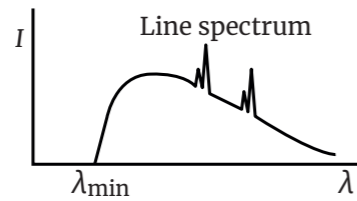# GCE Physics Unit 4 Option B, Medical Physics

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 (see unit 2.7). λ_{min} **can be calculated from the kinetic energy gained by the electrons = eV** where V is the p.d. that accelerated the electrons (see unit 4.4). The **intensity depends on the number of electrons** that are fired at the metal, more incident electrons means a higher intensity but the pattern will remain the same.

Line spectrum

I

λ_{min} λ

Ultrasound use high frequency sound waves generated by piezoelectric crystals to image the body. A piezoelectric crystal deforms when a voltage is applied between two of its faces, and also produces a voltage when deformed. As ultrasound is reflected when it meets a boundary between 2 materials, the reflected waves can be used to create an image. Different materials will reflect a different fraction of the waves depending on its **acoustic impedance**, Z.

$$Z = c\rho$$

The fraction of the energy reflected, R, can be given by this equation.

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

If the boundary was between air and skin, very little of the energy would penetrate. Therefore, a **coupling medium** is used, this is very similar to skin so ensures the transmission of the waves.

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.

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

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 (see unit 3.5).

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

As the **contrast between soft tissues in the digestive tract is poor**, imaging them requires X-ray **contrast media**. Usually they have high attenuation constants e.g. 'barium meals' for highlighting the stomach and intestines.

CT scans use a rotating beam X-ray to produce a 3D image of the body.

MRI scans work because different tissues contain different concentrations of hydrogen atoms.
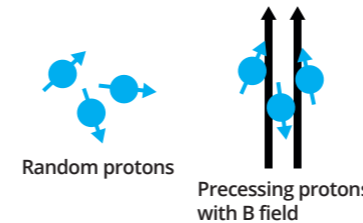
The proton in a hydrogen nucleus spins with a random direction. When a B field is applied these precess, rotate around the B field. The frequency of precession is known as the **Larmor frequency**. If waves of this frequency hit the protons, they will **absorb some energy** and then give out waves once the incident waves are stopped. The time taken for the protons to release the waves is known as the **relaxation time** and is different for different tissues.

The equation for the Larmor frequency is: $f = 42.6 \times 10^6 \, B$

Random protons   *Precessing protons with B field*

	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

Radiation in medicine:

The 3 types of radiation; alpha (α), beta (β) and gamma (γ) are used in medicine. They are all ionising, which can be used to kill cancer cells. However, they can also affect healthy cells so the dose received must be measured.

The absorbed dose, D, is the radiation energy absorbed per kg of tissue, 1 joule per kilogram = 1 Gray (Gy).

As different radiations have different ionising strengths, it is more common to consider the equivalent dose, H.

$$H = DW_R$$

Where, W_R is the radiation weighting factor.

Radiation	W_R
X-ray, γ, β	1
α	20

Some tissues will be affected more than others; therefore, the effective dose, E, must be considered.

$$E = HW_T$$

Both H and E are measured in Sieverts (Sv).

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.

Processor — *Photomultiplier* — *Scintillator* — *Collimator*

I = intensity in W m⁻² x = thickness in m f = frequency in Hz c = wave speed in m s⁻¹ θ = angle between the blood flow and the wave H = equivalent dose in Sv W_R = radiation weighting factor D = absorbed dose in Gy

λ = wavelength in m μ = attenuation constant in m⁻¹ Z = acoustic impedance in kg m⁻² s⁻¹ B = magnetic field strength in T v = wave speed in m s⁻¹ E = effective dose in Sv ρ = density in kg m⁻³ W_T = tissue weighting factor