PHYSICS 2: HSC COURSE 2nd edition (Andriessen et al)

CHAPTER 19 Electromagnetic radiation as a diagnostic tool (pages 376-7)

1. Electrons have an electric charge (negative) and when they are moving they can be deflected by a magnetic field. When moving or stationary they can be deflected by an electric field. Both these fields can be used to focus electrons. X-rays, however, do not have an electric charge and so cannot be deflected by electric and magnetic fields.

2. (a) 'Diagnosis' means to find out the nature of a medical problem.
(b) These X-rays have high energy and will cause ionisation of atoms or molecules deep in the body. They may ionise water molecules in the body resulting in the formation of hydroxyl and hydrogen free radicals and the destruction of cells and body tissue.

3. Electrons are emitted from a heated filament in a highly evacuated tube. The heated filament is the cathode. A very high potential difference (maybe over 100 000 volts) is applied between the cathode and the tungsten anode. The very fast electrons strike the anode, are absorbed and some of their energy is converted to X-rays, which are sent in a direction determined by the angle of the tungsten target. (This description should be accompanied by a diagram like the one in figure 19.2.)

4. (a) The graph should resemble figure 19.6. It should show some characteristic wavelengths as well as a range of photon energy due to Bremsstrahlung radiation.
(b) (i) The range of frequencies results from the slowing of electrons and the conversion of their energy to X- rays. The frequency of the X-rays depends on the amount by which the electrons have been slowed down. The amount can vary resulting in X-rays of a range of frequencies.
(ii) The sharp peaks correspond to particular frequencies. These frequencies will vary depending on what target material is used. The incoming electron knocks an inner electron out of an inner shell of an atom. An outer shell electron takes the place of the inner shell electron and in the process loses energy corresponding to X-radiation of a particular frequency.

(c) The new graph will be missing a section on the left hand side of the graph, corresponding to some of the low energy photons being removed by the filtering.

5. (a) Attenuation, or reduction in intensity, of X-rays depends on the atomic density of the material encountered. Atomic density refers to the number of protons in the nuclei of the atoms encountered by the X-rays. Bone has a high atomic density and so will absorb the X-rays readily and show up clearly in an X-ray image. Soft tissue has a moderate atomic density and hence will not absorb X-rays as well as bone. Soft tissue such as muscle and skin will show up very faintly on an X-ray image. Air, on the other hand, has a low atomic density, so air in the body will not absorb X-rays and will appear black on an X-ray image.
(b) The bone would be white, the muscle would be light grey and translucent in appearance and the air would be black. Bone would absorb X-rays, because bone has a high atomic density as outlined in part (a), and so the X-rays would not reach the photographic film which would show up as white behind the bone. Some X-rays would penetrate the muscle, with a medium atomic density, and reach the film, resulting in the light grey colour behind muscle. X-rays would not be stopped by air and these X-rays would reach the photographic film resulting in a black image.

6. Ultrasound is a high frequency sound wave with no known harmful effects on the body. X-rays are high frequency electromagnetic waves which can cause ionisation of water molecules in the body. This may lead to the formation of free radicals which may cause mutations. This is a harmful effect. As a result of this difference, ultrasound is used freely to image the foetus in the uterus. X-rays are not generally used on a pregnant woman or her foetus.

7.

Hard X-rays	**Soft X-rays**
Higher frequency	Lower frequency
More penetrating and will penetrate the body and be absorbed by bone	Less penetrating so will be absorbed by the skin before they reach bone
Preferred for imaging	Not needed for imaging and expose patient to additional X-rays of no value in obtaining an image

8. (a) When electromagnetic radiation travels from a more dense to a less dense medium it is refracted away from the normal. If the angle of incidence in the more dense medium is just large enough to cause the refracted ray to travel along the interface between the two media, we call this angle of incidence the critical angle.
(b) In an optical fibre, the core is more optically dense than the cladding. Hence a critical angle exists for light travelling in the core. If the critical angle is exceeded, the light will not enter the cladding but will be totally internally reflected in the core and hence able to travel along the optical fibre as in figure 19.14.
(c) The cladding is chosen to have a density less than that of the core. Hence a critical angle will exist in the core and light can be trapped in the core and travel along the optical fibre.
(d) The refractive index of the cladding is less than the refractive index of the core.

9. (a) In a coherent bundle, the fibres are in the same position relative to one another at each end of the fibre.
(b) A coherent bundle of optic fibres is used to transmit the reflected light back from the inside of the body to the eye or camera outside the body. It is necessary that an accurate image is produced and hence each fibre must remain in the same position relative to the other fibres. In this way, light from the far right of the object will emerge from the body and be at the far right of the image; and this matching of light beams will occur for each optic fibre. The result will be an image that is exactly the same as the object inside the body.
(c) It is dark inside the body and hence the inside of the body will not be visible unless light is passed from a powerful light source along an optic fibre, reflected off the inside of the body and transmitted back to the outside. The internal organs are not necessarily good reflectors of light, so the source must be bright to reflect as much light as possible and see the organs.
(d) If the fibres in the bundle are narrow and have a large core to cladding ratio, light reflected from many points on the object will be transmitted. Hence the resulting image will be made of many points and will therefore be clearer.

10. This statement is correct as without the transfer of light the internal organ would not be visible and so could not be observed and operated on or sampled. The light is transferred to the internal organ by a non-coherent bundle of optic fibres. Each fibre transfers light by total internal reflection. Illumination is important so there is no need to have a coherent optic fibre bundle. The light is reflected from the internal organ. This light must be transferred back to the outside of the body so that the image can be seen. Hence it is important that the optic fibre carrying this reflected light is coherent – each reflected beam must be kept in the same position relative to each other beam so that the image is not distorted. The additional parts of the endoscope needed to cut, operate or sample tissue would not be of any use if the organ could not be seen. Hence the transfer of light is the main principle behind the operation of the endoscope.

11.

Situation using CAT scan	**Problem with X-rays**	**Problem with ultrasound**
Soft tissue accurately imaged, resulting in fine detail being shown.	Soft tissue does not absorb conventional X-rays to any noticeable extent, so soft tissue will not show up, unless a contrast medium is used.	Ultrasound will not clearly distinguish one type of soft tissue from another.
Images of slices, close together, through the body can be taken.	Conventional X-rays cannot be used to image a slice of the body.	Ultrasound cannot accurately image slices close together.
The images of slices can be built up into a 3-dimensional image.	X-rays cannot do this as slices cannot be imaged.	Ultrasound cannot accurately image slices close together so a 3-dimensional image built up from ultrasound is not very clear.
The brain can be imaged through the bony skull.	Conventional X-rays would show up the skull rather than what was inside the skull.	Ultrasound would be reflected from the skull and not image what was underneath, unless the ultrasound was taken through a gap in the skull.

Can be used to investigate soft tissue damage where a contrast medium cannot be used.	X-rays will not show up soft tissue in this situation.	Ultrasound will not show enough contrast between soft tissues to detect tissue damage.
Can be used to scan the kidneys to obtain resolution better than 1 mm.	X-rays will not give clear images of the kidneys.	Ultrasound will not give this resolution - the resolution is determined by the wavelength of the ultrasound. In addition, the difference in intensity of the reflected ultrasound signals will not be great enough to give a clear image.
CAT scans provide a clear image of the lungs.	X-rays are quicker but do not provide as clear an image.	Ultrasound cannot image the lungs because the ultrasound is strongly reflected at any interface where there is air.
Complicated bone structure is imaged and a 3-dimensional image may be obtained.	Bone absorbs most of the rays giving a 2 -dimensional image of the part of the bone facing the X-rays and so the complex structure cannot be seen.	Ultrasound is reflected from bone and so no useful image is formed.

12. The endoscope can be inserted into the oesophagus through the mouth. The tumour in the oesophagus can be viewed because light is reflected off the oesophagus and the tumour. A small tool on the end of the endoscope can be used to remove a sample of the tumour. The sample is then removed from the oesophagus by this tool and sent for examination. 'Taking a biopsy' means removing a sample of the tumour.

13. An endoscope could be inserted into a small incision in the knee and the torn ligament examined because light is reflected off the ligament area. Through the same cut or through another, to gain better access, the ligament could be repaired by snipping and sewing using the needle and probe and scissors, that are accessories on the end of the endoscope.

14. The image of the lungs is not clear compared with the femur. The lungs do not show clear contrast, except for the black region, whereas the femur shows the bone, tumour, interior of femur, surrounding tissue and skin clearly.
The lungs show a 2-dimensional image and depth of field is not evident. The femur is shown in both horizontal and vertical sections because the scan can be accurately taken in many slices as indicated on parts (a) and (b) of the figure.
The damage on the lungs shows up as a general region, whereas the position of the tumour on the femur can be accurately determined and its size assessed.

15. The images obtained will vary. Comments describing any special features of the X-rays should be made.
For example, if a mammogram image is described, the method of imaging the breast tissue should be outlined. For a barium meal X-ray, the properties of the barium sulfate to allow it to be imaged should be outlined. The properties of bone and X-rays to enable an X-ray image of a fracture to be made should be outlined.

16. The images will vary and the descriptions should be true to the image, which should be printed with the description. In some cases, a probe from the endoscope or a needle used in stitching will be visible. Often a student has a video of an operation of a family member and this will provide images for description by the class.

17. (a) The part of the patient being imaged is positioned in the gap in the gantry. An X-ray tube rotates around the patient firing a very narrow beam into the patient, at regular, close intervals until an angle of 180° has been swept out. The beams are detected on the other side of the patient and the attenuation of the X-rays is used to build up an image of a slice through the patient. Powerful computers are needed to analyse the data obtained and construct the image.
(b) The absorption of X-rays is measured at many points along each scanning path. There may be 1° difference between each scanning path. By the time the scan is completed, there may be 30 000 different pieces of information to be processed to build up the image. Powerful computers are needed to process this information. Computers of lower power could handle fewer pieces of information and hence there

would not be as many distinct points imaged in a slice. Therefore the clarity of the image would not be as great.

18. The detail should include the organs and tissue that is visible and the clarity within the organs or tissue. The effect of bone on the image will be significant when discussing the image using ultrasound or X-rays.