Mark scheme for Option I

1 a i Intensity at the eardrum is $\frac{150\times10^{-3}}{58\times10^{-6}} = 2.586\times10^{3}\ \text{Wm}^{-2}$.

Sound intensity level is $10\log\frac{2.586\times10^{3}}{1.0\times10^{-12}}$

$= 154 \approx 150\ \text{dB}.$ **[3]**

ii The student is being exposed to extraordinarily high sound intensity levels and damage is certain to occur. **[1]**

b i The lowest intensity of sound that can be heard,

at a particular frequency. **[2]**

ii Sound intensity level is $10\log\frac{2.0\times10^{-10}}{1.0\times10^{-12}} = 23\ \text{dB}$

Drawing a horizontal line through 23 dB,

to intersect hearing curve at approximately 180 Hz and 12000 Hz, which is the required range. **[3]**

iii Curve gets higher,

and closes in at the ends, especially the high frequency end. **[2]**

2 a i The product of a medium's density and the speed of sound in the medium. **[1]**

ii To properly image, ultrasound must penetrate tissue/organs and be reflected back to source.

If there is mismatch of impedances, then the ultrasound will be mainly reflected and will not penetrate the body. **[2]**

b i $R = \left(\frac{410-1.6\times10^{6}}{410+1.6\times10^{6}}\right)^{2}$

$R = 0.99897553 \approx 1.0$ **[2]**

ii From i it follows that for all practical purposes no ultrasound enters tissue/all is reflected,

and hence a gel-like substance must be placed between the transducer and the skin in order to reduce the reflection coefficient. **[2]**

c To limit diffraction the wavelength must be less than the size of the object being scanned,

and this places a lower limit on the frequency being used (above 1 MHz for resolution at the mm level).

OR

To resolve two distinct objects as distinct, their separation must be of the order of the pulse length.

And to have a short pulse length requires a high frequency. **[2]**

Exam tip: You must understand that ultrasound is sent as pulses because the transducer acts both as an emitter and as a receiver, so there must be time for the reflection to be received.

3 **a** In X-ray imaging X-rays passing through the body are attenuated by different amounts by different parts of the body and a **2-dimensional** image is produced due to the contrast.

In CT scanning the amount of X-ray energy absorbed along different slices of the body is recorded and digitized.

This procedure, repeated for other slices of the body, produces detailed images that may be viewed from any angle with the use of powerful computers. **[3]**

b **i** The probability per unit length that a particular X-ray photon will be absorbed. **[1]**

ii Mainly the photoelectric effect (in which X-rays lose energy to electrons in tissue ejecting them from their atoms). **[1]**

iii The intensity reaching the bone through tissue is $I_1 = I_0 e^{-0.14 \times 9.0} = 0.28 I_0$

The intensity exiting the bone is $I_2 = 0.28 I_0 e^{-0.74 \times 4.0}$

$I_2 = 0.015 I_0$ **[3]**

iv The two intensities are sufficiently different for contrast,

and so an image is possible. **[2]**

c X-rays are not readily absorbed by photographic film, but visible light photons are.

So the idea is to use a screen that absorbs X-rays and re-emits visible light photons, which are then detectable on film. **[2]**

4 **a** The **spins** of hydrogen nuclei inside the body align with an externally applied magnetic field.

The spin down state has higher energy than that for spin up.

An RF (radio frequency) directed at the nuclei **forces a transition** from the spin up to the spin down state.

The hydrogen nuclei then make a transition to the lower energy state **emitting pulses of RF radiation.**

The place of origin of the RF pulse can be detected if the an **additional non-uniform magnetic field** is present. **[5]**

Exam tip: This is a complicated question - you must at least mention the words in bold.

b **E.g. Pulse oximetry:**

Measures the amount of oxygen that is absorbed in the haemoglobin of blood.

By measuring the absorption of the light at two different wavelengths.

E.g. The laser as a scalpel:

A laser beam can be made very thin and so when it is focused on a tiny spot a large intensity of light is achieved that can vaporize/cut tissue.

The advantages over an ordinary scalpel are that there is less bleeding and less damage to nerve cells, resulting in less pain to the patient during the recovery period after an operation. **[4]**

Exam tip: You may also want to refer to endoscopy.

5 **a** For monitoring it is essential that a detector outside the body receives radiation.

This can be achieved with gamma rays, as alphas and betas would be absorbed before exiting the body. **[2]**

b **i** Physical half-life is the time for the activity of a sample to be reduced to half by the process of radioactive decay.

The effective half-life is the time for the activity to be reduced to half both due to the combined effect of radioactive decay and the excretion of the radioactive material through natural bodily functions. **[2]**

ii A short physical half-life means that activity will be reduced quickly,

reducing the risk of damage to healthy cells. **[2]**

c In 6 hours approximately $3.6\times10^{7}\times6.0\times3600\times5.0\times10^{-13}=0.389\ \text{J}$ of energy will be released in the tumour,

giving a dose equivalent of $\frac{0.389}{22\times10^{-3}}=17.7\ \text{Gy}.$

and a dose equivalent of $1\times17.7=17.7\ \text{Sv}.$ **[3]**