PRESTON MANOR

A Level Physics Exam Packs

Medical Physics

Name:

Form:

Question	Mark

5 **(a)** Outline the main principles of the use of magnetic resonance to obtain diagnostic information about internal organs.

In your answer, you should make clear how the principles you describe allow body structures to be distinguished.

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(b) Describe one advantage and one disadvantage of MRI.

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[Total: 10]

Question			Expected Answers	Marks	Additional Guidance
5	a		Magnetic resonance: **some <u>nuclei</u> behave as small magnets / certain <u>nuclei</u> possess a net spin /** <u>**nuclei**</u> line up in the magnetic field	B1	Allow protons instead of nuclei in the context of hydrogen nuclei or a single proton instead of nuclei
			Need for a strong magnetic field	B1	There are 5 essential marks **(in bold)**
			the frequency of precession is known as Lamor frequency (1)		and a maximum of THREE extra marks (1)
			Application of RF pulses	B1	Maximum of **8 marks**
			produces resonance / flip energy states (1)		Do not allow 'atoms' for nuclei but penalise once only
			RF pulse turned off nuclei relax / flip back (and emit RF signal)	B1	**Please annotate scripts as follows:**
			RF detected (by coil receiver) and processed (1)		**Essential marks: ✓(ticks) on left hand side of candidate's work**
			Use of non-uniform field / gradient field (1)		**Extra marks: ✓(ticks) on right hand side of candidate's work**
			To locate position of nuclei in body (1)		
			QWC mark: difference in the relaxation times for hydrogen in different tissues / materials MAX (3) **MAX 8**	B1	
				MAX B8	

5	b		Advantage: not ionising radiation (as with X-rays) / better soft tissue contrast Disadvantage: heating effect of metal objects /effect on cardiac pacemakers / takes a long time to perform MRI scan	B1 B1	Accept can view soft tissue in brain / skull Do not allow not harmful Do not allow no side effects
			Total	**[10]**	

10 **(a)** State and describe **one** way in which X-ray photons interact with matter.

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(b) The intensity of a collimated beam of X-rays is reduced to 10% of its initial value after passing through 3.0 mm of soft tissue. Calculate the thickness of soft tissue that reduces the intensity to 50% of its initial value.

thickness = ... mm **[3]**

(c) X-rays are used to image internal body structures.

(i) Explain how image intensifiers are used to improve the quality of the X-ray image.

In your answer, you should explain clearly the process involved which makes the image brighter.

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(ii) Explain how contrast media are used to improve the quality of the X-ray image.

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[Total: 10]

END OF QUESTION PAPER

Question			Expected Answers	Marks	Additional Guidance
10	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		$I = I_0e^{-\mu x}$ $0.1 = e^{-\mu 3}$ $0.5 = e^{-\mu x}$ $\ln 0.5 / \ln 0.1 = x/3$ $x = 0.903$ (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
10	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	(B1)	This method produces good contrast for soft tissue /for similar Z values
			(Contrast media with) high atomic number / Z used / iodine or barium (used to give greater contrast)	(B1)	
			liquids injected or swallowed into soft tissue areas / or examples of such	(B1)	
			MAX B2	**B2**	
			Total	**[10]**	

7 **(a)** Describe the *piezoelectric effect.*

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(b) Describe how ultrasound scanning is used to obtain diagnostic information about internal structures of a body. In your description include the differences between an A-scan and a B-scan.

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(c) Fig. 7.1 shows the speed of ultrasound, density and acoustic impedance for muscle and bone.

material	speed of ultrasound / $m\,s^{-1}$	density / $kg\,m^{-3}$	acoustic impedance / $10^6\,kg\,m^{-2}\,s^{-1}$
muscle	1590	1080	1.72
bone	4080	1750	7.14

Fig. 7.1

(i) Show that the unit for acoustic impedance is $kg\,m^{-2}\,s^{-1}$.

[1]

(ii) An ultrasound pulse is incident at right angles to the boundary between bone and muscle. Calculate the fraction of reflected intensity of the ultrasound.

fraction of reflected intensity = ... **[2]**

(iii) What is meant by *acoustic impedance matching*? Explain why a gel is used to produce an effective ultrasound image.

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(iv) The frequency of the ultrasound in the muscle is 1.2 MHz. Calculate the wavelength of the ultrasound in millimetres (mm).

wavelength = ... mm **[2]**

(v) Suggest why it is desirable to have ultrasound of short wavelength for a scan.

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[Total: 13]

8 **(a)** Describe the use of image intensifiers and contrast media when X-rays are used to produce images of internal body structures.

In your answer, you should make clear how the appearance of the image is linked to the techniques used.

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(b) A student suggests an image intensifier uses the photoelectric effect. Explain why this suggestion is **incorrect**.

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(c) **(i)** Explain how the production of a CAT scan image differs from that of a simple X-ray image.

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(ii) Describe the advantages of a CAT scan compared to an X-ray image.

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Total: [10]

Question			Expected Answer	Mark	Additional Guidance
7	(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	

Question			Expected Answer	Mark	Additional Guidance
8	(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	

8 (a) State one reason for using non-invasive techniques in medical diagnosis.

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(b) Describe the use of medical tracers to diagnose the condition of organs.

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(c) Describe the principles of positron emission tomography (PET).

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[Total: 8]

9 **(a)** Describe the principles of ultrasound scanning.

In your answer, you should make clear how the steps in the process are sequenced.

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(b) Explain the difference between an ultrasound A-scan and B-scan.

.... [1]

[Total: 5]

TURN OVER PAGE FOR QUESTION 10.

Question			Expected Answers	Marks	Additional guidance
8	(a)		Less chance of infection	B1	
	(b)		Any <u>two</u> 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 <u>five</u> from: 1. A positron / beta-plus emitting tracer / source is used 2. The positron annihilates with an electron (inside the patient) 3. This produces <u>two</u> 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**	

Question			Expected Answers	Marks	Additional guidance
9	(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**	

7 **(a)** Describe in simple terms how X-ray photons are produced in a hospital X-ray machine.

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(b) Fig. 7.1 shows a simple X-ray intensifier screen.

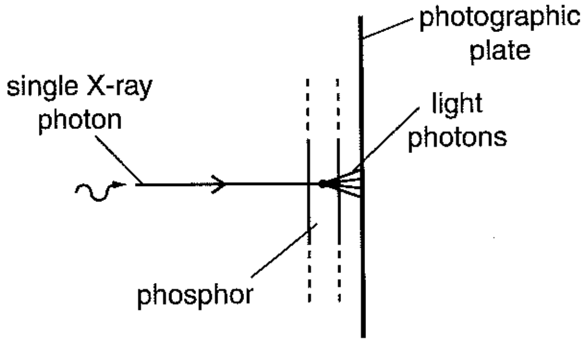

Fig. 7.1

A bright X-ray image can be produced using an image intensifier. A single X-ray photon incident on the phosphor produces about a thousand photons of visible light. The photons of visible light produce an image on a photographic plate.

(i) Explain what is meant by a *photon*.

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.... **[1]**

(ii) Explain why an X-ray photon has greater energy than a photon of visible light.

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.... **[1]**

(c) In an X-ray machine, accelerated electrons hit a metal target. Most of the kinetic energy of the electrons is converted into heat, but a small amount is converted into X-ray photons. Electrons having maximum kinetic energy create the shortest wavelength X-ray photons. Calculate the shortest wavelength of X-ray photons emitted from an X-ray machine operating at 120 kV.

wavelength = ... m **[3]**

(d) X-ray photons interact with matter. One of the interaction mechanisms of the X-ray photons with atoms is known as the **photoelectric effect**. State another interaction mechanism. Describe what happens to the X-ray photon interacting with a single atom using the mechanism you have stated.

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[Total: 9]

Question			Answers	Marks	Guidance
7	(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	

8 **(a)** Fig. 8.1 shows an MRI scanner.

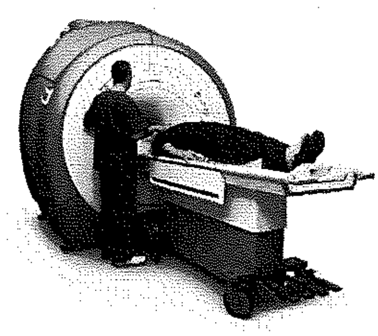

Fig. 8.1

The main components of an MRI scanner are a strong electromagnet, radio frequency transmitting coils, radio frequency receiving coils, gradient coils and a computer.

- Outline the principles of magnetic resonance.
- Describe how these components are used to obtain diagnostic information about the internal organs.

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(b) Discuss the major differences between an MRI scan and a positron emission tomography (PET) scan of the brain.

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[Total: 9]

Question			Answer	Marks	Guidance
8	(a)		Any <u>seven</u> from: 1. Protons / nuclei have spin / behave like (tiny) magnets 2. Protons / nuclei precess about the magnetic field (provided by the strong electromagnet) 3. Transmitting coils provide (pulses of) radio waves of frequency equal to the Larmor frequency 4. The protons / nuclei absorb energy / radio waves / resonate and flip into a higher energy state 5. When protons / nuclei flip back to a lower energy state they emit (photons of) radio waves 6. The relaxation time (of the protons/nuclei) depends on the (surrounding) tissues 7. The radio waves are picked up by the receiving coils 8. The gradient coils alter the magnetic flux density (through the body) 9. The Larmor frequency (of the protons / nuclei) varies through the body 10. The computer (processes all the signals from the receiving coils and) generates the image(s)	B1 × 7	**Show annotation on Scoris** **Not:** Atoms / particles for nuclei /protons. **Allow**: The protons / nuclei absorb energy / radio waves / resonate and get excited **Allow**: When protons / nuclei relax they emit (photons of) radio waves
	(b)		Ay <u>two</u> from: 1. PET scan: uses radioactive substance / uses positron-emitting substance / uses F(-18) / mention of gamma rays / mention of gamma photons 2. PET scan reveal the 'function' of the brain (AW) 3. MRI scan show variation in tissues (in the brain) (AW)	B1×2	**Allow**: MRI scan: no radioactive substance is required / mention of radio waves **Allow:** PET scans are used to diagnose dyslexia / Alzheimer (disease)
			Total	**9**	

7 **(a)** State two properties of X-rays.

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.... **[2]**

(b) Explain what is meant by the *Compton effect*.

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.... **[2]**

(c) The intensity I of a collimated beam of X-rays decreases exponentially with thickness x of the material through which the beam passes according to the equation $I = I_0 e^{-\mu x}$. The attenuation (absorption) coefficient μ depends on the material.

(i) State what I_0 represents in this equation.

.... **[1]**

(ii) Bone has an attenuation coefficient of $3.3\,\text{cm}^{-1}$. Calculate the thickness in cm of bone that will reduce the X-ray intensity by half.

thickness = ... cm **[3]**

(d) Explain the purpose of using a contrast medium such as barium when taking X-ray images of the body.

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[Total: 10]

Question			Answer	Marks	Guidance
7	(a)		Any <u>two</u> from: (X-rays) are EM waves Travel at speed of light / 3×10^8 <u>m s^{-1}</u> (in a vacuum) Travel in a vacuum / empty space Transverse waves Can cause ionisation Have wavelength of about 10^{-10} <u>m</u> (X-rays are high energy) photons (AW)	B1×2	**Allow**: reference to diffraction / interference / refraction / reflection / polarisation for 1 mark
	(b)		(X-ray) <u>photon</u> interacts with an (orbital) <u>electron</u>	B1	
			The (scattered) photon has a longer wavelength / lower frequency / lower energy **AND** The electron is ejected (from the atom at high speed)	B1	**Allow**: 'X-rays' instead of 'photons' for the second B1 mark
	(c)	(i)	Initial / original / incident <u>intensity</u>	B1	**Allow**: Initial / original / incident <u>power per</u> (unit) <u>area</u>
		(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)	B1	
			Idea of revealing tissue	B1	
			Total	**10**	

8 **(a)** In the treatment of patients, explain what is meant by a non-invasive technique. State one of its advantages.

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(b) Explain what is meant by a medical tracer. Name a medical tracer commonly used to diagnose the function of organs.

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(c) The main components of a gamma camera are the collimator, scintillator, photomultiplier tubes and the computer. Describe the function of each of these components.

In your answer, you must make clear how one of these components governs the sharpness of the image.

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(d) Fig. 8.1 shows an ultrasound transducer placed above an artery.

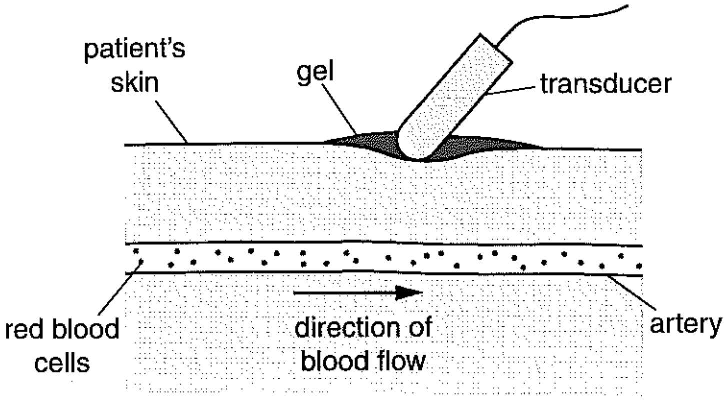

Fig. 8.1

(i) The speed of ultrasound in blood is $1500\,\text{m s}^{-1}$. Calculate the wavelength of the ultrasound of frequency $2.0 \times 10^{6}\,\text{Hz}$.

wavelength = ... m **[2]**

(ii) Describe how the ultrasound is used to determine the speed of the blood in the artery.

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[Total: 14]

Question			Answers	Marks	Guidance
8	(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)	$v = f\lambda$ $1500 = 2.0 \times 10^6 \times \lambda$ wavelength $= 7.5 \times 10^{-4}$ (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**	

7 (a) A magnetic resonance imaging (MRI) scanner is a valuable item of diagnostic equipment found in most hospitals. It is capable of generating a three-dimensional image of the patient. The following terms are used in the description of MRI scanners.

- Larmor frequency of the protons
- resonance of the protons
- relaxation times of the protons

Describe the operation of the MRI scanner with particular reference to these terms.

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(b) An MRI scan can take a long time and it does produce an unpleasant loud noise. State one other disadvantage and one advantage of an MRI scan.

disadvantage ....

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advantage ....

.... **[2]**

[Total: 8]

Question			Answer	Marks	Guidance
7	(a)		Any <u>six</u> from: 1. Protons / nuclei have spin or they behave like (tiny) magnets 2. Protons precess around the magnetic field (provided by the strong electromagnet) 3. The frequency of precession is known as the *Larmor frequency* 4. (Transmitting) coils provide (pulses of) radio waves (of frequency equal to the Larmor frequency) 5. The protons absorb energy (from the radio waves) / resonate and enter into a high energy state (AW) 6. When protons return back to their low energy state and they emit (photons of) radio waves 7. The *relaxation time* is the (average) time taken for the protons to return back to their normal / low energy state 8. The relaxation time depends on the tissues (A computer processes all the signals from the receiving coils and with the help of computer software generates a 3D image)	B1 × 6	**Not**: Atoms / particles **Note**: Must have reference to radio (waves) in 4 and 6 **Allow** 'excited' for 'high-energy state' **Allow**: Relaxing protons emit radio waves
	(b)		Disadvantage: Patient with metallic objects cannot be scanned / patient has to remain still (for a long time) / confined space / difficult for patient suffering from claustrophobia / or another suitable suggestion Advantage: Non-ionising /non invasive / better contrast (between soft tissues) / or another suitable suggestion	B1 B1	 **Not** '3 D image' because it is given in **(a)**
			Total	**8**	

6 **(a)** Describe briefly how X-rays are produced in an X-ray tube.

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(b) Describe the Compton Effect in terms of an X-ray photon.

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(c) A beam of X-rays of intensity $3.0 \times 10^9\ \mathrm{W\,m^{-2}}$ is used to target a tumour in a patient. The tumour is situated at a depth of 1.7 cm in soft tissue. The attenuation (absorption) coefficient μ of soft-tissues is $6.5\ \mathrm{cm^{-1}}$.

(i) Show that the intensity of the X-rays at the tumour is about $5 \times 10^4\ \mathrm{W\,m^{-2}}$.

[2]

(ii) The cross-sectional area of the X-ray beam at the tumour is $5\ \mathrm{mm^2}$. The energy required to destroy the malignant cells of the tumour is 200 J. The tumour absorbs 10% of the energy from the X-rays. Calculate the total exposure time required to destroy the tumour.

time = ... s **[3]**

(d) Describe the operation of a computerised axial tomography (CAT) scanner. State **one** of the advantages of a CAT scan image over a conventional X-ray image.

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[Total: 14]

Question			Answer	Marks	Guidance
6	(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 <u>thin</u> 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**	

7 **(a)** State **two** main properties of X-ray photons.

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.... **[2]**

(b) Fig. 7.1 shows an X-ray photon interacting with an atom to produce an electron-positron pair in a process known as pair production.

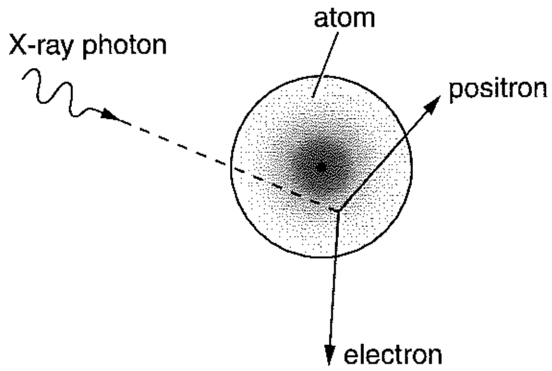

Fig. 7.1

Calculate the maximum wavelength of X-rays that can produce an electron-positron pair.

wavelength = ... m **[3]**

(c) Name an element used as a contrast material in X-ray imaging. Explain why contrast materials are used in the diagnosis of stomach problems.

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.... **[3]**

[Total: 8]

Question			Answer	Marks	Guidance
7	(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 $E = mc^2$	C1	**Allow**: $\frac{hc}{\lambda}$ and 1.02 MeV or 0.51 MeV for this first C1 mark
			$\frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{\lambda} = 2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2$	C1	**Allow**: Correct use of mass = 0.00055 u
			wavelength = 1.2×10^{-12} (m)	A1	**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: $\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 3.0 \times 10^8} = 2.4 \times 10^{-12}$ m scores zero
	(c)		Barium / iodine	B1	
			(Contrast medium absorbs X-rays because it) has large attenuation coefficient / has large absorption coefficient / has large Z values	B1	**Not**: X-rays are (easily) absorbed by the contrast material
			Ideal for imaging the outline (of soft tissues)	B1	**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**	

8 Technetium-99m is a common medical tracer injected into patients before they have a scan with a gamma camera. Technetium-99m is a gamma emitter with a half-life of about 6 hours. Each gamma ray photon has energy 2.2×10^{-14} J.

A patient is given a dose with an initial activity of 500 MBq.

(a) Explain what is meant by *activity*.

....

.... **[1]**

(b) Calculate the initial rate of energy emission from the dose of technetium-99m.

rate of energy emission = ... $\mathrm{J\,s^{-1}}$ **[2]**

Question 8 continues on page 16

(c) Name and describe the function of the main components of a gamma camera.

In your answer you should make clear how a good quality image can be achieved with these components.

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[Total: 8]

Question			Answer	Marks	Guidance
8	(a)		Rate of decay / disintegration of <u>nuclei</u> or Number of γ (photons) emitted per unit time	B1	The question has 500 Bq. Hence **allow** the following: Number of <u>nuclei</u> decaying per second / number of γ (photons) emitted per second **Not**: Rate of decay of atoms / molecules / particles
	(b)		(rate of energy =) $500 \times 10^6 \times 2.2 \times 10^{-14}$ rate of energy emission = 1.1×10^{-5} (J s^{-1})	C1 A1	
	(c)		**Collimator / lead tubes** <u>and</u> ...... gamma (ray photons) travel along the axis of lead tubes (AW)	B1	**Not** 'it collimates' **Allow**: parallel rays / uni-directional rays travel along the lead tubes (AW)
			Scintillator / Sodium Iodide (crystal) <u>and</u> .... gamma ray / gamma photon produces (many) <u>photons</u> of (visible) light	B1	
			Photomultiplier (tubes) / photocathode and dynodes <u>and</u> ...... (electrical) pulse / signal / electron<u>s</u> produced by photon(s) of visible light	B1	
			Computer <u>and</u> .... signals / pulses /electrons (from photomultiplier tubes) are used to generate an image	B1	**Not** 'information / data' in place of signals
			QWC: Quality of image improved by narrower / thinner / longer collimators OR longer scanning time	B1	
			Total	**8**	

9 (a) State **two** main properties of ultrasound.

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.... [2]

(b) Describe how the piezoelectric effect is used in an ultrasound transducer both to emit and receive ultrasound.

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(c) Explain why a gel is used between the ultrasound transducer and the patient's skin during a scan.

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(d) Explain a method using ultrasound to determine the speed of blood in an artery in the arm.

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.... [4]

[Total: 10]

Question			Answer	Marks	Guidance
9	(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**	

8 **(a)** Fig. 8.1 shows a B-scan image of an ultrasound scan of a 12 week foetus.

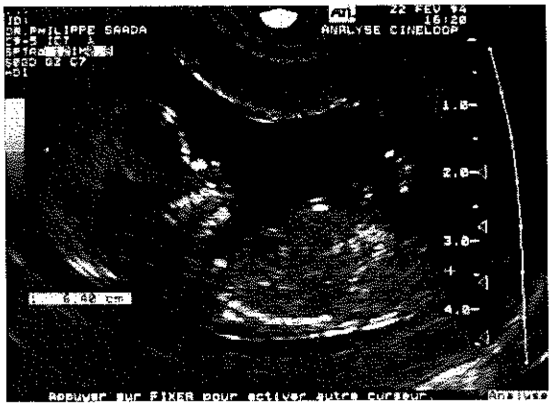

Fig. 8.1

The outline of the head of the foetus can be seen in Fig. 8.1. Describe and explain the principles of a B-scan.

In your answer you should make clear how it is possible to distinguish the boundaries between different materials.

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.... **[3]**

(b) Fig. 8.2 shows an image of the brain using a positron emission tomography (PET) scanner.

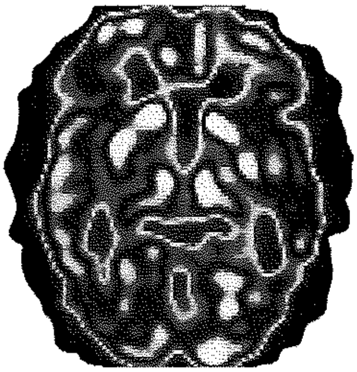

Fig. 8.2

The lighter regions in Fig. 8.2 show the active areas of the brain. Fluorine-18 is a common tracer injected into a patient before a PET scan.

Explain the basic principles of PET scanning, including how the image is formed.

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.... **[4]**

[Total: 7]

Question			Answers	Marks	Guidance
8	(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** positrons and electrons annihilate to produce photons travelling in opposite directions for 3. **Allow** an answer in terms of arrival times.
			Total	7	

8 **(a)** Fig. 8.1 shows an image of a patient from a gamma camera scan.

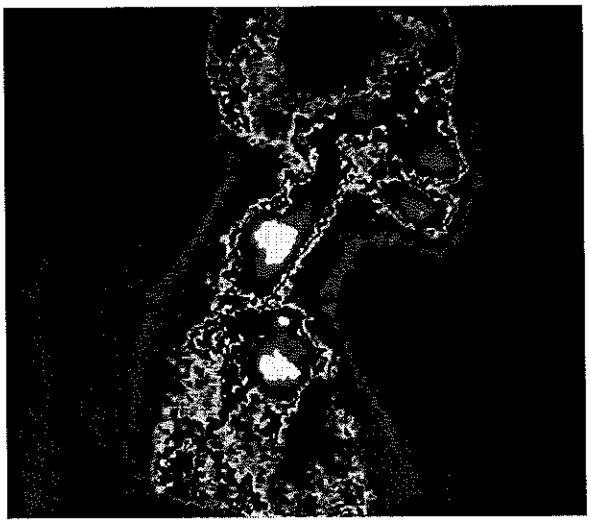

Fig. 8.1

The radioactive gamma-emitting tracer technetium-99m was injected into the patient before the scan. The image shows the distribution and intensity of gamma radiation emitted.

Discuss the advantages of using a gamma-emitting tracer in the patient rather than a beta-emitting tracer.

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.... [2]

(b) Many hospitals are equipped with computerised axial tomography (CAT) scanners.

Describe how the components of a CAT scanner are used to produce a three-dimensional image of a patient.

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Question			Answer	Marks	Guidance
8	(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)	B1	
			Gamma radiation is not (very) ionising / gamma radiation does little damage to cells / beta particles are (very) ionising / beta particle damage cells	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	B1	**Not**: Detector rotates around (the patient)
			A thin X-ray beam is used	B1	
			Image(s) of slice(s) / (cross) section(s) through the patient are taken	B1	
			X-ray tube moves / spirals along (the patient)	B1	**Allow**: Detectors 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	
			Total	**7**	

9 **(a)** Explain what is meant by *Doppler effect*.

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.... **[1]**

(b) Describe how high-frequency ultrasound can be used to determine the speed of blood through the arteries of a patient.

In your answer you should make it clear how the speed is determined.

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.... **[3]**

(c) A patient is scanned using ultrasound of frequency 2.4 MHz. The speed of ultrasound in the blood is $1.57\,\text{km}\,\text{s}^{-1}$. The acoustic impedance of blood is $1.66 \times 10^{6}\,\text{kg}\,\text{m}^{-2}\,\text{s}^{-1}$.
Calculate

(i) the density of blood

density = ... kg m^{-3} **[1]**

(ii) the wavelength of ultrasound in the blood.

wavelength = ... m **[1]**

(d) Fig. 9.1 shows a beam of ultrasound incident at right angles to the boundary between muscle and bone.

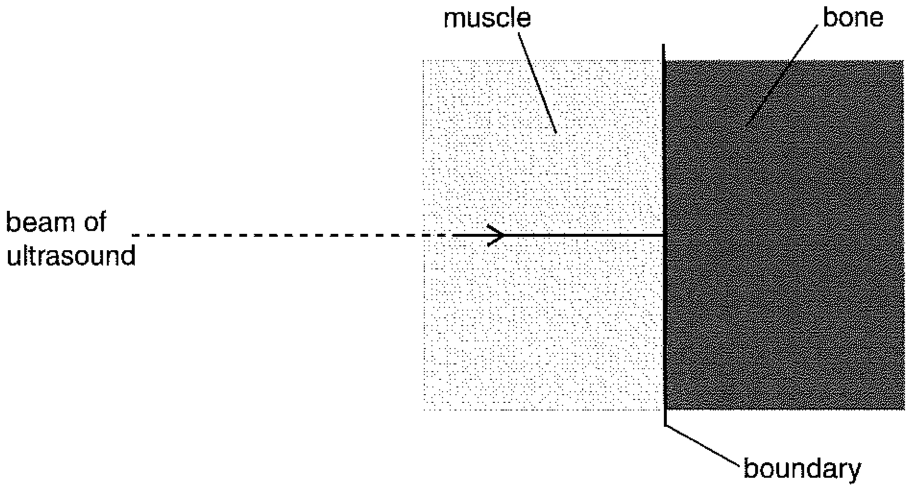

Fig. 9.1

The acoustic impedance of bone is 4 times that of muscle.

Calculate the percentage of ultrasound intensity transmitted into the bone.

intensity = ... % **[3]**

(e) During an ultrasound scan it is important that most of the ultrasound from the transducer is transmitted into the patient. Describe and explain how this is achieved.

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.... **[2]**

Question			Answer	Marks	Guidance
9	(a)		Change in the frequency / wavelength because of source / 'observer' moving	B1	**Allow**: There is blue / red shift because of relative motion between source and observer
	(b)		Any <u>two</u> from: 1. Ultrasound transducer / device / probe emits and detects ultrasound 2. The transducer / device / probe is placed at an angle (to the artery) 3. Ultrasound is <u>reflected</u> by the blood / cells	B1 × 2	
			QWC mark - change in frequency / wavelength (of the reflected ultrasound) is related to speed of blood	B1	**Allow**: speed of blood ∝ change in frequency **Allow**: $\Delta f = 2vf\cos\theta/c$, where v is the speed of blood, c = speed of ultrasound; no need to define the other labels **Note**: Do not award this mark if $\Delta f = fv/c$ is used to determine the speed v of the blood
	(c)	(i)	$Z = \rho c$ density = $1.66 \times 10^6/1570$ density = 1060 (kg m^{-3})	B1	**Allow**: 1100 (kg m^{-3})
		(ii)	$\lambda = 1570/2.4 \times 10^6$ wavelength = 6.5×10^{-4} (m)	B1	
	(d)		(fraction of intensity reflected =) $\dfrac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$	C1	
			(fraction of intensity reflected =) $3^2/5^2$ (= 0.36)	C1	
			intensity = 64%	A1	**Note**: 2 marks for 36% or 0.36
	(e)		Gel is used (between transducer and skin).	B1	
			The acoustic impedance / Z of gel is similar to that for skin hence less <u>reflection</u> (at the skin)	B1	**Allow**: There is acoustic / impedance matching so less <u>reflection</u> **Allow**: Without the gel, there is large difference between acoustic impedances of air and skin, hence large <u>reflection</u> **Note**: Must have reference to reflection
			Total	**11**	

7 **(a)** A patient has an X-ray scan taken in hospital. The high-energy X-ray photons interact with the atoms inside the body of the patient.

Explain what is meant by a *photon* and state **one** of its main properties.

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.... **[2]**

(b) An X-ray tube operates using a 150 kV supply. X-ray photons are produced inside the tube when a beam of high-speed electrons accelerated from the cathode collide with the metal anode. About 99% of the total kinetic energy of the electrons at the anode is converted into heat energy which heats the anode. The remaining energy is transformed into the energy of the X-ray photons.

The current in the electron beam between the cathode and the anode is 4.8 mA.

(i) Show that the number of electrons incident at the anode per second is $3.0 \times 10^{16}\,s^{-1}$.

[1]

(ii) The anode is made from metal of specific heat capacity $140\,J\,kg^{-1}\,K^{-1}$. It has a mass of 8.6 g. The X-ray tube is switched on. Calculate the initial rate of increase of temperature of the anode.

rate of temperature increase = ... $°C\,s^{-1}$ **[3]**

(iii) A single electron is responsible for producing an X-ray photon. Calculate the shortest wavelength of the X-rays produced from the X-ray tube.

wavelength = ... m **[2]**

(c) An X-ray scan of the heart and its blood vessels shows very poor contrast. Describe and explain a technique that can be used to reveal these blood vessels in an X-ray scan.

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.... **[2]**

Question			Answer	Marks	Guidance
7	(a)		Quantum / packet of (electromagnetic) <u>energy</u> Any <u>one</u> from: Can travel in a vacuum / has speed of 3×10^8 <u>$m\ s^{-1}$ in a vacuum</u> / has no charge / has no (rest) mass / causes ion-isation / has momentum	B1 B1	**Allow**: Particle of <u>energy</u> **Allow**: Travels at the speed of light / c <u>in a vacuum</u>
	(b)	(i)	number per second = $4.8 \times 10^{-3}/1.6 \times 10^{-19}$ number per second = $3.0 \times 10^{16}\ s^{-1}$	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) $2.4 \times 10^{-14} = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{\lambda}$ (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 <u>one</u> 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**	

7 **(a)** X-rays are produced in an X-ray tube when fast moving electrons hit a metal target.

Fig. 7.1 shows a typical graph of intensity I against wavelength λ of X-rays emitted by an X-ray tube.

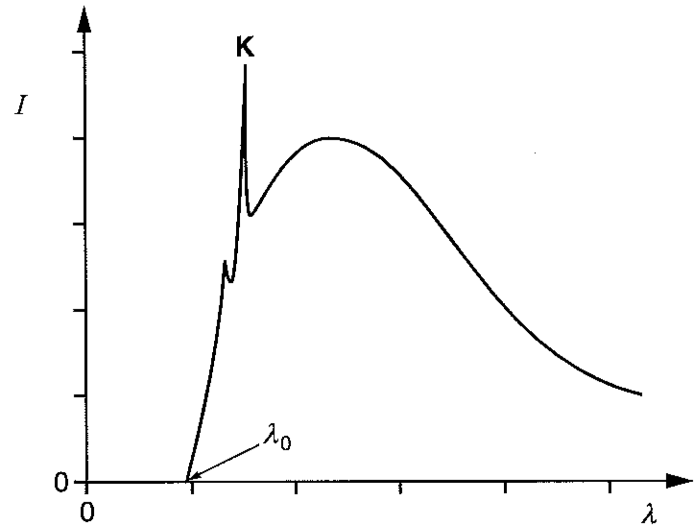

Fig. 7.1

High-speed electrons colliding with the atoms in the target metal can remove electrons from these atoms. The removal of such electrons creates 'gaps' in the lower energy levels of these atoms. These gaps are quickly filled by electrons in the higher energy levels making transitions to these lower energy levels. The electrons lose energy which is released as photons with particular wavelengths. These emission spectral lines are shown by the high intensity peaks such as **K** shown in Fig. 7.1.

Fig. 7.2 shows three of the energy levels, **A**, **B** and **C**, for the metal atoms of the target. The electron transition shown produces the peak **K**.

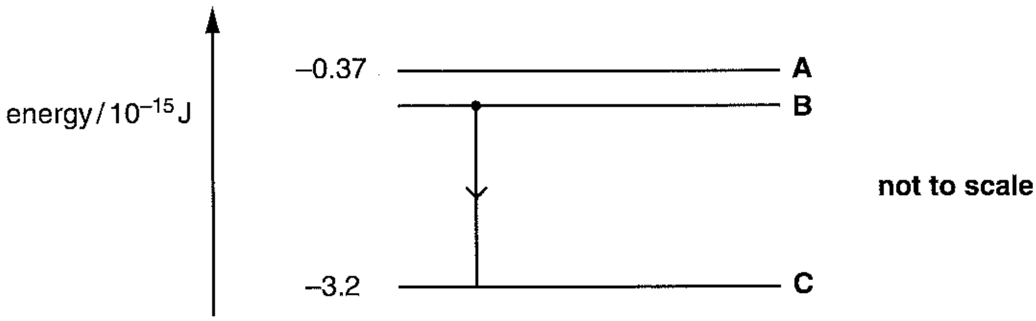

Fig. 7.2

(i) Explain what is meant by an *energy level* of an atom.

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.... **[1]**

(ii) The peak **K** occurs at a wavelength of 7.2×10^{-11} m. Calculate the value of the energy level **B**.

value of energy level = ... J **[3]**

(iii) In Fig. 7.1, the shortest wavelength λ_0 produced from an X-ray tube depends on the accelerating potential difference V. The maximum kinetic energy of a single accelerated electron is equal to the energy of a single X-ray photon of wavelength λ_0. Explain how λ_0 from the X-ray tube changes when the accelerating potential difference of the X-ray tube is **doubled**.

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.... **[2]**

(b) X-rays are used to scan the human body. A parallel beam of X-rays is incident on a muscle. The attenuation (absorption) coefficient μ for X-rays in muscle is $0.96\,\text{cm}^{-1}$.

(i) Calculate the fraction of X-ray intensity **absorbed** by 2.3 cm of muscle.

fraction = ... **[3]**

(ii) The attenuation coefficients for X-rays in bone and fat are $2.8\,\text{cm}^{-1}$ and $0.90\,\text{cm}^{-1}$ respectively. Two X-ray images are taken, one with bone and muscle and another with muscle and fat. State and explain which image will give better contrast.

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.... **[1]**

[Total: 10]

Question			Answers	Marks	Guidance
7	(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) × 10^{-15} (J) value of energy level = - 4.4 × 10^{-16} (J)	C1 C1 A1	**Note**: The answer must be <u>negative</u> 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 <u>and</u> 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**	