1)

Question			Answer	Marks	Guidance
	(a)		Quantum / packet of (electromagnetic) energy Any one from: Can travel in a vacuum / has speed of 3×10^8 m s^{-1} in a vacuum / has no charge / has no (rest) mass / causes ionisation / has momentum	B1 B1	**Allow**: Particle of energy **Allow**: Travels at the speed of light / *c* in a vacuum
	(b)	(i)	number per second = $4.8 \times 10^{-3}/1.6 \times 10^{-19}$ number per second = 3.0×10^{16} s^{-1}	M1 A0	**Note**: This must be seen to gain a mark
		(ii)	(incident power =) $150 \times 10^3 \times 4.8 \times 10^{-3}$ or (incident power =) $3.0 \times 10^{16} \times 150 \times 10^3 \times 1.6 \times 10^{-19}$ ($P = mc[\Delta\theta/\Delta t]$) $0.99 \times 720 = 0.0086 \times 140 \times [\Delta\theta/\Delta t]$ rate of temperature increase = 590 (°C s^{-1})	C1 C1 A1	**Note** an incident power of 720 (W) scores this C1 mark **Note**: Answer to 3 sf is 592 (°C s^{-1}) **Allow**: 2 marks for 598 (°C s^{-1}) or 600 (°C s^{-1}); 99% omitted **Allow**: 2 marks for 1.97×10^{-14} (°C s^{-1}); 3.0×10^{16} omitted
		(iii)	(photon energy = maximum KE of electron) $E = 150 \times 10^3 \times 1.6 \times 10^{-19}$ or $E = 2.4 \times 10^{-14}$ (J) $2.4 \times 10^{-14} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{\lambda}$ (Allow any subject) wavelength = 8.3×10^{-12} (m)	C1 A1	**Allow**: $E = 720/3.0 \times 10^{16}$ **Allow**: 1 mark 8.3×10^{-10} (m); $E = 2.4 \times \underline{10^{-16}}$ (J) used
	(c)		Contrast material / iodine is injected (into the vessels) Any one from: The contrast material • large attenuation / absorption coefficient • has high *Z* (atoms) (and hence reveal the outline of the blood vessels)	B1 B1	**Not**: barium for this B1 mark **Not** 'large μ'
			Total	**10**	

2)

Question			Answers	Marks	Guidance
	(a)	(i)	Discrete energy (of electrons in an atom) / quantised energy (of electrons in an atom) / permitted energy (states of electrons in an atom).	B1	
		(ii)	($E = \frac{hc}{\lambda}$) $E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{7.2 \times 10^{-11}}$ or $E = 2.763 \times 10^{-15}$ (J) value of energy level = - (3.2 - 2.763) $\times 10^{-15}$ (J) value of energy level = - 4.4 $\times 10^{-16}$ (J)	C1 C1 A1	**Note**: The answer must be negative to score the A1 mark **Note:** 4.4×10^{-16} (J) scores 2 marks
		(iii)	(λ_0 is) halved. Explanation: Reference to (photon / electron kinetic) energy doubled and E = hc/λ or $E \propto 1/\lambda$.	M1 A1	**Allow** explanation in terms of $eV = hc/\lambda$.
	(b)	(i)	($I = I_0 e^{-\mu x}$) fraction transmitted = $e^{-(0.96 \times 2.3)}$ fraction transmitted = 0.11 fraction absorbed or scattered = 1 – 0.11 fraction absorbed or scattered = 0.89	C1 C1 A1	**Allow** 3 marks for 89%. **Allow** 89/100
		(ii)	Bone and muscle have different (values for) μ hence better contrast. or Muscle and fat have similar (values for) μ hence poor contrast.	B1	
			Total	**10**	

3)

Question			Answers	Marks	Guidance
	(a)		Ultrasound reflected at boundary (between materials). B-scan takes place in different directions. QWC: The intensity of the reflected ultrasound depends on the acoustic impedances of the materials (and this is greater when the difference between the acoustic impedances is greater).	B1 B1 B1	**Allow** B-scan is 'multiple A-scans'. **Allow** *Z* instead of acoustic impedance. **Not** attenuation coefficient for *Z*.
	(b)		Any **four** from: 1. The brain / body is surrounded by a ring of (gamma) detectors /gamma camera(s). 2. The positrons (from the F-18 nuclei) annihilate electrons. 3. The annihilation of a positron and an electron produces two (identical gamma) photons travelling in opposite directions. 4. The delay time between these two photons / gamma rays is used to determine the location of the annihilation / F-18 / tracer. 5. Computer connected to detectors / gamma camera and an image is formed by the computer (using the electrical signals from the detectors).	B1×4	**Not** positron**s** and electron**s** annihilate to produce photons travelling in opposite directions for 3. **Allow** an answer in terms of arrival times.
			Total	**7**	

4)

Question			Answer	Marks	Guidance
	(a)		Gamma radiation will pass through the patient (and hence can be detected) / beta particles will be absorbed by the patient (and hence cannot be detected) Gamma radiation is not (very) ionising / gamma radiation does little damage to cells / beta particles are (very) ionising / beta particle damage cells	B1 B1	**Allow**: 'Body' in place of 'cells'
	(b)		X-ray tube rotates around (the patient) / X-ray beam passes through the patient at different angles A thin X-ray beam is used Image(s) of slice(s) / (cross) section(s) through the patient are taken X-ray tube moves / spirals along (the patient) The signals / information / pulses / data (from the detectors) are used by the computer (and its software) to produce a 3D image	B1 B1 B1 B1 B1	**Not**: Detector rotates around (the patient) **Allow**: Detectors moves / spirals along (the patient)
			Total	**7**	

5)

Question	Answer	Marks	Guidance
(a)	Any two from: • Can travel in a vacuum • Travel at the speed of light / c / 3×10^8 m s^{-1} in vacuum • No charge / no (rest) mass • (Highly) ionising	B1 × 2	**Not**: EM radiation / wave because not *particulate* nature **Not**: Short wavelength or high frequency **Not**: High energy photons **Not**: reflect / refract / diffract
(b)	$\frac{hc}{\lambda}$ and $E = mc^2$ $\frac{6.63\times10^{-34}\times3.0\times10^{8}}{\lambda} = 2\times9.11\times10^{-31}\times(3.0\times10^{8})^2$ wavelength = 1.2×10^{-12} (m)	C1 C1 A1	**Allow**: $\frac{hc}{\lambda}$ and 1.02 MeV or 0.51 MeV for this first C1 mark **Allow**: Correct use of mass = 0.00055 u **Allow**: 2 marks for 2.4×10^{-12} (m) for omitting factor of 2 **Note**: Using the de Broglie equation with $v = c$, also gives an answer of 2.4×10^{-12} (m); this scores zero – see below: $\lambda = \frac{h}{mv} = \frac{6.63\times10^{-34}}{9.11\times10^{-31}\times3.0\times10^{8}} = 2.4\times10^{-12}$ m scores zero
(c)	Barium / iodine (Contrast medium absorbs X-rays because it) has large attenuation coefficient / has large absorption coefficient / has large Z values Ideal for imaging the outline (of soft tissues)	B1 B1 B1	**Not**: X-rays are (easily) absorbed by the contrast material **Allow**: If there is a hole then the barium shows this up by flowing out / Barium is used to find blockage with explanation
	Total	**8**	

6)

Question	Answer	Marks	Guidance
(a)	Longitudinal (wave) Frequency (sound) ≥ 20 kHz	B1 B1	**Allow**: high frequency (sound) that cannot be heard **Allow** any value of frequency ≥ 20 kHz **Not**: It is non-ionising
(b)	Emission: (Piezoelectric film / crystal connected to an) alternating e.m.f / p.d / current making it vibrate / contract and expand / resonate (and hence emits ultrasound) (AW) Reception: (Ultrasound makes the piezoelectric film / crystal) vibrate / contract and expand / resonate and this produces (alternating) e.m.f. / p.d / current (AW)	B1 B1	**Note**: The alternating p.d. can be implied by the term *frequency* **Not** varying p.d.
(c)	Without the gel, the ultrasound would be reflected (at the skin /air interface) or The gel allows (maximum) transmission of ultrasound (into the body) Gel and skin has similar acoustic impedance / Z (values) or There is a large difference between the Z (values) of air and skin	B1 B1	**Allow**: Gel is used for impedance matching
(d)	Transducer placed at an angle to the artery / arm Ultrasound (pulses) are reflected by (moving) blood (cells) The frequency / wavelength (of ultrasound) is changed Change in frequency is related to the speed (of blood) or change in wavelength is related to the speed	B1 B1 B1 B1	**Allow**: The wavelength / frequency is Doppler shifted (AW) **Allow**: $\frac{\Delta f}{f} = \frac{2v\cos\theta}{c}$ where c is the speed of ultrasound and v is the speed of blood; no need to define the angle
	Total	**10**	

7)

Question			Expected Answer	Mark	Additional Guidance
	(a)		The application of a p.d. across a material / crystal causes an expansion / contraction / vibration (ora)	B1	**Allow**: reference to 'current' instead of p.d / e.m.f
	(b)		Any two from: • Pulses of ultrasound (sent into the body) • Wave / ultrasound / pulse / signal is reflected (at boundary of tissue) • Time of delay used to determine depth / thickness • The fraction of reflected signal is used to identify the tissue A-scan in one direction only / range or distance or depth finding B-scan uses a number of sensors or a sensor in different positions / angles (to build up a 2D/3D image)	B1 × 2 B1 B1	**Allow**: The reflected signal / ultrasound /amplitude / intensity is used to identify the tissue **Not**: 'B-scan is many A-scans'
	(c)	(i)	$Z = \rho c$; density → kg m^{-3} and speed → m s^{-1} (Hence Z → kg m^{-2} s^{-1})	M1 A0	
		(ii)	fraction = $\frac{(7.14-1.72)^2}{(7.14+1.72)^2}$ fraction = 0.37(4)	C1 A1	**Allow**: 37 %
		(iii)	(Acoustic) impedances of media are similar / identical No / reduced reflection (at boundary) Or The gel allows maximum transmission of ultrasound (into the body)	B1 B1	**Allow**: 'The Zs are the same'
		(iv)	$v = f\lambda$ wavelength = $\frac{1590}{1.2\times10^6}$ ($=1.33\times10^{-3}$ m) (Any subject) wavelength = 1.33 (mm)	 C1 A1	**Allow**: 1 mark for '4080/1.2 × 10^6 = 3.4 mm'
		(v)	Small wavelength means finer detail can be seen / greater resolution	B1	
			Total	13	

8)

Question			Expected Answer	Mark	Additional Guidance
	(a)		Any five from: 1. Intensifier used as X-ray would pass through film 2. Intensifier converts X-ray photon to many visible (light) photons (which are absorbed by film) 3. *Lower exposure / fewer X-rays needed 4. Iodine / barium (used as contrast material) 5. *High Z number / large attenuation coefficient / large absorption coefficient (used to improve image contrast) 6. Contrast media are ingested / injected into the body 7. *Scan shows outline / shape of soft tissue QWC mark is acquired from clear expression of any of the marking points 3, 5 or 7	B1 × 5	
	(b)		X-rays produce visible light or In photoelectric effect electrons are emitted	B1	
	(c)	(i)	Any two from: • Simple X-ray is one directional / produces single image • CT image(s) taken at different angles / X-ray tube is rotated • Computer processes data / image constructed from many slices	B1 × 2	
		(ii)	Any two from: 1. X-ray image is 2D / CT scan produces 3D image 2. Greater detail / definition / contrast with CT scan / 'soft tissues can be seen' 3. Image can be rotated	B1 × 2	
			Total	10	

9)

Question			Answers	Marks	Guidance
	(a)		Any **two** from: 1. Electrons are accelerated through high voltage 2. (High speed) electron(s) hit metal 3. kinetic energy of electron(s) 'produces' X-ray (photons)	B1×2	**Allow**: X-rays are produced by (large) deceleration of electrons
	(b)	(i)	Packet /quantum of (electromagnetic) energy	B1	**Allow**: 'particle of (electromagnetic) energy'
		(ii)	$E = hc/\lambda$ and X-rays have shorter wavelength Or $E = hf$ and X-rays have higher frequency	B1	
	(c)		(KE of electron =) $1.6\times10^{-19}\times120\times10^{3}$ $eV = \frac{hc}{\lambda}$ $1.6\times10^{-19}\times120\times10^{3} = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{\lambda}$ wavelength = 1.0×10^{-11} (m) or 1.04×10^{-11} (m)	C1 C1 A1	**Allow**: 2 marks for $1.0(4)\times10^{-n}$ (m) ($n \neq 11$ - powers of ten error) **Allow**: 1×10^{-11} (m)
	(d)		Compton (scattering) Incoming photon collides with an electron, the electron is ejected and the photon is scattered / has lower energy Or Pair production Incoming photon (disappears and) produces electron-positron pair	M1 A1 --- M1 A1	**Must use ticks on Scoris to show where the marks are awarded** **Allow**: (Simple) scatter(ing) M1 The photon is absorbed and re-emitted without change in energy/wavelength/frequency A1
			Total	**9**	

10)

Question			Answers	Marks	Guidance
	(a)		No entry into body / no cutting/incision of patient / no surgery Lower risk of infection / less trauma	B1 B1	
	(b)		Radioactive substance that is ingested / injected (into patient) Technetium(-99m) / Iodine(-131) / fluorine(-18)	B1 B1	**Not**: barium
	(c)		**Collimator** – gamma (ray photons) travel along the axis of lead tubes or allows parallel gamma (ray photons travel to the scintillator) Having thin / long / narrow (lead) tubes makes the image sharper / less blurred (**QWC mark**) **Scintillator** – gamma ray photon produces many/thousands of photons of (visible) light **Photomultiplier** - An electrical pulse is / electrons are produced from the light (photons) **Computer** – Signals (from photomultiplier tubes) are used to produce an image	B1 B1 B1 B1 B1	**Must use ticks on Scoris to show where the marks are awarded**
	(d)	(i)	$v = f\lambda$ $1500 = 2.0\times10^{6}\times\lambda$ wavelength = 7.5×10^{-4} (m)	C1 A1	
		(ii)	Ultrasound is reflected by (moving) blood (cells) The frequency / wavelength (of ultrasound) is changed (AW) The change of frequency is related to speed of blood / change of wavelength is related to speed of blood / 'Δfrequency $\propto$ speed of blood'	B1 B1 B1	**Must use ticks on Scoris to show where the marks are awarded** **Not**: Doppler effect mentioned
			Total	**14**	

11)

Question			Answer	Marks	Guidance
	(a)		Any two from: (X-rays) are EM waves Travel at speed of light / 3×10^8 ms^{-1} (in a vacuum) Travel in a vacuum / empty space Transverse waves Can cause ionisation Have wavelength of about 10^{-10} m (X-rays are high energy) photons (AW)	B1×2	**Allow**: reference to diffraction / interference / refraction / reflection / polarisation for 1 mark
	(b)		(X-ray) photon interacts with an (orbital) electron The (scattered) photon has a longer wavelength / lower frequency / lower energy **AND** The electron is ejected (from the atom at high speed)	B1 B1	**Allow**: 'X-rays' instead of 'photons' for the second B1 mark
	(c)	(i)	Initial / original / incident intensity	B1	**Allow**: Initial / original / incident power per (unit) area
		(ii)	$0.5 = e^{-(3.3x)}$ $\ln(0.5) = -3.3x$ $x = \ln(0.5)/(-3.3)$ $x = 0.21$ (cm)	C1 C1 A1	**Allow**: $\ln(2) = 3.3x$ **Allow**: 2 marks for 2.1×10^n; $n \neq -1$ (POT error)
	(d)		A contrast material has large attenuation coefficient / large atomic number / large Z (and hence easily absorbs X-rays) Idea of revealing tissue	B1 B1	
			Total	**10**	

12)

Question			Expected Answers	Marks	Additional guidance
	(a)		Less chance of infection	B1	
	(b)		Any two from: 1. Tracer is injected into the body / placed inside the body / circulates the body 2. Tracer is absorbed by organ / shows blockage 3. Beta detector / gamma camera (is used to detect radiation from the body)	B1×2	**Note:** No marks for ingesting substances (e.g barium)
	(c)		Any five from: 1. A positron / beta-plus emitting tracer / source is used 2. The positron annihilates with an electron (inside the patient) 3. This produces two gamma photons 4. The photons travels in opposite directions 5. The patient is surrounded by a ring of gamma detectors 6. The arrival times of the photons / delay time indicates location (of tumour inside the body) 7. A 3-D image is created (by the computer connected to the detectors)	B1×5	
			Total	**8**	

13)

Question			Expected Answers	Marks	Additional guidance
	(a)		Any three from 1 to 4: 1. A (piezoelectric) crystal / transducer is used to send pulse(s) of ultrasound (into the patient) 2. Wave / ultrasound / pulse / signal is reflected (at the boundary of tissue) 3. The (intensity of the) reflected signal depends on the acoustic impedances (at the boundary) 4. The (time of) delay is used to determine the depth / thickness ✎ QWC: Award a mark for correct sequencing of the steps in the process	B1×3 B1	**Must use ticks on Scoris to show where the marks are awarded** **Allow:** $\frac{I_{(r)}}{I_0}=\frac{(Z_2-Z_1)^2}{(Z_2+Z_1)^2}$ without symbols defined for the 3rd marking point **Note**: Do not allow marking points 2 or 3 for gel-skin interface
	(b)		A-scan is one directional / B-scan involves different directions or angles / B-scan consists of many A-scans / B-scan produces 2-D or 3-D image	B1	
			Total	**5**	

14)

Question			Expected Answers	Marks	Additional Guidance
	a		ANY ONE from X-rays interact with matter by: the photoelectric effect where an (orbital) electron is ejected from atom / atom is ionised Compton scattering where X-ray scattered by the interaction with (orbital) electron Pair production where X-ray photon interacts with the nucleus / atom and an electron and positron are produced [allow one mark for statement and one for explanation] **Max 2**	 **(B2)** **(B2)** **(B2)** **B2**	 Allow electrons ejected from metal surface if reference is made to free electrons Allow: X-ray diffraction **B1** X-ray passes through the 'slits' / atomic gap formed by the atoms **B1**
	b		$I = I_0e^{-\mu x}$ $0.1 = e^{-\mu 3}$ $0.5 = e^{-\mu x}$ ln 0.5 / ln0.1 = x/3 x = 0.903 (mm)	**C1** **C1** **A1**	Calculation of μ =0.768 C1 Substitution into second equation C1 Allow 0.9 (1sf) If question misread and 0.9 used for change μ = 0.035 and x = 19.7 (allow 20) give 2/3
	c	(i)	Absorption of X-rays by (silver halide molecules) by a photographic film Uses of fluorescent / scintillator/ phosphor Photon releases electron (that is accelerated onto a fluorescent screen) number of electrons increased /multiplied **MAX B2** QWC: Phosphor / Intensifier/ it converts X-ray photon into increased number of 'visible' photons	**(B1)** **(B1)** **(B1)** **(B1)** **B2** **B1**	

		(ii)	Different soft body tissue produce little difference in contrast/attenuation (Contrast media with) high atomic number / Z used / iodine or barium (used to give greater contrast) liquids injected or swallowed into soft tissue areas / or examples of such **MAX B2**	(B1) (B1) (B1) B2	This method produces good contrast for soft tissue /for similar Z values
			Total	**[10]**	

15)

Question			Answer	Marks	Guidance
	(a)		(Fast-moving) electrons hit a metal / an anode The kinetic energy of the electrons is transferred into X-rays / photons / EM waves	B1 B1	**Allow**: (X-rays are produced by large) deceleration of electrons
	(b)		An X-ray photon interacts an electron (within the atom) The electron is ejected and the energy / frequency of the (scattered) photon is reduced	B1 B1	**Allow**: The electron is ejected and the wavelength of the (scattered) photon is increased
	(c)	(i)	$I = I_0 e^{-\mu x}$ $I = 3.0 \times 10^9 \times e^{-(6.5 \times 1.7)}$ intensity = 4.8×10^4 (W m^{-2})	C1 C1 A0	
		(ii)	power of beam = $4.8 \times 10^4 \times 5.0 \times 10^{-6}$ (= 0.24 W) power absorbed by tumour = 0.24/10 = 0.024 (W) time = 200/0.024 time = 8.3×10^3 (s)	C1 C1 A1	Possible ecf from **(c)(i)** **Allow**: 2 marks for 8.3×10^2 (s) if 10% is omitted **Note**: Using 5×10^4 (W m^{-2}) gives an answer of 8000 (s)
	(d)		X-ray beam passes through the patient at different angles / X-ray tube rotates around the patient A thin fan-shaped beam is used (AW) Images of 'slices' through the patient (in one plane are produced with the help of computer software) X-ray tube / detectors are moved along (the patient for the next slice through the patient) Advantage: 3D image / better contrast between different (soft) tissues	B1 B1 B1 B1 B1	
			Total	**14**	