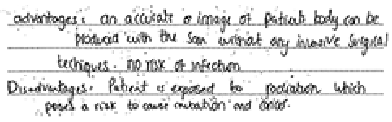
Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1		i	Material (introduced into the body and) used so its position in the body can be detected / function of organ can be determined	B1	**Allow** "used to produce images" for "detected" Do **not allow** "trace" for "position detected" **Ignore** treatment **<u>Examiner's Comments</u>** There are many possible answers to this question, but it was felt that the key point being looked for was the idea that a location in the body could be identified. General uses of tracers was not specific enough and several candidates simply stated that the tracer could be traced. Only around a quarter of candidates gave a suitable response to this question.
		ii	(Very) little ionisation (Most can) pass through the body tissue / can be detected outside / highly penetrating	B1 B1	**Allow** less ionising / least ionising Do **not allow** "zero ionisation" **Allow** other radiation would be absorbed within the body **<u>Examiner's Comments</u>** This relatively simple question was correctly answered by the majority of candidates. There was no additional detail required apart from the two simple facts although it was good to see many candidates putting these into context. Candidates should be reminded that in a question like this, only two responses should be given. Including a third runs the risk of a contradiction. Common misconceptions included the idea that the half-life of a source of gamma radiation was shorter (or longer) than alpha and beta, and that gamma radiation was 'safer'.
			Total	**3**	
2		i	Any two points from the following:	B1 x 2	**Ignore** references to scattering, Compton effect and photoelectric effect

			• (high-energy X-ray) photon interacts with nucleus / travels close to nucleus / disappears • Positron is the antiparticle of an electron • energy (of X-ray photon) is transformed into matter and antimatter • particle and antiparticle pair produced / (mechanism known as) pair production occurs		**Not** • atom instead of nucleus • approaches instead of travels close to • two photons annihilate • photon annihilates • electron and positron annihilate **Allow** photon is absorbed by nucleus **Allow** electrons and positrons are antiparticles (of each other) **Allow** energy (of photon) is transformed into mass **Ignore** electron positron pair (this is a rewording of the stem which states that X-ray photons produce electrons and positrons) **Allow** pair creation **<u>Examiner's Comments</u>** The most common correct responses related to photons interacting with nuclei and to "pair production". Candidates who scored no marks often simply reworded the stem of the question, or referred to photons interacting with atoms or electrons.
		ii	**Level 3 (5–6 marks)** Clear explanation of both scans **<u>and</u>** Clear discussion (compares the risks of either having a scan to fit a bolus or not, to a patient undergoing radiotherapy for skin cancer) *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Limited explanations of both scans **or** clear explanation of one scan **<u>and</u>**	B1 x 6	Use the annotations (for example) L2 for 4 marks, L2^ for 3 marks etc. Place the appropriate number of ticks below the annotation. **Indicative scientific points may include:** **Explanation** <u>CAT scan</u> • Thin fan-shaped beam of X-rays • Ring of detectors rotate around patient • Images of slices produced • Instruments move along patient to take several 2D images

			Basic discussion (e.g. compares the risks of one scan to the other) *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited explanation for example • CAT scan only • PET scan only • both scans attempted but with several errors **<u>or</u>** Limited discussion (eg compares advantages and disadvantages of having a CAT scan) *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 mark** *No response or no response worthy of credit*		• Software produces 3D image <u>PET scan</u> • Positron-emitting tracer injected • Positron annihilates electron producing two gamma photons • Gamma photons travel in opposite directions • Ring of gamma detectors around patient • Delay time between arrival of photons locates annihilation • Software produces 3D image **Discussion - balance of benefits and risks of having the scan** • Both types of scan deliver radiation dose to healthy tissue but • a bolus would mean a lower dose is needed during radiotherapy • Both types of scan are expensive / use NHS resources • but radiotherapy also costly and less would be needed with bolus • Scans can be long / scary / cause discomfort • but the same is true of radiotherapy and less would be needed • Both types of scan are risky but with a bolus the • improved effectiveness of radiotherapy may save a patient's life **<u>Examiner's Comments</u>** Most candidates were familiar with CAT and PET scans. Centres had prepared them well for discussing how they work plus their advantages and disadvantages. The most common errors were in thinking that: • X-rays are reflected/deflected in a CAT scan

					• technetium-99m is used as a tracer for a PET scan • gamma rays are fired at patients in CAT and/or PET scans. Exemplar 3  advantages: an accurate image of patient body can be produced with the scan without any invasive surgical techiques. no risk of infection Disadvantages: Patient is exposed to radiation which poses a risk to cause mutation and cancer. Some candidates did not respond adequately to the second part of the question, often merely rewording information from the stem. Some did not realise that the purpose of the scan in this question was to find the exact shape of a patient's body in order to produce a well-fitting bolus. This resulted in many potential Level 3 responses scoring Level 2. The exemplar above gives an example of this, where the candidate is discussing 'What are the advantages and disadvantages of having a scan as opposed to surgery?'
			Total	**8**	
3	a		$^{18}_{9}F \rightarrow ^{18}_{8}O + ^{0}_{1}\beta^{+}$ $(+\nu)$	C1 A1	Correct fluorine isotope Correct equation **ALLOW** numbers written to right of symbol **ALLOW** e / e^{+} / $\bar{e}$ / β for positron symbol with correct numbers **IGNORE** gamma in products **ALLOW** $^{0}_{0}\nu$ for neutrino **ALLOW** v_e for neutrino **<u>Examiner's Comments</u>** Most candidates will have gained the first mark for the correct isotope of fluorine. Those who didn't likely reversed the positions of the nucleon and proton number. It was noticeable that a large number of candidates were unable to balance the equation and while they had the correct values for the positron, the oxygen isotope was incorrect.

	b		$E = mc^2 = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 = 8.2 \times 10^{-14}$ (J) $E = hc / \lambda = 8.2 \times 10^{-14} = 6.63 \times 10^{-34} \times 3 \times 10^8 / \lambda$ $\lambda = 3.00 \times 10^8 \div 1.2367 \times 10^{20} =$ **2.4×10^{-12}** (m)	C1 C1 A1	Working leading to evaluation of E **ALLOW** factor of 2 leading to 1.6×10^{-13} (J) **NOT** use of $\lambda = h/mv$ where v is 3×10^8 alone **XP** **ALLOW** use of $\lambda = hc/mc^2$ or $\lambda = h/mc$ **ALLOW** Use of electron mass = 0.511 MeV giving 8.2×10^{-14} (J) Correct to at least 2 significant figures Answer of 4.9×10^{-12} or 1.2×10^{-12} allow 2/3 due to incorrect accounting for factor of 2 **<u>Examiner's Comments</u>** Well over half of the candidates were able to score 2 or more marks on this question. A great deal scored 2 marks due to the inclusion of a factor of two, which was then not removed (or vice versa). Some candidates used the formula for kinetic energy – which by coincidence may give the correct answer – however this was not credited, nor was the more common use of the de Broglie formula. Examiners sometimes had a difficult decision on this question, whether the response was a physics error or not, and if in doubt a candidate would be awarded the marks.
	c		X-rays formed when <u>electrons</u> (in an atom) de-excite Gamma rays come from the decay of <u>nuclei</u> (in unstable isotopes)	B1 B1	**ALLOW** X-rays may be produced by acceleration / deceleration of (fast moving) electrons / X-rays are produced when (fast moving) electrons are incident on a metal target / X-rays may be produced when electrons lose kinetic energy **ALLOW** gamma rays come from (the decay of) radioactive <u>nuclei</u> / gamma rays come from the <u>nucleus</u> of unstable atoms / gamma rays come from the de-excitation of <u>nuclei</u> / gamma rays come from <u>annihilation</u> of particle-antiparticle (pairs) / **IGNORE** gamma from fission **<u>Examiner's Comments</u>**

					The main principle behind this question was to distinguish between the X-ray production by electrons and gamma ray production by nuclei. Fairly specific details were required for each, although a wide range of answers were accepted. This question discriminated well among the candidates with roughly equal fractions getting 0, 1 and 2 marks.
	d		The half-life is short Advantage: Exposure of the patient to <u>ionising</u> radiation is kept as low as possible. Disadvantage: (Radiographers have a) short time to scan/diagnose the patient	B1 B1 B1	**ALLOW** activity is high **IGNORE** it decays quickly **ALLOW** F18 has to be manufactured on site before use / high activity means exposure is high during handling **IGNORE** short time to treat the patient **<u>Examiner's Comments</u>** Although apparently a simple set of ideas, the detail required for this question meant that only a small fraction of candidates were able to gain full marks. It was necessary to state that the half-life was (relatively) short, which many of the stronger candidates did not do. The advantage to the patient requires the use of the term 'ionising' as this is the fundamental issue with the radiation. Similarly, candidates had to make it clear that the disadvantage was due to the short time to carry out the scan rather than just a statement of needing to work quickly.
			Total	**10**	
4	a	i	There is no change in (acoustic) impedance	B1	**ALLOW** there is no change in the density (of the medium) **ALLOW** there is no boundary / there is nothing to reflect from **NOT JUST** there is nothing there **IGNORE** undefined symbols **<u>Examiner's Comments</u>** Many candidates gave vague answers such as 'it's all the same' or 'it is all air'. This response did require the idea

					that a boundary or some change must be present for the reflection to occur. Several candidates thought that it was absorbed at A. Around half of the candidates were able to score a mark on this question.
		ii	<u>Acoustic</u> impedance of C is different from B Change in <u>acoustic</u> impedance at B is greater (than at C) (relative to their surrounding medium/A)	C1 A1	**IGNORE** explanations in terms of density Second point gains both marks **ALLOW** soft tissue/skin/belly for C **ALLOW** skull/bone/head for B **<u>Examiner's Comments</u>** This question required the use of the term 'acoustic impedance' for any marks as this would lead to crediting quality responses. The term 'attenuation coefficient' was used by a large number of candidates in place of the acoustic impedance. Only around 40% used the term correctly and only half of this appreciated that this was the difference between B and C and their surrounding mediums rather than simply the difference between B and C. This question highlights the need for correct terminology and not vague statements.
	b		$v = \Delta f\, c / 2 f \cos \theta$ $= \frac{(10.0000 \times 10^6 - 9.9987 \times 10^6) \times 1600}{2 \times 10.0000 \times 10^6 \times \cos 50}$ **0.16** (ms^{-1})	C1 A1	IGNORE cancelling powers of 10 Correct to at least 2 significant figures **<u>Examiner's Comments</u>** This question was correctly done by around two thirds of candidates. Although not a particularly complex calculation, there are some challenges in it. Common mistakes were using the speed of light for *c*, using the reflected frequency for the change of frequency, power of ten errors and using the reflected frequency in the denominator. Many candidates wrote out the formula and rearranged it for *v* before substituting the numbers which help with the calculation. Those who avoided this occasionally made substitution/transcription errors.

	c		Longitudinal waves With a frequency greater than 20 kHz	B1 B1	**ALLOW** 20 kHz and above **<u>Examiner's Comments</u>** Many candidates attempted to answer this question in terms of the use of ultrasound, presumably prompted by the first line of the question. While many good responses were given along these lines, it was not the purpose of the question. Many candidates gave vague answers such as 'outside of the human hearing range' but a little under a half of candidates knew (and wrote) the value of 20 kHz. Only around one fifth were able to state it was a longitudinal wave.
	d		**Level 3 (5–6 marks)** Clear explanation of transducer **and** clear explanation of gel *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear explanation of transducer **OR** clear explanation of gel **or** Some explanation of transducer **and** some explanation of gel *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited explanation of transducer or gel *There is an attempt at a logical structure with a line of reasoning. The*	6 x B1	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Transducer** • High frequency alternating PD applied to the faces of the piezoelectric crystal. • Causes the piezoelectric crystal to stretch and compress / oscillate / resonate at high frequency. • Ultrasound waves sent in pulses • Between pulses, reflected ultrasound incident on the piezoelectric crystal causes the crystal to change shape / oscillate / resonate • An alternating PD is induced **Gel** • Acoustic impedance of air is different to body • Acoustic impedance of gel is similar to body • This allows greater transmission of the ultrasound

			information is in the most part relevant. **0 mark** *No response or no response worthy of credit*		waves into / out of the patient's body • There is less reflection of the ultrasound waves at the body boundary • Reference to $\frac{I_r}{I_0} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$ **<u>Examiner's Comments</u>** This level of response (LoR) question was designed to assess Section 6.5.3 (b), (e) and (f) of the specification. A holistic approach to marking is used, with marks given according to answers matching the descriptors for the various levels. No one answer is perfect for this question and examiners will expect a varied approach. The indicative scientific points are used as a basis; however other correct, relevant physics may also be taken into account. The nature of this question is such that it can be conveniently separated into two sections; a description of producing and receiving ultrasound by the transducer, and the purpose of the gel in this case. The key points in the production and receiving of ultrasound that examiners were looking for were: • an explanation of the piezoelectric effect • what causes it, and the effect on the crystal • how this produces the ultrasound waves • how a reverse of this will lead to its detection. The key points in the purpose of the gel were:- an explanation of acoustic impedance and an idea of what would happen if no gel were to be used – some idea of the term impedance matching and how this occurs with the gel. It was clear that many candidates had

					a good knowledge and understanding the use of ultrasound in this context and were able to describe this well, leading to a good number of candidates being given Level 3. The very best answers were detailed and well-structured and made every attempt to fully answer each section of the question using correct scientific terms. Many candidates wasted time and space describing how the ultrasound was reflected in the body, which is not required, or other irrelevant detail. Some drew diagrams, which can be helpful, but in this case did not really add to the text. For the most part, the description of the gel was done better than the description of production, most likely because the piezoelectric effect can be difficult to explain clearly. Candidates were not penalised for the use of incorrect values in the frequency of ultrasound here, or in any values of size (or voltage applied to) the transducer. The equation for reflection of ultrasound was given by several candidates but was not always explained to support the answer. Many strong candidates only answered one part of the question; this highlights the need to read it carefully – there will nearly always be two parts – and make sure that, as far as possible, equal weighting is given to both.
			Total	**13**	
5			D	1	**<u>Examiner's Comments</u>** The majority of candidates were able to recall the correct emission, with the remaining responses being fairly well split across the other options, suggesting some guess work was involved.
			Total	**1**	

6	a		Allows only those gamma rays / waves / photons travelling along axis (of the collimator) to get through (and reach scintillator)	B1	**Allow** less fuzzy / clear image **Allow** all the gamma rays / waves / photons are parallel / in the same direction (to each other) **Allow** <u>absorbs</u> those gamma rays / waves / photons not parallel (to the axis of collimator) **Allow** so the photons are travelling perpendicular to the scintillator **Do not allow** the gamma rays are travelling vertically, unless it is clear the collimator is also vertical **<u>Examiner's Comments</u>** This question was well answered by around half of the candidates who appreciated that the long, narrow collimator would allow only gamma rays which were parallel to each other to be received by the scintillator. This can be expressed in a number of ways and marks were given to candidates who were able to state this using alternative descriptions. A common confusion appeared between using the terms perpendicular and parallel, with some candidates incorrectly stating that the collimator allowed photons perpendicular to the tubes to pass. Essentially, the collimator allows for a clearer image to form and so this is an acceptable response.
	b		Turn gamma (photons) into (many photons of) light	B1	**Ignore** reference to rays / waves **Ignore** reference to flash **<u>Examiner's Comments</u>** Around half of the candidates were able to correctly explain that the gamma photons produced visible light in the scintillator. Several candidates thought that the scintillator produced electrons or a voltage when the gamma photons were incident on it instead. Many candidates gave the extra correct information that many visible photons are produced from one gamma photon, although this was not a required detail on this occasion.

	c		number of electrons = $\frac{0.32 \times 10^{-6} \times 1.2 \times 10^{-9}}{e}$ number of electrons = 2400	C1 A1	**Ignore** any POT error for C1 mark **<u>Examiner's Comments</u>** This calculation was done well by a large majority of candidates. There were few errors in the unit prefixes, with the most common one being 1.2 ns as 1.2 × 10^{-12} s. A small number of candidates calculated the charge correctly, but then took it no further to determine the number of electrons.
	d		Any sensible <u>diagnostic</u> suggestion, e.g. <u>detection</u> of cancer / scans of (named) organ / scans of tissue / bone scans / observing functionality of (named) organ	B1	**Not** medical <u>treatment</u> e.g. radiotherapy **Not** body scan **Ignore** PET scanner **Do not allow** CAT scan **<u>Examiner's Comments</u>** The key word here was "diagnostic" and responses were expected to state any reasonable diagnostic use of a gamma camera and a wide variety of responses were given and accepted. Common responses included checking for brain tumours and observing kidney failure. Although a gamma camera may be used in a PET scanner, this alone was not acceptable as it does not explain the diagnostic use. Candidate should be encouraged to write in a clear sentence structure as simple responses such as "cancer" cannot be given marks.
			Total	**5**	
7	a		Photon scattered with less energy / X-ray of lower frequency / X-ray of longer wavelength Electron removed (from the atom)	B1 B1	**Allow** X-ray for photon and vice versa **Ignore** wave **Not** electron scattered or electron removed from surface **<u>Examiner's Comments</u>** The Compton effect is part of the X-ray attenuation section of the specification 6.5.1(d). It appeared that some candidates were unfamiliar with this process and attempted to describe the photoelectric effect. There was a noticeable use of casual

					language in the description of the electron being removed from the atom and several candidates described the electron as moving up energy levels. Those who were able to obtain both marks generally gave clear and succinct responses.
	b	i	Identification from graph of two intensities and corresponding separation between them (x). Correct substitution into $I = I_0 e^{-\mu x}$ and fully correct calculation leading to $\mu = 0.84$ (cm^{-1})	C1 A1	**Note** check value of intensities to ± ½ small square. x missing implies $x = 1$. Graph misread lose all marks. May be seen from substitution into $I = I_0 e^{-\mu x}$. No POT error at this point **Note** I_0 and I must be in correct position in equation, so that ($I < I_0$). If I and I_0 are reversed, μ will be negative. **Penalise** this mark for negative answer, or working that would lead to negative answer. **Penalise** POT error here. **Allow** small range of values around 0.84 for variations in graph readings. **<u>Examiner's Comments</u>** The treatment of the logs was well done here (again, as with 22bi) and most of the candidates chose 0.0 and 1.0 cm to produce their values. The factor of 10^3 in the intensity was not needed for this calculation, so candidates who chose to ignore it (or did not see it) were unlikely to be penalised. The negative sign caused a problem if I and I_0 were reversed and candidates deliberately ignoring it would not score the second mark. There was a common alternative to using the 0.0 and 1.0 cm points where candidates used the "half-thickness" value at approximately 0.83 cm which would produce the same answer. As the graph scale on the vertical axis was simple, values which could have been from a "misread" would not be given further marks. Although readings were taken from a

					graph in the calculation, several candidates gave their final answer to 1sf despite calculating it correctly throughout.
		ii	$I = 1.3 \times 10^3$ / 1300 ($E = I \times A \times t$) = 2.6 = 1300 × 1.0 × $10^{-4} \times t$ t = 20 (s)	B1 C1 A1	**Allow** a value in the range 1.25 − 1.35 × 10^3. **Allow** ecf from incorrect reading of I at 1.0cm from (b)(i) **Allow** use of value of I from B1 except use of 3000 **POT** error allowed on area if area clearly included in the calculation, or if A included in equation **Note**: use of $I = 1.6 \times 10^3$ leading to t = 16 (s) with A included scores 2 marks **Examiner's Comments** Many candidates made a good attempt at this question, however the conversion between cm^2 to m^2 and missing the 10^3 on the intensity reading caused two potential power of ten errors.
		iii	A curve starting at x = 1.0cm with initially larger negative gradient at x = 1.0 cm Exponential curve	M1 A1	**Must not** have a positive gradient for more than half a square vertically Curve must not touch x-axis or be horizontal for more than 3 small squares **Examiner's Comments** Most candidates appreciated that a larger attenuation coefficient would lead to a line which would lead to a lower intensity than a continuation of the original line. Common (and understandable) errors included the line touching the x axis and a continuation of the original line of increasing gradient. Some candidates may have misinterpreted the question as they drew a second line from the (3.0, 0.0) point beneath the original line.
			Total	**9**	

8			**C**	1	**<u>Examiner's Comments</u>** This question involves several stages, the most critical being the correct conversion of the volume units to m^3. Very encouragingly, the majority were able to do this correctly and work through to the correct response. A was a common distractor for those who made no conversion from g and cm^3.
			Total	**1**	