**1.**

i. Explain what is meant by a ***tracer***.

Material (introduced into the body and) used so its position in the body can be determined / function of organ can be determined **[1]**

ii. $^{99m}_{43}Tc$ only emits gamma radiation.

Give **two** advantages of using a tracer which only emits gamma radiation.

1 (Very) little ionisation

2 (Most can) pass through the body tissue / can be detected outside / highly penetrating

**[2]**

**2.** High-energy X-ray photons can destroy living cells. In radiotherapy, these photons are targeted at cancer cells.

The radiation **dose** is the amount of energy that a patient's body absorbs from the high-energy X-ray photons.

**Fig. 6.2** shows how this dose changes with depth below the surface of the skin.

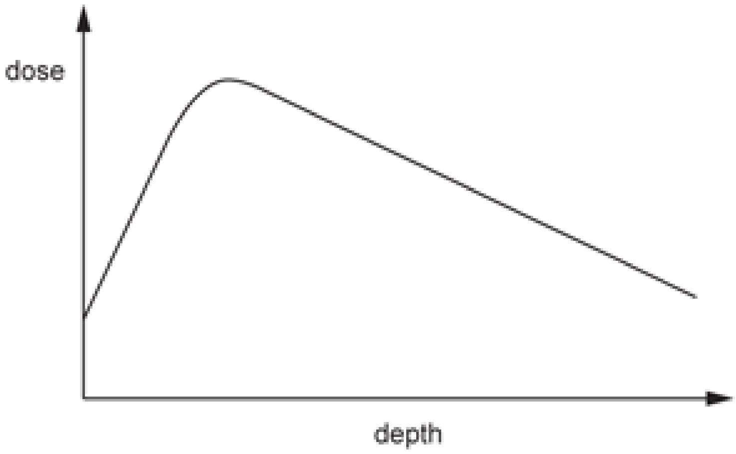



**Fig. 6.2**

The dose initially rises with depth because the high-energy X-ray photons produce electrons and positrons as they pass through the body. These electrons and positrons are quickly absorbed, increasing the dose.

i. Explain why high-energy X-ray photons produce electrons **and** positrons as they pass through the body.

(high-energy X-ray) photon interacts with nucleus / travels close to nucleus / disappears
• Positron is the antiparticle of an electron
• energy (of X-ray photon) is transformed into matter and antimatter
• particle and antiparticle pair produced / (mechanism known as) pair production occurs

**[2]**

ii. A 3D object called a **bolus** is used in radiotherapy for patients with skin cancer. A bolus targets the maximum radiation dose near the surface of the skin. So using a bolus makes the radiotherapy more effective.

A bolus can be made from PLA using a 3D printer. The bolus must fit the shape of the patient's body exactly. This shape is found beforehand by giving the patient either a CAT scan or a PET scan.

- Explain how CAT scans and PET scans work.
- Discuss the advantages and disadvantages of having a scan to produce a bolus for radiotherapy.

CAT scan
• Thin fan-shaped beam of X rays
• Ring of detectors rotate around patient
• Images of slices produced
• Instruments move along patient to take several 2D images Software produces 3D image

PET scan
• Positron-emitting tracer injected
• Positron annihilates electron producing two gamma photons
• Gamma photons travel in opposite directions
• Ring of gamma detectors around patient
• Delay time between arrival of photons locates annihilation
• Software produces 3D image

Discussion - balance of benefits and risks of having the scan
• Both types of scan deliver radiation dose to healthy tissue but
• a bolus would mean a lower dose is needed during radiotherapy
• Both types of scan are expensive / use NHS resources
• but radiotherapy also costly and less would be needed with bolus
• Scans can be long / scary / cause discomfort
• but the same is true of radiotherapy and less would be needed
• Both types of scan are risky but with a bolus the
• improved effectiveness of radiotherapy may save a patient's life

**[6]**

**3(a).** Radiographers commonly use molecules containing fluorine F-18 as tracers in positron emission tomography (PET) scanning.

Fluorine has a proton number of 9.

F-18 decays to oxygen (O) by $\beta^+$ decay.

Write the equation for the decay of a nucleus of F-18 using nuclear notation.

**[2]**

**(b).** The $\beta^+$ particle (positron) produced travels only a short distance in the patient before it meets an electron and is annihilated.

Calculate the wavelength $\lambda$ of gamma photons produced.

$\lambda$ = ....................................................m **[3]**

**(c).** X-rays and gamma-rays are produced by different physical processes.
Briefly describe both processes.

**[2]**

**(d).** F-18 has a half-life of 109.7 minutes.

Explain the advantage that this has for the patient but the disadvantage that this has for the radiographers.

**[3]**

**4(a).** Ultrasound B-scans can be used to image unborn babies.
**The figure below** shows a B-scan of an unborn baby.

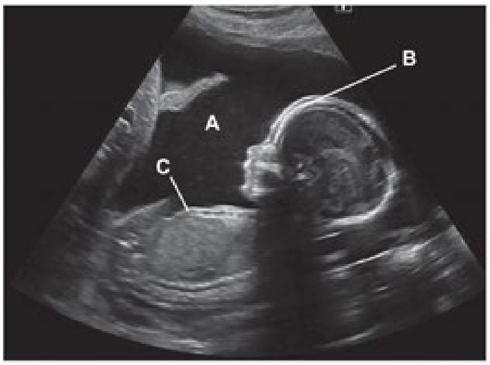



**Fig. 17.2**

i. Explain why no signal is received back from **A**.

**[1]**

ii. Explain why a greater signal is received back from **B** than **C**.

**[2]**

**(b).** Doppler ultrasound can be used to measure the speed of blood flow through blood vessels.

The speed of ultrasound in blood is 1600 $ms^{-1}$.

A transducer emitting ultrasound of frequency 10.0000 MHz is placed at 50° to the blood vessel.

The reflected ultrasound has a frequency of 9.9987 MHz.

$\Delta f = 0.0013 \text{ Hz} \times 10^6$

Calculate the speed *v* of the blood flow.

$$\Delta f = \frac{2f\, v \cos\theta}{c} \longrightarrow V = \frac{c\, \Delta f}{2f \cos\theta} = \frac{1600 \times (0.0013 \times 10^6)}{2 \times 10 \times 10^6 \times \cos 50} =$$

*v* = ............................................ $ms^{-1}$ **[2]**

$= 0.16$ m/s

**(c).** Explain what is meant by ultrasound.

$f > 20$ kHz

Longitudinal waves

With a frequency greater than 20 kHz

**[2]**

**(d). Fig. 17.1** is a labelled photograph of an ultrasound examination of a patient.

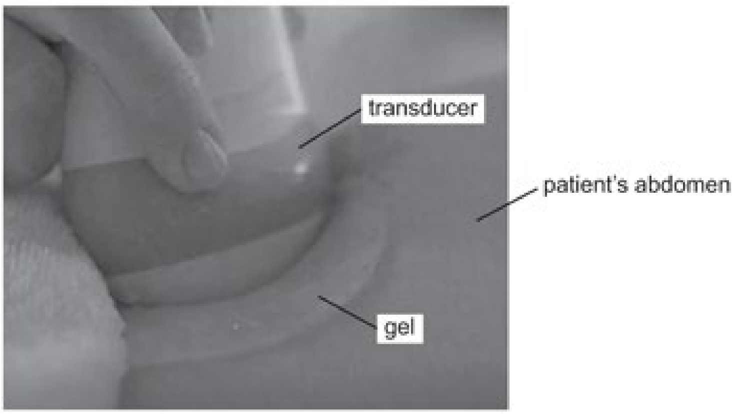



**Fig. 17.1**

Explain how the transducer both produces and receives ultrasound waves.

Explain the purpose of the gel.

Transducer
• High frequency alternating PD applied to the faces of the piezoelectric crystal.
• Causes the piezoelectric crystal to stretch and compress / oscillate / resonate at high frequency.
• Ultrasound waves sent in pulses
• Between pulses, reflected ultrasound incident on the piezoelectric crystal causes the crystal to change shape / oscillate / resonate
• An alternating PD is induced Gel
• Acoustic impedance of air is different to body
• Acoustic impedance of gel is similar to body
• This allows greater transmission of the ultrasound

**[6]**

**5.** Technetium-99m (Tc-99m) is a metastable isotope used in medical diagnosis.

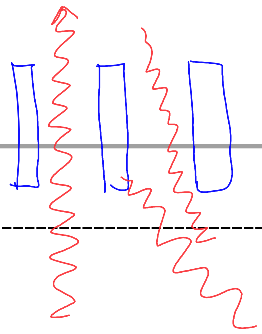
Which ionising radiation does Tc-99m emit?

**A** alpha
**B** beta-minus
**C** beta-plus
**D** gamma ✓

Your answer ☐ **[1]**

**6(a).** A gamma camera has several important components including a collimator, scintillator and photomultiplier tubes.

Suggest why the collimator needs to be long and narrow.



Allows only those gamma rays / waves / photons travelling along axis (of the collimator) to get through (and reach scintillator) **[1]**

**(b).** State the function of the scintillator.

Turn gamma (photons) into (many photons of) light **[1]**

$10^{-6}$

**(c).** In a single photomultiplier tube, a photon of light produces a 0.32 μA pulse of current for a duration of 1.2 ns.

Calculate the number of electrons responsible for this pulse of current.

$I = 0.32 \times 10^{-6}$ A

$t = 1.2 \times 10^{-9}$ s

number of electrons = ................................................ **[2]**

$Q = It = 0.32 \times 10^{-6} \times 1.2 \times 10^{-9} = \ldots$

$n = \frac{Q}{e} = \frac{\ldots}{1.6 \times 10^{-19}} = 2400$

**(d).** State one diagnostic application of a gamma camera.

Any sensible diagnostic suggestion, e.g. detection of cancer / scans of (named) organ / scans of tissue / bone scans / observing functionality of (named) organ

**[1]**

**7(a).**

Describe, in terms of X-ray photons, the attenuation mechanism of Compton scattering.

Photon scattered with less energy / X ray of lower frequency / X-ray of longer wavelength

Electron removed (from the atom)

**[2]**

**(b).** A parallel beam of X-rays is incident normally on a tissue as shown in **Fig. 24. 1**.

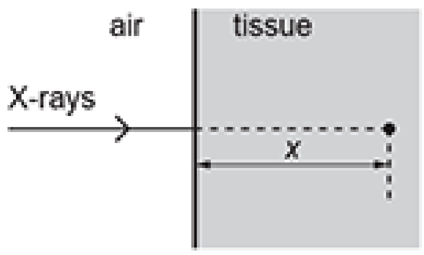



**Fig. 24.1**

The variation of the intensity *I* of the X-rays with depth *x* in the tissue is shown in **Fig. 24. 2**.

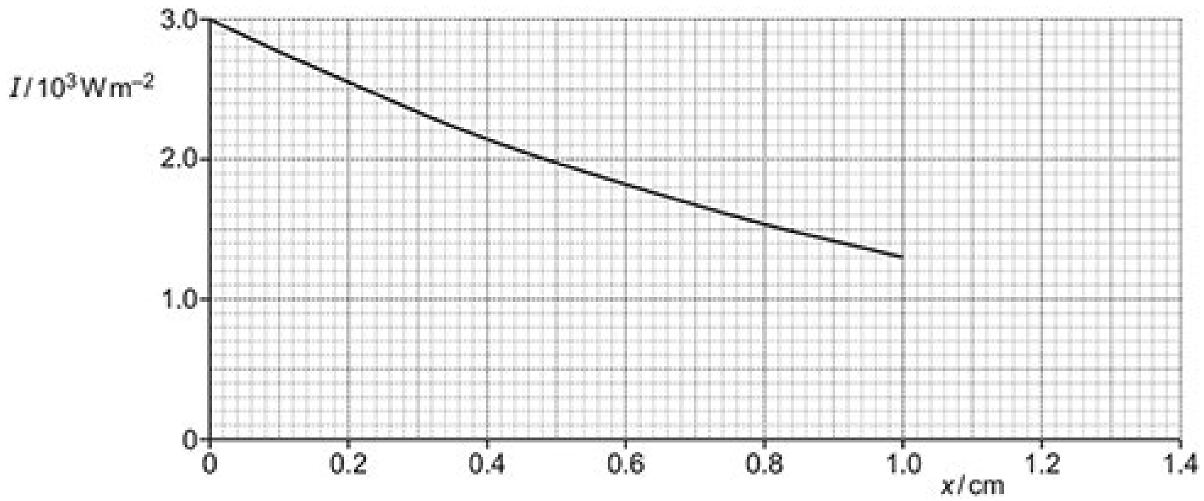



**Fig. 24.2**

The tissue has uniform structure between $x$ = 0 and $x$ = 1.0 cm.

i. Use the graph to determine the attenuation (absorption) coefficient $\mu$ in $cm^{-1}$ of the tissue.

μ = ........................................................ $cm^{-1}$ **[2]**

ii. Use the graph to determine the exposure time $t$ for the total radiant energy incident per cm2 at a depth of 1.0 cm to be 2.6 J.

$t$ = ...................................................... s **[3]**

iii. Beyond $x$ = 1.0 cm, the tissue has a larger attenuation coefficient than the value calculated in **(i)**.

On **Fig. 24.2**, sketch the variation of $I$ with $x$ beyond $x$ = 1.0 cm.

**[2]**

**8.** A small sample of muscle has volume 1.0 $cm^3$ and mass 1.10 g.
The speed of ultrasound in the muscle is 1600 $ms^{-1}$.
What is the acoustic impedance of the muscle?

**A** $1.76 \times 10^3$ kg $m^{-2}$ $s^{-1}$
**B** $1.76 \times 10^4$ kg $m^{-2}$ $s^{-1}$
**C** $1.76 \times 10^6$ kg $m^{-2}$ $s^{-1}$
**D** $1.76 \times 10^{12}$ kg $m^{-2}$ $s^{-1}$

Your answer ☐ **[1]**

**END OF QUESTION PAPER**