Medical Physics

⇒ Production of X-rays

→ X-rays are highly energetic Electromagnetic radiation
→ X-rays are extensively used in medicine

⇒ How do we produce X-rays

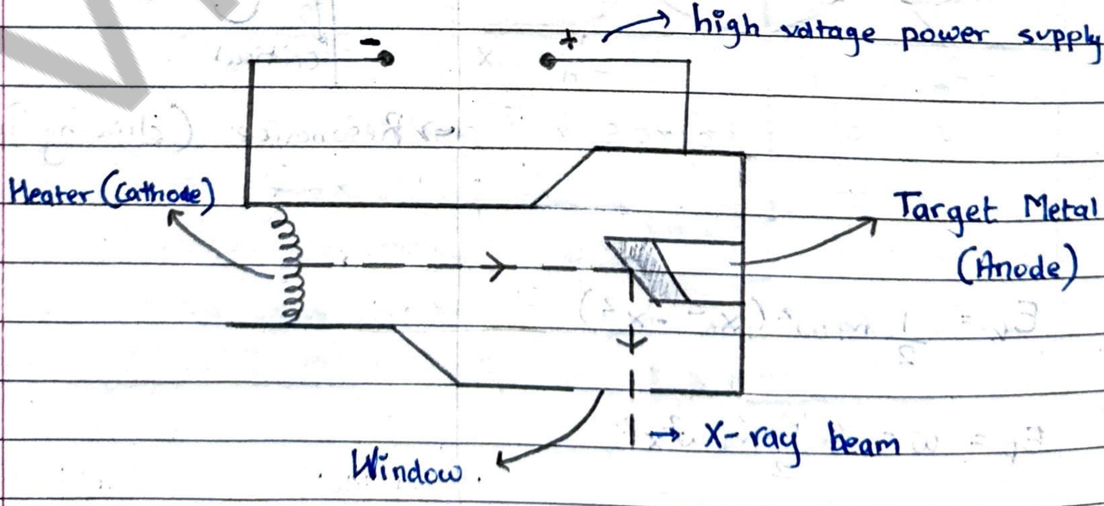
→ We need a very very high voltage supply. Ex: 1000s of volts upto 150000 volts

→ for an X-ray to be produced normally we would need 50 000 to 150 000 volts.

→ We need a heater called cathode, which is made out of filament wire metal. It releases electrons, which is accelerated towards the positive end of the circuit, where a target metal is placed, also called as anode. acc↑ freq↑

→ The electrons then decelerate and only 1% of their kinetic energy is converted to x-rays.

→ The x-rays emerge out of a window



PAGE NO.:
DATE: / /

⇒ Electron energy

→ If one volt of energy is supplied then the electron energy will be 1eV, conversion for same would be → $1 \times 1.6 \times 10^{-19}$ V

→ If 100kV of energy is supplied then the electron energy will be 100keV. conversion → $100 \times 10^3 \times 1.6 \times 10^{-19}$ V

⇒ Photon energy

→ $E_{ph} = \frac{hc}{\lambda}$ or $E_{ph} = hf$

Note: $h = 6.63 \times 10^{-34}$
Planck's constant

Q. Calculate the minimum wavelength of an x-ray when 100kV potential is used to accelerate the electrons.

Electron Energy = Photon Energy

$$100keV = E_{ph}$$

$$100 \times 10^3 \times 1.6 \times 10^{-19} = \frac{hc}{\lambda}$$

$$1.6 \times 10^{-14} = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{1.6 \times 10^{-14}}$$

$$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-14}}$$

$$\lambda = 1.2 \times 10^{-11} \text{ m}$$

⇒ X-ray Attenuation Mechanisms

→ **Simple Scatter**

→ The x-ray has energy lower than the minimum energy required to release an electron, so the x-ray performs a simple scatter in which it does not lose energy.

→ **Compton Scatter**

→ The x-ray has high energy, it removes the electron.

→ There is still some energy left and a lower energy photon is scattered. (higher λ and lower frequency)

→ **Pair Production**

→ The incoming x-ray has a high energy and interacts with the nucleus of an atom.

→ An electron-positron pair is produced. They normally annihilate each other as soon as they are produced. Then they form a pair of lower energy photons.

$\Delta E = \Delta m c^2$ → to find energy of incoming x-ray

(Δm → mass of e^-; c → speed of light)

$\Delta E = 2 \times 9.11 \times 10^{-31} \times 3.0 \times 10^8$

$= 1.6 \times 10^{-13}$ J

→ Frequency of each photon

$E = hf$

$E/h = f$

$f = \frac{1}{2} \times 1.6 \times 10^{-13} / 6.63 \times 10^{-34}$

Converting to eV

$\frac{\text{Energy}}{\text{Charge}} = \frac{1.6 \times 10^{-13}}{1.6 \times 10^{-19}} = 1.02 \times 10^6$ eV

$= 1.02$ MeV

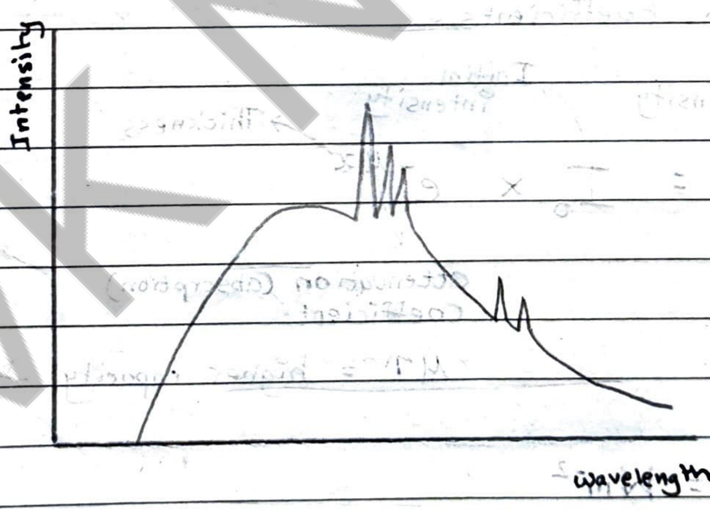
→ ENERGY and MOMENTUM are conserved.

→ electron and positron both move into opposite directions

⇒ Photoelectric effect:
- → The electron absorbs the x-ray
- → The electron uses this energy to escape the atom
- → An electron is released with some kinetic energy.

⇒ Characteristic Spectrum

- → This spectrum is produced by electrons striking the target
- → The narrow 'k' lines are characteristics of the target metal, these sharp peaks correspond to the emission line spectrum of the target metal. ∴ showing characteristics of the target.
- → They are produced by the bombarding electrons on target metal removes the electrons close to the nuclei. Each electron will have different decelerations
- → The gaps are filled with electrons dropping from a higher energy releasing a photon



→ maximum energy = minimum wavelength

Q. Find max accelerating p.d for the x-ray tube, when $\lambda_{min} = 2.5 \times 10^{-11}$

$eV = \frac{hc}{\lambda}$ $V = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{1.6 \times 10^{-19} \times 2.5 \times 10^{-11}}$

$V = \frac{hc}{e\lambda}$ $V = 49725V$

→ How will the graph change if the accelerating p.d is increased

ans → $eV = \frac{hc}{\lambda}$

if $eV \uparrow$ then $\lambda \downarrow$

∴ the graph shifts to the left.

the 'k' lines remain unchanged as they depend only on the target material.

⇒ Attenuation coefficients

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

- I → Final intensity
- I_0 → Initial intensity
- x → Thickness
- μ → attenuation (absorption) coefficient

$\mu \uparrow$ = higher capacity of absorbing X-rays

Units

→ $I, I_0 = Wm^{-2}$

→ $\mu = m^{-1}, cm^{-1}, mm^{-1}$

→ $x = m, cm, mm$

⇒ Rearranging for thickness

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

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

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

$$\ln\left[\frac{I}{I_0}\right] = -\mu x$$

multiplying both sides with -1

$$\ln\left[\frac{I_0}{I}\right] = \mu x$$

$$\boxed{\frac{\ln\left[I_0/I\right]}{\mu} = x}$$

⇒ Contrast in X-rays

→ An X-ray image having a wide range of degrees of blackening in different regions is said to have good CONTRAST.

→ A lot of tissue have similar X-ray attenuation coefficients

→ good contrast is achieved when neighbouring body organs have a very different attenuation coeffecient.

→ Barium is a good absorber of X-ray photons.

→ The patient is asked to swallow a barium meal and then Barium Sulfate coats the inside of stomach then the outline of stomach will show up clearly.

Q. The absorption coefficient of bone is $0.60\ cm^{-1}$, calculate the thickness of bone required to reduce the intensity of X-rays by half.

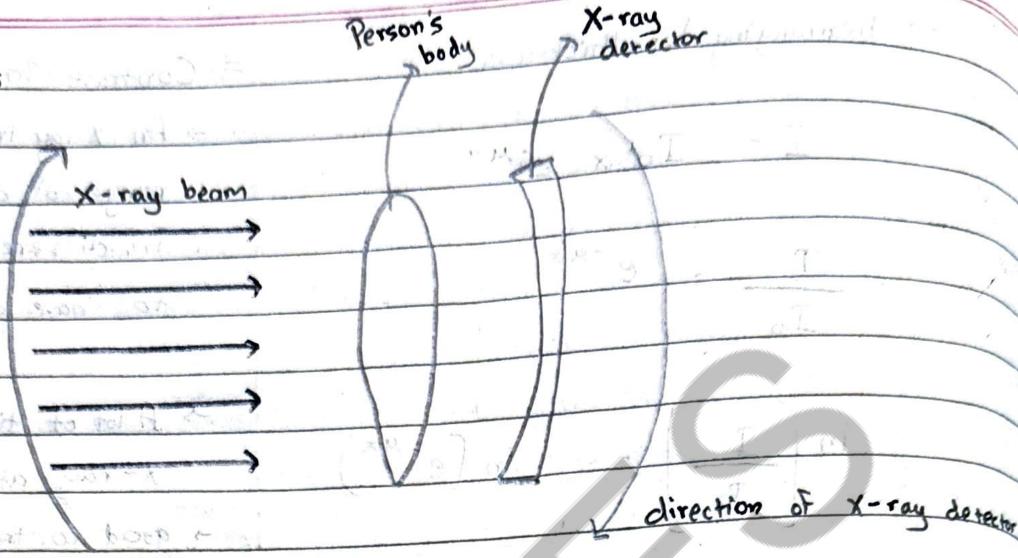
$$\frac{I_0}{2} = I_0 \times e^{-\mu x}$$

$$\frac{1}{2} = e^{-\mu x}$$

$$\frac{\ln(2)}{\mu} = x = \frac{\ln(2)}{0.60} = 1.16\ cm$$

PAGE NO.:
DATE: / /

⇒ CT scans



→ The x-rays are absorbed differently by different tissues and the intensities of the x-rays is recorded by the detector.

→ A three-dimensional image or 'slice' through the body may be obtained. In this technique, a series of X-ray images are obtained.

→ Each image is taken through the same section or slice of the body from a different angle.

→ A computer software produces a 3d image from the data.
  → A 2d image of the slice is computed
  → this is repeated for successive slices
  → the computer combines each slice to form a 3d image.

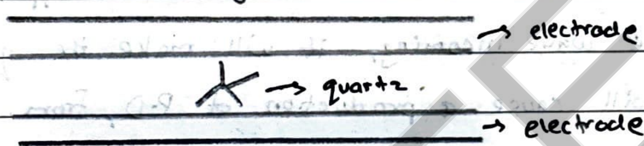
→ Advantages and disadvantages
  → X-ray scan is quicker and cheaper than CT
  → CT can produce 3d image, X-ray cannot.
  → X-ray can be harmful, CT are not harmful
  → CT scan can be prolonged.

★ Uses of piezoelectric transducers: microphones, watches, lighters

PAGE NO.:
DATE: / /

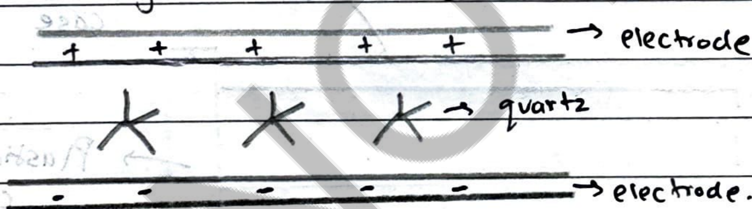
⇒ UltraSound

- → it is a sound of a frequency above 20000 Hz or 20 kHz
- → it is generated using piezo-electric transducer.
- → Transducers converts energy from one form to other.
- → This transducer converts electrical energy to ultrasound energy
- → piezo-electric transducer is made of "quartz crystal"
- → when crystals are unstressed (no force applied), the charges are balanced (positive and negative ions centers coincide)

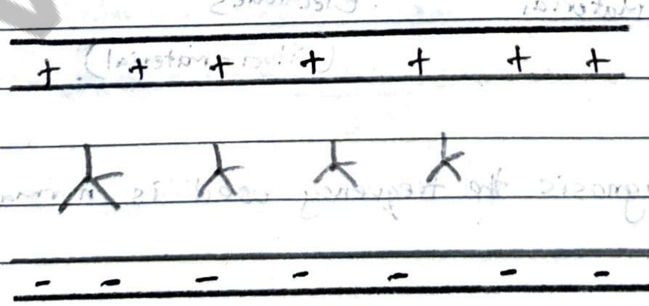


- → when crystals are compressed, the charges are not balanced (positive and negative ions centers do not coincide). PD is created.

acts as transducer converting mechanical to electrical



- → When quartz crystal is held between 2 electrodes, formed by depositing silver on the opposite side of the electrodes and PD is applied on the electrodes.



acts as a transducer converting electrical to mechanical

- → an electric field setup in the crystal as the ions are not rigidly held together, they will be displaced due to the force produced by electric field, as opposite ions will attract.

PAGE NO.:
DATE: / /

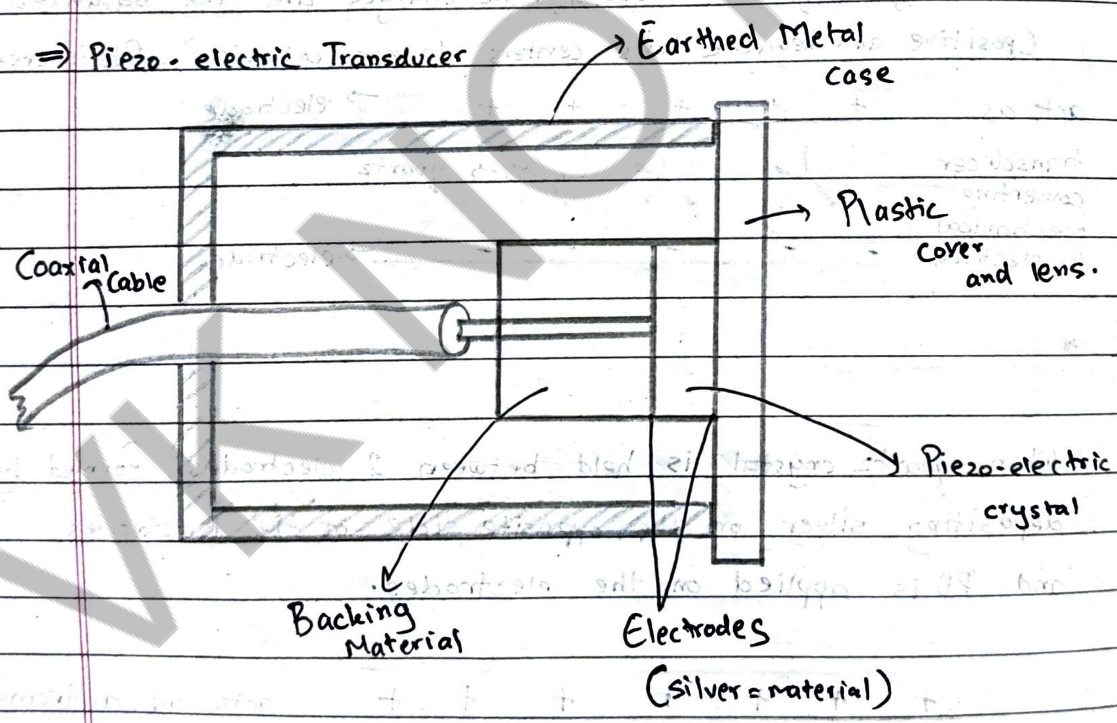
→ If an alternating e.m.f is applied across the electrode the crystal vibrates, with a frequency. The frequency of applied voltage.

→ The natural frequency of quartz is in range of the ultrasound so the driving frequency equals the natural frequency and resonance comes in.

→ Once resonance occurs the ultrasound is produced

→ It can be used to detect ultrasound. Suppose there is an ultrasound wave incoming, it will make the quartz crystal vibrate which will cause a production of P.D, from which we can detect ultrasound.

⇒ Piezo-electric Transducer



→ In medical diagnosis the frequency used is normally in MHz

⇒ Principles of ultrasound scanning

→ A piezo electric crystal transducer is used to send a pulse of ultrasound.

→ Ultrasound pulses are reflected at the boundary of each tissue

→ The intensity of the reflected wave depends on the acoustic impedance of the boundary

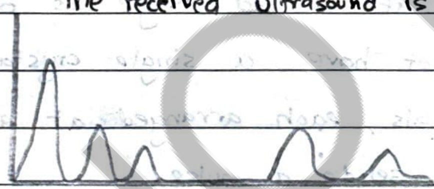
→ The time of delay is used to determine the thickness of the boundary.

Note: Thickness = distance travelled by ultrasound / 2 (→ $\frac{ct}{2}$)

→ The scan is called "A Scan"

→ we plot a V/t graph for the same

→ ex. The received ultrasound is amplified and shown on CRO



⇒ Acoustic Impedance

$$Z = \rho \times c$$

(ρ → density; c → speed of sound in tissue)

(Z →) base unit $= kg\,m^{-2}s^{-1}$

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

I_r → Reflected Intensity; I_0 → Original Intensity

if $Z_2 = Z_1$ then $\frac{I_r}{I_0} = 0$ → which means no ultrasound is reflected.

$\frac{I_r}{I_0}$ is called intensity reflection coefficient. it is denoted by α.

PAGE NO.:
DATE: / /

→ Acoustic impedance of air is much smaller than the soft tissues, when Ultrasound is incident from air to the soft tissue most of the intensity of wave is reflected, which will not give a good image.

In order to obtain a well defined image using ultrasound there must be no air gap between transducer and skin, so we use a water based jelly whose Z is similar to soft tissue.

⇒ Principles of ultrasound Scanning (continued)

→ B-scan consists of series of A scan, all taken from different angles, so that a 2d image is obtained

→ B-scan does not have a single crystal, it has an array of small crystals, each arranged at a slightly at a different angle and each sends a pulse.

→ Each reflected pulse is shown on the screen of CRO as a bright spot, the pattern of spots builds up to form 2d image representing the positions of the boundaries within the body.

→ Advantage of using ultrasound over X-rays

- → There is almost no health risk to both the patient and operator
- → Ultrasound equipment is much more portable and ez to use.

→ Higher frequency ultrasounds enable greater resolution to be obtained since λ will be shorter and there will be less diffraction

⇒ Medical Tracers

→ it is a substance which is injected or digested by the patient and is used for diagnosis or treatment of a patient.

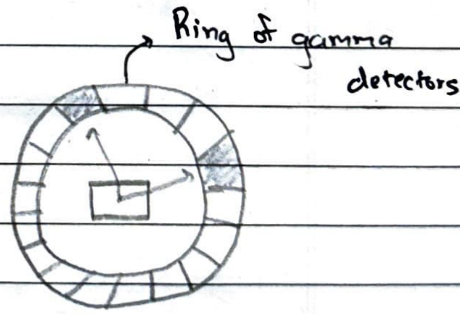
→ Properties:

- → They are typically gamma sources (to pass through tissue).
- → Their half life needs to be long enough to be detected but short enough so that they do not stay in the patient.
- → The activity must be large enough to be detected from outside of the body.
- → Must be non-toxic.

→ Examples:

- → Fluorine - 18
  - → used in PET scans
  - → half life 110 minutes
- → Iodine - 131 (thyroid conditions)
- → Iron - 59 (spleen metabolism)
- → potassium - 42 (blood composition)
- → Technetium 99m
  - → used to monitor major organs - heart, kidneys, brain
  - → half life 6 hours

⇒ PET Scan



→ The patient is surrounded by a ring of gamma detectors.

→ A tracer emits a positron (decays via beta plus radiation) is injected into the body.

→ The positron annihilates with an electron in the body

→ This produces two gamma ray photons that travel in opposite directions.

→ The delay between the detectors detecting each photon is used to determine the location of the annihilation.

→ A computer is connected to these detectors and is used to form an image.

→ Advantages

- → Non-invasive technique, can produce real time images

→ Disadvantages

- → radioactive source used
- → It is very expensive