RED TECH OFFICIAL FOR RADIOGRAPHER

THE PHYSICS OF RADIOLOGY AND IMAGING

1. **Fundamental Concepts**

Measurement and units ,
Density, mole, pressure, and gas laws
Mechanics, Temperature and heat,
Atomic structure, Electromagnetic radiation
Radiological mathematics

Measurement and Units:

- **Definition:** Measurement is the process of determining the size or extent of something. Units are standardized quantities used for measurement.
- **Key Concepts:**
- **Base Units:** Fundamental units (e.g., meter, kilogram, second).
- **Derived Units:** Combinations of base units (e.g., speed is meters per second).
- **Prefixes:** Modify units by powers of 10 (e.g., kilo- for thousand, milli- for thousandth).

Density, Mole, Pressure

- **Density:**
- **Definition:** Mass per unit volume (Density = Mass/Volume).
- **Units:** Typically expressed in kg/m^3 or g/cm^3.
- **Mole:**
- **Definition:** A unit in chemistry used to express amounts of a chemical substance.
- **Avogadro's Number:** 6.022×10^{23}, the number of atoms or molecules in one mole.
- **Pressure:**
- **Definition:** Force per unit area (Pressure = Force/Area).
- **Units:** Pascals (Pa) or atmospheres (atm).

GAS LAWS

- Boyle's law states that the volume (V) of a given mass of gas is inversely proportional to its pressure (P), at constant temperature.
- Charles's law states that volume of a given mass of gas, at constant pressure, is proportional to its temperature (T). The above two laws can be combined and stated as follows:
- PV/T = constant
- This is known as the perfect gas equation.

Mechanics:

- **Definition:** Mechanics deals with the motion and forces of objects.
- **Newton's Laws of Motion:** Describes the relationship between a body and the forces acting on it.
  - First Law: An object at rest stays at rest, and an object in motion stays in motion with a constant velocity unless acted upon by a net external force.
  - Second Law: The acceleration of an object is directly proportional to the net force acting upon it and inversely proportional to its mass.
  - Third Law: For every action, there is an equal and opposite reaction.

Temperature and Heat:

- **Temperature:**
- **Definition:** A measure of the average kinetic energy of particles in a substance.
- **Units:** Kelvin (K) or Celsius (°C).
- **Heat:**
- **Definition:** Energy transfer between substances due to a temperature difference.
- **Units:** Joules (J) or calories.

Atomic Structure:

- **Atom:** Basic unit of matter.
- **Subatomic Particles:** Protons, neutrons, and electrons.
- **Atomic Number:** Number of protons in an atom.
- **Isotopes:** Atoms of the same element with different numbers of neutrons.
- **Electron Shells:** Energy levels where electrons orbit the nucleus.

Electromagnetic Radiation:

- **Definition:** Energy in the form of electromagnetic waves.
- **Key Concepts:**
- **Wave-Particle Duality:** Light exhibits both wave and particle characteristics.
- **Spectrum:** Range of electromagnetic waves, including radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays.

Radiological Mathematics:

- **Radioactive Decay:** The process by which an unstable atomic nucleus loses energy by emitting radiation.
- **Half-Life:** The time it takes for half of a radioactive substance to decay.
- **Exponential Decay:** Mathematical model for radioactive decay.
- **Radiation Exposure and Dose:** Measured in units such as Gray (Gy) and Sievert (Sv).

1. What is the SI unit of length?
A) Kilogram
B) Meter
C) Second
D) Newton

Correct answer: B) Meter

2. If a quantity has a mass of 50 kg and a volume of 2 m^3, what is its density?

A) 25 kg/m^3

B) 50 kg/m^3

C) 100 kg/m^3

D) 2.5 kg/m^3

Correct answer: C) 100 kg/m^3 (Density = Mass/Volume)

3. Avogadro's number is used to define:
A) Mass
B) Volume
C) Amount of substance
D) Pressure

Correct answer: C) Amount of substance

4. According to Boyle's Law, if the pressure of a gas decreases, what happens to its volume (assuming constant temperature)?

A) Increases

B) Decreases

C) Remains constant

D) Doubles

Correct answer: A) Increases

5. Newton's First Law of Motion is also known as the law of:

A) Acceleration

B) Inertia

C) Action and reaction

D) Force

Correct answer: B) Inertia

6. The unit of force in the International System of Units (SI) is:

A) Newton

B) Joule

C) Watt

D) Pascal

Correct answer: A) Newton

7. Absolute zero on the Kelvin scale is equivalent to:

A) 0 K

B) 100 K

C) -273.15 °C

D) 100 °C

Correct answer: C) -273.15 °C

8. Which of the following is a measure of the total kinetic energy of particles in a substance?

A) Heat

B) Temperature

C) Specific heat

D) Thermal conductivity

Correct answer: A) Heat

9. The number of protons in an atom is called:

A) Atomic mass

B) Atomic number

C) Neutron number

D) Electron number

Correct answer: B) Atomic number

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10. Where are electrons located in an atom?
A) Nucleus
B) Proton cloud
C) Electron cloud (electron shells)
D) Neutron region

Correct answer: C) Electron cloud (electron shells)

11. Which of the following is not a form of electromagnetic radiation?
A) X-rays
B) Sound waves
C) Infrared radiation
D) Gamma rays

Correct answer: B) Sound waves

12. What is the order of the electromagnetic spectrum from longest to shortest wavelength?
A) Radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays
B) Gamma rays, X-rays, ultraviolet, visible, infrared, microwaves, radio waves
C) Radio waves, infrared, visible, ultraviolet, X-rays, microwaves, gamma rays
D) Ultraviolet, visible, infrared, microwaves, radio waves, X-rays, gamma rays

Correct answer: A) Radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays

13. What is the unit of measurement for the absorbed dose of ionizing radiation?

A) Becquerel

B) Sievert

C) Gray

D) Curie

Correct answer: C) Gray

14. The time it takes for a radioactive substance to lose half of its activity is known as:

A) Decay constant

B) Half-life

C) Absorption coefficient

D) Fission rate

Correct answer: B) Half-life

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THE PHYSICS OF RADIOLOGY AND IMAGING

2. Electricity, Electronics and Magnetism

Electric charge, Electrical potential

Conductors, insulators and semiconductors

Capacitance, Electrical current

Electrical power, Magnetism

Electromagnetic induction ,Alternating current

Electric Charge

- **Definition:** Electric charge is a fundamental property of matter that can be positive or negative. Like charges repel each other, and opposite charges attract.
- **Elementary Charge:** The charge of a proton is considered positive, and the charge of an electron is considered negative. The elementary charge is approximately 1.602×10−191.602×10−19 coulombs.

Electrical Potential

- **Definition:** Electrical potential, also known as voltage, is the electric potential energy per unit charge. It is the driving force that moves electric charges.
- **Unit:** The unit of electrical potential is the volt (V).

Conductors, Insulators, and Semiconductors

- **Conductors:**
- **Definition:** Materials that allow the flow of electric charge.
- **Example:** Copper, aluminum.
- **Insulators:**
- **Definition:** Materials that do not allow the flow of electric charge.
- **Example:** Rubber, glass.
- **Semiconductors:**
- **Definition:** Materials with conductivity between that of conductors and insulators.
- **Example:** Silicon, germanium.

Capacitance and Electric Current

- **Definition:** Capacitance is the ability of a system to store an electric charge.
- **Capacitor:** A device that stores electrical energy in an electric field.
- **Unit:** The unit of capacitance is the farad (F).
- **Electrical Current:**
- **Definition:** Electrical current is the flow of electric charge in a conductor.
- **Direction of Current:** Conventionally, current is considered to flow from the positive terminal to the negative terminal (opposite to the flow of electrons).
- **Unit:** The unit of electric current is the ampere (A).

Electric power and magnetism

- **Electrical Power:**
- **Definition:** Electrical power is the rate at which electrical energy is transferred or converted.
- **Formula:** $P=VI$, where P is power, V is voltage, and I is current.
- **Unit:** The unit of power is the watt (W).
- **Magnetism:**
- **Definition:** Magnetism is a property of certain materials that can attract or repel other materials.
- **Magnetic Field:** The region around a magnet where the magnetic force acts.
- **Magnetic Poles:** Every magnet has a north pole and a south pole.

Electromagnetic Induction:

- **Definition:** Electromagnetic induction is the process of generating an electromotive force (EMF) or voltage in a coil by changing the magnetic field around the coil.
- **Faraday's Law:** The induced electromotive force (EMF) in any closed circuit is equal to the rate of change of the magnetic flux through the circuit.
- **Alternating Current:**
- **Definition:** Alternating current (AC) is an electric current that periodically reverses direction.
- **Key Concepts:**
- **Frequency:** The number of complete cycles per unit time, measured in hertz (Hz).
- **AC Voltage:** Typically represented as $V(t)=V0\sin(2\pi f\, t)$, where $V0$ is the amplitude, f is the frequency, and t is time.

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1. What is the elementary charge of an electron?

A) 1.602×10−19 C

B) 1.602×10−12 C

C) 1.602×10−9 C

D) 9.81×10-3 C

Correct answer: A)1.602×10−19 C

2. What is the unit of electrical potential?

A) Ampere (A)

B) Joule (J)

C) Coulomb (C)

D) Volt (V)

Correct answer: D) Volt (V)

3. In a semiconductor, what happens to its conductivity when the temperature increases?

A) Increases

B) Decreases

C) Remains constant

D) Becomes infinite

Correct answer: A) Increases

4. Semiconductors have conductivity:
A) Much higher than conductors
B) Much lower than insulators
C) Between conductors and insulators
D) Equal to insulators

Correct answer: C) Between conductors and insulators

5. What is the unit of capacitance?

A) Henry (H)

B) Ohm (Ω)

C) Farad (F)

D) Watt (W)

Correct answer: C) Farad (F)

6. What is the drift velocity in a conductor?
A) The average velocity of electrons
B) The velocity of protons
C) The velocity of the current
D) The velocity of photons

Correct answer: A) The average velocity of electrons

7. What is the formula for electrical power?

A) $P=IV$

B) $P=I2R$

C) $P=V2/R$

D) All of the above

Correct answer: D) All of the above

8. What is the purpose of a magnetic shielding material?
A) To enhance the magnetic field
B) To redirect the magnetic field
C) To weaken the magnetic field
D) To block or reduce the magnetic field

Correct answer: D) To block or reduce the magnetic field

9. What does the frequency of an alternating current represent?
A) Voltage
B) Amplitude
C) Number of cycles per second
D) Resistance

Correct answer: C) Number of cycles per second

10. What is the potential difference across a component with a resistance of 5 ohms and a current of 2 amperes?

A) 10 V

B) 7.5 V

C) 2.5 V

D) 0.4 V

Correct answer: A) 10 V (By Ohm's Law: $V=IR$)

11. If the voltage across a capacitor is doubled while keeping the charge constant, what happens to the capacitance?

A) It doubles

B) It halves

C) It remains the same

D) It quadruples

Correct answer: C) It remains the same (Capacitance is constant when the charge and voltage change proportionally)

12. What is the purpose of a transformer in an electrical circuit?
A) To store electrical energy
B) To convert DC to AC
C) To change voltage levels
D) To regulate current

Correct answer: C) To change voltage levels

13. In an AC circuit, what does the root mean square (RMS) value represent?
A) The average value of current or voltage
B) The peak value of current or voltage
C) The frequency of the AC signal
D) The phase angle of the AC signal

Correct answer: A) The average value of current or voltage

14. What is the frequency of a signal with a period of 0.02 seconds?

A) 50 Hz

B) 25 Hz

C) 40 Hz

D) 20 Hz

Correct answer: A) 50 Hz (Frequency is the reciprocal of the period, f=T1)

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THE PHYSICS OF RADIOLOGY AND IMAGING

3. Physics of X-rays WITH MCQ PART 1

Discovery of X-rays
Production of X-rays
X-ray tube design
Historical X-ray tubes
Modern X-ray tubes, Filters
Scattered radiations

Discovery of X-Rays by WC Roentgen

- **Discoverer:** Wilhelm Conrad Roentgen, a German physicist
- **Year of Discovery:** 1895
- **Discovery Context:**
- **Investigation:** Roentgen was studying electricity conduction through gases in glass tubes.
- **Observation:** Positive electrodes emitted invisible rays.
- **Effects:** Rays made fluorescent screens glow and fogged photographic plates.

Discovery of X-Rays by WC Roentgen

- **Key Characteristics:**
- **Penetrating Power:** Rays penetrated black paper and thick objects.
- **Non-Deflection:** Not deflected in a magnetic field.
- **Nature:** Initially unknown, named X-rays by Roentgen.
- **Nature of X-Rays:**
- **Later Identification:** X-rays were shown to be electromagnetic radiation with very short wavelengths.
- **Recognition:**
- **Nobel Prize:** Roentgen received the Nobel Prize in Physics in 1901 for the discovery of X-rays.

PROPERTIES OF X-RAYS

- **Nature of X-Rays:**
  - Electromagnetic radiation with shorter wavelength (few nm).
- **Travel Characteristics:**
  - Travel in a straight line with a velocity equal to light.
- **Interaction with Fields:**
  - Not influenced by electric and magnetic fields.
- **Penetration Power:**
  - Penetrate through substances opaque to visible light.
- **Fluorescence Production:**
- Produce fluorescence in materials like calcium tungstate and cesium iodide.

PROPERTIES OF X-RAYS

- **Photographic Effects:**
  - Affect photographic film, forming a latent image.
- **Ionization and Excitation:**
  - Produce ionization and excitation in substances they pass through.
- **Chemical Changes:**
  - Produce chemical changes in substances they pass through.
- **Biological Effects:**
  - Produce biological effects in living organisms, potentially damaging or killing cells upon exposure.

Production of X-Rays

- **Mechanism:**
  - X-rays are produced when fast-moving electrons are stopped by a target material.
- **Electron Kinetic Energy:**
  - Fast-moving electrons possess kinetic energy.
- **Energy Conversion:**
  - When electrons are suddenly stopped, their kinetic energy is converted into heat and X-rays.
- **Target Material Role:**
  - The conversion of kinetic energy into X-rays occurs in the target material.
- **Basis for Production:**
  - The interaction between electrons and the target material forms the basis for X-ray production.

Electron Interactions in X-Ray Production

- **Ionization of Target Atoms (i):**
- Fast-moving electrons collide with target atoms, transferring energy and causing ionization.
- Multiple collisions alter the electron's direction.
- Most of the electron's energy becomes heat in the target.
- Secondary electrons (delta rays) may further ionize target atoms.

Characteristic X-rays (ii):

- Interaction with electrons in the K shell.
- Incident electron removes a K shell electron, creating a vacancy.
- Transition of an outer shell electron fills the vacancy, emitting characteristic X-rays.
- Ejected electrons may induce further interactions.

Interaction with Nuclear Field (iii):

- Electron reaches near the nucleus, attracted by its positive charge.
- Electron orbits the nucleus, decelerates, and emits X-ray photons (Bremsstrahlung).
- Photon energy depends on the degree of deceleration, ranging from zero to a maximum.
- More likely at high electron energies.

Direct Collision with Nucleus (iv):

- Electron hits the nucleus directly, stopping completely in a single collision.
- Entire electron energy is released as Bremsstrahlung radiation.
- Rare but capable of producing high-energy X-rays.

- Note :- Ionizational collisions dominate (>99%), leading to heat production and making X-ray tube less efficient in converting electron energy to X-rays.

Bremsstrahlung Radiation

- Bremsstrahlung, meaning "braking radiation," occurs when an electron undergoes radiative collision with a nucleus in the target. As the electron interacts with the nucleus, it may experience sudden deflection and acceleration, losing kinetic energy in the form of bremsstrahlung X-rays. The probability and energy of these X-rays depend on the electron's distance from the nucleus.
- **Probability and Energy:**
  - **Distance Matters:** The probability of bremsstrahlung increases with a large distance but yields low-energy X-rays. Conversely, close proximity produces high-energy X-rays with lower probability. Moderate distances result in moderate energy.
  - **Direction of Emission:** At low electron energies, X-rays are emitted equally in all directions. Higher energies yield increasingly forward-directed emissions.

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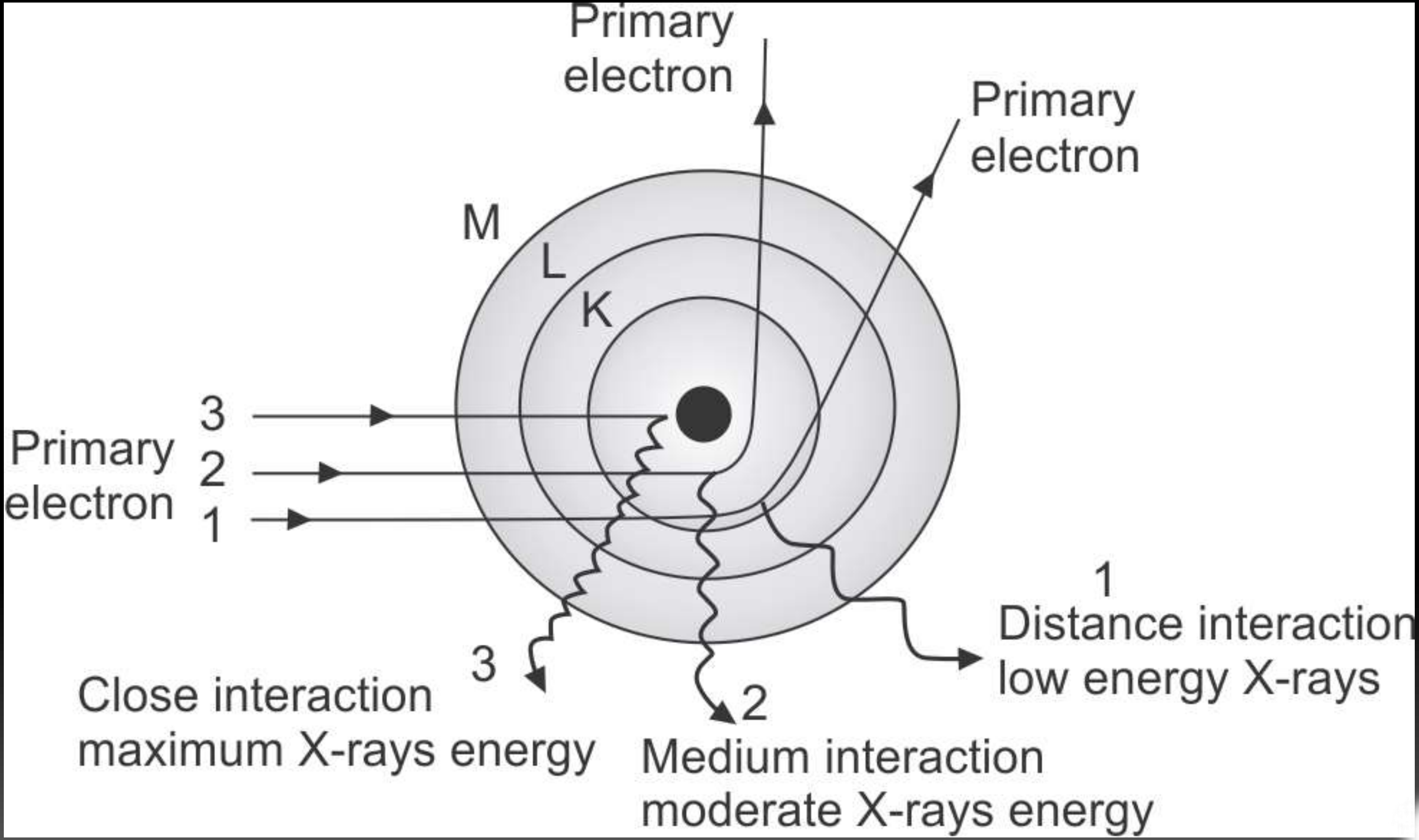

Primary
electron
Primary
electron
M
L
K
3
Primary
electron
2
1
1
Distance interaction
low energy X-rays
3
Close interaction
maximum X-rays energy
2
Medium interaction
moderate X-rays energy

Bremsstrahlung Radiation

- **Diagnostic Radiology Considerations:**
  - **Optimal Direction:** In diagnostic radiology, obtaining X-rays at 90 degrees to the electron beam is technically advantageous.
  - **Thicker Targets:** Thicker targets in diagnostic X-ray tubes stop the entire electron beam, producing X-rays in all directions. However, forward-directed X-rays are absorbed by the target.
- **Efficiency of X-ray Production:**
  - **Formula:** Efficiency = $9 \times 10^{-10} \times Z \times V$ (where Z is the atomic number, and V is the tube voltage).
  - **Factors:** X-ray production efficiency increases with higher accelerating voltage and atomic number of the target material.
  - **Radiative vs. Collisional Losses:** Efficiency can be expressed as the ratio of radiative energy loss to collisional energy loss.

Bremsstrahlung Radiation

- **Example with Tungsten Target:**
  - **Efficiency Calculation:** For a 100 keV electron interacting with a tungsten target (Z = 74), efficiency = (100 × 72) / 820,000 = 0.9%.
  - **Result:** Tungsten's efficiency is less than 1%, with over 99% of input energy appearing as heat.
- **Higher Photon Energy Impact:**
  - **Efficiency Relationship:** Higher photon energy leads to greater X-ray production efficiency and lesser heat production.
  - **6 MV Electron Example:** X-ray production efficiency exceeds 50%, resulting in lesser heat production.

Production of Characteristic X-rays in Electron Interactions

- Electrons incident on a target can produce characteristic X-rays.
- Interaction involves ejecting an electron from the K shell, leading to ionization.
- **kinetic Energy Interaction:** Electron with kinetic energy E_0 interacts with target atoms.
- Ejects an orbital electron from the K shell, causing ionization.
- Original electron has energy E_0 - E, where E is the energy given to the orbital electron.

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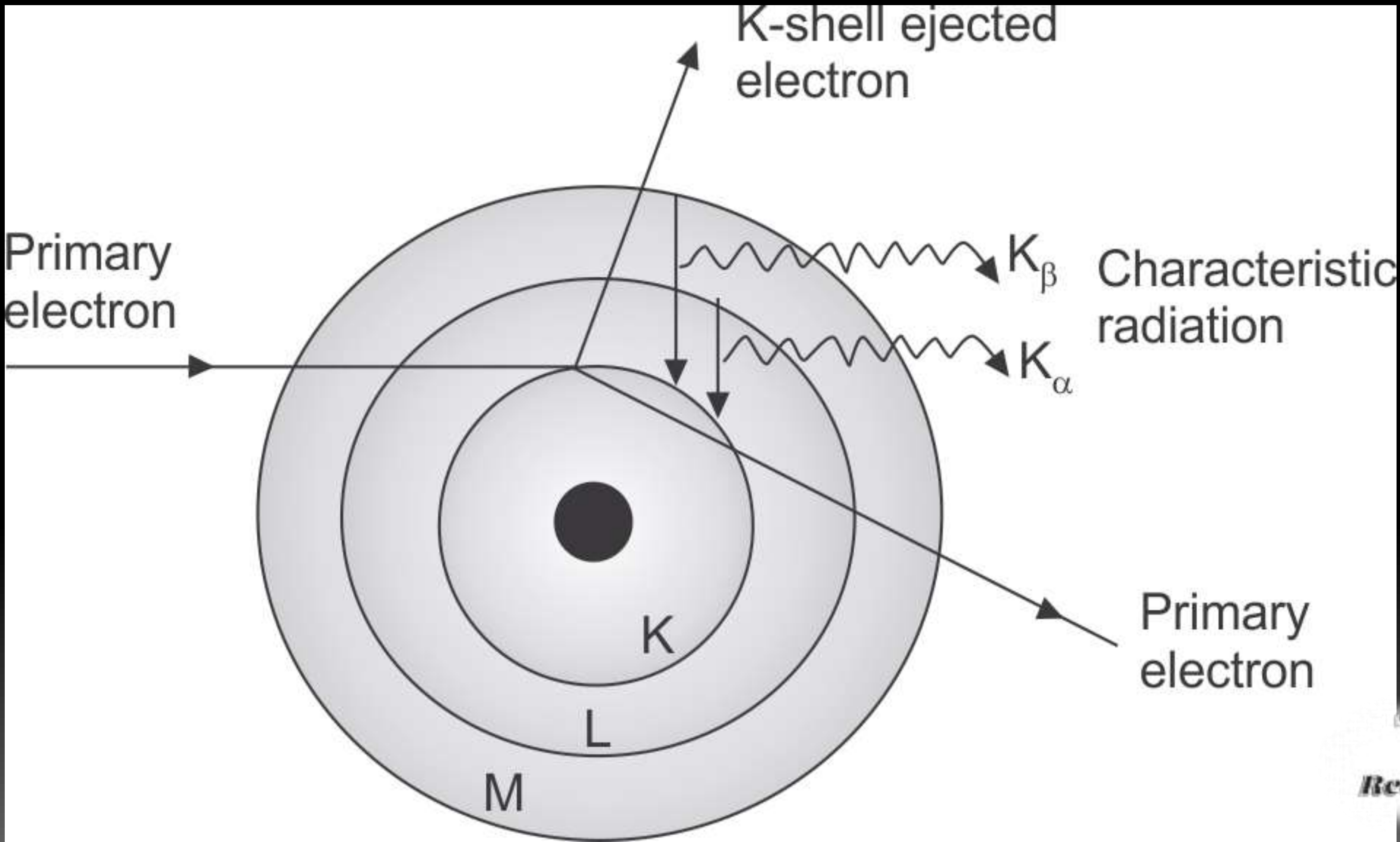
Production of Characteristic X-rays in Electron Interactions

- **vacancy Filling:** Outer orbital electrons (from M or L) fill the vacancy in the K shell.
- Energy difference in binding energies of the two shells radiated as characteristic X-ray photons.
- These X-rays have discrete energies characteristic of the element.
- K characteristic X-rays are crucial in diagnostic radiology.
- Other characteristic X-rays are entirely attenuated by the tube window and filters.


K-shell ejected electron
Primary electron
K_β
Characteristic radiation
K_α
Primary electron
K
L
M

Production of Characteristic X-rays in Electron Interactions

- **Threshold Energy :** K characteristic X-rays emitted only if incident electrons have energies greater than the binding energy of the K-shell electron.
- Kilovoltage must exceed the threshold energy (e.g., > 69.5 keV for tungsten).
- **Energy Dependency :** As incident electron energy increases above the threshold, the percentage of characteristic X-rays also increases.
- Example: 100 kVp X-rays spectrum consists of about 10% characteristic X-rays.

Essentials of X-Ray Production

- **Components:Electron Source (Cathode):** Initiates the process.
- **Target (Anode):** Stops electrons, leading to X-ray production.
- **High Voltage Supply:** Accelerates electrons.
- **Vacuum:** Ensures a suitable environment.
- **Tube Insert (Glass Envelope):** Encloses the components.

X-Ray Generation Mechanism

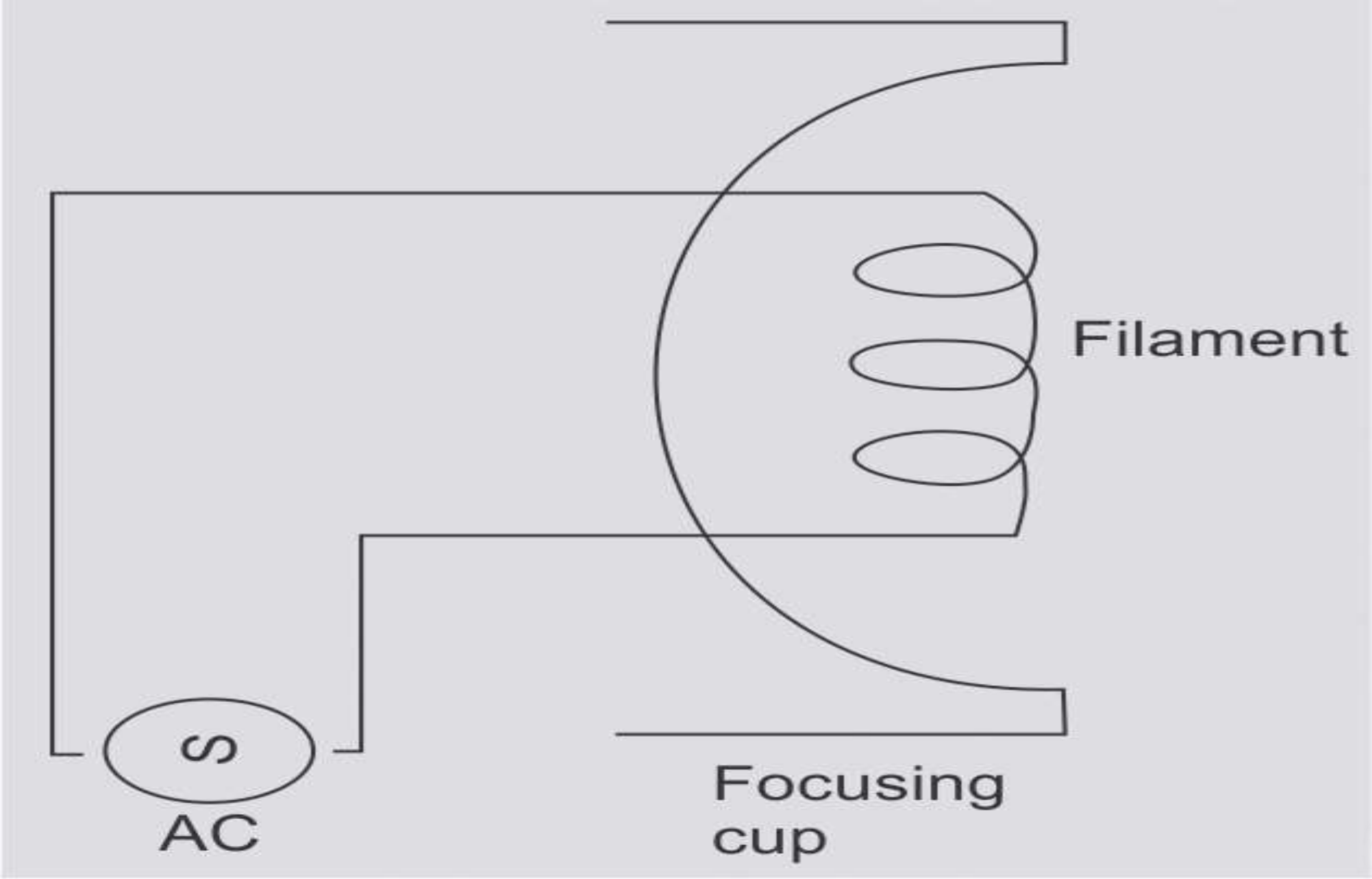
- **Electron Production:**
  - Electrons generated by ionization in gas or thermionic emission.
  - The cathode serves as the electron source.
- **Acceleration:**
  - High voltage applied between cathode and anode.
  - Accelerated electrons gain high kinetic energy.
- **X-Ray Production:**
  - Electron kinetic energy is converted into X-ray energy when electrons are stopped by the target.

X-Ray Tube Design and Applications

- **Design Considerations:**
  - Ensures tolerance to voltages from 20–150 kV.
  - Can handle currents up to 1000 mA.
- **Application Variations:**
  - **Radiography:** Tube currents typically range from 100 to 1000 mA.
  - **Fluoroscopy:** Lower tube currents, typically 1–5 mA.
- **Exposure Control:**
  - Varied exposure time over a wider range for different applications.
  - Critical for adjusting radiation dosage.

Cathode Design in X-Ray Tubes

  - Tungsten wire helical filament within a focusing cup.
  - Tungsten chosen for its high melting point, low vapor pressure, ductility, and low work function (4.5 eV).
  - Tungsten wire, 0.2 mm in diameter, coiled into a vertical spiral (0.2 cm in diameter, 1 cm in length).
  - Provides a large surface area for electron emission.
  - Voltage: 8–12 V, selectable filament current: 3–7 amperes.
  - Resistance heats the filament, releasing electrons through thermionic emission.
  - Thorium trace enhances efficiency and prolongs filament life.
  - At zero anode-cathode voltage, electrons form a space charge near the cathode.
  - Increasing voltage accelerates electrons toward the anode, aiding X-ray production.
- Focusing Cup **:** Controls electron distribution width and directs electrons toward the target.
  - Typically at the same potential as the filament (nonbiased X-ray tube).
- Filament Variations : X-ray tubes often equipped with two filaments of different lengths.
  - Filament selection determines focal spot length or area.


Filament
S
AC
Focusing
cup

Anode Design in X-Ray Tubes

- **Anode Function:**
  - Target electrode at a positive potential.
  - Target material selection crucial for efficiency and heat dissipation.
- **Ideal Target Properties:**
  - High melting point.
  - High atomic number for increased X-ray production efficiency.
  - High thermal conductivity for quick heat dissipation.
  - Low vapor pressure to prevent material evaporation.
  - Easily machined for a smooth surface.

Anode Design in X-Ray Tubes

- **Commonly Used Material: Tungsten (W)**
  - Melting point: 3387°C, High atomic number: 74.
  - Low thermal conductivity (embedded in copper for efficient heat removal).
- **Anode Design Variations:**
  - Stationary anode: Square or rectangular plate.
  - Rotating anode: Disk (75–200 mm diameter) with beveled edges for heat dissipation.
- **Rotating Anode Challenges and Solutions:**
  - Large diameter anodes used in CT and fluoroscopy (increased heat capacity).
  - Prone to mechanical damage, addressed by radial slots (stress relieved anodes).
- **Enhanced Durability:**
  - Tungsten-rhenium alloy (90% tungsten + 10% rhenium) to prevent cracking and surface pitting.
- **Other Anode Materials:**
  - Molybdenum (Mo, Z = 42) and rhodium (Rh, Z = 45) for mammographic X-ray tubes.
  - Capable of producing characteristic X-rays for soft tissue contrast studies.

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Focal Spot and Its Impact on Imaging

- **Focal Spot Defined:**
  - The area on the target where electrons are absorbed and X-rays are generated.
  - Crucial for image quality and heat management.
- **Small Focal Spot:**
  - Reduces penumbra (blurred edges), enhances picture sharpness.
  - Heat removal becomes challenging.
- **Large Focal Spot:**
  - Efficient heat removal.
  - Increased penumbra, reduced picture sharpness.
- **Balancing Act:**
  - Careful tube design to compromise between sharpness and heat dissipation.

Focal Spot and Its Impact on Imaging

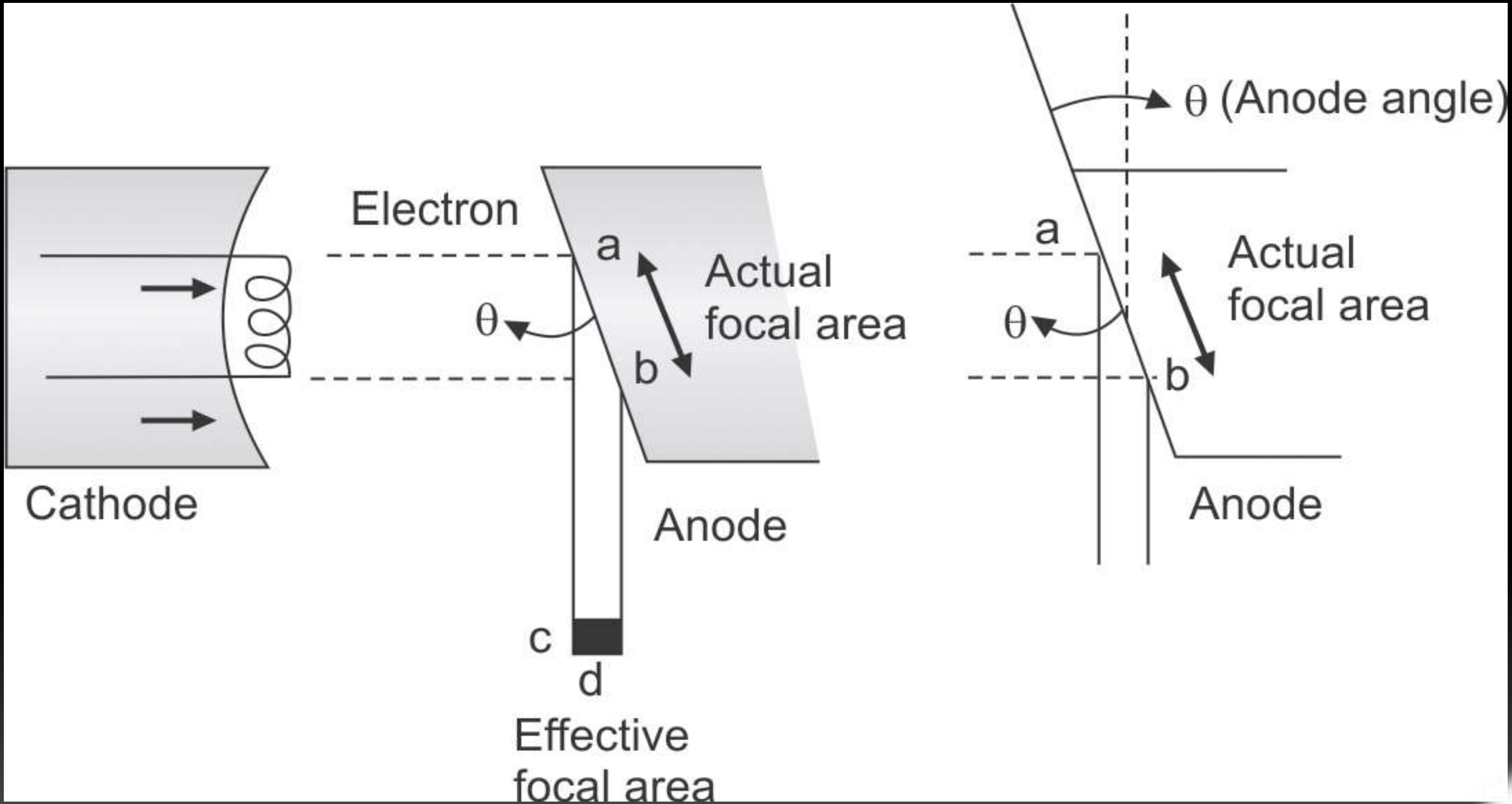
- **Two Focal Spot Types:**
  - **Actual Focal Spot:** Area struck by electrons on the anode.
  - **Effective Focal Spot:** Length and width of the X-ray beam projected down the central axis.
    - Effective spot size smaller than the actual spot.
    - Relation: Effective spot = Actual spot × sin(θ), where θ is the anode angle.
- **Variability:**
  - Effective focal spot size ranges from 0.3 mm to 2 mm square.
  - Common sizes: 0.3 mm, 0.6 mm, 1.0 mm, and 1.2 mm.
  - Major impact on spatial resolution, especially during object magnification.
- **Measurement Techniques:**
  - Focal spot size determined using pinhole camera, slit camera, and star pattern.

Line Focus Principle in X-Ray Tubes

- **Focal Area Dilemma:**
  - **Larger Size:** Efficient heat spreading.
  - **Smaller Size:** Acts as a point source for sharp images.
- **Solution: Steep Angle Mounting (θ):**
  - **Advantage:** Balances the need for heat dissipation and a point source.
  - **Objective:** Preserve image sharpness while quickly removing heat.
- **Actual vs. Effective Focus:**
  - **Actual Focus:** Larger area where electrons bombard the target.
  - **Effective Focus:** Small area from which X-rays appear to originate.
- **Line Focus Principle:**
  - **Definition:** X-ray tube target mounted at a steep angle (θ).
  - **Outcome:** Efficient heat removal and preserved image sharpness.
  - **Resultant Focal Area:** Appears small (effective focus) despite electron bombardment in a larger area (actual focus).

Anode Angle and Focal Spot Optimization

- Angle of the target surface concerning the central ray in the X-ray field.
- **Small Anode Angle:** Produces a smaller effective focal spot, Limited usable X-ray field.
- **Large Anode Angle:** Yields a larger usable X-ray field.
- Results in a larger effective focal spot.
- **Design Approach:**
  - Larger anode angle with a small filament length.
  - Balances smaller effective focal size with wide field coverage.
  - **Small Anode Angle (7–9°):**
    - Useful for limited field of view (FOV) imaging (e.g., cineangiography, neuroangiography).
  - **Larger Anode Angles (10°–13°):**
    - Necessary for general radiographic work.
    - Achieves larger FOV coverage at short focus to image distances (FID).
- **Modern X-ray Tube Design:**
  - Anode angles of 10°–13°, Focal spot sizes ranging from 0.6 mm to 1.3 mm.


θ (Anode angle)
Electron
a
Actual
focal area
θ
b
Cathode
Anode
c
d
Effective
focal area
a
Actual
focal area
θ
b
Anode

Tube Insert and Vacuum in X-Ray Tubes

- **Tube Insert Material: Borosilicate Glass (Pyrex)**
  - **Properties:**
    - Withstands high temperature.
    - Acts as an electrical insulator.
    - Contains a vacuum for electrode support.
- **Functions of the Tube Insert:**
  - **Absorbs Undesired X-rays:**
    - Prevents X-rays from emerging in undesired directions.
  - **Maintains Vacuum:**
    - Essential for avoiding electron-gas collisions.
  - **Acts as an Electrical Insulator:**
    - Prevents short circuits and arcing.
  - **Contains Cooling System:**
    - Removes heat generated at the target.

Tube Insert and Vacuum in X-Ray Tubes

- **Challenges with Glass Inserts:**
  - Tungsten vapor can condense and form a conducting layer, leading to arcing.
  - Susceptible to damage from electron bombardment.
- **Alternative: Metal Envelope**
  - **Material:** Low attenuation beryllium window for X-ray transmission.
  - **Challenge:** Prone to short circuits between cathode and anode.
  - **Solution:** Metaceramic or metal glass design with ceramic or glass insulations.
- **Vacuum Maintenance:**
  - **Purpose:**
    - Avoids electron-gas collisions causing ionization.
    - Prevents oxidation of electrodes.
    - Acts as an electrical insulator.
- **Required Vacuum Level:**
  - **Specification:** Less than 10–5 mm Hg.

Heat Management in X-Ray Tubes

- **conversion Efficiency:**
  - Less than 1% of electrical power is converted to X-rays.
  - Over 99% of electrical power is converted to heat.
- **Heat Removal Necessity:**
  - Excessive heat can melt the target, requiring efficient cooling systems.
- **Target Construction:**
  - Tungsten layer in a copper block.
  - X-ray tubes enclosed in metal cases filled with oil for insulation.
- **Cooling System Operation: Static Oil Cooling**
  - Heat from the focal area conducted to the anode disk.
  - Temporarily stored and later transferred to insulating oil by radiation.
  - Oil surrounds the glass envelope and copper block.

Heat Management in X-Ray Tubes

- **Heat Transfer Process:**
  - Convection: Heat taken up by the oil transferred to the housing.
  - Some designs use fans to assist convection and remove heat from the housing.
- **Rotating Anode Considerations:**
  - Long molybdenum neck prevents heat conduction to the rotor.
  - Anode assembly coating in black promotes heat radiation.
  - Heat radiation rate proportional to the fourth power of anode temperature.
- **Extended Operation: Circulating Oil Cooling**
  - Oil connected to a reservoir with a radiator and pump.
  - Additional cooling by air current and water.
- **Modern Techniques:**
  - Anode earthed, water circulated through the anode.
  - Water may be additionally cooled by Freon gas.

1. **What is the meaning of "Bremsstrahlung"?**

A. Bright light
B. Breaking radiation
C. Focused energy
D. Rapid movement

Correct answer: B. Breaking radiation

2. **In bremsstrahlung radiation, what is the process that leads to the emission of X-rays?**
A. Absorption
B. Reflection
C. Radiative collision between an electron and a nucleus
D. Transmission through a medium

Correct answer C. Radiative collision between an electron and a nucleus

3. **How does the distance between the bombarding electron and the nucleus affect bremsstrahlung production?**

A. The closer, the lower the energy

B. The closer, the higher the energy

C. The farther, the lower the probability

D. The farther, the higher the probability

Correct answer: B. The closer, the higher the energy

4. **At very large distances between the bombarding electron and the nucleus, what type of X-rays are created?**

A. High-energy X-rays

B. Low-energy X-rays

C. Medium-energy X-rays

D. Gamma rays

Correct answer: B. Low-energy X-rays

5. **In which region does the direction of X-ray emission become increasingly forward as the kinetic energy of the electron increases?**

A. Space charge limited region

B. Saturation region

C. Forward emission region

D. Bremsstrahlung region

Correct answer: B. Saturation region

6. **What is the term for the ratio of output energy emitted as X-rays to the input energy deposited by the electron in bremsstrahlung production?**

A. Efficiency

B. Intensity

C. Luminescence

D. Absorption

Correct answer: A. Efficiency

7. **Which factor does the bremsstrahlung production efficiency depend on?**

A. Tube current

B. Tube voltage

C. Atomic number of the target material

D. Focal spot size

Correct answer: C. Atomic number of the target material

8. **What type of X-rays are produced in greater abundance in bremsstrahlung radiation?**

A. Low-energy X-rays
B. Medium-energy X-rays
C. High-energy X-rays
D. Ultra-high-energy X-rays

Correct answer: A. Low-energy X-rays

9. **What happens to the efficiency of X-ray production as the kinetic energy of the incident electron increases?**

A. Increases

B. Decreases

C. Remains constant

D. Becomes unpredictable

Correct answer: A. Increases

10. **Who discovered X-rays in 1895?**
A. Marie Curie
B. Wilhelm Conrad Roentgen
C. Albert Einstein
D. Thomas Edison

Correct answer: **B. Wilhelm Conrad Roentgen**

11. **Why did Roentgen name the newly discovered rays "X-rays"?**

A. They were extremely bright.

B. Their nature was unknown.

C. They were discovered in the X-ray spectrum.

D. Named after his initials.

Correct answer: **B. Their nature was unknown.**

12. **What is the primary mechanism for the production of X-rays in an X-ray tube?**

A. Nuclear fusion

B. Electron-ion collisions

C. Photoelectric effect

D. Fluorescence

Correct answer: **B. Electron-ion collisions**

13. **In X-ray production, what happens when fast-moving electrons are suddenly stopped?**

A. Release of light

B. Conversion of kinetic energy into X-rays

C. Creation of magnetic fields

D. Formation of gamma rays

Correct answer: **B. Conversion of kinetic energy into X-rays**

14. **What is the nature of X-rays with respect to electric and magnetic fields?**

A. Influenced by both fields

B. Not influenced by either field

C. Influenced by electric fields only

D. Influenced by magnetic fields only

Correct answer: **B. Not influenced by either field**

15. **What is the main outcome of ionization collisions during electron interactions in X-ray production?**

A. Formation of X-rays

B. Release of fluorescence

C. Heat production

D. Production of secondary electrons

Correct answer: **C. Heat production**

16. **What is the term for the X-ray interaction involving the K shell electrons?**

A. Fluorescence

B. Bremsstrahlung

C. Characteristic X-rays

D. Ionization

Correct answer: **C. Characteristic X-rays**

17. **In the production of X-rays, which interaction involves the direct hit of an electron on the nucleus?**

A. Ionization collisions

B. Characteristic X-rays

C. Bremsstrahlung

D. Direct collision

Correct answer: **D. Direct collision**

18. **What is the primary energy conversion process in the production of X-rays?**
A. Nuclear fission
B. Conversion of light energy
C. Conversion of kinetic energy
D. Photoelectric effect

Correct answer: **C. Conversion of kinetic energy**

19. **What is the dominant interaction process (>99%) in the X-ray production, leading to heat production?**

A. Characteristic X-rays

B. Ionization collisions

C. Direct collisions

D. Fluorescence

Correct answer: **B. Ionization collisions**

20. **What did Roentgen use to detect X-rays during his discovery?**

A. Photographic plates

B. Fluorescent screens

C. Barium platinocyanide screen

D. Both A and B

Correct answer: **D. Both A and B**

21. **What is the term for the X-rays produced when an electron is decelerated by the nuclear attraction?**

A. Fluorescence

B. Characteristic X-rays

C. Bremsstrahlung

D. Ionization X-rays

Correct answer: **C. Bremsstrahlung**

22. **What did Roentgen conclude about the nature of X-rays due to their behavior in a magnetic field?**

A. They are charged particles.

B. They are neutral particles.

C. They are electromagnetic radiation.

D. They are sound waves.

Correct answer: **C. They are electromagnetic radiation.**

23. **What is the primary factor responsible for the fine energy splitting of characteristic X-rays?**

A. Speed of incident electrons

B. Subshells of the given orbit

C. Atomic mass of the target

D. Density of the target material

Correct answer: **B. Subshells of the given orbit**

24. **Which term describes a non-adjacent shell transition in characteristic X-ray production?**

A. Gamma transition

B. Alpha transition

C. Beta transition

D. Delta transition

Correct answer: **C. Beta transition**

25. **Why are characteristic X-rays other than K-shell transitions considered less important in diagnostic radiology?**

A. They have lower energy.

B. They are entirely attenuated by the tube window and filters.

C. They are harder to detect.

D. They have limited penetration power.

Correct answer: **B. They are entirely attenuated by the tube window and filters.**

26. **Why is the vacuum maintained in an X-ray tube?**
a. To increase the speed of electrons.
b. To avoid collisions between electrons and gas molecules.
c. To generate more X-rays.
d. To improve image quality.

Correct answer: B. To avoid collisions between electrons and gas molecules.

27. **Which material is commonly used for the tube insert or envelope in X-ray tubes?**
a. Aluminum
b. Borosilicate glass (Pyrex)
c. Steel
d. Copper

Correct answer: **B.** Borosilicate glass (Pyrex)

27. **What is the primary advantage of using a small anode angle in an X-ray tube?**
a. Larger effective focal spot.
b. Smaller effective focal spot.
c. Improved heat dissipation.
d. Increased usable X-ray field size.

Correct answer: **B.** Smaller effective focal spot.

28. **In which clinical application is a small anode angle (7–9°) most useful?**

a. General radiography.

b. Cineangiography.

c. Mammography.

d. Computed Tomography (CT)

Correct answer: **B.** Cineangiography.

29. **What is the primary objective of the line focus principle in X-ray tubes?**

a. To increase the tube voltage.

b. To reduce the anode angle.

c. To balance heat dissipation and point source for X-ray production.

d. To decrease the size of the filament.

Correct answer: c. To balance heat dissipation and point source for X-ray production.

30. **What impact does a smaller focal spot size have on image sharpness?**
a. Reduces penumbra.
b. Increases penumbra.
c. Enhances heat removal.
d. Widens the usable X-ray field.

Correct answer: a. Reduces penumbra.

31. **How is focal spot size typically measured in X-ray tubes?**
a. By the anode angle.
b. Using a pinhole camera.
c. By the length of the X-ray tube.
d. By the filament current.

Correct answer: **B.** Using a pinhole camera.

32. **Why is tungsten often embedded in copper when used as the target material in X-ray tubes?**
a. To increase the tube voltage.
b. To improve image quality.
c. To enhance heat dissipation.
d. To reduce the size of the focal spot

Correct answer: c. To enhance heat dissipation.

33. **Which material is commonly used for the cathode filament in X-ray tubes?**
a. Copper.
b. Tungsten.
c. Aluminum.
d. Lead.

Correct answer: **B.** Tungsten.

34. **What percentage of electrical power supplied to an X-ray tube is typically converted to heat?**

a. Less than 1%.

b. Approximately 25%.

c. About 50%.

d. Over 99%.

Correct answer: d. Over 99%.

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THE PHYSICS OF RADIOLOGY AND IMAGING

3. **Physics of X-rays WITH MCQ PART 2**

Discovery of X-rays
Production of X-rays
X-ray tube design
Historical X-ray tubes
Modern X-ray tubes, Filters
Scattered radiations

Modern X-ray Tube

Stationary Anode X-ray Tube :-

- **Historical Background:**
  - Earlier use of gas tubes for X-ray production.
  - Introduction of Coolidge's thermionic emission-based X-ray tube prototype.
- **Modern Stationary Anode X-ray Tube:**
  - Components: Cathode, anode, and evacuated glass envelope.
  - Cathode:
    - Tungsten filament in a coil.
    - Heated by low voltage electric current.
    - Includes a shallow focusing cup.

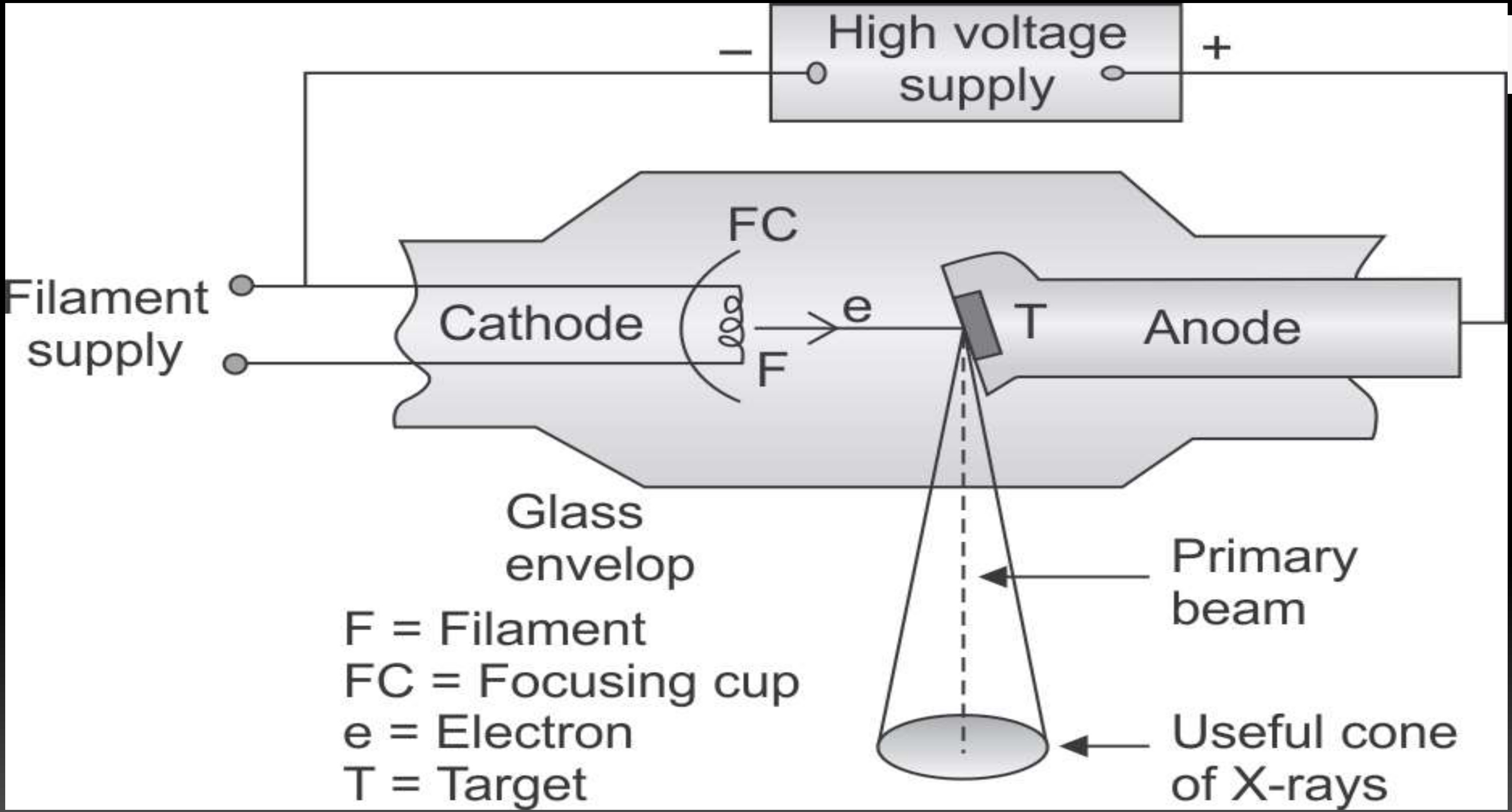
Stationary Anode X-ray Tube :-

- Anode:
  - Made of copper with an embedded tungsten plate as the target.
  - Positioned according to the line focus principle.
  - Anode angle typically **15–20 degrees**.
- High voltage supply applied between cathode and anode.
- Maintains a high vacuum (approximately 10–5 mm Hg) in the tube.

- **Electron Emission and Acceleration:**
  - Filament heating causes electron emission.
  - Focusing cup generates an electric field to focus electrons to the focal area.
  - Protects tube wall from electron bombardment.
  - Anode made positive to attract electrons, creating electron current.
  - Tube current measured by a milliammeter (mA).

Stationary Anode X-ray Tube :-

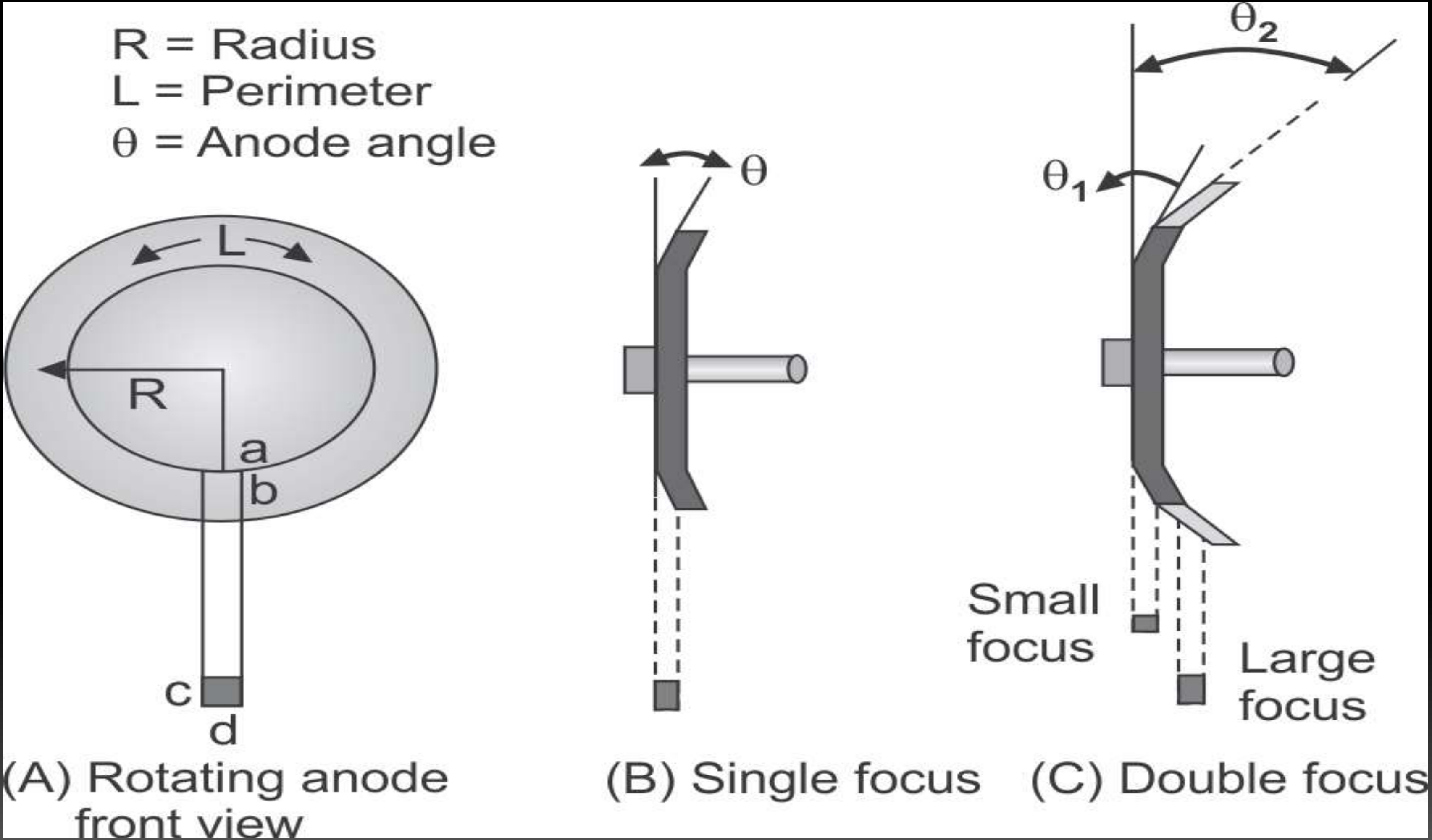
- **X-ray Production:**
  - High vacuum prevents electron-gas collisions.
  - Electrons acquire high velocities due to the applied voltage.
  - High kinetic energy in accelerated electrons.
  - When electrons abruptly stop in the target, X-rays are emitted.
  - About half of X-rays absorbed in the target, and the rest forms the primary X-ray beam.
- **Heat Management:**
  - Large heat production during X-ray generation
  - Equipped with a cooling system to remove heat quickly.
- **Applications:**
  - Stationary anode tubes have limited target area.
  - Suitable for small-sized and lightweight X-ray units.
  - Used in dental X-ray units, portable X-ray units, and portable fluoroscopy systems.



High voltage supply
–
+
Filament supply
Cathode
FC
F
e
T
Anode
Glass envelop
Primary beam
Useful cone of X-rays
F = Filament
FC = Focusing cup
e = Electron
T = Target

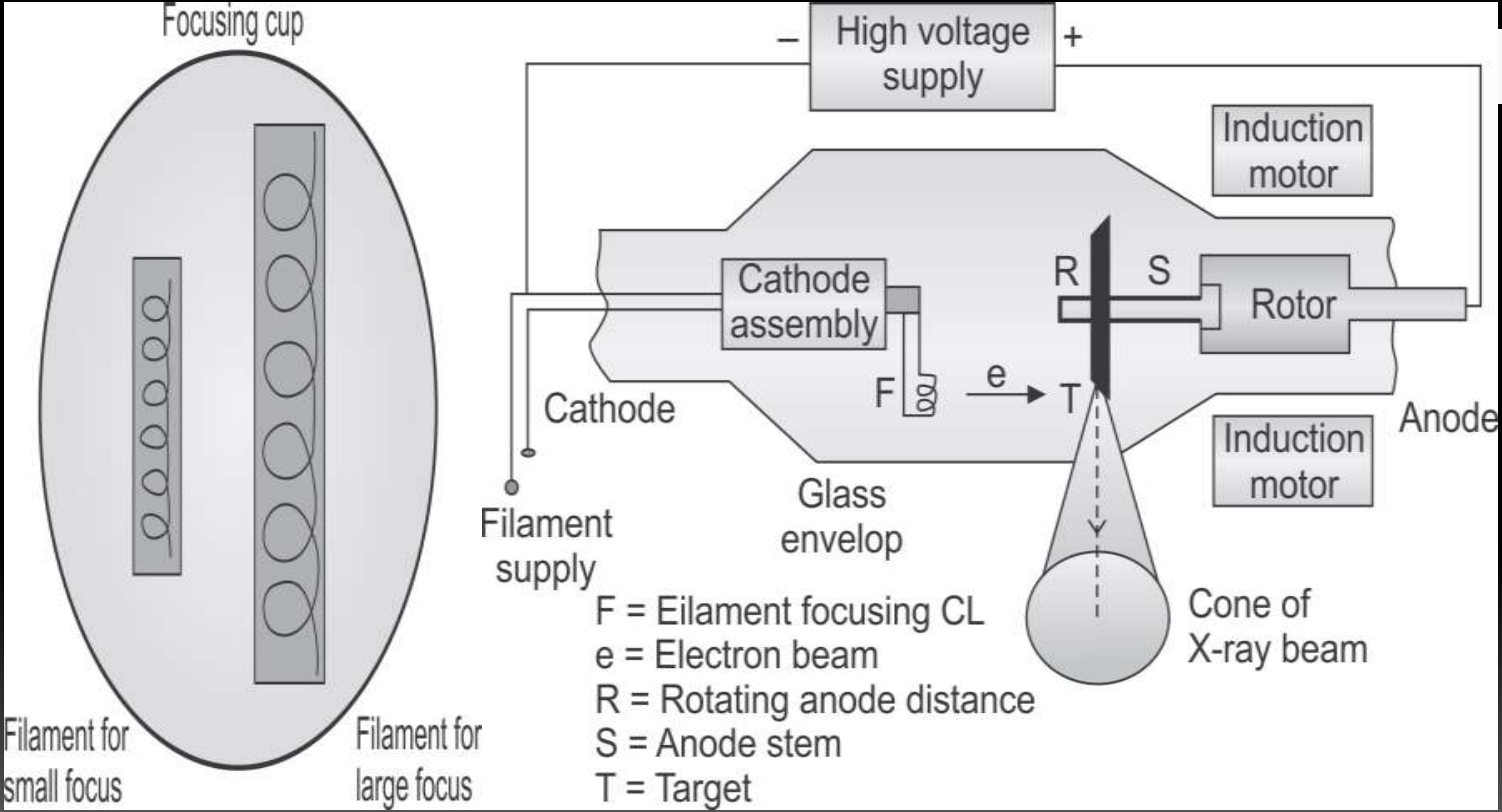
ROTATING ANODE X-RAY TUBE

- **Invention and Purpose:**
  - In 1933, the invention of the rotating anode X-ray tube.
  - Developed to increase heat loading and X-ray output.
- **Similar Principles:** While larger in size, the functioning principle of rotating anode tubes remains similar to stationary X-ray tubes.
- **Principle of Operation:**
  - A rotating anode consists of a radius (R) and circumference (L).
  - Electrons bombard an area of height (ab) and width (cd).
  - The X-rays always appear to originate from a focal spot of area cd × cd.
- **Loading Gain Calculation:**
  - Comparison of stationary and rotating anode focal areas.
  - Example: Stationary anode area 7.3 mm × 2 mm; rotating anode R = 30 mm and length 7.3 mm.
  - Loading gain = $2\pi \times 30 \times 7.3 / (7.3 \times 2) = 94.2$ (approximately).
  - Rotating anode increases loading by a factor of about 100.
- **Technological Advancement:**
  - The diameter of the tungsten disk determines the total length of the target track.
  - Influences the maximum permissible loading of the anode.


R = Radius
L = Perimeter
θ = Anode angle
L
R
a
b
c
d
θ
θ_2
θ_1
Small focus
Large focus
(A) Rotating anode front view
(B) Single focus
(C) Double focus

Cathode

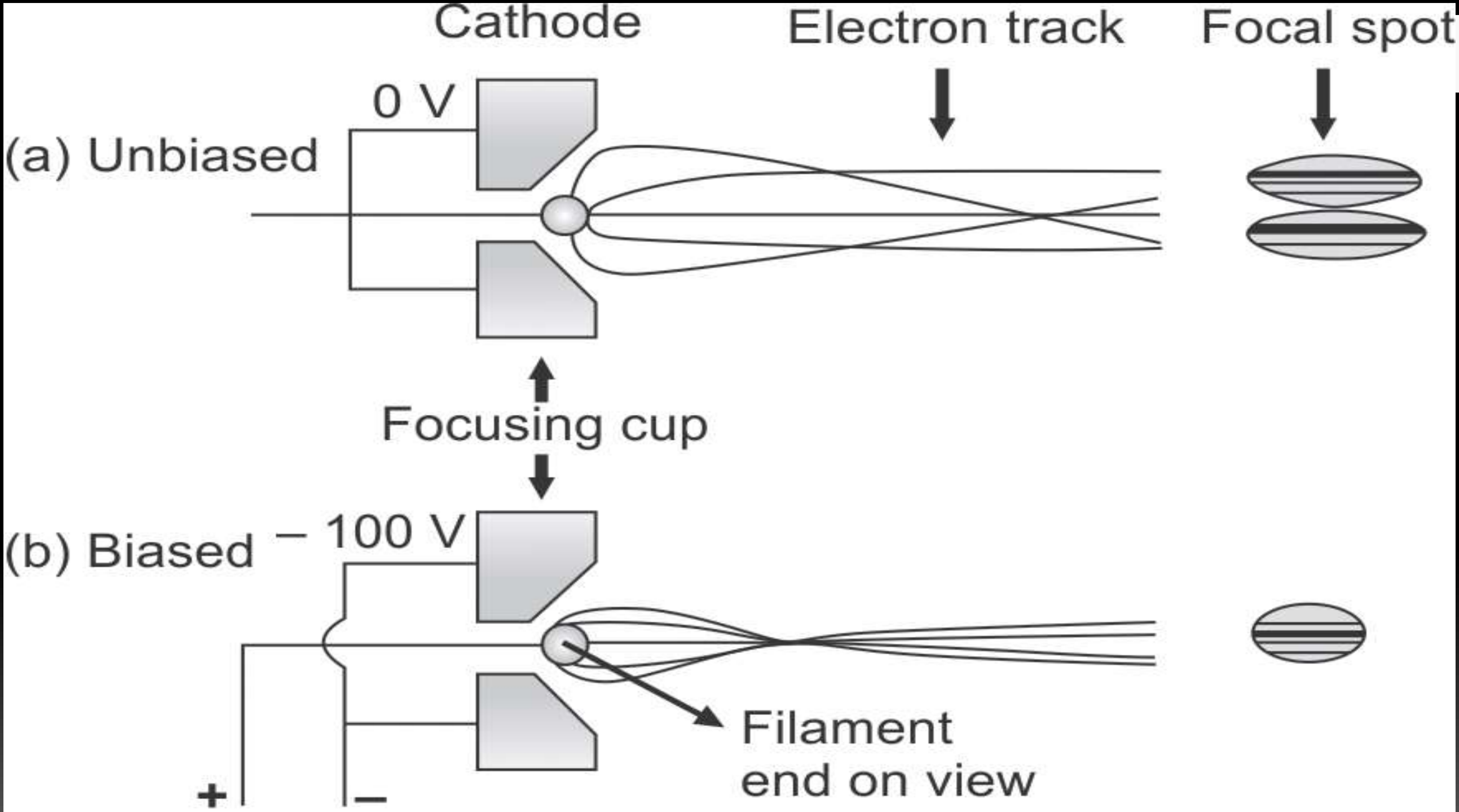
- **Cathode and Anode in a Glass Bulb:**
  - Rotating anode X-ray tube configuration, Components kept within a glass bulb.
- **Cathode:** - Tungsten filament.
  - Offset from the long axis to face the anode target near the periphery of the anode disk.
- **Dual Filaments:**
  - Rotating anode tubes typically equipped with two filaments.
  - One larger and one smaller filament set side by side in the cathode assembly.
  - Larger filament focuses electrons on a larger area of the anode for heavy tube loading.
  - Smaller filament focuses electrons on a smaller target area, suitable for high-resolution imaging.
- **Ensuring Focal Spot Alignment:**
  - Both filaments must focus electrons on the same part of the anode.
  - Maintains the focal spot at the same point for both operational modes.
  - Some tubes offer two target angles for two filaments, allowing each filament to have a separate focal spot.
  - Smaller target angle used with the smaller focal spot for specific applications.



Focusing cup
Filament for small focus
Filament for large focus
High voltage supply
−
+
Induction motor
Induction motor
Cathode assembly
R
S
Rotor
F
e
T
Cathode
Anode
Filament supply
Glass envelop
Cone of X-ray beam
F = Eilament focusing CL
e = Electron beam
R = Rotating anode distance
S = Anode stem
T = Target

Focusing Cup

- **Focusing Cup Function:**
  - The focusing cup, or cathode block, surrounds the filament.
  - Its primary role is to shape the width of the electron beam.
  - The electron beam is focused onto a small area known as the focal spot on the anode.
- **Two Energizing Methods:**
  - Focusing cup energization can be achieved in two ways .
  - **Unbiased Setup:** Applies the same voltage to both the focusing cup and filament.
    - Results in a wider electron spread, leading to a larger focal spot width.
  - **Biased Setup:** Utilizes insulated focusing cups and provides a more negative supply (e.g., -100 V) than the filament.
    - Creates a tighter electric field around the electrons.
    - Reduces electron spread, resulting in a smaller focal spot width.
- **Determinants of Focal Spot Size:**
  - The width of the focusing cup determines the focal spot width.
  - The length of the filament determines the focal spot length.


Cathode
Electron track
Focal spot
0 V
(a) Unbiased
Focusing cup
(b) Biased
− 100 V
Filament
end on view
+
−

Anode

- **Anode Configuration:**
  - The anode is shaped as a large saucer-shaped disk made of tungsten or a tungsten alloy.
  - The target track is positioned near the periphery to maximize its length.
- **Tungsten-Rhenium Alloy:**
  - The target track consists of a mixture of 90% tungsten and 10% rhenium (Z = 75).
  - Reduces the impact of thermal stresses on the anode.
- **Modern Anode Design:**
  - Modern rotating anodes use solid molybdenum as a base onto which a thin tungsten-rhenium focal track is coated.
  - Molybdenum has a higher specific heat capacity (250 J $Kg^{-1}K^{-1}$) compared to tungsten (130 J $Kg^{-1}K^{-1}$).
  - Molybdenum also has a lower mass due to its lower density.
- **Radial Slots and Graphite Layer:**
  - Some high-output X-ray tubes feature radial slots cut into the anode disk to reduce thermal stresses caused by repeated heating and cooling.
  - Heavy-duty X-ray tubes may include a graphite layer (carbon) in the back of the anode disk.
- **Beveled Edge:**
  - The anode disk is beveled at an angle ranging from 6 to 20 degrees.
  - The bevel is essential to achieve the line focus principle.

Anode Stem

- **Anode Disk Mounting:**
  - The anode disk is securely mounted on a stem.
  - This assembly is attached to the rotor.
- **Material of the Stem:**
  - The stem is typically made of molybdenum.
  - Molybdenum offers a high melting point of 2620°C and poor heat conduction.
- **Preventing Heat Flow:**
  - The molybdenum stem is designed to prevent the flow of heat from the tungsten anode disk to the bearings of the anode assembly.
  - This is achieved due to the small cross-sectional area of the molybdenum stem.
- **Protection of Bearings:**
  - By preventing excessive heat, the bearings are safeguarded from expansion and binding.
  - Heat-induced expansion could affect the smooth rotation of the anode assembly.
- **Considerations for Stem Length:**
  - Longer stems increase the inertia of the tungsten disk and place a greater load on the bearings.
  - It is preferable to keep the stem as short as possible to optimize the performance of the rotating anode.

Rotor

- **Anode Disk Connection:** The anode disk is linked to a rotor assembly.
- **Rotor Composition:** -The rotor consists of copper bars encircling a cylindrical iron core.
  - Surrounding the rotor are electromagnets, while the stator is located outside the glass envelope.
  - The combination of stator and rotor is referred to as an induction motor.
- **Principle of Induction Motor:**
  - Energizing the stator coils generates a rotating magnetic field.
  - This magnetic field induces current in the rotor's copper bars.
  - The induced current generates an opposing magnetic field, propelling the rotor to spin.
- **Rotation Speed:**
  - The rotor rotates at a speed ranging from 3000 to 9000 revolutions per minute (rpm).
  - This rotation ensures that electrons bombard a continually changing area of the anode.
- **Heat Dissipation:**
  - The rotor's surface is blackened to enhance heat dissipation via radiation.
  - Rotor support is constructed from steel, and the positive high-tension supply is made outside the glass envelope.
- **Rotor Speed Variation:**
  - Low-speed rotors operate on 60 Hz power (single phase) and rotate at about 3000 rpm.
  - High-speed rotors, functioning with 180 Hz power (3 phase), achieve a speed of 9000 rpm.
  - Increasing the rotation speed spreads the heat generated at the focal point over a larger area

Rotor

Frequency Control:

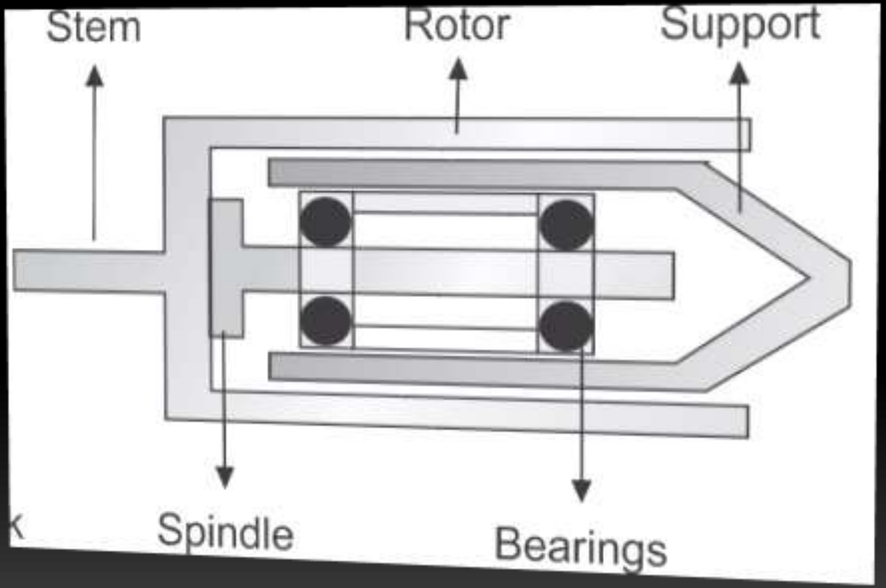
Modern X-ray tubes use higher rotor speeds by increasing stator supply frequency through frequency multiplying circuits.

Safety Mechanism:

X-ray machines are designed to ensure that the tube cannot be energized until the anode reaches its full speed.

A delay time (1–2 seconds) is integrated into the exposure buttons to guarantee safety during operation.

The power supplied to the induction coils generates eddy currents, leading to rotor heating.



Rotating Anode X-Ray Tube - Bearing and Lubrication

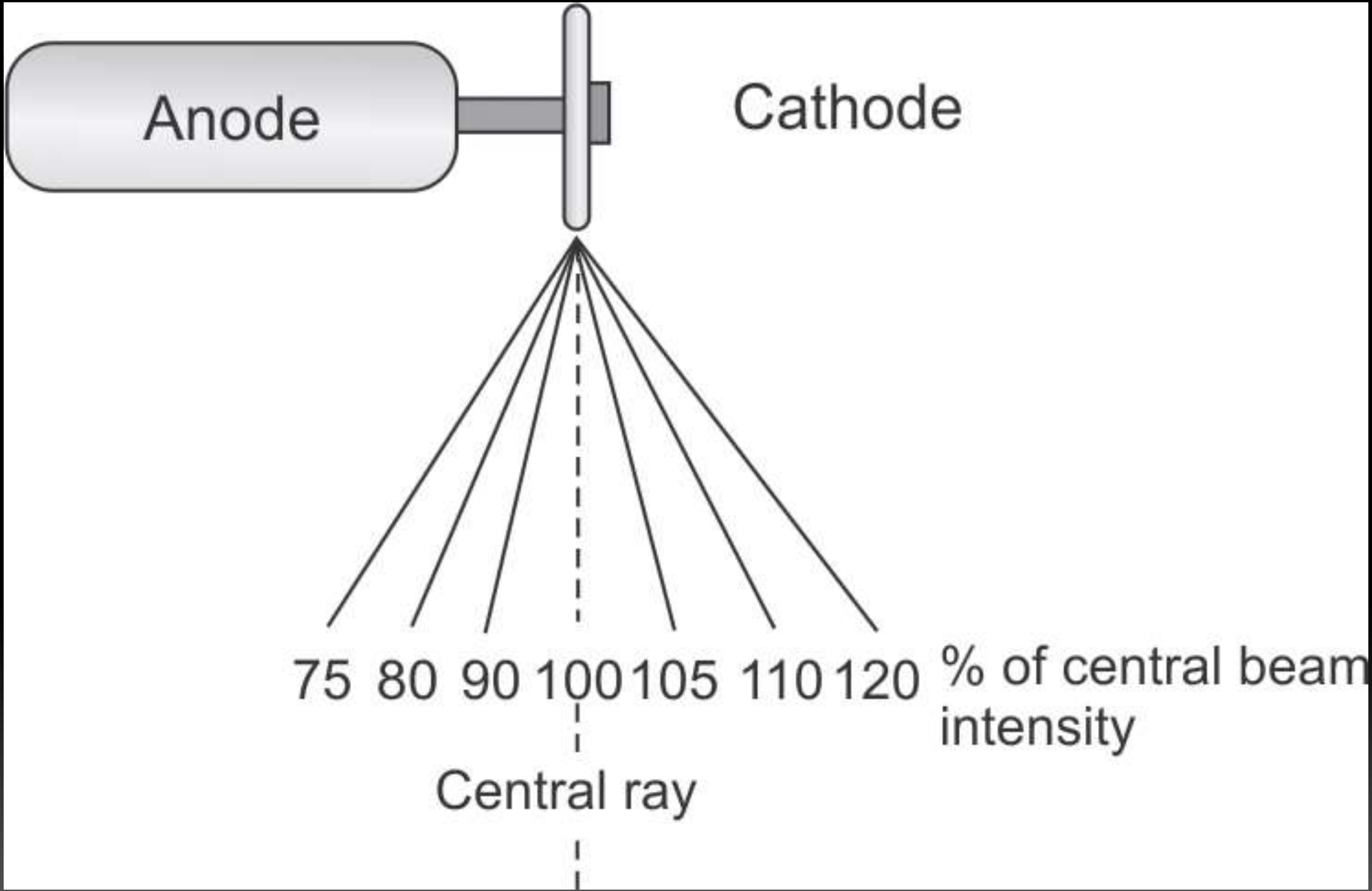
- **Bearings:** Made of steel ball races to support anode rotation in high vacuum.
- **Lubricants:** Coated with heat-resistant, nonvolatile materials like lead or silver due to vacuum conditions. Common lubricants would vaporize or wear off.
- **Operation:** X-ray unit initiates with motor, gradually achieving rotor speed. High voltage is applied for exposure, followed by rapid braking to preserve bearing life.
- **Heat Dissipation:** Heat from tungsten disk is radiated through vacuum to tube walls, then into surrounding oil and housing.
- **Life Limitation:** Continuous electron bombardment leads to anode pitting due to thermal stress, decreasing X-ray output and affecting focal spot size

Grid Controlled X-Ray Tube

- **Electrodes:** Three electrodes - anode, cathode, and focusing cup (grid).
- **Grid Function:** The focusing cup serves as a grid, controlling electron flow from filament to target.
- **Grid Voltage:** Grid is negatively charged relative to the filament, creating an electric field along the electron path, causing electrons to be concentrated.
- **On/Off Switch:** Increasing voltage across the filament-grid acts as a switch to control tube current. Close proximity reduces the required voltage.
- **Applications:** Grid-controlled X-ray tubes are valuable in procedures needing rapid switching and short exposure times, e.g., cine-angiography and pulsed fluoroscopy.

Heel Effect in X-Ray Imaging

- **Definition:** Reduced X-ray beam intensity towards the anode side of the X-ray field.
- **Cause:** X-ray photons on the anode side pass through a greater thickness of the anode compared to those on the cathode side.
- **Factors Influencing Heel Effect:** Anode angle, focus-to-film distance (FFD), and field size.
- **Importance:** More significant at smaller FFD; less significant at larger FFD.
- **Mitigation:** Increase anode angle and decrease field size for a balanced distribution of transmitted X-rays.
- **Patient Positioning:** Position the cathode side of the X-ray tube over thicker parts of the patient and the anode side over thinner parts to minimize the heel effect.


Anode
Cathode
75 80 90 100 105 110 120 % of central beam intensity
Central ray

Off-Focus Radiation in X-Ray Tubes

- **Definition:** X-rays produced when high-speed electrons interact with anode surfaces outside the focal spot area.
- **Main Source:** Scattered electrons at the target, which are accelerated back to the anode.
- **Effects:** Increases patient exposure, geometric blurring, background fog, and degrades image quality.
- **Mitigation:** Using small lead collimators close to the X-ray tube port to limit off-focus radiation.
- **Reducing Off-Focus Radiation:** Grounded anode X-ray tubes and those used in mammography are designed to minimize off-focus radiation.

Tube Housing in X-Ray Tubes

- **Functions:**
  - **Radiation Protection:** Internally shielded with lead to attenuate X-rays emitted in other directions.
  - **Electrical Protection:** Grounded to prevent electrical shock, and insulated sockets are used where high tension cables enter.
  - **Thermal Protection:** Filled with mineral oil, which acts as a cooling medium and expands at higher temperatures.
  - **Physical Protection:** Protects the tube insert from accidental damage caused by knocks and bumps.
- **Construction:** Steel casing lined with lead, and contains a Perspex/beryllium window that is convex upwards to reduce X-ray beam filtration by oil.
- **Safety Features:** Oil expansion activates a bellow-operated microswitch to prevent further tube use. It also prevents air entry into the tube insert.
- **Regulatory Compliance:** Must meet leakage radiation specifications set by authorities like the Atomic Energy Regulatory Board (AERB), ensuring safe operation.

Red Tech

X-ray Filtration

- **Purpose:** Reduce patient dose by removing low energy X-rays that are absorbed in the first few centimeters of tissue.
- **Components:**
  - **Inherent Filtration:** Caused by absorption of X-rays within the X-ray tube and its housing, typically between 0.5 mm and 1.0 mm of aluminum equivalent (Al).
  - **Added Filtration:** Results from absorbers placed in the X-ray beam path, such as aluminum (for low-energy X-rays) and copper (for high-energy radiation). Compound filters may combine these materials, with the high Z layer always facing the X-ray tube.
- **Total Filtration:** The sum of inherent and added filtration.
- **Recommended Filtration:**
  - For diagnostic X-ray units > 100 kVp: 2.5 mm Al.
  - Varies with application, e.g., mammography often uses Be (beryllium) and Mo (molybdenum) or Rh (rhodium) filters to enhance contrast, depending on the target material.
- **Advantages:** Filters significantly reduce patient dose (up to 80%) without affecting the maximum energy of the X-ray beam spectrum.
- **Specialized Filtration:** Heavy metal filters (e.g., Gd and Ho) are used in general radiography to enhance contrast for iodine and barium, reduce patient dose, and increase tube loading. These filters exploit the K-edge for better absorption of X-rays.

SCATTERED RADIATIONS

- **Radiation Types in Imaging**
- **Primary Radiation:** The X-rays directly involved in image formation.
- **Scattered Radiation:** X-rays that change direction after interacting with the patient's body; results in noise and affects contrast resolution.
- **Leakage Radiation:** Not involved in image formation, usually managed by design.
- **Image Quality Factors**
- **Spatial Resolution:** Primarily controlled by focal spot size.
- **Contrast Resolution:** Affected by scatter radiation or noise.
- **Control of Scattered Radiation**
- Scattered radiation contributes to image noise and affects contrast.

SCATTERED RADIATIONS

- Factors influencing scatter radiation:
  - **kVp (Peak Voltage):** Higher kVp increases X-ray energy, promoting Compton interaction and more scatter radiation. Using minimum kVp for the procedure helps reduce scatter.
  - **Field Size:** Larger fields result in more scatter radiation. Smaller fields reduce scatter, but may require higher exposure techniques.
  - **Patient Thickness:** Thicker patients or body parts generate more scatter radiation. Factors like compression can reduce thickness and improve image quality.
- **Optimal Technique Selection**
- Careful selection of kVp and mAs (tube current) balances image quality and patient dose.
- In some cases, using lower kVp can be compensated by increasing mAs.
- Smaller fields and proper techniques help manage scatter radiation.
- Mammography allows control of patient thickness, improving image quality.

BEAM RESTRICTORS OR COLLIMATORS

Classification

- **Aperture Diaphragms:** Simple lead sheet with an adjustable hole; versatile but generates penumbra.
- **Cones and Cylinders:** Metal structures restricting the circular beam; less penumbra but limited field sizes.
- **Collimators:** The most effective beam restrictors; well-defined X-ray fields.

Aperture Diaphragms

- Utilized in dental radiography and other areas with rectangular collimation.
- Adjustable hole determines beam size and shape.
- High penumbra; reduced by increasing the distance from the X-ray target.

Cones and Cylinders

- Reduced penumbra; better than aperture diaphragms.
- Proper alignment essential to prevent "cone cutting."
- Limited field size options.

BEAM RESTRICTORS OR COLLIMATORS

Collimators

- The best beam restrictors, attached to the tube housing.
- Consist of two sets of independently movable lead plate shutters.
- Provide well-defined rectangular X-ray fields.
- Include light and mirror arrangement to illuminate and align the X-ray field.
- Alignment of light beam and X-ray beam is critical.

Benefits of Collimators

- Cover less area of the patient, reducing patient dose.
- Generate less scatter radiation, improving image quality.
- Some collimators are equipped with Positive Beam Limitation (PBL), which automatically adjusts the X-ray field size based on cassette dimensions.
- PBL collimators limit the irradiated volume, reducing patient dose.

Topic MCQs

1. **What is the primary advantage of using a rotating anode X-ray tube compared to a stationary anode tube?**

a) Higher electron current
b) Reduced radiation exposure
c) Increased heat loading capacity
d) Smaller focal spot

Correct answer: **c) Increased heat loading capacity**

2. **What is the purpose of the rotor in a rotating anode X-ray tube?**

a) To focus electrons

b) To rotate the anode disk

c) To generate X-rays

d) To cool the anode

Correct answer **b) To rotate the anode disk**

3. **Which metal is commonly used for the anode disk in a rotating anode X-ray tube's target area?**
a) Copper
b) Aluminum
c) Tungsten
d) Iron

Correct answer: **c) Tungsten**

4. **How is the rotor in a rotating anode X-ray tube typically powered?**

a) By direct electric current (DC)
b) By solar panels
c) Through an induction motor
d) Using a hydraulic system

Correct answer: **c) Through an induction motor**

5. **Why is the surface of the rotor in a rotating anode tube often blackened?**

a) To absorb X-rays

b) To minimize radiation exposure

c) To improve aesthetics

d) To enhance heat dissipation by radiation

Correct answer: **d) To enhance heat dissipation by radiation**

6. **What is the main advantage of using a collimator as an X-ray beam restrictor compared to aperture diaphragms and cones/cylinders?**
a) Collimators have a larger penumbra.
b) Collimators provide a well-defined X-ray field.
c) Collimators require less maintenance.
d) Collimators are cheaper to manufacture.

Correct answer: **b) Collimators provide a well-defined X-ray field.**

7. **Which type of X-ray beam restrictor is commonly used in dental radiography and trauma/chest radiography?**

a) Collimator

b) Aperture diaphragm

c) Cone

d) Cylinder

Correct answer: **b) Aperture diaphragm**

8. **What term describes the undesirable effect where one side of the X-ray film may not be exposed due to misalignment of the X-ray source, cone, and film?**

a) Cone cutting

b) Penumbra effect

c) Scatter effect

d) Collimation error

Correct answer: **a) Cone cutting**

9. **Which type of beam restrictor is ideal for providing a limited number of field sizes with reduced penumbra?**

a) Collimator

b) Aperture diaphragm

c) Cone

d) Cylinder

Correct answer: **c) Cone**

10. **What feature do Positive Beam Limitation (PBL) collimators offer that enhances patient dose management?**

a) Automatically adjust the collimator opening based on cassette dimensions.

b) Reduce the penumbra effect.

c) Increase the X-ray beam intensity.

d) Provide a variety of rectangular X-ray fields.

Correct answer: **a) Automatically adjust the collimator opening based on cassette dimensions.**

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11. Which part of the rotating anode X-ray tube is most prone to damage due to continuous electron bombardment?

a) Rotor
b) Filament
c) Focal spot
d) Anode disk

Correct answer: **d) Anode disk.**

12. The primary reason for cooling systems in rotating anode X-ray tubes is to:
a) Increase tube efficiency
b) Reduce exposure time
c) Prevent tube overheating
d) Control the size of the focal spot

Correct answer: **c) Prevent tube overheating**

13. What is dynamic braking in the context of rotating anode X-ray tubes?

a) A method to increase exposure time

b) A technique to reduce anode rotation speed

c) The process of slowing down the rotor after exposure

d) An advanced cooling mechanism

Correct answer: **c) The process of slowing down the rotor after exposure**

14. In rotating anode X-ray tubes, why is the stem attached to the rotor typically made of molybdenum?
a) To enhance image quality
b) To improve heat conduction
c) To reduce the melting point
d) To prevent heat transfer to the bearings

Correct answer: **d) To prevent heat transfer to the bearings**

15. What are the primary functions of the bearings in a rotating anode X-ray tube?
a) Regulate tube current and voltage
b) Facilitate anode rotation and dissipate heat
c) Generate X-ray photons and reduce heat production
d) Maintain a high vacuum inside the tube

Correct answer: **b) Facilitate anode rotation and dissipate heat**

16. What type of lubricant is commonly used for the bearings in a rotating anode X-ray tube?
a) Oil
b) Grease
c) Graphite
d) Lead

Correct answer: **a) Oil**

17. Why can't common lubricants like oil or grease be used for the bearings in a high-vacuum X-ray tube?
a) They increase heat production
b) They vaporize under heat and destroy the vacuum
c) They lead to anode overheating
d) They reduce image quality

Correct answer: **b) They vaporize under heat and destroy the vacuum**

18. What is the primary function of dynamic braking in a rotating anode X-ray tube?
a) To slow down the rotor after exposure
b) To control tube voltage
c) To generate X-ray photons
d) To reduce the size of the focal spot

Correct answer: **a) To slow down the rotor after exposure**

19. Which material is commonly used for the stem that connects the anode disk to the rotor in a rotating anode X-ray tube?

a) Steel

b) Copper

c) Molybdenum

d) Tungsten

Correct answer: **c) Molybdenum**

20. Which of the following is a key characteristic of stationary anode X-ray tubes?
a) Ability to rotate the anode assembly
b) Long exposure times
c) Low heat capacity
d) High heat loading capacity

Correct answer: **c) Low heat capacity**

21. Stationary anode X-ray tubes are commonly used in:

a) Mammography

b) Radiography of large body parts

c) Dental radiography

d) Fluoroscopy

Correct answer: **c) Dental radiography**

22. In stationary anode X-ray tubes, the anode is typically made of:

a) Tungsten

b) Copper

c) Aluminum

d) Lead

Correct answer: **a) Tungsten**

23. What is the primary disadvantage of using stationary anode X-ray tubes for long exposure times?

a) Reduced patient dose
b) Risk of anode overheating
c) High image quality
d) Minimal heat generation

Correct answer: **b) Risk of anode overheating**

24. In stationary anode X-ray tubes, the focal spot size:
a) Can be easily adjusted
b) Is always large
c) Remains the same during operation
d) Is typically small

Correct answer: **c) Remains the same during operation**

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25. Which component of the rotating anode X-ray tube prevents heat transfer from the anode to the bearings?
a) Focusing cup
b) Filament
c) Stem
d) Rotor

Correct answer: **c) Stem.**

26. What is the primary function of the focusing cup in an X-ray tube?
a) To cool the anode
b) To produce X-ray photons
c) To focus electrons on the anode
d) To reduce patient dose

Correct answer: **c) To focus electrons on the anode**.

27. In an unbiased focusing cup setup, the voltage applied to the focusing cup is:
a) The same as the filament voltage
b) Zero (no voltage)
c) Equal to the tube current
d) Negative relative to the filament

Correct answer: **b) Zero (no voltage)**

28. How does biased focusing cup setup differ from the unbiased setup in X-ray tubes?

a) Biased focusing cup has a higher filament voltage

b) Unbiased focusing cup produces larger focal spot sizes

c) Biased focusing cup is negatively charged relative to the filament

d) Unbiased focusing cup reduces electron acceleration

Correct answer: **c) Biased focusing cup is negatively charged relative to the filament**

29. The beveled edge of the anode disk in a rotating anode X-ray tube is used to:
a) Increase the tube current
b) Enhance image quality
c) Achieve the line focus principle
d) Reduce the tube voltage

Correct answer: **c) Achieve the line focus principle**

30. **What happens when the stator coils of the induction motor in a rotating anode tube are energized?**

a) Electrons are emitted

b) X-rays are produced

c) A rotating magnetic field is generated

d) The rotor heats up

Correct answer: **c) A rotating magnetic field is generated**

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THE PHYSICS OF RADIOLOGY AND IMAGING

4. Generation and Control of X-rays WITH MCQ

Transformer , Rectifier circuit , Filament circuit
Kilovoltage (kV) control circuit
Single-phase X-ray generator ,Three-phase X-ray generator
High-frequency generator, Exposure switching and timers
Quality and intensity of X-rays , Generator rating and heat loading

TRANSFORMER

- Definition: A transformer is an electrical device that converts electrical energy from one coil to another coil.
- Principle: It operates based on mutual induction.
- Components: Transformers consist of two coils - primary and secondary, wound on an iron core.
- Objective: Transfer alternating voltage from the primary to the secondary coil.
- Voltage Application: Alternating voltage is applied to the primary coil, creating a changing magnetic flux in the iron core.
- Induced Voltage: The changing flux induces an alternating electromotive force (emf) in the secondary coil.
- Proportional Turns: The induced emf in the coils is directly proportional to the number of turns (Np and Ns) in each coil

TRANSFORMER

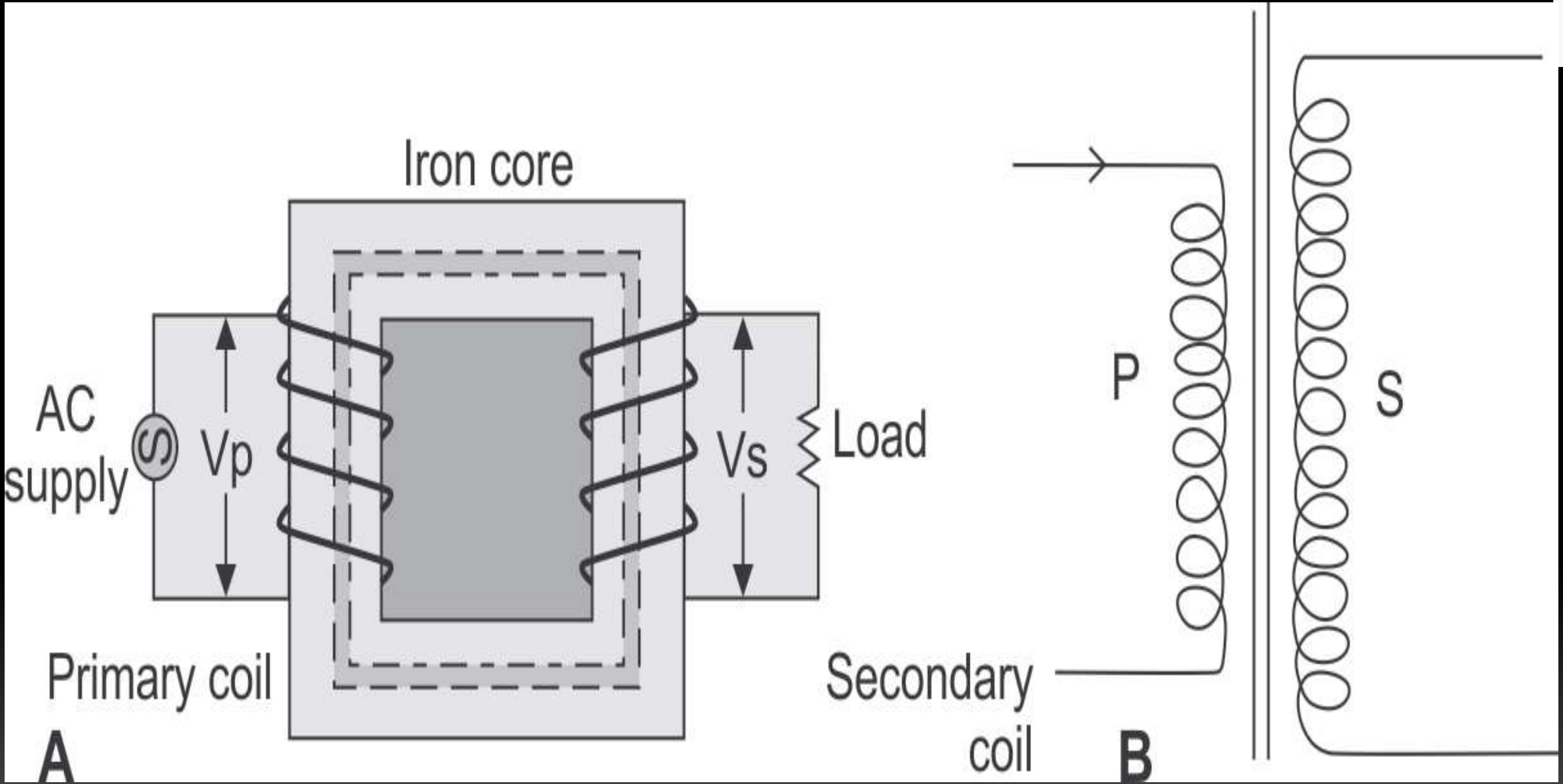
- **Transformer Equations**
- Voltage Relationships: $V_p \propto N_p$ and $V_s \propto N_s$, where V_p and V_s are the primary and secondary coil voltages.
- Turns Ratio: The turns ratio in a transformer is equal to the voltage ratio: $V_p / V_s = N_p / N_s$.
- Power Conservation: The power input in the primary (P_p) is equal to the power output in the secondary (P_s): $V_p \times I_p = V_s \times I_s$.
- Current Relationships: $V_p / I_p = V_s / I_s = N_p / N_s$

Types of Transformers

- Step-Up Transformer: Transfers power from low voltage and high current to high voltage and low current ($N_s > N_p$).
- Step-Down Transformer: Converts power from high voltage and low current to low voltage and high current ($N_s < N_p$).
- Isolation Transformer: When $N_s = N_p$, it provides electrical isolation without voltage transformation.

Summary.

- They rely on mutual induction, utilizing two coils on an iron core.
- Voltage and current relationships in transformers are determined by the turns ratio.
- Transformers come in three main types: step-up, step-down, and isolation transformers.


Iron core
AC supply
Vp
Vs
Load
Primary coil
A
P
S
Secondary coil
B

Transformer Efficiency and Rating

- Transformer Efficiency
  - Efficiency is the ratio of output power to input power. Efficiency = Ps / Pp × 100

Transformer Efficiency :- Efficiency is always less than 100%.

- Due to energy losses, actual output power is less than input power. Efficiency < 100%

Transformer Rating :- The maximum safe output that the secondary winding can provide.

- Rating Specifications :- Highest voltage provided, Maximum continuous current, Maximum current for a brief period (not exceeding one second)
- Slide 4: Transformer Rating Calculation
- Formula for Three-Phase Generators
  - kW = (kV × mA) ÷ 1000, Example: 100 kV and 500 mA → 50 kW rating
- Formula for Single-Phase Generators
  - kW = (kV × mA × 0.7) ÷ 1000 , The factor 0.7 accounts for the rms value of voltage.
- Kilowatt ratings of X-ray generators are determined under load.

Ratings help compare X-ray generators.

Transformer Losses

- Efficiency of a transformer is always less than 100%.
- Energy loss occurs in the form of heat.
- Main loss components:
  - Copper Losses
  - Eddy Current Losses
  - Hysteresis Losses
  - Flux Leakage
- **Copper Losses**
- Occur due to resistance in the copper coils.
- Power loss is I^2Rt, leading to heat generation.
- Reducing resistance by using low-resistivity materials and thicker wires is essential.
- Copper is commonly used due to its favorable properties

Transformer Losses

- **Eddy Current Losses**
- Iron core acts as a coil and induces eddy currents when the magnetic field changes.
- Eddy currents cause I^2Rt heat losses.
- Mitigation through the use of laminated cores made of thin metal sheets insulated with paper.
- Alternative core materials like stelloy or high-resistance ceramics can be employed.
- **Hysteresis Losses**
- Occur when the magnetic core is magnetized and demagnetized during each AC cycle.
- Energy lost due to molecular friction appears as heat.
- Reduction by selecting magnetic materials with low hysteresis loss, like mu-metal.
- Mu-metal is a ferromagnetic alloy with low hysteresis loss, containing 78% nickel, 17% iron, and 5% copper.
- **Flux Leakage**
- Not all magnetic flux linked with the primary coil is linked with the secondary coil.
- Results in energy loss.
- Minimized through good core design, such as the shell-type core.

High-Tension Transformer

- **High-Tension Transformer :-** Used to convert low voltage to high voltage for X-ray tube operation.
  - Generates voltages from 20–150 kV and current up to 1000 mA.
- Transformer Design
- Step-up transformer with two windings and a shell-type core.
- Secondary winding has more turns than the primary, determined by voltage ratio.
- Primary winding consists of a few hundred turns of thick, insulated copper wire.
- A stress shield (thin copper sheet) is fitted over the primary winding to protect it during secondary insulation breakdowns.
- **Secondary Winding** :- Secondary winding comprises around 100,000 or more turns of thin copper wire with insulating varnish.
- Layers separated by insulating paper with wax, reducing the risk of insulation breakdowns.

High-Tension Transformer

- Core Design:- Rectangular-shaped core is well laminated and earthed.
- Secondary winding is divided into two equal multiple parts, reducing insulation requirements, size, and cost
- **Current Measurement**:- Current is accurately measured on the secondary side.
- A milliampere meter (mA meter) is connected between the inner ends of the two secondary windings at the center of the coil.
- This minimizes the risk of electrical shock to the operator.
- Immersion in Oil or Plastic:- The entire transformer unit is immersed in an earthed metal tank filled with oil.
- Dental and mobile X-rays use plastic as an insulator due to lower heat production.
- Plastic transforms from a fluid state to a solid insulator as it solidifies.
- High-tension transformers are integral components in X-ray systems, enabling the generation of the high voltages necessary for imaging

Rectification in X-ray Systems

- - Rectification: The process of converting alternating current (AC) into direct current (DC).
- - Device responsible for this transformation is called a rectifier.
- - Critical for X-ray production to avoid back projection.
- Role of Rectifiers :- Rectifiers allow current to flow in one direction only.
- - Prevent back projection by supplying rectified DC voltage to the X-ray tube.
- - Integral components in X-ray circuits.

- **Types of Rectifiers**
- - Two main types: half-wave and full-wave rectifiers.

  Half-Wave Rectifier:- Single diode used for rectification.
- - Alternating voltage applied to the diode as input.
- - Output obtained across resistance R.
- - Diode permits current flow only during positive half-cycles.
- - Mainly used in mobile and dental X-ray units.
- - Multiple diodes may be used in series for higher voltages.

- **Full-Wave Rectifier** :- Utilizes multiple diodes or a bridge rectifier circuit.
- - Allows current flow in one direction during both halves of the AC cycle.
- - Provides a more continuous and smoother DC output.
- - Commonly used in medical X-ray machines.

Full-Wave Rectifier and Thyristor in X-ray Systems

- Full-Wave Rectifier:- Overcomes limitations of the half-wave rectifier.
- - Utilizes two or more diodes to utilize the entire input cycle.
- - Thyristor
- - A silicon-controlled rectifier with four-layer semiconductors (n-p-n-p).
- - Used for switching larger currents, handling what transistors cannot.

- S Full-Wave Rectifier
- - Input voltage in half-wave rectifier uses only one half of the cycle.
- - Full-wave rectifier uses multiple diodes to maximize input usage.
- - Current flows through resistance R during the entire input cycle.
- - Produces X-rays in two pulses per cycle, regardless of transformer polarity.
- - Common in high-end X-ray systems with rotating anode X-ray tubes.

Full-Wave Rectifier and Thyristor in X-ray Systems

- Thyristor Configuration
- - Anode and cathode: Main terminals for circuit connection.
- - Gate: Smaller third terminal for control.
- - Off State
- - Junctions J1 and J3 are forward biased, J2 is reverse biased.
- - Minimal current flows, and the thyristor is in the OFF state.
- Activation
- - Applying a positive voltage to the gate terminal allows holes to flow through J3, breaking down the barrier at J2.
- - Electron movement across J2 junction enables the thyristor to turn ON.
- - Continuous Conduction
- - Conduction continues even after the gate voltage is removed.
- - Ceases when the potential difference across anode and cathode drops to zero.
- - Thyristor conducts current in only one direction, suitable for switching alternating current.

- Full-wave rectifiers enhance efficiency in X-ray systems.
- - Thyristors play a critical role in managing large currents and controlling current direction.
- - Both components are integral in advanced X-ray technology.

Exposure Switching and Timers in X-ray Systems

- ***Exposure Switching***
  - Process of rapidly turning X-ray tube voltage on and off.
  - Crucial for preventing equipment damage.
- Two Categories of Switching
  - Switching in the primary circuit of the high voltage transformer.
- Switching in the secondary circuit.
- ***Switching in Primary Circuit***
- Single-phase low-power X-ray generators use mechanical contactors.
- Contactors controlled by a timer-activated electrical circuit.
- Limited accuracy and unsuitable for short exposures (< 8 msec).

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Exposure Switching and Timers in X-ray Systems

- Switching in Secondary Circuit
- Three-phase and constant potential X-ray generators use triode or tetrode switches.
- Electronic or phototimers provide accuracy of 1 msec or better.
- High-frequency generators use electronic timers with 2 msec accuracy.
- Grid-controlled X-ray tubes can be used to switch exposure in any generator.
- ***Exposure Timers***
- Control the duration of an X-ray exposure.
- Two Types:
  - Electronic Timers
  - Phototimers (Automatic Exposure Control)

Exposure Switching and Timers in X-ray Systems

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Exposure Switching and Timers in X-ray Systems

- ***Electronic Timers***
- Exposure duration determined by charging a capacitor through resistance.
- Exposure terminates when the capacitor reaches a specified value.
- Can control exposures accurately from < 1 ms to > 1 s.
- Digital timers offer microsecond accuracy with good reproducibility.
- ***Phototimers (Automatic Exposure Control)***
- Exposure terminates when the X-ray receptor receives a preselected amount of radiation.
- Uses radiation detectors, amplifier, density selector, comparator circuit, termination circuit, and a backup timer.
- Calibration ensures matching film speed to the phototimer signal.
- Provides multiple settings for adjusting X-ray exposure.
- ***Benefits of Phototimers*** :- Common in modern X-ray systems.
- Eliminate human error, ensuring consistent and precise exposure control.

Quality of X-Rays

- Quality reflects the penetrating power of X-ray radiation.
- For heterogeneous X-ray beams, quality is specified using parameters like:
  - Half-Value Layer (HVL)
  - Applied Voltage (kV)
  - Filtration
  - Effective Photon Energy

Quality of X-Rays

- ***Half-Value Layer (HVL)***
- HVL is the material thickness that reduces radiation intensity to half.
- It's reported alongside applied voltage and filtration.
- Commonly specified with aluminum or copper.

- ***Intensity of X-Rays***
- Intensity measures the quantity of radiation.
- It's the energy flowing through a unit area in a unit of time.
- Typically measured in roentgens per minute (R/min).

Factors Affecting Quality and Intensity

- Seven key factors influencing X-ray production:
  - Applied Voltage (kVp)
  - Tube Current (mA)
  - Filtration
  - Target Material
  - Exposure Time
  - Generator Waveform
  - Distance

Quality of X-Rays

- ***Applied Voltage (kVp)***
- Influences both quality and intensity.
- Higher kVp increases effective photon energy and intensity.
- X-ray production efficiency relates to applied voltage.
- Intensity increases as the square of the kilovoltage (Radiation exposure ∝ (kVp)^2).
- ***Tube Current (mA) :-*** Directly affects intensity but not quality.
- Higher tube current results in more X-rays.
- Intensity is proportional to the tube current (Intensity ∝ mA).
- ***Filtration***
- Filters (e.g., Al, Cu, Mo) selectively remove low-energy photons from the X-ray spectrum.
- Filters reduce patient skin exposure and affect both quality and quantity.
- Filtered beams are "hardened," with higher average photon energy.

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Factors Affecting X-ray Intensity and Quality

- ***Target Material (Z)***
- The atomic number (Z) of the target material impacts X-ray intensity.
- Higher atomic numbers result in increased X-ray production efficiency.
- Target material's atomic number influences the quality of characteristic X-rays.
- ***Exposure Time***
- Exposure time determines the duration of X-ray production.
- Total X-ray quantity is proportional to tube current and exposure time (mAs).
- ***Generator Waveform***
- The generator waveform (single-phase, 3-phase, or constant potential) affects X-ray spectrum quality.
- Different generators provide varying average applied voltage potential differences.

Factors Affecting X-ray Intensity and Quality

- ***Distance***
- X-ray beam intensity decreases with distance due to beam divergence.
- The inverse square law describes the nonlinear fall-off in intensity with distance.
- Doubling the distance from the X-ray source reduces intensity by a factor of 4.
- **Intensity Formula**
- Intensity (I) of X-ray radiation is given by the formula: I kVp^2 × mAs × Z / d^2
- kVp: Applied voltage, mAs: Tube current, Z: Atomic number of target material, d: Distance
- Key Takeaways
- Atomic number (Z) influences X-ray intensity and quality.
- Exposure time affects the total quantity of X-rays produced.
- Generator waveform impacts the X-ray spectrum.
- Distance from the source follows the inverse square law for intensity reduction.
- Formula: I kVp^2 × mAs × Z / d^2

Generator Rating and Heat Loading

- X-ray tube must be used within its specified application limits.
- Considerations for proper loading:
  - Focal spot loading: Avoid exceeding power input limits.
  - Anode loading: Prevent excessive consecutive exposures.
  - Housing: Ensure it can dissipate heat effectively.
- Overloading consequences:
  - Excessive heat production.
  - Evaporation of target surface layers, mainly tungsten.
  - Tungsten deposition inside the glass tube:
    - Increases inherent filtration.
    - Reduces tube output.
  - May lead to irregular conduction paths.
  - Results in electrical instability and breakdown.

Topic MCQs

1. Which factor primarily affects the intensity of X-rays?

a. Atomic number (Z) of the target material
b. Exposure time
c. Generator waveform
d. Distance from the X-ray source

Correct answer: **b. Exposure time**

2. What is the impact of higher atomic numbers (Z) of the target material on X-ray production?

a. It decreases X-ray intensity.
b. It has no effect on X-ray quality.
c. It increases X-ray production efficiency and intensity.
d. It reduces the duration of X-ray exposure.

Correct answer **c. It increases X-ray production efficiency and intensity.**

3. Exposure time in X-ray production is directly proportional to:

a. The atomic number (Z) of the target material. b.
b. The generator waveform.
c. The tube current (mA).
d. The distance from the target.

Correct answer: **c. The tube current (mA).**

4. How does the generator waveform affect the quality of the X-ray spectrum?

a. It has no impact on the X-ray spectrum quality.
b. Different generators provide the same X-ray spectrum quality.
c. The waveform affects the average applied voltage potential difference, influencing spectrum quality.
d. The waveform only influences X-ray intensity.

Correct answer: **c. The waveform affects the average applied voltage potential difference, influencing spectrum quality.**

5. According to the inverse square law, if the distance from the X-ray source is doubled, how does the X-ray beam intensity change?

a. It remains the same.

b. It is reduced by a factor of 2.

c. It is reduced by a factor of 3.

d. It is reduced by a factor of 4.

Correct answer: **d. It is reduced by a factor of 4.**

6. In the formula I = kVp^2 * mAs * Z / d^2, what does 'd' represent?

a. The atomic number of the target material
b. Exposure time
c. Distance between the target and the point of measurement
d. Generator waveform

Correct answer: **c. Distance between the target and the point of measurement**

7. What does the term "quality" refer to in the context of X-rays?

a. Quantity of X-rays
b. Penetrating power of the radiation
c. Energy of each X-ray photon
d. Number of X-ray photons per minute

Correct answer: **b. Penetrating power of the radiation**

8. How is the quality of an X-ray beam typically specified?
a. By the number of photons in the beam
b. By the energy of each X-ray photon
c. By the half-value layer, applied voltage, filtration, and effective photon energy
d. By the X-ray tube current (mA)

Correct answer: **c. By the half-value layer, applied voltage, filtration, and effective photon energy**

9. What is the half-value layer (HVL) of a radiation beam?

a. The thickness of the X-ray tube

b. The thickness of the patient's body

c. The required thickness of a material to reduce the beam intensity to one half

d. The number of X-ray photons per unit area

Correct answer: **c. The required thickness of a material to reduce the beam intensity to one half**

10. In the context of X-rays, what is "intensity"?

a. The energy of each X-ray photon
b. The number of X-ray photons per minute
c. The half-value layer
d. The penetration power of the radiation

Correct answer: **b. The number of X-ray photons per minute**

11. Which of the following factors affects both the quality and intensity of X-rays?

a. Tube current (mA)

b. Applied voltage (kVp)

c. Filtration

d. Exposure time

Correct answer: **b. Applied voltage (kVp)**

12. What is the primary effect of increasing the tube current (mA) in X-ray production?

a. Increase in X-ray quality
b. Increase in X-ray penetration power
c. Increase in the number of X-ray photons produced
d. Increase in the half-value layer (HVL)

Correct answer: **c. Increase in the number of X-ray photons produced**

13. How does filtration affect X-ray beams?

a. It reduces X-ray quality and increases quantity.

b. It selectively removes low-energy photons, increasing both quality and quantity.

c. It reduces X-ray intensity without affecting quality.

d. It has no impact on X-ray beams.

Correct answer **b. It selectively removes low-energy photons, increasing both quality and quantity.**

14. Which factor is used to measure the quantity of radiation in X-ray beams?

a. Half-value layer (HVL)
b. Filtration
c. Tube current (mA)
d. Applied voltage (kVp)

Correct answer: **c. Tube current (mA)**

15. In a half wave rectifier, what happens during one half of the input voltage cycle?

a. It is completely blocked, and no current flows.
b. Only one diode conducts, allowing current to flow.
c. Both diodes conduct, providing a continuous current flow.
d. The diodes alternate in conduction, producing two separate current pulses.

Correct answer: **b. Only one diode conducts, allowing current to flow.**

16. Why is a full wave rectifier used in high-end X-ray tubes, especially those with rotating anodes?
a. Full wave rectifiers are cheaper to manufacture.
b. They provide a more continuous and efficient X-ray output.
c. Full wave rectifiers are better for mobile X-ray units.
d. Full wave rectifiers generate less heat.

Correct answer: **b. They provide a more continuous and efficient X-ray output.**

Red Tech

17. What is a thyristor primarily used for in X-ray technology?

a. Switching larger currents that transistors cannot handle.
b. Generating X-rays in rotating anode X-ray tubes.
c. Controlling exposure time in X-ray units.
d. Modulating X-ray quality.

Correct answer: **a. Switching larger currents that transistors cannot handle.**

18. what kind of current can a thyristor switch?

a. Alternating current (AC) only.
b. Direct current (DC) only.
c. Both AC and DC.
d. Pulsed current.

Correct answer: **a. Alternating current (AC) only.**

19. What is the basic principle on which a transformer operates?

a) Electromagnetism
b) Induction
c) Conduction
d) Insulation

Correct answer: **b) Induction**

20. Which type of transformer transfers power from low voltage and high current to high voltage and low current?

a) Step-Down Transformer
b) Isolation Transformer
c) Step-Up Transformer
d) Conversion Transformer

Correct answer: **c) Step-Up Transformer**

21. What is the primary function of an isolation transformer?

a) Step-up voltage
b) b) Step-down voltage
c) Electrical isolation
d) Increase current

Correct answer: **c) Electrical isolation**

22. In a step-down transformer, what relationship holds true between the number of turns in the primary and secondary coils?

a) Np = Ns
b) Np > Ns
c) Np < Ns
d) It varies based on the transformer type

Correct answer: **b) Np > Ns**

23. What is the primary purpose of a step-down transformer in a household electrical system?

a) Increase voltage for transmission
b) Step down high voltage to a safe level for household use
c) Isolate circuits
d) Convert DC to AC

Correct answer: **b) Step down high voltage to a safe level for household use**

24. If the secondary coil of a transformer has 500 turns and the primary coil has 250 turns, what is the turns ratio?

a) 2
b) 0.5
c) 1
d) 0.25

Correct answer: **a) 2**

25. What are the primary sources of energy loss in a transformer used in X-ray machines?

a. Copper losses, eddy current losses, hysteresis losses, and flux leakage losses
b. Voltage losses, impedance losses, resistance losses, and core losses
c. Primary losses and secondary losses
d. Radiative losses and conductive losses

Correct answer: **a. Copper losses, eddy current losses, hysteresis losses, and flux leakage losses**

26. How can copper losses in a transformer be minimized?

a. By reducing the core thickness
b. By increasing the number of secondary turns
c. By using thinner wires for the coil
d. By using thicker wire with low resistivity for the coil

Correct answer: **d. By using thicker wire with low resistivity for the coil**

27. What is the purpose of using laminated cores in transformers?

a. To increase the size of the transformer
b. To reduce eddy current losses
c. To enhance hysteresis losses
d. To improve the resistance of the coil

Correct answer: **b. To reduce eddy current losses**

28. What type of alloy, containing nickel, iron, and copper, is commonly used to reduce hysteresis losses in transformer cores?

a. Stainless steel
b. Mu-metal
c. Aluminum
d. Stelloy

Correct answer: **b. Mu-metal**

29. What does the flux leakage refer to in a transformer?

a. Loss of energy due to poor insulation
b. Wasted magnetic field produced by the core
c. Inefficiency of transformer cooling
d. Loss of energy due to overloading

Correct answer: **b. Wasted magnetic field produced by the core**

30. How is the intensity of an X-ray beam affected by the distance from the X-ray source?

a. It decreases linearly with distance.
b. It remains constant regardless of the distance.
c. It decreases proportionally to the square of the distance
d. It increases with distance.

Correct answer: **c. It decreases proportionally to the square of the distance.**

RED TECH OFFICIAL FOR RADIOGRAPHER

THE PHYSICS OF RADIOLOGY AND IMAGING

5. Radiation Units and Interactions with Medium **WITH MCQ**

Radiation units: Activity ,Exposure-roentgen, Absorbed dose-Gray/Rad
RBE, Equivalent dose and effective dose Radiation interaction with matter
Attenuation, Coherent or Rayleigh scattering,
Compton scattering, Photoelectric effect ,Pair production
Relative importance of attenuation process

Radiation Units

- **Purpose:** Radiation units express physical entities numerically for comparison.
- **Quantification:** It involves measurable physical effects; for example, heat is quantified by expansion in materials, relying on a linear relationship between quantity and effect.
- **Radiological Physics:** Quantities of interest include (i) nuclear disintegrations, (ii) ionizing photons, (iii) energy transfer, (iv) energy absorption, and (v) biological effectiveness.
- **ICRU Units (1981):** Standardized units based on SI units ensure consistency in radiological measurements.
- **Fluence and Flux:**
  - **Fluence (Φ):** Measures photons passing through a unit area (cm^2).
  - **Flux:** Rates of photon passage per sec (cm^2/s).
  - **Energy Fluence (Ψ):** Measures energy passing through a unit area (J/m^2).

Activity

- It's the count of unstable nuclei regaining stability through radio-disintegration, directly correlating with the radiation release quantity.
- Radiation units are fundamental for precise and standardized radiological measurements, ensuring safety and effectiveness in radiation physics applications.
- **Curie (Ci):** Measures disintegration rate; 1 Ci = 3.7 x 10^10 disintegrations per second (dps) from 1 gram of radium (Ra-226).
- **Subunits:** Smaller units are also used, such as 1 mCi = 3.7 x 10^7 dps and 1 μCi = 3.7 x 10^4 dps.
- **Becquerel (Bq):** The SI unit, equal to 1 dps. Mega Becquerel (MBq) and giga Becquerel (GBq) are practical units; 1 MBq = 10^6 Bq and 1 GBq = 10^9 Bq.
- **Relation:** 1 mCi = 37 MBq is a useful conversion.
- **Activity vs. Dose:** Activity measures nuclear emissions and lacks practical applications in diagnostic radiology. For dose assessment, exposure and absorbed dose are defined.

Exposure - Roentgen (R)

- **Definition:** Exposure represents the quantity of ionizing photons in a field, measured in terms of ionization in air around a point. It is source-related.
- **Measurement Basis:** Ionizing photons are quantified based on the total charge they produce in a given medium, with air commonly used as the universal medium.
- **Minimum Ionization Energy:** Approximately 34 eV of energy is required for photons to produce ionization in air.
- **Unit:** The unit of exposure is the Roentgen (R), defined as the quantity of X or gamma radiation that, when associated with corpuscular emission, produces ions carrying 1 electrostatic unit of electricity in 0.001293 grams of air (1 cc of dry air at STP).
- **Temperature and Pressure Corrections:** Open-air chambers require adjustments for temperature and pressure variations that can alter the number of air molecules present.

Exposure - Roentgen (R)

- **SI Unit:** In the SI unit system, exposure is defined as the amount of photons that produce one coulomb of charge in one kilogram of air, denoted as 1 coulomb/kilogram in air (C/kg). The Roentgen unit can be related to the SI unit as $1\ R = 2.58 \times 10^{-4}$ C/kg in air.
- **Submultiples:** Common submultiples used are 1 milliroentgen (mR) and 1 microroentgen (μR).
- **Practical Use:** Radiation monitors are calibrated in Roentgen and milliroentgen (mR), commonly used for measuring the output of X-ray machines.
- **Limitations:** The Roentgen is not a unit of dose (absorbed energy) and is suitable for photon energies up to 3 MeV. It is specifically defined for X and gamma radiations in air.

Kerma - Kinetic Energy Released in the Medium

- **Kerma Definition:** Kerma stands for Kinetic Energy Released in the Medium. It describes the initial interaction of photons with atoms in a medium. X and gamma rays transfer kinetic energy to charged particles (electrons and protons) in the process.
- **Measurement:** Kerma (K) quantifies the kinetic energy transferred to charged ionizing particles by photons in a material of unit mass. It is measured in joules per kilogram (J/kg), with the SI unit being gray (Gy) and the special unit being rad.
- **Air Kerma:** When the reference material is air, it's referred to as "air kerma."
- **Calculation:** Kerma for X and gamma rays can be calculated using the mass energy transfer coefficient (μtr/ρo) of the material and the energy fluence (ψ). The mass energy transfer coefficient accounts for the fraction of photon energy transferred as kinetic energy to charged particles.

Kerma - Kinetic Energy Released in the Medium

- **Factors:** The ratio of the mass energy transfer coefficient to the mass attenuation coefficient decreases with increasing photon energy due to increased Compton scattering. For example, it's 0.68 for 20 keV photons in tissue but decreases to 0.18 at 50 keV.
- **Formula:** Kerma (K) is calculated using the formula: $K = \psi(\mu tr/\rho o)E$, where ψ is the energy fluence and $(\mu tr/\rho o)E$ is the mass energy transfer coefficient at energy E.
- Kerma is a fundamental concept in understanding the initial energy deposition of X and gamma rays in a medium, crucial in radiation physics and dosimetry.

Absorbed Dose - Gray (Gy) / Rad (r)

- **Definition:** Absorbed dose (D) represents the amount of energy absorbed per unit mass of a substance due to radiation exposure. It accounts for the energy transfer from radiation to the medium, including bremsstrahlung losses.
- **Units:** The traditional unit for absorbed dose is the rad (r), where 1 rad = 100 ergs/gram. The SI unit is the gray (Gy), equal to 1 joule per kilogram (1 J/kg).
- **Relationship:** 1 Gy = 100 rads, 1 mGy = 100 mrad, and 1 µGy = 100 µrad.
- **Biological Relevance:** Absorbed dose measures the energy delivered in the medium and is suitable for describing biological effects. It is used in radiotherapy to quantify the radiation dose to patients.
- **Calculation:** Absorbed dose is determined as the difference between kerma and bremsstrahlung loss, representing the true energy absorbed in the medium.

- **Mass Energy Absorption Coefficient:** The true absorbed dose is related to the mass energy absorption coefficient (µen/ρo) of the medium. This coefficient accounts for the energy transfer and is always less than the mass energy transfer coefficient. However, in diagnostic X-ray energies with low Z materials, they are nearly equal due to minimal bremsstrahlung loss.
- Absorbed dose units, gray and rad, are fundamental for quantifying the energy deposition in a medium and are essential in radiation therapy and radiological dosimetry.

Relative Biological Effectiveness (RBE)

- **Definition:** RBE measures the effectiveness of different radiations in producing biological effects. It's defined as the dose of 250 kVp X-rays required to achieve a specific effect divided by the dose of reference radiation needed for the same effect.
- **Effects:** RBE assessment considers various endpoints like chromosomal mutation, cataract formation, and acute lethality, among others.
- **Dependence on LET:** RBE depends on the linear energy transfer (LET) of the radiation in the medium. LET describes the average energy deposition per unit path length of the incident radiation and is expressed in keV/μm.
- **Dependence on Dose and Dose Rate:** RBE values also depend on the total dose and dose rate of the radiation.
- **Typical RBE Values:**
  - X-rays, γ-rays, electrons: 1
  - Thermal neutrons: 5
  - Fast neutrons, protons: 10
  - Heavy particles: 20

Topic MCQs

1: What is the primary purpose of radiation units?

A. To generate heat in materials.
B. B. To quantify physical entities and enable numerical comparisons.
C. To measure radioactivity in the environment.
D. To determine the temperature of radiation sources.

Correct answer: B. To quantify physical entities and enable numerical comparisons.

2. In radiological physics, what is the key parameter used to express quantities of interest?

A. The color of the radiation source.
B. The rate of nuclear disintegrations per unit time.
C. The pressure exerted by ionizing photons.
D. The speed of radiation particles.

Correct answer B. The rate of nuclear disintegrations per unit time.

3. Which organization introduced standardized radiation units based on the International System of Units (SI) in 1981?

A. WHO (World Health Organization)
B. IAEA (International Atomic Energy Agency)
C. FDA (Food and Drug Administration)
D. ICRU (International Commission on Radiation Units and Measurements)

Correct answer: D. ICRU (International Commission on Radiation Units and Measurements)

4. What does the term "fluence" (Φ) measure?

A. The temperature of a radiation source.
B. The number of photons passing through a unit area.
C. The rate of radiation emissions.
D. The energy absorbed in a material.

Correct answer: B. The number of photons passing through a unit area.

5. What is the SI unit for absorbed dose?

A. Rad
B. Becquerel (Bq)
C. Gray (Gy)
D. Roentgen (R)

Correct answer: C. Gray (Gy)

6. What does RBE stand for, and what does it measure?

A. Radiation Biological Exposure; measures the exposure to different radiation types.
B. Relative Biological Effectiveness; measures the effectiveness of different radiations in producing biological effects.
C. Radiation Biological Efficiency; measures the efficiency of radiation therapy.
D. Radiological Biological Evaluation; evaluates biological responses to radiation.

Correct answer: B. Relative Biological Effectiveness; measures the effectiveness of different radiations in producing biological effects

7. What is the typical RBE value for thermal neutrons?

A. 1
B. 5
C. 10
D. 20

Correct answer: B. 5

8. What is the primary medium used to measure exposure in the Roentgen (R)?

A. Water
B. Air
C. Lead
D. Steel

Correct answer: B. Air

9. What does the term "Effective Dose" take into account?

A. It calculates the total radiation dose absorbed by a specific organ.
B. It assesses the overall health risks associated with radiation exposure, considering all exposed tissues and their radiosensitivities.
C. It measures the instantaneous effect of radiation exposure on biological tissues.
D. It quantifies the biological effectiveness of different radiation types.

Correct answer: B. It assesses the overall health risks associated with radiation exposure, considering all exposed tissues and their radiosensitivities.

10. Which of the following measures the number of unstable nuclei regaining stability through radio-disintegration within a unit of time?

A. Dose
B. Exposure
C. Activity
D. Flux

Correct answer C. Activity

11. What is the fundamental concept behind the term "Kerma" in radiation physics?

A. The temperature of a radiation source.
B. The number of radioactive disintegrations.
C. The energy transferred to charged particles in a medium by photons.
D. The measurement of air pressure

Correct answer: C. The energy transferred to charged particles in a medium by photons.

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12. Which radiation type typically has an RBE value of 1?

A. Heavy particles
B. Thermal neutrons
C. Fast neutrons
D. X-rays

Correct answer: D. X-rays

13. What does "Fluence" measure?

A. The number of photons passing through a unit area.
B. The amount of energy passing through a unit area. C.
C. The biological effects of radiation. D.
D. The temperature of radiation sources.

Correct answer A. The number of photons passing through a unit area.

14. What is the unit of absorbed dose in the traditional system of units?

A. Gy
B. Bq
C. R
D. Ci

Correct answer: C. R

15. Which of the following particles is NOT involved in the initial interaction of photons with atoms in a medium, as described by Kerma?

A. Electrons
B. Protons
C. Neutrons
D. Ions

Correct answer: C. Neutrons

Equivalent Dose and Effective Dose

- **- Variation in Radiosensitivity:** Different tissues in the human body exhibit varying sensitivities to radiation exposure. This can result from nonuniform exposure, the seriousness of the damage, and its potential for cure.
- **Equivalent Dose (H):** Equivalent dose quantifies the absorbed dose in a specific tissue or organ, adjusted for the RBE of the radiation type. It is expressed in sieverts (Sv) and is calculated as $H = D \times RBE$.
- **Effective Dose (E):** Effective dose considers the total detriment to the health of an exposed person, considering all exposed tissues and their individual radiosensitivities. It is expressed in sieverts (Sv).
- **Dose Weighting:** Effective dose involves summing the equivalent doses for all exposed tissues, each weighted by tissue-specific radiation risk factors (wT). The formula is $E = \Sigma (wT \times H\_T)$, where H_T is the equivalent dose for tissue T.
- Understanding RBE, equivalent dose, and effective dose is crucial for assessing the potential health risks associated with radiation exposure and guiding radiation protection practices.

Radiation Interaction with Matter

- **Overview:** When X or γ radiation passes through a medium, it interacts with atoms, resulting in the production of moving electrons. These electrons subsequently interact with other atoms, leading to ionization, excitation, and the deposition of energy on cells. This energy transfer can cause damage to cells and generate heat. X and γ photons indirectly ionize matter through these interactions.
- **Dual Nature:** Radiation-matter interaction exhibits both wave-like and particle-like properties. X and gamma rays interact with structures similar in size to their wavelength. Low-energy photons tend to interact with atoms, medium-energy with electrons, and high-energy photons with nuclei. These interactions occur through five mechanisms: (i) coherent scattering, (ii) photoelectric absorption, (iii) Compton scattering, (iv) pair production, and (v) photodisintegration. In diagnostic radiology, Compton scattering and photoelectric absorption are the most important interactions.

Attenuation

- **Definition:** Attenuation is the combined effect of photon absorption and scattering, leading to the removal of photons from a radiation beam. When a beam passes through an absorber of thickness x, both absorption and scattering processes occur.
- **Attenuation Formula:** The number of transmitted photons (I) can be described using the equation: $I = I_0 e^{(-\mu x)}$, where I_0 is the number of incident photons, μ is the linear attenuation coefficient of the absorber material, x is the thickness of the absorber, and e is the base of natural logarithm.

Linear Attenuation Coefficient

- **Definition:** The linear attenuation coefficient (μ) quantifies the reduction in radiation intensity per unit path length, with units in cm^-1. It reflects the fraction of photons removed from a monochromatic radiation beam.
- **Linear Attenuation Coefficient Formula:** The linear attenuation coefficient is calculated using the equation: $\mu = -(1/x) * \ln(I/I0)$, where I/I0 represents the fraction of removed photons per unit thickness of the medium. This relationship is exponential, with more photons removed initially and fewer as the thickness increases.
- **Energy and Density Dependence:** The linear attenuation coefficient varies with photon energy and material density. In the diagnostic energy range (30–100 keV), μ generally decreases with increasing energy, except at K-edges. For soft tissue, μ ranges from 0.35 to 0.16 cm^-1.

Mass Attenuation Coefficient

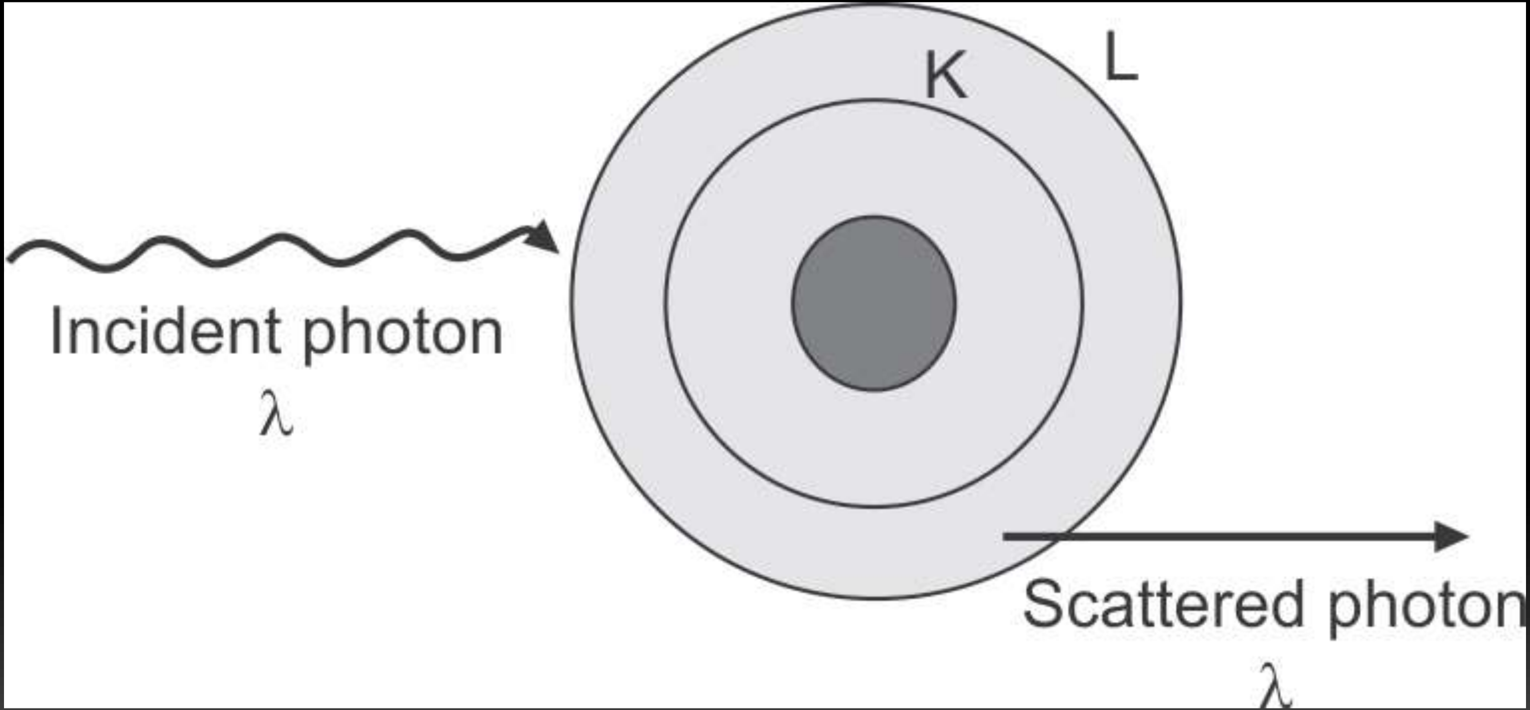
- **Definition:** The mass attenuation coefficient (μ/ρ) is obtained by dividing the linear attenuation coefficient (μ) by the density (ρ) of the material, with units in cm^2/g. It is independent of material density.
- **Mass Attenuation Coefficient Formula:** μ/ρ = μ, where μ/ρ is the mass attenuation coefficient, μ is the linear attenuation coefficient, and ρ is the density of the material.
- **Mass Thickness:** The product of ρ and x is known as the mass thickness and is expressed in g/cm^2. The mass attenuation coefficient allows for the quantification of material attenuation independent of its physical state.

Half Value Layer (HVL)

- **Definition:** The half value layer (HVL) represents the thickness of a material required to reduce the intensity of a radiation beam to half of its original value. It is a significant parameter in radiological physics.
- **HVL Calculation:** HVL is inversely related to the linear attenuation coefficient (μ), and it can be calculated using the formula: HVL = 0.693/μ.
- **Quality of Beam:** HVL is an indirect measure of the quality of the beam, particularly in a narrow beam geometry. In a narrow beam setup, scattered photons are not considered by the detector.
- **Broad Beam Geometry:** In contrast, broad beam geometry is characterized by a wider beam, and scattered photons are always present. Measurements under broad beam conditions may lead to an underestimation of attenuation, which is typical in most patient imaging scenarios.
- **Attenuation with Multiple HVLs:** If an attenuator has 'n' thicknesses of HVL, the reduction of beam intensity is given by the relation (1/2)^n.
- **Radiation Intensity:** Table 5.3 provides information on how radiation intensity decreases with increasing HVLs, particularly for heavily filtered X-ray beams.
-

Coherent or Rayleigh Scattering

- **Definition:** Coherent or Rayleigh Scattering is a type of interaction where a photon interacts with an electron of an atom, causing the atom to become excited.
- **Emission of Scattered X-rays:** The excited atom releases excess energy as scattered X-rays with the same wavelength and energy as the incident photons.
- **Direction of Scattering:** In coherent scattering, the direction of the scattered photon is different from that of the incident photon. However, there is no change in the wavelength (energy) of the photon.
- **No Energy Transfer:** This process does not transfer energy to the electron, leading to no ionization occurring as a result.
- **Forward Scattering:** In coherent scattering, most of the photons are scattered in the forward direction, with minimal scattering occurring at small angles.
- **Energy Dependency:** The scattering angle increases as the X-ray energy decreases. Coherent scattering is primarily observed in low-energy photons, such as in mammography (15–30 keV).


K
L
Incident photon
λ
Scattered photon
λ

Compton Scattering

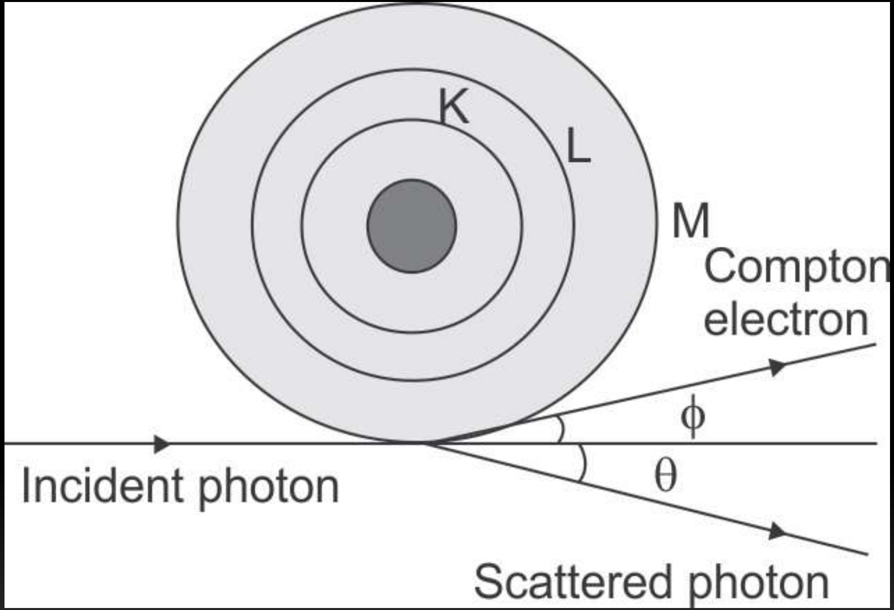
- **Interaction Process:** Compton scattering involves a photon interacting with a free electron (valence) of an atom and gets scattered. During this process, the photon loses a portion of its energy.
- **Ejected Electron:** The ejected electron receives the remaining energy and may lose it through ionization and excitation of atoms in the tissue, contributing to the patient's dose.
- **Scattered Photon:** The scattered photon may either continue to travel through the medium without further interaction or undergo Compton scattering or photoelectric absorption.
- **Wavelength Change:** The wavelength of the scattered photon is longer compared to the incident photon, resulting in a shift to lower energy.
- **Energy Relationship:** The energy of the incident photon (E0) is related to the energy of the scattered photon (Esc) and the angle of scatter (θ) using the formula: $E_{sc} = E_0 / [1 + (E_0(1 - \cos\theta) / 511\ \text{keV})]$. The fraction of energy transferred to the scattered photon decreases as the incident photon energy increases for a given scattering angle.

Compton Scattering

- **Collision Types:** The collision angle (φ) between the photon and the electron determines the energy exchange. A direct hit (φ = 0) results in maximum energy for the electron and minimum energy for the scattered photon, while a grazing hit (φ = 90) results in the electron receiving minimal energy and the scattered photon gaining maximal energy.
- **Probability of Interaction:** The probability of Compton scattering depends on the electron density in the medium, which is constant for most tissues except hydrogen. The probability of Compton interaction decreases with an increase in X-ray energy, inversely proportional to the incident energy.
- **Material Density:** The probability of Compton scattering is also proportional to the density of the material. Hydrogenous materials have a higher probability for Compton scattering. **Diagnostic Energy Range:** Compton scattering occurs across a wide range of energies in tissues and is particularly important in X-ray imaging. It is the predominant interaction in the diagnostic energy range for soft tissue (100 keV-10 MeV).

Compton Scattering

Impact in Imaging: Scattered X-rays, as a result of Compton scattering, do not provide useful image information, reduce image contrast, and pose radiation hazards in radiography and fluoroscopy. In fluoroscopy, a significant amount of radiation is scattered from the patient, contributing to occupational radiation exposure



1. **What happens in Compton scattering?**

A. The photon is absorbed by an electron.

B. The photon interacts with an atom and produces ionization.

C. The photon changes direction without changing wavelength.

D. The photon is absorbed by a nucleus.

Correct answer: **C. The photon changes direction without changing wavelength.**

2. What is the relationship between the incident photon energy (E0) and the energy of the scattered photon (Esc) in Compton scattering?

A. E0 = Esc

B. E0 > Esc

C. E0 < Esc

D. Esc = E0 / [1 + (E0(1 - cos θ) / 511 keV)]

Correct answer: **D. Esc = E0 / [1 + (E0(1 - cos θ) / 511 keV)]**

3. In Compton scattering, what happens to the ejected electron that receives energy from the incident photon?

A. It travels in the same direction as the incident photon.

B. It receives maximum energy.

C. It contributes to ionization and excitation of atoms in the tissue.

D. It retains all the energy and does not interact further.

Correct answer: **C. It contributes to ionization and excitation of atoms in the tissue.**

4. What is the primary factor that determines the probability of Compton scattering in a medium?

A. The atomic number (Z) of the material.
B. The wavelength of the incident photon.
C. The density of electrons in the medium.
D. The density of the material.

Correct answer: **C. The density of electrons in the medium.**

5. In which energy range is Compton scattering most predominant for soft tissue?

A. Below 10 keV
B. 10 keV to 50 keV
C. 100 keV to 10 MeV
D. Over 20 MeV

Correct answer: **C. 100 keV to 10 MeV**

Photoelectric Effect in Radiology

- The photoelectric effect involves a photon colliding with an atom, ejecting a bound electron from K or L shells, creating a photoelectron with kinetic energy (E - orbital binding energy).
- All photon energy transfers to the electron, requiring the photon energy to be equal or greater than the orbital binding energy for the effect to occur.
- After the photoelectric effect, the atom becomes ionized, with a vacancy in the shell filled by an electron from a higher orbit, leading to characteristic X-rays or Auger electrons.
- This interaction mainly involves tightly bound electrons, notably in the K shell, leading to most photoelectric interactions occurring there.
- The probability of photoelectric cross-section per unit mass is proportional to Z^3/E^3, where Z is the atomic number, and E is the incident photon energy.

Photoelectric Effect in Radiology

- As X-ray photon energy increases, subject contrast decreases. A higher atomic number increases subject contrast, making barium (Z = 56) and iodine (Z = 53) effective contrast agents.
- Exceptions exist; absorption increases significantly as incident photon energy surpasses the K-shell binding energy, known as K-edge absorption.
- Elements exhibit sharp absorption edges due to binding energies. For example, iodine's K-shell binding energy at 33.2 keV results in a six-fold increase in absorption at the K-edge.

1. What is the primary outcome of the photoelectric effect in radiology?

A. Production of characteristic X-rays

B. Scattering of incident photons

C. Ionization of atoms

D. Increase in subject contrast

Correct answer: **A. Production of characteristic X-rays**

2. In the photoelectric effect, when does the incident photon transfer all of its energy to the ejected electron?

A. When the photon energy is equal to the electron's binding energy

B. When the photon energy is less than the electron's binding energy

C. When the photon energy is greater than the electron's binding energy

D. When the photon energy exceeds 1 MeV

Correct answer: **A. When the photon energy is equal to the electron's binding energy**

3. Which shell of an atom is most commonly involved in the photoelectric effect in radiology?

A. M shell

B. L shell

C. K shell

D. N she

Correct answer: **C. K shell**

4. The probability of the photoelectric effect per unit mass is primarily dependent on which factors?

A. Atomic number (Z) and incident photon energy (E)

B. Density and atomic mass of the material

C. Photon wavelength and density of the material

D. The velocity of the incident photon

Correct answer: **A. Atomic number (Z) and incident photon energy (E)**

Red Tech

5. What is K-edge absorption in the context of the photoelectric effect?

A. The point at which an element becomes fully ionized

B. The threshold energy for a photon to cause photoionization

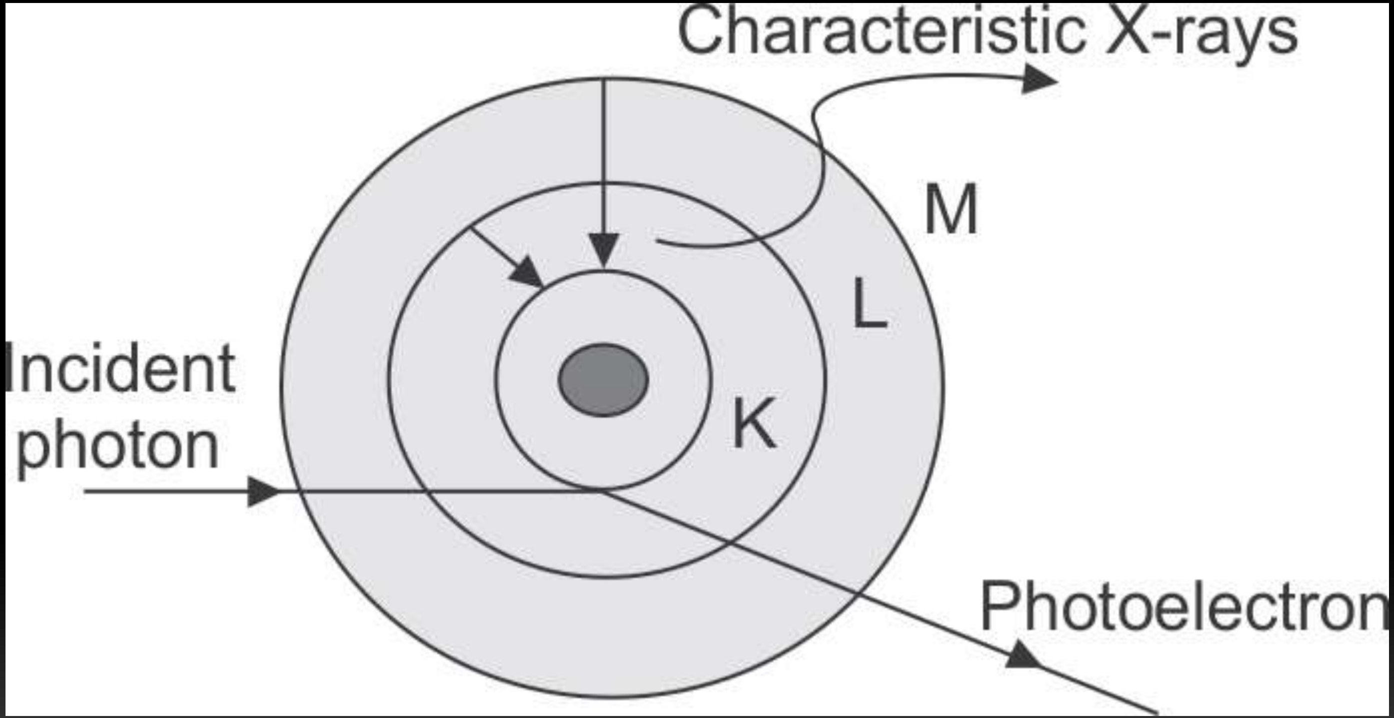
C. The energy level of an electron in the K shell

D. The energy at which Auger electrons are released

Correct answer: **B. The threshold energy for a photon to cause photoionization**

Pair Production in Radiation Physics

- **Overview:** Pair Production is a fundamental interaction in radiation physics.
- **Process:**
  - Occurs when a photon with energy > 1.02 MeV interacts with the strong nuclear field.
  - The photon can suddenly convert into a positron and electron pair.
  - Each particle requires 0.511 MeV, and the excess energy is shared as kinetic energy.
- **Energy-Mass Conversion:** Einstein's theory of mass-energy equivalence is evident in this process.
- **Threshold Energy:** Pair production requires a minimum threshold energy of 1.02 MeV.
- **Factors Affecting Probability:**
  - Probability increases with higher photon energy.
  - Probability is proportional to the atomic number squared (Z^2) of the material.
- **Energy Loss:**
  - The electron loses energy through excitation, ionization, and filling orbital vacancies.
  - The positron loses energy via ionization, excitation, and bremsstrahlung.
- **Outcome:** Pair production results in the creation of two 0.511 MeV photons ejected in opposite directions.
- **Importance:** This interaction is significant for photons with energy > 5 MeV.


Characteristic X-rays
M
L
K
Incident
photon
Photoelectron

1. What is the minimum threshold energy required for the pair production process to occur?

A) 0.511 MeV

B) 1 MeV

C) 1.02 MeV

D) 2 MeV

Correct answer: **C) 1.02 MeV**

2. What happens when a photon undergoes pair production in a strong nuclear field?

A) It scatters in a different direction.
B) It disappears and becomes a positron-electron pair.
C) It emits characteristic X-rays.
D) It changes its wavelength.

Correct answer: **B) It disappears and becomes a positron-electron pair.**

3. In pair production, what is the energy of each created particle (positron and electron)?

A) 1.02 MeV

B) 0.511 MeV

C) 2.04 MeV

D) It varies depending on the incident photon's energy.

Correct answer: **B) 0.511 MeV**

4. How does the probability of pair production change with an increase in atomic number (Z) of the material?

A) It remains constant.
B) It decreases.
C) It increases linearly.
D) It increases proportionally to Z^2.

Correct answer: **D) It increases proportionally to Z^2.**

5. Pair production is most significant for which range of photon energy?

A) Less than 1 MeV B)

B) 1 MeV - 5 MeV C)

C) Greater than 5 MeV

D) It is equally significant across all energy ranges.

Correct answer: **C) Greater than 5 MeV**

Differential Absorption:

- X-rays interact with human tissues through Compton scattering and the photoelectric effect.
- Compton scattered X-rays contribute to noise and reduce image quality, while the photoelectric effect provides diagnostic information.
- Bones, with their high absorption characteristics, appear as light areas (white) on radiographs.
- Soft tissues allow X-rays to pass through, resulting in dark areas (black) on radiographs.
- Differential absorption is the key to creating radiographic images.

Atomic Number:

- Probability of photoelectric absorption is proportional to the atomic number (Z) cubed.
- Bones have a higher atomic number (Z) compared to soft tissues, resulting in a higher probability of photoelectric absorption in bones.
- This probability decreases with increasing X-ray energy.
- Compton scattering, on the other hand, is independent of tissue atomic number and becomes dominant at higher photon energies.

Mass Density:

- Interaction of X-rays with tissues is proportional to mass density, regardless of the interaction type.
- Mass density is expressed as the quantity of matter per unit volume (kg/m^3).
- Tissues with higher mass density have a greater number of electrons and thus greater interaction with X-rays.
- Mass density plays a crucial role in imaging lung cavities with air (low mass density) and soft tissues (higher mass density).

Red Tech

Photon Energy:

- In diagnostic radiology, X-ray energy typically ranges from 20 to 150 kVp, with effective photon energy ranging from 15 to 100 keV.
- The relative importance of interactions changes with energy:
  - At low energies, photoelectric absorption is the dominant interaction and provides excellent soft tissue and bone differentiation.
  - At high energies, Compton scattering becomes dominant, and differentiation between soft tissue and bone diminishes.
- Low energy X-rays (e.g., mammography) rely heavily on photoelectric absorption, while higher energy X-rays (e.g., chest radiography) emphasize Compton scattering.

Contrast Agents:

- Contrast agents with high atomic numbers and mass densities, such as barium and iodine, help visualize internal organs.
- The choice of kVp techniques can optimize the visibility of contrast agents and differentiate specific anatomical structures.

Red Tech

1. What is the primary reason that Compton scattering is undesirable in diagnostic radiography?

A) It provides useful information for image formation.

B) It increases the subject contrast.

C) It reduces image quality and introduces noise.

D) It is the main contributor to image contrast.

Correct answer: **C) It reduces image quality and introduces noise.**

2. Which atomic property is primarily responsible for the probability of the photoelectric effect in a given material?

A) Atomic mass

B) Atomic number (Z)

C) Electron configuration

D) Atomic volume.

Correct answer: **B) Atomic number (Z).**

3. Why does mass density play a significant role in X-ray interactions with tissues?

A) It affects the speed of X-rays in the material.

B) It determines the intensity of X-ray beams.

C) It influences the probability of interaction with X-rays.

D) It affects the energy of X-ray photons.

Correct answer: **C) It influences the probability of interaction with X-rays.**

4. At which energy range do low kVp X-rays, such as those used in mammography, primarily rely on photoelectric absorption for image contrast?

A) 100-150 keV
B) B) 50-70 keV
C) C) 20-40 keV
D) D) 10-20 keV

Correct answer: **C) 20-40 keV**

5. Contrast agents like barium and iodine are effective in visualizing internal organs because they:

A) Have low atomic numbers and mass densities.

B) Have a high atomic number and mass density.

C) Depend on Compton scattering for image contrast.

D) Are used with high kVp techniques.

Correct answer: **B) Have a high atomic number and mass density.**

Particle Radiation Types

- Particle radiation includes alpha, beta, proton, electron, positron, and neutrons.
- Heavier particles (alpha and protons) behave differently from lighter particles (electrons and positrons).
- **Ionization and Excitation**
- Charged particles interact with matter via electrical forces, leading to ionization and excitation.
- About 70% of charged particle energy is lost via excitation.
- Ionization results in the ejection of an electron, forming ion pairs. Secondary ionization may also occur, producing delta rays.

Specific Ionization

- Specific ionization measures the number of ion pairs produced per unit path length and is expressed in IP/cm.
- Specific ionization increases with particle charge and decreases with particle velocity.
- Larger particles lose energy by interacting with greater electric fields.
- ***Path Length and Range***
- Path length is the actual distance a particle travels in a medium.
- Range is the depth of penetration in the medium.
- For electrons, path length is greater than range, while for heavy particles, path length equals range.

Linear Energy Transfer (LET)

- LET quantifies the energy deposited per unit path length (eV/cm).
- High LET radiation (e.g., alpha and protons) causes more damage in biological systems than low LET radiation (e.g., X-rays, electrons).
- ***Scattering***
- Scattering refers to the deflection of particles from their original tracks.
- Elastic scattering preserves total kinetic energy, while inelastic scattering involves kinetic energy loss.

Electron Interaction

- Electrons undergo elastic and inelastic collisions, losing energy via excitation, ionization, and radiative processes.
- Bremsstrahlung radiation is emitted when electrons decelerate, with emission angles depending on electron energy and absorber's atomic number (Z2).
- ***Neutron Interaction***
- Neutrons are uncharged particles that interact with light atomic nuclei, producing recoil nuclei that lose energy through excitation and ionization.
- Neutron interactions are not relevant in diagnostic radiology and imaging.

1. Which radiation interaction with matter involves a photon scattering in a way that changes its direction without changing its wavelength?

a. Coherent scattering

b. Pair production

c. Photoelectric effect

d. Compton scattering

Correct answer: **a. Coherent scattering**

2. In diagnostic radiology, which interaction leads to a decrease in subject contrast as the X-ray photon energy increases?

a. Coherent scattering

b. Pair production

c. Photoelectric effect

d. Compton scattering

Correct answer: **c. Photoelectric effect**

3. What process involves a photon interacting with an atom, ejecting one of its bound electrons from the K or L shells, and releasing characteristic X-rays or Auger electrons as a result?

a. Coherent scattering
b. Pair production
c. Photoelectric effect
d. Compton scattering

Correct answer: **c. Photoelectric effect**

4. The linear attenuation coefficient is defined as the reduction in radiation intensity per unit path length and depends on:

a. The photon's energy
b. The type of interaction
c. The material's atomic number
d. The direction of scattering

Correct answer: **a. The photon's energy**

5. Which interaction between radiation and matter results in a change in direction without a change in wavelength, and no energy transfer or ionization occurs?

a. Photoelectric effect

b. Pair production

c. Compton scattering

d. Coherent scattering

Correct answer: **d. Coherent scattering**