



Questions:

- 1. Explain the production of X-rays in an X-ray tube.*
- 2. What is the difference between Bremsstrahlung radiation and characteristic radiation?*
- 3. Define: voxel, Hounsfield Unit.*
- 4. What is pitch in CT imaging? Explain the effect of increasing pitch on: patient dose and spatial resolution.*
- 5. Explain the Doppler effect in ultrasound imaging.*
- 6. Explain the physical principle of the piezoelectric transducer in medical ultrasound imaging.*
- 7. Name and explain three ultrasound imaging artifacts: based on their physical origin and their appearance on the image.*

Exercise 1:

An ultrasound examination is performed at a frequency of 5 MHz. The speed of sound in soft tissue is 1540 m/s.

- 1. Calculate the wavelength*
- 2. Estimate the minimum detectable structure size*
- 3. Comment on the result.*

Exercise 2:

A monoenergetic X-ray beam passes through 15 cm of soft tissue. The linear attenuation coefficient is $\mu = 0.25 \text{ cm}^{-1}$.

- 1. Write the X-ray attenuation law*
- 2. Calculate the transmitted-to-incident intensity ratio I_{trans}/I_0*
- 3. Explain how this result influences energy selection in chest radiography*

Good Luck



Answers:

1. (The draw of X-ray tube is required) The X-ray tube consists mainly of a cathode and an anode enclosed in a vacuum. (2pts)

- At the cathode, a tungsten filament is heated by an electric current. This heating causes electrons to be released by thermionic emission.
- A high voltage (kVp) is applied between the cathode (negative) and the anode (positive), accelerating the electrons across the vacuum.
- The accelerated electrons strike the metal target (anode), usually tungsten.
- When electrons interact with the atoms of the target, X-rays are produced.
- More than 99% of the electron energy is converted into heat, and less than 1% is converted into X-rays.

2. (The draw of the two radiation is required) Difference between Bremsstrahlung radiation and characteristic radiation (2 pts)

Bremsstrahlung radiation : Produced when high-speed electrons are decelerated by the electric field of the nucleus of the target atoms. Results in a continuous X-ray spectrum.

Characteristic radiation: Occurs when an incoming electron ejects an inner-shell electron (K or L shell) of the target atom. An outer-shell electron fills the vacancy, emitting an X-ray photon with discrete (characteristic) energy.

3. Definitions: voxel and Hounsfield Unit (2 pts)

A voxel (volume element) is the smallest three-dimensional unit of a CT image. It represents a small volume of tissue defined by pixel area × slice thickness.

The Hounsfield Unit is a quantitative measure of X-ray attenuation in CT imaging.

$$CT \text{ number} = \frac{\mu_{\text{tissue}} - \mu_{\text{water}}}{\mu_{\text{water}}} \times 1000$$

4. (2 pts) Pitch is defined as: $Pitch = \frac{\text{Table movement per rotation}}{\text{Slice thickness}}$

Effect of increasing pitch

Patient dose: Increasing pitch → table moves faster → less overlap of radiation so Patient dose decreases

Spatial resolution: Higher pitch → fewer projections per slice so Reduced spatial resolution and increased image noise

5. **(1pt)** *The Doppler effect refers to the change in frequency of ultrasound waves reflected by moving blood cells.*
- *When blood moves toward the transducer, the reflected frequency increases.*
 - *When blood moves away, the frequency decreases.*
6. **(1.5 pts)** *A piezoelectric transducer operates based on the piezoelectric effect.*
- *Certain crystals (e.g., PZT) deform when an electric voltage is applied.*
 - *Applying an alternating voltage causes the crystal to vibrate, generating ultrasound waves.*
 - *Returning echoes deform the crystal, producing an electric signal.*
 - *The same transducer acts as both transmitter and receiver.*
 - *This process allows real-time ultrasound imaging.*
7. **(1.5 pts)** *Ultrasound imaging artifacts*
- *Reverberation*
Origin: Multiple reflections between strong reflectors
Appearance: Parallel, repeated lines on the image
 - *Acoustic Shadowing*
Origin: Strong attenuation by bone or air
Appearance: Dark region behind the structure
 - *Posterior Enhancement*
Origin: Low attenuation through fluid
Appearance: Increased brightness behind fluid-filled structures

Exercise 01 solution : (4 pts)

1. Wavelength calculation

$$\lambda = \frac{c}{f} = \frac{1540}{5 \times 10^6} = 3.08 \times 10^{-4} \text{ m}, \lambda = 0.308 \text{ mm}$$

2. Minimum detectable structure size

Minimum detectable size \approx wavelength so the minimum size $\approx 0.3 \text{ mm}$

3. Comment

This frequency allows detection of **sub-millimeter structures**, providing **high spatial resolution**, but penetration depth is reduced compared to lower frequencies.

Exercise 02 solution : (4 pts)

1. X-ray attenuation law

$$I_{\text{trans}} = I_0 e^{-\mu x}$$

2. Intensity ratio calculation

$$I_{\text{trans}} = I_0 e^{-\mu x}$$

$$\frac{I_{\text{trans}}}{I_0} = e^{-0.25 \times 15} = e^{-3.75} \approx 0.023 \Rightarrow 2.3\%$$

3. Interpretation for chest radiography

Only a **small fraction of X-rays is transmitted,**