

A2 PHYSICS 9702

Crash Course

PROSPERITY ACADEMY

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MEDICAL PHYSICS

COMPLETE NOTES



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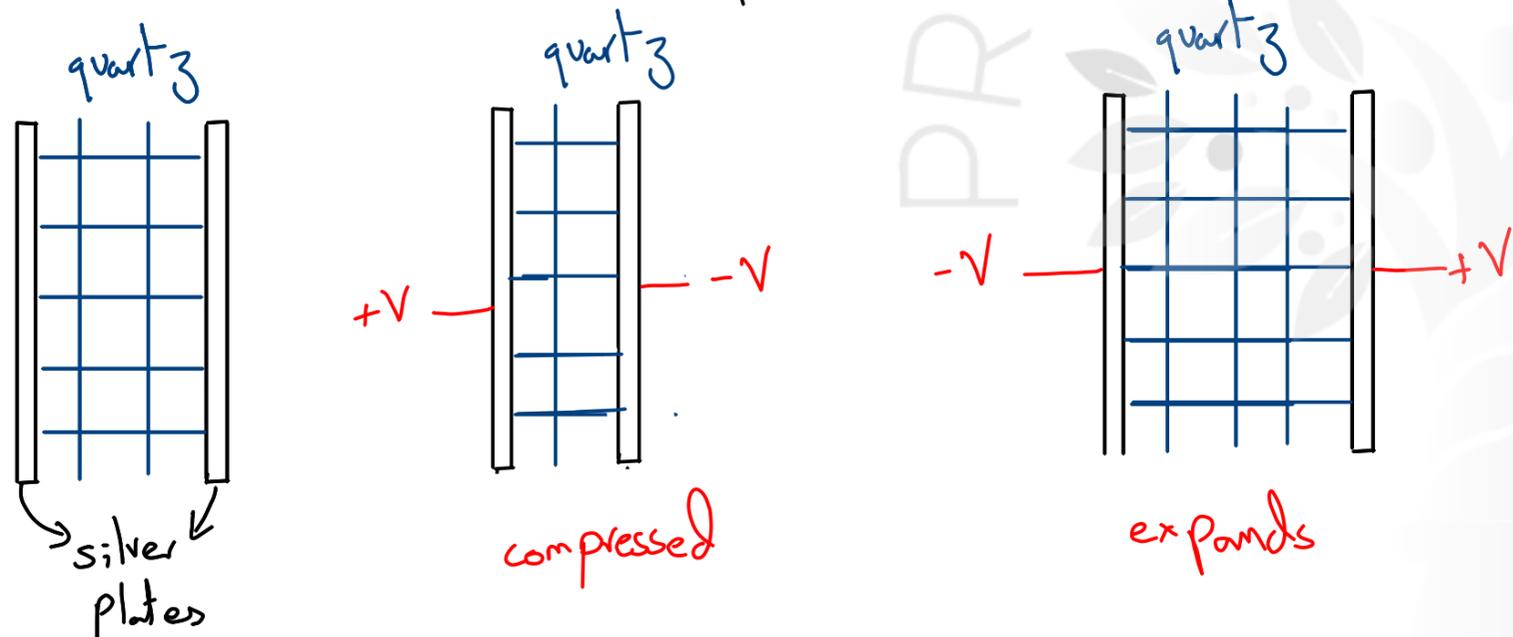


Ultrasounds:-

Sound waves of frequencies greater 20 KHz

Medical diagnosis:- 400 KHz - 600 MHz $[I \propto f^2]$

How are ultrasounds produced?



- Quartz is sandwiched between 2 silver plates (Piezoelectric crystal)

- Quartz has a complex tetrahedral structure

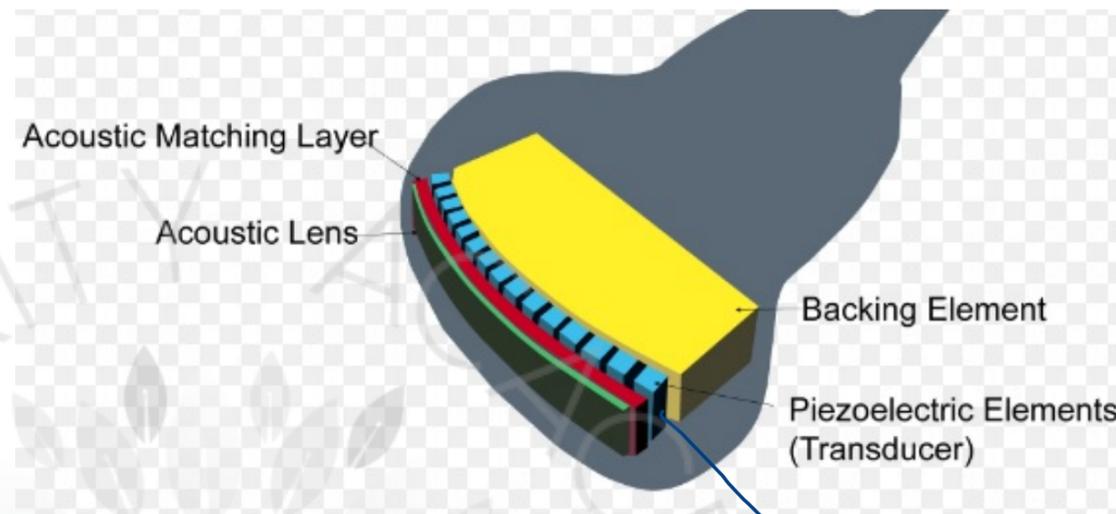
- made up of Si and O

- the Si and O atoms are not coincident

11 Explain the main principles behind the generation of ultrasound to obtain diagnostic information about internal body structures.

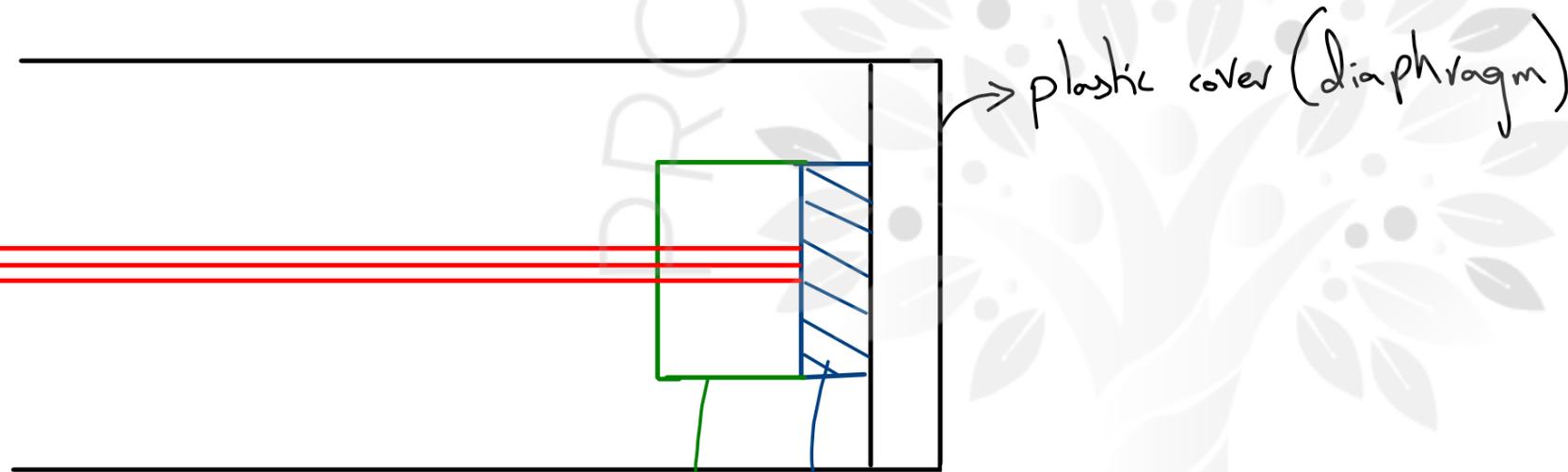
Piezoelectric crystal are used to produce ultrasounds. Piezoelectric crystals are made up of quartz and they are sandwiched between 2 silver plates. As the silicon and oxygen atoms in quartz are not coincident, the application of an alternating voltage causes the crystal to compress and expand periodically. The crystal is cut so that its natural frequency matches the driver frequency and it resonates. This resonance produces high amplitude ultrasounds.

Ultrasound probe (transceiver)



Backing Element
Piezoelectric Elements (Transducer)

→ You have an array of crystals.



→ plastic cover (diaphragm)

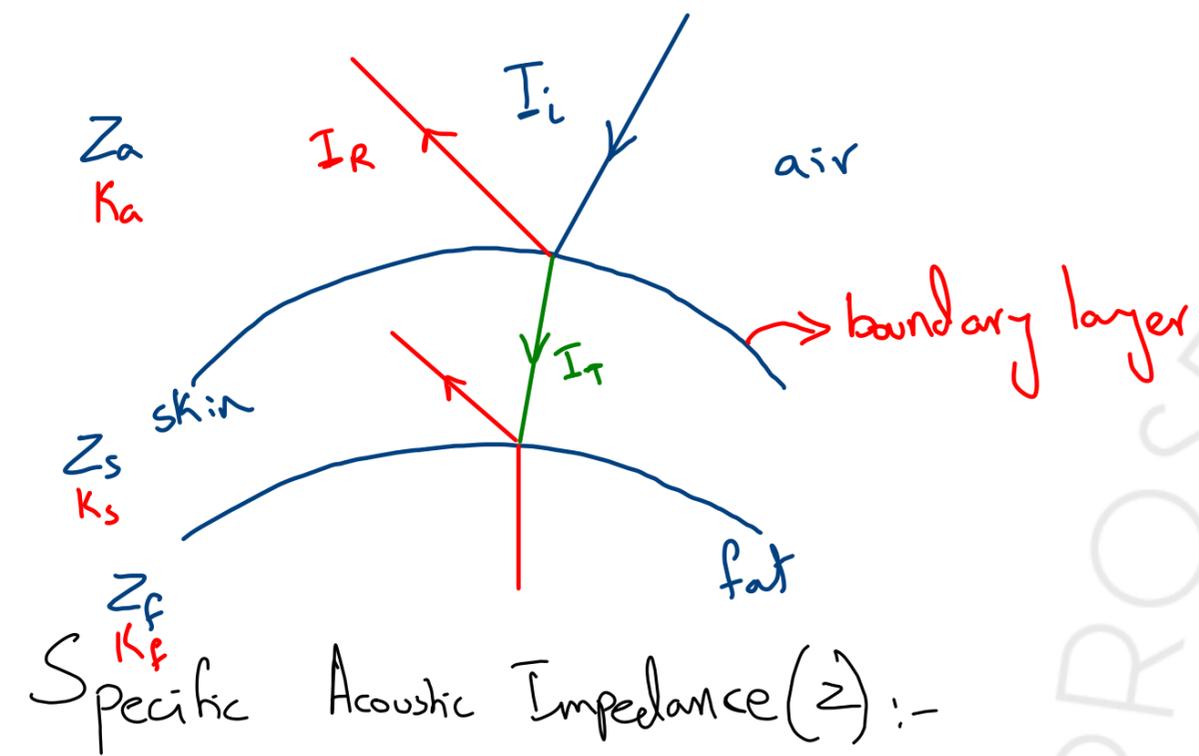
→ piezo electric crystals

coaxial cable

(duplex transmission:- transmits and receives simultaneously)

- backing material:-
- 1) prevents backward emitted sound
 - 2) prevents echoes
 - 3) ensures coupling:- propagation from coaxial cable to piezoelectric crystal

Calculations:-



Specific Acoustic Impedance (Z):-

$$Z = \rho \times c$$

The product of the density of the medium into the speed of sound in that medium

Absorption coefficient / linear attenuation coefficient (K):-

$$I = I_0 e^{-Kx} \quad (\text{decay equation})$$

The absorption coefficient multiplied by the distance travelled in a medium is the exponent e is raised to in the decay equation.

x : distance travelled in tissue

1) As ultrasounds propagate through a medium, they attenuate (using the decay equation).

2) At every boundary layer, some of the ultrasound is transmitted while some is reflected

3) The fraction of the reflected sound is given by:-

Intensity reflection coefficient (α):-

$$\alpha \text{ (factor reflected)} = \frac{I_R}{I_i} = \left(\frac{\Delta Z}{\Sigma Z} \right)^2$$

Using for air-skin boundary:-

$$\frac{I_R}{I_i} = \alpha = \left(\frac{Z_a - Z_s}{Z_a + Z_s} \right)^2$$

$$* \text{ factor transmitted} = \frac{I_T}{I_i} = (1 - \alpha)$$

$$* I_i = I_R + I_T$$

Q. Calculate the intensity at D in terms of I_0 .

$$Z_f = 1.38 \times 10^6 \text{ Kg m}^2 \text{ s}^{-1}$$

$$Z_m = 1.70 \times 10^6 \text{ Kg m}^2 \text{ s}^{-1}$$

$$K_f = 3.0 \text{ m}^{-1}$$

$$K_m = 23.0 \text{ m}^{-1}$$

$$\alpha = \left(\frac{\Delta Z}{\Sigma Z} \right)^2 = \left[\frac{(1.7 - 1.38) \times 10^6}{(1.7 + 1.38) \times 10^6} \right]^2$$

$$\frac{I_R}{I_i} = \alpha = 0.01079$$

$$I_R = 0.1079 I_i$$

$$① I = I_0 e^{-Kx}$$

$$I_A = I_0 e^{-3(3)} \Rightarrow I_A = I_0 e^{-9}$$

② factor transmitted at A:-

$$(1 - \alpha) = \frac{I_T}{I_i} \Rightarrow (1 - 0.01079) \times I_i = I_T$$

$$I_T = (0.98921) I_i$$

$$I_T = (0.98921) (e^{-9}) I_0$$

③ Attenuation in 4m of muscle:-

$$I = I_0 e^{-Kx}$$

$$I = (0.98921) (e^{-9}) I_0 (e^{-23(4)})$$

$$I = (0.98921) (e^{-9}) (e^{-92}) I_0$$

Shortcut method:-

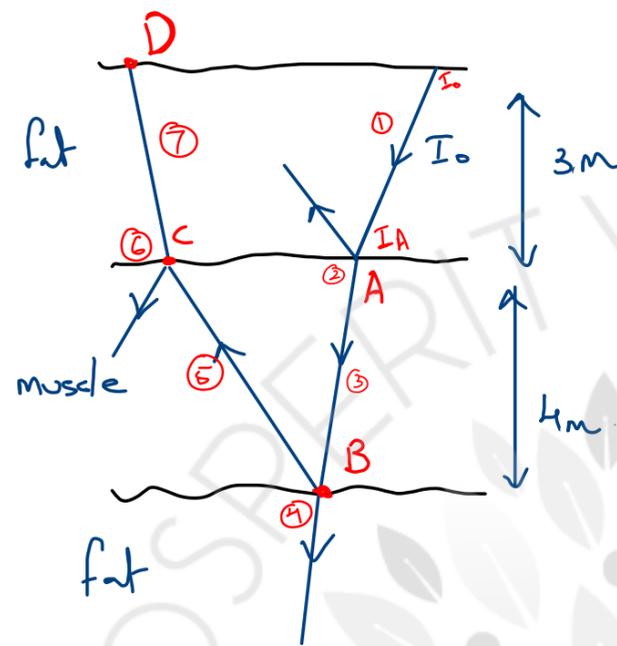
① 2 attenuations in 3m of fat:- $[e^{-3(3)}]^2$

② 2 transmissions across fat-muscle boundary:- $(1 - \alpha) = (0.98921)^2$

③ 2 attenuations in 4m of muscle:- $[e^{-23(4)}]^2$

④ 1 reflection at fat-muscle boundary:- $\alpha = (0.1079)$

$$I = (e^{-9})^2 \times (0.98921)^2 \times (e^{-92})^2 \times (0.1079) \times I_0$$



④ factor reflected at B

$$\alpha = \frac{I_R}{I_i} \Rightarrow I_R = \alpha \times I_i$$

$$I_R = (0.1079) (0.98921) (e^{-9}) (e^{-92}) I_0$$

⑤ Attenuation in 4m of muscle:-

$$I = I_0 e^{-Kx}$$

$$I = (0.1079) (0.98921) (e^{-9}) (e^{-92}) I_0 (e^{-92})$$

$$I = (0.1079) (0.98921) (e^{-9}) (e^{-92})^2 I_0$$

⑥ factor transmitted at C:-

$$\frac{I_T}{I_i} = (1 - \alpha) \Rightarrow I_T = (1 - \alpha) I_i$$

$$I_T = (0.1079) (0.98921)^2 (e^{-9}) (e^{-92})^2 I_0$$

⑦ Attenuation in fat for 3m:-

$$I = I_0 e^{-Kx}$$

$$I_D = (0.1079) (0.98921)^2 (e^{-9})^2 (e^{-92})^2 I_0$$

Q2. Find intensity at G in terms of I_0

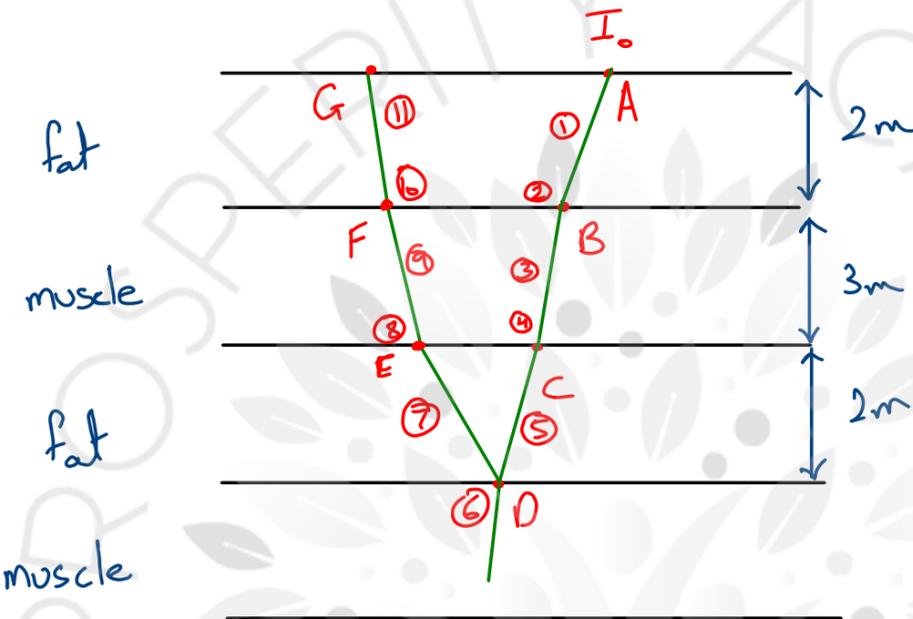
$$Z_f = 1.38 \times 10^6 \text{ Kg m}^2 \text{ s}^{-1}$$

$$Z_m = 1.70 \times 10^6 \text{ Kg m}^2 \text{ s}^{-1}$$

$$K_f = 3.0 \text{ m}^{-1}$$

$$K_m = 23.0 \text{ m}^{-1}$$

$$\alpha = \left(\frac{\Delta Z}{\Sigma Z} \right)^2 = \left[\frac{(1.70 - 1.38) \times 10^6}{1.70 + 1.38 \times 10^6} \right]^2 = 0.1079 = \alpha$$



Shortcut method:-

- ① Attenuating in 2m of fat $\times 4$:- $(I = I_0 e^{-Kx}) \rightarrow (e^{-3(2)})^4$
- ② Transmission across fat-muscle boundary $\times 4$:- $\frac{I_T}{I_i} = (1 - \alpha) = (1 - 0.1079)^4$
- ③ Attenuating in 3m of muscle $\times 2$:- $e^{-Kx} \Rightarrow [e^{-23(3)}]^2$
- ④ Reflecting across fat-muscle boundary $\times 1$:- $\frac{I_R}{I_i} = \alpha = (0.1079)^1$

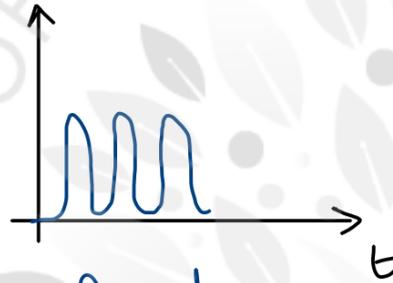
$$I = I_0 (e^{-6})^4 (0.98921)^4 (e^{-69})^2 (0.1079)$$

Ultrasound imaging:-

1) A-Scan:- (Along one line of action)

- the intensity received back at the probe gives us an idea of the nature of the boundary

- You send periodic pulses of ultrasounds

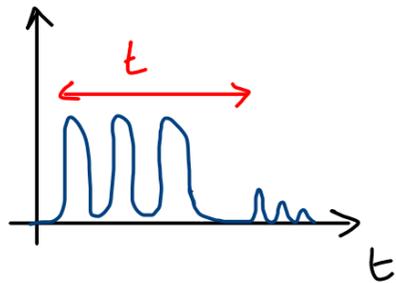


- In each layer the ultrasound attenuates and at each boundary layer ultrasounds are reflected

↳ this is received back at the probe

B Scans:- (Along multiple lines of action)

- Multiple A-scans at different



- the time delay between reflected pulses gives us the depth of the boundary

$$\text{distance} = \text{speed} \times \frac{\text{time}}{2} \quad (\text{echolocation})$$

Advantages of Ultrasound:-

- cheap
- Quick
- reliable
- does not cause anxiety / claustrophobia
- easy to use (less training required)
- Use higher frequencies of ultrasounds to produce more detailed images
- modern medicine has introduced colourful ultrasounds
- portable
- does not cause dosage of patient

Disadvantages of Ultrasound:-

- Cannot produce very fine images like CT scans
- Cannot be used to examine dense structures

- 8 (a) Outline the use of ultrasound to obtain diagnostic information about internal body structures.

① pulses of ultrasound are generated and directed
 ② into the body. They reflect at each boundary layer
 attenuate in every layer. Upon reflection, the
 ③ signals are received back and processed. The time
 ④ delay between pulses gives the depth of the
 boundary while the intensity of the received
 ⑤ signal gives idea of the nature of the boundary
 layer. [5]

- (b) The intensity I of a parallel beam of ultrasound is related to its initial intensity I_0 and the thickness x of the medium through which it has travelled by the relation

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

where μ is a constant for the medium.

Fig. 8.1 shows the constant μ for different media.

medium	μ/m^{-1}
blood	2
bone	130
muscle	23

Fig. 8.1

- (i) Use the information in Fig. 8.1 to suggest why

1. ultrasound is not used to examine structures within bones,

* Ultrasounds cannot penetrate bones easily due to their large μ . Most of the ultrasounds will get reflected at the muscle-bone boundary

2. bones may be at risk when using high intensities of ultrasound to treat diseased joints.

* Ultrasounds will be absorbed by the bone and there is a chance of fracture/heating up of bone [4]

- (ii) Determine the ratio

fraction of intensity of ultrasound transmitted through 10 mm of muscle $\rightarrow I/I_0$
 fraction of intensity of ultrasound transmitted through 10 mm of bone $\rightarrow I/I_0$

muscle:-

$$\begin{aligned}
 I &= I_0 e^{-\mu x} \\
 \frac{I}{I_0} &= e^{-\mu x} \\
 \frac{I}{I_0} &= e^{-23(10 \times 10^{-3})}
 \end{aligned}$$

bone:-

$$\begin{aligned}
 \frac{I}{I_0} &= e^{-\mu x} \\
 &= e^{-130(10 \times 10^{-3})} \\
 &= 2.9
 \end{aligned}$$

ratio = [3]

$$\frac{e^{-23(10 \times 10^{-3})}}{e^{-130(10 \times 10^{-3})}}$$

7 (a) Explain briefly the **use** of ultrasound to obtain diagnostic information about internal body structures.

Done



[5]

(b) The variation of the intensity I of a parallel beam of ultrasound with the thickness x (measured in metres) of a muscle is given by the expression

$$I = I_0 e^{-23x},$$

where I_0 is the initial intensity.

Calculate the fractional intensity $\frac{I}{I_0}$ transmitted through a muscle of thickness 5.5 cm.

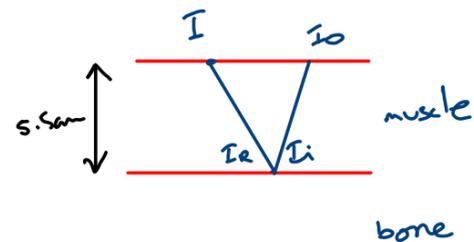
$$\frac{I}{I_0} = e^{-23(5.5 \times 10^{-2})}$$

$$= 0.28$$

$$\frac{I}{I_0} = 0.28 \quad [2]$$

(c) Having travelled through muscle 5.5 cm thick, the beam is reflected from a muscle/bone boundary. At this boundary, 35% of the incident intensity is reflected.

Calculate the fractional intensity $\frac{I}{I_0}$ that is received back at the transmitter.



- ① 2 attenuations in 5.5 cm of muscle = $(0.28)^2$
- ② 1 reflection off muscle-bone boundary = 0.35

$$I = I_0 (0.28)^2 (0.35)$$

$$\frac{I}{I_0} = 0.02744$$

$$\frac{I}{I_0} = 0.03 \quad [2]$$

$$\alpha = \frac{I_R}{I_i} = 0.35$$

11 (a) Explain the main principles behind the use of ultrasound to obtain diagnostic information about internal body structures.

Done

[4]

(b) Data for the acoustic impedances and absorption (attenuation) coefficients of muscle and bone are given in Fig. 11.1.

	acoustic impedance / $\text{kg m}^{-2} \text{s}^{-1}$	absorption coefficient / m^{-1}
muscle	1.7×10^6	23
bone	6.3×10^6	130

Fig. 11.1

The intensity reflection coefficient is given by the expression

$$\frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

The attenuation of ultrasound in muscle follows a similar relation to the attenuation of X-rays in matter.

A parallel beam of ultrasound of intensity I enters the surface of a layer of muscle of thickness 4.1 cm as shown in Fig. 11.2.

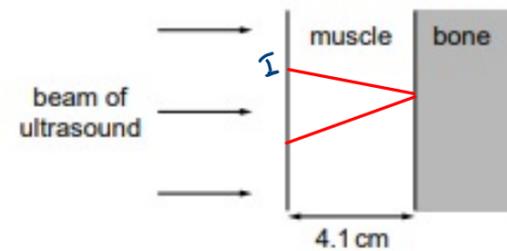


Fig. 11.2

- ① 2 attenuations in 4.1 cm of muscle = $(0.39)^2$
- ② 1 reflection at muscle bone boundary = (0.33)

The ultrasound is reflected at a muscle-bone boundary and returns to the surface of the muscle.

Calculate

(i) the intensity reflection coefficient at the muscle-bone boundary,

$$R = \left(\frac{\Delta Z}{\Sigma Z} \right)^2$$

$$R = \left[\frac{(6.3 - 1.7) \times 10^6}{(6.3 + 1.7) \times 10^6} \right]^2 = 0.330625$$

coefficient = 0.33 [2]

(ii) the fraction of the incident intensity that is transmitted from the surface of the muscle to the surface of the bone,

$$I = I_0 e^{-kx}$$

$$\frac{I}{I_0} = e^{-kx}$$

$$= e^{-23(4.1 \times 10^{-2})} = 0.39$$

fraction = 0.39 [2]

(iii) the intensity, in terms of I , that is received back at the surface of the muscle.

$$I = I_0 (0.39)^2 (0.33)$$

$$I = 0.05 I_0$$

intensity = 0.05 I [2]

6 A parallel beam of ultrasound is incident normally on the surface of a layer of fat of thickness 1.1 cm, as shown in Fig. 6.1.

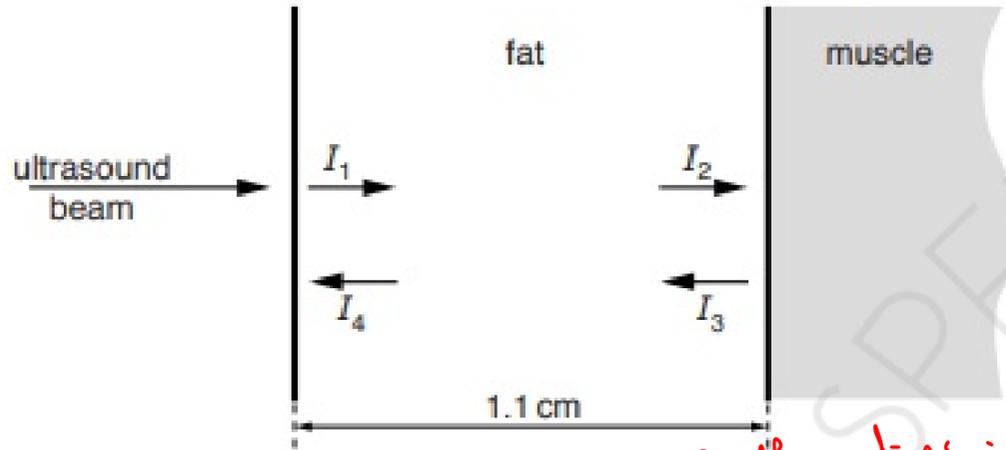


Fig. 6.1

For the ultrasound,
 I_1 is the intensity just after entering the surface of the fat layer,
 I_2 is the intensity incident on the fat-muscle boundary,
 I_3 is the intensity reflected from the fat-muscle boundary,
 I_4 is the intensity received back at the surface of the fat layer.

Some data for the fat are given in Fig. 6.2.

specific acoustic impedance Z	$1.4 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$
density ρ	940 kg m^{-3}
absorption (attenuation) coefficient μ	48 m^{-1}

Fig. 6.2

(a) Calculate the time interval between a short pulse of ultrasound initially entering the layer of fat and then returning back to the surface of the fat layer.

$Z = \rho \times c$
 $1.4 \times 10^6 = 940 \times c$
 $c = 1489.36 \text{ ms}^{-1}$

$t = \frac{\text{distance}}{\text{speed}} = \frac{(2 \times 1.1 \times 10^{-2})}{1489.36}$
 $t = 1.5 \times 10^{-5}$
 1.5×10^{-5}

time =s [3]

① 2 attenuations in 1.1 cm of fat = $(0.59)^2$
 ② reflection at fat-muscle boundary
 $\rightarrow \alpha = \frac{I_R}{I_i} = \frac{I_3}{I_2}$

(b) Calculate the ratio $\frac{I_2}{I_1}$.

$I_2 = I_1 e^{-\mu x}$
 $\frac{I_2}{I_1} = e^{-48(1.1 \times 10^{-2})} = 0.59$

ratio =0.59.....[2]

(c) Intensity I_4 is 0.33% of intensity I_1 .

Determine the ratio $\frac{I_3}{I_2}$.

$I_4 = I_1 (0.59)^2 \times \frac{I_3}{I_2}$
 $\frac{0.33}{100} \times I_1 = I_1 (0.59)^2 \times \frac{I_3}{I_2} \Rightarrow \frac{I_3}{I_2} = \frac{0.33}{100} \times \frac{1}{(0.59)^2}$
 9.5×10^{-3}

ratio = 9.5×10^{-3}[2]

(d) The specific acoustic impedance of the muscle is greater than that of the fat.

State the effect, if any, on the value of the ratio $\frac{I_3}{I_2}$ of an increase in the difference between the specific acoustic impedance of the muscle and that of the fat.

.....increases.....

$\alpha = \frac{I_3}{I_2} \uparrow = \left(\frac{\uparrow \Delta Z}{\Sigma Z} \right)^2$

X-rays :- High energy electromagnetic radiation

X-ray production :-

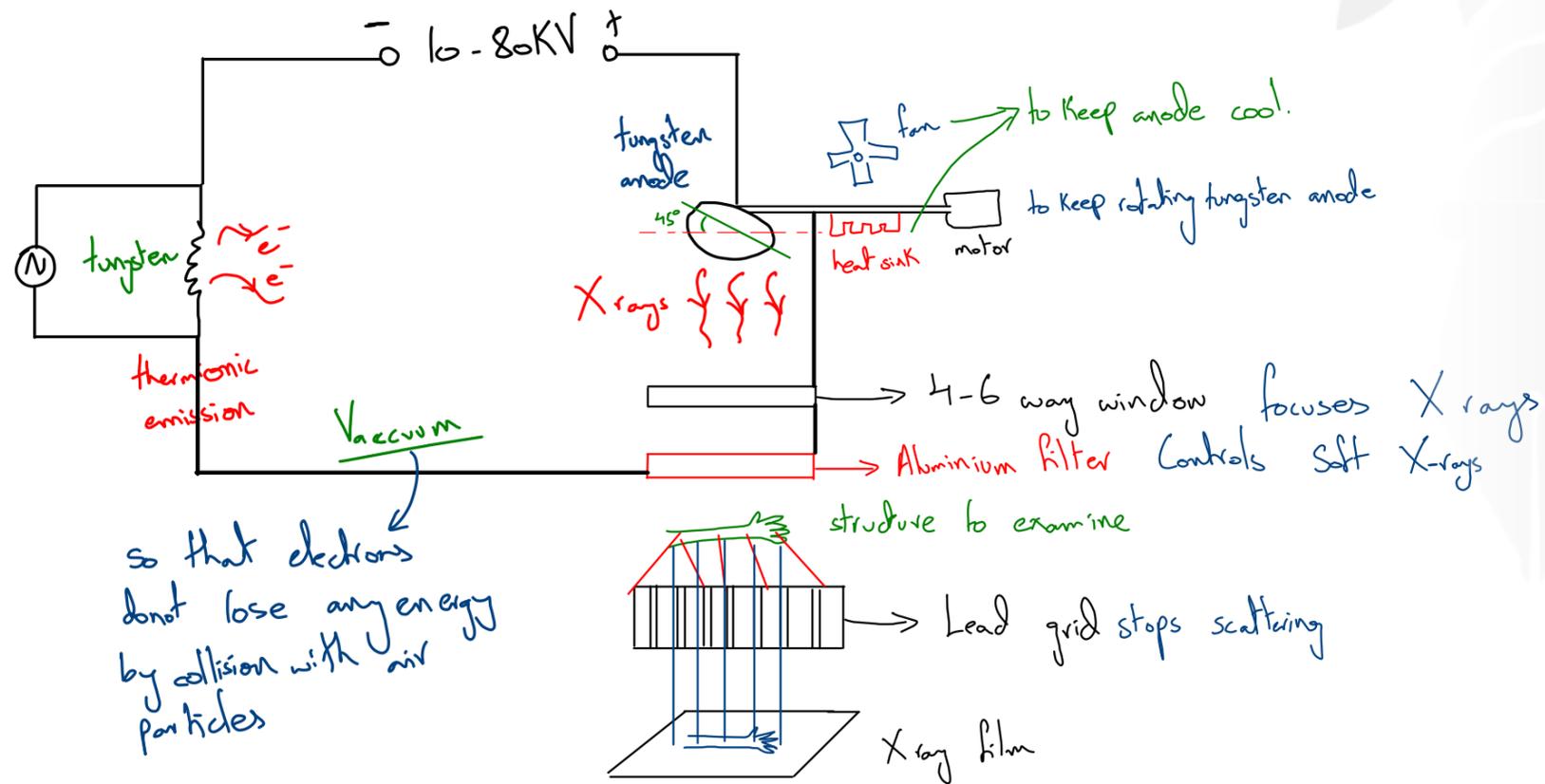
X ray :- $\lambda : 10^{-8} - 10^{-10}$

$$E = \frac{hc}{\lambda}$$

We needed a very high quantum jump :-

- 1) Heat \rightarrow Melting
- 2) Electrical energy \rightarrow Melting / We didnot have this much electrical power
- 3) Electromagnetic spectrum \rightarrow You need an X-ray photon to produce an X-ray photon

Direct electron bombardment :-



Velocity of electrons :-

$$V = \frac{W}{Q} \Rightarrow W = V \times Q$$

$$K.E = V \times Q$$

$$\frac{1}{2} m v^2 = V \times Q$$

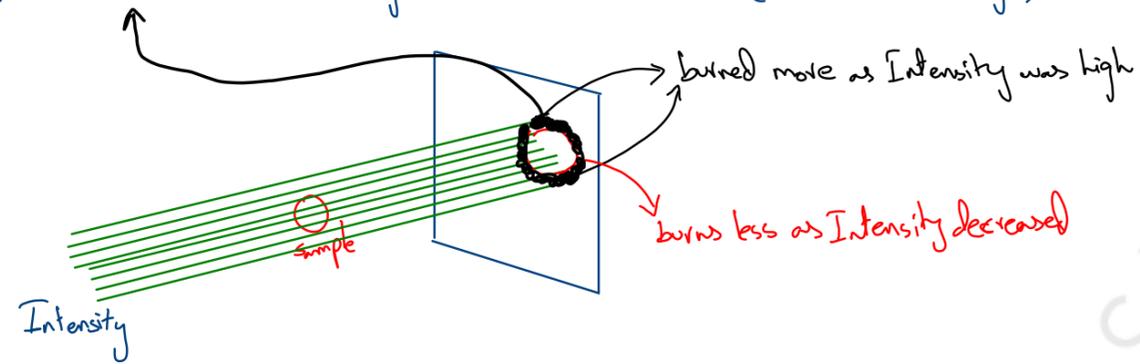
$$\sqrt{v^2} = \sqrt{\frac{2V_e}{m_e}}$$

$$v = \sqrt{\frac{2V_e}{m_e}}$$

X-ray imaging:-

* Drinking Barium sulphate, improves X-ray scans

1) Shadow:- Allows you to see outlines (Defines the image)



2) Sharpness:- Defines how well the edges of a structure can be distinguished

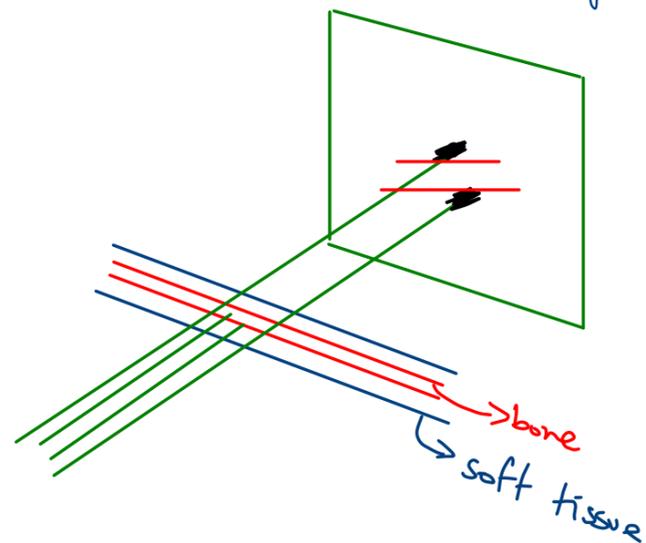
How to increase sharpness:-

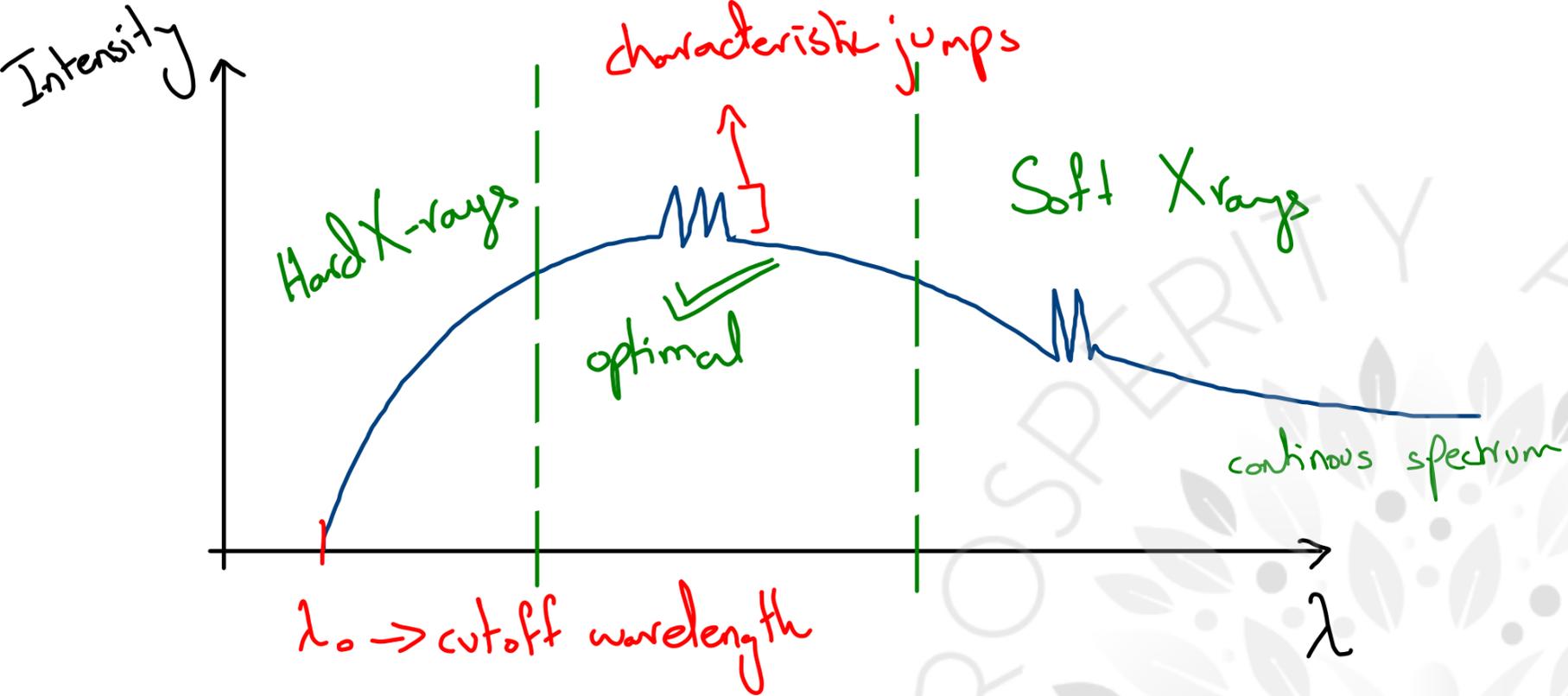
- 1) Make window small and control aperture
- 2) Use a lead grid
- 3) Make anode small

3) Contrast:- Difference in degrees of blackening between structures. (Allows you to distinguish b/w 2 objects being analysed.)

How to control contrast:-

- Adjust accelerating voltage





1) Hard X-rays: $\uparrow E = \frac{hc}{\lambda \downarrow} \Rightarrow$ - Hard X-rays have the highest energy and intensity.

- Penetrate very easily
- Burn the photographic film

2) Soft X-rays: $\downarrow E = \frac{hc}{\lambda \uparrow} \Rightarrow$ - Soft X-rays have low energy and intensities.

- They get absorbed easily
- Contribute most to the patient's dosage

Q. Why is there a continuous spectrum?

Ans. In direct electron bombardment, the electrons have a range of energies. As they hit other electrons they cause them to perform upward transitions and then during downward transitions, photons are released. Therefore the photons released have a range of energies and a continuous spectrum is produced.

Q. Why is there a sharp cut-off wavelength?

Ans. This corresponds to the greatest quantum jump. The fastest moving electron caused this greatest quantum jump.

Q. What are the characteristic jumps?

Ans. Electrons in other energy shells jump to fill the void created by upward transition jumps of the electrons.

Intensity of an X-ray beam:-

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

I_0 : initial intensity

I : final intensity

μ : absorption coefficient

x : distance moved in the tissue

Half value thickness:-

It is the length of material required to decrease the initial intensity by exactly half

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

$$\frac{1}{2} I_0 = I_0 e^{-\mu x_{1/2}}$$

$$\frac{1}{2} = \frac{1}{e^{\mu x_{1/2}}}$$

$$\ln(e^{\mu x_{1/2}}) = \ln(2)$$

$$\mu x_{1/2} = \ln 2 \Rightarrow$$

$$x_{1/2} = \frac{\ln 2}{\mu}$$

12 An X-ray beam is used to produce an image of a model of a thumb. A parallel beam of X-ray radiation of intensity I_0 is incident on the model, as illustrated in Fig. 12.1.

transmission through soft tissue = 1.5cm $\Rightarrow e^{-0.90(1.5)}$
 transmission through bone = 1.3cm $\Rightarrow e^{-3(1.3)}$

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

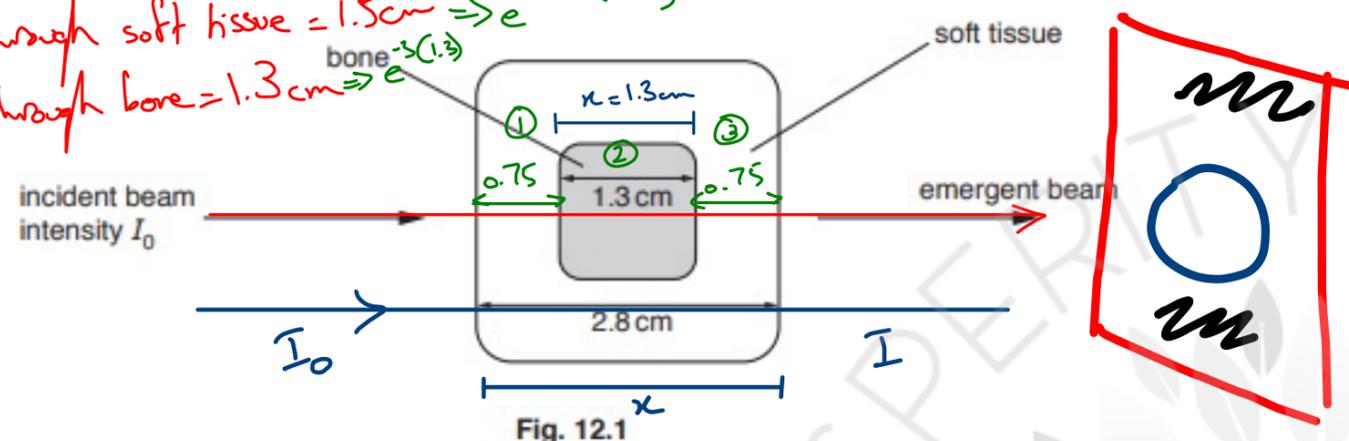


Fig. 12.1

Data for the attenuation (absorption) coefficient μ in bone and in soft tissue are shown in Fig. 12.2.

	μ/cm^{-1}
bone	3.0
soft tissue	0.90

Fig. 12.2

(a) Calculate, in terms of the incident intensity I_0 of the X-ray beam, the intensity of the beam after passing through

(i) a thickness of 2.8cm of soft tissue,

$I = I_0 e^{-\mu x}$
 $I = I_0 e^{-0.90(2.8)}$
 $I = 0.080 I_0$

intensity = 0.08 I_0 [2]

(ii) the bone and soft tissue, as shown in Fig. 12.1.

$I = I_0 e^{-\mu x}$
 $I = I_0 e^{-0.90(0.75)}$
 $I = I_0 e^{-\mu x}$
 $I = I_0 e^{-3(0.75)} \times e^{-3(1.3)}$

$I = I_0 e^{-\mu x}$
 $I = I_0 e^{-0.90(0.75)} \times e^{-3(1.3)}$
 $I = I_0 e^{-0.90(1.5)} \times e^{-3(1.3)}$
 $I = I_0 e^{-0.90(1.5)} \times e^{-3(1.3)}$

intensity = $5.3 \times 10^{-3} I_0$

$0.0053 I_0$

(b) (i) State what is meant by the contrast of an X-ray image.

Difference in degrees of blackening between structures.

(ii) By reference to your answers in (a), suggest whether the X-ray image of the good contrast.

Yes the image will have good contrast as the difference in intensities is big.

11 (a) Electrons are accelerated through a potential difference of 15 kV. The electrons collide with a metal target and a spectrum of X-rays is produced.

(i) Explain why a continuous spectrum of energies of X-ray photons is produced.

Due to the excitation voltage, there is a range of accelerations of electrons that are directly bombarded onto the anode. The anode's electrons gain a range of energies and as they return to their original energy level, they release a range/continuous spectrum of X rays. [3]

(ii) Calculate the wavelength of the highest energy X-ray photon produced.

$$E = \frac{hc}{\lambda}$$

$$W = V \times Q$$

$$15000 \times 1.6 \times 10^{-19} = \frac{(6.63 \times 10^{-34})(3 \times 10^8)}{\lambda}$$

$$\lambda = 8.275 \times 10^{-11}$$

wavelength = 8.3×10^{-11} m [3]

(b) A beam of X-rays has an initial intensity I_0 . The beam is directed into some body tissue. After passing through a thickness x of tissue the intensity is I . The graph in Fig. 11.1 shows the variation with x of $\ln(I/I_0)$.

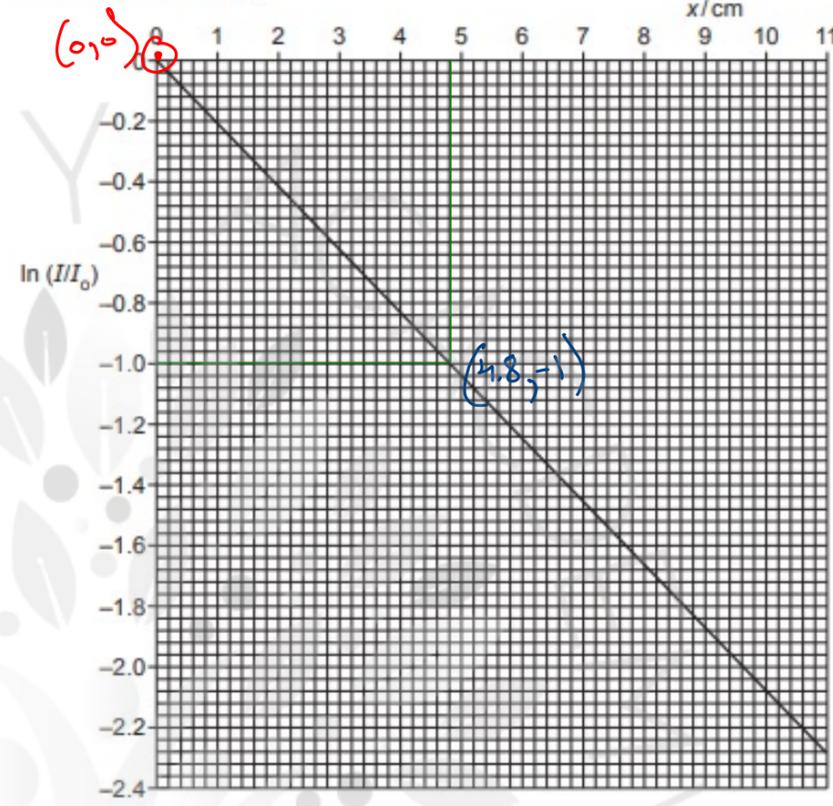


Fig. 11.1

linear law

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

$$\ln\left(\frac{I}{I_0}\right) = \ln(e^{-\mu x})$$

$$\ln\left(\frac{I}{I_0}\right) = -\mu x + 0$$

$$y = mx + c$$

(i) Determine the linear attenuation (absorption) coefficient μ for this beam of X-rays in the tissue.

$$\frac{y_2 - y_1}{x_2 - x_1} = -\mu \Rightarrow \frac{-1 - 0}{4.8 - 0} = -\mu = 0.2083$$

$$\mu = 0.21 \text{ cm}^{-1} [2]$$

(ii) Determine the thickness of tissue that the X-ray beam must pass through so that the intensity of the beam is reduced to 5.0% of its initial value.

$$I = I_0 \times \frac{5}{100}$$

$$\frac{I}{I_0} = \frac{5}{100}$$

$$\Rightarrow \frac{5}{100} = e^{-\mu x}$$

$$\Rightarrow \ln\left(\frac{5}{100}\right) = \ln(e^{-0.21 \times x})$$

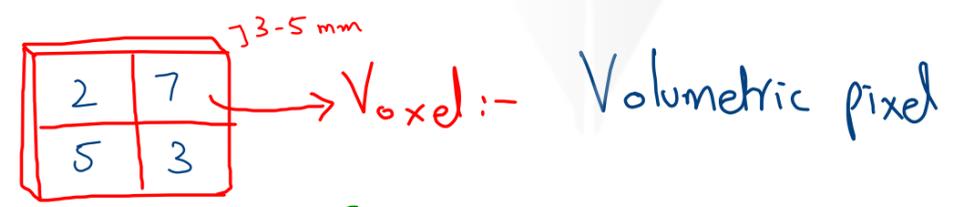
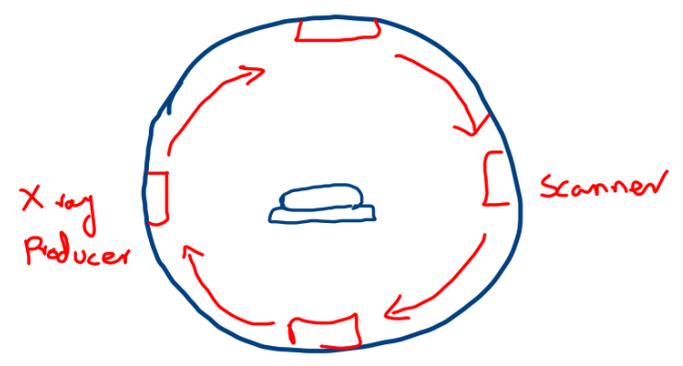
$$\ln\left(\frac{5}{100}\right) = -0.21 \times x$$

$$x = \frac{\ln(5/100)}{-0.21} = 14.26$$

thickness = 14 cm [2]

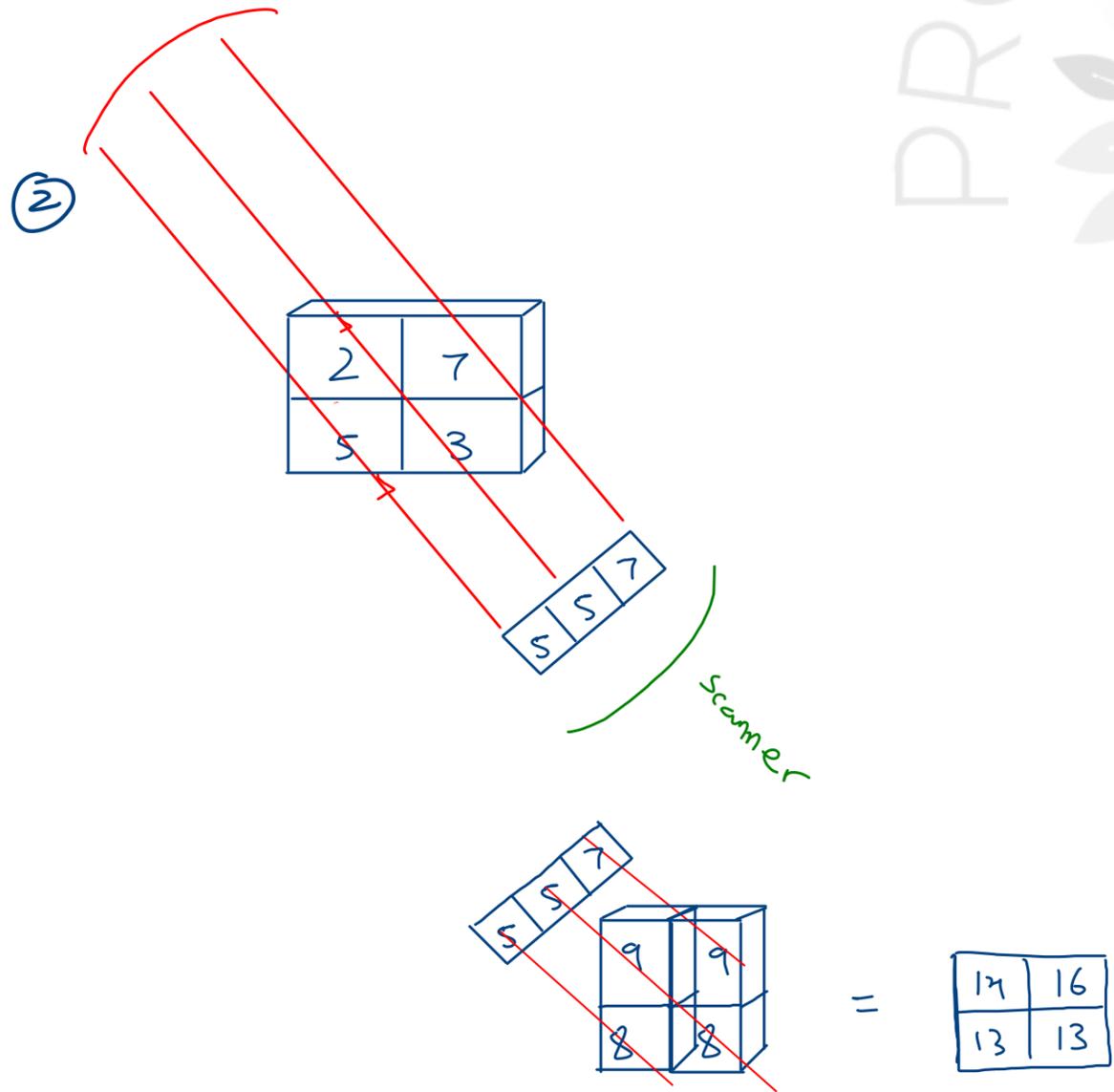
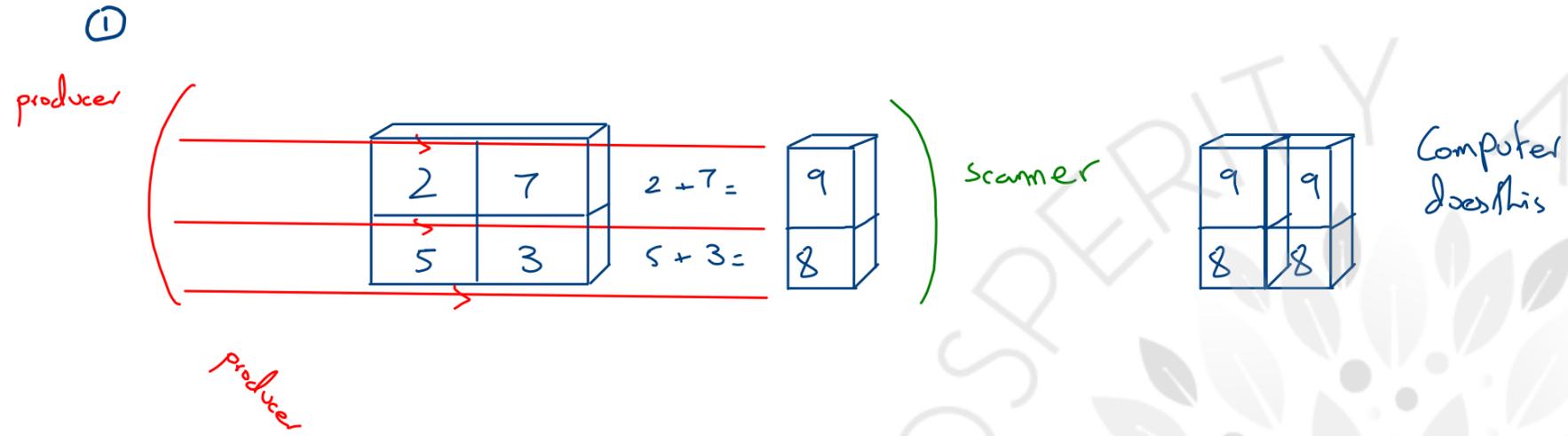
CAT Scans:- 3D image

Computed Axial tomography

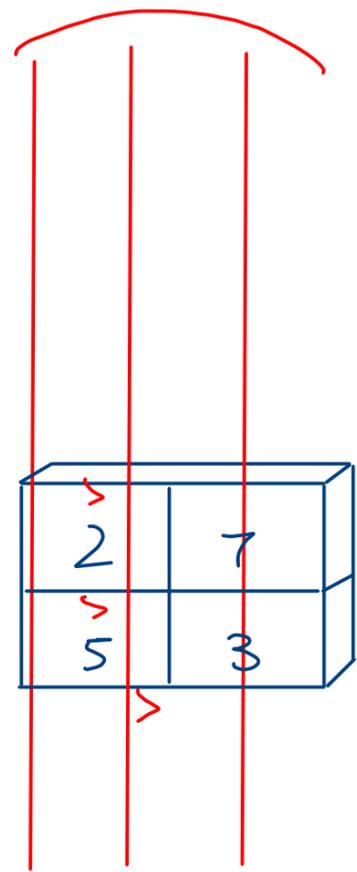


(only 4 voxels in CAIE)

Method :- Bg intensity :- $2+7+5+3=17$



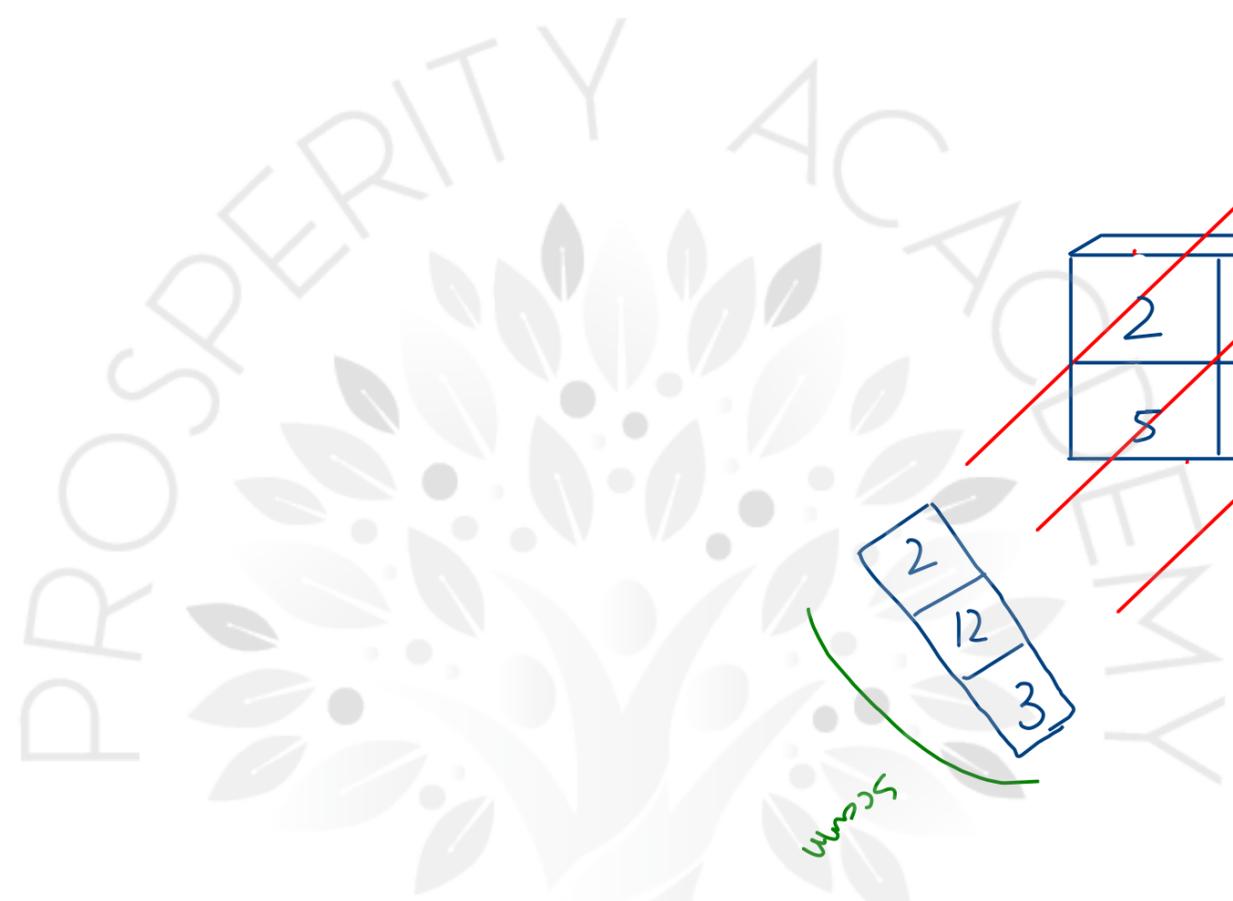
producer (3)



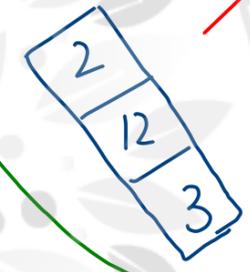
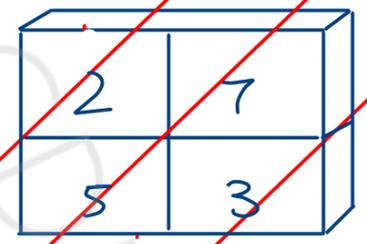
7 | 10

Scann

$$\begin{array}{|c|c|} \hline 7 & 10 \\ \hline 7 & 10 \\ \hline \end{array} + \begin{array}{|c|c|} \hline 14 & 16 \\ \hline 13 & 13 \\ \hline \end{array} = \begin{array}{|c|c|} \hline 21 & 26 \\ \hline 20 & 23 \\ \hline \end{array}$$



producer (3)



23	38
32	26

21	26
20	23

final addition matrix

CAIE only has 4 scans.

* Shortcut method :-

$$\begin{array}{|c|c|} \hline x_1 & x_2 \\ \hline 2 & 7 \\ \hline 5 & 3 \\ \hline x_3 & x_4 \end{array} \times 3 = \begin{array}{|c|c|} \hline 6 & 21 \\ \hline 15 & 9 \\ \hline \end{array} + \begin{array}{|c|c|} \hline \text{Bg intensity} \\ \hline 17 & 17 \\ \hline 17 & 17 \\ \hline \end{array} = \begin{array}{|c|c|} \hline y_1 & y_2 \\ \hline 23 & 38 \\ \hline 32 & 26 \\ \hline y_3 & y_4 \end{array}$$

$$\begin{aligned} 3x_1 + \text{Bg intensity} &= y_1 \\ x_1 &= \frac{y_1 - \text{Bg intensity}}{3} \end{aligned}$$

Advantages of CT scans:-

- 1) Produces very fine images in comparison to ultrasound.
- 2) reliable
- 3) Allows to study dense structures

Disadvantages:-

- expensive
- takes time
- anxiety / claustrophobia
- not portable
- A lot of training is required
- dosage of patient
- not efficient / waste power

10 (a) Briefly explain the principles of CT scanning.

X rays are taken at different angles of a section/slice. The X rays are processed and a 2D image of the slice is generated. The process is repeated for many slices along the patient's axis. All of the 2D slices are combined to make up a 3D image. A lot of processing power is needed to build up this 3D image. This 3D image can be rotated and seen from different angles on a computer screen. [6]

(b) A simple section through a body consists of four voxels, as illustrated in Fig. 10.1.

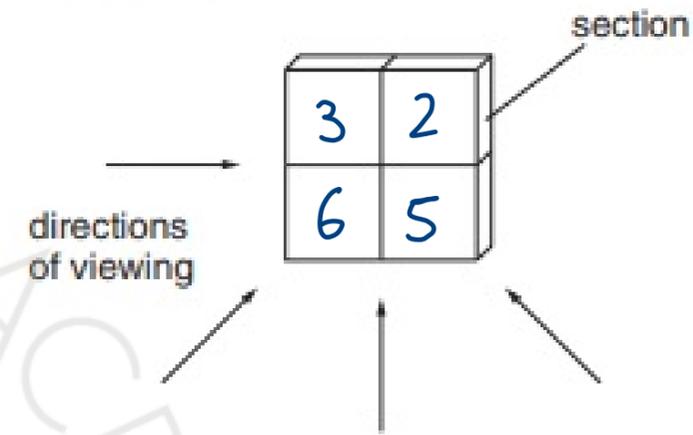


Fig. 10.1

An X-ray image of the section is obtained by viewing along each of the directions shown in Fig. 10.1.

The detector readings for each direction of viewing are summed to give the pattern of readings shown in Fig. 10.2.

25	22
34	31

final matrix

Fig. 10.2

For any one direction, the total of the detector readings is 16. *by intensity*

(i) For the pattern of readings of Fig. 10.2, state the magnitude of the background reading.

background reading = 16 [1]

(ii) On Fig. 10.1, mark the pattern of pixels for the four-voxel section. [2]

$$\mu_1 = \frac{25 - 16}{3} = 3$$

10 A simple model of one section of a CT scan is shown in Fig. 10.1.

A	B
D	C

Fig. 10.1

The model consists of four voxels with pixel numbers A, B, C and D.

In this model, the voxels are viewed in turn along four different directions D_1 , D_2 , D_3 and D_4 as shown in Fig. 10.2.

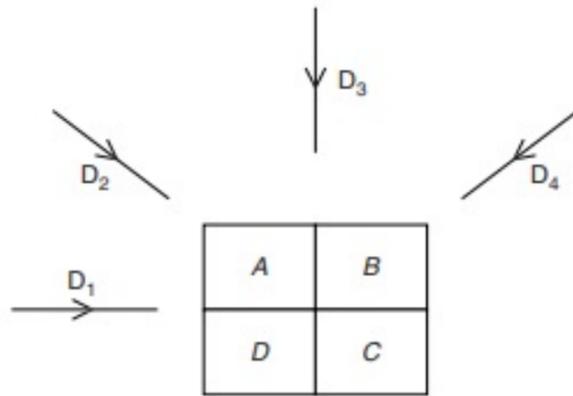


Fig. 10.2

The pixel readings in each of the four directions are noted.

The total pixel reading for any one direction is 19.

The pixel readings for all of the directions are summed to give the pattern of readings shown in Fig. 10.3.

25	34
28	46

final matrix

Fig. 10.3

(a) State the background reading in this model.

background reading = 19 [1]

(b) Determine each of the pixel readings.

A = <u>2</u>	B = <u>5</u>
D = <u>3</u>	C = <u>9</u>

[4]

(c) Use your answers in (b) to determine the pixel readings along

(i) the direction D_3 .

5, 14

[1]

(ii) the direction D_4 .

2, 8, 9

[2]

PET Scans:-

Positron emission tomography

antielectrons (β^+)

1) We give the patient a tracer which they have to eat.

substance containing radioactive nuclei which is going to be absorbed by the tissue being studied.

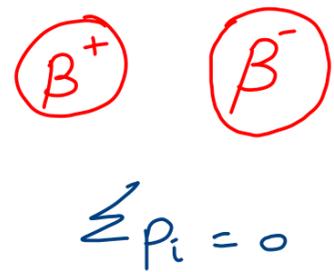
The tracer for PET scans is a β^+ emitter with a short half life

2) The tracer reaches the tissue we want to study and β^+ particles are being emitted continuously

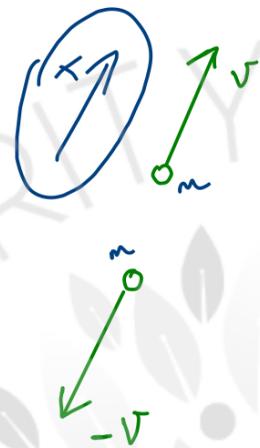
3) β^+ particles come into contact with electrons nearby, and Anihilation occurs

Anihilation:- When a matter and its antimatter particle, their mass converts completely into energy

4) Upon annihilation, 2 γ photons are released that travel in opposite directions.

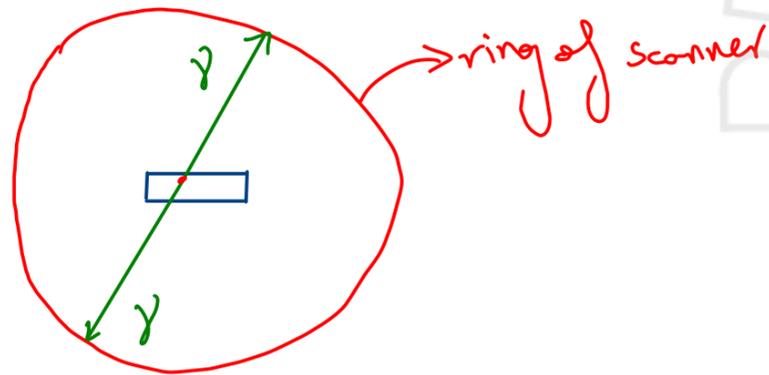


momentum is always conserved



$$\begin{aligned} \sum p_f &= mv + m(-v) \\ &= 0 \end{aligned}$$

5) The patient is enveloped in a scanner



6) The γ photons from one annihilation event reach the scanner at 180° angles to each other. The time delay between them reaching allows us to pinpoint the location of the annihilation.

7) Millions of readings and a lot of processing builds up a detailed image of the tracer concentration in the tissue.

11 Positron emission tomography (PET scanning) obtains diagnostic information from a person. The information is used to form an image.

(a) PET scanning uses a tracer.

Explain what is meant by a tracer.

substance containing radioactive nuclei which is going to be absorbed by the tissue being studied. [1]

(b) PET scanning involves annihilation.

(i) Explain what is meant by annihilation.

When a matter and its antimatter particles interact, their mass converts completely into energy. [1]

(ii) State the names of the particles involved in the annihilation process.

electron and positron [1]

(c) (i) Calculate the total energy released in one annihilation event in (b).

$$E = mc^2$$
$$E = 2(9.11 \times 10^{-31}) (3 \times 10^8)^2$$
$$= 1.638 \times 10^{-13}$$

energy = 1.64×10^{-13} J [1]

(ii) Calculate the wavelength of each gamma photon released.

$$E = \frac{hc}{\lambda} \Rightarrow \frac{1.64 \times 10^{-13}}{2} = \frac{(6.63 \times 10^{-34}) (3 \times 10^8)}{\lambda}$$
$$\lambda = 2.426 \times 10^{-12}$$

wavelength = 2.43×10^{-12} m [2]

(d) Explain how the gamma photons are used to produce an image. [3]

The 2 gamma photons travel in opposite directions and are detected by a scanner ring outside the body. The time delay between arrival of 2 gamma photons allows us to pinpoint location of annihilation. An image of tracer concentration in tissue is produced.

[Total: 9]