OCR (A) A-Level Physics

6.5 Medical Imaging

Flashcards

How are X-rays produced?

How are X-rays produced?

By rapidly accelerating or decelerating charged particles – their kinetic energy is transferred into high-energy photons

How can you differentiate between X-rays and Gamma rays?

How can you differentiate between X-rays and Gamma rays?

X-rays and gamma rays have frequencies that overlap, so you cannot distinguish them by their wavelengths. Instead you have to use their method of production – gamma rays come from radioactive decay or particle collisions with a mass defect, whereas X-rays are produced by accelerating charged particles.

Why are X-rays used in medical imaging often referred to as ‘soft X-rays’?

Why are X-rays used in medical imaging often referred to as ‘soft X-rays’?

Because they have energies that are lower than gamma rays.

Describe the general structure of an X-ray tube.

Describe the general structure of an X-ray tube.

Heated filament (cathode) and tungsten anode with a potential difference between them of up to 200kV and sealed in a vacuum tube.

How does an X-ray tube work?

How does an X-ray tube work?

Electrons are emitted from the heated filament via thermionic emission and drawn towards the anode. They collide with the anode and some of their E_k is released as X-rays in all directions (the rest is transferred to heat energy within the anode).

Why does the X-ray tube need a vacuum?

Why does the X-ray tube need a vacuum?

To prevent electrons from colliding with molecules of air before they gain enough energy to release X-rays.

How is the anode prevented from overheating?

How is the anode prevented from overheating?

By either rotating it so that a new section of it is in contact with the X-rays all the time, or by using water as a coolant, circulating it through the anode.

How are the X-rays focused into one beam?

How are the X-rays focused into one beam?

The vacuum tube is encased in a material that is thinner in one area, so only X-rays that pass through that section are released from the tube. They then pass through a collimator– a series of straight, parallel tubes that absorb any rays that are not travelling parallel to the axis of the tubes.

Why is it better for X-rays to be in a beam rather than emitted in all directions?

Why is it better for X-rays to be in a beam rather than emitted in all directions?

Because it allows them to be directed at specific areas (like a broken bone) and minimises the patient's exposure to them.

What is X-ray attenuation?

What is X-ray attenuation?

When a material absorbs X-rays, decreasing the intensity exponentially.

How can you calculate the intensity of X-rays leaving a material?

How can you calculate the intensity of X-rays leaving a material?

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

I_0 = initial intensity ($W\ m^{-2}$)

μ = attenuation (absorption) coefficient (m^{-1})

x = thickness of the material (m)

Explain the process of taking an X-ray of a patient.

Explain the process of taking an X-ray of a patient.

X-rays are directed at an area of a patient's body and pass through the bone and soft tissue. Since bone has a higher attenuation coefficient, it absorbs more X-rays than soft tissue does. If photographic film is placed behind the patient, the areas where the bone is will not blacken as much as the areas of soft tissue, creating an image of the inside of the patient's body. However, nowadays, digital detectors are used in place of photographic film.

The greater the attenuation (absorption) coefficient...

The greater the attenuation (absorption) coefficient...

...The more the material will absorb incident X-rays.

Explain the process of simple scattering.

Explain the process of simple scattering.

- X-rays of energy between 1 and 20keV are directed at a material
- The X-rays will reflect off layers of atoms or molecules in the material because they have insufficient energy to undergo more complex processes (like the photoelectric effect)

Explain the process of the photoelectric effect.

Explain the process of the photoelectric effect.

- X-rays of energy less than 100keV are directed at a material
- The X-rays can be absorbed by electrons in the material if they have the same energy as the ionisation energy of the atoms
- When an X-ray is absorbed, a photoelectron is released and another electron may de-excite, releasing another photon in the process

Explain the process of the Compton Effect.

Explain the process of the Compton Effect.

- X-rays of energy between 0.5 and 5MeV are directed at a material
- The X-rays will lose a small amount of their energy to electrons in the absorbing materials due to an inelastic collision between the photon and electron.
- The scattered X-ray photon will have less energy than before (greater wavelength)
- The Compton electron will be scattered in a different direction as momentum must be conserved.

Explain the process of pair production.

Explain the process of pair production.

- An X-ray of energy greater than 1.02MeV passes through the electric field of an atom
- An electron-positron pair is produced
- The positron will annihilate with another electron and produce two photons
- This process is not very important in medical X-rays as the photon energies are usually not high enough to cause pair production.

Define contrast media and give two examples.

Define contrast media and give two examples.

High attenuation coefficient materials that have heavy atoms with a large proton number (and therefore a large number of electrons). They are easily identified in X-ray images as they absorb a lot of X-rays.
Examples of contrast media include Barium (Z=56) or Iodine (Z=53) – compared to soft tissue (Z≈7).

Define the relationship between attenuation coefficient and proton number.

Define the relationship between attenuation coefficient and proton number.

$$\mu \propto Z^3$$

What does the CAT stand for in CAT scan?

What does the CAT stand for in CAT scan?

Computerised Axial Tomography

What is a CAT scan and how do they work?

What is a CAT scan and how do they work?

A CAT scan is a 3D X-ray image of a patient's body made up of lots of 2D images. An X-ray tube generates a fan-shaped beam that is directed onto a patient that is laying down. There is a ring of detectors behind the patient to detect the beam intensity. The tube and the detectors rotate around the patient and up and down their body to create a 3D image of their whole body.

Compare CAT scans to conventional X-ray images.

Compare CAT scans to conventional X-ray images.

CAT scans give a better resolution image, and having a 3D image makes it easier to assess the injury. However, CAT scans take significantly longer than conventional X-rays, so the patient is exposed for longer.

Define medical tracer.

Define medical tracer.

A compound made of a radioactive isotope and specific elements that collects in a particular location in the body. Medical tracers can be used to locate things such as cancerous tumours in the body.

How are tracers used in a non-invasive diagnosis and which type of radiation is best-suited for it?

How are tracers used in a non-invasive diagnosis and which type of radiation is best-suited for it?

The tracer is administered to the patient and its radioactive emissions are detected from the outside. Gamma emitters are the best for this since they are the least ionising and most penetrative.

What are the characteristics of radioisotopes used in medicine and why are they important?

What are the characteristics of radioisotopes used in medicine and why are they important?

They usually have high activities and short half-lives. This is so the image can be obtained quickly, the patient is not exposed to harmful radiation for longer than necessary, and only a small amount of the radioactive substance is required.

Why are many of the radioactive sources needed for medical tracers produced on-site?

Why are many of the radioactive sources needed for medical tracers produced on-site?

Because they have such short half-lives, meaning they need to be used almost immediately.

What is Technetium-99m?

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What is Technetium-99m?

A gamma-only emitter. It is in a metastable state (shown by the m in its name), meaning it remains in an excited state for a prolonged period of time. In this state, it has a half-life of 6 hours. After this, it will decay into Technetium-99, which is a stable isotope with a half life of 210,000 years.

What is a gamma camera used for?

What is a gamma camera used for?

Detecting gamma photons emitted by medical tracers inside the body.

Describe the general structure of a gamma camera.

Describe the general structure of a gamma camera.

- Collimator which only allows photons travelling a certain direction through
- Scintillation crystal which emits many visible light photons for every incident high-energy photon
- Photocathode which produces an electron for every incident visible photon
- Photomultiplier tube which amplifies the signal
- Computer which detects the signal and displays the image on a screen.

Explain briefly the process that occurs in a gamma camera when gamma photons are incident on it.

Explain briefly the process that occurs in a gamma camera when gamma photons are incident on it.

Photons are collimated and then incident on a scintillation crystal, which absorbs the gamma photons and releases thousands of visible light photons. These are then directed to a photocathode where an electron is produced for every incident visible photon. The electrons are passed into a photomultiplier tube which releases more electrons. The position of impact on the scintillator is used to locate the emission site of the original gamma photon The signal is detected by the computer and the image is displayed.

Describe the structure of a PET scanner.

Describe the structure of a PET scanner.

A ring of gamma cameras placed around a patient in order to create a 3D image.

Explain the process of a PET scan.

Explain the process of a PET scan.

A positron emitter is administered to the patient. The positrons travel only a few millimetres before annihilating with an electron and releasing two gamma photons which are detected at two diametrically opposed detectors in the camera ring. The arrival times are recorded and speed is known so the location of annihilation can be calculated. Since annihilation is very close to the initial positron emission, the location of the tracer can be estimated. This is repeated until a 3D image can be produced.

Give an example of a radioisotope commonly used in PET scans.

Give an example of a radioisotope commonly used in PET scans.

Fluorine-18 (made by bombarding Oxygen-18 with protons).

Has a half-life of approximately 110 minutes.

What is fluorodeoxyglucose and how is it used?

What is fluorodeoxyglucose and how is it used?

Glucose substituted with Fluorine-18. It is used in PET scans to locate areas in the body with high respiration rates such as cancerous tumours or active areas of the brain.

Evaluate the pros and cons of PET scans.

Evaluate the pros and cons of PET scans.

Pros: non-invasive, accurately demonstrate organ function, can be used to observe the effects of various medications.

Cons: expensive, require tracers to be made on-site.

Define ultrasound.

Define ultrasound.

Longitudinal sound waves with a frequency greater than the range of human hearing (> 20kHz).

What are the pros of using ultrasound?

What are the pros of using ultrasound?

It is non-ionising, non-invasive, quick and affordable.

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What is ultrasound used for?

What is ultrasound most commonly used for?

Finding the boundary between two media.

Explain the Piezoelectric effect.

Explain the Piezoelectric effect.

A piezoelectric material either:

1. Generates a pd when it is contracted or expanded
2. Will contract or expand when a pd is applied.

How do piezoelectric crystals work?

How do piezoelectric crystals work?

Applying a pd to a piezoelectric crystal will cause it to produce ultrasound waves, and a piezoelectric crystal absorbing ultrasound waves will produce an alternating pd. They tend to be made from quartz, polymeric or ceramic materials.

How does an ultrasound transducer work?

How does an ultrasound transducer work?

It has an alternating pd that causes a piezoelectric crystal to contract and expand at a resonant frequency of the crystal to maximise intensity. Once the ultrasound has been created, the pd is turned off and the reflected signal is detected by the transducer.

What is an ultrasound A-scan?

What is an ultrasound A-scan?

It uses a single transducer to emit a signal and then detect the reflected signal. It is used to determine the distance from the device to the point of reflection (usually a boundary between media) by using the time and the speed of sound in the medium.

What is an ultrasound B-scan?

What is an ultrasound B-scan?

A series of A-scans that are stitched together to create a 2D image. The transducer is moved across the patient’s skin and uses the time and speed to calculate distance to a boundary at each point.

Why are ultrasounds pulsed?

Why are ultrasounds pulsed?

To allow time for the reflected signal to be received by the transducer.

Why do smaller wavelengths give more detailed images?

Why do smaller wavelengths give more detailed images?

They allow the sound waves to diffract around smaller points of detail on the object that is being scanned.

What is acoustic impedance?

What is acoustic impedance?

The product of a sound wave’s density and the speed of sound in the medium.

$Z = \rho c$

Unit: $kg\ m^{-2}\ s^{-1}$

Explain what happens when an ultrasound hits a boundary between two media.

Explain what happens when an ultrasound hits a boundary between two media.

A fraction of the wave’s energy/intensity is reflected and the rest is transmitted. The amount is dependent on the acoustic impedance of each medium.

What is the reflection coefficient?

What is the reflection coefficient?

The ratio of the reflected intensity to the original intensity: I_r / I_0

How can you calculate the reflection coefficient using the impedances of two media?

How can you calculate the reflection coefficient using the impedances of two media?

$$I_r / I_0 = (Z_2 - Z_1)^2 / (Z_2 + Z_1)^2$$

Where Z_1 is the impedance of the first medium and Z_2 is the impedance of the incident medium.

This formula only applies when the ultrasound is incident on the boundary at 90° (angle of incidence = 0°)

When Z_1 and Z_2 are very close, what happens?

When Z_1 and Z_2 are very close, what happens?

Most of the energy/intensity is transmitted.

When Z_1 and Z_2 are very different, what happens?

When Z_1 and Z_2 are very different, what happens?

Most of the energy/intensity is reflected.

How can reflection be minimised when using a transducer against a patient's skin?

How can reflection be minimised when using a transducer against a patient's skin?

Since the impedances of air and skin are very different, most of the intensity would be reflected. However, using an impedance matching gel between the transducer and the skin (that has a Z similar to skin) minimises reflection.

Define the Doppler Effect.

Define the Doppler Effect.

When there is a change in frequency of a wave when it is reflected or emitted by a moving source.

What is Doppler imaging?

What is Doppler imaging?

A non-invasive technique to measure blood flow.

Explain the process of Doppler imaging.

Explain the process of Doppler imaging.

1. Ultrasound waves are sent into a blood vessel
2. The iron in the blood cells reflects the waves back to the transducer and the frequency is shifted depending on the direction and how fast the cells are moving

Give the formula for the change in frequency of the ultrasound waves during Doppler imaging.

Give the formula for the change in frequency of the ultrasound waves during Doppler imaging.

$\Delta f = (2fv\cos\theta) / c$

f = original frequency, **v** = speed of blood flow, **θ** = the angle between the probe and the direction of blood flow

c = the speed of ultrasound in blood.