Remote Sensing

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Remote Sensing - Introduction

- When you are unwell, you may have external symptoms such as rash or unusual skin colour which the doctor can use to diagnose your illness.
- Alternatively, you may be required to report on your internal symptoms – aches, pains and so on.
- The human body is opaque to light, so how can a doctor know what is going on inside you? Although light does not penetrate the human body, other electromagnetic radiations do.
- The best known are X-rays, good for showing up bones. Other examples would be the ultrasound and magnetic resonance.
- These techniques are often described as non-invasive. This is because they do not involve cutting the patient open to discover what is wrong.
- Nor do they involve inserting surgical instruments into any of the body's orifices. Both of these procedures that can allow infections to enter the body. Any damage to the body may take time to heal and can lead to permanent scarring.

THE DUCK IS DEAD - diagnosis

- A woman brought a very limp duck into a veterinary surgeon. As she laid her pet on the table, the vet pulled out his stethoscope and listened to the bird's chest. After a moment or two, the vet shook his head sadly and said, "I'm sorry, your duck, Cuddles, has passed away."

  The distressed woman wailed, "Are you sure?“. "Yes, I am sure. The duck is dead," replied the vet. "How can you be so sure?" she protested.. "I mean you haven't done any testing on him or anything. He might just be in a coma or something."

  The vet rolled his eyes, turned around and left the room. The vet returned a few minutes later with a black Labrador Retriever. As the duck's owner looked on in amazement, the dog stood on his hind legs, put his front paws on the examination table and sniffed the duck from top to bottom. He then looked up at the vet with sad eyes and shook his head. The vet patted the dog on the head and took it out of the room.

cont…

- A few minutes later he returned with a cat. The cat jumped on the table and also delicately sniffed the bird from head to foot. The cat sat back on its haunches, shook its head, meowed softly and strolled out of the room.

The vet looked at the woman and said, "I'm sorry, but as I said, this is most definitely, 100% certifiably, a dead duck”. The vet turned to his computer terminal, hit a few keys and produced a bill, which he handed to the woman.

The duck's owner, still in shock, took the bill.

"$250?!!" she cried, "$250 just to tell me my duck is dead???!!"

Do you know why?

Verdict justified

- The vet shrugged, "I'm sorry. If you had just taken my word for it, the bill would have been $20, ….

…. but with the ***LAB*** Report and the ***CAT*** Scan, it's now $250.“

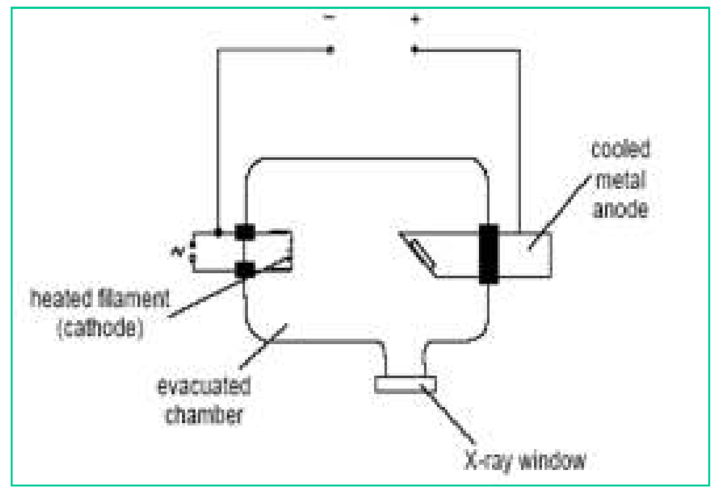
……………………………..END…………………………….

X-rays

X-ray Machine & tube

- Figure beside shows a patient undergoing an X-ray to check for bone degeneration.
- The X-ray machine is above the patient; it contains the X-ray tube that produces the X-rays which pass downwards through the patient's body.
- Below the patient is the detection system. In this case, an electronic detector is being used, but often photographic film is used in the detection system.

- The diagram beside shows the principles of the modern X-ray tube.
- The tube itself is evacuated.
- The cathode (-) electrode is the heated filament from which electrons are emitted.
- The anode (+) electrode is a rotating metal made of tungsten. (often called target metal)



The production of X-rays

- An external power supply produces a voltage up to 200 kV between the two electrodes. This accelerates a beam of electrons across the gap between the anode and cathode.

- The kinetic energy of an electron arriving at the anode is 200 keV (electron volt). When the electrons strike the anode at high speed, they lose some of their kinetic energy in the form of X-ray photons which emerge in all directions.

- Part of the outer casing, the window is thinner than the rest and allows 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. This produces parallel-sided beam called a collimated beam.

- Only a small fraction, about 1% of the kinetic energy of the electrons is converted to X-rays. Most of the incident energy is transferred to the anode, which eventually become very hot. This explains why the anode is rotates, the region that is heated turns out o the beam so that it can cool down by radiating heat to its surroundings. Some X-ray tube have water circulating through the anode to remove this excess heat.

- http://www.youtube.com/watch?v=Bc0eOjWkxpU (How X-ray tube works)
- Show animation in shockwave flash object.

The production of X-rays

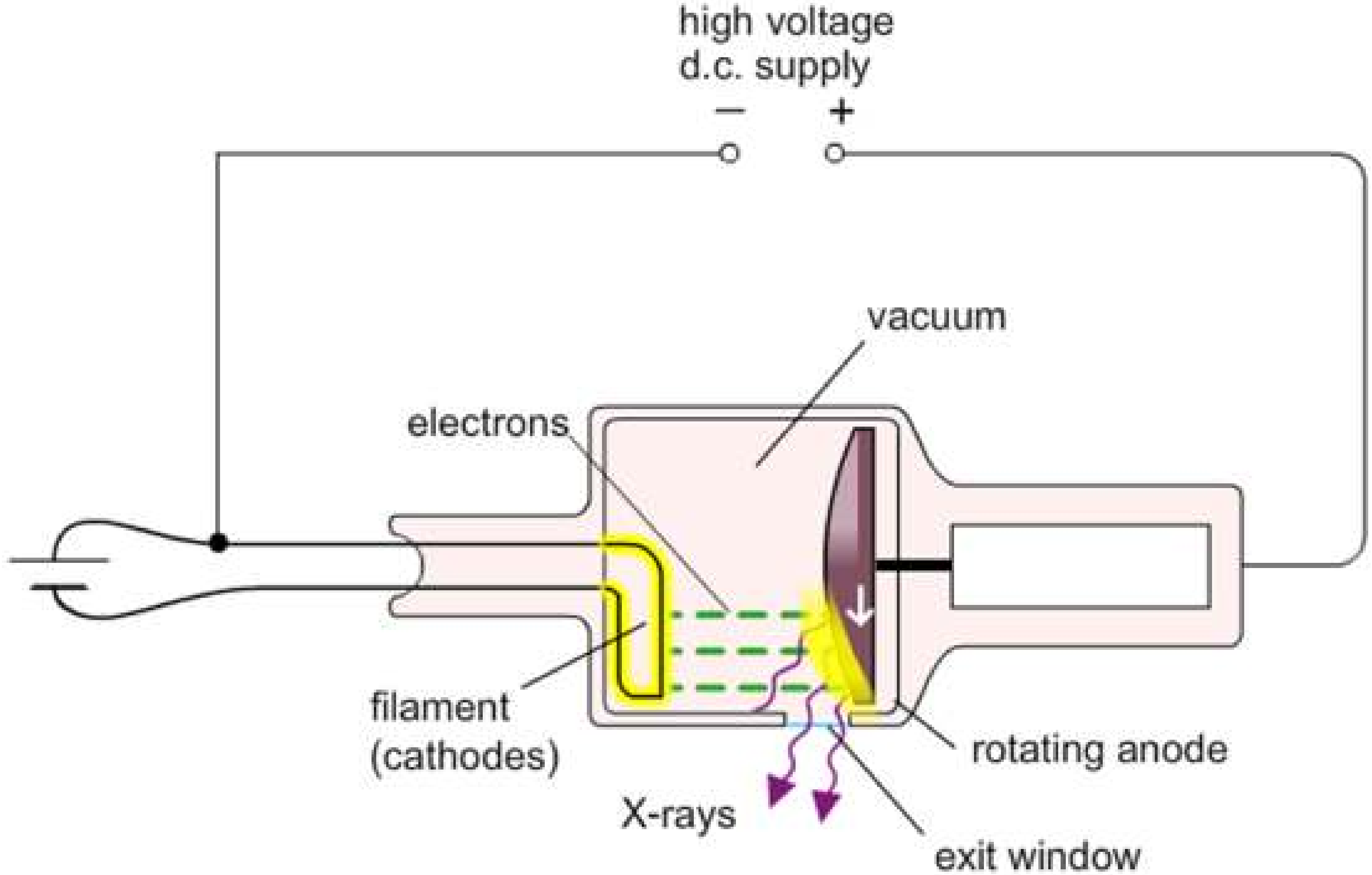
Intensity of the beam

- The intensity of the X-ray beam is determined by the rate of arrival of electrons at the metal target, that is the tube current.
- This tube current is controlled by the heater current of the cathode. The greater the heater current, the hotter the filament and hence the greater the rate of emission of thermo-electrons.

Hardness of the beam

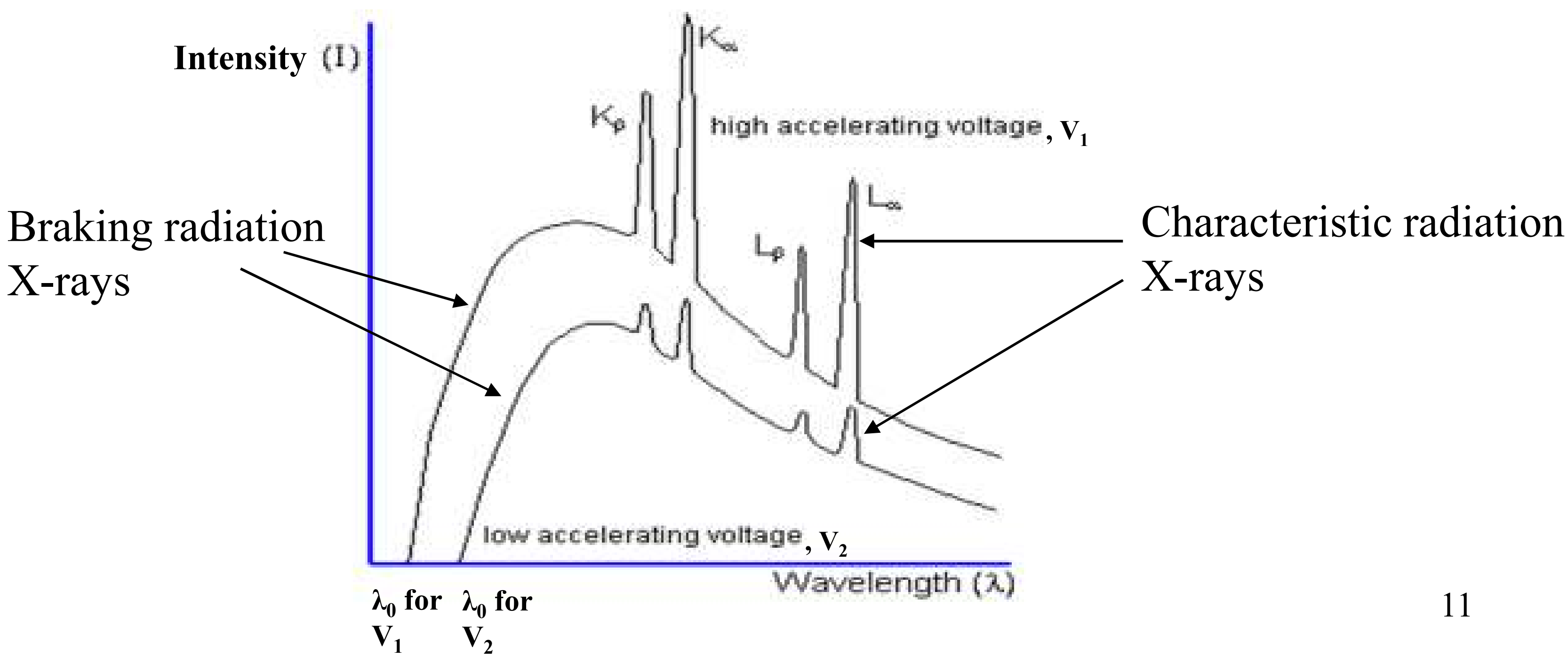
- The hardness of the X-ray beam (the penetrating of the X-rays) is controlled by the accelerating voltage between the cathode and anode.
- More penetrating X-rays have higher photon energies and thus a larger accelerating potential is required.

Simplified design of an X-ray tube



X-ray spectrum

- The X-rays that emerge from an X-ray tube have a range of energies, as represented in the X-ray spectrum shown below.
- The spectrum has 2 components, the broad "hump" known the Bremsstrahlung radiation (braking radiation) and few sharp lines known as characteristic radiation.
- This 2 radiation arises from the different ways in which an electron loses its energy when it crashes into the anode.



Braking radiation & Characteristic radiation

- The braking radiation comes about because the electrons when incident on the metal target, will not all have the same decelerations but will instead have a **wide range of values**. Energy of photon depends on how much KE is lost – hence a continuous range.
- The **cut-off wavelength** corresponds to **an electron that is stopped in one collision in the target so that <u>all of its kinetic energy</u> is given up as one X-ray photon. ($\lambda_0 = hc / eV$)**
- Maximum energy of photon occurs when all KE of electrons is converted to X-rays.

- Characteristic X-rays are superimposed on the continuous spectrum of the braking radiation X-rays.
- They are produced when an **incident electron knocks electrons out of the K-shell(lowest shell)** of the target atom.
- An electron from the L or M shell may move into the vacancy in the K-shell. In doing so, the electron emits a high energy photon which gives the characteristic X-rays.

Difference between continuous and characteristic spectrum

Continuous	Characteristic
Has continuous range of wavelength	Has discrete wavelength
Produced by loss of KE of incident electron	Produced by electron transition from higher shell to innermost shell

- In practice, the characteristic X-rays are relatively unimportant in medical applications.
- Now we know that X-rays of a whole range of energies are produced in the X-ray tube.
- The lowest energy X-rays will not have sufficient energy to penetrate through the body, so will have no effect on the resulting image. However, they will contribute to the overall X-ray dose that the patient receives.
- These X-rays must be filtered out, this is done using aluminium absorbers across the window of the tube.

X-ray attenuation

- Bones look white in an X-ray photograph. This is because they are good absorbers of X-rays, so that little radiation arrives at the photographic film to cause blackening.
- Flesh and other soft tissues are less absorbing, so the film is blackened.
- Modern X-ray systems use digital detectors instead of photographic films. The digital images are easier to process, store and transmit using computers.
- X-rays are a form of ionising radiation; that is they ionise atoms and molecules of the material they pass through.
- In the process, X-rays transfer some of their energy to the material, and so a beam of X-ray is gradually absorbed as it passes through a material.
- The gradual decrease in intensity of the beam of X-rays as it passes through matter is called **attenuation.**

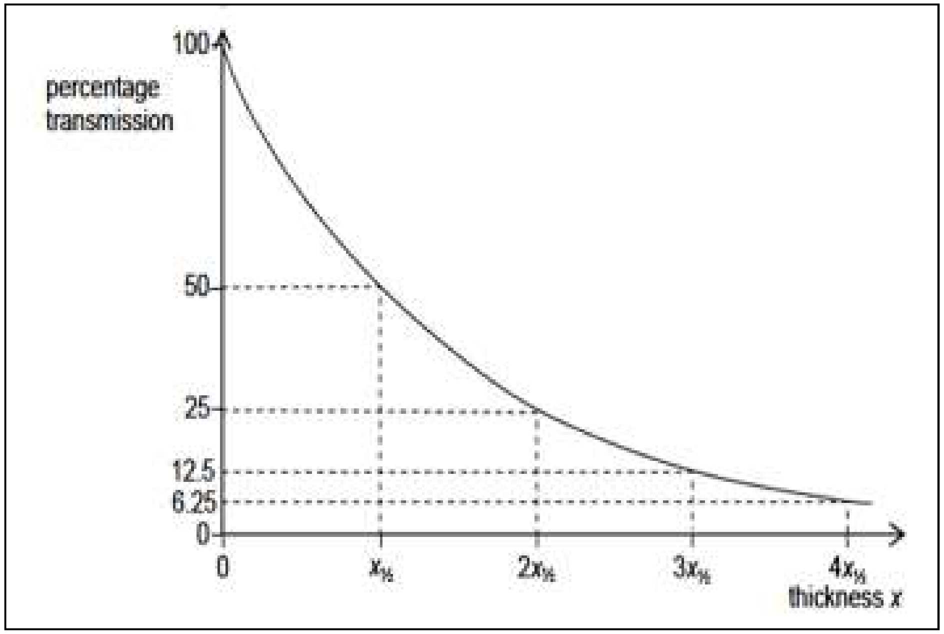
- We can write equation to represent attenuation of X-rays as they pass through a uniform material as follows:

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

I_0 = initial intensity
X = thickness of material
I = transmitted intensity
μ = attenuation / absorption coefficient of the material

X-ray attenuation

- The graph of the decrease in intensity for the X-rays is an exponential graph.
- In radioactive decay, we have the concept of half life of the radioactive isotope which is the time taken for half the nuclei in any sample of the isotope to decay.
- Likewise, we refer to the **half-value thickness (HVT)** of an absorbing material.
- This is the thickness of the material that will reduce the transmitted intensity of X-ray beam of a particular frequency to half its original value.



- Use equation $I = I_0 e^{-\mu x}$ to show that the half thickness x, is related to the attenuation coefficient, μ by the equation on the right.

$$\boxed{\text{HVT, } x_{1/2} = \frac{\ln 2}{\mu}}$$

Example

- The attenuation coefficient of bone is 600 m^{-1} for X-rays of energy 20 keV. A beam of such X-rays has an intensity of 20 Wm^{-2}, Calculate the intensity of the beam after passing through a 4.0 mm thickness of bone.

1.8 W m^{-2}

- The linear absorption coefficient of copper is 0.693 mm^{-1}. Calculate:
  a) the thickness of copper required to reduce the incident intensity by 50 %
  b) the fraction of the incident intensity (I/I_0) of a parallel beam that is transmitted through a copper plate of thickness 1.2 cm

a.) $0.693x_{½} = \ln 2$

$x_{½} = 1.0\ mm$

b.) $I/I0 = e^{-(0.693 \times 12)}$

$I/I0 = 2.4 \times 10^{-4}$

Improving X-ray images

- The quality of an X-ray image is described by ***sharpness*** and ***contrast.***
- ***Sharpness*** refers to a ***clear boundary between different tissues*** or **the ease with which the edges of structures can be determined.**
- A shadow image where the bones and other organs are clearly outlined is said to be a 'sharp image'.
- But although an image may be sharp, it may still not be clearly visible because there is ***little difference in the degree of blackening*** between e.g. bone and surrounding tissue.
- An image having a **wide range of degrees of blackening** is said to have good contrast.
- ***Contrast*** refers to ***different intensity (brightness) in the image*** of various parts of the internal organ.

Improving Sharpness

- The image is sharp if the boundary is clearly visible.

- **A sharp image requires a parallel X-ray beam** which can be achieved by:

  i) reducing the area of the target anode.

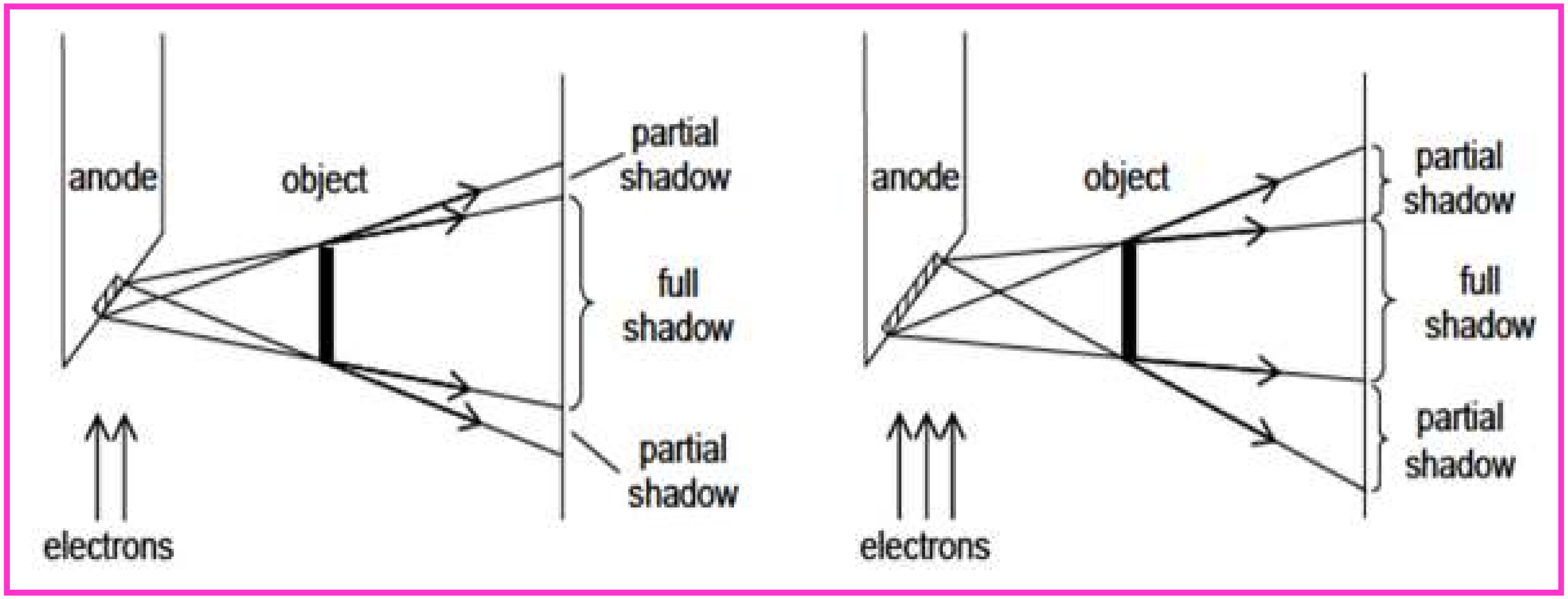
  ii) limiting the size of the aperture.

  iii) collimation of beam.

  iv) reducing scattering of the emergent beam.

Sharpness – reducing the area of the target anode in the X-ray tube

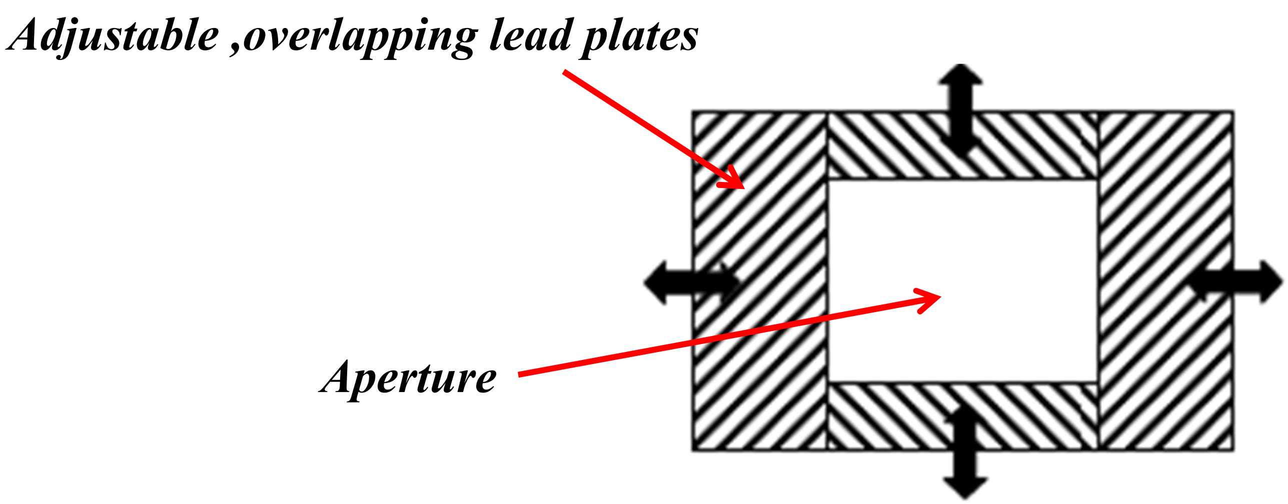
- Secondary/partial shadows/penumbra can cause images to be blur.
- The full shadow produces an area that is white on the film, meanwhile, where there is no shadow, the image will be black.
- In the region of partial shadow or greyness, the image gradually changes from white to black.
- **If the image is to be sharp, this area of greyness must be reduced as much as possible. To do so, the area of the target anode should be kept to a minimum.**



Sharpness – limiting the size of the aperture through which the X-ray beam passes

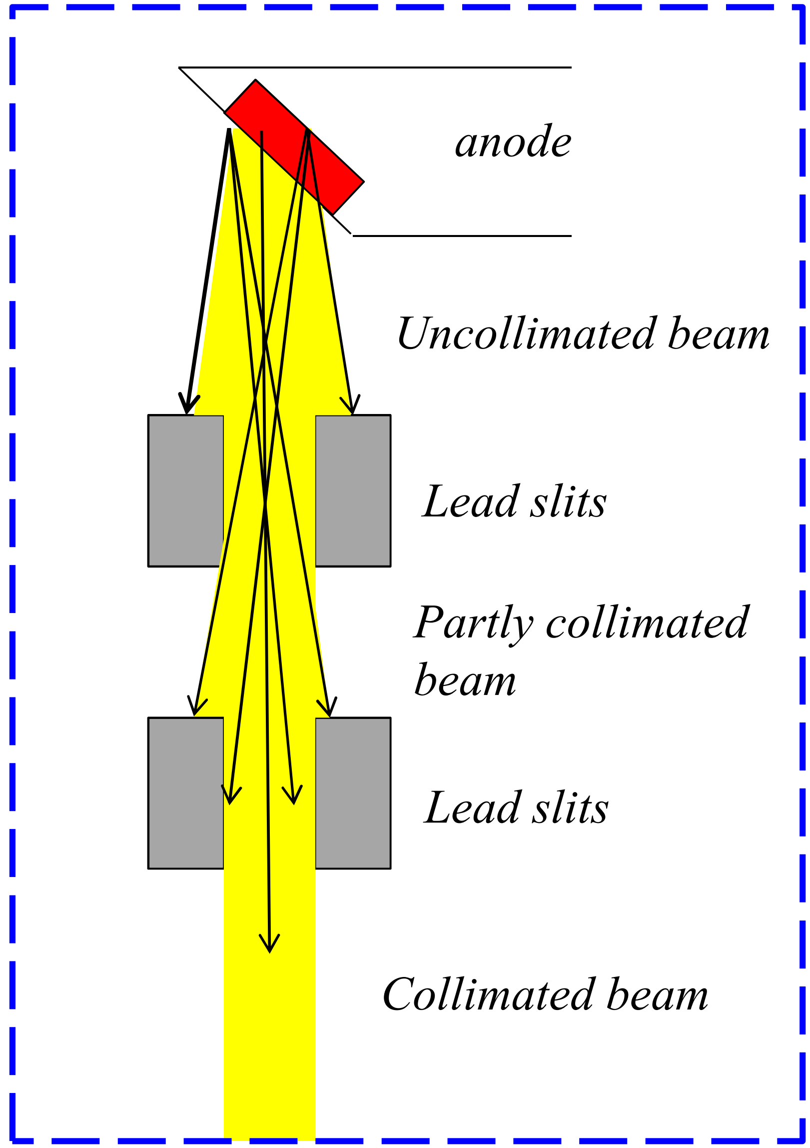
- A reduction in the grey area at the edge of the image can also be achieved by limiting the size of the aperture through which the X-ray beam passes.

- This is achieved by using ***overlapping metal sheet plates***, through which the X-ray beam passes after leaving the tube.



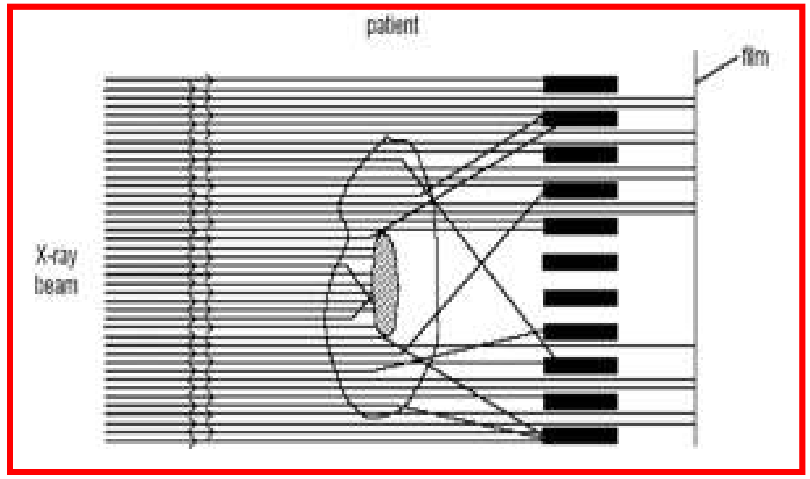
Sharpness – Collimation of the beam

- The beam is passed through the slits, ensuring that it is parallel sided beam and does not fan out.
- The first set of slits produces a partly collimated beam but, due to the finite size of the anode target, there is still some spreading of the beam.
- The second set of slits reduces this spread further making the final beam almost parallel sided.



Sharpness - reducing scattering of the emergent beam

- Inevitably, some X-rays are scattered as they pass through the body. If these reach the detector they cause fogging and this reduces the sharpness of the image.
- Scattered X-rays approach the detector screen at an angle, and so an anti-scatter screen can be used to absorb them.
- This is made up of a series of plates which are made of a material (lead) which is opaque to X-rays, separated by plates made of aluminium which is transparent to X-rays.
- The plate is placed just above the screen, and the lead absorb the scattered X-rays.



Improving Contrast

- Good contrast is achieved when neighbouring body organs and tissues ***absorb the X-ray photons to very different extents*** e.g. bone and muscle.
- It is not the case e.g. if stomach or blood vessels are being investigated.
- In such a case, to improve contrast, especially for soft tissues, a ***contrasting medium*** is used.
- The patient is asked to swallow a solution of barium sulphate (barium meal taken orally) which is a ***good absorber of X-ray photons***, causing the outline of the stomach to show up clearly.
- Blood vessels can be made to show up visibly by injecting a radio-opaque dye (organic iodine compound) into the bloodstream.

Computed tomography(CT scan) or Computerised axial tomography (CAT scan)

- The image produced on a photographic plate or film is a 'shadow' or 'flat' image, and there is little or no indication of 'depth' i.e. the position within the body is not apparent. This is a 2-dimensional view.
- Soft tissues lying behind structures that are very dense also cannot be detected
- ***Tomography*** is a technique whereby a ***3-dimensional image is obtained or constructed by 'slicing' or sectioning the body using a CT scanner through different angles using computer technology and techniques.***
- Data from each ***individual X-ray image and angle of viewing*** is fed into a powerful computer, enabling a 3-D image of the entire object to be reconstructed, which can then be viewed from any angle.

Basic principles of CT or CAT scan

- Can be ***illustrated*** using a simple cube with the aim of producing an image of a slice or section through the body from measurements made about its axis.
- The section or cube is divided into a series of smaller units called ***voxels*** (volumetric pixel) which ***absorbs the X-ray beam to different extents due to its structure.***
- The image of each voxel would have a particular intensity called ***pixel***, and these various pixels are built up from measurements of the X-ray intensity along different directions through the slice or section.
- It is operated by using a moving X-ray emitter, a detector and a powerful computer program to store and process data. Reconstruction of these pixels in their correct positions is done to display the 3D image of the internal organ being scanned.

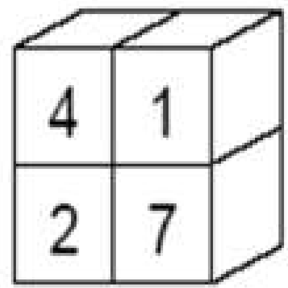
Basic principles of CT or CAT scan

A patient is receiving a CT scan for cancer.

Outside of the scanning room is an imaging computer that reveals a 3D image of the body's interior.

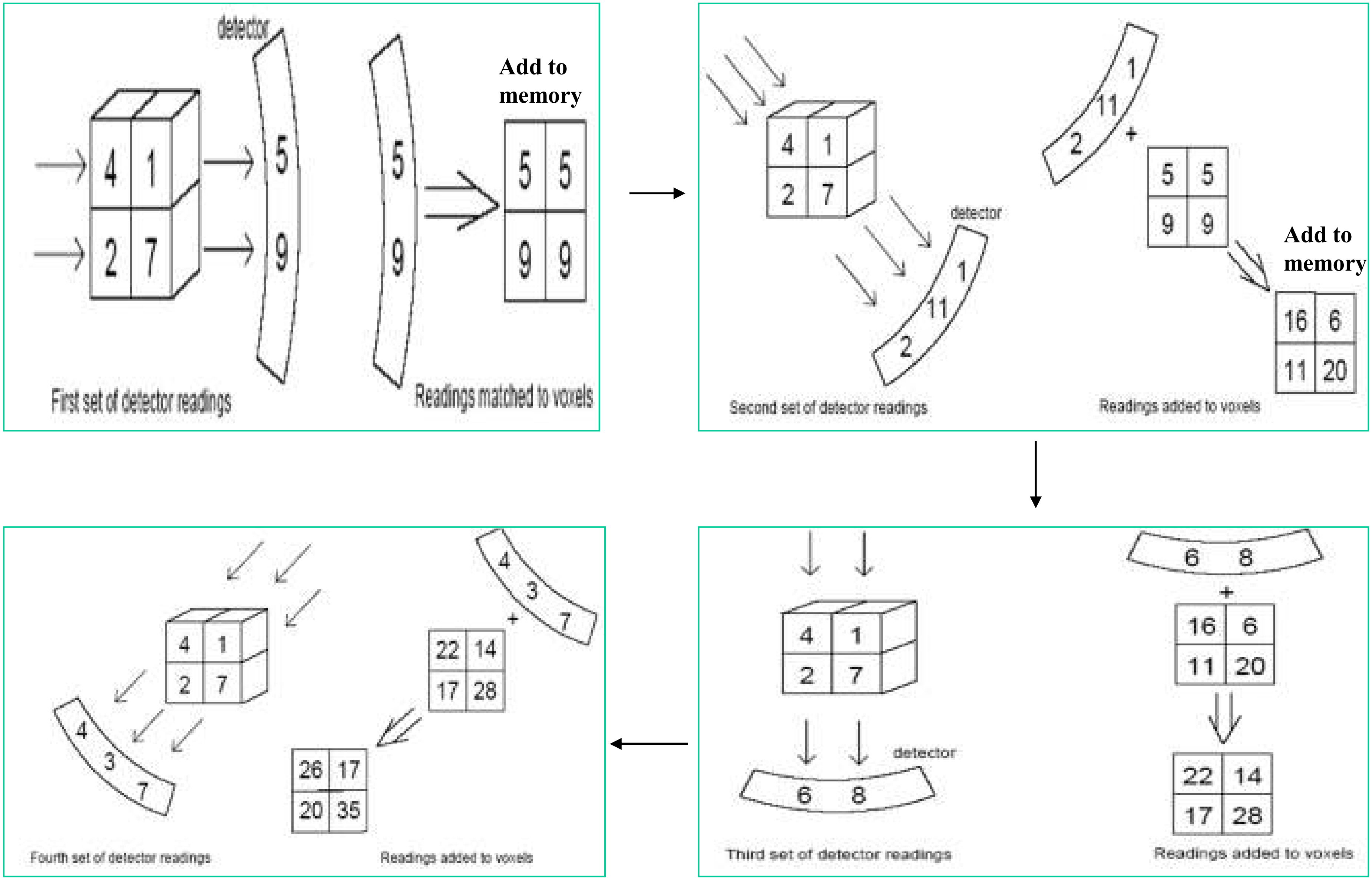
Re-construction of the slice / section

- Suppose a simple cube showing a ***four-voxel*** section.

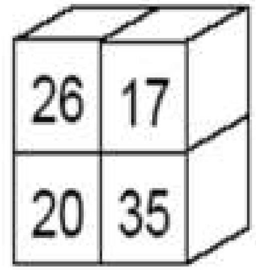


- The image of each voxel would have a ***particular intensity***, stored in a ***pixel.*** The pixels are built up from measurements of X-ray intensity made along a series of different directions around the section of the body.
-
- The number on each voxel is the ***pixel intensity*** that is to be reproduced.

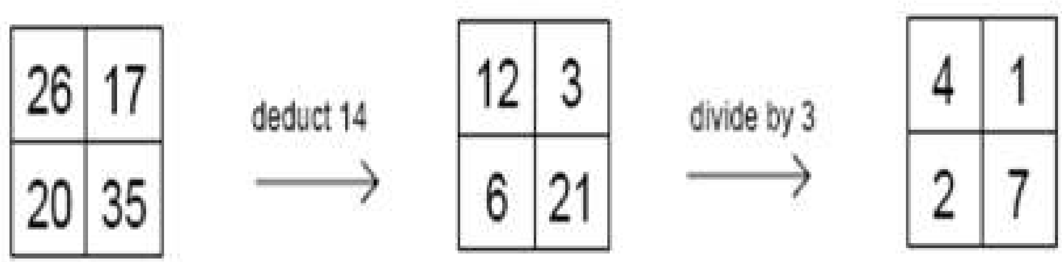
Detector readings (illustrations - ***clockwise***)



Final pattern



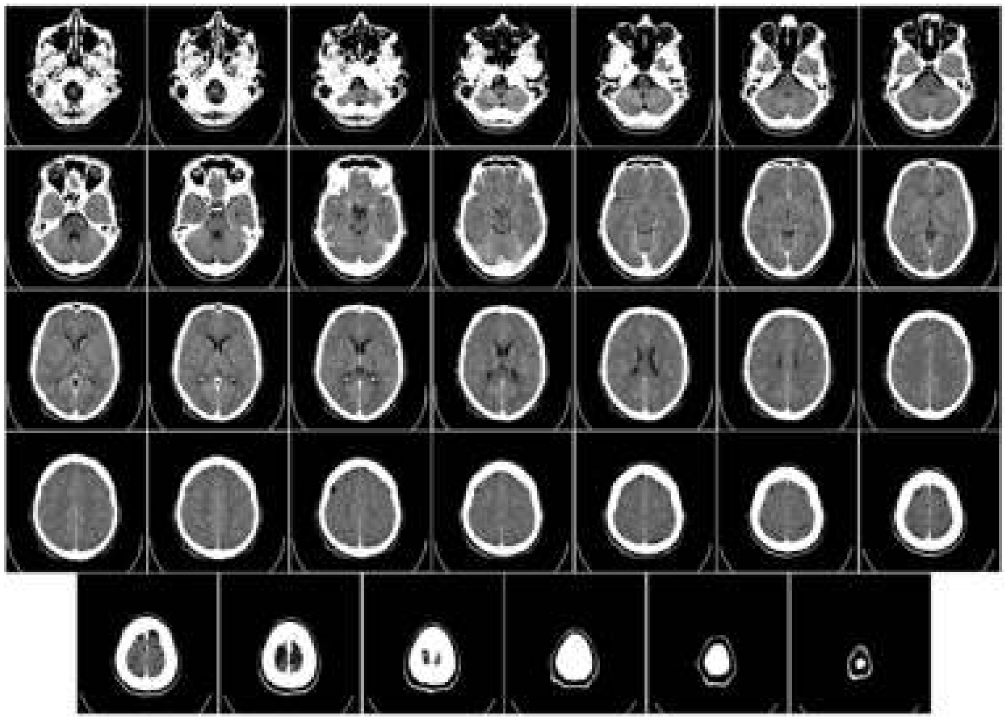
- In order to obtain the original pattern of pixels, two operations must be performed.
- Firstly, the ‘background’ intensity must be removed. The ‘background’ intensity is the total of each set of detector readings. In this case, 14 is deducted from each pixel.
- Secondly, after deduction of the ‘background’, the result must be divided by three to allow for the duplication of the views of the section since 4 sets of readings were taken.



CT cont…

- In practice, the image of each section is built up from many small pixels, each viewed from many different angles.
- The ***greater the number of voxels, the better the definition,*** similar to a digital camera.
- All the data for all the sections can be stored in a computer memory to create a three-dimensional image. Views of the body from different angles may constructed.
- The collection of the data and its construction into a display on a screen requires powerful computers and complicated software programming and programs. In fact, the reconstruction of each pixel intensity value requires more than one million computations.
- The computer allows for the ***contrast and brightness of the image to be varied*** so that an optimum image can be obtained.

Basic principles of CT or CAT scan



- ***slices of the human skull from base to top.***

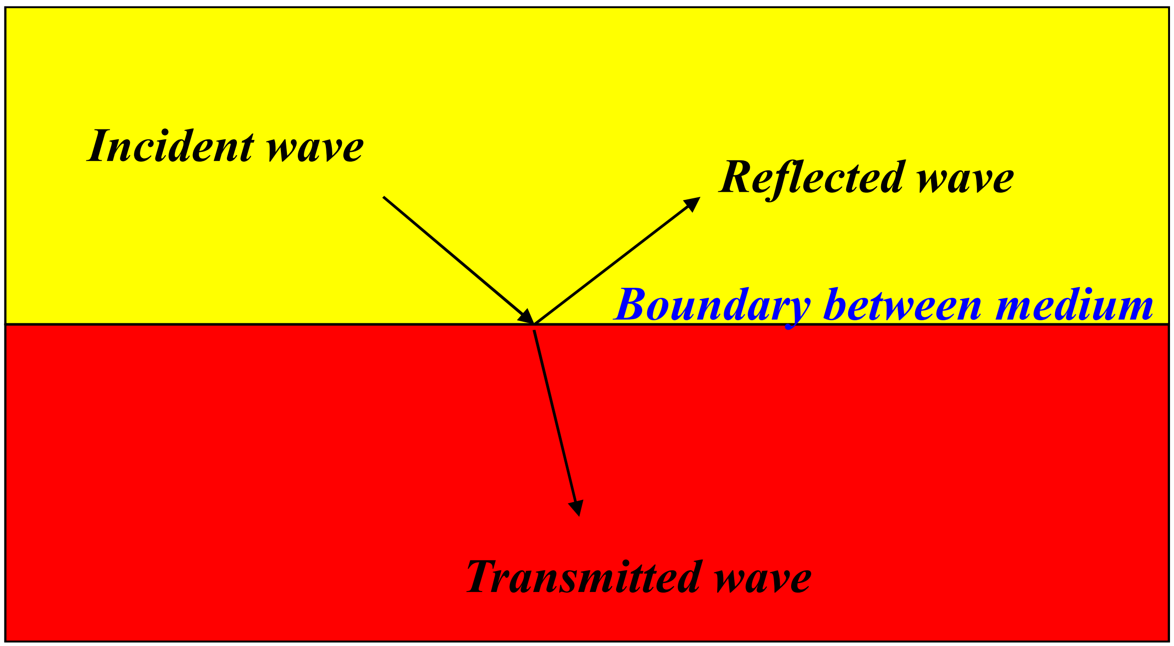
- ***A full 3D computer model of the skull***

Summary of the physical principles of the technique of X-rays in obtaining diagnostic information about the structures of a human body

- X-rays are produced by bombarding metal targets with high speed electrons. The electrons are accelerated through very large potential differences and when they strike the metal target they suffer large decelerations and radiation in the X-ray region is emitted.
- X-rays can darken photographic plates the same way as visible light. They can be used to obtain ‘shadow’ pictures of the internal structure of a human body. As long as there is a difference between the absorption properties of the organ under consideration and the surrounding tissues, X-ray images can be obtained.

- The voltage of the accelerating potential controls the hardness of the X-ray beam, and the current through the heated metal filament determines its intensity.
- The quality of the image produced on the photographic plate depends on its sharpness and contrast.
- The sharpness is affected by the design of the X-ray apparatus in terms of the size of its target anode, the size of its aperture, collimation of beam and the use of a lead grid.
- Contrast can be improved by using contrast medium such as barium or iodine.

Ultrasound

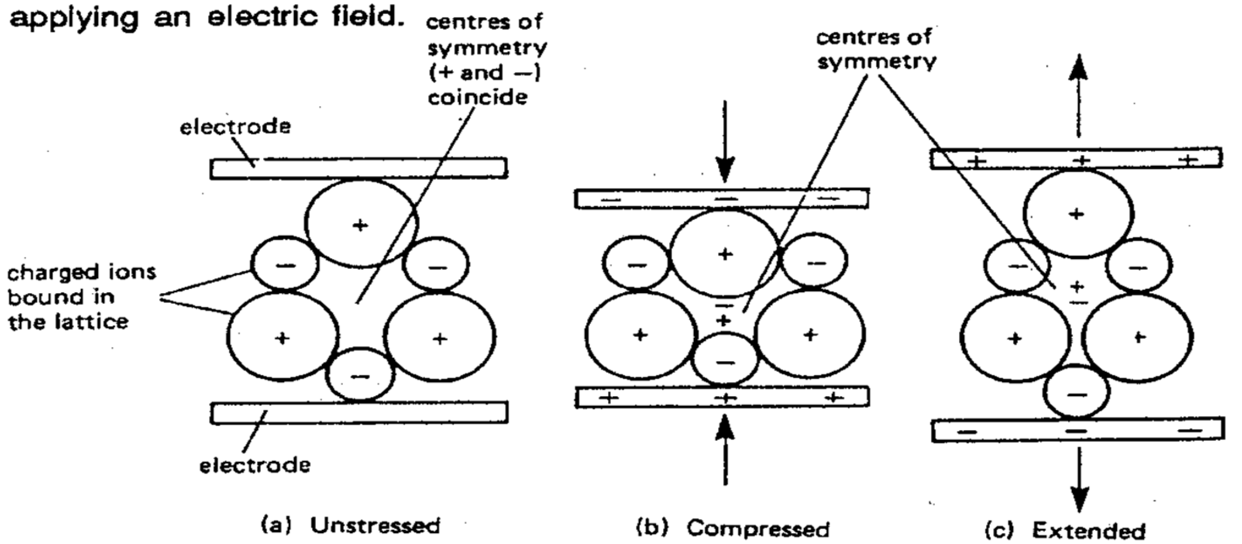

Incident wave
Reflected wave
Boundary between medium
Transmitted wave

Generation & Detection of Ultrasound waves using Piezo-Electric Transducer

Generation:

- Ultrasonic waves may be generated using piezo-electric transducer. The basis of this is a piezo electric crystal such as quartz.
- Two opposite sides of the crystal are coated with thin layers of sliver to act as electrical contacts.
- When a crystal is unstressed, the centres of charge of the positive and negative ions bound in the lattice of piezo-electric crystal coincide, so their effects are neutralised.

applying an electric field.



The piezo-electric effect

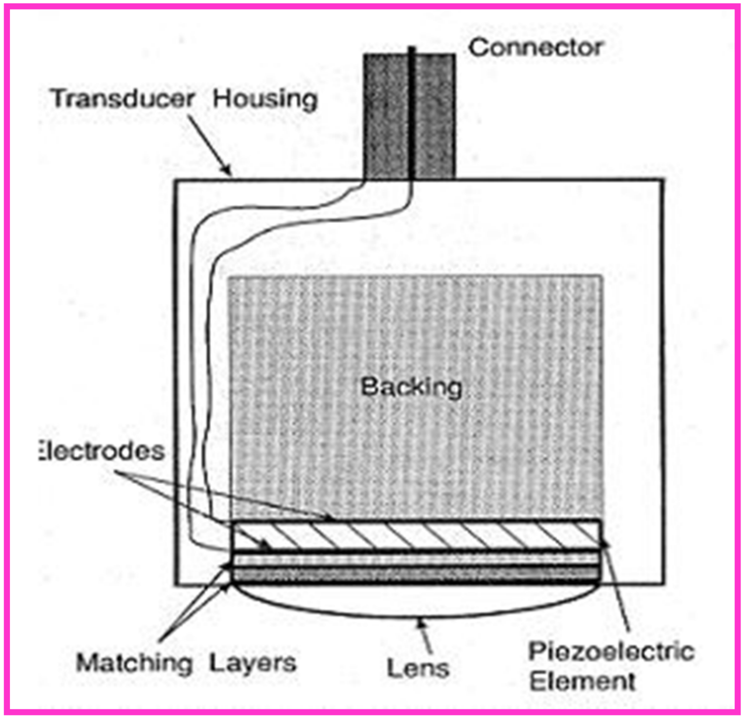
Generation & Detection of Ultrasound waves using Piezo-Electric Transducer

- As these ions are not held rigidly in position, they will be displaced slightly when an electric field is applied.
- If a constant voltage is applied across the electrodes, the positive ions are attracted towards one side of the electrode while the negative ions the other side of the electrode. This causes distortion of the silica units.
- Depending on the polarity of the applied voltage, the crystal becomes either thinner or thicker as a result of the altered charge distribution.
- An alternating voltage applied across the silver electrodes will set up mechanical vibrations in the crystal. And to produce ultrasonic waves, the frequency of vibration is set above 20 KHz.

Detection:

- Ultrasonic waves can also be detected using piezo-electric transducer. When an ultrasonic wave is incident on an unstressed piezo-electric crystal, the pressure variations alter the positions of positive and negative ions within the crystal.
- This induces opposite charges on the silver electrodes, producing a potential difference between them. This varying potential difference can then be amplified and processed.

Generation & Detection of Ultrasound waves using Piezo-Electric Transducer



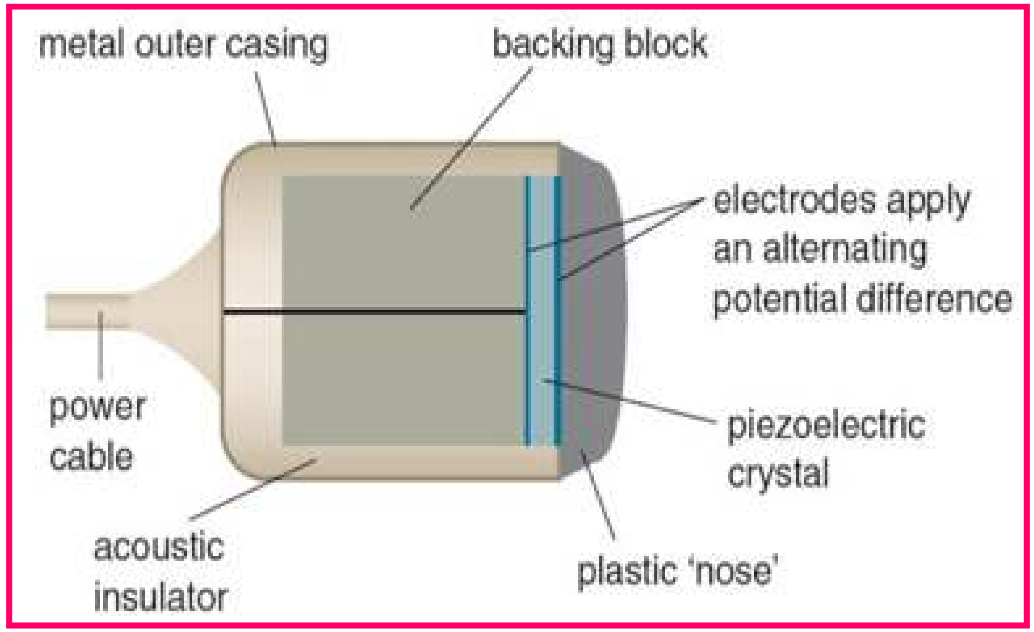
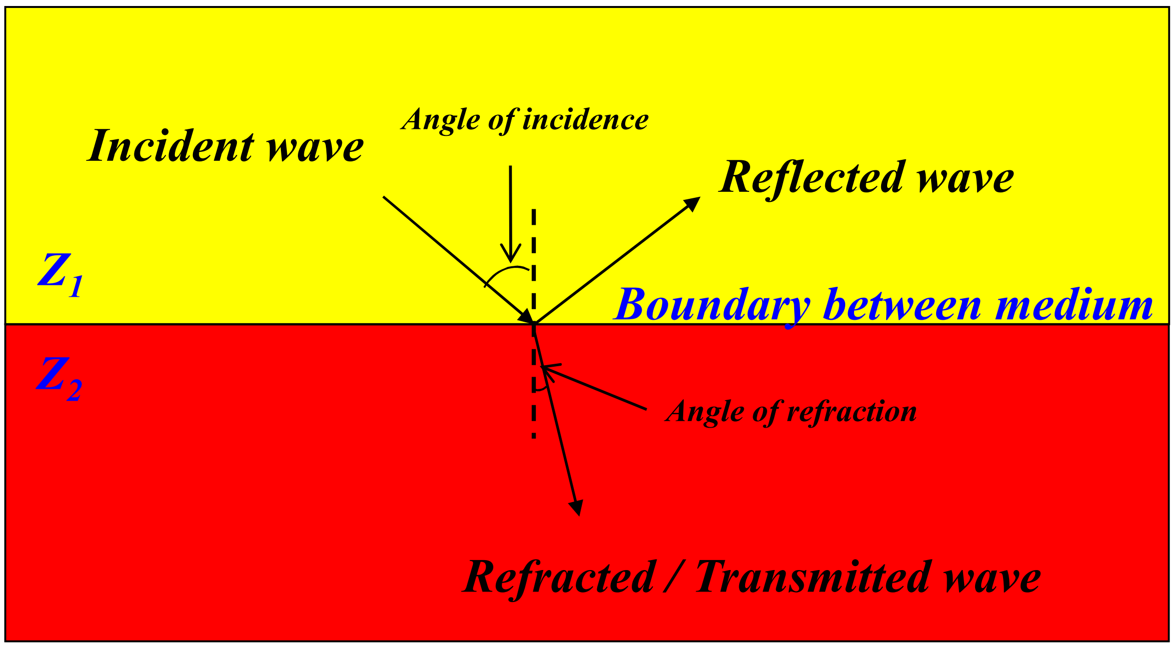


Diagram of a typical piezo-electric transducer.

Basic principles of Ultrasound waves

- The principle of ultrasound scan is to direct the ultrasound waves into the body. These pass through various tissues and are partially reflected at each boundary where the wave speed changes.
- The reflected waves are then detected and used to construct an internal image of the body.



Basic principles of Ultrasound waves

- When the beam of ultrasound reaches a boundary between two different medium, it will be partially refracted (transmitted beam changed direction), and partially reflected.
- **It is the changed of speed which causes the refraction of a wave.**
- For ultrasound, we are interested in the **fraction of the incident intensity of ultrasound that is reflected at the boundary.** This depends on a quantity known as the **acoustic impedance, *Z*** of each material.
- This quantity depends on the density and speed of sound in the material. Mathematically, its equation is given by:

$$Z = \rho c$$

; **ρ is density (kgm^{-3})**
c is speed (ms^{-1})
Z is acoustic impedance ($kgm^{-2}s^{-1}$)

Typical values of specific acoustic impedance and speed of ultrasound

Medium	***Speed/m s^{-1}***	***Specific acoustic impedance/kg m^{-2} s^{-1}***
Air	330	430
Water	1500	1.5×10^6
Blood	1600	1.6×10^6
Fat	1500	1.4×10^6
Muscle	1600	1.7×10^6
Soft tissue	1600	1.6×10^6
Bone	4100	$5.6 – 7.8 \times 10^6$

Calculating reflected intensities

- When an ultrasound beam reaches the boundary between two materials, the greater the difference in acoustic impedances, the greater the fraction of the waves that is reflected.
- For normal incidence the ratio of the reflected intensity I_r to the incident intensity I_0 is given by:

$$\boxed{\frac{I_r}{I_0} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}}$$

- The ratio of $\mathbf{I_r / I_0}$ is known as the **intensity reflection coefficient** of the boundary.
- It can be seen that the intensity reflection coefficient is very large for ultrasound entering or leaving the human body. (boundary between air and soft tissue – about 99.9% of intensity is reflected)
- In order for ultrasound to the transmitted from the transducer into the body and also return to the transducer, it is important to ensure that there is no air trapped between the transducer and the skin. This is achieved by means of coupling medium such as a gel that fills any spaces between the transducer and the skin. (only 0.03% of intensity is reflected.)

Calculating reflected intensities

- The intensity of the ultrasound waves can also be affected by absorption of the medium. As waves pass through the body, they are gradually absorbed.
- Their absorption follows the same exponential pattern as we saw earlier for X-rays.

$$\boxed{I = I_0 e^{-kx}}$$

- whereby k is the absorption coefficient, equivalent to the quantity μ in the absorption equation for X-rays. The coefficient k depends not only on the medium but also on the frequency of ultrasound.

- Typical values of linear absorption coefficient, k of ultrasound.

Medium	***Linear absorption coefficient/cm^{-1}***
Water	***0.0002***
Bone	***1.3***
Muscle	***0.23***
Air	***1.2***

- 2 techniques are in common use for the display of an ultrasound scan:
  A-scan
  B-scan

A-scan

- A short pulse of ultrasound is transmitted into the body through the coupling medium.
- At each boundary some of the energy of the pulse is transmitted and some is reflected.
- The transducer detects the reflected pulses as it now acts as a receiver.
- The signal is amplified and displayed on a c.r.o.
- Reflected pulses received at the transducer from deeper in the body tend to have lower intensity than those reflected from boundaries near the skin
- This is due not only to the energy being absorbed by the various media but also on the return of the reflected pulse to the transducer, some of the energy of the pulse will again be reflected at intervening boundaries.
- To allow for this, ***echoes received later at the transducer are amplified more than those received earlier.***
- A vertical line is observed on the c.r.o. corresponding to the detection of each reflected pulse.
- The time-base of the c.r.o. is calibrated so that knowing the speed of the ultrasound wave in each medium, the distance between boundaries can be determined.

B-scan

- A much more complicated scan.
- This consists of a series of A-scans all taken from different angles so that an image can be formed.
- The ultrasound probe consisting of a generator/detector, for a B-scan does not consist of a single crystal, but rather an array of smaller crystals each one at a different angle to its neighbours.
- The separate signals received from each of the crystals in the probe is processed by a computer software and a pattern of spots is built up to create an image for immediate viewing, photographing or to be stored in computer memory.

Advantages/disadvantages of ultrasound scanning

Advantages

- Health risk to patient and operator is very much less compared to use of X-rays.
- The equipment is much more portable and easy to use.
- Modern techniques allow for the detection of very low intensity reflected pulses, hence boundaries between tissues where there is little change in acoustic impedance can be detected.

Disadvantages

- As compared to X-rays, it is difficult to use ultrasound in the examination of the lungs because the air in the lungs prevents transmission.
- Images obtained using X-rays are sharper than those obtained using ultrasonic waves.
- Ultrasound may not be used to examine structures within bones, as the intensity of the ultrasound beam will be greatly reduced when it strikes the bone.
- Also bone absorbs ultrasound greatly, and this may cause the temperature of the bone to increase and hence may not be useful for diseased joints or brittle bones due to ultrasonic vibrations.

Summary of the physical principles of the technique of ultrasound in obtaining diagnostic information about the structures of a human body

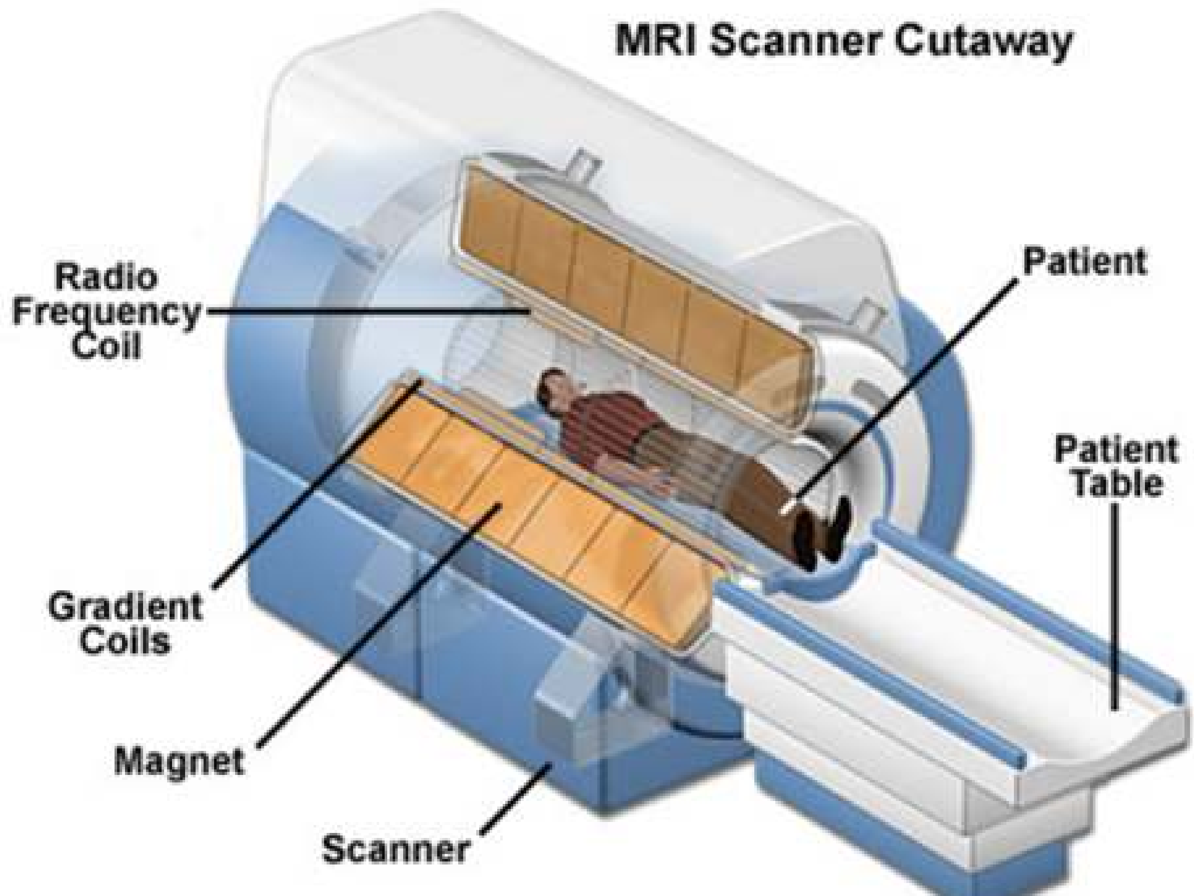
- Waves at frequencies above the audible range of 20 kHz are called ultrasonic waves. These waves are longitudinal pressure waves. Ultrasonic waves in the megahertz frequency range are used in medical applications. The higher the frequency, the higher the resolution(i.e. the ability to discriminate adjacent objects close together)
- The generation of ultrasonic waves using piezo-electric transducers is based on the piezoelectric effect. An example of a piezo-electric crystal is quartz which has a complex structure.
- When the crystal is unstressed, the centres of charge of the positive and negative ions bound in the lattice of the piezo-electric crystal coincide, so their effects are neutralised.
- If a constant voltage is applied across the electrodes, the silicate units become distorted as positive ions (silicon) are attracted to one side of the electrode and the negative ions (oxygen) to the other side of the electrode. The crystal becomes either thinner or thicker due to the altered charge distribution depending on the polarity of the applied voltage.
- An alternating voltage applied across the electrodes hence sets up mechanical vibrations in the crystal. Resonance occurs when the frequency of the applied voltage is equal to the natural frequency of the crystal and the oscillations reaching a maximum amplitude.

Continue…

- When an ultrasonic wave meets a boundary between 2 media, some of the wave energy is reflected and some is transmitted into the medium. The intensity of the transmitted wave has the added problem of being absorbed by the tissue as well exponentially.
- The relative magnitudes of the reflected and refracted intensities depend on the specific acoustic impedance z which is defined as the product of the medium's density and the speed of the sound wave through the medium.
- If the ultrasonic waves were to try to pass from one medium into another of much larger impedance, most of the wave energy would be reflected and little would be transmitted. Alternatively, if the 2 media were of similar impedance, the majority of the wave energy would be transmitted with very little reflection occurring. This means that in order to use ultrasound to obtain diagnostic information about internal structures of the human body, the impedances of human tissue, bone, muscle, and etc should be taken into account.
- The air/tissue interface have greatly differing impedances, hence a coupling medium which is usually oil or a water-based jelly is usually used.
- In ultrasonic scanning, short sharp pulses of ultrasound from a transducer are transmitted into the body and the reflected waves from the different media under study are then detected and analysed.

MRI

Magnetic resonance imaging

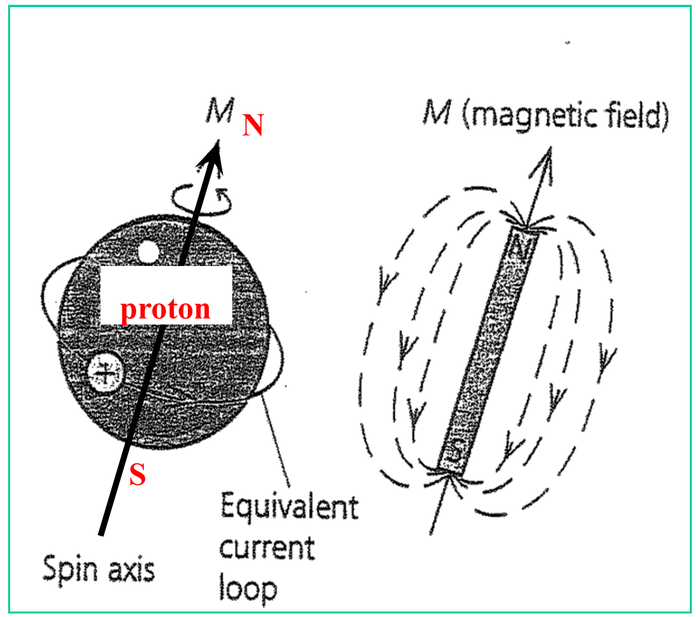


MRI

- MRI is another technique from nuclear medicine. However, it does not rely on nuclides that are radioactive; rather it relies on the fact that some atomic nuclei behave like tiny magnets in an external magnetic field.
- As in CAT scanning, MRI scanning involves em radiation, in this case the radio frequency waves.
- The patient lies on a bed in a strong magnetic field., RF waves are sent into their body, and the RF waves that emerge are detected. From this, a picture of a patient's insides can be built up and interpreted by a computer.
- As we will see, MRI gives rather different information from that obtained by other non-invasive techniques we have been looking at.

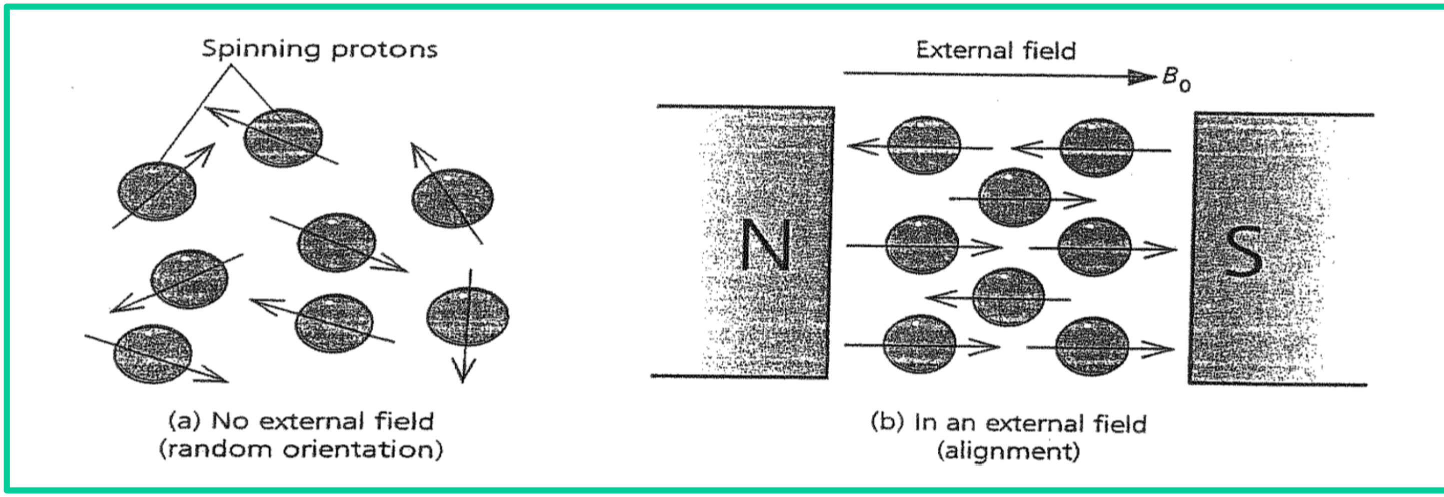
Principle of MRI

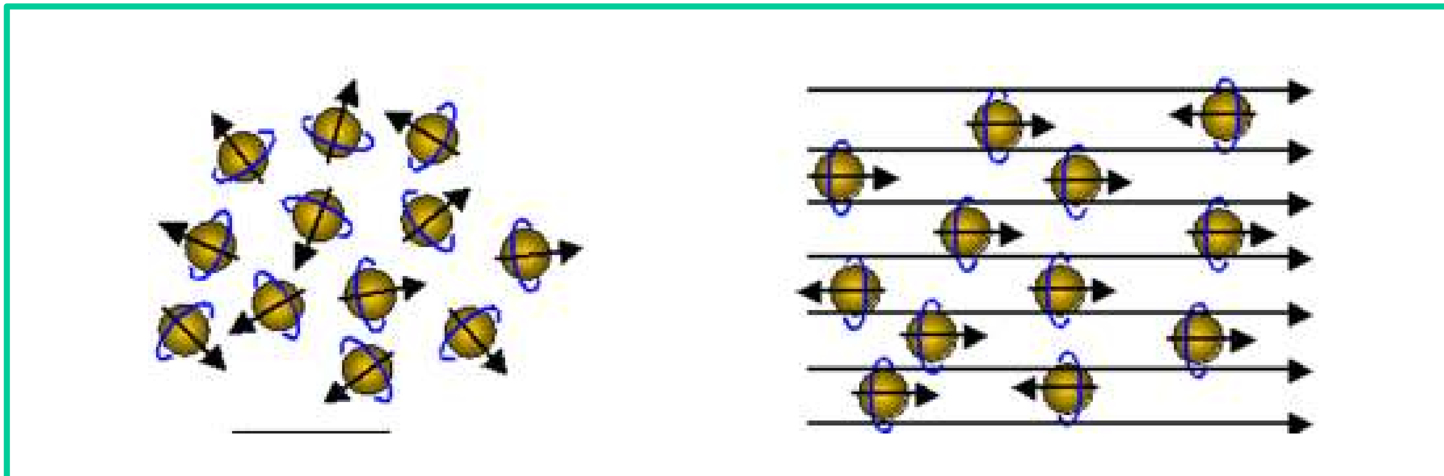
- The nuclei of certain atoms have a property called "**spin**" and it is this property that causes them to behave as tiny magnets in a magnetic field. Nucleus of an atom spins when it has an odd number or protons and/or odd number of neutrons.
- In MRI, it is usually the nuclei of hydrogen atoms that are studied, since hydrogen atoms are present in all tissues.
- A hydrogen nucleus is a proton, so we will consider protons from now on.
- A proton has a positive charge. Because it spins, it behaves like a tiny magnet with N and S poles. **(the spinning acts like a tiny current loop which generates a magnetic field along the spin axis).**
- When there is no present of external magnetic field, the number of protons are aligned randomly.
- When a very strong magnetic field is applied, the protons respond by lining up in the field just like how a compass will.
- It is observed that most will line up with N poles facing the S pole of external field. **(the group of protons that behave like this are said to have low energy state.)**



Principle of MRI

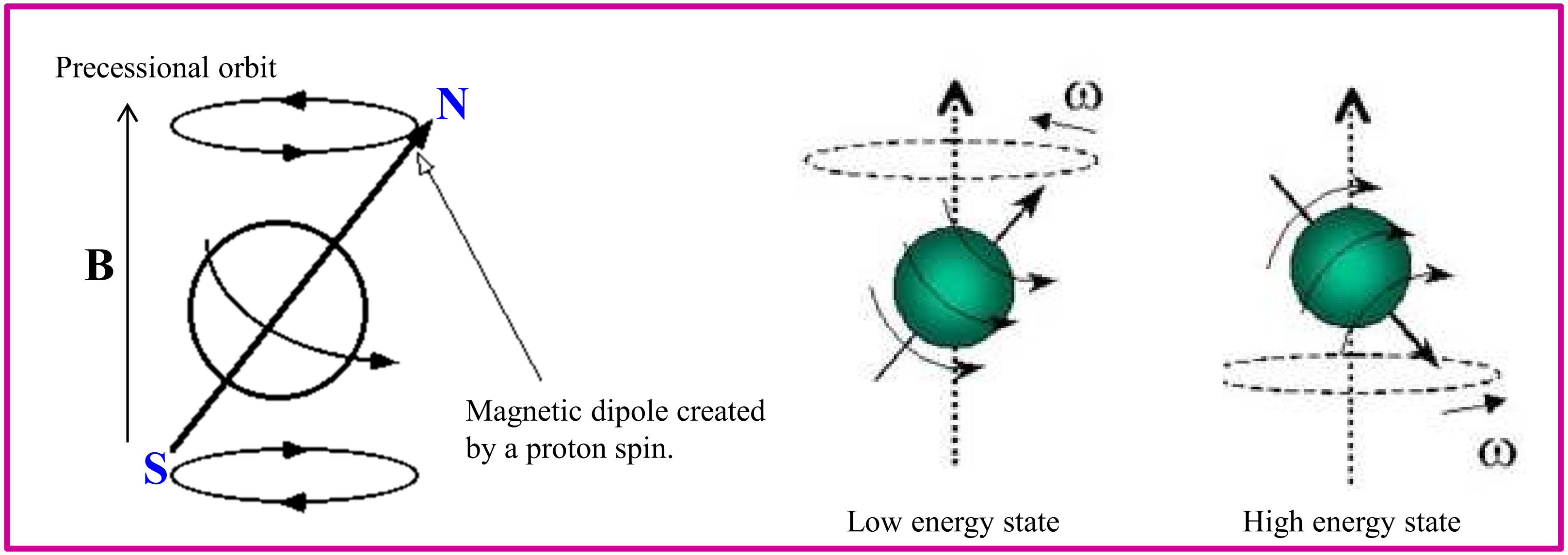
- There are also a few that will line up in the other way round, **which is an unstable, higher energy state protons.**





Principle of MRI

- But in practice, a proton does not align itself directly along the external field.
- In practice, its magnetic axis rotates around the direction of the external magnetic field.



- **This rotation is known as precession.**
- The angular frequency of precession is called the Larmor frequency, ω_0 which depends on the nature of the nucleus and the strength of the magnetic field.
- The frequency is directly proportional to the external magnetic field strength, B_o and is given by $f_o = (42.57 \times 10^6)\, B_o$ for the hydrogen atom.
- For large magnetic fields like 1 or 2 Tesla, the precession frequency, f_o is of the order of 50 MHz, which is in the radio frequency range.

Principle of MRI cont…

- If an external stimulus pulse of em radiation of radio frequency of the same frequency as the Larmor frequency is incident on the precessing proton, the proton will **resonate in phase with each other**, absorbing energy and 'flipping' to the higher energy state, E_2. (You should recall that resonance requires a system with a natural frequency of vibration; when the proton is stimulated with energy of the same frequency, it absorbs the energy.)
- Now we come to the useful bit. If we switched off the RF waves source, the protons will gradually relax and return to their lower energy state. The protons do so by releasing their excess energy by emitting it in the form of RF waves / radiation.
- This short time between the end of the RF pulse and the re-emitting of the radiation is known as the **relaxation time.**
- **The rate of relaxation tells us something about the environment of the protons.**
- This entire process of precessing and resonating in phase and emitting RF radiation is known as **nuclear magnetic resonance.**

Principle of MRI cont…

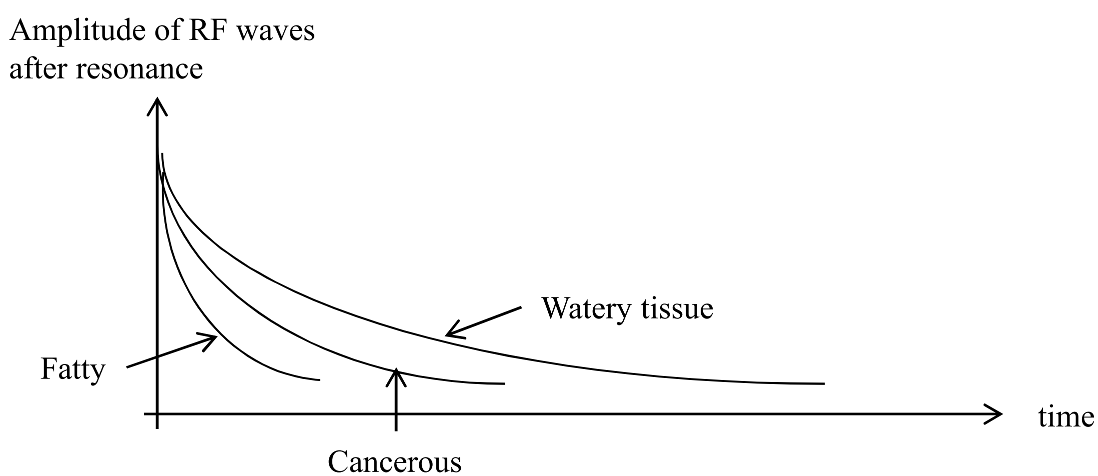
- These relaxation times depend on the environment of the nuclei. For biological materials, it depends on their water content:

  i.) Water and watery tissues (eg. Cerebrospinal fluid) have relaxation time of several seconds.

  ii.) Fatty tissues – have shorter relaxation time, several hundred miliseconds.

  iii.) Cancerous tissues – have intermediate relaxation times.

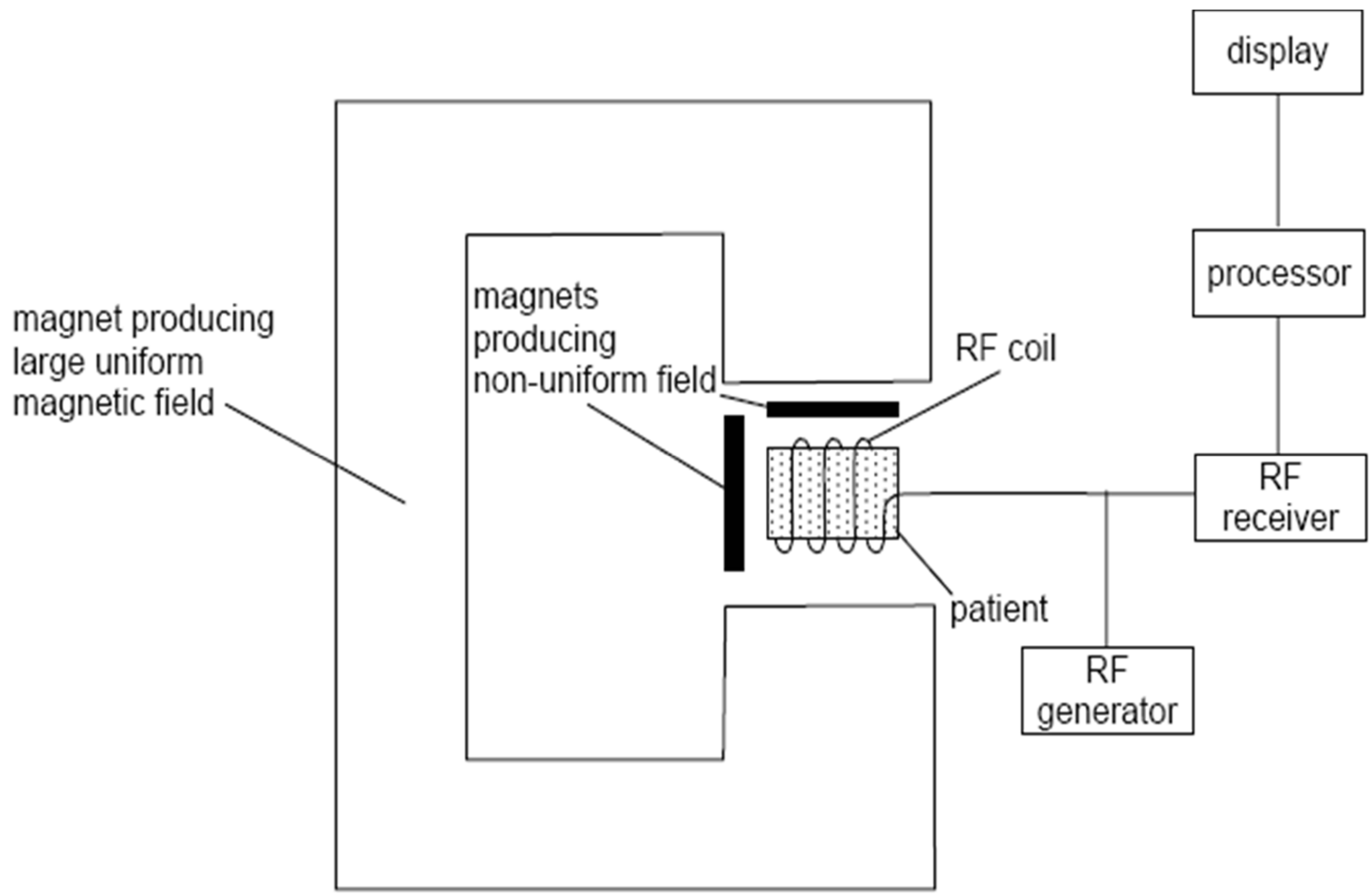
- This means different tissues can be distinguished by the different rates at which they release energy after they have been forced to resonate. That is the basis of medical applications of nuclear magnetic resonance.



Principal of the MRI scanner

- The patient is positioned in the scanner between the poles of a large magnet that produces a very large uniform magnetic field in excess of 1 Tesla.
- This magnetic field causes all the hydrogen nuclei within the person to precess with the same Larmor frequency.
- **In order that the hydrogen nuclei in only one small part of the body may be detected, a gradient coil (non-uniform magnetic field) is also applied across the patient.**
- This gradient coil is accurately calibrated and **results in a different magnitude of magnetic field strength** at each point in the body of the patient.
- **Since the Larmor frequency is dependent on the strength of the magnetic field, the Larmor frequency will also be different in each part of the patient.**
- The particular value of the magnetic field strength together with the radio-frequency that is emitted, enables the hydrogen nuclei in the part under investigation to be located.
- Radio-frequency pulses are produced in coils near the patient which pass into the patient.
- The emitted pulses produced as a result of de-excitation of the hydrogen nuclei are picked up by the receiving coils and pass it to the computer.
- A computer is used to control the non-uniform magnetic fields and RF pulses, and which stores and analyses the received data, producing and displaying the image.

Schematic diagram of a MRI scanner



Advantages/disadvantages of MRI

Advantages

- does not use ionising radiation which causes a hazard to patients & staffs.
- patients feels nothing during scan, and no after effect.
- any selected plane and orientation can be imaged.
- excellent soft tissue contrast than CAT scan.

Disadvantages

- high capital and running costs.
- examination can be claustrophobic. (fear of being closed in small spaces)
- hazards with implants e.g. pacemaker.(medical device to regulate heart beat)
- Machine makes tremendous amount of noise during a scan.
- Require patients to hold very still for extended periods of time.

Summary of the physical principles of the technique of MRI in obtaining diagnostic information about the structure of a human body

- Atoms which have an unequal number of neutrons and protons in their nucleus, spin. Because the nuclei is charged, their spinning motion causes them to behave like magnets.
- In a magnetic field they will align themselves and rotate or precess about the direction of the field while spinning. The frequency of the precession depends on the magnetic field and on the nature of the nucleus which is called the Larmor frequency and which is found in the radio-frequency part of the electromagnetic spectrum.
- By applying a pulse of radiation of this frequency, the atoms will resonate and when the pulse ends, the atoms will return to their equilibrium state.
- As this happens, RF radiation is emitted which occurs over a short period of time called the relaxation time. This is the time taken between the end of a pulse and the emission of the RF radiation.
- This forms the basis of magnetic resonance image formation.