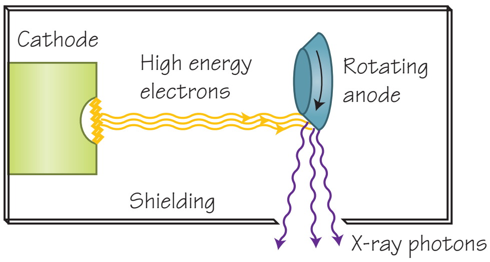
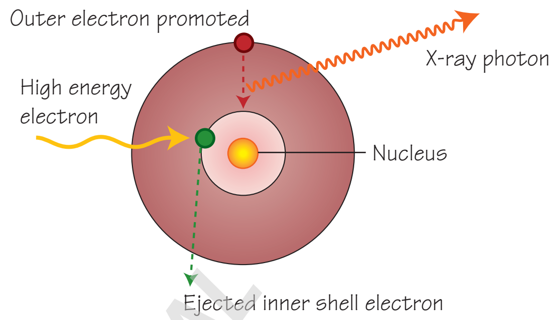
1 Plain X-ray (XR) imaging

1.1 The X-ray machine



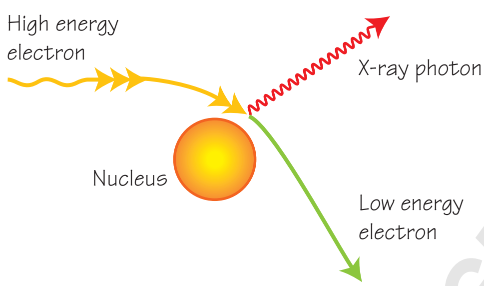
A stream of high energy electrons produced by an electron gun accelerate from a cathode filament and strike a rotating tungsten anode. X-ray photons are generated within the anode which rotates to dissipate heat. The beam of X-ray photons is shielded and coned to reduce the scatter of X-rays produced

1.2 Characteristic radiation generation



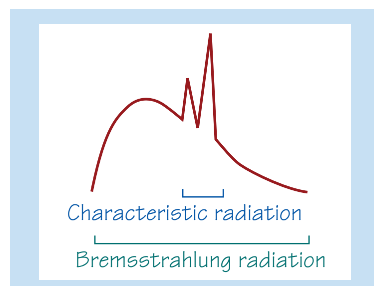
High energy electrons collide with and eject an inner shell tungsten electron (green) with subsequent promotion of an outer shell electron (red) to take its place. X-ray photons of a uniform 'characteristic' energy are generated

1.3 Bremsstrahlung radiation



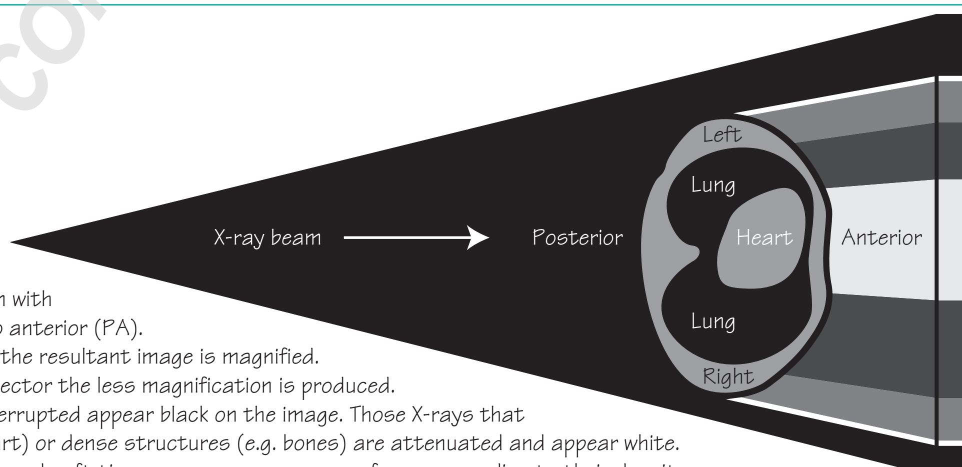
A high energy electron that passes near a tungsten nucleus is deflected and decelerated with generation of an X-ray photon. X-ray photons of variable energy are generated in this way and therefore a non-uniform energy spectrum is produced. This is known as Bremsstrahlung 'Braking' radiation

1.4 The X-ray spectrum



Bremsstrahlung radiation produces a wide spectrum of X-ray energies within the X-ray beam. Characteristic radiation generation however produces a relatively narrow band of X-ray energy. Imaging techniques optimise this characteristic band of X-rays in producing a radiograph

1.5 Image generation



A chest X-ray (CXR) is usually taken with the beam passing from posterior to anterior (PA).
The X-ray beam is divergent and so the resultant image is magnified.
The closer the patient is to the detector the less magnification is produced.
X-rays which hit the detector uninterrupted appear black on the image. Those X-rays that pass into thick structures (e.g. heart) or dense structures (e.g. bones) are attenuated and appear white.
Other structures such as the lungs and soft tissues appear as a range of grey, according to their density

Plain XR physics

On 8 November 1895, the German physicist Wilhelm Conrad Röentgen discovered the X-ray, a form of electromagnetic radiation which travels in straight lines at approximately the speed of light. X-rays therefore share the same properties as other forms of electromagnetic radiation and demonstrate characteristics of both waves and particles. X-rays are produced by interactions between accelerated electrons and atoms. When an accelerated electron collides with an atom two outcomes are possible:

1 An accelerated electron displaces an electron from within a shell of the atom. The vacant position left in the shell is filled by an electron from a higher level shell, which results in the release of X-ray photons of uniform energy. This is known as *characteristic radiation*.

2 Accelerated electrons passing near the nucleus of the atom may be deviated from their original course by nuclear forces and thereby transfer some energy into X-ray photons of varying energies. This is known as *Bremsstrahlung radiation*.

The resultant beam of X-ray photons (X-rays) interacts with the body in a number of ways:

- *Absorption* – this prevents the X-rays reaching the X-ray detector plate. Absorption contributes to patient dose and therefore increases the risk of potential harm to the patient.
- *Scatter* – scattering of X-rays is the commonest source of radiation exposure for radiological staff and patients. It also reduces the sharpness of the image.
- *Transmitted* – transmitted X-rays penetrate completely through the body and contribute to the image obtained by causing a uniform blackening of the image.
- *Attenuation* – an X-ray image is composed of transmitted X-rays (black) and X-rays which are attenuated to varying degrees (white to grey). Attenuation can be thought of as a sum of absorption and scatter and is determined by the thickness and density of a structure. In the chest, structures such as the lungs are relatively thick but contain air, making them low in density. The lungs therefore transmit X-rays easily and appear black on the X-ray image. Conversely, bones are not thick but are very dense and therefore appear white. Attenuation can be controlled by varying the power or 'hardness' of the X-ray beam.

The XR machine (tube)

Most modern radiographic machines use electron guns to generate a stream of high energy electrons, which is achieved by heating a filament. The high energy electrons are accelerated towards a target anode. The electrons hit the anode, thereby generating X-rays as described above. This process is very inefficient with 99% of this energy transferred into heat at 60 kV. The dissipation of heat is therefore a key design feature of these machines to sustain their use and maintain their longevity. The material for the target anode is selected depending on the chosen task and the energy of the X-ray beam can be modified by filtration to produce beams of uniform energy.

Most modern radiology departments now employ digital imaging techniques and there are two principal methods in everyday use: computed radiography (CR) and digital radiography (DR). CR uses an exposure plate to create a latent image which is read by a laser stimulating luminescence, before being read by a digital detector. DR systems convert the X-ray image into visible light which is then captured by a photo-voltage sensor that converts the light into electricity, and thus a digital image. The final digital images are stored in medical imaging formats and displayed on computer terminals.

Applying physics to practice

- If the subject to be imaged is placed further from the detector, the image created will be magnified. This is based on the principle that X-ray beams travel in diverging straight lines.
- Scatter from the patient and other objects degrades the resolution. This will cause the image to be blurred.
- Beams of lower energy are absorbed more than beams of higher energy. This affects the difference in clarity between the soft tissue detail and artefact.

Image quality

The clarity of the image can be expressed as 'unsharpness'. This can be classified into:

- *Inherent unsharpness* – this is caused by the structures involved not having sharp, well-defined edges.
- *Movement unsharpness* – this can be reduced by using short exposures, as with light photography.
- *Photographic unsharpness* – this is dependent on the quality and type of imaging equipment and the method of capturing the image.

Newer digital imaging systems now allow the post-processing of data to enhance various aspects of the image.

Contrast

The contrast of an image is dependent on the variation of beam attenuation within the subject. There are *five principal densities* that can be seen on a plain radiographic image.

Plain XR densities

• **Black**	Air/gas
• **Dark grey**	Fat
• **Light grey**	Soft tissue/fluid
• **White**	Bone and calcified structures
• **Bright white**	Metal

The contrast may be increased by lowering the energy of the X-ray beam. However, this has negative impact on image quality and increases the dose of radiation.

Contrast agents are often used to enhance anatomical detail. A desirable contrast agent is one that has high photoelectric absorption at the energy of the X-ray beam. The contrast agents most commonly used in plain X-ray imaging are barium, gastrografin (water soluble) and iodinated compounds. Precautions in the use of iodinated contrast agents are discussed in Chapter 6.

Advantages and disadvantages of plain XR imaging

Advantages	Disadvantages
• Inexpensive	• Radiation exposure
• Fast	• Imaging three-dimensional structures in a two-dimensional format
• Simple	• Low tissue contrast
• Readily available	• Overlapping anatomy
	• No dynamic or functional information