TOPIC 1 Ultrasound and Piezoelectric Effect

SQ 20.1.1 Define radiation.

Definition

Radiation is the transfer of energy through space or matter in the form of waves or particles.

SQ 20.1.2 For what are radiations mainly used in medical physics?

Answer

In medical physics radiations are mainly used for diagnosis, that is imaging, and for treatment.

SQ 20.1.3 Differentiate between ionizing and non-ionizing radiations.

Ionizing Radiations

They have enough energy to remove electrons from atoms, producing ions.

Non-Ionizing Radiations

They do not have enough energy to remove electrons from atoms.

SQ 20.1.4 Give examples of ionizing and non-ionizing radiations used in medicine.

Ionizing

X-rays, gamma rays and positrons.

Non-Ionizing

Ultrasound waves and radiowaves.

SQ 20.1.5 How do X-rays and gamma rays interact with matter?

Answer

Interaction of X-rays and gamma rays with matter occurs through the photoelectric effect and Compton scattering.

SQ 20.1.6 How do non-ionizing radiations interact with matter?

Answer

Ultrasound waves and radiowaves are reflected, refracted or absorbed when they interact with matter.

SQ 20.1.7 Give the medical uses of X-rays and gamma rays.

X-rays

They are commonly used to image bones and internal organs.

Gamma Rays and Positrons

They are used in nuclear medicine, such as SPECT and PET scans and cancer treatment, due to their high penetrating power.

SQ 20.1.8 Give the medical uses of ultrasonic waves and radiowaves.

Ultrasonic Waves

They are used in ultrasound imaging to examine soft tissues, monitor fetal development and study internal organs safely without ionizing radiation.

Radiowaves

They are used in MRI, where they help produce detailed images by interacting with atomic nuclei.

SQ 20.1.9 What is ultrasound imaging?

Definition

Ultrasound is a widely used non-invasive medical imaging technique that allows visualization of internal body structures such as tissues, organs, and the fetus during pregnancy.

SQ 20.1.10 What is the dual role of an ultrasound transducer?

Answer

The transducer plays a dual role; it generates ultrasound waves and detects the reflected signals from inside the body.

SQ 20.1.11 What is the origin of the word piezoelectric?

Answer

The word piezoelectric comes from the Greek word “piezein”, which means to press, and “electric” refers to the production of electricity.

SQ 20.1.12 Who discovered the piezoelectric effect and how?

Answer

The effect was discovered in 1880 by two French brothers, Pierre Curie and Jacques Curie. They found that when mechanical pressure was applied to crystals such as quartz, tourmaline and Rochelle salt, they generated an electric charge.

SQ 20.1.13 Why is the piezoelectric effect possible in certain crystals?

Reason

These crystals have no centre of symmetry, and inside them there are small regions with positive and negative charges. Normally these charges are balanced.

SQ 20.1.14 Define the direct piezoelectric effect.

Definition

When pressure is applied to the crystal, the balance of charges is disturbed and the charges move slightly, causing an electric field to appear on the surface. This is called the direct piezoelectric effect.

SQ 20.1.15 Define the converse piezoelectric effect.

Definition

If we apply an electric field to the crystal, it changes shape a little. This is called the converse piezoelectric effect.

SQ 20.1.16 Which effect is used to generate and which to detect ultrasound?

Answer

A transducer generates ultrasound waves by the converse effect, in which an applied alternating voltage makes the crystal vibrate, and it detects the returning echoes by the direct effect.

TOPIC 2 Diagnostic Use of Ultrasound in Medical Imaging

SQ 20.2.1 What frequency range is used in ultrasound imaging?

Answer

Ultrasound imaging sends high frequency sound waves, typically in the range of 1 MHz to 15 MHz, into the body using a device called a transducer.

SQ 20.2.2 How is an ultrasound image formed?

Answer

The waves travel through the body and reflect off boundaries between different tissues. The reflected echoes are then collected and analyzed to create an image.

SQ 20.2.3 What is the key advantage of ultrasound?

Answer

Ultrasound does not use ionizing radiation, making it a safe, non-invasive and repeatable imaging method.

SQ 20.2.4 What determines whether an ultrasound wave is reflected at a boundary?

Answer

When the waves encounter a boundary between two tissues with different acoustic impedances, determined by tissue density and sound speed, part of the wave is reflected.

SQ 20.2.5 How does the transducer detect the reflected waves?

Answer

The transducer switches to receive mode and detects the reflected waves using the direct piezoelectric effect. These echoes are converted into electrical signals and processed by the machine.

SQ 20.2.6 How does the computer construct the final image?

Answer

A computer calculates the time delay and intensity of the returning echoes to construct a visual image. Areas with stronger reflections appear brighter in the image.

SQ 20.2.7 How does acoustic impedance difference affect image quality?

Answer

A higher difference between two tissues, for example soft tissue and bone, causes stronger echoes, producing clear boundaries in the image.

SQ 20.2.8 How does frequency affect ultrasound image quality?

Answer

Higher frequency ultrasound offers better resolution but less penetration. Lower frequency waves penetrate deeper but have lower image clarity.

SQ 20.2.9 Why is a gel used in ultrasound scanning?

Reason

A special gel is applied between the transducer and the skin to remove air gaps and improve sound wave transmission.

SQ 20.2.10 Give the applications of ultrasound in obstetrics and the abdomen.

Obstetrics

It helps monitor fetal growth, estimate gestational age and identify abnormalities during pregnancy.

Abdomen

It is used to examine vital organs such as the liver, kidneys, gallbladder, pancreas and bladder.

SQ 20.2.11 Give the applications of ultrasound in cardiology and urology.

Cardiology

Echocardiography allows doctors to evaluate the heart's structure and function in real time.

Urology

It is used for examining the prostate, testicles and urinary system.

SQ 20.2.12 How is ultrasound used in the musculoskeletal system?

Answer

In the musculoskeletal system it aids in detecting ligament injuries, joint inflammation and other soft tissue conditions.

SQ 20.2.13 How can ultrasound measure blood flow speed?

Answer

Ultrasound can measure blood flow speed using the Doppler effect, by detecting shifts in sound frequency.

TOPIC 3 X-rays

SQ 20.3.1 Why do light elements emit spectral lines in the visible region?

Reason

The transitions of electrons in hydrogen or other light elements result in the emission of spectral lines in the infrared, visible or ultraviolet region, due to the small energy differences between the transition levels.

SQ 20.3.2 How are electrons arranged in heavy atoms?

Answer

In heavy atoms the electrons are assumed to be arranged in concentric shells labelled K, L, M, N and O, with the K-shell being closest to the nucleus.

SQ 20.3.3 Why do heavy atoms emit X-rays?

Reason

The inner shell electrons are tightly bound and a large amount of energy is required to knock them out. After excitation, when the atom returns to its normal state, photons of larger energy are emitted, giving rise to X-rays.

SQ 20.3.4 Define characteristic X-rays.

Definition

X-rays which consist of a series of specific wavelengths or frequencies are called characteristic X-rays, because their energies depend upon the type of target material.

SQ 20.3.5 Describe the X-ray tube.

Description

It consists of a high vacuum tube. When the cathode is heated by the filament it emits electrons, which are accelerated towards the anode, that is the target.

SQ 20.3.6 Write the maximum kinetic energy of an electron striking the target.

Formula

$(KE)_{max} = Ve$

Here V is the potential difference between the cathode and the target.

SQ 20.3.7 Explain the production of K(α) X-rays.

Explanation

When a fast moving electron knocks out an electron from the K-shell, a vacancy or hole is produced. An electron from the L-shell jumps to occupy this hole, emitting a photon.

Formula

$hf_{K\alpha} = E_L - E_K$

SQ 20.3.8 Explain the production of K(β) X-rays.

Explanation

An electron from the M-shell may also jump to occupy the hole in the K-shell.

Formula

$hf_{K\beta} = E_M - E_K$

SQ 20.3.9 How do characteristic X-rays appear in the spectrum?

Answer

The characteristic X-rays appear as discrete lines on a continuous spectrum.

SQ 20.3.10 What is bremsstrahlung?

Definition

The continuous X-ray spectrum is due to an effect known as bremsstrahlung or braking radiation. When the fast moving electrons bombard the target they are suddenly slowed down on impact.

SQ 20.3.11 Why is bremsstrahlung in the X-ray region?

Reason

An accelerating charge emits electromagnetic radiation, and the rate of deceleration is so large that the emitted radiation corresponds to short wavelength.

SQ 20.3.12 What determines the minimum wavelength of the continuous spectrum?

Answer

When an electron loses all its kinetic energy in the first collision, the entire kinetic energy appears as an X-ray photon of energy hf_{max}, corresponding to λ_{min}.

Formula

$\lambda_{min} = \frac{hc}{eV}$

SQ 20.3.13 Why does the continuous spectrum contain longer wavelengths?

Reason

Other electrons do not lose all their energy in the first collision. They may suffer a number of collisions before coming to rest, giving rise to photons of smaller energy or X-rays of longer wavelength.

SQ 20.3.14 Define attenuation of X-rays.

Definition

As X-rays travel through the body they lose energy because they interact with atoms. This process is called attenuation. The intensity of the beam decreases gradually, following an exponential pattern.

SQ 20.3.15 What are image intensifiers used for?

Answer

Image intensifiers are used in real-time X-ray imaging. They help reduce radiation exposure by brightening the image, making it easier to see.

SQ 20.3.16 What is contrast in X-ray images and on what does it depend?

Definition

Contrast in X-ray images means how clearly we can tell different tissues apart.

Dependence

Contrast depends on the energy of the X-rays.

SQ 20.3.17 Differentiate between hard and soft X-rays.

Hard X-rays	Soft X-rays
They are of high energy.	They are of low energy.
They are used for bone imaging.	They are better for soft tissues such as the breast.

SQ 20.3.18 What are contrast media?

Definition

Contrast media are special substances like iodine or barium that absorb X-rays well. They are injected or swallowed to temporarily enhance the visibility of internal structures, organs and blood vessels.

TOPIC 4 Computed Tomography Scanning

SQ 20.4.1 Define computed tomography.

Definition

Computed tomography, commonly known as a CT-scan, is a medical imaging technique that combines X-ray technology with computer processing, to generate high resolution cross-sectional and 3D images of internal body structures.

SQ 20.4.2 What is the limitation of an ordinary X-ray?

Limitation

An ordinary X-ray shows a flat two-dimensional image of the body, where different parts like bones and organs overlap each other. This makes it hard to see individual structures clearly.

SQ 20.4.3 How does a CT-scanner build up an image?

Method

A CT-scanner takes many X-ray images of the same body section from different angles. A computer combines these images to make a detailed cross-sectional slice.

Result

The scanner moves slightly along the body and repeats the process, and all the slices are combined to create a 3D image.

SQ 20.4.4 Describe the arrangement of a CT-scanner.

Arrangement

In a CT-scanner the X-ray tube rotates around the patient while the detectors stay in place. This setup collects complete information from all sides.

SQ 20.4.5 Explain the meaning of the name computed axial tomography.

Meaning

Computed means a computer processes the data.
Tomography comes from the Greek word tomos, meaning slice.
Axial means the scan is taken along the body's axis.

SQ 20.4.6 Who invented the CT-scanner and when?

Answer

The CT-scanner was invented by Sir Godfrey Hounsfield of England and Allan Cormack of South Africa in the early 1970s. Both scientists were awarded the Nobel Prize in Physiology or Medicine in 1979.

SQ 20.4.7 Give the advantages of a CT-scan over an ordinary X-ray.

Advantages

CT-scans produce 3D images, allowing doctors to see the size, shape and exact location of organs, bones and other structures.
This makes it easier to distinguish between tissues even when they have very similar densities.

SQ 20.4.8 How does a CT-scan help in cancer treatment?

Answer

A CT-scan can clearly show the position and size of a tumour, which helps doctors accurately target it during treatment using high energy X-rays or gamma rays.

SQ 20.4.9 What is the disadvantage of a CT-scan?

Disadvantage

CT-scans involve exposure to X-rays, which are a form of ionizing radiation. Although the amount is relatively low, it still carries a small risk to the patient.

SQ 20.4.10 How much radiation does a CT-scan deliver?

Answer

On average the radiation dose from a CT-scan is comparable to, or a few times greater than, one year of natural background radiation, or roughly equal to the dose received during four long-distance flights.

SQ 20.4.11 For which patients are special precautions taken during a CT-scan?

Answer

Doctors take special precautions especially when scanning pregnant women or patients with existing health concerns.

TOPIC 5 Positron Emission Tomography Scanning

SQ 20.5.1 How do medical imaging methods using ionizing radiation work?

Answer

They rely on how radiation interacts with matter. As photons pass through tissue they may be absorbed or scattered, and the pattern of energy deposition and attenuation produces measurable signals at a detector.

SQ 20.5.2 How does nuclear medicine differ from ordinary imaging?

Answer

In nuclear medicine the radiation originates inside the patient from an administered radiopharmaceutical, and the detected signal reflects physiological function rather than only anatomy.

SQ 20.5.3 Describe the SPECT technique.

Description

In SPECT a gamma-emitting tracer is introduced into the body and a rotating gamma camera records many projection views.

Result

These projections are reconstructed to form cross-sectional images of tracer distribution, providing 3D information about perfusion and organ function.

SQ 20.5.4 How does PET extend the idea of SPECT?

Answer

PET uses positron-emitting tracers. After emission the positron travels a short distance in tissue and annihilates with an electron, producing two gamma photons emitted in nearly opposite directions.

SQ 20.5.5 What is coincidence detection in PET?

Answer

Detecting the two gamma photons in coincidence allows the system to localize the event and reconstruct a quantitative map of tracer uptake.

SQ 20.5.6 What does PET image?

Answer

PET is a non-invasive technique that images metabolic and biochemical activity at the cellular or molecular level.

SQ 20.5.7 **Give the main uses of PET scanning.**

Uses

PET is highly valuable for early cancer detection and staging, for evaluating brain function, and for identifying cardiac abnormalities before clear anatomical changes appear.

SQ 20.5.8 **Describe the working of a PET scan.**

Working

A small amount of radioactive tracer is injected into a vein. The tracer is carried by the blood and builds up more in tissues that are very active, such as many cancers or working parts of the brain and heart.

Detection

As the unstable nuclei decay they emit positrons, which annihilate with electrons producing two gamma-ray photons detected by a ring of detectors.

SQ 20.5.9 **What do brighter areas on a PET image mean?**

Answer

Brighter areas on the PET image correspond to regions of higher tracer concentration, and therefore higher tissue activity.