24 Medical physics

24.1 Production and use of ultrasound

Candidates should be able to:	
1	understand that a piezo-electric crystal changes shape when a p.d. is applied across it and that the crystal generates an e.m.f. when its shape changes
2	understand how ultrasound waves are generated and detected by a piezoelectric transducer
3	understand how the reflection of pulses of ultrasound at boundaries between tissues can be used to obtain diagnostic information about internal structures
4	define the specific acoustic impedance of a medium as $Z = \rho c$, where c is the speed of sound in the medium
5	use $I_R / I_0 = (Z_1 - Z_2)^2 / (Z_1 + Z_2)^2$ for the intensity reflection coefficient of a boundary between two media
6	recall and use $I = I_0 e^{-\mu x}$ for the attenuation of ultrasound in matter

- **Piezo-electric** effect is the property exhibited by some nonconducting crystals of becoming electrically polarized when mechanically strained and of becoming mechanically strained when an electric field is applied.
- Piezoelectric crystals are materials that produce p.d. when they are deformed.
- When a p.d. is applied to the crystal it deforms and when revered it expands.
- If an AC is applied to the crystal it will vibrate at the same frequency.
- Quartz is the most common form of piezo crystals.
- An ultrasound transducer is made up of piezoelectric crystal.
- When the crystal is transmitting, it converts the pd into sound waves.
- When the crystal received the return wave, it converts the sound waves into AC.
- The signal is then process and used for medical diagnosis.
- The sound waves that are transmitted into the body are reflected back to the transducer by boundaries between tissues.
- When these echoes hit the transducer, the signals are sent to the ultrasound.
- Using the speed of sound and the time of each echo's return (time delay), the scanner calculates the distance from the transducer to the tissue boundary.
- This distance is used to generate 2D images of the internal structure of the body.
- The **acoustic impedance** (Z) of a medium is defined as **the product of the speed of the ultrasound in the medium and the density of the medium**

$$Z = \rho c$$

Here ρ is the density of the material (kgm^{-3}) and c is the speed of sound in the material (ms^{-1})

- At the boundary between media of different acoustic impedances, some wave energy is reflected while others are transmitted.
- The greater the difference of Z between the two media, the greater the reflection and the smaller the transmission.

- Materials with same Z would give no reflection.
- Materials with large Z difference would give much larger reflections.
- Intensity reflection coefficient (α) can be calculated from

$$\alpha = \frac{I_r}{I_0} = \frac{(z_2 - z_1)^2}{(z_2 + z_1)^2}$$

Here I_r is the intensity of the reflected wave (Wm^{-2}), I_0 is the intensity of the incident wave (Wm^{-2}), Z_1 acoustic impedance of one material ($kgm^{-2}s^{-1}$) and Z_2 acoustic impedance of the second material ($kgm^{-2}s^{-1}$).

- **Attenuation of ultrasound** is the reduction of energy due to the absorption of ultrasound as it travels through a material.
- It is expressed in decibels per centimetre.
- The equation for intensity (I) of the ultrasound can be found with

$$I = I_0 e^{-\mu x}$$

Here I_0 is the intensity of the incident beam (Wm^{-2}), μ is the absorption coefficient (m^{-1}) and x is the distance travelled through a material (m).

24.2 Production and use of X-rays

Candidates should be able to:

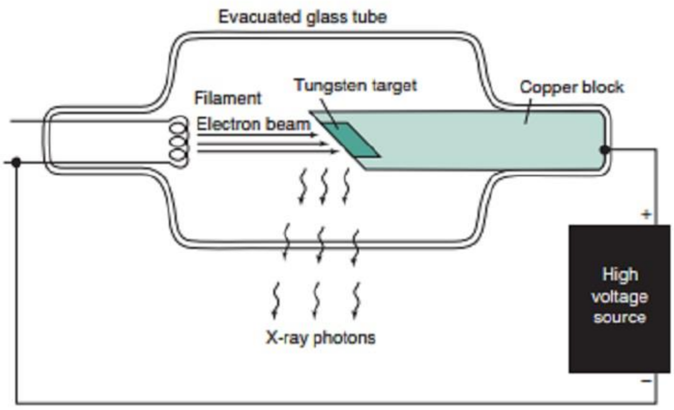
1 explain that X-rays are produced by electron bombardment of a metal target and calculate the minimum wavelength of X-rays produced from the accelerating p.d.

2 understand the use of X-rays in imaging internal body structures, including an understanding of the term contrast in X-ray imaging

3 recall and use $I = I_0 e^{-\mu x}$ for the attenuation of X-rays in matter

4 understand that computed tomography (CT) scanning produces a 3D image of an internal structure by first combining multiple X-ray images taken in the same section from different angles to obtain a 2D image of the section, then repeating this process along an axis and combining 2D images of multiple sections

- X-rays are created when high KE electrons bombard the surface of a metal.
- Their wavelengths range from 10^{-8} to 10^{-13} m
- In the cathode of an x-ray tube, the electrons are released through thermionic emission.
- The electrons are then accelerated at high p.d. towards the anode.
- They then collide with the metal target.
- The sudden deceleration upon collision produces x-rays.
- X-rays are produced when the bombarding electrons knock of an electron out of an inner shell of the target metal atoms.
- The electrons from higher states drop down to fill the vacancy emitting x-ray photons.



- The minimum wavelength produced from the accelerating p.d. is equal to

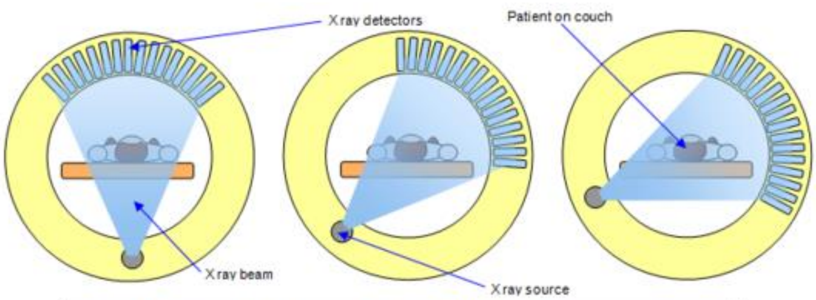
$$\lambda_{min} = \frac{hc}{eV}$$

  Here e is the charge of an electron (C), V is the voltage across the anode (V, h is Planck's constant (6.63×10^{-34} Js) and c is the speed of light.
- X-rays are used in imaging internal body structures.
- **Contrast** allows a clear difference between tissues to be seen.
- Bones absorb X-rays and therefore appear white on an x-ray photograph.
- As the radiation pass through the body, they are absorbed and scattered.
- The attenuation of the radiation can be calculated using the equation

$$I = I_0 e^{-\mu x}$$

  Here I is the intensity of the reflected beam (Wm^{-2}), I_0 is the intensity of the incident beam (Wm^{-2}), μ is the linear absorption coefficient (m^{-1}) and x is the distance travelled through the material (m)

- While x-ray imaging can only produce 2D images, a CAT scan can produce a 3D image.
- A CAT scan works by having an x-ray tube rotate around a stationary patient.
- The scanner takes images of the same slice at many different angles.
- This process is then repeated for different slices.
- A software is then used to piece the images together to build a 3D image.



CT scanner with the X ray source and detectors shown in three positions

24.3 PET scanning

Candidates should be able to:

1 understand that a tracer is a substance containing radioactive nuclei that can be introduced into the body and is then absorbed by the tissue being studied

2 recall that a tracer that decays by β^+ decay is used in positron emission tomography (PET scanning)

3 understand that annihilation occurs when a particle interacts with its antiparticle and that mass-energy and momentum are conserved in the process

4 explain that, in PET scanning, positrons emitted by the decay of the tracer annihilate when they interact with electrons in the tissue, producing a pair of gamma-ray photons travelling in opposite directions

5 calculate the energy of the gamma-ray photons emitted during the annihilation of an electron-positron pair

6 understand that the gamma-ray photons from an annihilation event travel outside the body and can be detected, and an image of the tracer concentration in the tissue can be created by processing the arrival times of the gamma-ray photons

- A **radioactive tracer** is a **substance that can be absorbed by tissue in order to study the tissue**.
- **Positron Emission Tomography (PET)** is an **imaging test that uses radiotracers to visualize tissues and organs by measuring changes in metabolic processes.**
- A common radiotracer used in PET is fluorodeoxyglucose.
- The fluorine nuclei undergo **B^+ decay** emitting **positron**.
- These tracers are usually orally ingested or injected into patients.
- Once inside the patient's body, they appear on the screen as a bright area for diagnosis.
- Upon entering the body, the short half-life of the tracer emits positrons immediately.
- The positrons travel less than 1mm before it collides with an electron.
- This will result in **annihilation** between the particle and antiparticle.
- The annihilation produces pure energy and mass-energy and momentum are conserved.
- The annihilation produces a pair of gamma-ray photos travelling in opposite directions.
- Since mass-energy and momentum are conserved the gamma-ray photons produces have an energy and frequency that can be determined from

$$E = hf = m_e c^2$$

$$p = \frac{E}{c}$$

Here m_e is the mass of an electron in (kg)

- The gamma-ray photons travel outside the body and hit detectors in a line known as the line of response.

- The more photons from a single point, the more tracer that is present in the tissue being studied and will appear brighter on the image.
- The image of the tracer concentration can be created by processing the arrival times of the gamma-ray.