AQA Physics A-level

Topic 10: Medical Physics

Key Points

The Structure of the Eye

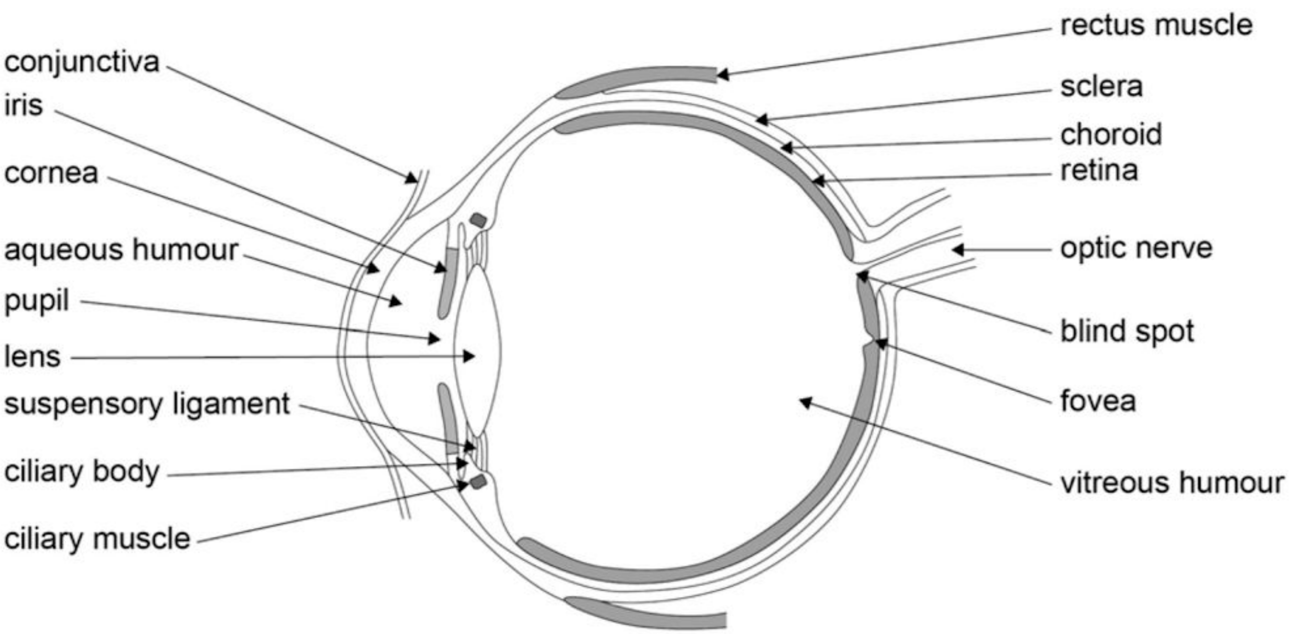

Image taken from the AQA Medical Physics Teaching Guide.

Functions

The role of the eye is to recognise and process **electromagnetic radiation** in the range of wavelengths of around **380nm - 760nm**. It converts what is seen into **electrical signals** which are then processed fully by the **brain**. You also however need to know the roles of the individual constituents of the eye:

- **Sclera**: a tough fibrous coating that surrounds the eye and is transparent at the front but opaque around the rest of the eye
- **Choroid**: a layer of tissue that lines the sclera and contains blood vessels to provide food and oxygen to the eye. It also contains a black pigment to reduce reflection inside the eye which would result in image blurring
- **Ciliary body**: the thickened edge of the choroid made up of ciliary muscles and circular muscle fibres, responsible for changing the shape of the lens
- **The Retina**: A light sensitive layer at the back of the eye, on which light is focused

The Lens

The lens sits near the front of the eye and is responsible for **focussing** light of different distances away, onto the **light-sensitive retina** at the back of the eye. You should be familiar with how the lens achieves this:

- The lens is held in place by the **suspensory ligamen**t, which is connected to the **ciliary muscle**
- When the muscle is relaxed, there is still tension in the ligament so that the lens always has a **slight curvature**
- With this slight curvature, the focal range is between 5m and infinity, meaning it has its **maximum range**
- To focus on objects that are closer than 5m away, the ciliary muscle **contracts**
- This process is known as **accommodation**, and results in increased tension, and so **increased curvature**, in the lens

Fluid Functions

The lens splits the eye into **two chambers**, each filled with a **transparent fluid**:

- The **gelatinous vitreous humour** between the **lens and retina**
- The **watery aqueous humour** between the **lens and cornea**

These fluids exert a **pressure** on the **sclera** that allows the eye to remain roughly **spherical**.

The other main purpose of these fluids is to **reduce** the amount of **refraction** that occurs at the lens. This is since the primary function of the lens is to make **focussing adjustments** rather than for image formation.

Most of the **refraction** and **image formation** that occur in the eye, take place when the light first enters the eye at the interface between the **air** and the **cornea**.

The Retina

The **retina** is responsible for converting light into **electrical signals** that can be processed by the brain. This job is carried out by **photodetectors**, which consist of two main parts:

1. **Rods** are sensitive to low light intensities and form basic gray scale images that only give a basic perception of the image
2. **Cones** are sensitive to high light intensities and different wavelengths, meaning they can produce a much more detailed colour image - each cone is connected via a nerve fibre, directly to the brain

Each rod and cone pair can be thought of as being like a **photoelectric cell**. The energy carried by the light is converted into **electrical energy** in the form of electric pulses sent to the **brain**.

Photopigments

Both rods and cones contain **photopigments** that carry out a given purpose. The main pigment you need to be familiar with is **visual purple**, also known as **rhodopsin**:

- It contains **vitamin A** as well as **proteins**
- When light is present on it, the visual purple **bleaches** and produces a **small emf**
- **Enzyme** action reverses the bleaching
- When light intensity is **low**, the rate of this enzyme action is faster than the bleaching effect, and so the rods become more **sensitive**
- For maximum sensitivity, the visual purple must have time to **fully regenerate** in a process called **dark adjustment**
- Dark adjustment can take as long as **45 minutes**

Fovea and Blindspot

The **fovea** is the region directly opposite the pupil. You should know that:

- It is entirely made up of **close-packed cones**
- These cones have a yellow tint, meaning the fovea is sometimes known as the **yellow spot**
- Moving away from the fovea, the density of **cones decreases** whilst the density of **rods increases**
- If you look **directly** at an object, the image is formed on the **fovea** by the cones which produce a high detail image
- In **low light** situations, the **outer** part of the retina, where the density of rods is higher, is used, which is why objects can appear to **vanish** if looked at directly in low lighting

The region below the fovea is the **optic papilla**. It is often referred to as the **blind spot** because it is the region where all the retina's nerve fibres converge to form the **optic nerve**, and has **no rods or cones**. This means it isn't sensitive to light and so can't detect light radiation.

Colour Vision

The human eye is sensitive to **electromagnetic radiation** in the wavelength range of **380 nm to 760 nm**. As wavelength varies in this range, so does the colour of the visible light. **Red** light has the largest wavelength, whereas **blue** light has the shortest. The eye detects colour as follows:

- All colours can be produced from the three **primary colours** blue, red and green
- Cones contain **three** different types of light sensitive material, each of which is **sensitive** to one of the three primary colours
- When light is incident on the retina, the three different materials will be stimulated by different amounts depending on the **intensity** of the primary colour they are sensitive to

Vision Defects

There are **three** main types of vision defects that you should know about, as well as understanding the steps that can be taken to correct them:

1. **Myopia** is the technical name for short-sightedness, which is where people struggle to focus on distant objects. It occurs if the cornea and lens are too powerful or if the eyeball is too long. A diverging lens is used to correct it.
2. **Hypermetropia** is the technical name for long-sightedness, which is where people struggle to focus of near objects. It occurs if the cornea and lens are too weak or if the eyeball is too short. A converging lens is used to correct it.
3. **Astigmatism** is a condition caused by the cornea being irregularly shaped or the lens having varying focal lengths in different planes. It is corrected using a cylindrical lens.

The Outer Ear

The **human ear** consists of **three** main sections:

1. Outer Ear
2. Middle Ear
3. Inner Ear

The **outer ear** is the exterior part of the ear and is the first point of contact in the detection of sound waves. The key parts of the outer ear are the:

- **External Auditory Meatus**
- **Tympanic Membrane**, also known as the **eardrum**, which has a diameter of around **1 centimetre**
- **Pinna**, also known as the **ear flap**
- **Ceruminous glands**, also known as **wax glands**, that secrete wax to protect the eardrum and keep it pliable

The Structure of the Middle Ear

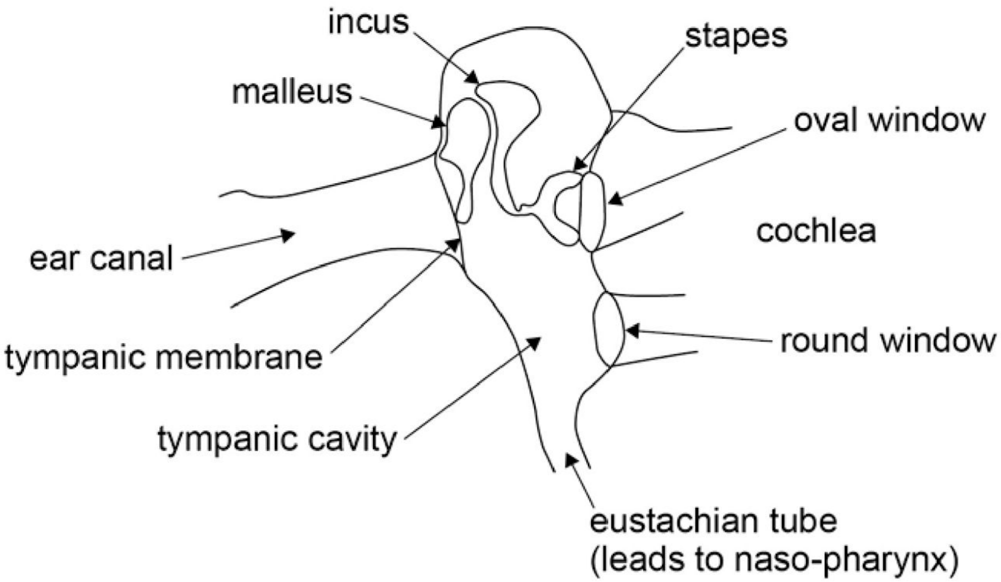

Image taken from the AQA Medical Physics Teaching Guide.

The Middle Ear

The **middle ear** is made up of the following components:

- The **tympanic cavity** sits in the centre of the middle ear and is filled with **air**
- The tympanic cavity communicates through the **Eustachian tube** to the **nasopharynx**, which is more commonly known as the **throat**
- The **auditory ossicles** are three small bones known as the **hammer/malleus**, **anvil/invus**, **stirrup/stapes**
- The **hammer** connects the **eardrum** and the **anvil**, which in turns connects to the **stirrup**
- The other end of the stirrup connects to the **oval window**, which is a membrane covering that leads into the **inner ear**
- The **round window** is a second membrane covered opening that connects the middle and inner ears

Pressure Increases

One of the functions of the **middle ear** is to **amplify** the sound waves that enter the ear. This process is as follows:

- The **auditory ossicles**, or ear bones, have a lever like action
- The bones rock and **transfer energy** through the **tympanic cavity**
- Whilst this happens, the amplitude of the soundwaves is amplified by a factor of around **1.5**
- There is a large area difference between the **area** of the **eardrum** and the **oval window**
- This area difference causes the **pressure** of the waves to be further increased by a factor of around **15**
- Consequently, the pressure of the soundwaves is roughly **20 times higher** at the **oval window** than at the **eardrum**

The Inner Ear

The **inner ear** is a bony chamber consisting of the **cochlea** and **balance organs**. The balance organs detect the **orientation** of the body as well as **velocity changes**, but don't contribute to hearing. However, the cochlea does play a key part in hearing:

- The cochlea is also known as the **hearing organ**
- It is a spiral-shaped, **helical** structure, which contains **three** membranous channels
- The **upper vestibular channel** is connected to the oval window and to the lower tympanic channel
- The other end of this **tympanic channel** is connected to the round window
- Both the upper vestibular and lower tympanic channels are filled with a fluid called **perilymph**
- The third channel sits between the other two, and is filled with a fluid called **endolymph**
- Around **25000 hair cells** act as receptors for hearing and make up an organ known as the **Corti**, found on the **basilar membrane** in the **cochlear channel**

The Hearing Process

You should be able to describe the steps that are involved with hearing:

1. Sound exists as **pressure waves** in air
2. These pressure waves cause the **eardrum** to vibrate
3. The eardrum vibration, leads to vibrations in the **ossicles** and then the **oval window**
4. Pressure waves are produced in the **cochlea fluid**, which travel up the **vestibular channel**
5. Vibrations cause **displacements** in the **basilar membrane**, causing action in the **cilia** which trigger **nervous activity**
6. **Higher frequencies** act at the **base** of the cochlea, **lower frequencies** act at the **apex**, causing the intensities of different frequencies of sound to be detected

Logarithmic Responses

Intensity is a measure of the quantity of energy that arrives on the ear per unit **area**, per unit **time**. The unit used for intensity is **Wm^{-2}**. When considering **human hearing**:

- The **threshold intensity** (I_0) is the **minimum** intensity that the human ear can detect and is equal to **1 pWm^{-2}** at a frequency if 1kHz
- The **maximum** intensity is **1 Wm^{-2}**
- The **perceived loudness** of a sound is **not linear** with the signal intensity - instead it is a **logarithmic** relationship
- Consequently, a logarithmic scale for sound intensity is used, and the unit associated with this scale is the **bel**

$$\textit{Relative Intensity (bels)} = \log_{10} \frac{I_1}{I_0}$$

One bel is the base 10 logarithm of the ratio between sound intensities with **relative** intensities in the ratio of **10:1**.

Sensitivity

The sensitivity of the human ear, **varies** across the hearing frequency range:

- The **2-5 kHz** is the **most sensitive** range, with the most sensitive frequency being **3 kHz**
- The sensitivity at the extremes of the hearing range, depends on the **intensity** of the sound as well as its **frequency**
  - An intensity of **30 dB** is required to detect a frequency of **100Hz**
- As a person gets **older**, the highest audible frequency **decreases**, and the relative intensity of sound required at the extremes of their hearing range **increases**
- Hearing **deteriorates** at a **faster rate** if repeatedly exposed to loud sounds, which is why factory workers and musicians often have to take precautions to reduce the sound they are exposed to in their professions
- The **imbalance of sensitivity** across the hearing range means that we don't hear **physiological noises** such as joint movements and blood flow

The Heart

The heart is a **large muscle** that is responsible for **pumping blood** around the body. It consists of a left and right side, each split into **two chambers,** an **atrium** and a **ventricle**. Before considering methods of monitoring the heart, it will help to understand the basic processes that occur in the heart:

- The **left atrium** pumps blood from the **lungs** to the **body**
- The **right atrium** pumps blood from the **body** back to the **lungs**
- Blood enters the atria through **veins**, where it is pumped into the ventricles
- The ventricles pump blood into **arteries** which pass blood out to the rest of the body

However, as well as oxygenating and pumping blood around the body, the heart generates **electrical signals**. A group of cells in the right atrium pulse roughly **70 times each minute** and it is these pulses that cause the **contractions** of the atria and ventricles.

Electrocardiography (ECG)

Electrocardiography is a method of monitoring the heart from the **surface** of the body. It involves connecting **electrodes** to different positions on the body. They are connected to:

- The **chest**, since it is close to the heart
- The **limbs**, since the arteries are close to the surface, except for the right leg which is too far away from the heart to produce sufficient readings

The electrodes detect the **electrical signals** that the heart generates and an electrocardiogram can be plotted. An **electrocardiogram** is a plot of the **potential difference** between a pair of electrodes, against **time**.

Obtaining an ECG

Since the electrodes are connected to the **surface** of the body, the electrical signals are very **weak**. This is because they have largely been **absorbed** and **weakened** by the body. To improve the readings recorded:

- The skin should be rubbed with **abrasive paper** to remove dead skin cells and unwanted hairs which can cause additional resistance at the electrode-skin interface
- **Electrode gel** should be applied, which contains a **strong electrolyte** such as **glycerol**, to further **reduce resistance**
- It is also important that the **electrodes** don’t undergo **reactions** with any chemical produced by the skin

Unwanted Signals

To ensure the readings taken are accurate measurements of the heart's condition, any **unwanted signals** that may **interfere** with the electrode readings should be **reduced** as much as possible. Unwanted signals can come from several sources, including:

- If the patient is tense, **muscle tremors** can cause unwanted signal noise
- Nearby **electrical equipment** and cables can induce a **charge** on the patient

Unwanted noise can be reduced by the use of a **differential amplifier**. Note that the amplifier power connections must be fully **insulated** from the patient to prevent potential electrocution.

Interpreting Electrocardiograms

You should understand how to interpret a typical electrocardiogram.

- A P wave is where the signal leads to the **atria contracting**
- A Q wave occurs about **0.2 seconds** later and is the point at which the **ventricles contract**
- A further 0.2 seconds later, the T wave represents the point at which the **ventricles relax**

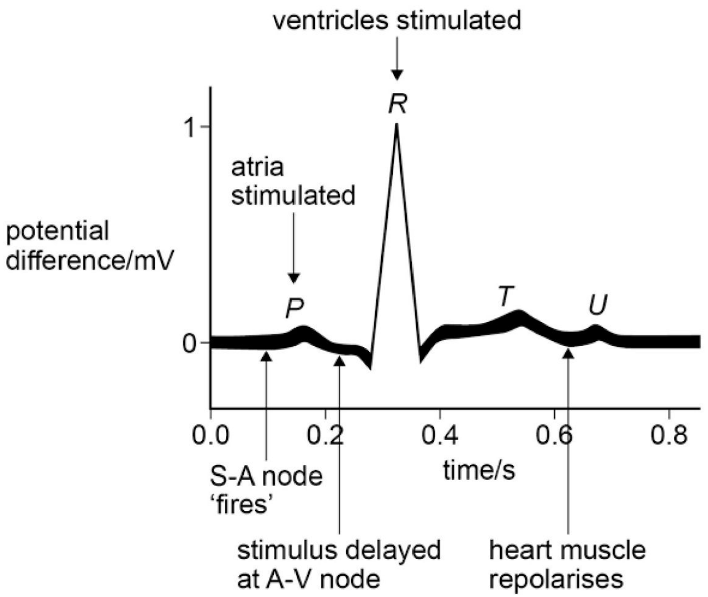

Image taken from the AQA Medical Physics Teaching Guide.

Optical Fibres

Optical fibres are long strands of glass, or similar material, that light can travel down. They make use of **total internal reflection**:

- Light rays enter the fibre and are **incident** on the inside of the core at an angle greater than the **critical angle**
- This causes the light to **totally internally reflect**
- The light leaves at the other end of the fibre with very little loss in **intensity**

When fibres are bundled together, they are a useful tool for **carrying light**. Light however can **leak** from the cores into adjacent ones, and this should be avoided by adding **cladding** to the cores.

It also important to note that if the fibre is **curved**, at certain points along the core the angle of incidence may fall **below** the critical angle. Greater curvature can be obtained at the cost of **numerical aperture**.

Coherent Bundles and Endoscopes

A **coherent bundle** of fibres is one where all the fibres are **orderly** arranged. If the ends are cut square and polished, the bundle can be used to **transmit images**. Each fibre absorbs part of the light that makes up the image, and it is carried to the other end, where the fibres are arranged such that the image is visible. You should be know that:

- An **incoherent bundle** is one where the fibres aren't orderly arranged, and this type of bundle is only useful for **transporting light** - an image **cannot** be transmitted along the fibre
- For coherent bundles, the **smaller the diameters** of the fibres, and the more tightly packed they are, the smaller the **grain** of the final image

An **endoscope** is a tool used for **medical imaging**, which makes use of coherent bundles of optical fibres to carry images of inside the human body.

Ultrasonics

Ultrasound waves are sound waves with frequencies **higher** than the range of human hearing. This means frequencies greater than around **20 kHz.** They are used in a process known as ultrasonic scanning:

- **Ultrasonic scanning** uses high frequency ultrasound waves for **medical imaging** and **diagnosis**
- The waves used have wavelengths of around **1 mm**
- Due to the wavelength of the waves used, the **resolution** of ultrasonic scanning is **limited**
- Ultrasonic scanning is a **non-invasive** form of scanning, unlike endoscopes
- No **side-effects** of the process have been found

Producing Ultrasound Waves

One way of producing ultrasound waves is by using **piezoelectric crystals**, such as **quartz**:

- When a **potential difference** is applied across the crystals, they **mechanically deform**
- When the crystals are caused to **contract or expand**, a potential difference is **produced** across them

These **piezoelectric crystals** are used in an ultrasound generating device known as an ultrasonic transducer. **Ultrasonic transducers** serve **two** purposes:

1. To **generate** pulses of ultrasound at a specific frequency
2. To **detect** returning echoes of ultrasound

Ultrasonic Transducers

You should be familiar with the process of **ultrasound generation** using an **ultrasonic transducer**:

- An **alternating p.d** is applied across the transducer, causing forced **vibrations**
- The **frequency** of the vibrations is **equal** to that of the p.d
- The **amplitude** of vibrations is at its **highest** when the frequency is equal to the **natural frequency** of the crystal
- The crystal sends out pulses of ultrasonic waves into the adjacent medium
- If short pulses are required, a **damping material** such as an **epoxy resin** should be attached to the back of the crystal

Ultrasound Reflection

Ultrasound reflection takes place when a pulse reaches the **interface** between two media. The size of the echo depends on the **properties** of the **materials**:

- All materials have an **acoustic impedance**, which is equal to the **density** of the material **multiplied by** the **velocity** of sound travelling through it
- The greater the **difference** in acoustic impedance between materials, the greater the echo that will be produced
- The intensity of the echo at a **bone-soft tissue** boundary is much greater than between two soft tissues, although both produce a echo that is **detectable**

By considering the **incident** and **reflected intensity**, alongside the **acoustic impedance** (Z) of each material, the **intensity reflection coefficient** can be calculated:

$$\frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$$

A-Scans

One type of **ultrasound scanning** is known as an **A-scan**. It is this type of scan that is used to determine the **time of gestation** and monitor **foetus growth**. You should be able to explain the processes involved:

- A **transducer** is placed onto the **surface** of the body over the area being scanned
- It emits **short pulses of ultrasound**, only **microseconds** in length
- When the pulse is emitted, the cathode ray **oscilloscope** dot starts moving
- The pulse travels into the body and reflects at **interfaces**, causing some of the **energy** to be **reflected** back to the transducer where it causes an **electrical signal**
- The signal causes the oscilloscope spot to **deflect** upwards
- The **time** taken for the echo can be calculated from the trace, and the **distance** can be calculated accordingly, allowing an image to be formed

You should be aware that the body **attenuates** the pulse, and so the further away the interface is from the transducer, the greater the echo needs to be **amplified**. This is achieved by a **swept-gain amplifier**, connected to the oscilloscope time base.

B-Scans

A second type of ultrasound scanning is known as a **B-scan**. This type of scanning is used for **more complex** imaging than A-scans are. The key **difference** is that whilst in A-scans the echo signals are applied to the Y-plate of the oscilloscope, in B-scans they are instead used to control the **brightness** of the oscilloscope spot. You should also know that:

- Echos are only received when the interface is **normal** to the ultrasound beam, meaning the **probe** needs to be **rocked** whilst being moved across the body's surface
- If the rocking is done incorrectly, an **air space** between the probe and body will be created, which will **reflect** the waves **before** they reach the body
- **Oil** is often applied to the body to ease the probe movement
- B-scans are used to locate the **placenta**, as well as before and during **amniocentesis** which is a process involving removing fluid around the foetus using a tube, to carry out genetic tests

Production of X-Rays

The **X-rays** used in medical physics are generated using an **evacuated tube** and **high voltages**:

- A **tungsten filament** is used to produce streams of electrons through **thermionic emission** - when a current passes through, the metal heats up and the electrons gain sufficient kinetic energy to be released
- The electrons are **accelerated** over a **potential difference** of between **20 kV** and **120 kV**
- The accelerated electrons collide with a **metal target** and release X-rays due to the **energy release** as the electrons are slowed down by the metal
- The X-rays released have a **continuous spectrum** of energies
- The **maximum** energy depends on the **potential difference** that was applied

Line Spectrum

As well as a **continuous spectrum of energies**, a **line spectrum** that is **characteristic** of the target **material** can be produced:

- **Incident** electrons interact with **atomic** electrons in the metal
- If the incident electrons have **sufficient energy**, they can release **inner** orbital electrons in the metal, leaving **vacancies**
- Atomic electrons from higher orbits fall down **energy levels** to fill this vacancy, and results in a photon of radiation being emitted
- The **positions** of the spectral lines are **unaffected** by the **potential difference** applied, however their **intensity** is roughly proportional to the **square** of the pd applied

Rotating Anode X-Ray Tube

A key piece of apparatus in X-ray production is the **rotating anode X-ray tube**:

- A potential difference of **20-120 kV** is applied between the anode and cathode
- The **cathode filament** releases streams of electrons through **thermionic emission**
- The anode consists **of a bevelled** disc of **tungsten**, with a diameter of around 70 mm and a thickness of about 6 mm
- The anode is **rotated** at speeds of around 3000 revolutions per minute
- The streams of electrons are accelerated from the cathode to the anode and are **focussed** on the bevelled edge of the disc
- Since the disc is continually turning, the area of the anode with electrons incident on it is constantly changing, and so the **temperature** of the disc doesn't get as high as would otherwise happen
- This allows **greater tube currents** and **accelerating voltages** to be used

Image Contrast Enhancement

A criteria for achieving **clear** X-ray images is that the **difference** in **density** of the part of body being scanned, and the density of the surrounding area, should be as **large** as possible. If this is not the case, a **contrast medium** may be used:

- The contrast medium used, should be a compound that has a very **high proton number**
- A common medium used is **barium**
- It is often referred to as a 'barium meal' and consists of a thick solution of **barium sulfate** that is **swallowed** by the patient
- The solution passes into the **gastrointestinal tract** and allows it to stand out from the tissue surrounding it

Absorption of Radiation

When a stream of single energy **X-rays** passes through a material, the **intensity** of the radiation is **attenuated** due to absorption. The quantity of **absorption** depends on:

- The **thickness** of the material
- The **atomic number** of the material
- The **density** of the material

$$\frac{\textit{fractional reduction of intensity in a thin layer}}{\textit{thickness of a thin layer}} = \mu\textit{, Linear Attenuation Coefficient (a constant)}$$

Linear Attenuation Coefficient

One way of producing ultrasound waves is by using **piezoelectric crystals**, such as **quartz**:

$$\mu = \frac{\ln 2}{x}$$

X-Ray Filters

An X-ray tube emits **photons** of a range of **different** energies:

- The **maximum** energy depends on the pd across the tube
- The **minimum** energy depends on the **material** and **thickness** of the tube's wall

Due this variation in photon energy, there is also a range of different **penetrating** powers:

- Most **low energy** photons are **absorbed** by initial layers of body tissue and so don't reach deeper regions of the body
- This means they are of little use when carrying out X-ray imaging, and can even cause **harm** to the tissue they are absorbed by
- To make the beam safer and more useful, a **filter** is applied to the X-ray beam, that is responsible for **reducing** the intensity of **low energy** photons
- This means the beam can **penetrate** more easily into deeper body regions, and so the beam is said to be '**harder**'

X-Ray Filters

An **ideal** X-ray filter would remove all the low energy photons, and leave the higher energy photons **unaffected**. In reality however, filters will affect **all** photon energies and have **two** effects:

1. **Removes** lower energy photons, and so '**hardens**' the beam
2. Reduces the **entire** beam's **intensity**

When choosing a material for an X-ray filter, it must discriminate against **lower energy** photons, which is something that occurs in the **photoelectric effect**:

- The **probability** of a photon interacting through this effect is **inversely proportional** to the **cube** of its energy
- The **scattering** probability is inversely proportional to the energy
- Since the photoelectric effect varies with the cube of atomic number, **copper** is used as a filter for **therapy**, and **aluminium** is used for **radiography**

Sharpness and Contrast

There are a number of factors that affect the sharpness and contrast of an X-ray image:

- To reduce **geometric unsharpness**, the **distance** between the focal spot and the film should be **large** - it is usually around **1m**
- The distance of the film from the object should be **small**
- A **smaller focal spot** can improve sharpness, but too small a spot can cause a **concentration** of energy in the target, which can lead to harmful **heating effects**
- The **exposure time** determines the **density/blackening** of the film, so should be relatively long, however it is often determined by the amount of movement of the body part being imaged
- Ideally, **voltage** and **exposure** would be set, and then the **tube current** would be chosen to produce the desired density, however this current level is often too high for the tube's **rating** and so the focal spot would have to increase
- A **balance** between all the factors must be found to obtain the best image possible

Beam Size

The **beam size** must be controlled to **minimise** the radiation that the patient receives:

- A **diaphragm** consisting of two perpendicular pairs of **metal sheets** is used
- The beam size is determined by the **aperture** of the diaphragm and its **distances** to the film and target
- As a result of the diaphragm being close to the target, the edge of the beam isn't very **sharp**
- In **therapeutic work** a sharp edge is required and so **collimators** are used

Scattered Radiation

An **X-ray film** is irradiated by **two** different types of photons:

1. **Primary photons** are the photons that pass through the body as required, and produce the resultant image
2. **Secondary photons** are as a result of scattering, and irradiate the whole film roughly evenly, reducing the image contrast

To reduce the amount of secondary photons reaching the film, a **grid** of fine strips of **lead** is used. However, this grid also absorbs small amounts of primary photons and so to counteract this, a **longer exposure** is used. This helps to maintain a suitable **film density**.

Intensifying Screen

Intensifying screens can be used to increase the **resulting exposure** of the film. This allows a **shorter** X-ray exposure time to be used, whilst achieving the same **density**. You should be familiar with the **structure** of an intensifying screen:

- Stiff 1mm thick sheet of **cardboard**
- **Fluorescent layer** consisting of crystals of a material such as **calcium tungstate**
- Between the cardboard and fluorescent layer there is a **white material** such as **magnesium oxide** - this redirects a large amount of visible light towards the film, that otherwise would've been lost
- A tough waterproof material is added on top to protect the screen from **scratching** and damage

Intensifying screens are placed either side of the film in a **cassette**. A **pair** of screens positioned like this, can result in an intensification factor of around **30** times. A metal cassette back is added behind the back screen to reduce radiation **scattering** back, which would result in a reduction of the film contrast.

Image Intensifier

Another method to intensify X-ray images, and one that **increases** the **light output** whilst keeping the **X-ray dose** low, is an **image intensifier**:

- The X-ray pattern is directed onto a **fluorescent screen**
- A corresponding pattern of **light** is emitted from this screen
- The light pattern is incident on a **photocathode**
- A directly corresponding pattern of **electrons** are emitted from the photocathode
- These electrons are **accelerated** by a pd of around **25kV** towards a fluorescent screen
- The high energy electrons now produce a much **brighter** image, than emitted from the first screen

The brightness is increased by an order of around **5000 times**, although the electron lens **decreases** the size of the pattern in the process. The viewing screen is viewed through a **lead glass window**. The image can also be **photographed**.

Indirect Flat Panel Detector

Flat-panel detectors are a **faster** and **more sensitive** method of producing an X-ray image, than using a traditional film method:

- A **scintillator** converts **X-ray** photons into **light** photons
- The light photons are directed at a photo-diode array, consisting of **low-noise photo diodes**
- Each diode acts as a **pixel**/picture element
- When the diodes absorb the light photons, they are converted to a stored **electrical charge**
- The charges are read by **electronic scanning**, and produce **digital signals** that are used to form a **digital image**

The **high sensitivity level** means that a **lower dose** of radiation is required to achieve a given image quality. The digital image that is produced is also more **transportable**.

CT Scans

CT scans are used to produce **cross-sectional images** of the body:

- A **collimated**, **monochromatic X-ray** is rotated around the region being scanned
- The intensity transmitted, is recorded by **detectors**
- The **detected intensities** are used to form an image of the cross-section
- The process is repeated for each required cross-section

Advantages	Disadvantages
Good images of bone fractures, organ calcification, the brain and abdominal organs.	Highly ionising.
Higher resolution than ultrasound.	Low contrast between similar density tissues.
Produces a full cross-sectional image.	More expensive than standard X-ray imaging.
Non-invasive.	Require patients to hold their breath.

MRI Process

You should be familiar with the basic processes involved in **MRI scanning**:

- The patient lies within a large, strong, cylindrical **magnet**
- Spinning **hydrogen nuclei** move and align with the **magnet field**
- A **pulse** of electromagnetic radiation is emitted, and causes the nuclei to **realign** in new positions
- When the pulse stops, the nuclei return into their equilibrium position, releasing **radiofrequency radiation** in the process
- The time that this occurs over is known as the **relaxation time**
- Different **tissue types** have different relaxation times
- **Detectors** detect the emitted radiation pulses, and are combined to form a **sectional image**

Advantages

You should know the advantages of MRI scanning:

- **Non-invasive**
- Doesn't use **ionising** radiation
- **No** known harmful effect
- Better at differentiating between **different** soft tissue types than CT scans
- **Higher resolution** imaging of soft tissue
- Produces both **3D** and **cross sectional** images

Disadvantages

You should also know the disadvantages of MRI scanning:

- **Higher cost** than most other types of medical scanning
- Cannot be used on patients with **metallic implants**
- **Bone** and **calcium** aren’t detected in MRI scans
- Require patient to remain **still** for large periods of time

Radionuclides

Radionuclides target **specific areas** of the body. The condition of that region can be determined by the amount **absorbed**. **Radionuclides** should meet the following conditions:

- Should only emit **gamma photons**
- Have a relatively **short half-life**, to prevent the patient being **exposed** to more radiation than necessary
- The **energy** of the gamma **photons** that are emitted should be able to be detected by **gamma cameras**

The most widely used radionuclide in **diagnosis** is **technetium 99m** since:

- It decays by emitting **two gamma photons**
- Has a half-life of **6 hours**
- Can be produced using a **molybdenum-technetium** generator in a hospital lab

Other Radionuclides

You should also be aware of the following two types of radionuclides:

Iodine 131:

- Used for **diagnosis** and **therapy** of **thyroid glands**
- Emits both **beta** and **gamma** radiation
- Since the thyroid absorbs the **iodine**, the beta radiation hazards are reduced
- Has a half life of **8 days**

Indium 111:

- Used to label **blood cells** and **antibodies**
- Expensive
- Very **effective** at this type of labelling
- Has a half life of **2.8 days**

Positron Emission Tomography Scans

PET scanning produces **3D** and **cross-sectional** images of the body. You should be familiar with the process involved:

- Patient is **injected** with a **radionuclide**
- The patient lies on an examination table which is moved into the scanning machine
- Throughout the scanning process, the patient must remain as **stationary** as possible
- The radionuclide **breaks down** once it has been absorbed by the **specific** body part, and emits **positrons** that are **annihilated** - this results in **gamma photons** being emitted
- **Detectors** detect the gamma photons and an image is formed
- A scan takes roughly **30-60 minutes**

Gamma Camera

Gamma cameras are used to build up images:

- Gamma photons from the patient pass through a **lead collimator**
- They travel through to a large diameter crystal of **sodium iodide**
- Due to the collimator, each photon reaching the crystal has come from a position in the body that is directly below where it is incident on the crystal
- **Scintillation** occurs in the crystal and **light photons** are produced

The light photons produced then pass into **photomultiplier tubes**. The output pulses from these tubes are used to form an **image**. The process of producing these pulses is as follows:

- Light is incident on a **photocathode** resulting in **electrons** being emitted
- The electrons are **accelerated** to a series of **electrodes** known as **dynodes**
- Each dynode is more positive than the previous, until the electrons reach the **anode**
- The electron beam reaching the anode outputs an **electrical pulse**

Physical, Biological and Effective Half-Lives

When a **radioactive sample** is placed in the body for the purpose of radiotherapy, the radiation it emits will reduce with time because of:

1. The normal **physical decay** process
2. **Biological processes** leading to the secretion of the material from the body

Consequently, different types of half-life can be considered:

- The **physical half-life** is the time taken for half of the sample's initial nuclei to decay
- The **biological half-life** is the time for half the sample's initial nuclei to be excreted from the body through biological processes
- The **effective half-life** is the time taken for the sample's initial rate of decay to fall by half

High Energy X-rays in Therapy

High energy X-rays are used in **radiotherapy**. They are needed to **kill** or **contain malignant tumours** that are deep with the body:

- The X-rays **penetrate** the body, and since they are high-energy, aren't absorbed by the **surface tissue**
- The radiation is **highly ionising** and so **kills** all cells, including healthy ones, that are acted on by a sufficient dosage

To reduce the damage that **healthy cells** in the body experience:

- The tumour is precisely **located** using detailed **scanning**
- The **energy** of the X-rays is carefully chosen
- **Multiple** beams and **rotating** beams can be used to **target** the required area
- A fine **collimated** X-ray beam can be used

Radioactive Implants

Another method of killing **malignant tumours** is through the use of a radioactive implant:

- A radioactive material is **implanted** into the area surrounding a tumour
- The material chosen emits **beta radiation**
- Beta radiation has a **medium penetrating power**, meaning it will lose most of its **energy** in the region immediately surrounding it
- This results in the tumour cells being killed, whilst very few **healthy cells** are affected

A commonly used material for radioactive implants is **Iridium 192**, since it has a half-life of 74 days, which means it is active long enough to kill the required tumorous cells.