Medical Imaging

1. 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]

2. 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]**

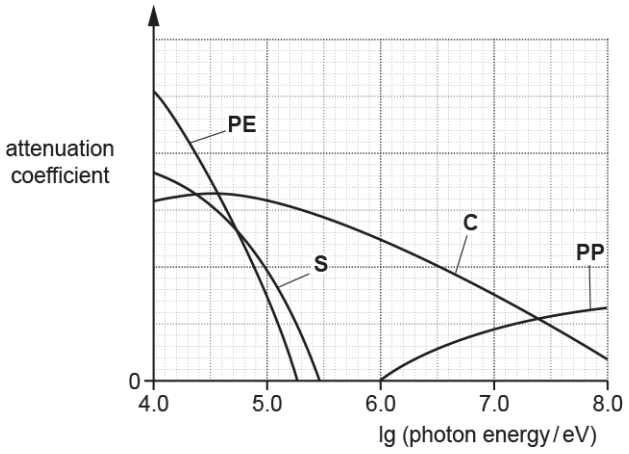
3. State what is meant by the *piezoelectric effect*.

---

[1]

4. X-ray photons interact with atoms.

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 10^5 eV.

State the attenuation mechanisms for these photons.

[1]

5. 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]

6. 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]**

7. 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?

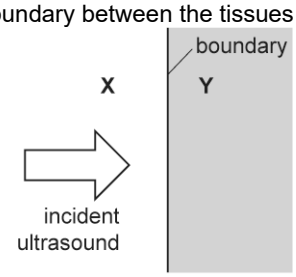
A simple scattering
B Compton effect
C pair production
D photoelectric effect

Your answer ☐ **[1]**

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

Tissue	Density	Acoustic impedance
X	ρ	1.5 Z
Y	1.3 ρ	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]**

9. 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.

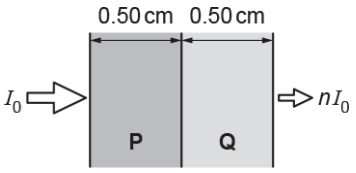
The percentage uncertainty in L is 1.2 % and the percentage uncertainty in c is 1.8 %. The percentage uncertainty in M is negligible.

What is the percentage uncertainty in Z?

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

Your answer ☐ **[1]**

10. 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]**

11. 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_o.

Which of the following statements is / are correct?

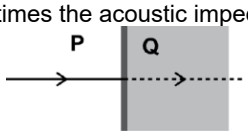
1. λ_o is halved when *V* is doubled.
2. λ_o is unchanged when the temperature of the cathode is increased.
3. λ_o is independent of the cathode material.

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

Your answer ☐

[1]

12. 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]

13. Which is **not** a component used in a gamma camera?

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

Your answer ☐

[1]

14. A beam of ultrasound is incident normally at a boundary between two tissues **F** and **G**.

The table below shows some data on the two tissues.

	Tissue F	**Tissue G**
Density of tissue	ρ	1.2ρ
Speed of ultrasound in tissue	c	1.5c

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

A 0.83%
B 8.2%
C 9.1%
D 29%

Your answer ☐ **[1]**

15. What is the correct SI unit for acoustic impedance?

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

Your answer ☐

[1]

16. Describe the X-ray attenuation mechanisms of *simple scatter* and *pair production*.

simple scatter .....

pair production .....

[2]

17. Explain how an ultrasound transducer can **emit** ultrasound.
You do **not** need to describe the design of the transducer.

[2]

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

[2]

19. 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]

20. 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]

21. 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.

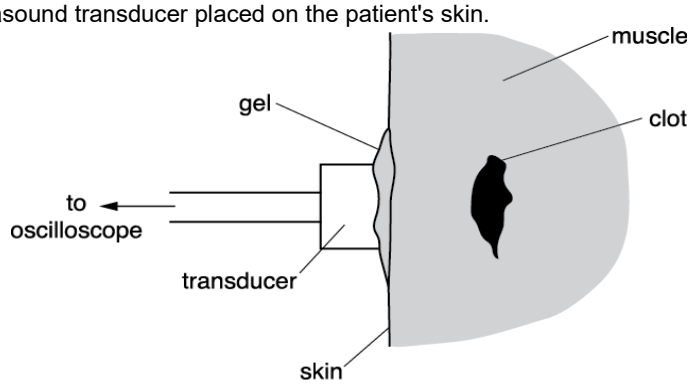


Fig. 24.1 (not to scale)

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

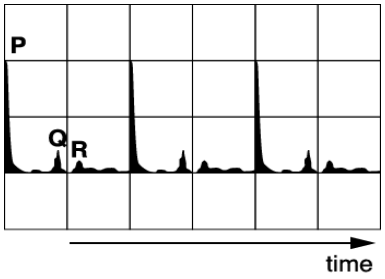


Fig. 24.2

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]

22. 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]

23. The diagram below shows a beam of X-rays incident normally on some soft tissue.

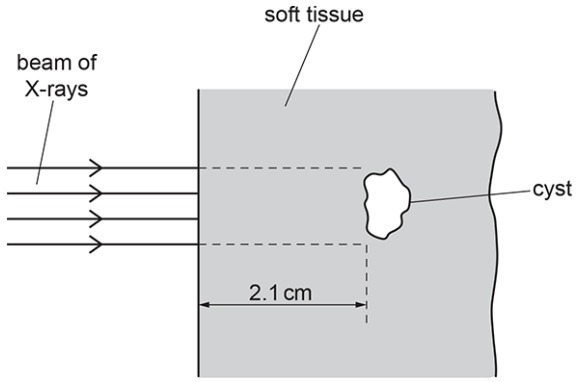


Fig. 2

The attenuation coefficients of the cyst and the soft tissues were similar. This prevented imaging the cyst using a two-dimensional X-ray image.

Name a different X-ray technique that could be used to image the cyst. Explain the advantage of this technique.

---

[2]

24. 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.

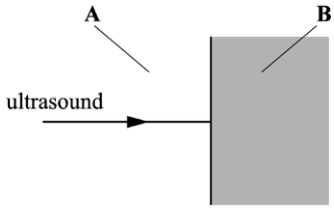


Fig. 24.1

The material **A** is unchanged. The acoustic impedance of material **A** is 2.5×10^6 kg m^{-2} 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.

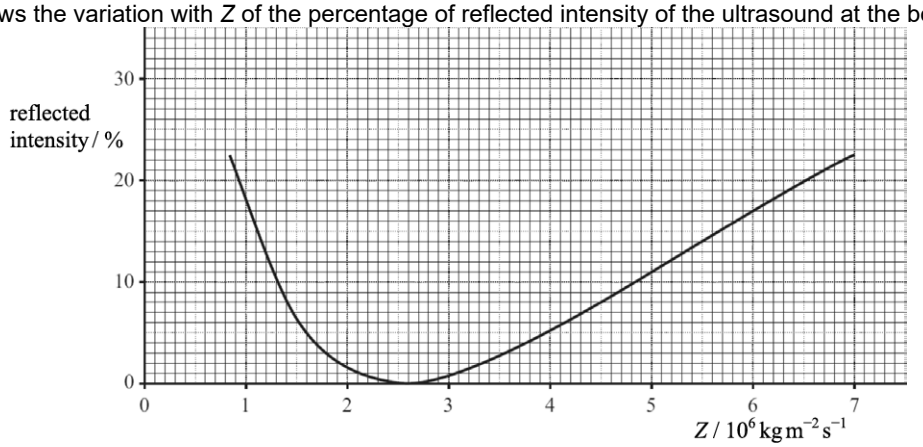


Fig. 24.2

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

[3]

25. A high-energy X-ray photon interacts with an electron of an atom through the **Compton effect**.

Describe this effect.

[2]

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

[3]

27. Calculate the maximum wavelength of the X-rays for the pair production process.

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

28. Describe the basic structure of an X-ray tube and explain how X-ray photons are produced.

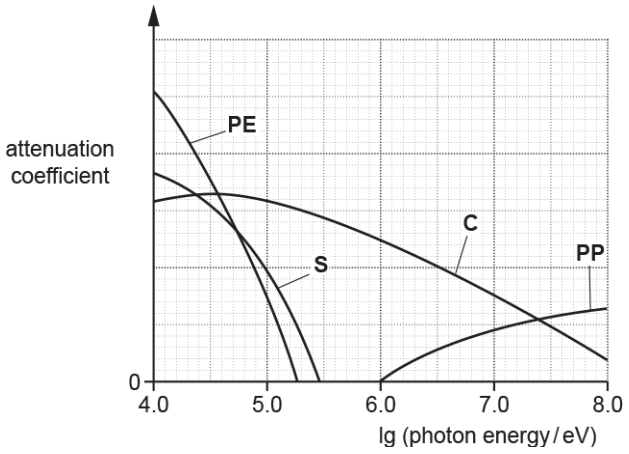
You may draw a labelled diagram.

---

[3]

29. X-ray photons interact with atoms.

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.



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

[3]

30. The medical tracer technetium-99m is used in imaging organs such as the brain.

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]

31. This question is about the medical use of ultrasound.

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]

32. The medical tracer fluorine-18 is used in positron emission tomography (PET).
Fluorine-18 is a beta-plus emitter with a short half-life.

Describe how the fluorine-18 nuclei are located in a patient using a PET scanner.

[4]

33. The diagram below shows a beam of X-rays incident normally on some soft tissue.

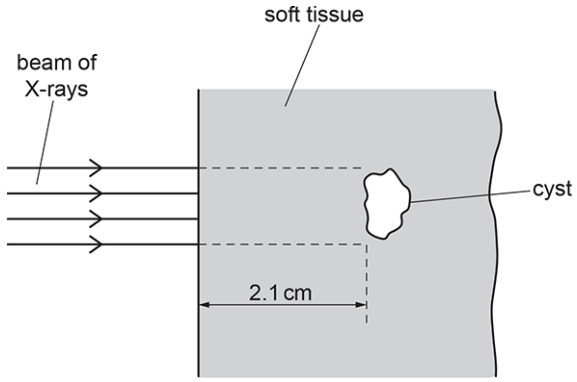


Fig. 2

The attenuation (absorption) constant of the soft tissue is 0.85 cm^{-1}.
The intensity of the beam is 4.6×10^3 W m^{-2}.
There is a small cyst 2.1 cm from the surface of the soft tissue. The cross-sectional area of the cyst normal to the beam is 3.4×10^{-4} m^2.

The beam is switched on for 30 s.

Calculate the X-ray energy incident on the cyst in a period of 30 s.

energy = ... J **[4]**

34. Describe how the components of a computerised axial tomography (CAT) scanner can produce high-quality images of the internal structures of a patient.

---

[4]

35. 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.

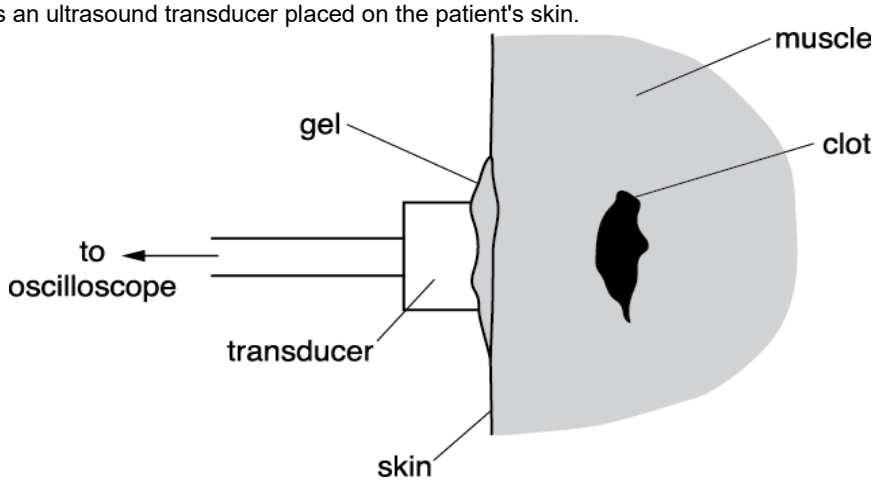


Fig. 24.1 (not to scale)

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

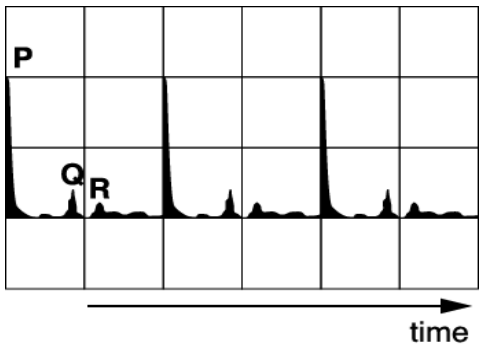


Fig. 24.2

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 μs.
Determine the acoustic impedance *Z* of patient's muscle. State an appropriate unit for your answer.

Z = ... unit: ..... **[4]**

36. 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]

37. 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.

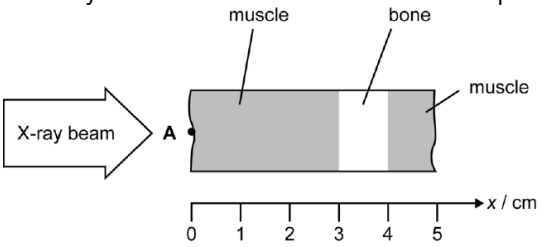


Fig. 23.1

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

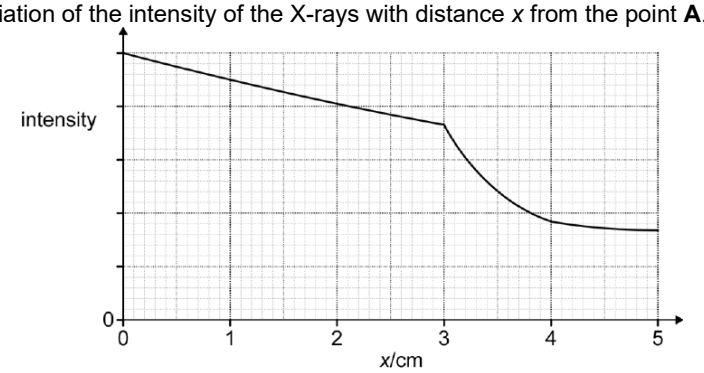


Fig. 23.2

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

[4]

38. 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]

39 (a). Fluorine-18 is a common radioactive isotope used in positron emission tomography (PET). Fluorine-18 emits positrons. A patient is injected with a radiopharmaceutical containing fluorine-18.

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

---

[4]

(b). The half-life of fluorine-18 is 110 minutes.
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]

40. 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]

41. The nuclear reaction below shows how the isotope of fluorine-18 ($^{18}_{9}F$) is made from the isotope of oxygen-18 ($^{18}_{8}O$).

$$^{18}_{8}O + {}^{1}_{1}p \rightarrow {}^{18}_{9}F + {}^{1}_{0}n + \gamma$$

The oxygen-18 nucleus is **stationary** and the proton has kinetic energy of 0.25×10^{-11} J.
The binding energy of the $^{18}_{8}O$ nucleus is 2.24×10^{-11} J and the binding energy of the $^{18}_{9}F$ nucleus is 2.20×10^{-11} 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]

END OF QUESTION PAPER