed – used for x-ray production, therefore.
- Voltage varies from 0 to peak value; no x-ray production at 0 volts!

Single-phase vs. three-phase power source

- Three phase: 3 single-phase currents, out of phase with one another.
  - Voltage never drops to 0; stays closer to peak value.
- Advantages
  - More x-ray photons produced; more mean energy of the beam (quality and quantity).
  - Exposure time can be reduced – less patient dose.

Alternating Current

- Half wave rectification: suppression of negative half of AC cycle only.

Single versus three-phase power

More x-ray photons
Higher energy
Exposure time reduced.
X-ray production
Bremsstrahlung radiation

Electron hitting target atom may be:
• Completely stopped >> max. energy x-ray OR
• Deflected >> lower energy x-ray photon

If you plot the energy of all photons in the resulting x-ray beam, a continuous spectrum results, with energies of x-ray photons ranging from near-zero to a maximum. Maximum energy will be equal to kVp.

X-ray Production
Characteristic Radiation

Physical Factors Affecting X-Ray Beam

Machine Controls
Factors affecting beam quality:

- Tube current (mA)
- Time
- Tube potential (kVp)
- Distance
- Intensity
- Target
- Filtration
- Collimation

Effect of current on x-ray production

More current ➔ More X-rays

Tube current (mA)
- Time
- Tube potential (kVp)
- Distance
- Intensity
- Target
- Filtration
- Collimation

Effect of time on x-ray production

Increased time ➔ More X-rays

Tube current (mA)
- Time
- Tube potential (kVp)
- Distance
- Intensity
- Target
- Filtration
- Collimation

Energy of a ray varies with voltage

Increasing voltage ➔ Higher energy X-rays

Increasing voltage (and more X-rays)
Inverse Square Law:
Intensity of the beam varies inversely as the square of the distance from the source.

<table>
<thead>
<tr>
<th>Tube current (mA)</th>
<th>Time</th>
<th>Tube potential (kVp)</th>
<th>Distance</th>
<th>Intensity</th>
</tr>
</thead>
</table>

\[
\frac{I_1}{I_2} = \left(\frac{D_2}{D_1}\right)^2
\]

\(I_1\) = Initial beam intensity
\(I_2\) = Beam intensity at a new location.
\(D_2\) = distance of the new location from the source
\(D_1\) = original distance from the source when intensity was \(I_1\)

Problem:
If the intensity of the beam at 2m from an x-ray source is \(x\), what will the intensity be at a distance of 1m?

Ans.:
\[
\frac{x}{I_2} = \frac{1}{4}
\]

\(I_2 = 4x\)

Factors affecting beam quality:

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Filtration removes most of the low energy photons (long wavelength) that only add to the patient’s skin exposure.

- Reduces patient dose
- Improves image contrast

Mean (average) energy of the beam goes up.

Filtration
Effect on X ray Beam
Types:
• Inherent (x-ray tube and its housing)
• Added filtration (Aluminum)
• The patient

Federal regulation stipulates the thickness of filter material for the different voltages used:
- Below 50 kVp: 0.5 mm Al equivalent
- 50-70 kVp: 1.5 mm Al equivalent
- Above 70 kVp: 2.5 mm Al equivalent

Filtration:

- Is the process of shaping a beam to make it no bigger than the size of the receptor.

Collimation

- Tube current (mA)
- Time
- Tube potential (kVp)
- Distance
- Intensity
- Target
- Filtration
- Collimation

Advantages of beam limiting devices:
- Less patient exposure
- Less operator exposure
- Less scatter generation and so improved contrast.

Beam Hardening:
- Intensity of x-ray decreases but mean energy of beam goes up
- Most of the low energy photons get absorbed

Radiographic Units

- Exposure: measure of ionization produced in air by x-/gamma rays
- Absorbed Dose: energy imparted to matter by ionizing radiation per unit mass of irradiated material.
- Dose Equivalent: Absorbed Dose x Quality Factor

Radiographic Units:

- Exposure: C/kg Roentgen (R) 1R=2.58x10^-4 C/kg.
- Absorbed Dose Gy (Gray) RAD 1 Gy=100 rad
- Effective dose Sv (Sievert) REM 1 Sv=100 rem
- Radioactivity Bq Ci (Curie) 1 Ci=3.7x10^10 Bq
### Occupational Exposure:

- **MPD**: Max. Permissible Dose Equivalent:
  - Max. dose that a person or specified parts thereof shall be allowed to receive in a stated period of time.
  - Whole body MPD: 20 mSv per year.
  - Based on ALARA PRINCIPLE (As Low As Reasonably Achievable)

### Attenuation

Reduction in the intensity of x-ray beam as it traverses matter by either absorption or deflection of photons from the beam

- Measured using the half value layer (HVL): defined as the thickness of any material required to reduce the intensity of the beam in half.

### Half value layer: a measure of attenuation

Factors affecting attenuation:
- Energy of radiation, atomic number (Z) of material through which it passes, tissue density, electron density etc.

### Differential attenuation

- Different body parts attenuate the x-ray beam to different extents depending on their density, thickness, energy of the beam, beam size etc.
- Image contrast.

### Scatter Radiation: reduces contrast……

Aim: To reduce the intensity of scatter radiation:
- Field size: Collimation.
- Kilovoltage: Sufficient kVp only.
- Part thickness: too much thickness of tissue generates too much scatter.

**Scatter (secondary) radiation is also a health hazard!**

### Types of radiation

- Primary radiation: Produced at focal spot and exiting tubehead through glass window – used to expose radiograph. MAIN BEAM.
- Secondary radiation: Radiation produced by alteration of direction of collimated primary beam by other objects as patient’s face.
- Stray (Leakage) radiation: Radiation produced at the focal spot and exiting the tubehead at points other than the glass window.
Interactions of x-rays with matter

In the diagnostic range: 3 types of interactions can occur depending on the nature of the beam.

Coherent scatter, Photoelectric absorption and Compton scatter.

- X-ray interactions with matter: probability increases with atomic number and thickness of absorbing material.

Coherent Scattering

- Incoming x-ray photon is deflected by an outer orbital electron.
- Resultant photon has a change in direction without loss of energy.
- Only interaction where no energy loss occurs.
  - 8% of all interactions

Photoelectric Effect

- X-ray photon strikes an electron near the nucleus with enough energy to knock it off its orbit.
- Photon is totally absorbed and its energy transferred to the ejected /recoil electron.

- Approximately 30% of all interactions.
- Most important interaction in diagnostic radiology
Compton Scatter

Caused when an x-ray photon scatters off an electron, ejecting it from orbit
- Recoil electron
  - Scattered photon: may exit tissue or interact with more material

Compton scattering decreases contrast
- 62% of all interactions