Module 6 Section 5: Medical Imaging

X-Ray imaging

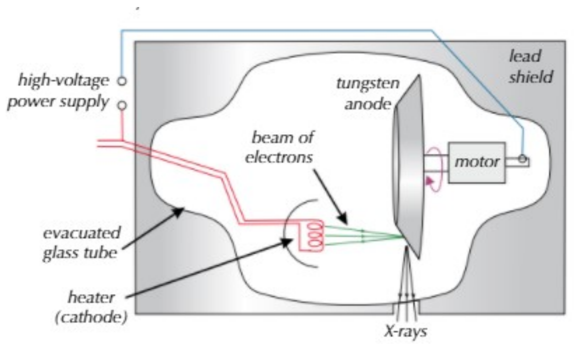
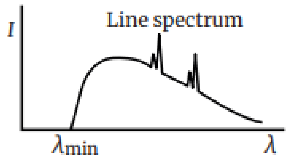
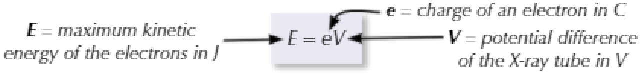


Figure 1: *An X-ray tube.*

X-rays are produced when electrons are fired at a metal target. The kinetic energy of the electrons is converted into heat and roughly 1% is converted into X-ray photons. This process produces a spectrum like this. The **line spectrum** is produced as some of the electrons in the metal are displaced by the fired electrons and **electrons drop from higher levels**, releasing photons as they drop. **λ_{min} can be calculated from the kinetic energy gained by the electrons = eV** where V is the p.d. that accelerated the electrons.





X-rays are also produced when beam electrons knock out electrons from the inner shells of the tungsten atoms. Electrons in the atoms' outer shells fall into the vacancies in the inner energy levels, and release energy in the form of X-ray photons — see Figure 3.

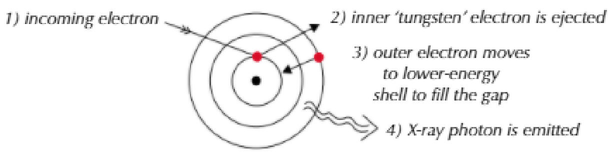


Figure 3: *X-rays are emitted when outer electrons move to inner energy shells to fill vacancies in tungsten atoms.*

X-Ray Attenuation

High energy X-rays are used to treat cancer as they are ionising and can penetrate the tissues to affect the DNA in the cancer cells. To reduce the effect on healthy cells, the X-rays are focussed into beams from different directions.

Lower energy X-rays are used in diagnosis by imaging parts of the body. The attenuation of the X-rays depends on the **density of electrons in a material**. Therefore, they do not penetrate bone as easily as tissue and the difference in attenuation can be used to create an image.

The intensity, **energy per unit area per unit time**, of the X-rays decreases with thickness according to this equation:

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

μ is a constant dependent on the material, called the attenuation constant. The value **for half-thickness** can be derived in a similar way as for half-life.

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

Uses of Nuclear Radiation

Radioactive tracers are used to image different organs or organ systems in the body. The process involves injecting a radioactive material, with a short half-life, into the body; for example, technetium-99m. When the material decays it will emit γ waves which are then detected by a gamma camera outside the body. Different radioisotopes are concentrated in different parts of the body so are specifically chosen for different roles. For example, technetium concentrates in the blood so can be used to image blood flow through the lungs.

PET scanners use the annihilation of a positron and electron to create 2 γ waves. Detectors measure the gamma waves on opposite sides of the body and therefore can pinpoint the source very accurately. This can be used to generate a 3D image of the body.

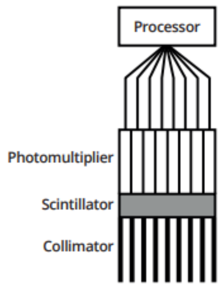
Gamma cameras are used in both these methods.

Collimators produce a parallel beam of gamma radiation.

The **scintillator** produces flashes of light when high energy particles strike them.

The **photomultiplier** has an arrangement of electrodes so that electrons emitted from one electrode by the photoelectric effect are effectively multiplied in number to make a much larger current.

This is then processed to produce an image.



	Advantages	Disadvantages
X-ray + CT	Clear images Low cost	High radiation dose
Ultrasound	No radiation – no side effects Moving images possible Low cost	Cannot be used to study the brain or lungs Low resolution
MRI	No side effects High quality images Can image any part of the body	High cost

Ultrasound

There are two types of ultrasound scan:

	Description	Example
A	1D, time delay compared to known depth of tissues	A tumour would change the expected depth
B	2D, array of detectors used to image structures	Foetal scans

Ultrasound doppler scans can be used to study blood flow in the body as the motion of the blood causes a change in the frequency of the reflected waves.

$$\frac{\Delta f}{f} = \frac{2v}{c}\cos\theta$$