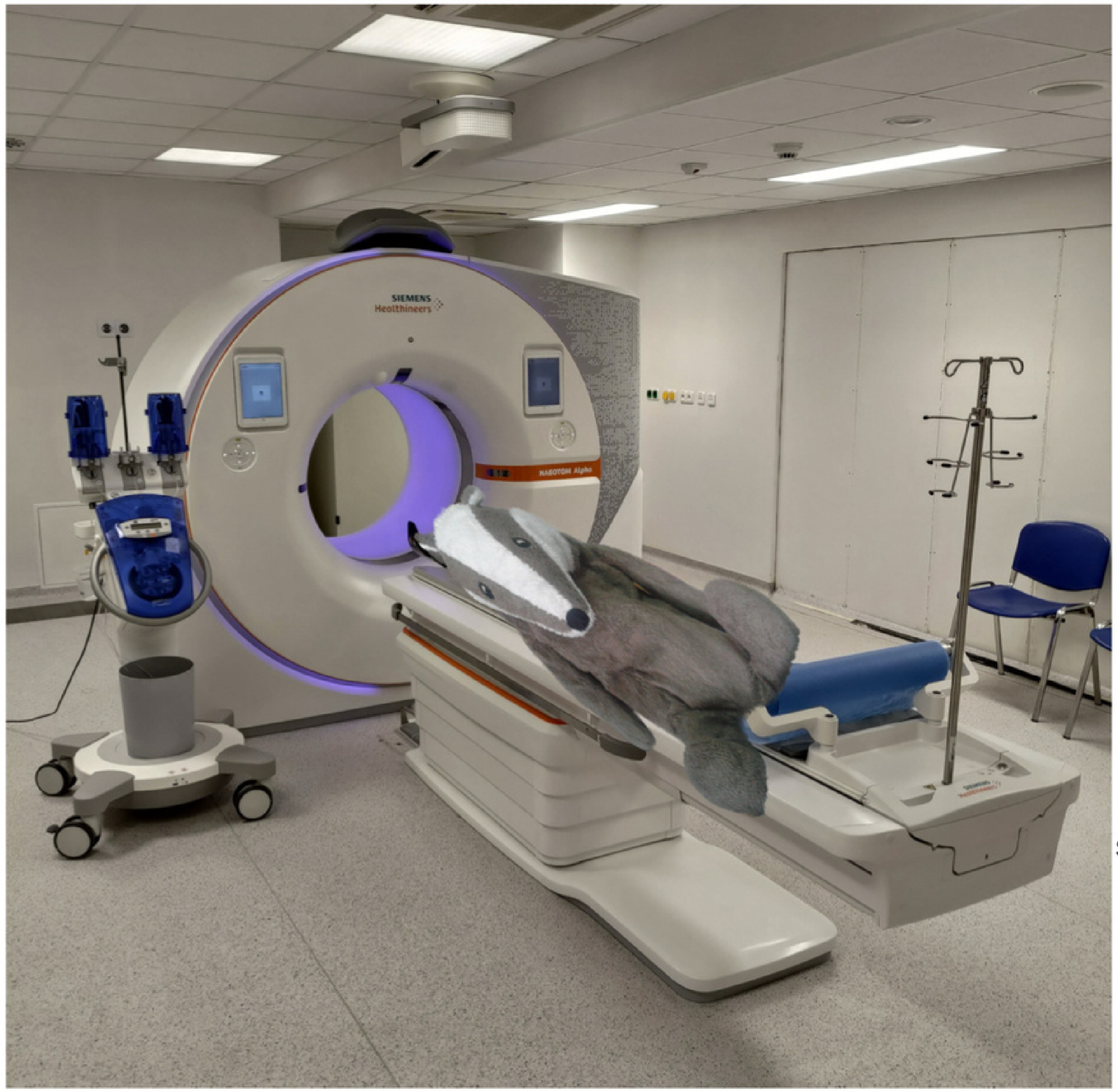
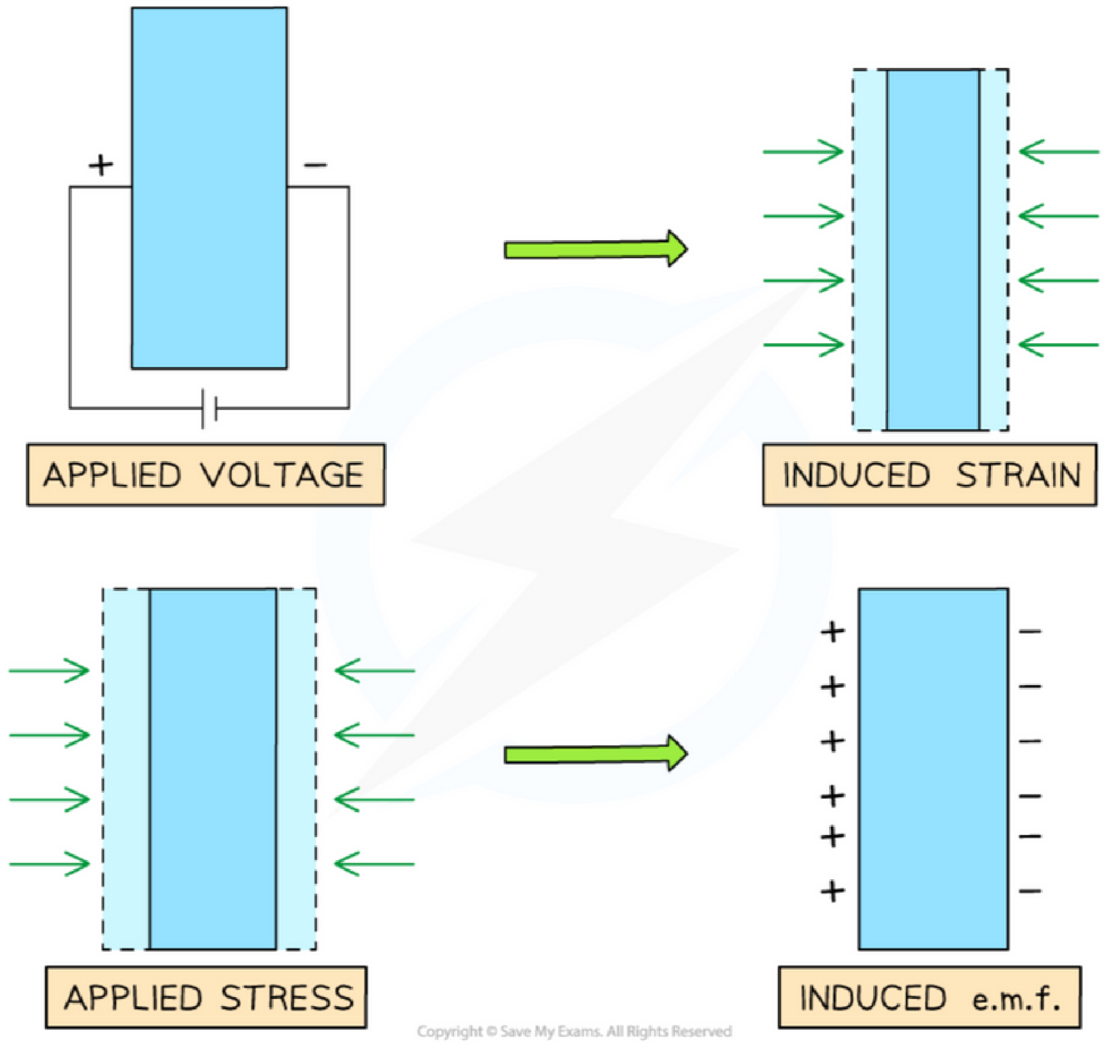
9702 C24 Medical physics



Piezoelectric Transducer

piezo electric effect = ability of particular materials to generate a p.d. by transferring mechanical energy to electrical energy



When piezoelectric crystals:

1.Deformed(compression/expansion) --> produce a p.d.

2.p.d. applied -->deformed(compression/expansion)

3.alternating p.d. --> vibrate at same frequency as the altnerating voltage (resonance can be induce if crystals are cut at a certain size)

transducer is device made up of piezoelectric crystal(e.g. quartz). It is a device convert energy from one form to another

Ultrasound

ultrasound = a high frequency(>20000Hz) sound above the range of human hearing

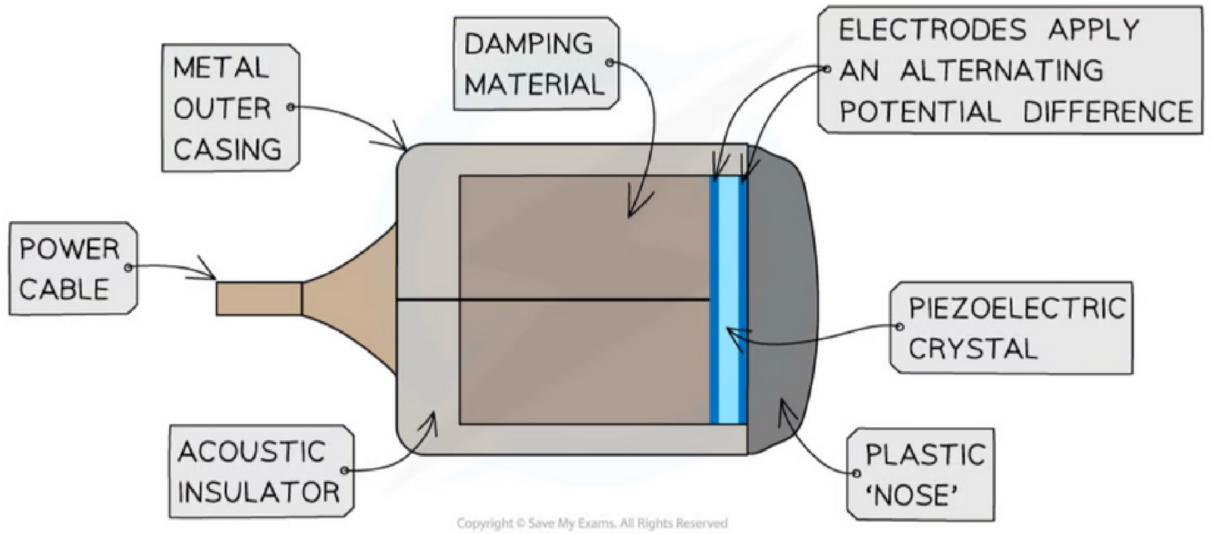
ultrasound tranducer is made up of piezoelectric crystal and electrodes which produce an alternating p.d.

-->crystal is heavily damped, usually with epoxyresin, to stop crystal from vibrating too much (so produces short pulses + inc resolution)

<u>A piezoelectric crystal can act as both a reciever or transmitter of ultrasound:</u>

recieving ultrasound = sound waves --> alternating p.d.

transmitting ultrasound = alternating p.d. --> sound waves



1.alternating p.d. applied across piezoelectric crystal, causing it to change shape(deform)

2.alterning p.d. causes crytal to vibrate and produce ultrasound waves

3.crystal vibrates at the frequency of the alterning p.d. so crystals must be cut to a certain size to produce resonance

4.when ultrasound wave returns, crystal vibrates which produces an alternating p.d. across the crystal

5.this recieved signals which can then be process for medical diagnosis

Ultrasound Imaging

1.Transducer(piezoelectric crystal) emits a pulse of ultrasound to tissue

2. The pulse of ultrasound reflects at boundaries in the body

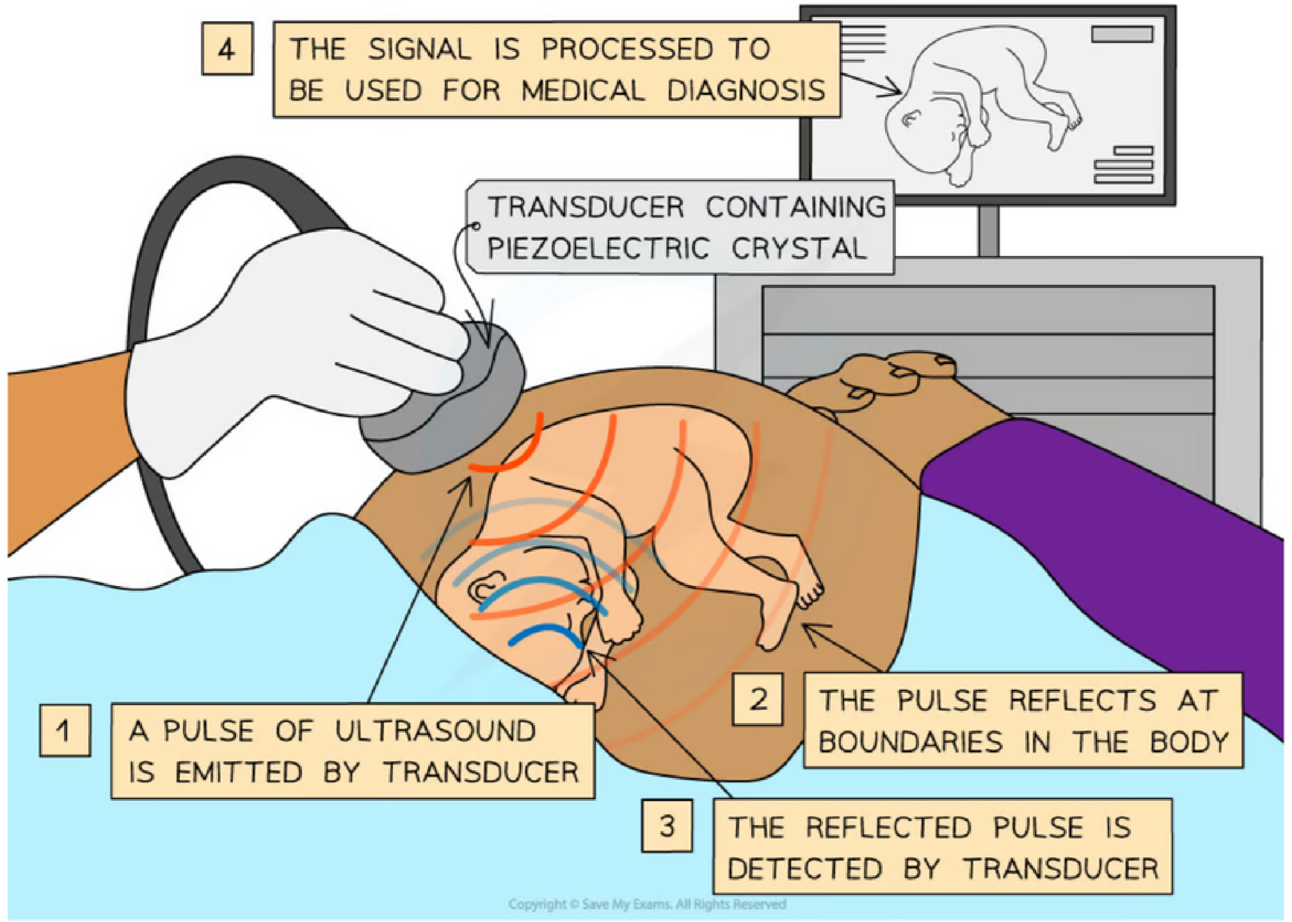
3.The reflected pulse is detected by transducer

4.The signal is processed and displayed so that it can be used for medical diagnosis

Depth of the boundary= time between transmission and receipt of the pulse(i.e. time delay)

Nature of the boundary = amount of transmitted intensity recieved (i.e. reflected intensity)

inc frequency of ultrasound = inc resolution



see next page

- Air has an acoustic impedance of $Z_{air} = 400\ kg\ m^{-2}\ s^{-1}$
- Skin has an acoustic impedance of $Z_{skin} = 1.7 \times 10^6\ kg\ m^{-2}\ s^{-1}$

large difference Z = large ultrasound reflect

Therefore coupling gel is used as coupling gel has similar z to skin. So that **little reflection when waves travel in or out of the body**

Specific Acoustic Impedance

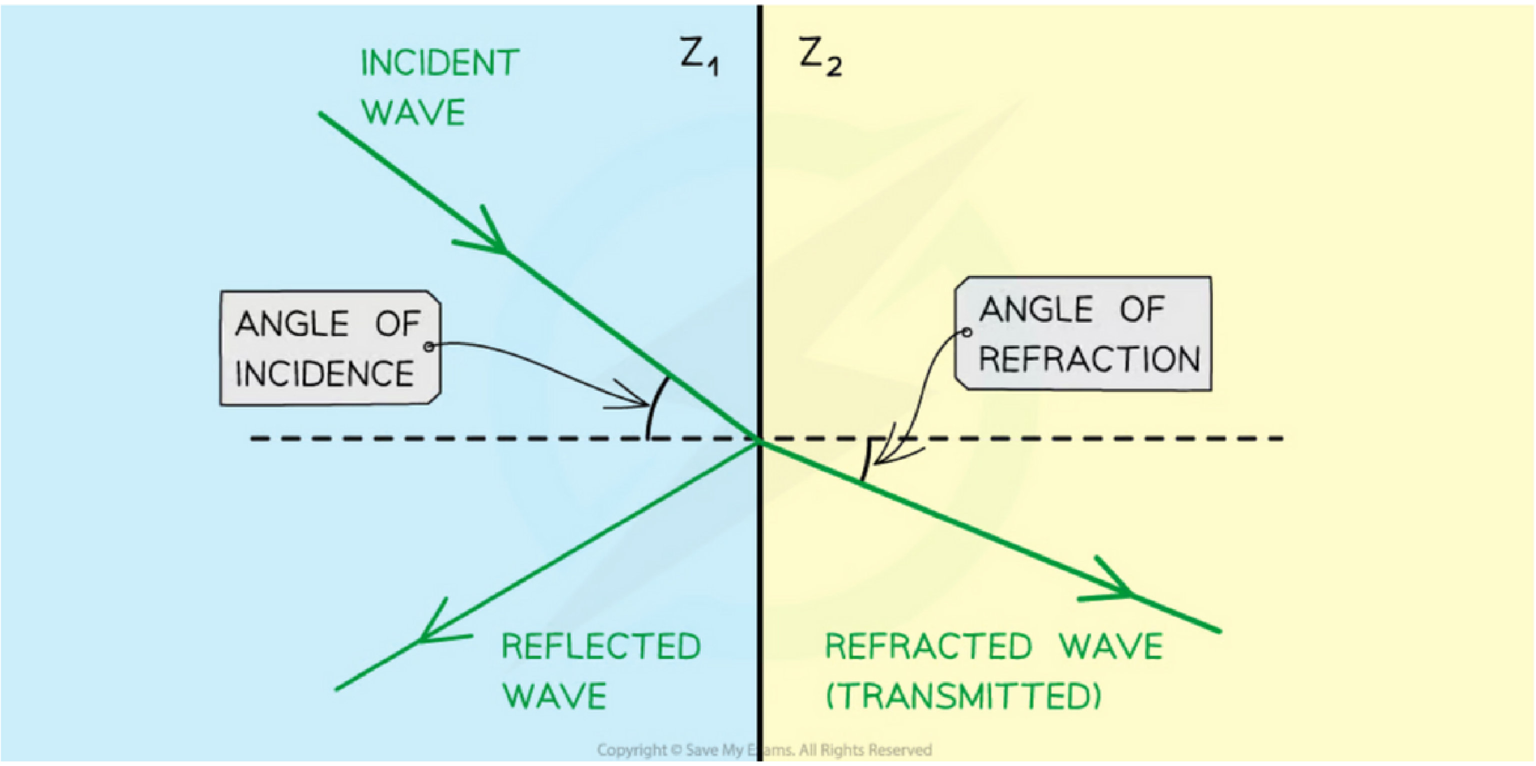
acoustic impedance(Z) = product of speed of ultrasound(wave) in medium and density of medium = Z=ρc

$$Z = \rho c$$

Where:

- Z = acoustic impedance ($kg\,m^{-2}\,s^{-1}$)
- ρ = the density of the material ($kg\,m^{-3}$)
- c = the speed of sound in the material ($m\,s^{-1}$)

denser materials = faster sound can travel



intensity reflect coefficient(α) = ratio of intensity of reflected wave relative to incident(transmitted) wave

$$\alpha = \frac{I_r}{I_0} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

incident intensity = transmitted intensity + reflected intensity

Where:

- α = intensity reflection coefficient
- I_R = intensity of the reflected wave ($W\,m^{-2}$)
- I_0 = intensity of the incident wave ($W\,m^{-2}$)
- Z_1 = acoustic impedance of one material ($kg\,m^{-2}\,s^{-1}$)
- Z_2 = acoustic impedance of a second material ($kg\,m^{-2}\,s^{-1}$)

$\alpha < 1$, $(Z_2 - Z_1)^2$ small = mostly transmission

$\alpha > 1$, $(Z_2 - Z_1)^2$ large = mostly reflection

$\alpha = 0$ = no reflection

Attenuation of Ultrasound in Matter

attenuation of ultrasound = reduction of energy due to the absoprtion of ultrasound as it travels through a material

attenuation coefficient of ultrasound is expressed in **<u>decibels per centimetre</u>** lost for every increase in MHz (generally 0.5dB/cm is lost for every 1Hz)

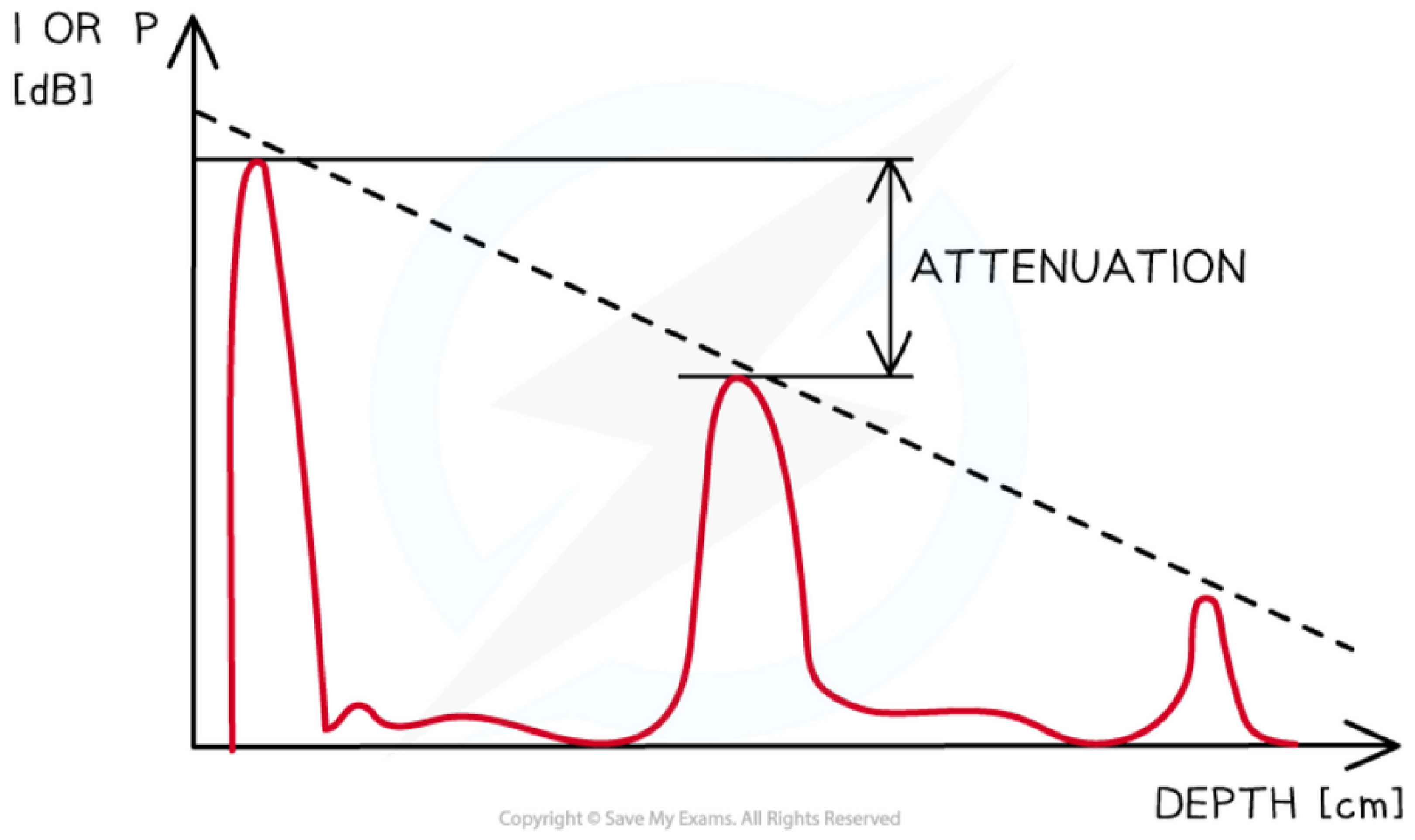
$$I = I_0 e^{-\mu x}$$

Where:

- I_0 = the intensity of the incident beam ($W\,m^{-2}$)
- I = the intensity of the reflected beam ($W\,m^{-2}$)
- μ = the absorption coefficient (m^{-1})
- x = distance travelled through the material (m)

absorption coefficient is the same as attenuation coefficient

$$\text{absorption \%} = 100\% - \text{reflection \%}$$
$$= 100\% - \left(\frac{I}{I_0} \times 100\right)$$



Production and Use of X-rays

X-rays are produced when bombarded **electron rapidly decelerate and transfer Ek into photons** of EM radiation

X-rays - single exposure

$$E_{max} = eV = hf_{max} = \frac{hc}{\lambda_{min}}$$

Maximum frequency: $f_{max} = \frac{eV}{h}$

Minimum wavelength: $\lambda_{min} = \frac{hc}{eV}$

Where:

- e = charge of an electron (C)
- V = voltage across the anode (V)
- h = Planck's constant (J s)
- c = speed of light ($m\ s^{-1}$)

(longer wavelength of X-ray are more penetrating and more dangerous)

x-rays are ionising - can cause mutations to body cells

x-rays provide detailed image of soft tissue

when treating patients, the aims are to:

1.reduce expore to radiation as much as possible -by using aluminium filters to absorb long wavelength X-rays

2.improve contrast of the image - using the correct level of X-ray hardness(hard X-rays for bones, soft X-rays for tissue) + using a contrast media

contrast = difference in ° of blackening between structures

-->high contrast = absorption coefficient is very difference

sharpness=how well defined the edge of structures are → improve by using a narrower X-ray beam + reducing X-ray scattering by using a collimator or lead grid + smaller pixel size

Attenuation of X-rays in Matter

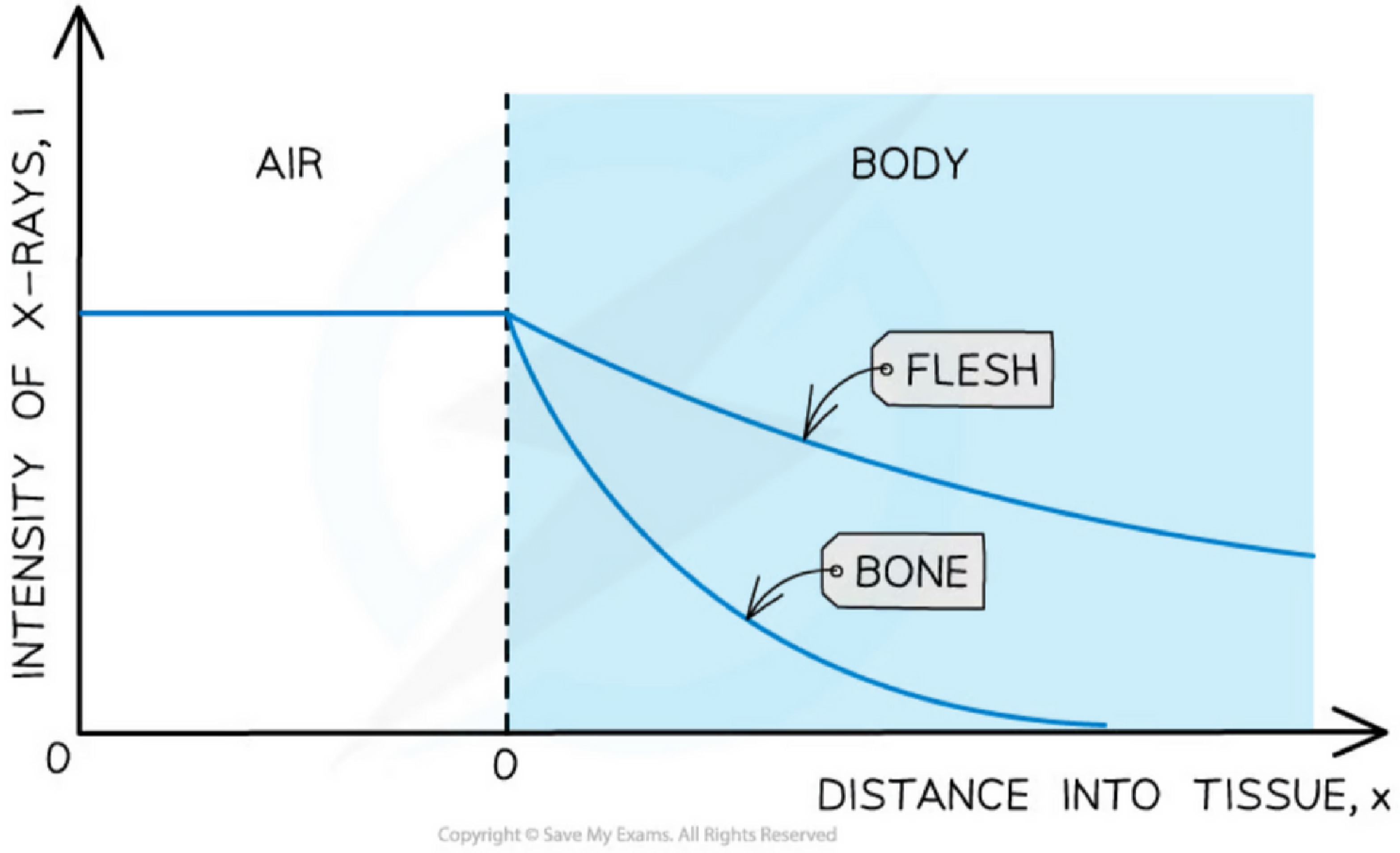
Bones absorb X-ray radiation - this is why they appear white on X-ray photograph

when collimated beam of X-rays passes through the body, there are absorbed and scattered

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

Where:

- I_0 = the intensity of the incident beam ($W m^{-2}$)
- I = the intensity of the reflected beam ($W m^{-2}$)
- μ = the absorption coefficient (m^{-1})
- x = distance travelled through the material (m)



CT Scan

Computed Tomography(CT) or Computerised axial tomography(CAT) scan is type of X-ray medical device

How CT Scan works?

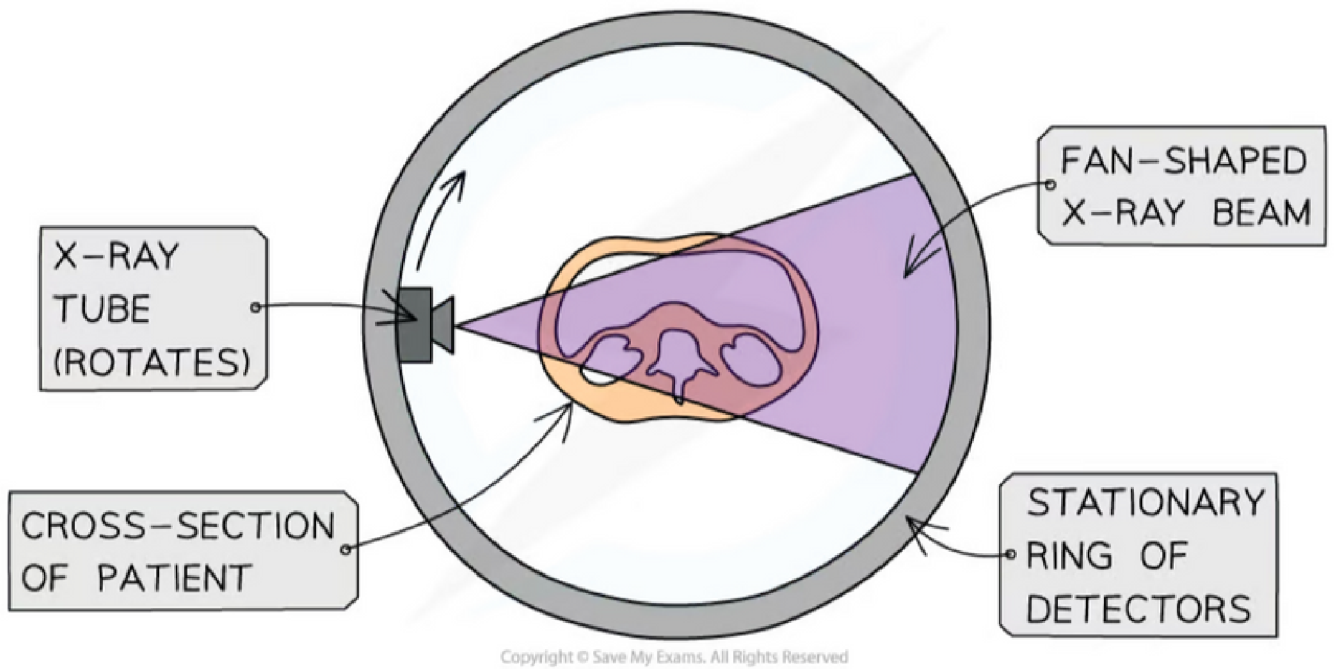
1.X-ray tube rotates around stationary patient

2.CT scanner takes X-ray images of the same slice, at many different angles

3.This process is repeated, then images of successive slices are combined togehter

4.Computer pieces the images together to build a 3D image - 3D image can be viewed from different angles

Advantages	Disadvantages
Produces a 3D image of body	Exposure to ionising radiation more normal X-ray
Can distinguish between tissues with similar attenuations coefficients	More expensive than normal X-ray
Produces more detailed images	Possible side effects from contrast media



PET Scan

Positron Emission Tomography(PET) is a type of nuclear medical procedure that images tissues and organs by measuring the metabolic activity of the cells of body tissues

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

A **radioactive tracer** that **decay by positive beta decay is used in PET scanning** e.g. fluorodeoxyglucose

-->fluorine nuclei undergoes positive beta decay - emitting a positron

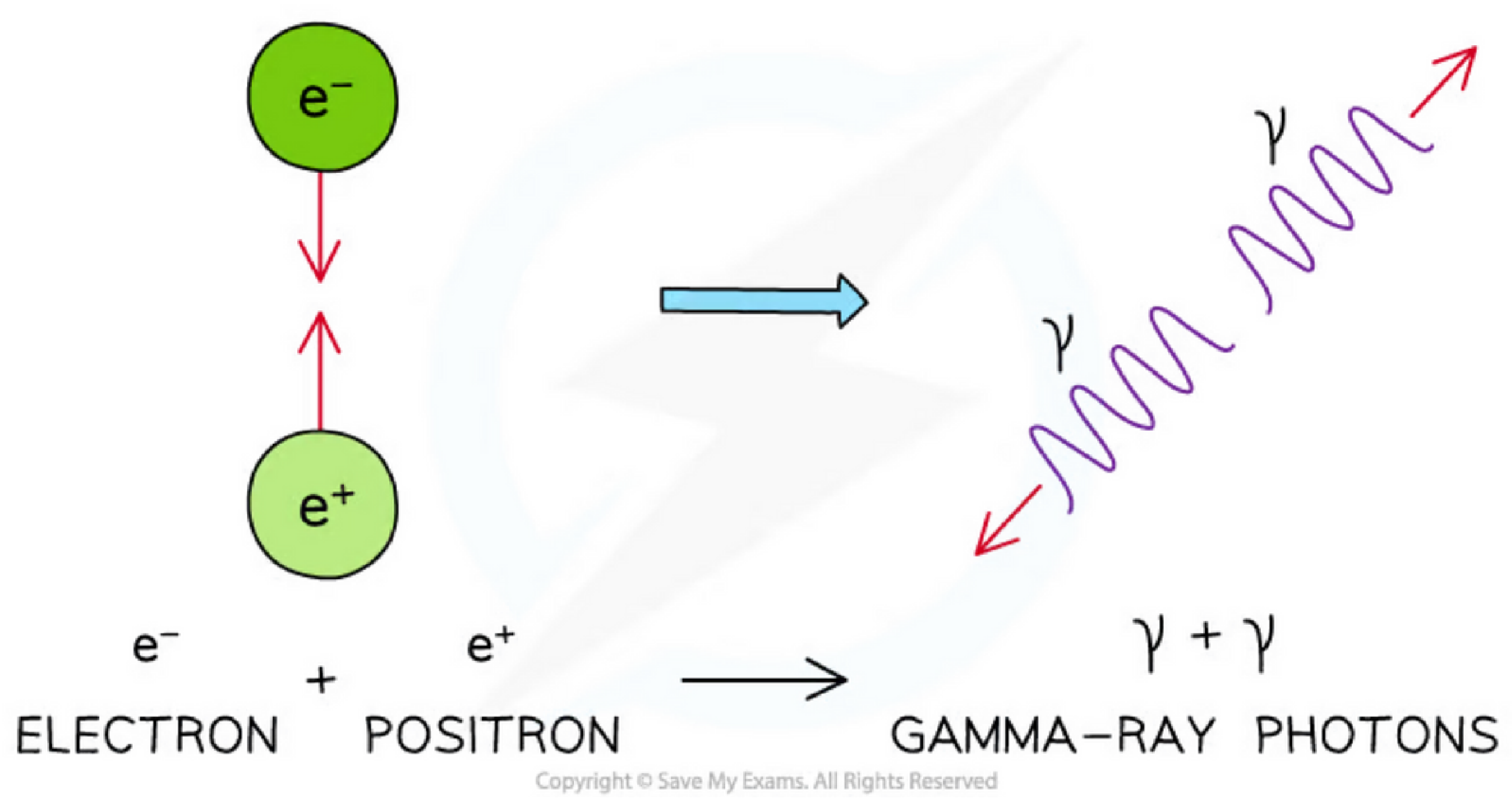
-->radioactive tracer is useful as they binds to organic molecules present in body e.g. glucose/water, so that PET scan can be visualise

When a positron is emitted from a tracer in the body, it travel less than 1mm before it collides with an electron

Positron and electron will annihilate, and their **mass becomes pure energy** in the form of two γ-rays which move apart in opposite directions

Annihilation also happen with other particles:

Annihilation = when a particle meets its equivalent antiparticle they are both destroyed and their mass is converted into energy



(all collsions: mass,energy and momentum are conserved)

The energy E of the photon is given by

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

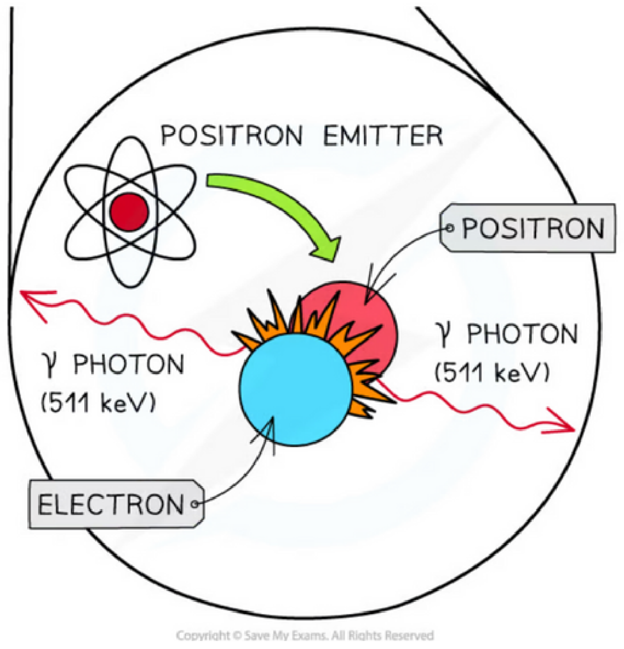
The momentum p of the photon is given by

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

Where:

- m_e = mass of the electron or positron (kg)
- h = Planck's constant (J s)
- f = frequency of the photon (Hz)
- c = the speed of light in a vacuum ($m\,s^{-1}$)

Scanning and Detection of PET Scanning



1.Tracer is introduce to the body so it begins emitting positrons

-->tracer should have a short half-life as much as possible to reduce radiation exposure time

2.Positrons travel a small distance(<1mm) and **annihilate** when they interact with electrons in the tissue

3.Annihilation produces a pair of γ-ray photons which travel in opposite directions (to conserve momentum)

4.γ-ray photon is incident on a **crytal scintillator**, an electron in the crystal is excited to a higher energy state, as the excited electron travels through the crystal, it excites more electrons

5.When the excited electrons move back down to their original state, the lost energy is transmitted as visible light photons

6.**Photomultiplier tube** is then amplified and converted visible light photons to an electric signal