Question 1

8 **(a)** Table 8.1 shows some data relating to the properties of air, gel and body tissue. The data are given to three significant figures.

Table 8.1

material	density / kg m^{-3}	speed of sound / m s^{-1}	specific acoustic impedance / kg m^{-2} s^{-1}
air		340	440
gel	1200	1400	
tissue	1090		1.68×10^6

(i) Show that the specific acoustic impedance of gel is 1.68×10^6 kg m^{-2} s^{-1}.

[1]

(ii) Complete Table 8.1 by calculating the missing values to three significant figures. Use the space below for any working that you need.

[2]

(b) Use the information in **(a)** to calculate the intensity reflection coefficient for:

(i) an air–tissue boundary

intensity reflection coefficient = ... [2]

(ii) a gel–tissue boundary.

intensity reflection coefficient = ... [1]

(c) Use your answers in **(b)** to explain why gel is applied to the skin during ultrasound scanning.

....

....

.... [2]

[Total: 8]

Question 2

9 Ultrasound is used to produce diagnostic information about internal body structures.

(a) Explain how ultrasound waves are detected.

....

....

....

.... [3]

(b) An alternating voltage V varies with time t according to

$$V = V_o \sin \omega t.$$

The voltage is applied to an ultrasound probe.

The root-mean-square (r.m.s.) voltage is 66 V. The frequency of the ultrasound generated by the probe is 4.3 MHz.

Determine the values of

(i) V_o

V_o = ... V [1]

(ii) ω.

ω = ...rad s^{-1} [1]

(c) Table 9.1 contains information about air and soft tissue.

Table 9.1

	density / kg m^{-3}	speed of ultrasound / m s^{-1}	specific acoustic impedance / ....
air	1.30	330	4.3×10^2
soft tissue		1600	1.7×10^6

(i) Determine the unit for the specific acoustic impedance values shown in Table 9.1. [1]

(ii) Calculate the density of soft tissue.

density = ... $kg\,m^{-3}$ [1]

(iii) Use data from Table 9.1 to explain why ultrasound cannot be used to produce an image inside an air-filled cavity such as the lungs.

....

....

....

.... [2]

[Total: 9]

Question 3

10 Positron emission tomography (PET scanning) involves the detection of gamma-radiation in order to identify the position of origin of positrons in the body.

(a) (i) Positrons are not naturally present in the body.

Explain how positrons come to be present in the body during PET scanning.

....

....

.... [2]

(ii) Explain how positrons cause the emission of gamma-radiation from the body during PET scanning.

....

....

....

.... [3]

(b) Show that the wavelength of the gamma-radiation that is detected during PET scanning is approximately 2.4 pm. Explain your reasoning.

[4]

[Total: 9]

Question 4

9 **(a)** **(i)** Explain how X-rays are produced for use in medical diagnosis.

....

....

....

.... [3]

(ii) State why X-ray images are taken of multiple sections of the body during computed tomography (CT) scanning.

....

.... [1]

(b) An X-ray image is taken of the structure shown in Fig. 9.1.

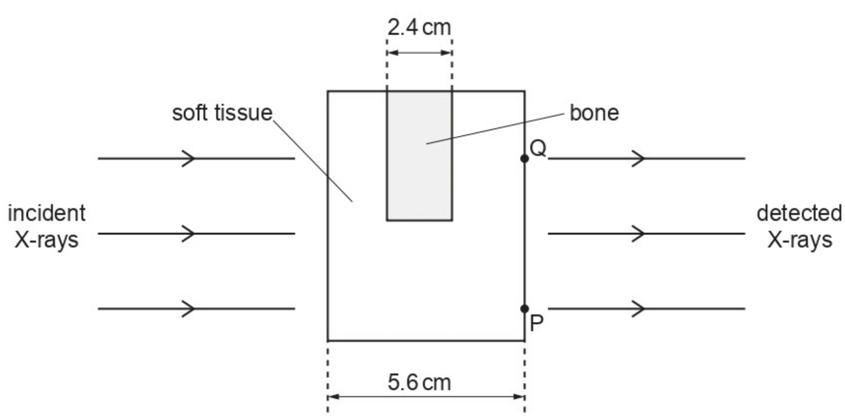

Fig. 9.1

The linear attenuation coefficient of bone is 3.4 cm^{-1}.
The linear attenuation coefficient of soft tissue is 0.89 cm^{-1}.

The incident X-rays are parallel and have a uniform intensity I_0 across the structure.

Determine, in terms of I_0, the intensity of the detected X-rays from:

(i) point P

detected intensity = ... I_0 [2]

(ii) point Q.

detected intensity = ... I_0 [2]

(c) Explain, with reference to your answers in **(b)**, whether the X-ray image of the structure in Fig. 9.1 has good contrast.

....

....

.... [1]

[Total: 9]

Question 5

10 In an X-ray tube, electrons are accelerated through a potential difference of 75 kV. The electrons then strike a tungsten target of effective mass 15 g.

The electron energy is converted into the energy of X-ray photons with an efficiency of 5.0%. The rest of the energy is converted into thermal energy.

(a) The X-ray tube produces an image using a current of 0.40 A for a time of 20 ms.

The specific heat capacity of tungsten is 130 $J\,kg^{-1}\,K^{-1}$.

Determine the temperature rise ΔT of the tungsten target.

ΔT = ... K [3]

(b) The linear attenuation coefficient of the X-ray photons in muscle is $0.22\,cm^{-1}$.

Calculate the thickness t of muscle that will absorb 80% of the incident X-ray intensity.

t = ... cm [2]

(c) Table 10.1 shows the linear attenuation coefficient μ for the X-ray photons in different tissues.

Table 10.1

	$\mu\,/\,cm^{-1}$
bone	3.0
blood	0.23
muscle	0.22

Two X-ray images are taken, one of equal thicknesses of bone and muscle and another of equal thicknesses of blood and muscle.

Explain why one of these images has good contrast, but the other does not.

....

....

....

.... [2]

[Total: 7]

Question 6

11 Positron emission tomography (PET scanning) obtains diagnostic information from a person. The information is used to form an image.

(a) PET scanning uses a tracer.

Explain what is meant by a tracer.

....

.... [1]

(b) PET scanning involves annihilation.

(i) Explain what is meant by annihilation.

....

.... [1]

(ii) State the names of the particles involved in the annihilation process.

.... [1]

(c) **(i)** Calculate the total energy released in one annihilation event in **(b)**.

energy = ... J [1]

(ii) Calculate the wavelength of each gamma photon released.

wavelength = ... m [2]

(d) Explain how the gamma photons are used to produce an image.

....

....

....

....

....

.... [3]

[Total: 9]

Question 7

11 **(a)** State, for an X-ray image, what is meant by:

(i) *sharpness*

....

.... [1]

(ii) *contrast*.

....

.... [1]

(b) A parallel X-ray beam passes through a thickness of 2.3 cm of soft body tissue. The intensity of the emerging beam is 12% of the intensity of the incident beam.

Calculate the linear attenuation (absorption) coefficient μ of the soft body tissue. Give a unit with your answer.

μ = ... unit .... [3]

(c) In medical diagnosis, X-rays may be used to produce a single X-ray image or may be used in computed tomography (CT scanning).

Suggest an advantage and a disadvantage of CT scanning compared with single X-ray imaging for diagnosis.

advantage: ....

....

disadvantage: ....

....

[2]

[Total: 7]

Question 8

11 **(a)** State the purpose of computed tomography (CT scanning).

....

.... [1]

(b) Outline the principles of CT scanning.

....

....

....

....

....

....

....

....

....

.... [5]

[Total: 6]

Question 9

11 **(a)** State how, in a modern X-ray tube, the intensity of the X-ray beam and its hardness are controlled.

intensity: ....

....

hardness: ....

....
[2]

(b) A model of a limb consists of soft tissue and bone, as illustrated in Fig. 11.1.

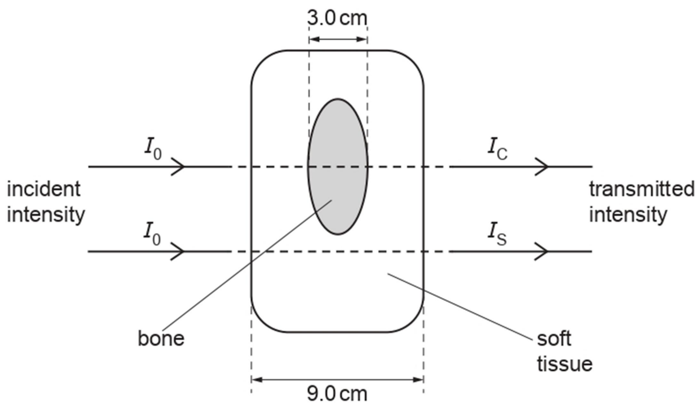

Fig. 11.1

The soft tissue has a thickness of 9.0 cm. The bone within the soft tissue has a thickness of 3.0 cm.

Data for the linear attenuation (absorption) coefficient μ of X-rays in soft tissue and in bone are shown in Table 11.1.

Table 11.1

	μ / cm^{-1}
soft tissue	0.92
bone	2.9

A parallel beam of X-rays of intensity I_0 is incident normally on the model.

Calculate, in terms of I_0:

(i) the transmitted intensity I_S through soft tissue alone

I_S = ... I_0 [2]

(ii) the transmitted intensity I_C through soft tissue and bone.

I_C = ... I_0 [2]

(c) By reference to your answers in **(b)**, suggest, with a reason, whether good contrast on an X-ray image would be obtained.

....

.... [1]

[Total: 7]

Question 10

11 **(a)** Electrons are accelerated through a potential difference of 15 kV. The electrons collide with a metal target and a spectrum of X-rays is produced.

(i) Explain why a continuous spectrum of energies of X-ray photons is produced.

....

....

....

....

.... [3]

(ii) Calculate the wavelength of the highest energy X-ray photon produced.

wavelength = ... m [3]

(b) A beam of X-rays has an initial intensity I_o. The beam is directed into some body tissue. After passing through a thickness x of tissue the intensity is I. The graph in Fig. 11.1 shows the variation with x of ln (I/I_o).

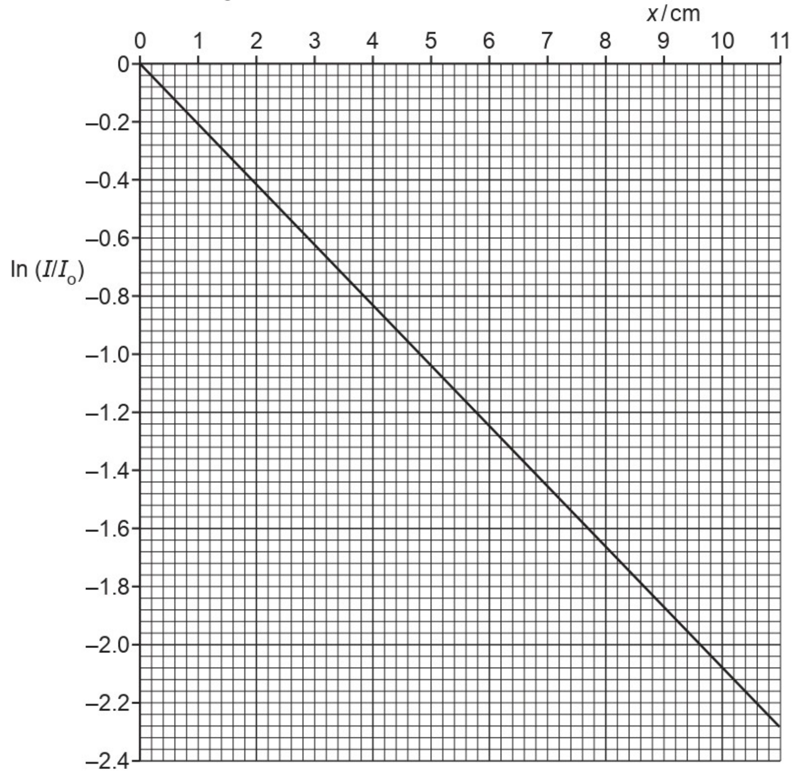

Fig. 11.1

(i) Determine the linear attenuation (absorption) coefficient μ for this beam of X-rays in the tissue.

μ = ... cm^{-1} [2]

(ii) Determine the thickness of tissue that the X-ray beam must pass through so that the intensity of the beam is reduced to 5.0% of its initial value.

thickness = ... cm [2]

[Total: 10]

Question 11

7 Electrons in a beam are travelling at high speed in a vacuum. The electrons are incident on a metal target, causing X-ray radiation to be emitted.

The variation with wavelength λ of the intensity I of the emitted X-ray radiation is shown in Fig. 7.1.

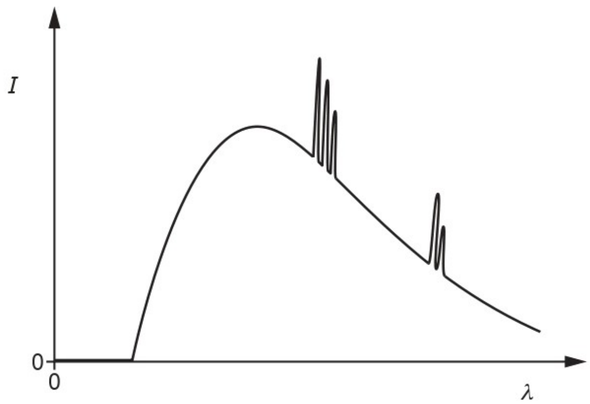

Fig. 7.1

Explain why:

(a) there is a continuous distribution of wavelengths

....

....

....

....

.... [3]

(b) at certain wavelengths, there are narrow peaks of increased intensity.

....

....

....

....

.... [3]

[Total: 6]

Question 12

10 (a) Outline briefly the principles of computed tomography (CT scanning).

....

....

....

....

....

....

....

....

....

.... [5]

(b) One section of a model designed to illustrate CT scanning is divided into four voxels.
The pixel numbers K, L, M and N of the voxels are shown in Fig. 10.1.

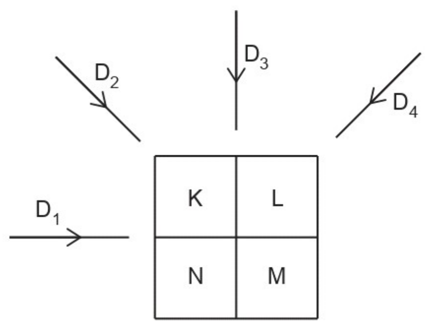

Fig. 10.1

The section is viewed, in turn, from four different directions D_1, D_2, D_3 and D_4, as shown in Fig. 10.1.

The detector readings for each direction are noted and these are summed to give the values shown in Fig. 10.2.

42	45
51	30

Fig. 10.2

The background reading is 24.

Determine the pixel numbers K, L, M and N shown in Fig. 10.1.

K = ...

L = ...

M = ...

N = ...
[3]

[Total: 8]

Question 13

5 (a) Explain the principles of the **detection** of ultrasound waves for medical diagnosis.

....

....

....

....

....

....

....

.... [4]

(b) By reference to specific acoustic impedance, explain why there is very little transmission of ultrasound waves from air into skin.

....

....

....

....

....

.... [3]

[Total: 7]

Question 14

4 (a) (i) By reference to an ultrasound wave, explain what is meant by *specific acoustic impedance*.

....

....

.... [2]

(ii) An ultrasound wave is incident normally on the boundary between two media. The media have specific acoustic impedances Z_1 and Z_2.

State how the ratio

$$\frac{\text{intensity of ultrasound reflected from boundary}}{\text{intensity of ultrasound incident on boundary}}$$

depends on the relative magnitudes of Z_1 and Z_2.

....

....

....

.... [2]

(b) (i) State what is meant by the *attenuation* of an ultrasound wave.

....

.... [1]

(ii) A parallel beam of ultrasound is passing through a medium.
The incident intensity I_0 is reduced to $0.35I_0$ on passing through a thickness of 0.046 m of the medium.

Calculate the linear attenuation coefficient μ of the ultrasound beam in the medium.

μ = ... m^{-1} [2]

[Total: 7]

\

Question 15

4 (a) (i) Explain why ultrasound used in medical diagnosis is emitted in pulses.

....

....

.... [2]

(ii) Explain the principles of the **detection** of ultrasound waves used in medical diagnosis.

....

....

....

....

.... [3]

(b) The specific acoustic impedances Z of some media are given in Table 4.1.

Table 4.1

media	Z / kg m^{-2} s^{-1}
air	4.3×10^2
gel	1.5×10^6
soft tissue	1.6×10^6

(i) The specific acoustic impedances of two media are Z_1 and Z_2. The intensity reflection coefficient α for the boundary of these two media is given by:

$$\alpha = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}.$$

Calculate, to three significant figures, the fraction of the ultrasound intensity that is reflected at a boundary between air and soft tissue.

α = ... [1]

(ii) Use your value in **(b)(i)** to explain why gel is applied to the surface of the skin during an ultrasound scan.

....

....

....

....

....

.... [2]

[Total: 8]

Question 1

8(a)(i)	specific acoustic impedance = 1200 × 1400 = 1.68 × 10^6 kg m^{-2} s^{-1}	**A1**
8(a)(ii)	density of air shown in table as 1.29	**A1**
	speed of sound in tissue shown in table as 1540	**A1**
8(b)(i)	intensity reflection coefficient = $(Z_1 - Z_2)^2 / (Z_1 + Z_2)^2$ = $(1680000 - 440)^2 / (1680000 + 440)^2$	**C1**
	= 0.999	**A1**
8(b)(ii)	intensity reflection coefficient = $(Z_1 - Z_2)^2 / (Z_1 + Z_2)^2$ = $(1680000 - 1680000)^2 / (1680000 + 1680000)^2$ = 0	**A1**
8(c)	without gel, (almost) all of the (incident) ultrasound is reflected (from skin)	**B1**
	with gel, (almost) all of the (incident) ultrasound is transmitted (into the body)	**B1**

Question 2

9(a)	piezo-electric crystal	**B1**
	(ultrasound) wave causes shape change / vibrations (of crystal)	**B1**
	shape change / vibrations causes e.m.f. (which is detected)	**B1**
9(b)(i)	93 V	**A1**
9(b)(ii)	2.7 × 10^7 rad s^{-1}	**A1**
9(c)(i)	kg m^{-2} s^{-1}	**B1**
9(c)(ii)	$\rho = Z / c$ = 1.7 × 10^6 / 1600 = 1100 kg m^{-3}	**A1**
9(c)(iii)	intensity reflection coefficient ≈ 1 **or** Z_1 and Z_2 are very different	**B1**
	almost no / no ultrasound transmitted (into air filled cavity)	**B1**

Question 3

10(a)(i)	introduction of tracer (into the body)	**M1**
	containing a β^+ emitter	**A1**
10(a)(ii)	positron interacts with electron	**B1**
	(pair) annihilation occurs	**B1**
	mass of particles converted into gamma photons	**B1**
10(b)	(annihilation of electron and positron) produces two photons	**B1**
	$E = (\Delta)mc^2$	**B1**
	$E = hf$ **and** $f = c / \lambda$ **or** $E = hc / \lambda$	**B1**
	λ = {[2×] 6.63 × 10^{-34} × 3.00 × 10^8} / {[2×] 9.11 × 10^{-31} × (3.00 × 10^8)^2} = 2.4(3) × 10^{-12} m or 2.4(3) pm (*full substitution and answer with unit needed*)	**B1**

Question 4

9(a)(i)	electrons are accelerated (by an applied p.d.)	**B1**
	electrons hit target	**B1**
	X-rays produced when electrons decelerate	**B1**
9(a)(ii)	images of the multiple sections are combined to create a 3-D image	**B1**
9(b)(i)	$I = I_0 \exp(-\mu x)$	**C1**
	$= I_0 \exp(-0.89 \times 5.6)$ $= 0.0068\ I_0$	**A1**
9(b)(ii)	$I = I_0 \exp(-2.4 \times 3.4) \times \exp(-0.89 \times 3.2)$	**C1**
	$= 1.7 \times 10^{-5}\ I_0$	**A1**
9(c)	comparison of intensities or values in **(b)** leading to conclusion consistent with these values	**B1**

Question 5

10(a)	energy = mcΔT	**C1**
	energy = ItV $(\Delta T =) \dfrac{0.40 \times 0.020 \times 75\ 000 \times 0.95}{0.015 \times 130}$	**C1**
	=290 K	**A1**
10(b)	$I = I_o e^{-\mu t}$ $0.20 = e^{-0.22t}$	**C1**
	t = 7.3 cm	**A1**
10(c)	*either* (linear) attenuation coefficients / μ very different for bone and muscle	**M1**
	(very) different amounts (of X-rays) absorbed so good contrast or (very) different intensities transmitted so good contrast	**A1**
	or (linear) attenuation coefficients / μ similar for blood and muscle	**(M1)**
	similar amounts (of X-rays) absorbed so poor contrast or similar intensities transmitted so poor contrast	**(A1)**

Question 6

11(a)	substance containing radioactive nuclei that is introduced into the body *or* substance containing radioactive nuclei that is absorbed by the tissue being studied	**B1**
11(b)(i)	a particle interacting with its antiparticle so that mass is converted into energy	**B1**
11(b)(ii)	electron(s) and positron(s)	**B1**
11(c)(i)	$E = 2mc^2$ $= 2 \times 9.11 \times 10^{-31} \times 3.00 \times 10^{-82}$ $= 1.64 \times 10^{-13}$ J	**A1**
11(c)(ii)	$\lambda = \frac{2hc}{E}$ $= \frac{2 \times 6.63 \times 10^{-34} \times 3.00 \times 10^8}{1.64 \times 10^{-13}}$	**C1**
	$= 2.43 \times 10^{-12}$ m	**A1**
11(d)	Any 3 from: • the two gamma photons travel in opposite directions • gamma photons detected (outside body / by detectors) • gamma photons arrive (at detector) at different times • determine location of production (of gamma) • image of tracer concentration in tissue produced	**B3**

Question 7

11(a)(i)	ease with which edges can be distinguished	**B1**
11(a)(ii)	difference in degrees of blackening	**B1**
11(b)	$I = I_0 \exp(-\mu x)$	**C1**
	$0.12 = \exp(-\mu \times 2.3)$ $\ln 0.12 = -2.3 \times \mu$	**C1**
	$\mu = 0.92$ cm^{-1}	**A1**
11(c)	advantage: produces 3-dimensional image	**B1**
	disadvantage: (much) greater exposure to radiation	**B1**

Question 8

11(a)	to produce a 3-dimensional image of structure/body	**B1**
11(b)	X-rays (are used)	**B1**
	scanning in sections	**B1**
	scanning from many angles	**B1**
	image of each section is 2-dimensional	**B1**
	scanning repeated for many sections **or** images of many sections combined together	**B1**

Question 9

11(a)	intensity: vary filament current/p.d. across filament	**B1**
	hardness: vary accelerating potential difference	**B1**
11(b)(i)	$I = I_0 e^{-\mu x}$	**C1**
	$I_S = I_0 \exp(-0.92 \times 9.0)$ $= 2.5 \times 10^{-4} I_0$	**A1**
11(b)(ii)	$I_C = [\exp(-0.92 \times 6.0) \times \exp(-2.9 \times 3.0)] I_0$	**C1**
	$= 6.7 \times 10^{-7} I_0$	**A1**
11(c)	conclusion consistent with values in **(b)(i)** and **(b)(ii)** e.g. $I_S \gg I_C$ so good contrast	**B1**

Question 10

11(a)(i)	electrons decelerate (on hitting target) so X-ray photons produced	**B1**
	range of decelerations	**B1**
	photon energy depends on (magnitude of) deceleration	**B1**
11(a)(ii)	$eV = \frac{hc}{\lambda}$	**C1**
	$\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{1.6 \times 10^{-19} \times 15000}$	**C1**
	$= 8.3 \times 10^{-11} m$	**A1**
	or *E* = *hf* <u>and</u> *c* = *f*λ <u>and</u> electron energy = eV *or* *E* = *hc* / λ <u>and</u> electron energy = eV electron energy = $1.6 \times 10^{-19} \times 15000$ $= 2.4 \times 10^{-15}$	**(C1)**
	$\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{2.4 \times 10^{-15}}$	**(C1)**
	$\lambda = 8.3 \times 10^{-11} m$	**(A1)**
11(b)(i)	μ = – gradient *or* ln $(I / I_o) = -\mu x$	**C1**
	(e.g. 2.08 / 10.0) = **0.21** cm^{-1}	**A1**
11(b)(ii)	$\ln(0.05) = -\mu x$	**C1**
	$x = \frac{\ln 0.05}{-\mu}$ $e.g. x = 14 cm$	**A1**

Question 11

7(a)	X-ray photon produced when electron is decelerated	**B1**
	larger acceleration results in larger photon energy	**B1**
	continuous range of accelerations so continuous spectrum of wavelengths/frequencies	**B1**
7(b)	electron in (inner shell of) target atom is excited (on collision)	**B1**
	electron de-excites causing emission of a photon	**B1**
	discrete energy levels so discrete photon wavelengths	**B1**

Question 12

10(a)	X-rays are used	**B1**
	section (of object) is scanned	**B1**
	scans/images taken at many angles/directions **or** images of each section are 2-dimensional	**B1**
	(images of (many)) sections are combined	**B1**
	(to give) 3-dimensional image of (whole) structure	**B1**
10(b)	K = 6 L = 7 M = 2 N = 9 3 marks: all four correct 2 marks: three correct and one incorrect **or** all correct with two numbers transposed 1 mark: two correct and two incorrect	**B3**

Question 13

5(a)	pulses of ultrasound	**B1**
	ultrasound incident on quartz crystal	**B1**
	waves make crystal oscillate	**B1**
	oscillations (of crystal) generates an e.m.f. (across the crystal)	**B1**
5(b)	specific acoustic impedances of air and skin are very different	**B1**
	intensity reflection coefficient depends on difference between acoustic impedance	**B1**
	most ultrasound reflected so little transmission	**B1**

Question 14

4(a)(i)	product of density and speed	**M1**
	speed of ultrasound in medium	**A1**
4(a)(ii)	the greater the difference between Z_1 and Z_2, the closer the ratio is to 1 **or** if difference between Z_1 and Z_2 large, ratio is close to 1	**B1**
	the closer together Z_1 and Z_2, the closer the ratio is to 0 **or** if difference between Z_1 and Z_2 small, ratio close to 0	**B1**
4(b)(i)	loss of intensity/amplitude/power (of the wave)	**B1**
4(b)(ii)	$I = I_0 e^{-\mu x}$	**C1**
	$0.35 = e^{-0.046\mu}$ $\mu = 23\ m^{-1}$	**A1**

Question 15

4(a)(i)	Any 2 from: • allows the reflected signal to be distinguished from the emitted signal • detection occurs in the time between emitted pulses • (reflection of ultrasound) detected by same probe / transducer / crystal • cannot emit and detect at same time (hence pulses)	**B2**
4(a)(ii)	piezo-electric crystal	**B1**
	ultrasound makes crystal vibrate / resonate	**B1**
	vibration produces (alternating) e.m.f. / p.d. across crystal	**B1**
4(b)(i)	$= (1.6 \times 10^6 - 4.3 \times 10^2)^2 / (1.6 \times 10^6 + 4.3 \times 10^2)^2$ = **0.999**	**B1**
4(b)(ii)	without the gel most of the ultrasound is reflected	**B1**
	Z values more similar / α reduces so less (ultrasound) is reflected / more (ultrasound) is transmitted	**B1**