

Q1. Explain the classification of electromagnetic radiations based on their origin.

Ans:

Electromagnetic waves are disturbances in electric and magnetic fields that propagate through space, carrying energy and momentum. They don't require a medium to travel, unlike mechanical waves, and travel at the speed of light in a vacuum. These waves are characterized by oscillating electric and magnetic fields that are perpendicular to each other and to the direction of wave propagation.

Electromagnetic waves are produced when charged particles are accelerated. Electromagnetic waves are classified based on their energies or wavelengths which depend on the energy and acceleration of the charged particle involved in their production.

Radio Waves and Microwaves: Radio waves are produced artificially by time-varying electric currents, consisting of electrons flowing back and forth in a specially shaped metal conductor called an antenna. Radio waves are a type of electromagnetic radiation with the lowest frequencies and the longest wavelengths in the electromagnetic spectrum, with frequencies below 300 gigahertz (GHz) and wavelengths greater than 1 millimeter. Radio waves with frequencies above about 1 GHz and wavelengths shorter than 30 centimeters are called microwaves.

IR radiation: Infrared is electromagnetic radiation (EMR) with wavelengths longer than that of visible light but shorter than microwaves. The infrared spectral band begins with the waves that are just longer than those of red light, so IR is invisible to the human eye. IR includes wavelengths from around 780 nm to 1 mm. IR is commonly divided between longer-wavelength thermal IR, emitted from terrestrial sources, and shorter-wavelength IR or near-IR, part of the solar spectrum. Infrared radiation is emitted by molecules whenever a molecule undergoes a transition among rotational-vibrational levels.

Visible light: Visible light is produced when electrons in atoms absorb energy and jump to a higher energy state, then fall back to their original state by releasing this energy as photons. This class is in the wavelength range 4000 Å to 8000 Å.

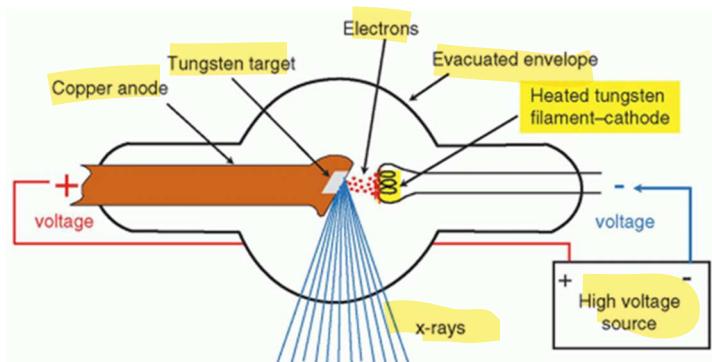
Ultraviolet radiation: Ultraviolet light is produced when electrons undergo transitions in an atoms or molecules undergo transition in its rotational energy value. The wavelength range is 1000 Å to 4000 Å.

X-Rays: X-Rays are produced due to transitions among innermost shells of a high-Z atom or when a fast moving electron undergoes a change in its velocity. The wavelength range is 0.1 Å to 100 Å.

Gamma rays: Gamma rays are produced when nucleons undergo transitions inside a nucleus. The wavelength range is 0.01 Å to 1 Å.

Q2. What are X-rays? Explain production of X-rays.

Ans:

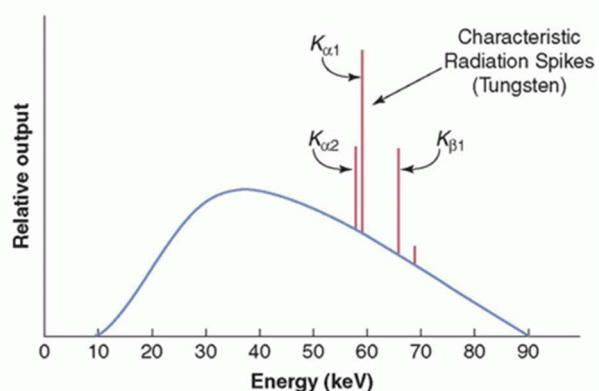
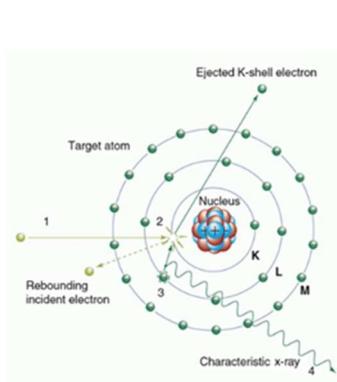


X-Rays are electromagnetic radiations of wavelength range 0.1\AA to 100\AA . X-rays are produced when highly energetic electrons interact with matter, converting some or all of their kinetic energy into electromagnetic radiation. Based on the origin, X-rays are classified as Continuous (Bremsstrahlung) and Characteristic X-Rays.

Construction: An x-ray tube contains an electron source, the filament circuit which produces electrons through thermionic emission. An external power source provides high voltage to accelerate the electrons. Collimators make a fine pencil of electron beam. The x-ray tube mounted within a tube housing in vacuum environment includes a metal enclosure and a protective radiation shielding.

Continuous X-Ray (Bremsstrahlung Radiation): Fast moving electrons strike the target electrode. Coulomb force of attraction by nucleus of an atom in the target decelerates the incident electron resulting. The change in kinetic energy of the electron is converted to x-ray photon (*i.e.*, bremsstrahlung radiation). The magnitude of energy lost by an electron is determined by the closest distance between the incident electron and the nucleus and is not quantized.

Characteristic X-Ray: The incident electron interacts with the K-shell electron via a repulsive electrical force. If the K-shell electron is removed, a vacancy is created in the K-shell. If an electron from the L-shell fills the vacancy, K_{α} characteristic x-ray photon is emitted. If an electron from the M-shell fills the vacancy, K_{β} characteristic x-ray photon is emitted. If an electron from the N-shell fills the vacancy, K_{γ} characteristic x-ray photon is emitted. Similarly, L-series, M-series and so on are generated. The wavelength of a characteristic X-Ray depends on the atomic number of the target atom. So the name characteristic X-Ray.



Q3. Explain Rayleigh scattering.

Ans:

Rayleigh scattering is the elastic scattering of light or other electromagnetic radiation by particles significantly smaller than the radiation's wavelength. This phenomenon is famously responsible for the blue appearance of the daytime sky and the red hues seen during sunrises and sunsets.

Rayleigh scattering occurs when light interacts with particles, such as gas molecules in Earth's atmosphere that are significantly smaller than the wavelength of the light. This causes their electrons to oscillate and reradiate light in all directions. The alternating electric field of the light wave induces a temporary dipole in the molecule, which then re-radiates the electromagnetic energy in different directions, scattering the light. This process is elastic because the light's energy doesn't change. The scattered radiation has the same wavelength and energy as the incident radiation, indicating an elastic collision where no energy is lost or gained. A key characteristic is that shorter wavelengths (λ) of light, like blue and violet, are scattered much more strongly than longer wavelengths, such as red and orange.

$$\text{The intensity of scattered light } I \propto 1/\lambda^4$$

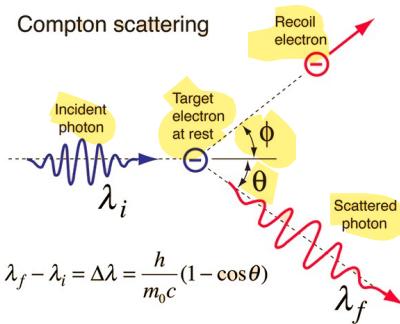
The sky appears blue because atmospheric molecules scatter shorter blue and violet wavelengths of sunlight more effectively than longer ones. During sunrise and sunset, sunlight travels through a greater portion of the atmosphere, scattering away most blue light and allowing red and orange light to be more visible.

Rayleigh scattering contributes to the blue color observed in some biological structures, including certain bird feathers, butterfly wings, and human eyes, due to microscopic features scattering light. In optical fibers, Rayleigh scattering caused by tiny imperfections can lead to signal loss.

Q4. Explain Compton scattering.

Ans:

When a high-energy X-ray hits a low atomic number target, it interacts with a loosely bound electron in the target. The photon transfers a portion of its energy and momentum to the electron, knocking it out of its atomic shell. The incident X-ray is scattered at an angle and carries lower energy or a longer wavelength. This is Compton scattering. Compton scattering is considered an elastic collision because the energy spent to remove the loosely bound electron is negligible compared to the energy of the incident X-ray. The energy and momentum exchange between the photon and electron provides strong evidence for light acting as discrete particles.

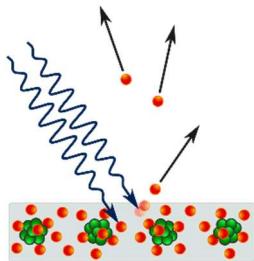


The change in the photon's wavelength, $\Delta\lambda$, is directly related to its scattering angle θ and is given by,

$$\Delta\lambda = \lambda_f - \lambda_i = \frac{h}{m_0 c} (1 - \cos\theta).$$

$\frac{h}{m_0 c}$ is called the Compton wavelength. It supports Einstein's concept of photons and hence the particle nature of light. In diagnostic imaging, Compton scattering contributes to image noise and reduced contrast because the scattered X-rays are not useful for creating a clear image.

Q5. Explain photo electric effect.



Ans:

The photoelectric effect is the emission of electrons from a material when it is shone with electromagnetic radiation such as ultraviolet light. Electrons emitted in this manner are called photoelectrons. This effect shows that electrons are dislodged only when the light exceeds a certain frequency—regardless of the light's intensity or duration of exposure. Albert Einstein proposed that a beam of light is not a wave propagating through space, but discrete energy packets. Study of the photoelectric effect led to understanding the quantum nature of light and electrons. Part of the incident photon energy is used to liberate the electron from its atomic binding and the rest contributes to the electron's kinetic energy as a free particle.

For a given metal surface, there exists a certain minimum frequency of incident radiation below which no photoelectrons are emitted. This frequency is called the threshold frequency or work function. Increasing the frequency of the incident beam increases the maximum kinetic energy of the emitted photoelectrons. The number of emitted electrons increases with intensity.

When an electron within some material absorbs the energy of a photon and acquires more energy than its binding energy, it may be ejected. If the photon energy is too low, the electron is unable to escape the material. If the intensity of low-frequency light is increased, it only increases the number of low-energy photons. Thus, an increase in intensity will not create a packet of enough energy to dislodge an electron. Thus the energy of the emitted electrons will not depend on the intensity of the incoming light of a given frequency, but only on the energy of the individual photons.

Q6. Explain pair production.

Ans:

Pair production is the creation of a subatomic particle and its antiparticle from a neutral boson. For example, the creation of an electron and a positron pair when a 1.02 MeV photon interacts with a nuclear field. This process converts energy into matter and requires a photon energy of at least the combined rest mass energy of the electron-positron pair. The photon interacts with the strong electric field near an atomic nucleus, which absorbs some of the photon's momentum, allowing the energy to become the mass of the new particles.

As energy must be conserved, for pair production to occur, the incoming energy of the photon must be above a threshold of at least the total rest mass energy of the two particles created. Conservation of energy and momentum are the principal constraints on the process. All the quantum numbers, angular momentum, electric charge of the produced particles must sum to zero. Thus the created particles shall have opposite values of each other.

The probability of pair production in photon–matter interactions increases with photon energy and also increases approximately as the square of the atomic number (number of protons) of the nearby atom.

Q7. Explain principle of CT scan and type of scanners.

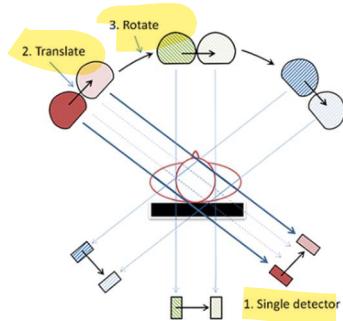
Ans:

A computed tomography scan (CT scan) is a medical imaging technique used to obtain detailed internal images of the body. CT scanners use a rotating X-ray tube and a row of detectors placed in a gantry to measure X-ray attenuations by different tissues inside the body. The multiple X-ray measurements taken from different angles are then processed on a computer using tomographic reconstruction algorithms to produce cross-sectional images of a body. CT scans can be used in patients with metallic implants or pacemakers, for whom magnetic resonance imaging (MRI) is contraindicated. On the basis of image acquisition and procedures, type of scanners are,

- a. Sequential CT: In sequential CT, the CT table moves stepwise. The table increments to a particular location and then stops which is followed by the X-ray tube rotation and acquisition of a slice. The table then increments again, and another slice is taken. The table movement stops while taking slices. This results in an increased time of scanning.
- b. Spiral CT: Spiral CT or helical CT is an imaging technique in which an entire X-ray tube is spun around the central axis of the area being scanned. The main limitation of this type of CT is the bulk and inertia of the equipment (X-ray tube assembly and detector array on the opposite side of the circle) which limits the speed at which the equipment can spin. Some designs use two X-ray sources and detector arrays offset by an angle, as a technique to improve temporal resolution.
- c. Electron beam tomography: Electron beam tomography (EBT) is a specific form of CT in which a large enough X-ray tube is constructed so that only the path of the electrons, travelling between the cathode and anode of the X-ray tube, are spun using deflection coils. This type has a major advantage since sweep speeds can be much faster, allowing for less blurry imaging of moving structures, such as the heart and arteries.
- d. Dual energy CT: Dual energy CT, also known as spectral CT, is an advancement of computed Tomography in which two energies are used to create two sets of data. A dual energy CT may employ dual source, single source with dual detector layer, single source with energy switching methods to get two different sets of data. Dual source CT is an advanced scanner with a two X-ray tube detector system, unlike conventional single tube systems. These two detector systems are mounted on a single gantry at 90° in the same plane. Dual source CT scanners allow fast scanning with higher temporal resolution by acquiring a full CT slice in only half a rotation. Fast imaging reduces motion blurring at high heart rates and potentially allowing for shorter breath-hold time. This is particularly useful for ill patients having difficulty holding their breath or unable to take heart-rate lowering medication. Single source with energy switching is another mode of dual energy CT in which a single tube is operated at two different energies by switching the energies frequently.

Q7. Explain construction and working of computed tomography scan apparatus.

Ans:



Construction:

A CT scanner's core instrumentation includes a rotating gantry housing an X-ray tube and a ring of detectors, a patient table that moves through the gantry, and a computer system for image reconstruction. The X-ray tube produces narrow X-ray beams that pass through the patient at various angles as the tube rotates. Detectors capture the transmitted X-rays, which are then converted into digital signals by the data acquisition system (DAS) and processed by the computer to create cross-sectional images.

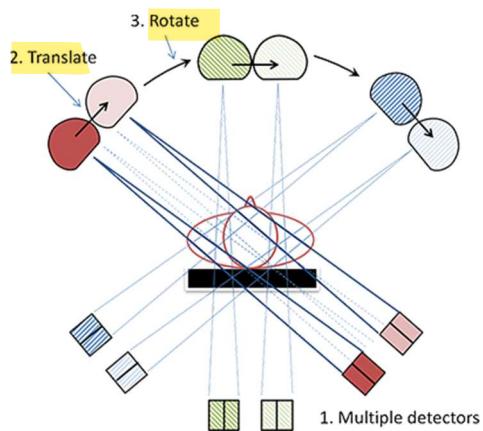
Gantry is the donut-shaped structure that houses the X-ray tube, detectors, and other components. A high-amperage X-ray tube generates narrow X-ray beams that rotate around the patient. Detectors are arrays of solid-state detectors that measure the intensity of the X-ray beams after they pass through the patient's body. Data Acquisition System (DAS) system converts the analog signals from the detectors into digital data for the computer. A powerful computer processes the vast amount of data collected by the DAS, using algorithms to reconstruct detailed cross-sectional images from the multiple X-ray projections. The patient lies on a motorized table that slowly moves the body through the gantry, allowing for the acquisition of slices at different levels. Filters reduce patient dose by removing low-energy X-rays, while collimators narrow the X-ray beam to minimize scatter radiation.

Working:

The X-ray tube emits a controlled beam of X-rays as it rotates within the gantry. As the X-ray beam passes through the patient from various angles, the detectors opposite the X-ray source measure the transmitted X-rays. The signals from the detectors are transmitted to the DAS, which converts them into digital data. The computer uses digital data from hundreds or thousands of X-ray projections to reconstruct detailed, cross-sectional images.

Q8. Explain construction and working of dual energy computed tomography scan apparatus.

Ans:



A Dual-energy CT (DECT) uses a single X-ray tube to acquire datasets at two different energy levels, enabling material differentiation and advanced analysis like virtual non-contrast or virtual non-calcium images. Data acquisition involves hardware designs like rapid KVP switching, dual-source systems, or dual-layer detectors to capture these two energy spectra. Image reconstruction then employs sophisticated algorithms to process this dual-energy data, separating material compositions (like iodine and water) and generating multiple image types beyond conventional CT.

Construction:

DECT scanner hardware is designed to acquire data at two distinct X-ray energy levels. The X-ray tube's voltage (Kilovolt Peak, KVP) is rapidly switched between high and low settings for each X-ray projection. Two X-ray tubes and two detector arrays are positioned 90 degrees apart to acquire datasets simultaneously at different KVP settings. This detector has two layers of scintillators; a thin inner layer selectively absorbs low-energy photons, while the outer thick layer absorbs high-energy photons. The core principle is to obtain projection data at two different energy spectra to exploit the energy-dependent nature of X-ray interactions with tissues. Polychromatic X-rays are generated by a single tube or multiple tubes, filtered to create distinct energy distributions. The detector, whether a standard array, dual-layer, or photon-counting detector, measures the attenuation of these different energy X-rays as they pass through the patient. This acquisition results in two distinct datasets: one with lower energy photons and one with higher energy photons.

Image Reconstruction:

Sophisticated algorithms use the two energy datasets to differentiate materials and generate new image types. Algorithms solve a system of equations using the attenuation measurements from both energy levels to calculate the proportions of different materials (e.g., water, calcium, iodine) within a voxel. Image sets are reconstructed at various specific X-ray energies, allowing for optimal visualization of different contrast agents or structures. Images are generated that specifically map the distribution and concentration of materials, such as Iodine Maps (to highlight iodinated contrast media) and Virtual Non-Calcium Images (VNCa) (to remove the high attenuation signal from bone, improving visualization of tissues like the bone marrow).

Effective Atomic Number (Zeff) and Electron Density (Rho) Maps provide information about the elemental composition and electron density of tissues, enhancing characterization.

Reconstruction can be performed directly on the raw data (raw-data based) or after the initial projection images have been created (image-based).

Q9. What are the safety measures to be taken in computed tomography scanning?

Ans:

Patient-Focused Safety Measures:

- a. Patient should communicate medical history.
- b. Patient should inform the technologist if one is pregnant or might be.
- c. Patient should disclose any known allergies, especially to iodine-based contrast material, which is often used to highlight organs.
- d. Patient should inform doctor of conditions such as diabetes, asthma, or kidney disease, as these may affect the scan or require specific precautions.

Preparation for contrast media:

- a. Patient may be asked to avoid food and drink for several hours before the scan if contrast is involved.
- b. Patient may be allowed to drink clear fluids up to a certain time before the scan.
- c. Patient should remove all jewelry, piercings, dentures, eyeglasses, and hairpins.

During the scan:

- a. Patient has to stay very still as it is crucial to prevent image blur and ensure a clear diagnostic result.
- b. Patient may be asked to hold breath for short periods to help with image clarity.

Technologist and Facility Safety Measures:

- a. A CT scan is only ordered when the clinical benefit outweighs the risk.
- b. The scan is planned to obtain the best possible images with the lowest possible dose of radiation, especially for children.
- c. Radiologists consider kidney function and allergies before administering contrast material and may use alternative imaging methods if necessary.
- d. CT technologists may use lead shields or protective gloves when performing scans to reduce operator exposure.