Medical imaging (Chapter 32 TB):

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

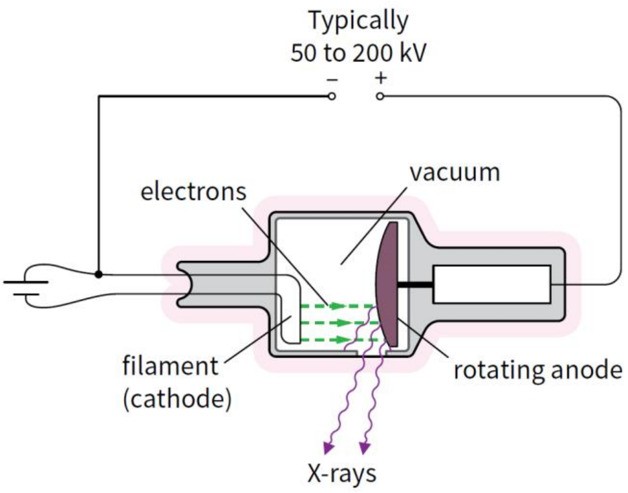

Figure 32.4 A simplified diagram of an X-ray tube.

- 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

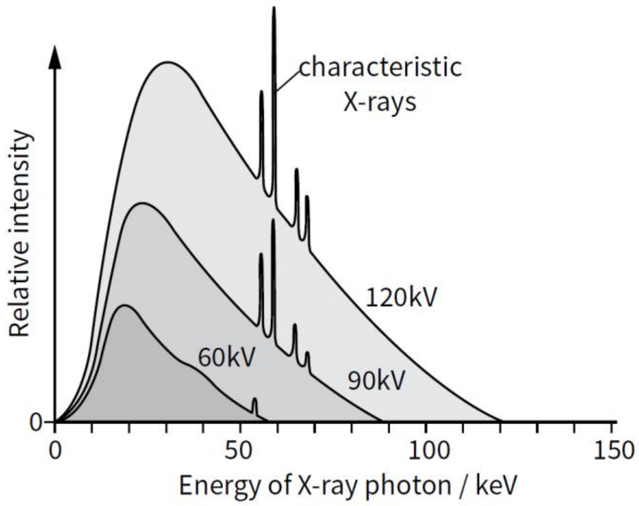

Figure 32.5 X-ray spectra for a tungsten target with accelerating voltages of 60 kV, 90 kV and 120 kV. The continuous curve shows the braking radiation while the sharp spikes are the characteristic X-rays.

- 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

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

- **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
  - Increasable 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

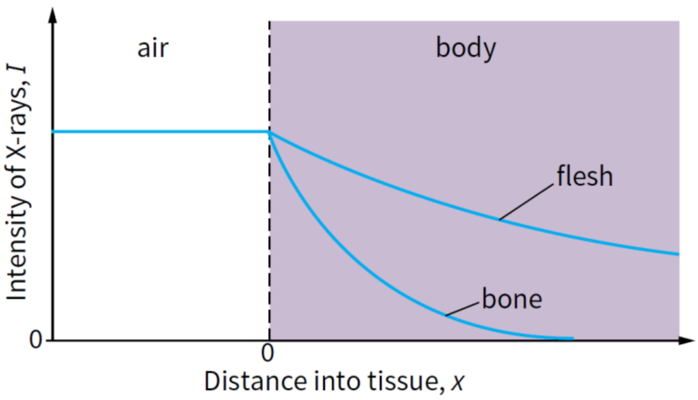

Figure 32.6 The absorption of X-rays follows an exponential pattern.

- 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

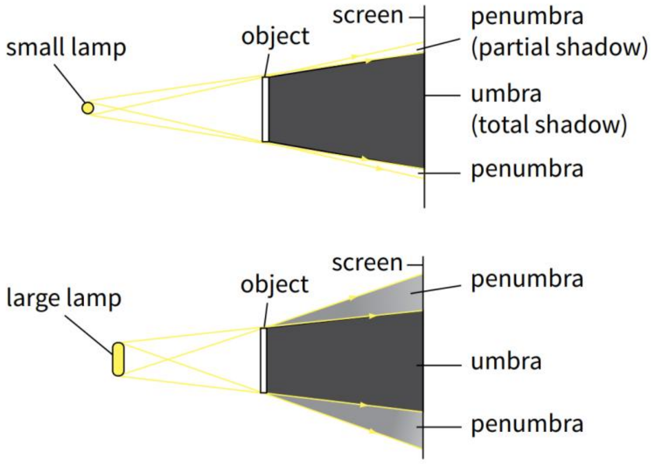

Figure 32.9 The small lamp casts a smaller penumbra and this improves the sharpness of the shadow.

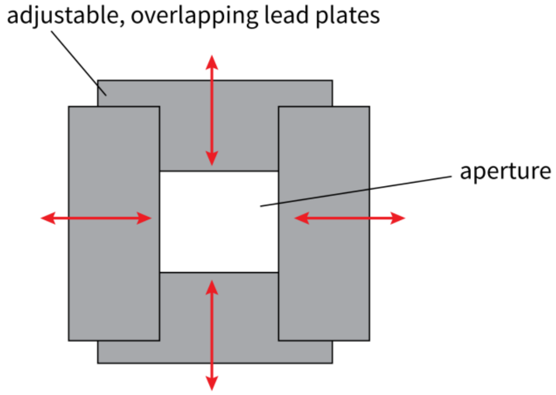

Figure 32.11 The smaller the aperture, the narrower the X-ray beam.

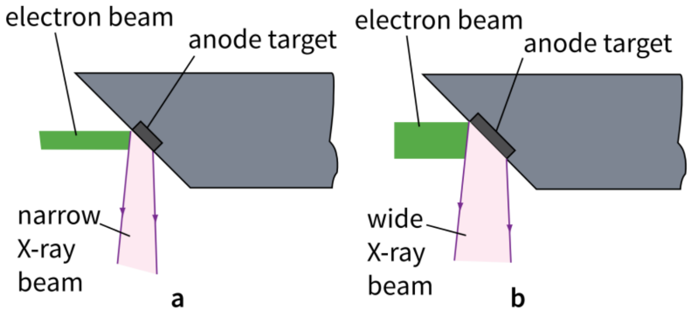

Figure 32.10 A wide anode target results in a wide X-ray beam, giving fuzzy edges to the shadow image.

- **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:

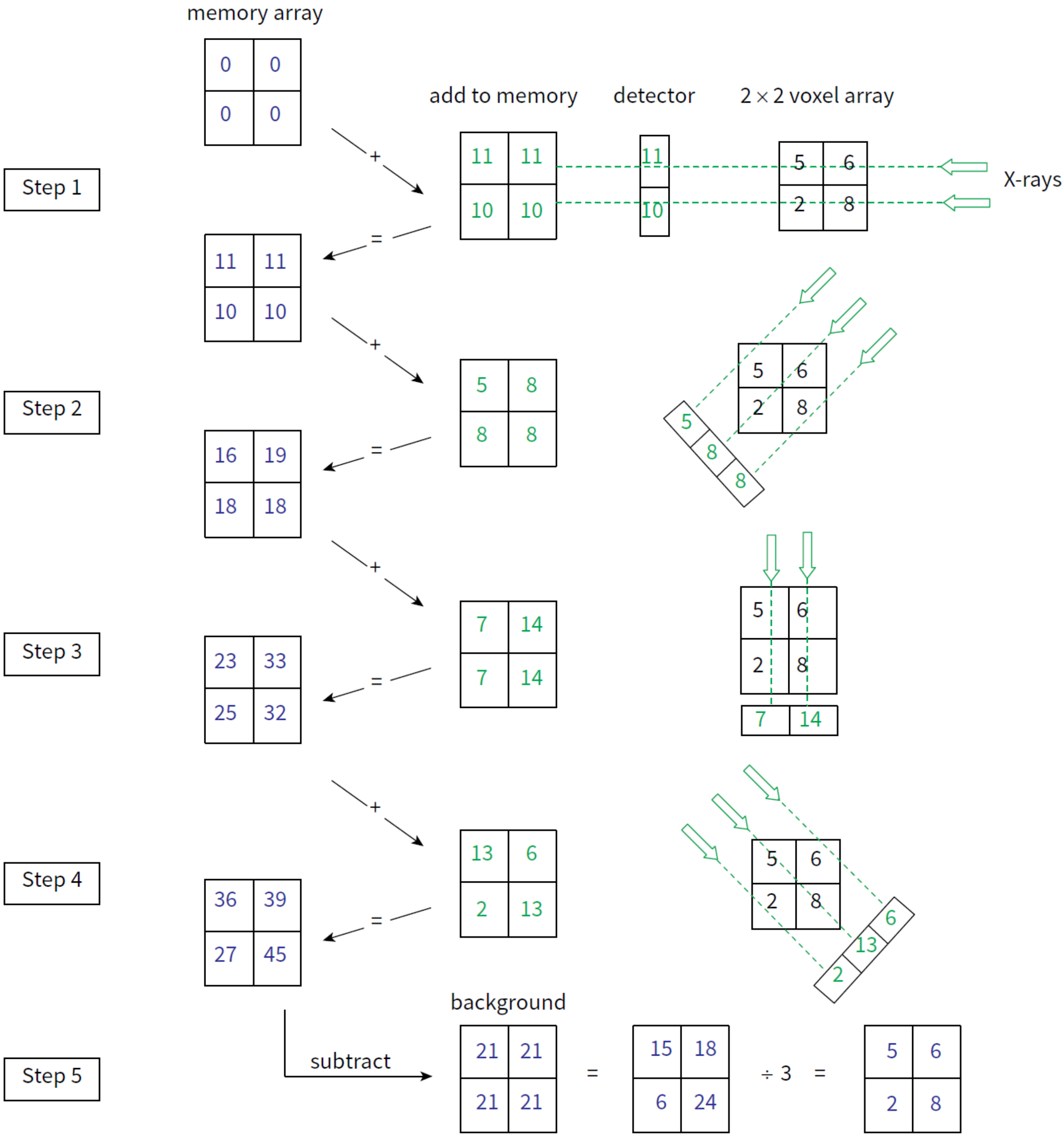

Figure 32.19 Data is built up from a CT scan of a 2 × 2 voxel array, and then processed to deduce the original array.

- 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: kg m^{-2} 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 nucli to be located / changes the Larmor frequency