

OCR A-LEVEL PHYSICS A • H556

PHYSICS



EXAM QUESTION PACK

6.5 MEDICAL IMAGING

SCORE

/110

PERCENTAGE

%

STEMUP

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1(a) Fig. 8.1 shows a B-scan image of an ultrasound scan of a 12 week fetus.



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.

[3]

Blank lined paper for writing.



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.

[41]

- 2 A radiographer in a hospital directs a parallel beam of X-rays at the leg bone of a patient. The attenuation (absorption) coefficient of bone is 0.7 cm^{-1} .

The answers below are given to one significant figure.

What is the percentage intensity of X-rays transmitted through bone of thickness 0.7 cm ?

- A 0 %
- B 40 %
- C 50 %
- D 60 %

Your answer

[1]

- 3 The potential difference across the cathode and the anode of an X-ray tube is V . The minimum wavelength of the X-ray photons emitted from the tube is λ_0 .

Which of the following statements is / are correct?

- 1 λ_0 is halved when V is doubled.
- 2 λ_0 is unchanged when the temperature of the cathode is increased.
- 3 λ_0 is independent of the cathode material.

- A 1, 2 and 3
- B Only 2 and 3
- C Only 1 and 2
- D Only 2

Your answer

[1]

- 4 PET scanners are expensive because they require a near-by or on-site particle accelerator that produces fluorine-18. Discuss the ethical issues this raises in the treatment of patients.

[2]

5(a) State what is meant by the *piezoelectric effect*.

[1]

- (b) In an experiment, a beam of ultrasound is directed at the boundary between two materials **A** and **B**. Fig. 24.1 shows the beam incident at right angles to the boundary between these two materials.

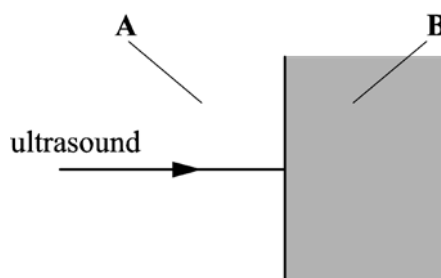


Fig. 24.1

The material **A** is unchanged. The acoustic impedance of material **A** is $2.5 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$. The material **B** is varied. The acoustic impedance of **B** is Z .

Fig. 24.2 shows the variation with Z of the percentage of reflected intensity of the ultrasound at the boundary.

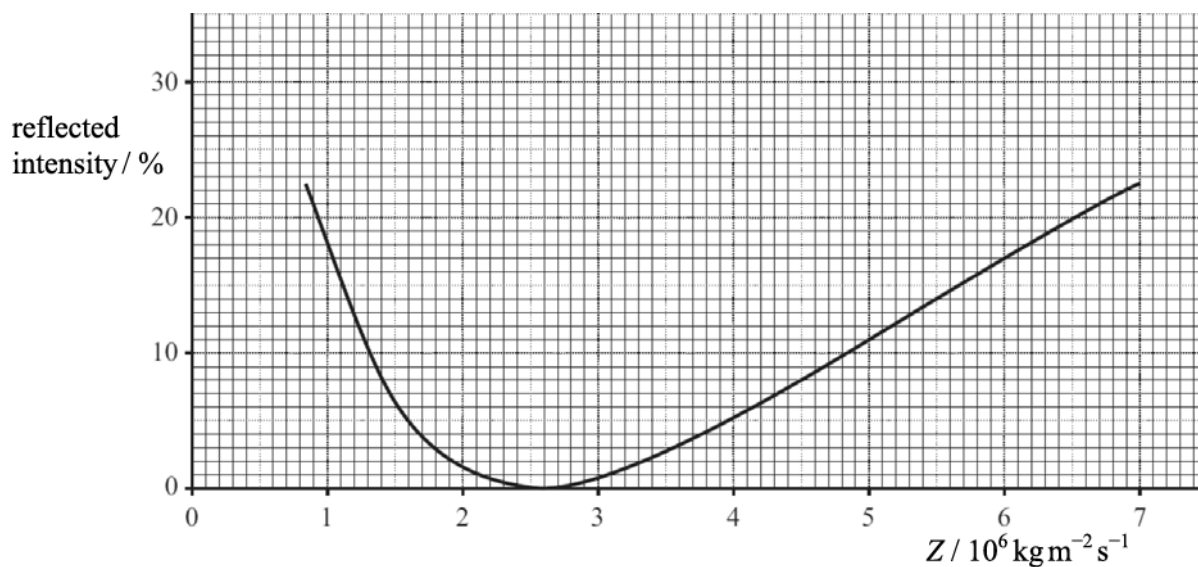


Fig. 24.2

Explain why the curve shown in Fig. 24.2 has a dip.

[3]

- (c) Describe and explain a method using ultrasound to determine the speed of blood in an artery in an arm. State one major advantage of this technique for the patient.

[4]

6 What is the correct SI unit for acoustic impedance?

- A kg s
B $\text{kg m}^{-2} \text{s}^{-1}$
C $\text{kg m}^{-3} \text{s}^{-1}$
D $\text{kg m}^{-2} \text{s}^{-2}$

Your answer

[1]

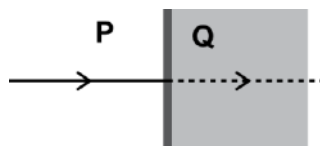
7 Which is **not** a component used in a gamma camera?

- A X-ray tube
B collimator
C computer
D photomultiplier tubes

Your answer

[1]

- 8 The diagram below shows a beam of ultrasound incident at the boundary between two materials.
The acoustic impedance of material P is 1.5 times the acoustic impedance of material Q.



What is the percentage of the ultrasound intensity **transmitted** at the boundary?

- A 20 %
- B 30 %
- C 80 %
- D 96 %

Your answer

[1]

9(a) Describe the X-ray attenuation mechanisms of *simple scatter* and *pair production*.

simple scatter _____

pair production _____

[2]

(b) Calculate the maximum wavelength of the X-rays for the pair production process.

maximum wavelength = _____ m [3]

(c) An X-ray image of a patient's arm is required.

Fig. 23.1 shows a parallel beam of X-rays is incident on a cross-section of the patient's arm.

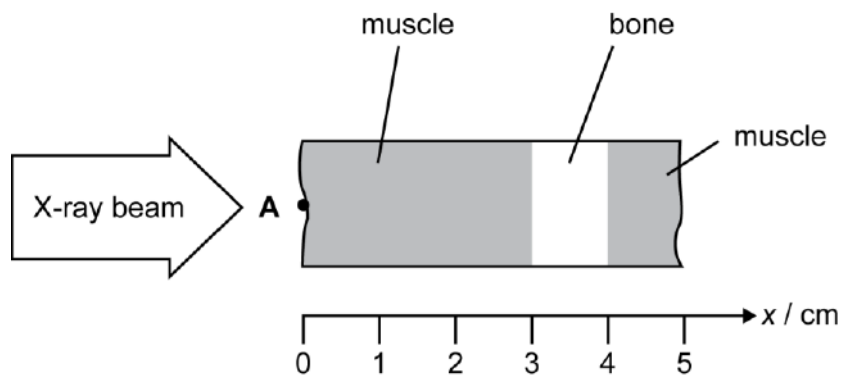


Fig. 23.1

Fig. 23.2 shows the variation of the intensity of the X-rays with distance x from the point A.

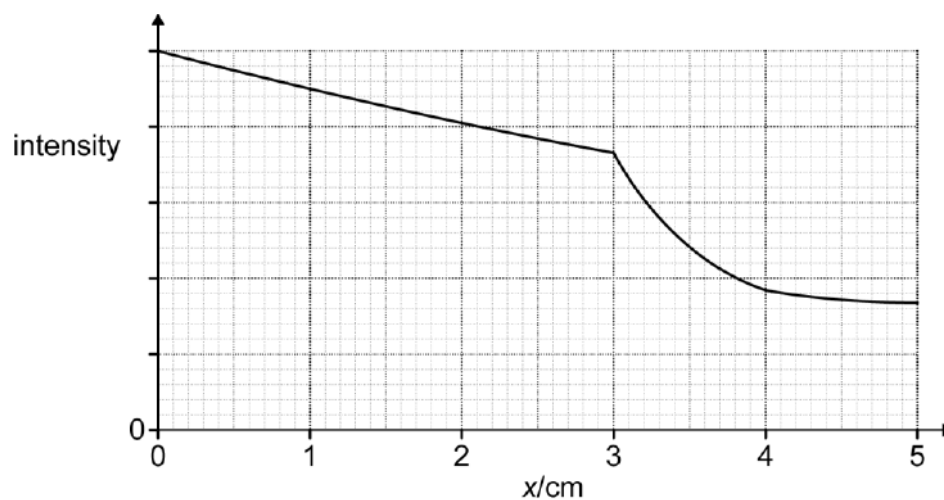


Fig. 23.2

Explain the shape of the graph shown in Fig. 23.2.

[4]

10(a) A patient is having an X-ray scan. The X-rays interact with the atoms in the patient. Name and describe the **three** methods by which X-rays interact with matter.



In your answer, you should make clear why the transmitted intensity of the X-rays decreases.

[4]

- (b) A radiographer uses X-rays of wavelength 1.4×10^{-11} m to investigate how the intensity I of X-rays transmitted through bone varies with its thickness x .
 Fig. 8.1 shows a graph of $\ln(I)$ against x .

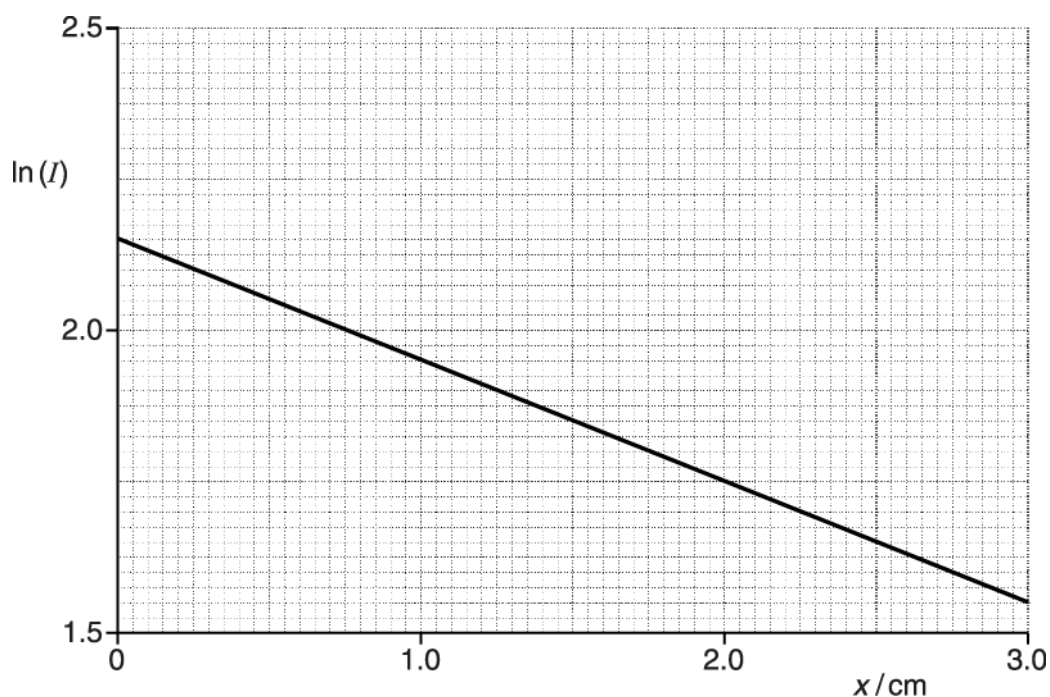


Fig. 8.1

(i) Calculate the energy of a single X-ray photon of this wavelength.

energy = ... J [2]

(ii) Use Fig. 8.1 to determine the absorption (attenuation) coefficient μ of bone.

μ = ... cm^{-1} [2]

11(a) An ultrasound transducer has a material inside that uses the piezoelectric effect to both emit and receive ultrasound.

Explain what is meant by the *piezoelectric effect*.

----- [1]

(b)

(i) Define the *acoustic impedance* of a material.

----- [1]

(ii) Suggest **one** main difference between a pulse of ultrasound of frequency 1 MHz in air and the same ultrasound pulse passing through a patient.

----- [1]

- (c) A parallel beam of ultrasound is incident at right angles to a boundary between muscle and fat. The table of Fig. 10.1 gives some information about these two materials.

Material	Density / kg m ⁻³	Speed of ultrasound / m s ⁻¹
muscle	952	1450
fat	1070	1580

Fig. 10.1

Determine the percentage of ultrasound intensity **transmitted** at the boundary between muscle and fat.

intensity transmitted = _____ % [3]

- 12 Ultrasound is reflected at a boundary between two materials.

Which property of the materials governs the intensity of the ultrasound reflected at the boundary?

- A density
- B decay constant
- C acoustic impedance
- D attenuation coefficient

Your answer ☐

[1]

13 A gamma camera is connected to a computer and a display. Sophisticated software is used to produce a quality scan (image) of the patient.

(i) Briefly describe the function of the collimator, scintillator and photomultiplier tubes in a gamma camera.

[3]

(ii) Fig. 23 shows two types of lead collimator tubes T and S available for a gamma camera.



Fig. 23

Tube T is thin and long. Tube S is broad and short.

Discuss which type of tube would be more suitable in a gamma camera.

[2]

14(a) A patient with a blood clot in his muscle is having an ultrasound A-scan.
Fig. 24.1 shows an ultrasound transducer placed on the patient's skin.

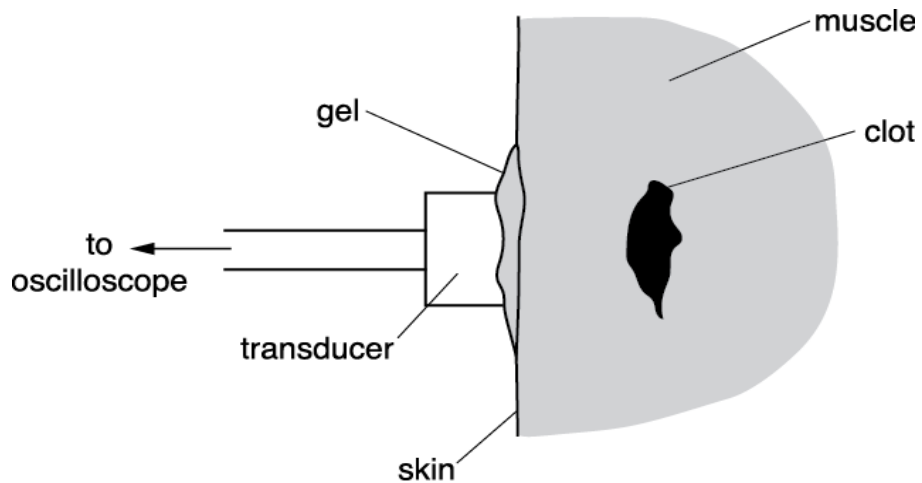


Fig. 24.1 (not to scale)

The ultrasound transducer produces pulses of ultrasound. An oscilloscope is connected to the transducer. Fig. 24.2 shows part of the oscilloscope display.

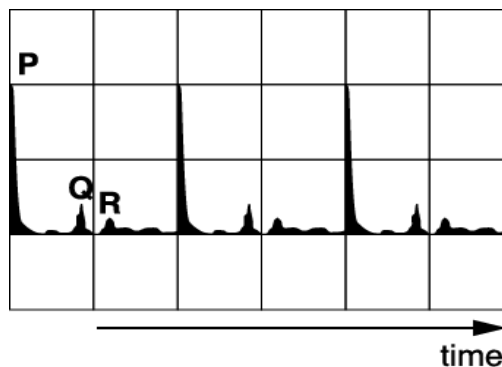


Fig. 24.2

In Fig. 24.2, P is one of the signal pulses produced by the transducer.
Explain the origin of the pulses Q and R.

[2]

- (b) The **front** of the blood clot is 1.5 cm from the skin.
The density of the patient's muscle is 1070 kg m^{-3} .
The time difference between pulses **P** and **Q** in Fig. 24.2 is $19 \text{ }\mu\text{s}$.
Determine the acoustic impedance Z of patient's muscle. State an appropriate unit for your answer.

$Z =$ _____ unit: _____ [4]

- 15 There are four important attenuation mechanisms by which X-ray photons may interact when they pass through matter.

In which mechanism is the X-ray photon scattered with a longer wavelength?

- A simple scattering
- B Compton effect
- C pair production
- D photoelectric effect

Your answer

[1]

Describe how a PET scanner is used to locate an area of increased activity within the patient.

[4]

Calculate the time t in minutes for the activity of the radiopharmaceutical to decrease to 30% of its initial activity.

$t =$ _____ minutes [3]

- (c) PET scanners are not available in all hospitals. This is because fluorine-18 requires expensive on-site particle accelerators and fluorine-18 has a very small 'shelf-life'.

Suggest the impact this may have on the treatment and diagnosis of patients in the country.

[1]

- 17 The acoustic impedance Z of a material in the shape of a cube can be determined using the equation

$$Z = \frac{Mc}{L^3}$$

where M is the mass of the material, L is the length of each side of the cube and c is the speed of ultrasound in the material.

The percentage uncertainty in L is 1.2 % and the percentage uncertainty in c is 1.8 %. The percentage uncertainty in M is negligible.

What is the percentage uncertainty in Z ?

- A 2.2 %
- B 3.0 %
- C 4.2 %
- D 5.4 %

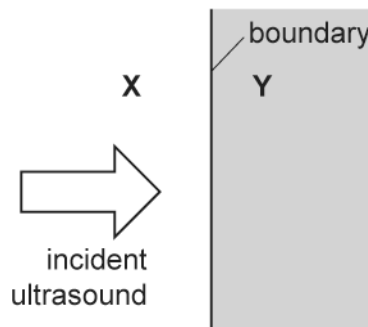
Your answer

[1]

18 The table shows some data on two tissues in a patient.

Tissue	Density	Acoustic impedance
X	ρ	$1.5 Z$
Y	1.3ρ	Z

Ultrasound in tissue X is incident at the boundary between the tissues X and Y.



What is the percentage of the ultrasound intensity reflected at the boundary?

- A 1.7 %
- B 4.0 %
- C 13 %
- D 20 %

Your answer

[1]

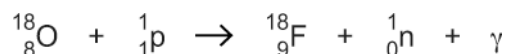
19 A contrast material is used while taking an X-ray image of a patient.
Which statement is correct?

- A Iodine is a contrast material.
- B Technetium is a contrast material.
- C A contrast material must have a short half-life.
- D A contrast material is used for acoustic matching.

Your answer

[1]

The nuclear reaction below shows how the isotope of fluorine-18 ($^{18}_9\text{F}$) is made from the isotope of oxygen-18 ($^{18}_8\text{O}$).



The oxygen-18 nucleus is **stationary** and the proton has kinetic energy of $0.25 \times 10^{-11} \text{ J}$.

The binding energy of the $^{18}_8\text{O}$ nucleus is $2.24 \times 10^{-11} \text{ J}$ and the binding energy of the $^{18}_9\text{F}$ nucleus is $2.20 \times 10^{-11} \text{ J}$. The proton and the neutron have zero binding energy.

(i) Explain why a high-speed proton is necessary to trigger the nuclear reaction shown above.

----- [2]

(ii) Estimate the minimum wavelength λ of the gamma ray photon (γ).

$\lambda =$ ----- m [3]

(iii) Fluorine-18 is a positron emitter.

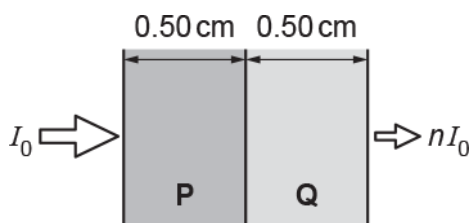
Name a medical imaging technique that uses fluorine-18 and state one benefit of the technique.

----- [2]

21 Explain how ultrasound is used to measure the speed of blood flow in an artery.

[2]

- 22 The intensity of a beam of X-rays incident on material **P** is I_0 .
The beam passes through 0.50 cm of material **P** and 0.50 cm of material **Q**.



The absorption (attenuation) coefficients of **P** and **Q** are 0.60 cm^{-1} and 0.20 cm^{-1} respectively.
The intensity of the beam after passing through both **P** and **Q** is nI_0 .

What is the value of n ?

- A 0.67
- B 0.74
- C 0.82
- D 0.90

Your answer

[1]

You may draw a labelled diagram.

[3]

- (b) A beam of X-rays is directed at tissues in a patient.
The X-ray photons interact with the atoms of the tissues.

Simple scatter is one of the attenuation mechanisms.

Name and describe **two** other attenuation mechanisms.

1

2

[4]

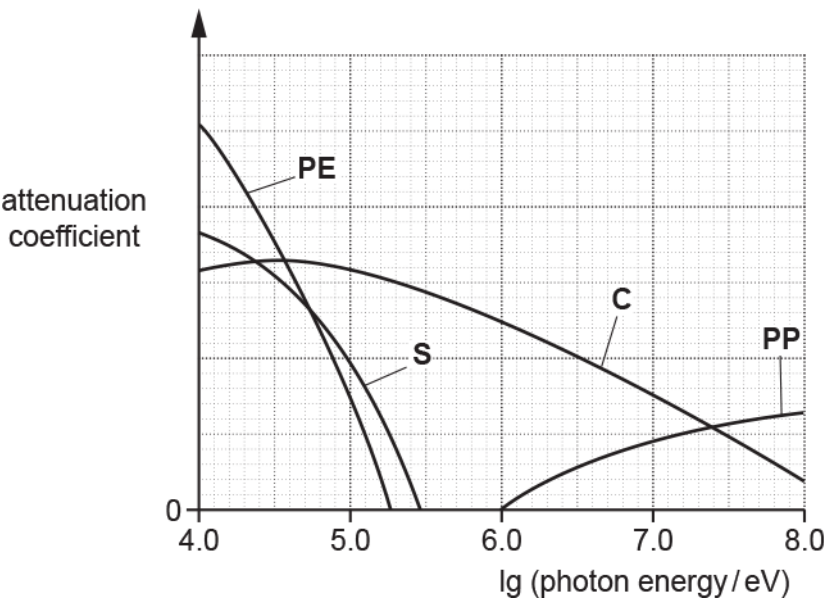
24(a) Explain how an ultrasound transducer can **emit** ultrasound.
You do **not** need to describe the design of the transducer.

[2]

(b) Explain how the reflection of ultrasound at a boundary between two tissues depends on the physical properties of the tissues.

[3]

The attenuation coefficient against lg(photon energy) graphs for simple scattering (S), photoelectric effect (PE), Compton effect (C) and pair production (PP) are shown below.



For the X-ray tubes used in hospital, the X-ray photons have energy of about 10⁵ eV.

State the attenuation mechanisms for these photons.

[1]

26(a) The medical tracer technetium-99m is used in imaging organs such as the brain.

Explain the advantages of using technetium-99m for this purpose.

[2]

(b) A gamma-camera uses powerful computers and sophisticated software to produce three- dimensional images of the patient's organ.

Name and describe the remaining three main components of the gamma camera.

[3]

27 The Doppler effect is used to measure the speed of blood flow in arteries.

Which medical diagnostic method uses this technique?

- A barium scan
- B CAT scan
- C PET scan
- D ultrasound scan

Your answer ☐

[1]

28(a) This question is about the medical use of ultrasound.

In ultrasound scanning, explain what is meant by **impedance (acoustic) matching** and how it may be achieved.

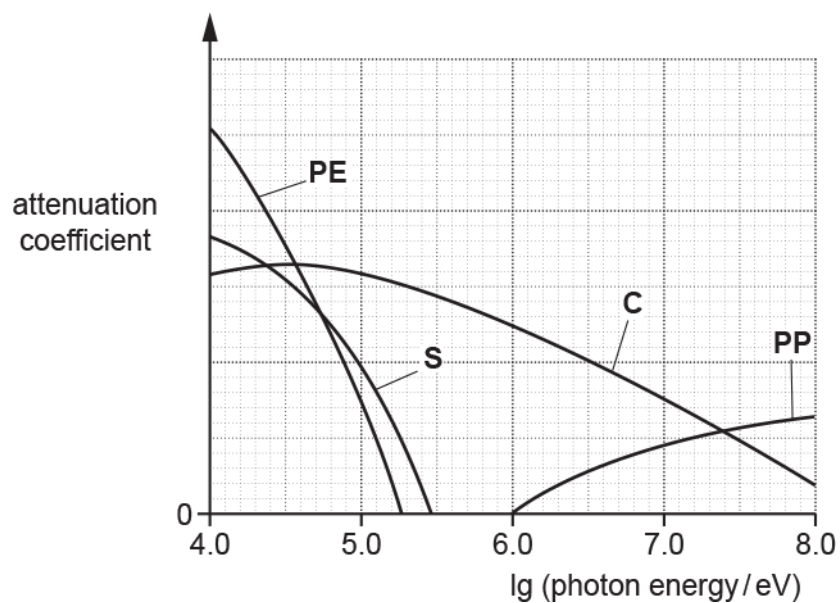
[2]

(b) There are several different types of ultrasound scanning techniques.

Explain how an A-scan could be used to measure the thickness of a patient's eye lens.
You may draw a diagram to help with your answer.

[3]

The attenuation coefficient against $\lg(\text{photon energy})$ graphs for simple scattering (S), photoelectric effect (PE), Compton effect (C) and pair production (PP) are shown below.



With the help of a calculation, explain the minimum photon energy for pair production.

[3]

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1	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. Examiner's Comments Generally, candidates answered this question about the principles of a B-scan extremely well. Some candidates gave unnecessary details of ultrasound transducers and acoustic matching with a gel. A pleasing number of candidates picked up the QWC mark for explaining how the intensity of the reflected ultrasound at the boundary between materials depended on the acoustic impedances. A very small number of candidates used the term <i>attenuation coefficient</i> rather than <i>acoustic impedance</i> in their descriptions.
	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.	B1 × 4	Not positrons and electrons annihilate to produce photons travelling in opposite directions for 3. Allow an answer in terms of arrival times.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			5. Computer connected to detectors / gamma camera and an image is formed by the computer (using the electrical signals from the detectors).		Examiner's Comments The majority of the candidates gave decent explanations of the basic principles of PET scanning and scored two or more marks. The quality of the answers was good, with many candidates showing excellent understanding of the annihilation of positron-electron, the production of two gamma photons and the detection of these photons to form an image. The question discriminated well.
			Total	7	
2			B	1	
			Total	1	
3			A	1	
			Total	1	
4			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	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
5	a		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.
	b		The fraction f of the incident intensity of ultrasound reflected at the boundary is given $f = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$ There is reflection when $Z \neq 2.5 \times 10^6 \text{ (kg m}^{-2} \text{ s}^{-1}\text{)}$ At $Z = 2.5 \times 10^6 \text{ (kg m}^{-2} \text{ s}^{-1}\text{)}$ there is impedance (acoustic) matching and hence no reflection of ultrasound.	B1 B1 B1	
	c		The transducer is placed at an angle to the arm or artery and ultrasound is reflected by the moving blood cells. The wavelength or the frequency of the reflected ultrasound is altered. Since $\Delta f = \frac{2vf \cos \theta}{c}$, the change in frequency $\propto$ speed of the blood. The technique is non-invasive / no incision needed / minimises risk of infection.	B1 B1 B1 B1	
			Total	8	
6			B	1	
			Total	1	
7			A	1	
			Total	1	
8			D	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
9	a		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	
	b		$\frac{hc}{\lambda} = 2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2$ $\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2}$ $\lambda = 1.2 \times 10^{-12} \text{ (m)}$	C1 C1 A1	Allow 2 marks for $2.4 \times 10^{-12} \text{ (m)}$; factor of 2 omitted in the first line.
	c		The intensity decreases with thickness of muscle / bone. The decrease is exponential. The attenuation (absorption) coefficient μ of bone must be greater than the μ of muscle because there is a significant decrease in the intensity from $x = 3.0 \text{ cm}$ to 4.0 cm .	B1 B1 B1 B1	
			Total	9	

Mark Scheme

[illegible]

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		i	$(E =) \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{1.4 \times 10^{-11}} \text{ or } (f =) 2.14 \times 10^{19} \text{ (Hz)}$	C1	Examiner's Comments Most candidates picked up two marks for calculating the energy of a photon of wavelength 1.4×10^{-11} m. There were very few errors and the omission rate was less than 5%.
		i	energy = 1.4×10^{-14} (J)	A1	
		ii	gradient = $(-)\mu$	C1	Allow correct substitution into $\ln I = \ln I_0 - \mu x$; coordinates read to $\pm \frac{1}{2}$ small square Allow 1 SF answer of 0.2 (cm^{-1}) Allow answer in the range 0.19 to 0.21 (cm^{-1}) Ignore sign Examiner's Comments This was a perfect question for the upper quartile candidates. The answers from these candidates showed excellent understanding of the exponential decay equation and natural logs. The absorption coefficient μ was equal to the - gradient of the straight line on the $\ln(I)$ against x graph. Middle and low scoring candidates struggled to determine the gradient because of misunderstanding of the $\ln(I)$ values. This is illustrated with the following incorrect answers: $\bullet \mu = \frac{\ln 2.15 - \ln 1.95}{1.0} = 0.098 \text{ cm}^{-1}$ $\bullet \mu = \frac{e^{2.15} - e^{1.95}}{1.0} = 1.56 \text{ cm}^{-1}$ The correct analysis was much simpler; $\mu = \frac{2.15 - 1.95}{1.0} = 0.20 \text{ cm}^{-1}$
		ii	$\mu = 0.20 \text{ (cm}^{-1}\text{)}$	A1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
11	a		Applying a p.d across the material makes it expand / compress / deform / strain (ORA)	B1	Allow: Applying a varying p.d. produces vibrations / ultrasound Allow: Ultrasound hitting the material produces a varying e.m.f. Allow: voltage or p.d. instead of e.m.f. Not current Examiner's Comments Most candidates knew about the piezoelectric effect but some lost the mark for describing the effect as '<i>application of a voltage produces vibration</i>'. It's an alternating p.d. that would produce vibrations in the material.
	b	i	(acoustic impedance =) speed (of ultrasound in the material) × density (of material)	B1	Not $Z = \rho c$ Examiner's Comments Acoustic impedance was correctly defined by almost all candidates. The most frequent slip was to confuse the speed of ultrasound c with the speed of light c.
		ii	Any one from: • Speed / wavelength is different • Travel slow(er) in air (ORA) • Ultrasound has short(er) wavelength in air (ORA) • Reflection(s) occur inside patient (ORA) • Greater attenuation (of ultrasound) inside patient (ORA)	B1	Penalise wrong physics, e.g 'travel faster in air' Not frequency Not acoustic impedance Examiner's Comments It was the brief answers that often scored a mark. No credit was given for incorrect physics such as: • <i>The speed of ultrasound is greater in air.</i> • <i>The frequency of ultrasound is different in the body.</i>
	c		$(Z_{(m)} =) 1.38 \times 10^6 / (Z_{(f)} =) 1.69 \times 10^6$	C1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			$\frac{(1.38 - 1.69)^2}{(1.38 + 1.69)^2} \quad \text{or} \quad 0.01(02)$	C1	
			intensity transmitted = 99 %	A1	Note: 1.0(2)% scores 2 marks Examiner's Comments The modal mark for this question was three, with most candidates answering the question with confidence and familiarity. The most common mistake was to leave the answer as 1.02 %. Surprisingly, a small number of candidates made an error when subtracting 1.02 from 100; the answer was given as 98.
			Total	6	
12			C	1	
			Total	1	
13		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	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
14	a		The reflection of the ultrasound produces the pulses Q and R	B1	
			Pulses Q and R are due to reflections from the front and back of the clot	B1	
	b		speed = $2 \times 1.5 \times 10^{-2} / 19 \times 10^{-6}$ (= 1579 m s ⁻¹) $Z = \rho c = 1070 \times 1579$ $Z = 1.7 \times 10^6$ unit: kg m ⁻² s ⁻¹	C1 C1 A1 B1	Allow 2 marks for 8.4×10^5 ; factor of 2 omitted
			Total	6	
15			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
16	a		The patient is surrounded by (gamma) detectors or Increased activity is where F-18 accumulates (AW)	B1	Allow 'diametrically opposite detectors'
			The positrons (from the F-18) <u>annihilate</u> electrons (inside the patient)	B1	
			Each annihilation produces two gamma photons travelling in <u>opposite</u> directions	B1	Not gamma rays / radiation
			The arrival times are used to locate position (of increased activity)	B1	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		$\lambda = \ln 2 / 110$ or $6.3 \times 10^{-3} \text{ (min}^{-1}\text{)}$ $0.30 = e^{-6.3 \times 10^{-3} t}$ $t = \frac{\ln(0.30)}{-6.3 \times 10^{-3}}$ $t = 190 \text{ (minutes)}$	C1 C1 A1	Allow $1.05 \times 10^{-4} \text{ (s}^{-1}\text{)}$ This is the same as $0.30 = e^{-1.05 \times 10^{-4} t}$ Note: This mark is for a ln expression (any subject) Allow 2 marks for $1.15 \times 10^4 \text{ (s)}$ 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.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	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	
17			D	1	
			Total	1	
18			B	1	
			Total	1	
19			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	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
20	a	i	Proton is repelled (by nucleus)	B1	
			(High-speed) proton can get close to (oxygen) nucleus	B1	Allow 'proton can experience the strong (nuclear) force' Not 'collide / hit nucleus'
		ii	$E = [0.25 - (2.24 - 2.20)] \times 10^{-11} \text{ (J) or } 0.21 \times 10^{-11} \text{ (J)}$ $\lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{0.21 \times 10^{-11}} \text{ (Any subject)}$ $\lambda = 9.5 \times 10^{-14} \text{ (m)}$	C1 C1 A1	Allow 2 marks for 6.9×10^{-14} ; $E = 0.29 \times 10^{-11}$ used Allow 1 mark for a value correctly calculated based on any other incorrect value for E (e.g. $8(.0) \times 10^{-14}$ for $E = 0.25 \times 10^{-11}$ and $5(.0) \times 10^{-13}$ for $E = 0.04 \times 10^{-11}$)
		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.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		X-ray (tube) moves around the patient A thin (fan-shaped X-ray) beam is used (Images / scans of) cross-sections through the patient are taken Any <u>one</u> from: • A three-dimensional image is produced • (Soft) tissues can be identified	B1 B1 B1 B1	Allow 'X-rays passed through different angles.' Allow 'slice(s)' Allow 'good contrast image' <u>Examiner's Comments</u> 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	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
21			• <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 60°) (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	
22			A	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
23	a		(Evacuated tube with) cathode / heater / filament and target / metal / anode	B1	Ignore polarity of high voltage supply throughout
			High voltage (supply) connected between cathode and anode	B1	Note the first two B1 marks can be scored on a labelled diagram
			(Accelerated) electrons hit the target / metal / anode and their KE is transformed into X-ray (photons)	B1	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.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		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	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
24	a		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 <u>Examiner's Comments</u> 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.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		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	5	
25			All except pair production / PP	B1	Allow PE, S and C
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
26	a		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
	b		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	5	
27			D	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
28	a		(special coupling) gel is used that has the same / 'matching' (acoustic) impedance as skin / body	B1	Allow Z Allow gel and impedance is the same / matching for two materials / mediums
			Reduced / less / zero reflection (at the skin)	B1	Allow more transmission
	b		(Pulses of) ultrasound sent into the eye	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
			Reflections from front and back of lens (and pulses displayed on oscilloscope)	B1	
			(Thickness of lens) determined from speed (of ultrasound) and time (difference)	B1	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	5	
29			(energy =) $9.11 \times 10^{-31} \times (3.0 \times 10^8)^2$ (energy =) $2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2 / 1.60 \times 10^{-19}$ $\lg 1.0(2) \times 10^6 = 6$ (as on graph) OR (energy =) 1.0×10^6 (eV) or $\lg 1.0 \times 10^6 = 6$ (from graph) (energy =) 1.6×10^{-13} J and evidence of mc^2 $2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2 \approx 1.6 \times 10^{-13}$	B1 B1 B1 B1 B1 B1	Note this is 8.2×10^{-14} (J) Note this is $1.0(2) \times 10^6$ eV Note this can be shown in a variety of ways
			Total	3	