

Medical imaging (Chapter 32 TB):

- Principles of the production of X-rays by electron bombardment of a metal target:

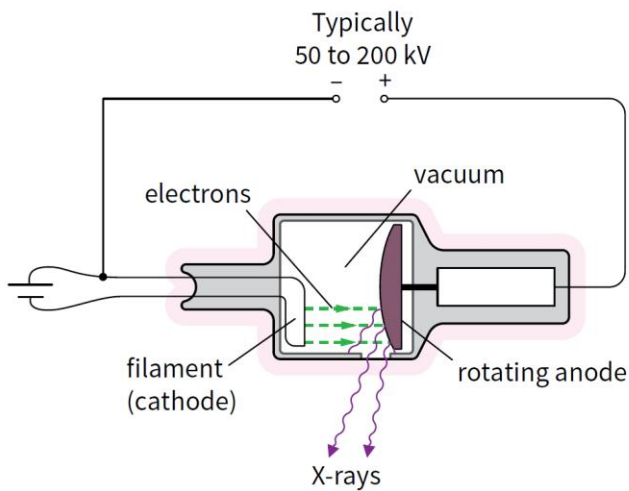


Figure 32.4 A simplified diagram of an X-ray tube.

- Contains two electrodes:
 - Cathode – the heated filament from which electrons are emitted
 - Anode – the rotating anode (to avoid overheating) made of a hard target metal (tungsten)
- External power supply produces a voltage between the two electrodes, resulting to the acceleration of a beam of electrons across the gap between the cathode and the anode, bombarding the anode (metal target) at high speed, stopping the electrons, hence losing a small amount of their kinetic energy in the form of X-ray photons which emerge in all directions
- The window, is thinner than the rest allowing X-rays to emerge into the space outside the tube; the width of the X-ray beam can be controlled using metal tubes beyond the window to absorb X-rays, which produces a parallel-sided beam called a collimated beam

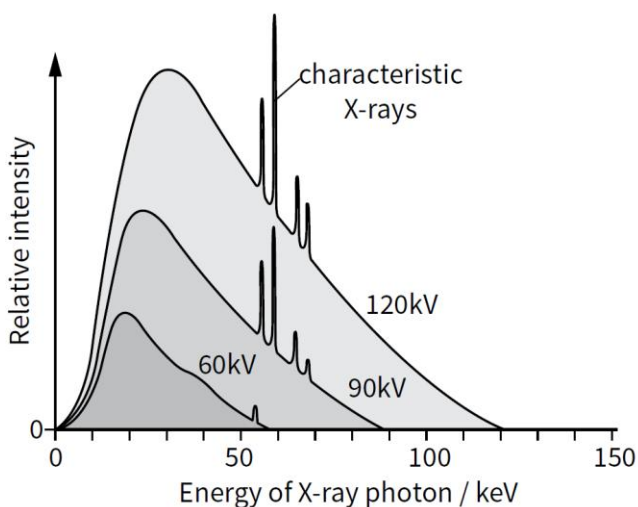


Figure 32.5 X-ray spectra for a tungsten target with accelerating voltages of 60 kV, 90 kV and 120 kV. The continuous curve shows the braking radiation while the sharp spikes are the characteristic X-rays.

- X-ray photons produced when electrons is accelerated have range of accelerations when hitting the target metal, hence the distributions of wavelengths forming the broad background **braking radiation**; the **characteristic radiation** are due to the de-excitation of orbital electrons in the target metal (anode); the sharp cut-off at short wavelength is because an electron gives all of its energy to a single photon and is stopped in a single collision, as well as where its minimum wavelength gives the maximum energy

$$f_{\max} = \frac{eV}{h} \quad \text{or} \quad \lambda_{\min} = hc / E_{\max}$$

- **Hardness** of an X-ray beam: the measure of the penetration of the beam; the greater the hardness, the greater the penetration / shorter wavelength / higher frequency / higher photon energy
 - Inceasable by increasing the accelerating potential difference (p.d. between anode and cathode)
 - Soft X-rays are less penetrative (long wavelengths), so it is more likely to be absorbed in the body, hence it possesses a greater health hazard than short-wavelength radiation; minimised by using aluminium sheet filter placed in the X-ray beam from tube
- The gradual decrease in the intensity of X-rays as it passes through matter is called **attenuation**
- Intensity is the power / rate of energy transfer per unit cross-sectional area; unit: W m^{-2}

$$I = \frac{P}{A}$$

- Attenuation of X-rays passing through a uniform material given by:

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

- I_0 is the initial intensity
- x is the thickness of the material
- I is the transmitted intensity
- μ is the attenuation coefficient; unit: m^{-1} or cm^{-1} , etc

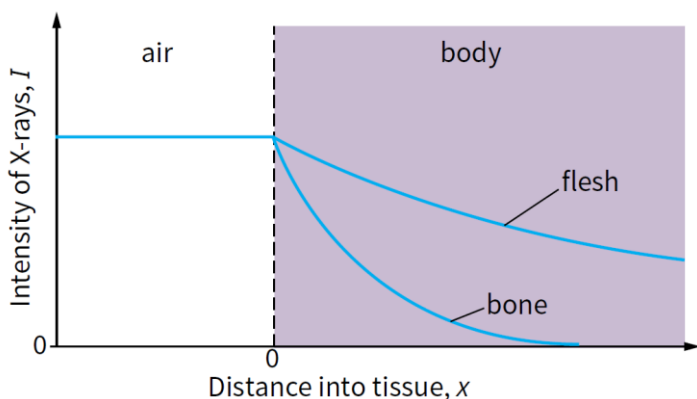


Figure 32.6 The absorption of X-rays follows an exponential pattern.

- Half-thickness of an absorbing material given by:

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

- **Sharpness:** ease with which edges of structures can be seen

➤ Determined by the width of the X-ray beam (sharp image achieved by a narrow beam of parallel X-rays) controlled by:

- Width of the electron beam and the metal target
- Size of aperture at the exit window (reduced by adjustable lead plates)
- Collimation of beam – ensuring parallel-sided beams when passed through the lead slits

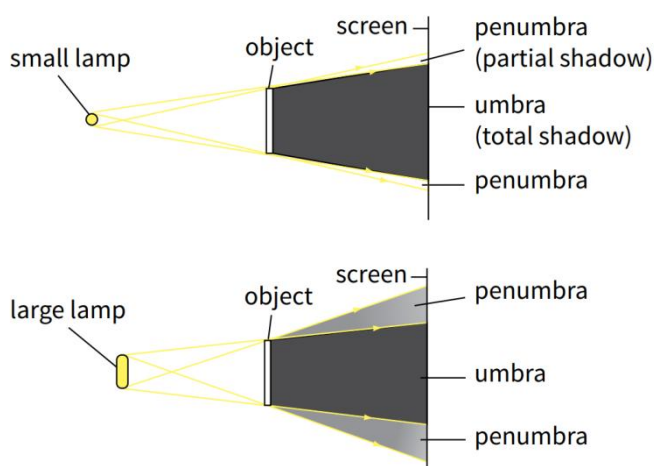


Figure 32.9 The small lamp casts a smaller penumbra and this improves the sharpness of the shadow.

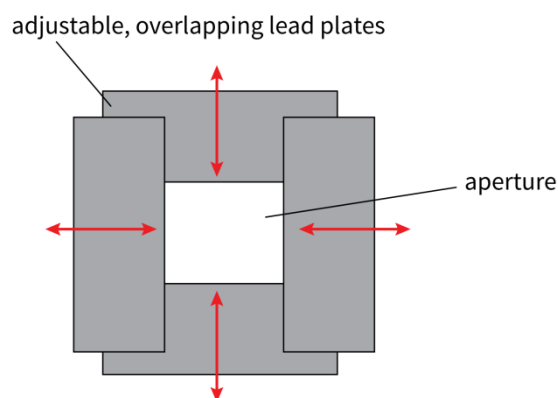


Figure 32.11 The smaller the aperture, the narrower the X-ray beam.

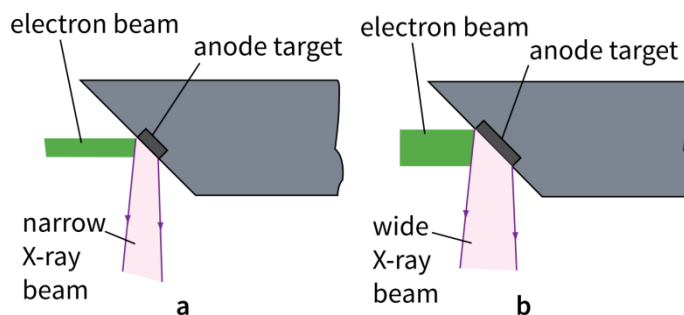


Figure 32.10 A wide anode target results in a wide X-ray beam, giving fuzzy edges to the shadow image.

- **Contrast:** difference in degree of blackening between structures
 - Good contrast when the ratio between the intensity of the incident and the emergent X-ray beam of different organs are far apart
- Principles of computed tomography or CT scanning:
 - X-ray images of one slice is taken from different angles, all in the same plane
 - Combined to produce a 2D image of one slice
 - Repeated for many slices and images combined
 - To build up 3D image of whole body structure using the computer that can be rotated and viewed from different angles

- Advantages of CT scan over the standard X-ray image: image gives depth / 3D image formed / final image can be rotated viewed from any angle
- Disadvantages of CT scan over the standard X-ray image: greater exposure to X-ray radiation / more expensive / higher health risks / person must remain stationary#
- The image of an 8-voxel cube can be developed using CT scanning:

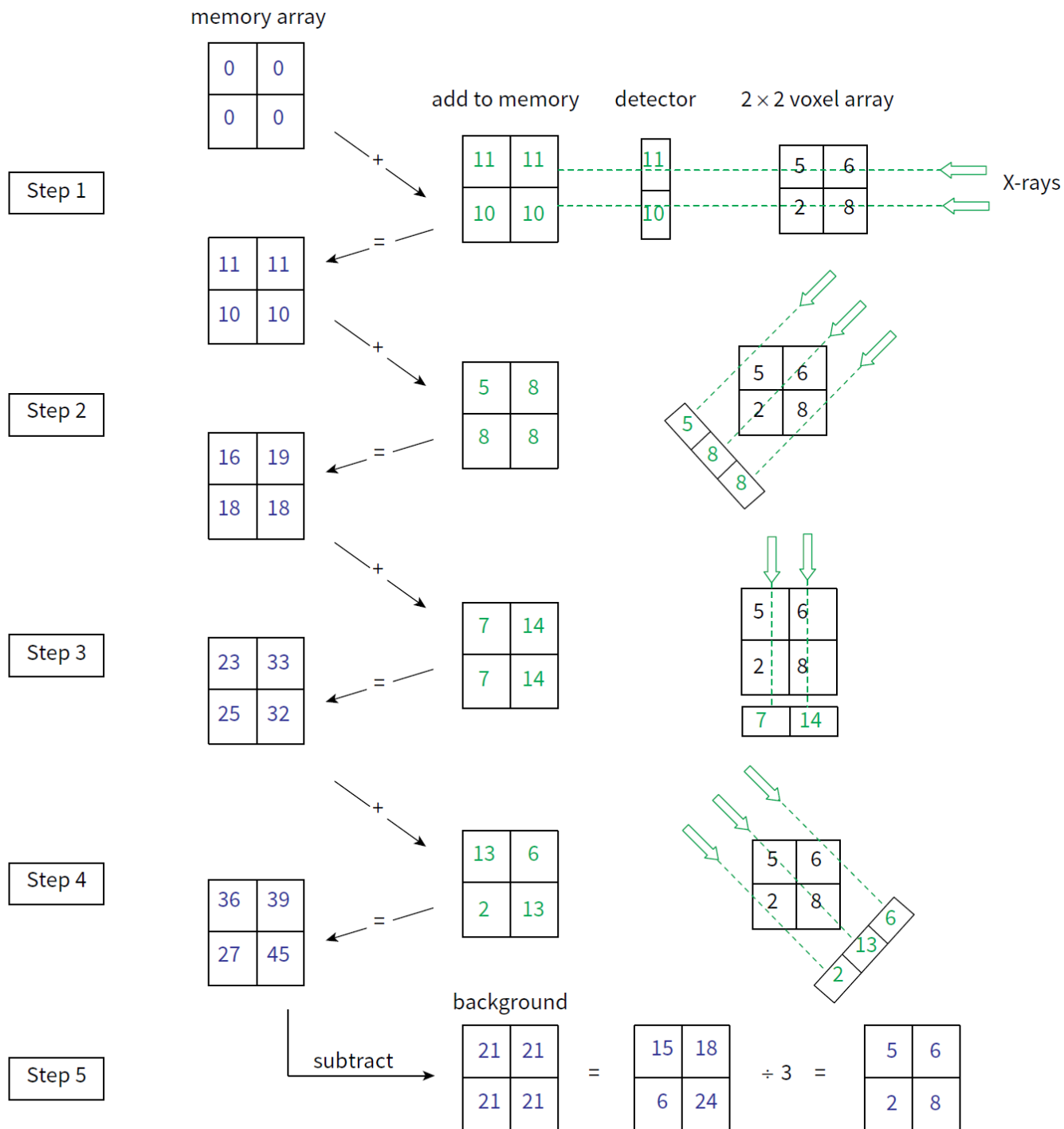


Figure 32.19 Data is built up from a CT scan of a 2 × 2 voxel array, and then processed to deduce the original array.

- Principles of the generation and detection of ultrasonic waves using piezo-electric transducers:

- Potential difference is applied across the piezo-electric transducer (quartz crystal) causing it to change shape (distort)
- Applying alternating p.d. causes oscillations/vibrations
- When applied frequency is natural frequency, crystal resonates
- Natural frequency of crystal is in the ultrasound range (hence usage of ultrasound waves), alternating p.d. produced across the crystal
- Principles behind the use of ultrasound to obtain diagnostic information about internal structures:
 - Pulse of ultrasound produced by quartz crystal / piezo-electric crystal
 - Gel/coupling medium on the skin to reduce reflection at skin
 - Reflected from the boundaries between media
 - Reflected pulse/wave detected by ultrasound transmitter
 - Reflected wave processed and displayed
 - Intensity of reflected pulse/wave gives information about boundary
 - Time delay gives information about the depth of boundary
- Ultrasound at higher frequencies allows smaller structures to be observed/resolved
- **Specific acoustic impedance** Z of a medium: product of medium density and the speed of sound in the medium; unit: $\text{kg m}^{-2} \text{s}^{-1}$

$$Z = \rho c$$

- The intensity reflection coefficient α is given by the expression:

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

- α is the ratio of the reflected intensity to incident intensity
- Z_1 and Z_2 are the specific acoustic impedances of media on each of the boundaries
- The greater the difference in acoustic impedances, the greater the reflected fraction of the ultrasound waves
- The intensity I decreases with as it passes through the body of distance x , hence attenuation of ultrasound in matter is given by:

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

- Ultrasound relies on the reflection of ultrasound at the boundaries between different tissues, hence the thickness of an organ is given by:

$$\text{thickness of bone} = \frac{\text{distance travelled by ultrasound}}{2} = \frac{c\Delta t}{2}$$

- Principles behind the use of nuclear magnetic resonance imaging (NMRI) to obtain diagnostic information about internal structures:
 - Strong uniform magnetic field is applied
 - Nuclei precess about the field direction

- Radio frequency pulse is applied, at the Larmor frequency, causing resonance (nuclei absorbs the energy)
- On relaxation, nuclei emit the radio frequency pulse
- Emitted pulse is detected and processed
- Non-uniform field superimposed on uniform field
- Allows the position of resonating nuclei to be determined
- Allows for the position of detection to be changed (different slices to be studied)
- The function of the non-uniform magnetic field, superimposed on the large constant magnetic field, in diagnosis using NMRI:
 - Strong uniform magnetic field aligns the nuclei / gives rise to Larmor frequency in the r.f. region
 - Non-uniform magnetic field enables the nuclei to be located / changes the Larmor frequency