# 32 - Medical Imaging

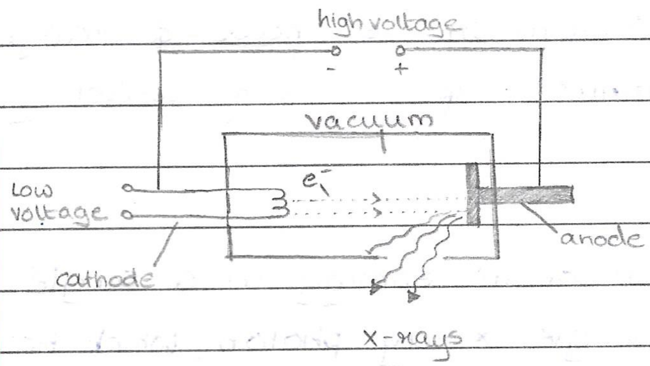
Q-1) How are x-rays produced?

> The x-ray tube consists of a cathode (heated filament) and an anode (hard metal eg: tungsten).

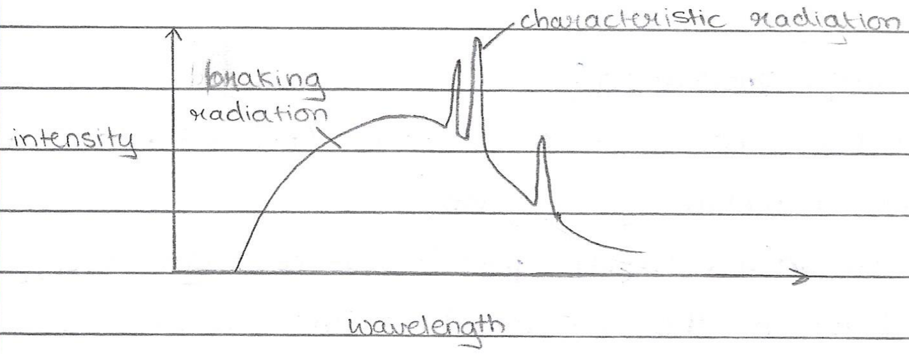
An external power supply produces a high voltage (50 - 200 kV) between the electrodes. This accelerates a beam of electrons from the cathode to the anode. When the high speed electrons strike the anode, they lose some of their k.e. in the form of x-ray photons which emerge in all directions.

Only a small fraction of the k.e is converted to x-rays. Most of it is transferred to the anode, which becomes hot. It's cooled by rotating (so target area is increased) or circulating water through it.

The outer-casing has a window to allow the x-rays to emerge out of the tube. The width of the x-ray beam can be controlled by using metal tubes to absorb the x-rays which produces a parallel side beam.



Q-2) The x-ray spectrum.




> **Breaking radiation:**

it's when an $e^-$ loses energy by interacting with nuclei and emitting EM radiation and x-ray photons.

> **Characteristic radiation:**

it's when an $e^-$ jumps from a higher to a lower energy level emitting a single x-ray photon.

* When $e^-$ undergo deceleration due to interactions with atoms of the target, EM radiation in the form of x-ray photons is emitted. The wavelength of the photons depends on the magnitude of deceleration. $e^-$ have a range of decelerations $\therefore$ a continuous spectrum of wavelength of x-rays is produced.

* When an $e^-$ gives up all of its energy in a single collision, it produces a single x-ray photon, which has a minimum wavelength (max frequency). Hence there is a sharp cut-off at short wavelengths.

using $E = hf$ and $E = hc/\lambda$ $\to$ $E = \overset{\text{charge of } e^-}{e}V \to$ voltage

$\lambda_{min} = \dfrac{hc}{eV}$ AND $f_{max} = \dfrac{eV}{h}$

Low energy photons are much more readily absorbed (are far less penetrating) and may cause tissue damage. They don't contribute to the x-ray image ∴ it's an advantage to filter out the low-energy photons by using aluminium absorbers across the window of the x-ray tube.

Q-3) Controlling intensity and hardness of the x-ray tube.

- Intensity is the power per unit cross-sectional area.
- Hardness is the penetration of the x-ray beam.
  ↳ shorter wavelength = greater penetration.

Soft-x-rays : less penetrating ∴ more hazardous

Hard x-rays : more penetrating

(more $e^-$ per second)

* Intensity can be increased by increasing the current / ~~so~~
  A higher intensity means the x-ray image will be formed in a shorter time.

* Hardness can be increased by increasing the voltage so x-rays of higher energies are produced.
  A filter to absorb the soft x-rays can also be used so the average energy of x-rays is higher.
  (aluminium filter)

Q-4) Attenuation of x-rays

> The Intensity of the transmitted x-ray beam is given by:

$$I = I_0 e^{-\mu x}$$ → same for ultrasound

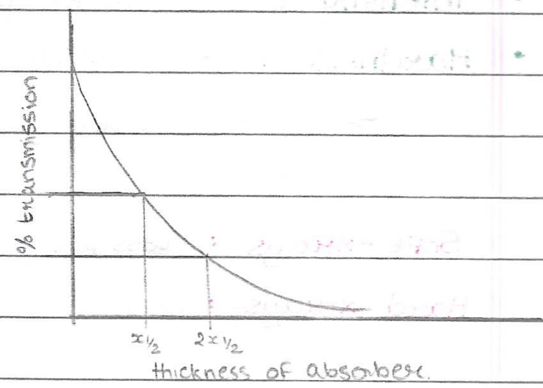
$I$ = transmitted intensity

$I_0$ = intensity of incident x-rays

$\mu$ = linear attenuation (absorption) co-efficient

$x$ = thickness of medium through which x-ray passes.

Half value thickness (HVT) is the thickness of the medium required to reduce the transmitted intensity of x-rays to half its initial value.




$$\therefore \quad \tfrac{1}{2} I_0 = I_0 e^{-\mu x_{1/2}}$$

$$\therefore \quad \mu x_{1/2} = \ln 2$$

Q-5) Sharpness of x-rays.

> Sharpness is related to the ease with which the edges of the structures can be determined.

Causes of loss of sharpness:

- Large area of target anode giving rise to partial shadows (penumbra).

- Scattering of x-rays by the tissues.

## Improving Sharpness:

① Reduce the size of the aperture of lead box through which x-rays pass on leaving the x-ray tube.

② Reduce area of the target anode.

③ Use an anti-scatter lead grid in front of the photographic film to absorb the scattered x-ray photons

Q-6) Contrast of x-rays.

> Contrast is the difference in the degree of blackening of the image between one organ and another

## Increasing contrast

① Use a contrast medium
eg: stomach is examined by giving the patient Barium Sulfate

② Backing the photographic film with a flourescent film.

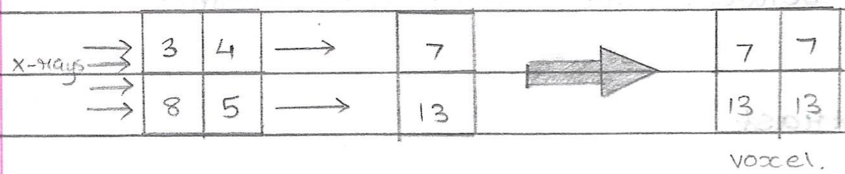
Q-7) Reducing the dosage of x-rays

> x-rays can damage living tissues and may cause mutations which can lead to growth of cancerous tissues.
To keep the dosage to a minimum, intensifier screens or image intensifiers (for digital systems) are used. It contains phosphor which emits many light photons which blacken the film.

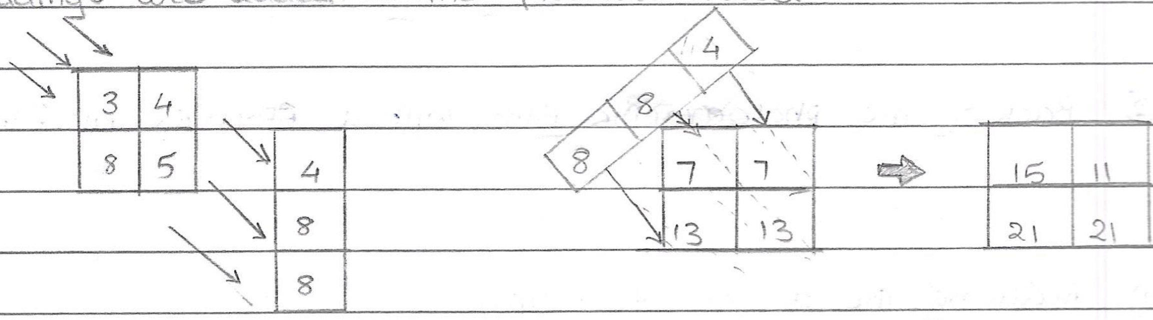
Q-8) Principles of CT scanning.

> The aim of CT scanning is to produce an image of a section through the body from measurement made about its axis.

- A series of x-ray images are taken of the slice/section.
- Each image is taken from a different angle to obtain a 3D image.
- Data for each individual x-ray image and the angle of viewing is fed to a high power computer.
- The computer produces an image of the slice.
- This is repeated for successive slices and the images are combined to build a 3D image of the body part.




The x-ray tube and detector is rotated through 45° and readings are added to the previous voxel




etc... at 4 different angles

$$\begin{bmatrix}29 & 32\\ 44 & 35\end{bmatrix} - 20 \rightarrow \begin{bmatrix}9 & 12\\ 24 & 15\end{bmatrix} \div 3 \rightarrow \begin{bmatrix}3 & 4\\ 8 & 5\end{bmatrix}$$ original.

Background radiation = 7+13 OR 4+8+8 ... = 20

Q-9) Difference between x-ray image and CT scan.

> X-rays.

- shadow image or flat image (2D)
- it shows bones/organs which are at different depths within the body, superimposed on one another.

  i.e difficult to distinguish between front & back bones of ribs.

> CT scanning

- 3D image built by the computer
- The computer enables different sections to be viewed at different angles.
- Longer time of exposure to x-rays than x-ray imaging.

Q-10) Principles of generation of ultra-sound waves.

> Ultrasound waves may be produced using a piezo electric transducer (quartz). The two sides of the crystal are coated with silver which act as electrodes.

- When unstressed, the centres of charge of positive (silicon) and negative (oxygen) ions coincide.
- When a p.d is applied across the electrodes, the ions are attracted to the opposite charges.
- Depending on the polarity of the applied voltage, the crystal becomes thinner or thicker as a result of altered charge distribution.
- An alternating voltage applied across the electrodes causes the crystal to vibrate. The vibrations have maximum amplitude when applied frequency is equal to natural frequency of the crystal (resonance)
- The vibrations may be in the ultrasonic range (greater than 20kHz) thus producing ultrasonic waves in the surrounding medium.

* If ultrasound waves are incident on the crystal, the pressure variations in the wave will give rise to voltage variations across the crystal. ∴ The crystal may be used as a detector (receiver).

Q-11) Principles behind use of ultrasound.

> • The ultrasound transducer is placed on the skin with jelly between the transducer and the skin.

• Short pulses of ultrasound waves are transmitted into the body where they are partly reflected at the boundaries of the media.

• The reflected pulses return to the transducer. They are detected and converted to voltage pulses. The voltage pulses are amplified and displayed on the c.r.o screen.

•- The intensity of reflected pulse gives information about the boundary.

- The time delay gives information about the depth.

Q-12) What is acoustic impedance?

> Acoustic impedance is the product of density of a medium and the speed of sound in the medium.

$$Z = \rho c$$ unit = $kg\,m^{-2}s^{-1}$

The difference in the acoustic impedances determines the fraction of the incident intensity that is reflected.

$$\frac{I_R}{I} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$ $\rightarrow$ $\frac{I_R}{I}$ = intensity reflection co-efficient denoted by $\alpha$.

Q-13) What is precession?

> When a strong magnetic field is applied across a part of the body, the Hydrogen nuclei (protons) allign themselves along the direction of the magnetic field. The nuclei rotate about the direction of the magnetic field just like the axis of a spinning top.
This rotation is known as precession.

Q-14) What is the Larmor frequency?

> The angular frequency of precession is called the Larmor frequency.

constant : gyro magnetic ratio

$$W_0 = \gamma B_0$$ → magnetic flux density (strength)

Larmor frequency

$$* \quad \gamma = \frac{W_0}{B_0} = \frac{2\pi F_0}{B_0}$$

The Larmor frequency depends on:

① Nature of the nucleus.

② Strength of magnetic field (magnetic flux density).

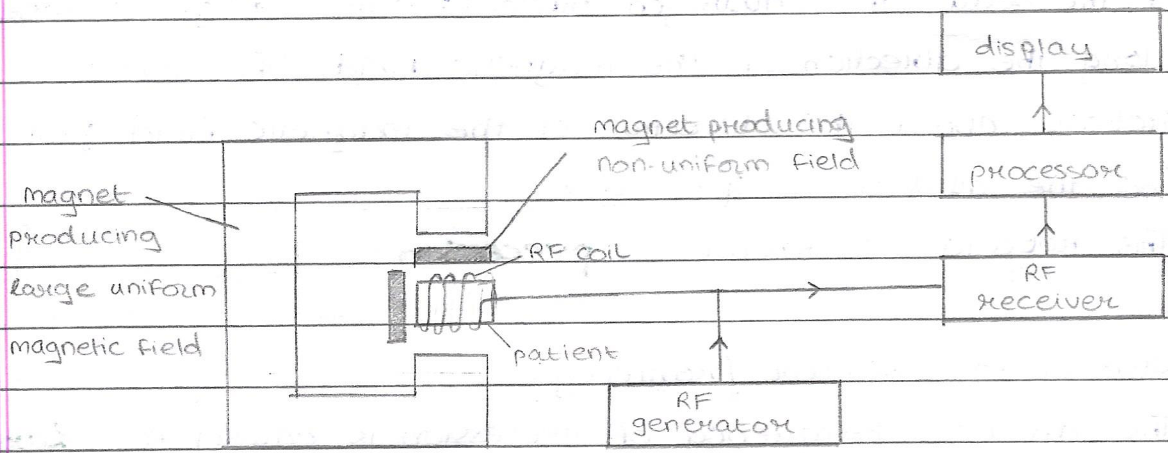
Q-15) What is relaxation time?

> If a pulse of EM radiation (radiowaves) of same frequency as Larmor frequency is applied, the nuclei will resonate by absorbing the energy.

After the pulse ends, the nuclei will return to their equilibrium state, emitting RF radiation.
The time between end of RF pulse and re-emitting radiation is known as relaxation time.

Q-16) Principles of Nuclear magnetic resonance imaging (NMRI) :

> MRI scanner




- Nuclei of certain atoms have a property called spin due to which they behave like tiny magnets in a magnetic field.
- When a strong magnetic field is applied, the nuclei precess about the direction of the magnetic field. The frequency is known as the Larmor frequency
- The precessing nuclei are exposed to RF radiation of frequency equal to the Larmor frequency. The nuclei absorb the radiation, and move to a higher energy level, causing resonance.
- When the RF radiation is switched off, the nuclei return to equilibrium state, emitting RF radiation which is detected and processed by a computer to produce an image
- A non-uniform magnetic field is also applied (along with the uniform field) in different regions of subject which allows :
  - location of precessing nuclei to be determined
  - thickness / location of slice to be changed.

since Larmor frequency changes with the applied magnetic field strength.