# HSC Physics Notes - Medical Physics

## 9.4 - 1. The properties of ultrasound waves can be used as diagnostic tools

1. identify the differences between ultrasound and sound in normal hearing range

**Ultrasound** is very high frequency sound. Ultrasound waves are sound waves with frequency greater than that of normal human hearing. That is, the **frequency** → **greater than 20 000 hertz**.

- Sound waves are longitudinal waves and need a medium in which to travel.
- Ultrasound waves are used because of their **shorter wavelengths** enable to penetrate human flesh and fat. This also enables *much higher imaging resolution* compared to audible sound.

2. describe the piezoelectric effect and the effect of using an alternating potential difference with a piezoelectric crystal

The **piezoelectric effect** is the ***conversion of electrical energy to mechanical energy*** resulting in the *change in shape of a piezoelectric crystal when it is subjected to a potential difference*.

The piezoelectric effect is utilised by an **ultrasound transducer**, capable of **detecting the reflected ultrasound produced**. The material used to vibrate at such a fast rate to produce the frequencies for ultrasound is known as piezoelectric crystal. If an electric field (potential difference) is applied across the crystal, the shape of the crystal changes.

**Naturally occurring crystalline substances exhibiting the piezoelectric effect include quartz and lithium sulfate**. These crystalline substances can be used as a piezoelectric crystal and therefore applied in medical ultrasound transducers to detect shapes and bodily organs → *ultrasound will reflect from some body parts and pass through others*. Therefore the **piezoelectric effect** in piezoelectric crystals **can be used to determine bodily dysfunctions**; however, most commonly used to observe a growing foetus in the womb.

3. define acoustic impedance and identify that different materials have different acoustic impedances

**Acoustic impedance**, *Z*, is a **measure of how readily sound will pass through a material**. Acoustic impedance is defined by the formula:

$$Z = \rho v$$

where;
**Z** = acoustic impedance of a material ($kg\ m^{-2}\ s^{-1}$)
**ρ** = density of the medium ($kg\ m^{-3}$)
**v** = velocity of the sound material ($m\ s^{-1}$)

- Because **all mediums/materials have a different density**, then regular **sound will travel at different velocities** through each of the mediums. From this knowledge, the acoustic impedance of a sound wave can be calculated. This may require reference to $v = f\lambda$ , when given other details.

4. describe how the principle of acoustic impedance and reflection and refraction are applied to ultrasound

**Acoustic impedance**, reflection and refraction of ultrasound frequencies will occur just as often as normal sound waves. **Ultrasound frequencies must be used rather than normal sound to penetrate past certain tissues and organs** in the human body (for practical application).

When ultrasound waves are emitted into the human body, **some waves will be reflected back off tissue and others will pass through** or refract → eventually reflecting off the dense human bone. Reflected ultrasound waves are often very weak because they are *impeded by human cells and tissue as the energy is absorbed by them*. The absorbed energy of the ultrasound waves is converted into heat energy.

The production of heat energy in human tissue is an issue for ultrasound scans and therefore the ultrasounds are emitted at extremely low energy levels. This prevents damage to human tissue. However, this heating effect because of the impedance, reflection and refraction of ultrasounds can be used to provide relief to arthritis sufferers and stimulate blood flow in damaged tissue.

5. <u>define</u> the ratio of reflected to initial intensity as:

The acoustic impedances of two adjoining tissues are used to calculate **the intensity of the reflected pulse compared with the incoming one**.

$$\frac{I_r}{I_0} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$$

where;

$I_0$ = intensity of the pulse, incident on the surface ($W\,m^{-2}$)
$I_r$ = intensity of the pulse reflected back ($W\,m^{-2}$)
$Z_1$ and $Z_2$ = the acoustic impedances of media 1 and 2 ($kg\,m^{-2}\,s^{-1}$)

- The ratio of the reflected ultrasound should almost always be less than its incident ultrasound wave. The ratio will be given as a decimal point which should be converted to a percentage.

6. <u>identify</u> that the greater the difference in acoustic impedance between two materials, the greater is the reflected proportion of the incident pulse

If there is a very large difference in acoustic impedance between the two materials, a large fraction of the ultrasound will be reflected back.

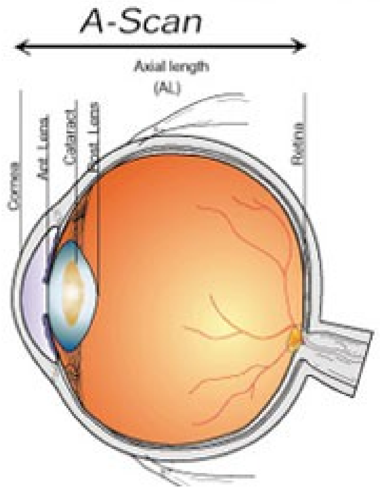
- This is what happens when ultrasound is **directed through the air to the skin**. The very large difference in the acoustic impedance of air and skin means that most of the ultrasound will be reflected off the skin and will not enter the body.
- To ***minimise this reflection at the skin surface, a gel with an acoustic impedance similar to that of skin is placed on the skin***. The signal can pass from the transducer through the skin without reflection.

7. <u>describe</u> situations in which A scans, B scans and sector scans would be used and reasons for the use of each

<u>A scan:</u>

An **A-scan** is a **range-measuring system** that records the time for an ultrasonic pulse to travel to an interface in the body and be reflected back.

- **ultrasound pulses** are directed into the body in **one line** and the reflected signal is detected. The intensity of the reflected beams is ***plotted on a graph as a function of time***. → position of various features can be determined from the time lapse, with knowledge of the speed of sound in the different tissues.
- **One dimensional**




A-scans are **used in ophthalmology** for the diagnosis of <u>eye disease</u> and for *measurements of distances in the eye*. A-scan provides data on the length of the eye and masses in the eye, which is a **major determinant in common sight disorders**.

<u>B scan:</u>

A **B-scan** displays the **reflected ultrasound as a spot**, the **brightness of which is determined by the intensity** of the reflected ultrasound pulse.

- By *moving the transducer probe*, the body is viewed from a range of angles. **A series of spots are obtained, each series corresponding to a different line through the body.**
- **Two dimensional**

Also known as *ultrasonography,* B scans are used in the medical field by doctors and analysts of the **human eye** and premature images of **foetal features (primitive sonogram)**. B-scans are able to determine precise positions of parts of the eye (where A scans are not sufficient) and therefore used to ***seek out abnormalities***.

<u>Sector scan:</u>

Sector scans are in the shape of a sector. They are made from a **series of B scans which build up an image of the sector** in the body through a series of dots of **varying intensities**. Because of the large reflected impedances when there is a large gap, a gel with similar impedance to human skin is place onto the transducer to minimise the level of reflection which would alter the end image.

- Used in ultrasounds to observe the internal body parts and brain of a foetus through the fontanelle
- Sector scans only require a very small 'window' to reflect the ultrasound waves and produce an image on the screen → thus the process is effective and doctors are trained to **search for abnormalities during the foetal stages of pregnancy**.

8. describe the Doppler Effect in sound waves and how it is used in ultrasonics to obtains flow characteristics of blood moving through the heart

The **Doppler effect** is the **apparent change in frequency observed when there is a relative movement between a source of sound and the observer**.

This can be best observed when a car passes you from behind or moves between two observers. A stationary car noise will be heard at the same frequency and time by both observers. However, if the car approaches an observer the frequency will become *apparently* greater → and smaller when the source of the car sound moves away.

In Doppler ultrasound, the change in **frequency is measured** and analysed to give information about **rate of blood flow** in the body, and particularly through the heart.

- An **ultrasound is directed into the body** (from the transducer). Some of this ultrasound is reflected off blood cells moving with the blood. Due to the ***movement of the blood cells, the reflected ultrasound that is received by the transducer will have changed in frequency*** compared with the incoming signal.
- Information is colour-coded to indicate whether the blood is flowing towards or away from the transducer. The colour varies across the artery, showing that the blood flows more quickly in the centre of the artery.

9. outline some cardiac problems that can be detected through the use of the Doppler effect

Cardiac problems are able to be detected using ultrasound technologies with the Doppler effect in mind. When the scan is combined with Doppler colour flow imaging, the valves can be checked to see if they open and shut correctly and if they leak. Problems include;

| Cardiac Problem | Specific technology/how is it done |
|---|---|
| **Abnormal heart wall motion** | By **analysing the reflected ultrasounds** from blood cells, and **comparing this to a known healthy heart wall motion**, abnormalities can be detected |
| **Disease** | **Using the colour imaging system**, a colour detected that should not be where it is currently located in the blood flow of the heart could lead to disease |
| **Fluid accumulation** | Uses an **echo-cardiogram** with the combination of all technologies from the **Doppler effect and B-scans** which can render full images for detection |

1. solve problems and analyse information to calculate the acoustic impedance of a range of materials, including bone, muscle, soft tissue, fat, blood and air and explain the types of tissues that ultrasound can be used to examine

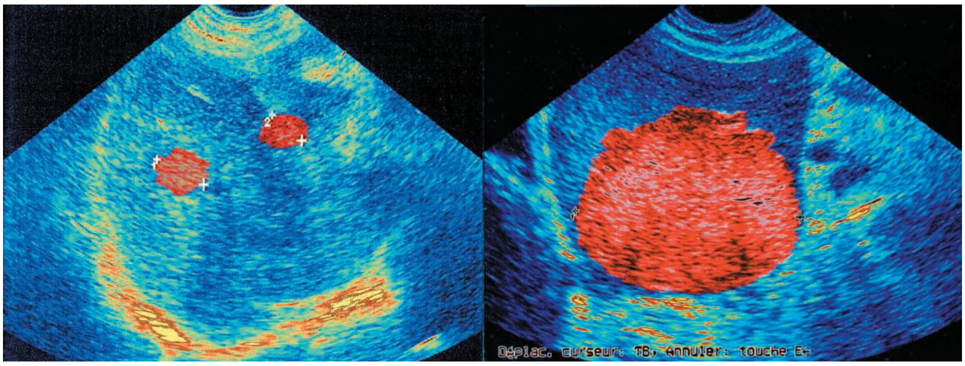
This requires the calculation of acoustic impedance ($Z$) using the density of a material or tissue (which will be provided) and also the knowledge of the speed of sound in that medium. $\mathbf{V_{air} = 330ms^{-1}}$

$$Z = \rho v$$

Ultrasounds are able to examine a number of tissues and materials in the human body using a vary degree of intensity and the density of the tissue. The most obvious uses for ultrasound scans is for the **analysis of foetal development** (pregnancy ultrasound) and therefore must be able to pass through skin, fat, flesh (tissue) and the foetus' developing bone and cartilage. In addition, ultrasounds are used to **analyse the blood flow** rate and monitor **heart wall motion** using the Doppler colouring effect → here, ultrasounds must pass through the delicate heart tissue and so must be a rather low intensity.

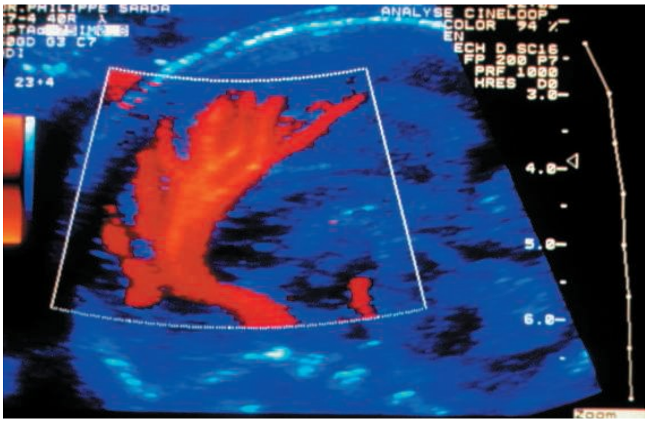
Developing research has shown that ultrasounds emitted at extremely **high intensities have the power to destroy cancer cells and cancerous tissue** in the liver. Ultrasounds are used to destroy the lens of an eye for cataract reconstruction → ultrasounds must pass through cornea and eye humour (jelly like substance).

2. gather secondary information to observe at least two ultrasound images of body organs



← A comparison of early stage and late stage development of **disease in the liver**

Sector scan of an **infant's brain** →



3. identify data sources and gather information to observe the flow of blood through the heart from a Doppler ultrasound video image

Using an education DVD supplied by the school, we were able to watch an ultrasound taking place on a patient's heart. The **Doppler ultrasound imaging system used a colour-coding system** to identify the speed and motion of the bloodstream in the arteries and ventricles of the heart. Information to identify constituents of the ultrasound was derived from the Charles Sturt University HSC Online and Jacaranda Physics textbook.

- The **motion of the heart walls** was monitored by observing the movement of the heart itself.
- During the ultrasound, ***a dark region of bluish-tinge was detected*** in the arteries that flowed from the heart into the rest of the body → ***this indicated an abnormally slow blood flow***. The patient was identified to have a severe case of type 2 diabetes who required an insulin and sugar injection to boost the rate of blood flow.

  If the heart was left to pump blood at this rate, the body would gradually lose sensation and result in a lack of oxygenated blood to brain, resulting in blackout.

4. identify data sources, gather, process and analyse information to describe how ultrasound is used to measure bone density

Determining the **bone density** of certain patients is important for **early detection of osteoporosis** (a disease and condition that gradually reduces the density of bones → leading to weak and brittle bones). Conventional *X-rays of normal frequency are not suitable for detection of bone density changes below 30%* and therefore are ineffective for many bone density issues which require very early detection for treatment.

- **Ultrasound measurement of bone density is more effective than x-ray and the technique is readily available, often through mobile units at pharmacies.**

The patient inserts a foot into a warm water bath and ultrasound *waves are directed through the heel*. **The speed of the ultrasound through the bone and the ultrasound attenuation** (degree of absorption) **are measured.** Normal bone has a higher speed of ultrasound and larger attenuation than osteoporotic bone.

It is, however, not possible by this method to detect or measure sites of fracture in the spine or hip where osteoporosis sufferers experience many bone density losses, albeit the method is effective for determining *bone density loss in the heel and wrist*. **Ultrasound bone density screening technology is very cost-effective** in comparison with all bone density technology.

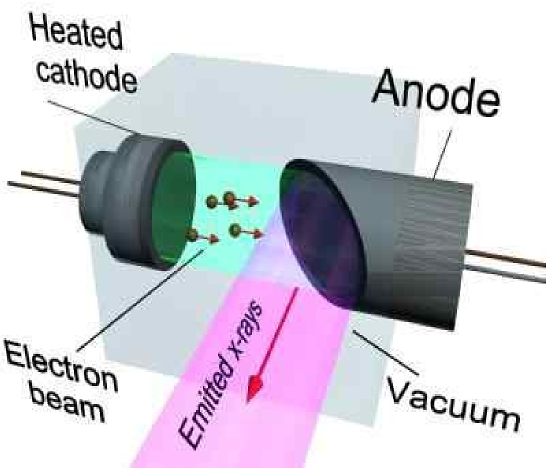
5. solve problems and analyse information using:

$$Z = \rho v \quad \text{and} \quad \frac{I_r}{I_0} = \frac{[Z_2 - Z_1]^2}{[Z_2 + Z_1]^2}$$

*Note:* You will need to know how to combine these two formulae and use **v = *f*λ**

## 2. The physical properties of electromagnetic radiation can be used as diagnostic tools

1. describe how X-rays are currently produced




Similar principles are used to produce X-rays that resulted from the high voltage jumps when dealing with cathode discharge tubes (*Refer to **Ideas to Implementation***).

A **cathode filament is heated** to very hot temperatures in order to produce a beam of electrons which have a **potential difference from 25000V - 250000V**.

- The *cathode accelerates the electrons* → this electron beam hits a positively charged anode. **The anode is usually made from Tungsten in order to withstand** the massive amounts of **heat** that are generated.

The production of X-rays is not very efficient as **only about 1%** of the energy reaching the target **is converted to X-rays**, the **rest being converted to *heat***. This heat is conducted through the coper mount to be cooled across a larger area.

This method allows for the emitted **X-rays to have their path altered and directed** where it is necessary.

2. compare the differences between 'soft' and 'hard' X-rays

The frequency of the X-radiation depends on the amount by which the electron has been slowed, or, in other words, the amount of braking that has occurred.

Hard X-rays are those types of X-rays which have **qualitatively *high energy photons***. These high energy photons are the **result of less slowing of the electron** so it has much more energy. Hard X-rays (or those with higher energies) have **high frequencies but lower wavelengths**. Soft X-rays, in contrast, have lower energy levels and therefore lower frequencies.

**Hard X-rays are preferred for medical use and diagnosis because they have a much higher penetrating power** and their energy will not be absorbed by human tissue as easy as soft x-rays. Soft x-rays are not useful for imaging and only expose the patient to unnecessary and possibly harmful radiation.

3. explain how a computer axial tomography (CAT) scan is produced

**Computed axial tomography** scanning **uses X-rays** to obtain an **image of a *cross-section* through the body.** Very slight differences in X-ray attenuation (absorption) can be measured and so soft tissue can be accurately imaged.


A CAT scan consists of an **X-ray tube** which is **mounted on a frame called a *gantry***. The patient being scanned is positioned on a bed and placed in the gap in the gantry where the x-ray beams will be shone through the patient in the region required. **Each scan creates a 'slice'** which is used to form a larger x-ray image. The data from the scan is collected, displayed and reconstructed by a computer.

The **computer analyses the absorption of the X-rays at each measured point in the slice**.

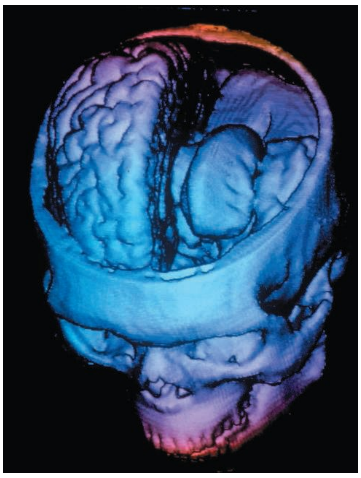
- When the scans are reconstructed, the attenuation of each slice is calculated and assigned a certain shade depending on the energy loss of that x-ray. The final image results in a very accurate x-ray in a **180° plane**.

The production of such powerful x-rays results in the **generation of both high levels of heat and soft x-rays**. The **large amounts of heat** (because of the high voltages) **must be cooled** across a large area which is an **inefficient and uneconomical process**. The heat coupled with the constant moving of the gantry results in the failure of many x-ray tubes and must be replaced which is extremely expensive.
In addition, **soft x-rays must be filtered out to prevent unnecessary exposure to harmful x-rays**, however, the filtering of soft x-rays is difficult and the patient is left exposed to many of them.

4. describe circumstances where a CAT scan would be a superior diagnostic tool compared to either X-rays or ultrasound

**CAT scans are a far superior diagnostic tool when softer tissue needs to be scanned which only differs in density by small percentages**. Brain scans are particularly important for many patients and can only be conducted using CAT scan technology which allows images of the brain to be taken, *penetrating through the extremely dense skull*.

- By taking a large amount of slices, the high energy x-rays can penetrate the skull and distinguish between the different brain materials.
- Can produce a **three-dimensional image**.

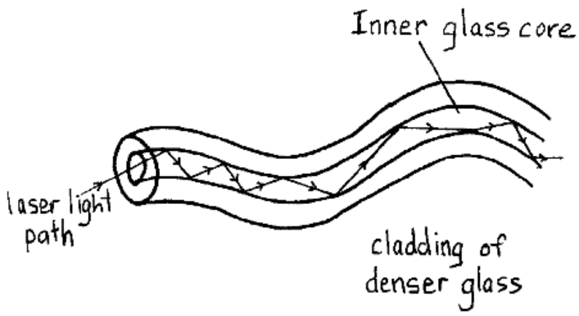


X-rays are not suitable for scanning and brain imaging as **most x-rays will be reflected from the dense skull and simply show an x-ray of the skull rather than the brain tissue**. Moreover, ultrasounds are not suitable for this either as all ultrasound frequencies will be reflected from the skull, unable to penetrate and image the brain.

**CAT scans** provide a **much higher resolution and image quality of soft tissue**, compared to conventional x-ray scans. This is additionally valuable when imaging areas that have experienced bone fracture or spinal disc rupture. These scans are *also useful for scanning for abnormalities in the kidneys, lungs and liver → able to detect abnormalities of 1mm*.

5. explain how an endoscope works in relation to total internal reflection

**Endoscopes are optical instruments using light for looking inside the body to examine body organs, cavities and joints**. Modern endoscopes use **optical fibres** to *transfer light* to and from the area being examined.




In the optical fibres of the endoscope, **light undergoes total internal reflection by reflecting off an inner glass tube** which is surrounded by a much denser outer cladding. The light travels up this tube which is used to transfer the light.

Total internal reflection will only occur when the ***incident ray exceeds the critical angle***.

6. discuss differences between the role of coherent and incoherent bundles of fibre in an endoscope

| Part | Description | Function |
|---|---|---|
| Coherent bundle | Optical fibres are kept in the **same position relative** to each other | **Transmits the image** of the body part back to the eyepiece. The **image is *clear* because the fibres keep the certain light in the same place** |
| Incoherent bundle | Optical fibres are ***NOT*** kept in a **relative position** to each other | **Guides the light** to the area to be examined. Incoherent bundles will *create a blurred image* and therefore only used to guide the light |

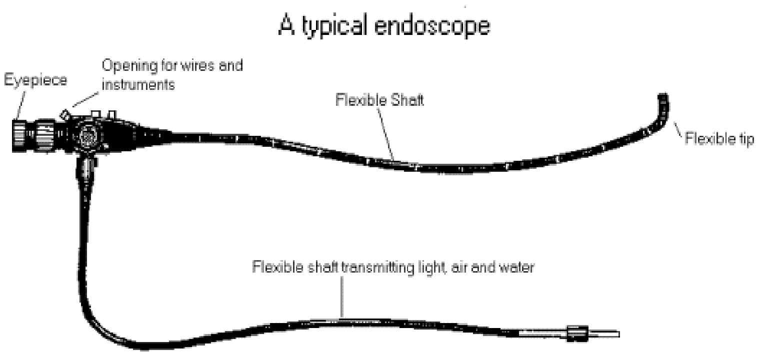
7. explain how an endoscope is used in:

– observing internal organs

An **endoscope can be used to simply view and observe internal organs** including a **colonoscopy** (through the anus), **colposcopy** (through the vagina) or a **gastroscopy** (through the mouth). Each process is used by doctors and trained medical staff to examine the target region for ulcers, infections, tumours or any abnormalities that can cause discomfort or medical concern.

In each case to view the internal organs, the endoscope is placed into an opening on the patient so that an image can be transferred through the fibres to create an image on the screen. Because the internal body is extremely dark having no light inside, **incoherent bundles of optical fibre are used to illuminate the area** → these are best for illuminating the internal organs (*discussed above*) because they *do not require many internal reflections* and therefore have **less loss of energy through the fibre wall**. They are also much cheaper than coherent fibres.
The **coherent fibres**, however, are used to **transmit the clear image of the internal organs so fine details may be observed**. An endoscope is far more efficient to use than an ultrasound, x-ray or CAT scan because it provides the clearest, coloured image which is not distorted.

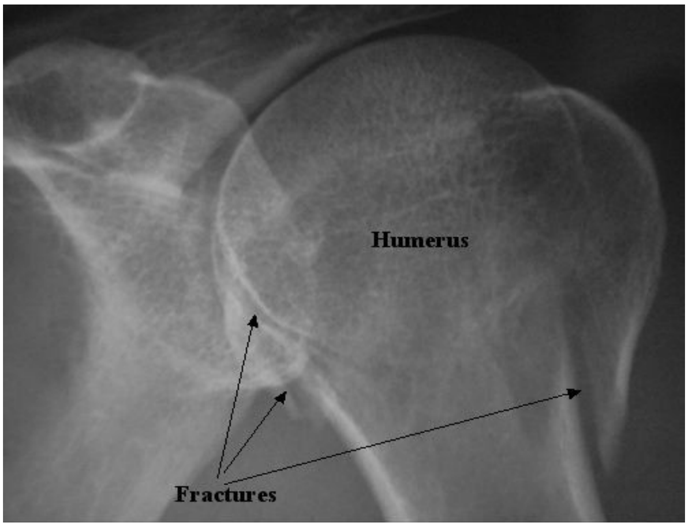
– obtaining tissue samples of internal organs for further testing




If a tumour is detected, **a small sample may be taken for analysis, using the sampling implements** in the endoscope. Such a sample is called a **biopsy**. Polyps (abnormal growth of tissue projecting from a mucus membrane) may be surgically removed using an endoscope with an attachment.

Attachments can be placed on the flexible tip of the endoscope where sample tissue may be removed by making **surgical incisions** or **scraping mucus tissue** from the surface of the organ.

1. gather information to observe at least one image of a fracture on an X-ray film and X-ray images other body parts




2. gather secondary information to observe a CAT scan image and compare the information provided by CAT scans to that provided by an X-ray of the same body part

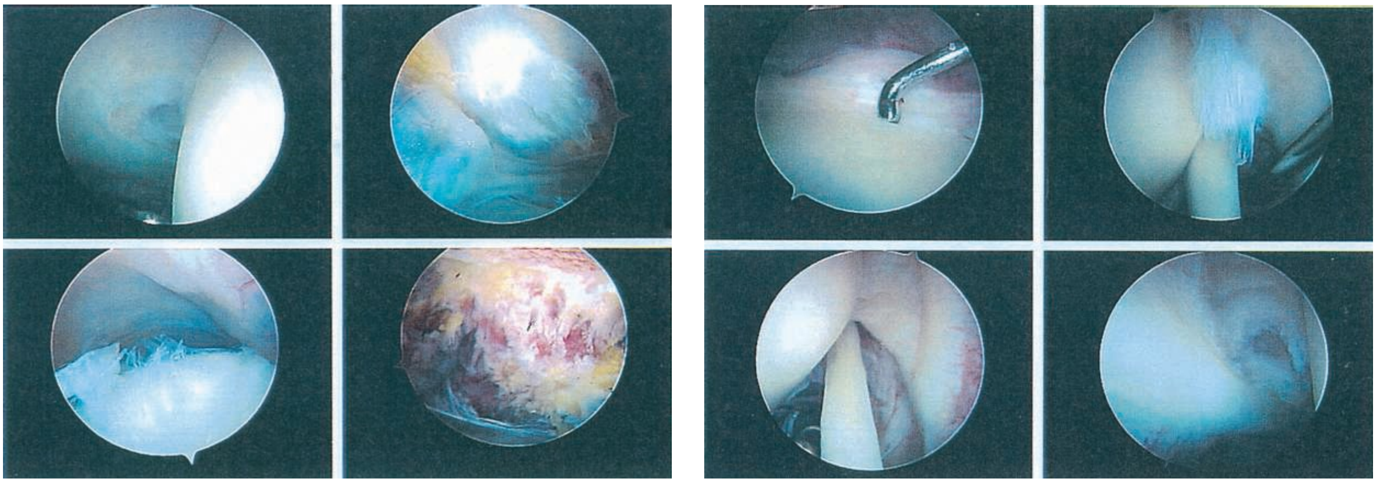
3. perform a first hand investigation to demonstrate the transfer of light by optical fibres

Light from a **light box** is produced through a narrow beam of intense light across a white bench-top. The thin **beam will hit a perspex prism** and by moving this prism to achieve a certain angle → where the **critical angle is exceeded, the light can be totally internally reflected so that no visible light is escaping the prism** in a dark room.

The transfer of light in optical fibres, however, using this principle is in a long straight way and not in one prism. This can be modelled by shining the same **beam against one mirror angled toward another mirror**

**which will continue to reflect in a forward direction** depending on the angle of each mirror. This process is of course slightly different to the exact transfer of light which is totally internal and occurs in a vacuum fibre. The **mirrors act as the less dense glass in the optical fibre**, albeit they are so reflective that no light should dissipate past the mirror.

4. gather secondary information to observe internal organs from images produced by an endoscope



## 3. Radioactivity can be used as a diagnostic tool

1. outline properties of radioactive isotopes and their half lives that are used to obtain scans of organs
**Isotopes** are different forms of the same element which have a varying mass number due to a variance in the number of neutrons. *When the ratio of protons:neutrons is too high or the molecular weight of the element is too heavy the element* is considered **radioactive**.

- **Radioactive** isotopes will emit radiation in the form of either alpha (α), beta (β) or gamma (γ) particles. Each radioisotope will emit a certain type of radiation (which you will be told) and will affect what the radioisotope decays to. (*Refer to Chemistry: Production of Materials* ***5****)*
- The **decayed element is known as the daughter nucleus**.

Radioactive isotopes are used because of the emission of such radiation which can be traced and plotted using computer aided technology as the radioisotopes pass through the body or organs.

Because radioisotopes decay, they have a **half-life** which is a **measure of 'how long an isotope takes to decay to half its original quantity'**.
**Radioactive isotopes which have a long half-life are not suitable for medical diagnosis** or tracking in the human system because they will take too long to decay and **expose the patient to radiation** of alpha, beta and gamma particles.

2. describe how radioactive isotopes may be metabolised by the body to bind or accumulate in the target organ
For radioactive isotopes to be used and be effective they **must be attached to a naturally occurring substance that would be metabolised by the target organ**. The substance that the radioisotope will be attached to is labelled the radio-pharmaceutical.

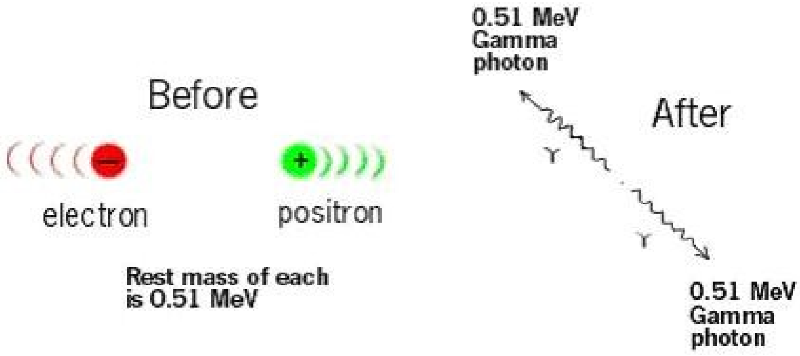
**Radioactive isotopes that are chosen for disease diagnosis** are those which only **emit gamma radiation** because they **cause little damage** to the patient, the **radiation is easily detected** and will **not be ionised in the body**. Two of the most common radioactive isotopes are Technetium-99m and Iodine-123.

The **accumulation of the radioactive isotope is effective in showing how and *where* the isotope is being metabolised** in the body. The radioisotope will leave a path that can be detected and traced to identify any abnormalities or diseases.

3. identify that during decay of specific radioactive nuclei positrons are given off
**Certain radioisotopes decay by the emission of positrons**. Positrons **are positively charged *beta particles***. That is, they are identical to electrons except that they have positive charge instead of negative charge. Positrons are **formed when a proton disintegrates to form a neutron and a positron**.

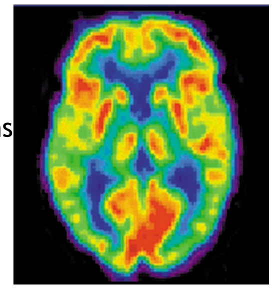
4. <u>discuss</u> the interaction of electrons and positrons resulting in the production of gamma rays

**When a positron meets an electron they 'annihilate' each other, converting their combined energy and mass into two gamma rays (γ rays)**. The energy of each of these gamma rays is 0.51 **MeV** (million electron volts) and they travel in opposite directions → momentum and electrical charge must be conserved in the interaction in accordance with the respective laws. This process is sometimes called pair annihilation.




5. <u>describe</u> how the positron emission tomography (PET) technique is used for diagnosis

Using particular **radio-pharmaceuticals**, **a cross-sectional image through an organ can be obtained** or a region of the body can be imaged, allowing the **function of an area to be determined**.



The radiopharmaceutical is usually injected into the patient but sometimes the chemical is inhaled. **After a short period of time the radiopharmaceutical has accumulated in particular areas of the body and begun to decay by the emission of positrons**. The positrons will almost instantaneously come into contact with electrons in the target organ and undergo pair annihilation → resulting in the production of two gamma rays which travel in opposite directions.

- **Modified gamma cameras detect these gamma emissions** and transmit the information to a computer for translation.
- By **knowing attenuation coefficients for the absorption of gamma rays** in the target tissue, an **close approximate can be made for the accumulating radioisotope**. The measurement from any angles and intensities aids the computer's response to the accurate targeting of the accumulated radioactive isotope.

Because the specific radioisotope is chosen to attach to a 'metabolite' in the body, then doctors are able to determine what part of the body this radioisotope will best detect abnormalities in. The diagnosis of disease and unknown deformities are displayed in coloured regions on a computer.

***Often used in the brain***.

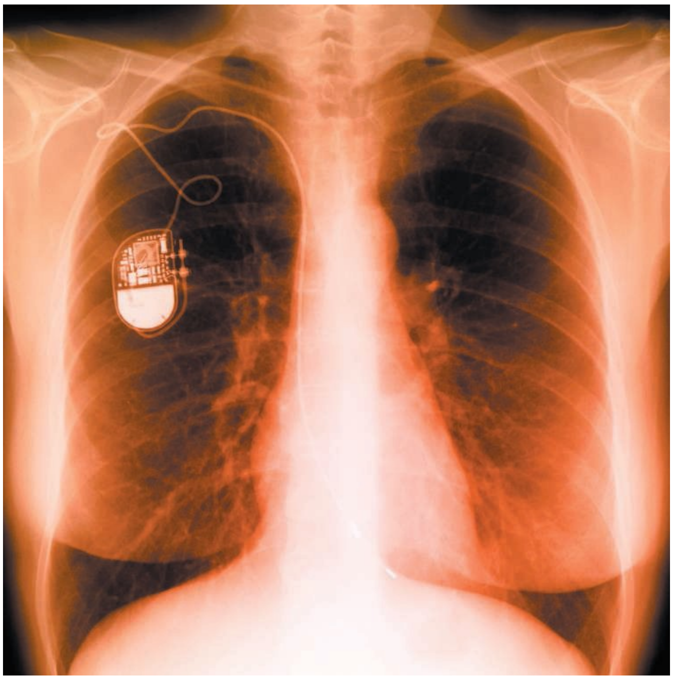
1. perform an investigation to compare an image of a bone scan with an X-ray image


CAT Bone Scan

X-ray of broken bone

The CAT scan/bone scan is a far more comprehensive method of taking an image for medical diagnosis of disease or fractures. Slices of the bone are compiled to form a three-dimensional image.

2. gather and process secondary information to compare and scanned image of at least one healthy body part or organ with a scanned image of its diseased counterpart



X-ray of healthy lungs (showing a pacemaker at the heart)

X-ray of lungs showing damage to the right and left tuberculosis

## 4. The magnetic field produced by nuclear particles can be used as a diagnostic tool

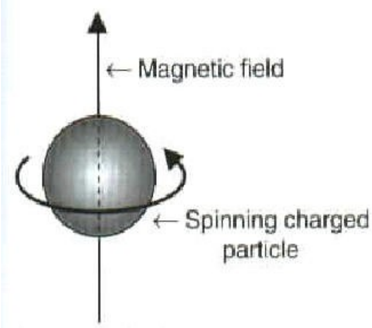
1. identify that the nuclei of certain atoms behave as small magnets

In certain atoms, such as hydrogen, carbon-13 and fluorine-19 the **nuclei of these atoms can act as small magnets by exhibiting a magnetic field**. A magnetic field is exhibited due to the **imbalance of charge** in the isotopes.

- Hydrogen exhibits the strongest magnetic field and most easily detected.

2. identify that protons and neutrons in the nucleus have properties of spin and describe how net spin is obtained

The concept of spin is derived from *quantum physics* and quantum mechanics. In this theory, **protons and neutrons spin in a circular motion with an angular velocity and angular momentum**. The spin in particular of protons and neutrons is the ***rotation about its axis***.




- If the nucleus of an atom has a net spin, it may behave as a small magnet

The model that deals with nuclear spin is called the **Nuclear Shell Model**. **Each nucleon has an energy level associated with it**, just like the energy levels of electrons. Each nucleon has a **total angular momentum which is a combination of the spin angular momentum and the orbital angular momentum**. Net spin is the total spin exhibited by all neutrons and paired protons in the nucleus which is calculated by the following:

- Net spin is a **whole number** if mass number is even but atomic number is odd
- Net spin is **zero** when the *mass and atomic number are both even*
- Net spin is a **factor of ½** when the mass number is odd

3. explain that the behaviour of nuclei with a net spin, particularly hydrogen, is related to the magnetic field they produce

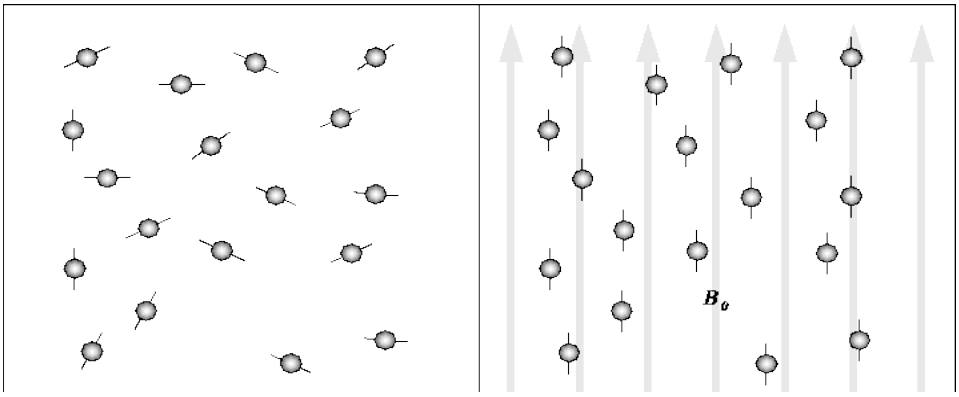
The nuclei of atoms which have a *net spin* produce a magnetic field, and because of this they **behave in particular ways**.

**Hydrogen's nucleus is composed of one proton** and that proton with net spin will have any random orientation of the magnetic field as the proton spins and rotates with angular velocity/momentum. **The magnetic field's orientation will be randomly orientated until an external magnetic field is applied.**

4. describe the changes that occur in the orientation of the magnetic axis before and after the application of a strong magnetic field

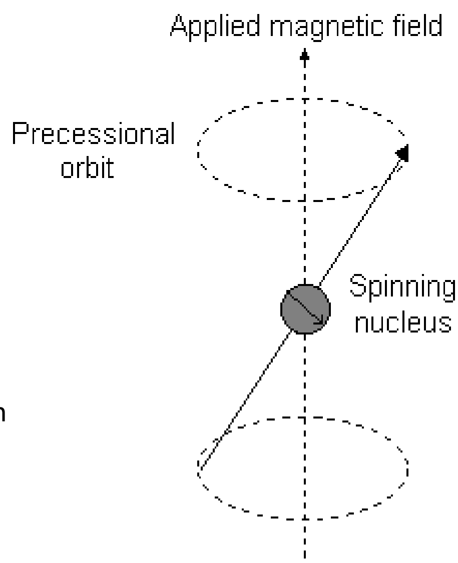
**Protons become aligned along their magnetic axis due to the interaction of their magnetic field with an external magnetic field**. They align themselves either in the direction of the external magnetic field (*parallel*) or in the opposite direction to the external magnetic field (*anti-parallel*).

Additionally, **when hydrogen's nucleus is subjected to an strong external magnetic field, an absorption or release of energy occurs**. The release or absorption of different energies occurs because of the constantly changing orientation of the magnetic axes of the protons within each hydrogen atom. → due to these energy releases by the application of a strong magnetic field on an atom's nucleus, an **MRI** (Magnetic Resonance Imaging) can be taken of a patient to determine the position of these nuclei in the patient's body.




5. define processing and relate the frequency of the processing to the composition of the nuclei and the strength of the applied external magnetic field

**Precession is the movement, in a conical path, of the axis of a spinning object.**




The precession of an atom's nucleus, which is undergoing a net spin, is very similar to the same as the **motion experienced by a spinning top**. A spinning top going fast will be upright but eventually begin to trace out an elliptical path as gravity pushes the spinning top downward. This wobbling and *distorted conical path* that the spinning top will trace out is the same that nuclei of certain atoms experience when a strong external magnetic field is applied against them. It is the **nuclei's response to the force exerted by the external magnetic field**.

**The frequency with which a nucleus precesses in a given magnetic field is called the Larmor frequency**. The Larmor frequency is different for different nuclei in the same magnetic field. We can use the Larmor frequency in a given magnetic field to *identify an element*.

- The Larmor frequency in a certain field is calculated: the product of an element's Larmor frequency in any magnetic field and the specific magnetic field strength.

For example, the Larmor frequency of a hydrogen nucleus in an external magnetic field of 1.6T is:

$$Larmor\ frequency = 42.57\mathrm{B}_0\,MHz \quad \text{where, } B_0 = 1.6\text{T}$$

$$\therefore\ Larmor\ frequency = 42.57 \times 1.6\,MHz = 68.11\,MHz$$

6. discuss the effect of subjecting precessing nuclei to pulses of radio waves

While atomic nuclei are in the presence of an external magnetic field and precessing, **pulses of radio waves can be directed into the nuclei of these atoms**. Radio pulses of certain frequencies and beamed into a patient. *The frequency is chosen to correspond exactly with the Larmor frequency.* This is the frequency of precession of the protons. **The protons will resonate with the radio frequency, and so absorb its energy, move to a higher energy level and precess in phase with one another.**

Precessing nuclei that have had pulses of radio waves beamed into them will absorb the energy and as a **result of the conservation of energy, energy is released once the radio waves are removed** or turned off. The strength and duration of this energy emitted by precessing nuclei is recorded and analysed. From this energy emission a 'slice' can be created of a patient's body where the energy has been emitted.

- To distinguish which slice of a patient's body is from where, different **gradients** of magnetic field strengths are taken throughout the body.
- The **precessing transverse magnetic field is in effect a changing field and will induce a small AC emf in a receiving coil**.
- Radio frequency pulses can also be used to change the spin direction of the nucleus from parallel to anti-parallel with the field (180° pulse) or to precess at the maximum angle from the field (90° pulse). This is done by varying the pulse size and strength.

7. explain that the amplitude of the signal given out when precessing nuclei relax is related to the number of nuclei present

When the **radio frequency pulse is removed**, the **protons move back to their original energy level**. This process is called **relaxation** and the time it takes to do that is called the relaxation time.

*When nuclei relax back into their original energy state they re-phase and dissipate their energy into nearby atoms of close precessing frequencies*. The energy emitted has a certain amplitude and frequency; however, the frequency of each precessing nucleus only depends on the nucleic composition.

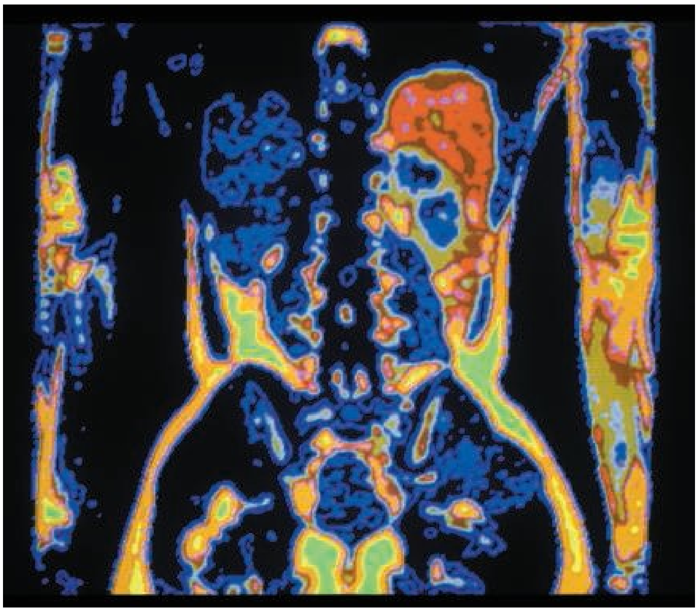
- The **amplitude of the signal given out as a result of a relaxing precessing nuclei is a direct bearing on the density of those nuclei** present in the area being analysed.
- *nuclei↑ amplitude↑*
- The greater the density of hydrogen protons, the larger the signal and the **brighter the image** on an MRI scan.

8. explain that large differences would occur in the relaxation time between tissue containing hydrogen bound molecules and tissues containing other molecules

Because the brightness of an image detected by an MRI scan is determined by the density of hydrogen nuclei, then any tissue containing significant amounts of water or water compounds which are not extensively connected with other molecules will appear very bright. It is difficult, however, to distinguish between soft tissue and other tissues which still contain parts of hydrogen nuclei.

When relaxation time is taken into consideration - **there is a large difference between relation times for nuclei to return to their natural energy state** → this is *indicated by the brightness variation on the MRI scan*. **Tissues containing molecules other than hydrogen bounded molecules will have a very short relaxation time because there is a lack of hydrogen nuclei**.

1. perform an investigation to observe images from magnetic resonance imaging (MRI) scans, including a comparison of healthy and damaged tissue



← **A magnetic resonance image (MRI) of a patient's lung showing cancer on the right side.**

In addition, the class attended a field trip to a medical facility and observed MRI scans of a patient's brain.

2. identify data sources, gather, process and present information using available evidence to explain why MRI scans can be used to:

– detect cancerous tissues

Cancerous tumours contain different amounts of water from normal tissue or are surrounded by watery tissue. **They can be distinguished in an MRI scan because of the different brightness due to different proton density**.

– identify areas of high blood flow

There is an **increased flow of oxygenated blood to areas that are stimulated**. **Knowledge of the magnetic properties of oxygenated blood allows parts of the brain** involved in processing sensory data or motor tasks **to be identified and studied**.

High blood flow is **illuminated on the MRI scan by a brighter colour** than the rest of the surrounding tissue and nerves.

– distinguish between grey and white matter in the brain

**Grey matter in the brain contains hydrogen bound in a different way from that in white matter**. As a result, the relaxation times for hydrogen protons are different in grey matter and white matter. This means they are able to be distinguished in an MRI scan.

The fact that nerve cells of grey matter can be distinguished from those of white matter can be used in the diagnosis of brain dysfunctions and where there is an excess of fluid on the brain cause abnormalities.

3. gather and process secondary information to identify the function of the electromagnet, radio frequency oscillator, radio receiver and computer in the MRI equipment

**Electromagnets:**

- Are **used to generate a very strong magnetic field which will affect the net spin and magnetic axis of protons in the hydrogen atoms of a patient's body**.
- It does this (*Refer to above*) in order so **dark and bright areas can be located** in the brain, spine and other sensitive/hydrogen-bonded tissues.
- Electromagnets powerful enough to produce **such a strong magnetic field are extremely expensive to establish, maintain and run** → thus the very high cost of using MRI scans and are therefore only used in specific situations. Due to the energy losses to heat, magnetic fields no larger than 0.5T are possible.
- Electromagnets are created by passing a direct current through a coil of copper wire.

**Radio Frequency Oscillator/Radio Receiver:**

- The role of the the radio frequency oscillator is to **amplify and and decrease the frequency of certain radio waves being passed into the patient's body**.
- The radio receiver is used detect and **measure the frequency of the radio waves emitted as the protons of hydrogen relax back to their normal energy state**. The different frequencies measured can correspond to different tissues of an organ.

**Computer:**

- The computer is used in magnetic resonance imaging technology so that the **data and slices of a patient's body can be compiled and turned into 3D images**.
- The computer acts as the central processing unit and all data passes through **in order to display a coloured image which medical staff are trained to interpret for abnormalities** and dysfunctions.

4. identify data sources, gather and process information to compare the advantages and disadvantages of X-rays, CAT scans, PET scans, and MRI scans

| | X-ray | CAT | PET | MRI |
|---|---|---|---|---|
| **Operating costs** | Least expensive | Quite expensive | Quite expensive | Extremely expensive |
| **Resolution** | 0.1mm | 0.25mm | 5-15mm | 0.3-1mm |
| **Safety/Comfort** | Small ionising radiation | Higher than X-rays | Moderate dose | Claustrophobia/No radiation problems |

| | | | | |
|---|---|---|---|---|
| **Examination Time** | Very short | Moderate | Can be long depending on tracer | Relatively long, however, some short |
| **Imaging of soft tissue** | Poor, cannot image soft tissue | Good for abdomen scan | Good for growths, tumours, liver | Excellent resolution, good for kidneys |
| **Imaging of blood circulation** | Contrast medium required | Limited use with digital techniques | Good for blood flow studies | Best resolution for blood flow |
| **Bone Imaging** | Very good - sole purpose | Good for complicated structures | Good for bone cancer detection | Limited use due to weak signal |

5. gather, analyse information and use available evidence to assess the impacts of medical applications of physics on society

Medical applications of physics on our modern society have made significant economical, medical and ethical impacts on society. These applications present both advantageous and disadvantageous properties for society:

- Advantages of early diagnosis - patient's are able to be **treated earlier and faster**, thus saving many lives and enabling those who are unable to be completely treated to live a prolonged and life in ease. Compared to the painful life of disability or disease. *Chest X-rays have enabled the early detection of tuberculosis in miscellaneous chest infections* which would have otherwise been left undetected and left the patient in a critical state bordering death.
- Economical impact - the cost of building and running many of these medical physics machines is a **huge detriment on the economy**, much of which is funded by tax payer money. PET and MRI consume a large amount of electricity and also need to be monitored meaning a further impact on staff. Despite this, early diagnosis may be arguably said to be of much greater value - saving people's lives.
- Ethical Issues - the **diagnosis of problems in foetuses and certain other patients with neurological or pathological defects is problematic amongst numerous religious groups**. Despite the moral good will of early detection, many conservatives (such as Catholic Fundamentalists) believe that such diagnosis is tampering with God's creation. This includes *ultrasound and the injection of radio-pharmaceuticals for PET or MRI*.
- Knowledge - Society uses this knowledge to **provide for better and more efficient health provision**. For example, keyhole surgery is a much *cheaper and less invasive procedure that has been made possible by endoscopy.'*

Obtained from scientific magazines, textbooks and a visit to a Medical centre utilising such applications of medical physics on patients.