Mark scheme – Medical Imaging

Question			Answer/Indicative content	Marks	Guidance
1			B	1	
			Total	**1**	
2			D	1	
			Total	**1**	
3			The material expands or contracts when a p.d. is applied across its opposite faces.	B1	**Allow**: When a p.d. is applied across its opposite faces the material expands or contracts.
			Total	**1**	
4			All except pair production / PP	B1	**Allow** PE, S and C
			Total	**1**	
5			**C**	1	
			Total	**1**	
6			**A**	**1**	<u>**Examiner's Comments**</u> The majority of the candidates did get the correct answer **A**. A significant number of candidates opted for **C**, confusing contrast material with medical tracers.
			Total	**1**	
7			**B**	**1**	
			Total	**1**	
8			**B**	**1**	
			Total	**1**	
9			**D**	1	
			Total	**1**	
10			A	1	
			Total	**1**	
11			A	1	
			Total	**1**	
12			D	1	
			Total	**1**	
13			A	1	

			Total	**1**	
14			B	1	**Examiner's Comments** The correct response is **B**. The formula booklet is pretty essential here as the ultrasound reflection formula is one of the least memorable. Although there are a couple of stages to this calculation, most candidates were able to answer this correctly and this suggests a confidence (and perhaps suitable practice) in this topic. However, and unusually, some candidates did not provide a response to this question. **OCR support** An awareness of the Data, Formulae and Relationship booklet and its content and structure is valuable here, avoiding the need to recall potentially complex formulae. Candidates can save themselves time by using the booklet frequently in preparation for the examination and thereby gain an appreciation of its value.
			Total	**1**	
15			B	1	
			Total	**1**	
16			Simple scatter: X-ray (photon) is scattered by an atomic electron.	B1	
			Pair production: An X-ray (photon) transforms into an electron and positron pair.	B1	
			Total	**2**	
17			Piezoelectric (effect) mentioned An alternating p.d. applied to the film / crystal produces vibrations / resonance (and this in turn produces ultrasound)	B1 B1	**Allow** 'applied p.d. changes the shape of a crystal / film' **Allow** alternating current / a.c. **Allow** expand and contract for vibrations (AW) **Allow** a named film / crystal **Examiner's Comments** Many candidates showed good knowledge of the piezoelectric effect. A significant number of candidates incorrectly believed that the vibrations of the piezoelectric film, or the crystal, were because of a steady

					potential difference applied to its end; a very high frequency alternating e.m.f. is required to force the crystal to oscillate. The modal score for this question was 2 marks.
			Total	**2**	
18			• <u>Pulses</u> (of ultrasound waves) are aimed at / reflected from the (moving) blood (cells in the artery). • The probe / transducer is placed at an angle (usually 600) (to the artery) • The (detected) frequency of <u>returning/reflected</u> waves is different to that of the emitted waves. • (Knowing the speed of ultrasound in blood and) the <u>ratio</u> of the frequencies enables the speed (of blood flow) to be calculated/**AW**	B1 x 2	**Max** 2 marks from 4 marking points **Allow** ultrasound is emitted at an angle **Allow** there is a change in frequency when the wave is reflected **Allow** v found using formula $\Delta f = 2fv\cos\theta/c$ with c defined as velocity of (ultra)sound (in the medium) **not** light **<u>Examiner's Comments</u>** There were 4 opportunities to score marks here, so most candidates were able to score at least one. The most usual marks to be scored were about the probe being placed at an angle, and that the frequency of the reflected wave was different from that of the emitted wave.
			Total	**2**	
19			(special coupling) gel is used that has the same /'matching' (acoustic) impedance as skin / body Reduced / less / zero reflection (at the skin)	B1 B1	**Allow Z** **Allow** gel **and** impedance is the same / matching for two materials / mediums **Allow** more transmission
			Total	**2**	
20			Doctors have to make difficult decisions about who can and cannot have a PET scan. Some patients will miss out on PET scans because of their location / not all patients will have access to the scans.	B1 B1	
			Total	**2**	
21			The reflection of the ultrasound produces the pulses **Q** and **R** Pulses **Q** and **R** are due to reflections from the front and back of the clot	B1 B1	
			Total	**2**	

22			Emits gamma (photons / radiation / waves / rays) Any **one** from: (Diagnosing the) function of organ Detecting tumour Small half-life (Gamma rays) can be detected outside body / passes through patient / least ionising Position of tracer located	B1 B1	**Not** injected into a patient / non-invasive **Allow** for half-life is a few hours
			Total	**2**	
23			CAT (CT) scan Any <u>one</u> from • A CAT scan will give 3D image • A CAT scan gives better contrast	M1 A1	Insufficient: more detail / clearer image **<u>Examiner's Comments</u>** Many candidates used a technique that did not use X-rays (such as ultrasound) so could score no marks. Those that correctly identified the CAT scan did, in general, identify a correct advantage. Answers which were vague (along the lines of clearer) could not be credited. This question is directly from the learning outcome 6.5.1(g)
			Total	**2**	
24			The fraction *f* of the incident intensity of ultrasound reflected at the boundary is given $f = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$	B1	
			There is reflection when $Z \neq 2.5 \times 10^6$ (kg m^{-2} s^{-1})	B1	
			At $Z = 2.5 \times 10^6$ (kg m^{-2} s^{-1}) there is impedance (acoustic) matching and hence no reflection of ultrasound.	B1	
			Total	**3**	
25			Electron removed / ejected (from atom) <u>Photon</u> (scattered with) increased wavelength / lower frequency / lower energy	B1 B1	Needs a comparative statement **<u>Examiner's Comments</u>** While many candidates were aware of the Compton effect and were able to give some description, the lack of use of appropriate scientific terminology meant that some were unable to score any marks. The first marking point requires it to be clear that an electron is removed from the atom. A significant number of candidates described this in terms of moving shells, or excitation. The second marking point required the candidate to express that the photon had a

					lower energy (or equivalent) which again was often answered carelessly. Despite some good general descriptions, over half the candidates did not achieve a mark on this question. **Misconception** As the Compton effect is further evidence for the particulate nature of light, it is important that this description is given in terms of photons. Several candidates gave an otherwise good description but gave it in terms of waves.
			Total	**2**	
26			density (of tissue) **or** speed (of ultrasound in tissue) **or** acoustic impedance mentioned Same Z, no reflection / different Z gives reflection $I_r/I_0 = [Z_1 - Z_2]^2/[Z_1 + Z_2]^2$ **and** intensity mentioned	B1 B1 B1	**Not** ρ **or** c **or** Z **Allow** same Z, total transmission / different Z gives some transmission **Allow** fraction of intensity reflected = $(Z_1 - Z_2)^2/(Z_1 + Z_2)^2$ **<u>Examiner's Comments</u>** The majority of the candidates scored a mark for mentioning acoustic impedance of the tissues. This term was confused with attenuation coefficient (from X-rays) by some of the candidates. Examiners could not give any credit if this confusion was evident in the answers. A pleasing number of candidates knew that the reflection of ultrasound at the boundary was significant when the difference in the acoustic impedances was large, or the equivalent, that there was no reflection when the acoustic impedances matched. For many candidates, it was the difference in density of the tissues, and not acoustic impedance, that governed the fraction of the reflected intensity at the boundary. Only a small percentage of the candidates omitted this question.
			Total	**3**	
27			$\frac{hc}{\lambda} = 2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^{8})^2$	C1	

			$\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^{8})^{2}}$	C1	
			$\lambda = 1.2 \times 10^{-12}$ (m)	A1	**Allow** 2 marks for 2.4×10^{-12} (m); factor of 2 omitted in the first line.
			Total	**3**	
28			(Evacuated tube with) cathode / heater / filament **and** target / metal / anode High voltage (supply) connected between cathode and anode (Accelerated) electrons hit the target / metal / anode and their KE is transformed into X-ray (photons)	B1 B1 B1	**Ignore** polarity of high voltage supply throughout **Note** the first two B1 marks can be scored on a labelled diagram **Allow** a specific value in the range 10 kV to 1 MV **Note** expecting 'high' or qualified by values in range above **<u>Examiner's Comments</u>** This question comes directly from the requirements of the learning outcomes 6.5.1(a) and 6.5.1(b) of the specification. In the first outcome, the basic structure of the X-ray tube outlines the components as heater (cathode), anode, target metal and high-voltage supply. Candidates generally gave poor answers with some components missed out, and quite often getting the anode and cathode very mixed up. On many scripts a cell or a battery was being used, instead of a high-voltage supply. In contrast some candidates incorrectly had a high-voltage supply connected to the heater in order to 'supply fast moving electrons released through thermionic emission'. There were missed opportunities with the explanation of the production of X-rays. Candidates did use terms such as Bremsstrahlung, but basic notion that the kinetic energy of the electrons was being used in the production of the X-ray photons eluded many candidates.
			Total	**3**	
29			(energy =) $9.11 \times 10^{-31} \times (3.0 \times 10^{8})^{2}$ (energy =) $2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^{8})^{2}$ / 1.60×10^{-19} lg1.0(2) × 10^{6} = 6 (as on graph) **OR** (energy =) 1.0×10^{6} (eV) **or** lg1.0 × 10^{6} = 6 (from graph)	B1 B1 B1 B1 B1 B1	**Note** this is 8.2×10^{-14} (J) Note this is $1.0(2) \times 10^{6}$ eV

			(energy =) 1.6×10^{-13} J **and** evidence of mc^2 $2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2 \approx 1.6 \times 10^{-13}$		**Note** this can be shown in a variety of ways
			Total	**3**	
30			**Collimator**: Allows gamma (photons) parallel to the axis of the tubes to pass through **Scintillator**: gamma (photons) produces (many) light (photons) **Photomultiplier** (tubes): light (photons) produces electrons / current / electrical pulse / p.d. / signal	B1 B1 B1	**Ignore** any other components named / described **Allow** photon / waves / rays **Allow** idea of tubes allowing the gamma (photons) to travel in the same direction **Allow** crystal (or named crystal) for scintillator **Allow** high-energy photons produce (many) low-energy photons
			Total	**3**	
31			(Pulses of) ultrasound sent into the eye Reflections from front and back of lens (and pulses displayed on oscilloscope) (Thickness of lens) determined from speed (of ultrasound) and time (difference)	B1 B1 B1	**Allow** ultrasound reflected by any part of the eye **Allow** 'sound' / wave (since ultrasound is in the question) **Ignore** transducer placed close / next to eye **Allow** thickness $= \frac{ct}{2}$ with c = speed (of ultrasound) and t = time (difference) **Allow** this mark even when the reflections are from incorrect boundaries
			Total	**3**	
32			The positrons / beta-plus particles <u>annihilate</u> electrons (within the patient) Two gamma-photons are produced these (photons / rays) travel in opposite directions The difference in the arrival times at the detectors is used to locate the point of annihilation / nuclei	B1 B1 B1 B1	**Allow** 'two gamma rays' instead of 'two gamma-photons' **Allow** gamma symbol **Allow** delay time **<u>Examiner's Comments</u>** This question covers part of the diagnostic methods in the diagnostic methods in medicine topic from module 6. This question is directly from the learning outcome 6.5.2(e). Candidates were expected to describe the basic principles of the PET scanner and use this to describe how to locate fluorine-18 nuclei. This question was poorly answered by many

					candidates and over half scored zero marks. Of that, there were a significant number who gave no response. However, there were some excellent responses that demonstrated a genuine understanding of the process. Several candidates thought that the beta-plus particles were electrons and from that point would have difficulty in making progress. The short half-life seemed to cause some confusion, and several candidates felt that this was a key part of the question. Of the candidates who explained the principles of operation clearly, some were unable to explain that it is a time difference between the arrival of the gamma rays at the detectors that is used for location.
			Total	**4**	
33			(intensity $I = I_0e^{-\mu x}$) = $4.6 \times 10^3 \times e^{-0.85 \times 2.1}$ Either: (power =) $4.6 \times 10^3 \times e^{-0.85 \times 2.1} \times 3.4 \times 10^{-4}$ Or (energy per unit area =) $4.6 \times 10^3 \times e^{-0.85 \times 2.1} \times 30$ energy = $4.6 \times 10^3 \times e^{-0.85 \times 2.1} \times 3.4 \times 10^{-4} \times 30$ energy = 7.9 (J)	C1 C1 C1 A1	intensity = 772 (W m^{-2}) power = 0.262 (W) energy per unit area = 23160 J m^{-2} energy at surface = 47 (J) 2 marks **Examiner's Comments** There were many routes to a final answer in this question. Those candidates who set out their working carefully, used letters to represent the calculated quantity, and set this out in several stages tended to be the most successful. Some calculated the energy at the surface before going on to apply the attenuation formula, and others carried out the attenuation on the intensity. Each method can be credited at various stages, but it is important that a clear structure is shown. Many candidates attempted to change cm^{-1} to m^{-1} by dividing by 100, whereas the better candidates appreciated that the units of distance and attenuation constant would cancel in the exponent. Several candidates used the incorrect formula energy = power / time which can be a common misconception. The correct formula is in the data booklet if required.
			Total	**4**	
34			X-ray (tube) moves around the patient A thin (fan-shaped X-ray) beam is used	**B1** **B1**	**Allow** 'X-rays passed through different angles.'

			(Images / scans of) cross-sections through the patient are taken Any **one** from: • A three-dimensional image is produced • (Soft) tissues can be identified	**B1** **B1**	**Allow** 'slice(s)' **Allow** 'good contrast image' **Examiner's Comments** The majority of the candidates gave decent answers here for the CAT scanner. Answers were often very detailed and demonstrated a good understanding of the stages and the components used in the production of 3D X-rays images. Some even managed to give additional details on the absorption mechanisms. However, examiners only required simplistic answers in terms of a thin beam of rotating X-rays, which enabled cross-sectional scans (slices) of the patient and how computer software was used to generate 3D image of the patient. A small number of candidates outlined hybrid scanners with mixture of MRI scanners, gamma camera and PET scanners. Most of descriptions here earned the mark just for '3D image'. The omission rate for this last question was small enough for examiners to confidently say that there were no time issues with this H556/02 question paper.
			Total	**4**	
35			speed = 2 × 1.5 × 10^{-2}/19 × 10^{-6} (= 1579 m s^{-1})	C1	
			$Z = \rho c$ = 1070 × 1579	C1	
			Z = 1.7 × 10^{6}	A1	**Allow** 2 marks for 8.4 × 10^{5}; factor of 2 omitted
			unit: kg m^{-2} s^{-1}	B1	
			Total	**4**	
36			The transducer is placed at an angle to the arm or artery **and** ultrasound is reflected by the moving blood cells.	B1	
			The wavelength or the frequency of the reflected ultrasound is altered.	B1	
			Since $\Delta f = \frac{2vf\cos\theta}{c}$, the change in frequency ∝ speed of the blood.	B1	

			The technique is non-invasive / no incision needed / minimises risk of infection.	B1	
			Total	**4**	
37			The intensity decreases with thickness of muscle / bone.	B1	
			The decrease is exponential.	B1	
			The attenuation (absorption) coefficient μ of bone must be greater than the μ of muscle	B1	
			because there is a significant decrease in the intensity from x = 3.0 cm to 4.0 cm.	B1	
			Total	**4**	
38			Any **two** from: Photoelectric (effect) Photon (is absorbed and an) electron removed (from the atom) Compton (scattering / effect) Photon scattered / deflection with longer wavelength / low frequency / low energy and electron removed (from the atom) Pair production Photon (absorbed) and produce electron-positron (pair)	 M1 A1 M1 A1 M1 A1	**Ignore** if interaction between photons and electrons is not one-to-one **Not** X-ray wave etc; must refer to photon **Not** reflected **Not** X-ray wave etc; must refer to photon **Not** X-ray wave etc; must refer to photon **<u>Examiner's Comments</u>** Most candidates correctly recalled the names of the remaining attenuation mechanisms and gave good descriptions. The mark scheme required descriptions in terms of the X-ray **photons**. The Compton effect was the most complicated mechanism, but many answers correctly described the scattering of the photon with reduced energy (or longer wavelength). A small number of candidates wrote about pair production as if it was the annihilation of an electron-positron pair. The majority of the candidates scored some marks for their answers.
			Total	**4**	
39	a		The patient is surrounded by (gamma) detectors or Increased activity is where F-18 accumulates (AW) The positrons (from the F-18) <u>annihilate</u> electrons (inside the patient)	**B1** **B1**	**Allow** 'diametrically opposite detectors'

			Each annihilation produces two gamma photons travelling in <u>opposite</u> directions The arrival times are used to locate position (of increased activity)	**B1** **B1**	**Not** gamma rays / radiation **Allow** 'delay time' **Examiner's Comment** Most candidates scored two or more marks for their description of the PET scanner. Most candidates knew that the annihilation of positrons and electrons was central to the scanning technique. A small number of candidates either confused the PET scanning with CAT scanning or assumed that the gamma detectors were monitoring the emission of positrons from the patient.
	b		λ = ln2/110 or 6.3×10^{-3} (min^{-1}) $0.30 = e^{-6.3\times10^{-3}t}$ $t = \frac{\ln(0.30)}{-6.3\times10^{-3}}$ t = 190 (minutes)	**C1** **C1** **A1**	**Allow** 1.05×10^{-4} (s^{-1}) This is the same as $0.30 = e^{-1.05\times10^{-4}t}$ **Note:** This mark is for a **ln** expression (any subject) **Allow** 2 marks for 1.15×10^4 (s) as the final answer **Examiner's Comment** This was not an easy question. It required knowledge and understanding of activity, decay constant and natural logs. It is good to report that most of the candidates produced immaculate answers. The common mistakes made were: • Using either ln(1/3) or ln(0.70) rather than ln(0.30) in the calculations. • Assuming the decay was linear rather than exponential.
	c		Any sensible suggestion, e.g. 'post-code' lottery, some patients may not get the treatment because of where they live, longer waiting lists, etc.	**B1**	**Examiner's Comment** Almost all candidates gave a plausible suggestion in this last question in the paper. It is good to report that physicists are mindful of the impact of science on society.
			Total	**8**	
40		i	Collimator: Only gamma rays / photons travel along the axes of lead tubes are detected. (AW)	B1	
		i	Scintillator: A gamma ray photon produces thousands / many photons of (visible) light. (AW)	B1	

		i	Photomultiplier: An electrical pulse is produced from each photon of visible light entering a photomultiplier tube. (AW)	B1	
		ii	The long and thin tubes would be suitable because gamma photons over smaller spread of angles / area of patient would be detected. (AW)	B1	
		ii	This would produce a clearer / sharper / less blurred image (scan) of the patient. (AW)	B1	
			Total	**5**	
41		i	Proton is repelled (by nucleus) (High-speed) proton can get close to (oxygen) nucleus	**B1** **B1**	**Allow** 'proton can experience the strong (nuclear) force' **Not** 'collide / hit nucleus'
		ii	E = [0.25 - (2.24 - 2.20)] × 10^{-11} (J) **or** 0.21 × 10^{-11} (J) $\lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{0.21 \times 10^{-11}}$ (Any subject) λ = 9.5 × 10^{-14} (m)	**C1** **C1** **A1**	**Allow** 2 marks for 6.9 × 10^{-14}; E = 0.29 × 10^{-11} used **Allow** 1 mark for a value correctly calculated based on any other incorrect value for E (e.g. 8(.0) × 10^{-14} for E = 0.25 × 10^{-11} and 5(.0) × 10^{-13} for E = 0.04 × 10^{-11})
		iii	Used in PET (scans) Any <u>**one**</u> from: Used to diagnose function of organ / brain / body Detection of cancer / tumour Non-invasive / no surgery / no infection 3D (image)	**M1** **A1**	Enter text here.
			Total	**7**	