Anglo-Chinese Junior College

Physics Preliminary Examination
Higher 2

A Methodist Institution
(Founded 1886)

CANDIDATE NAME		CLASS	

CENTRE NUMBER	S	3	0	0	4	INDEX NUMBER				

PHYSICS **9749/02**

Paper 2 Structured Questions

28 August 2025
2 hours

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class and index number in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Answer **all** the questions.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiners' use only	
1	/ 7
2	/ 7
3	/ 5
4	/ 11
5	/ 10
6	/ 9
7	/ 11
8	/ 20
Total	/ 80

DATA AND FORMULAE

Data

speed of light in free space,	c	=	3.00×10^{8} m s^{-1}
permeability of free space,	μ_o	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space,	ε_o	=	8.85×10^{-12} F m^{-1}
			$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge,	e	=	1.60×10^{-19} C
the Planck constant,	h	=	6.63×10^{-34} J s
unified atomic mass constant,	u	=	1.66×10^{-27} kg
rest mass of electron,	m_e	=	9.11×10^{-31} kg
rest mass of proton,	m_p	=	1.67×10^{-27} kg
molar gas constant,	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant,	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant,	k	=	1.38×10^{-23} J K^{-1}
gravitational constant,	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall,	g	=	9.81 m s^{-2}

Formulae

uniformly accelerated motion,	s	=	$ut + \frac{1}{2}at^2$
	v^2	=	$u^2 + 2as$
work done on/by a gas,	W	=	$p \Delta V$
hydrostatic pressure,	p	=	$\rho g h$
gravitational potential,	ϕ	=	$-\frac{Gm}{r}$
temperature	T/K	=	T/°C + 273.15
pressure of an ideal gas	p	=	$\frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule,	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.,	x	=	$x_o \sin \omega t$
velocity of particle in s.h.m.,	v	=	$v_o \cos \omega t$
		=	$\pm \omega \sqrt{x_o^2 - x^2}$
electric current	I	=	$Anvq$
resistors in series,	R	=	$R_1 + R_2 + \ldots$
resistors in parallel,	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential,	V	=	$\frac{Q}{4\pi\varepsilon_o r}$
alternating current/voltage,	x	=	$x_o \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\mu_0 N I}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_0 n I$
radioactive decay,	x	=	$x_o \exp(-\lambda t)$
decay constant,	λ	=	$\frac{\ln 2}{t_{1/2}}$

[Turn over

For Examiner's Use

Answer **all** the questions in the spaces provided.

1 A rigid bar of mass 450 g is held horizontally by two supports A and B, as shown in Fig. 1.1.

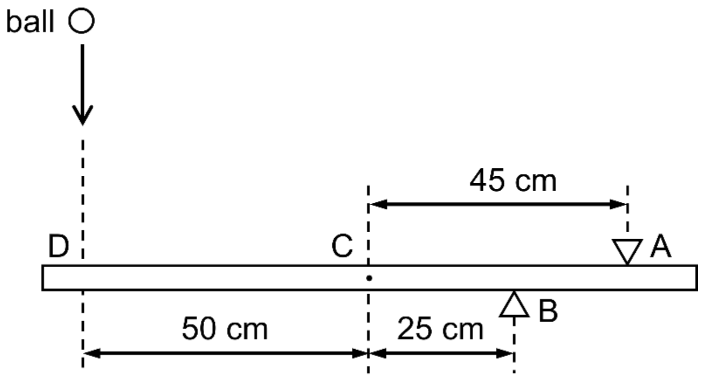

Fig. 1.1

Support A is 45 cm from the centre of gravity C of the bar and support B is 25 cm from C. A ball of mass 140 g falls vertically onto the bar such that it hits the bar at point D, which is 50 cm from C, as shown in Fig. 1.1.

The variation with time *t* of the velocity *v* of the ball before, during and after hitting the bar is shown in Fig. 1.2.

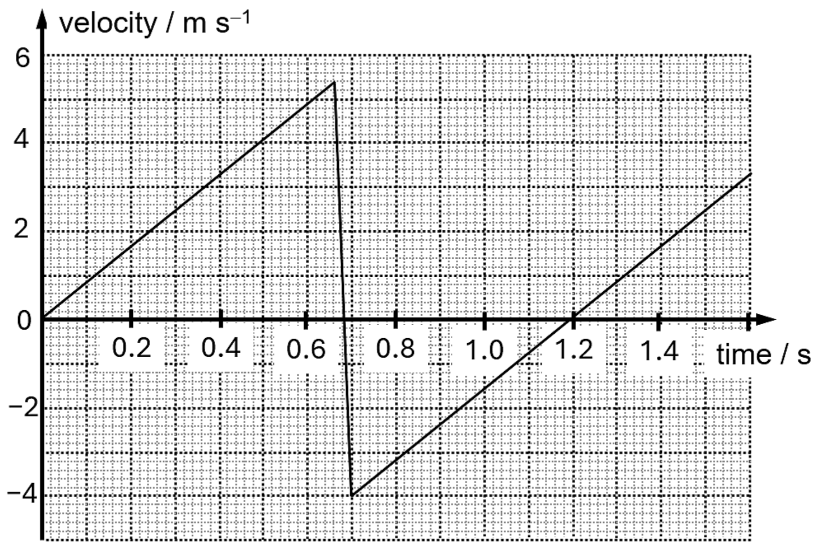

Fig. 1.2

For Examiner's Use

(a) For the time that the ball is in contact with the bar, use Fig. 1.2 to determine

(i) the change in momentum of the ball,

change in momentum = ………...……… N s [2]

(ii) the magnitude of the force exerted by the ball on the bar.

force = ………...……… N [3]

(b) Hence, for the time that the ball is in contact with the bar, calculate the magnitude of the force exerted on the bar by support A.

force = ………...……… N [2]

[Total: 7]

For Examiner's Use

2 A plane is flying with a velocity v of 220 m s^{-1} at an angle of 30° with respect to the horizontal, as shown in Fig. 2.1.

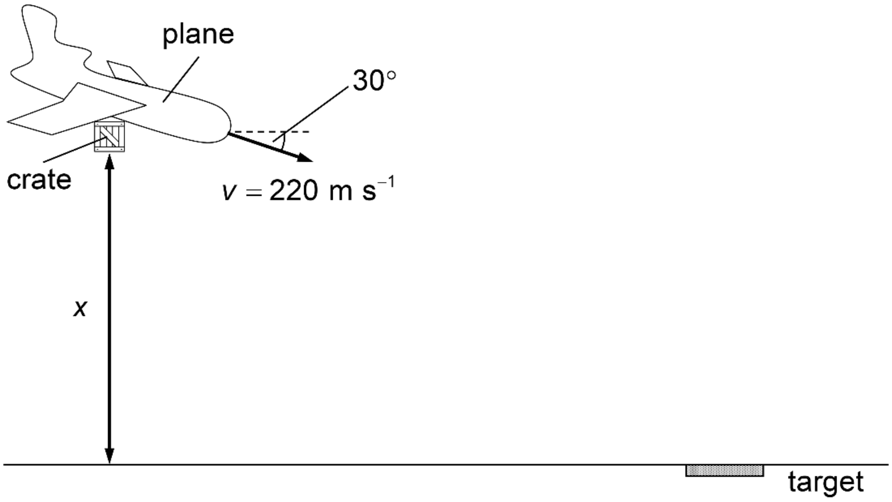

Fig. 2.1

At an altitude of x, a crate is released from the plane. The crate hits the target on the ground after 16.8 s. Assume air resistance is negligible.

(a) (i) Calculate the value of x.

x = …………………… m [2]

(ii) Determine the speed attained by the crate just before it hits the target.

speed = …………………… m s^{-1} [3]

(iii) On Fig. 2.2, sketch the variation with time *t* of the horizontal velocity v_x of the crate. Label this graph S.

Fig. 2.2

[1]

(b) If air resistance is not negligible, on Fig. 2.2, sketch the variation with *t* of v_x. Label this graph R. [1]

[Total: 7]

For Examiner's Use

3 A student, aspiring to be an astrophysicist is contemplating about the possibility of building a spacecraft that can house astronauts for a prolonged period.

Fig. 3.1 shows the spacecraft rotating in space. The spacecraft has a ring structure and uses its own rotation to create an artificial gravity that is similar to Earth for the inhabitants.

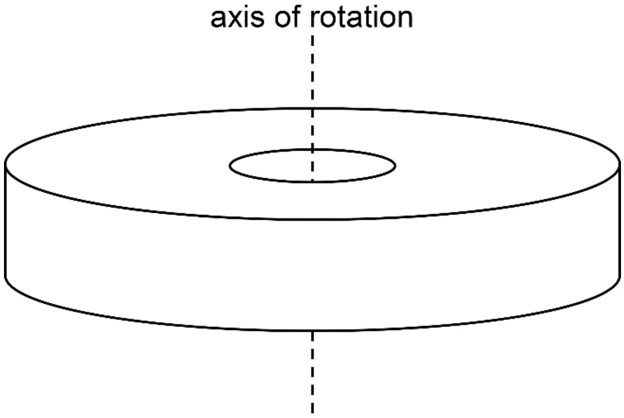

Fig. 3.1

(a) Fig. 3.2 shows the cross section of the spacecraft and how the astronaut is positioned.

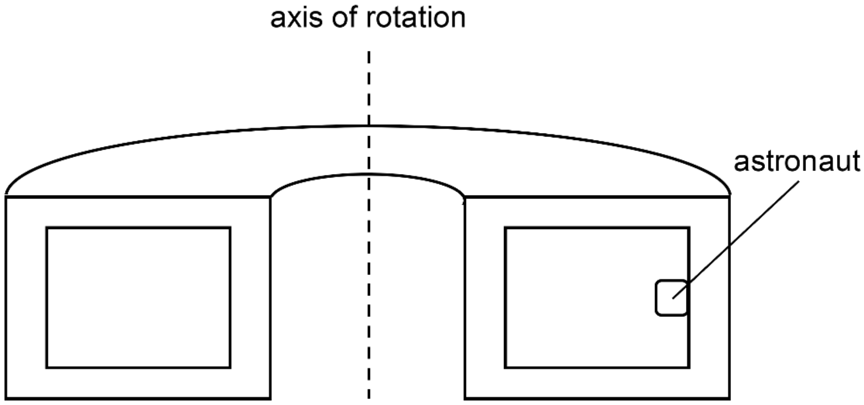

Fig. 3.2

On Fig. 3.2, draw arrow(s) to represent the force(s) acting on the astronaut. [1]

For Examiner's Use

(b) The astronaut in the spacecraft has a constant speed of 100 m s^{-1}.

(i) Explain why the astronaut experiences a resultant force.

....

....

....

.... [2]

(ii) Determine the radius of the spacecraft so that the resultant force experienced by the astronaut is equal to his weight on Earth.

radius = ... m [2]

[Total: 5]

[Turn over

For Examiner's Use

4 **(a)** State what is meant by a polarised wave.

....

....

.... [1]

(b) Two sheets of polaroid P and Q are placed close to each other. Their directions of polarisation are parallel to each other, as shown in Fig. 4.1.

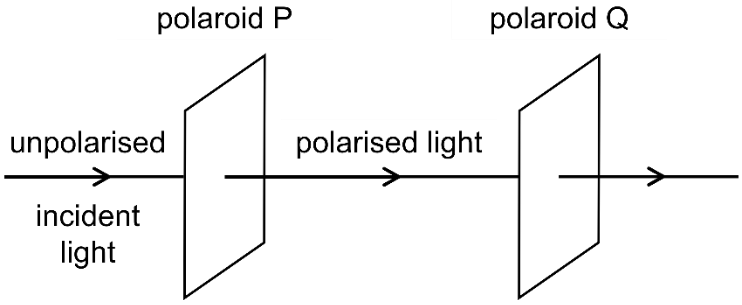

Fig. 4.1

A monochromatic beam of unpolarised light is incident on polaroid P. The beam after passing through polaroid Q has an amplitude of A_0.

Polaroid Q is now rotated about the axis of the light beam by $30°$.

Determine the amplitude of the light, in terms of A_0, after passing through polaroid Q.

amplitude = ... [2]

(c) State what is meant by the diffraction of light waves.

....

....

.... [1]

For Examiner's Use

(d) After passing through polaroid Q, the light is incident normally on a single slit and a diffraction grating.

Fig. 4.2 shows two of the emerging beams from the grating. The angle between the two first-order emerging beams is $16°$.

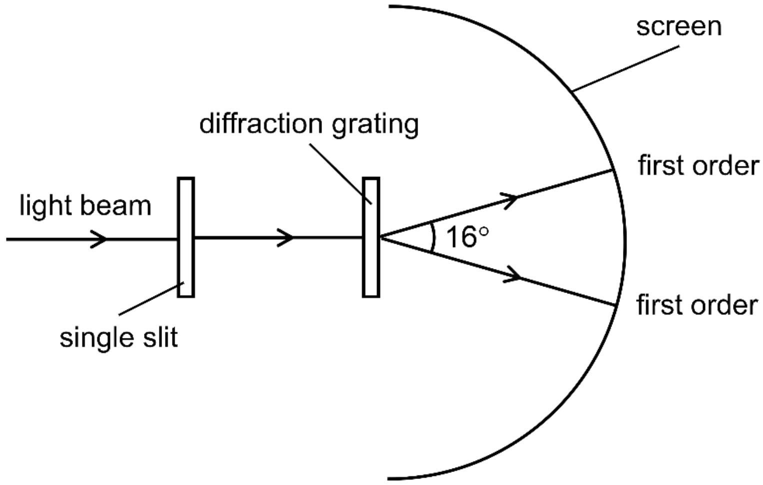

Fig. 4.2 (not to scale)

The grating has a line spacing of 3.4×10^{-6} m.

(i) Calculate the wavelength of the light.

wavelength = …………..……… m [2]

(ii) Hence, state the colour of the visible light beam.

…………………………………………………………………………………… [1]

For Examiner's Use

(iii) Determine the total number of emerging beams from the grating that can be observed on the screen.

number of emerging beams = …………..……… [2]

(iv) State and explain the change(s), if any, to the diffraction pattern on the screen when polaroids P and Q are removed.

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………..………………….. [2]

[Total: 11]

For Examiner's Use

5 **(a)** Define *resistance* of a circuit component.

……………………………………………………………………………………………....

……………………………………………………………………………………..…… [1]

(b) Fig. 5.1 shows a potential divider circuit consisting of two resistors of resistances *A* and *B*.

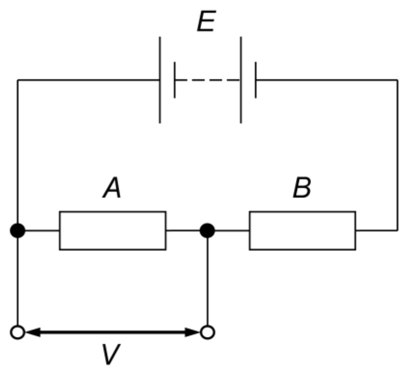

Fig. 5.1

The battery has an e.m.f. *E* and negligible internal resistance.

By considering the current in circuit, show that the potential difference *V* across the resistor of resistance *A* is given by the expression

$$V = \frac{A}{A+B}E$$

[1]

(c) The resistances *A* and *B* are 1500 Ω and 4000 Ω respectively. A voltmeter is connected in parallel with the 1500 Ω resistor and a thermistor is connected in parallel with the 4000 Ω resistor, as shown in Fig. 5.2.

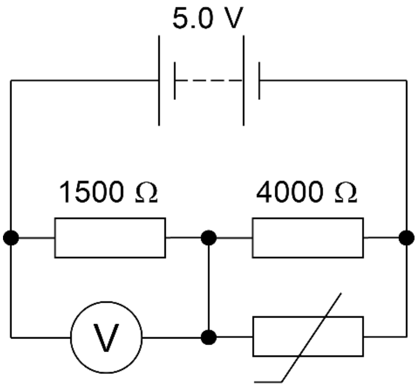

Fig. 5.2

The battery has an e.m.f. of 5.0 V and the voltmeter is ideal.

(i) State and explain the change in the reading of the voltmeter as the temperature of the thermistor is raised.

....

....

....

....

.... [3]

(ii) The resistance of the thermistor at 20 °C is 2700 Ω.

Calculate the reading on the voltmeter when the temperature of the thermistor is 20 °C.

voltmeter reading = ... V [3]

For Examiner's Use

(iii) For the same change in temperature, state and explain how the change in the voltmeter reading will be different if the battery has significant internal resistance.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………… [2]

[Total: 10]

[Turn over

For Examiner's Use

6 **(a)** Define *magnetic flux density*.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

………………………………………………………………………………………………… [2]

(b) A horseshoe magnet is placed on a top-pan balance. A rigid copper wire is held horizontally between the poles of the magnet as shown in Fig. 6.1.

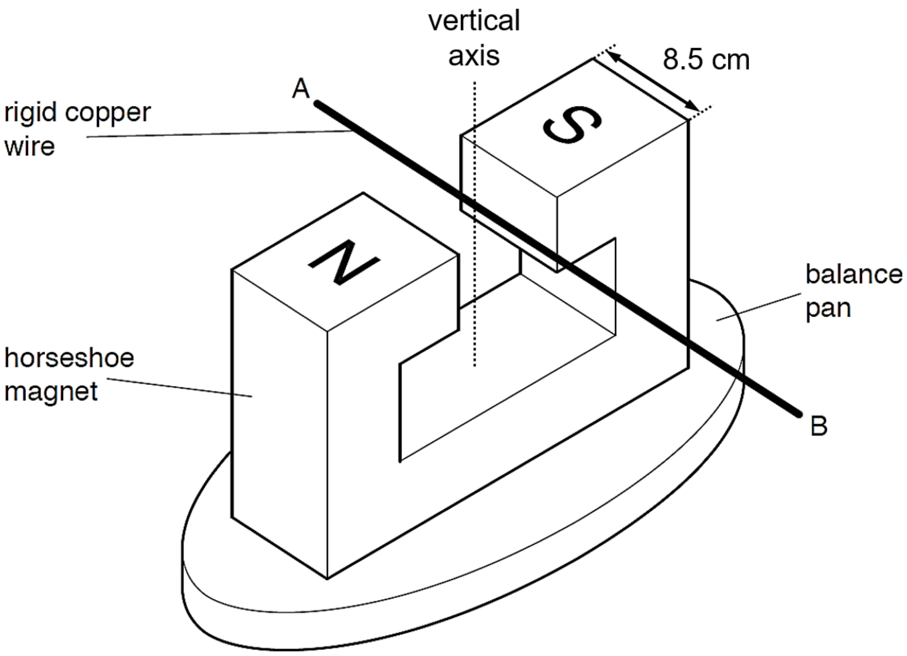

Fig. 6.1

The wire is clamped at ends A and B.

When a direct current of 4.6 A is switched on in the wire, the reading on the balance increases.

(i) State and explain the direction of the force acting on the wire.

…………………………………………………………………………………………

…………………………………………………………………………………………

………………………………………………………………………………………… [2]

(ii) Hence, state the direction of the current in the wire.

………………………………………………………………………………………… [1]

For Examiner's Use

(iii) The width of each pole is 8.5 cm and the magnetic flux density *B* in the region between the poles of the magnets is 3.7 mT. Assume that the magnetic flux density exists only between the poles.

Calculate the force on the wire.

force = ……………………… N [2]

(iv) The wire is now rotated about the vertical axis through $45°$ as shown by the top view in Fig. 6.2.

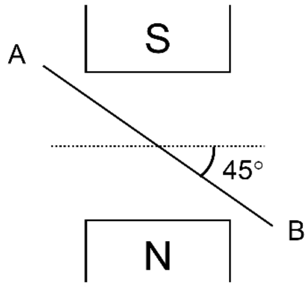

Fig. 6.2

Explain why the reading on the balance remains the same when the wire is rotated about the vertical axis.

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………… [2]

[Total: 9]

[Turn over

For Examiner's Use

7 **(a)** Explain, with reference to the variation of binding energy per nucleon with nucleon number, why the following nuclear fission reaction of iron-56 ($^{56}_{26}\text{Fe}$) to fluorine-20 ($^{20}_{9}\text{F}$) and chlorine-37 ($^{37}_{17}\text{C}l$) would **not** result in an overall release of energy.

$$^{56}_{26}\text{Fe} + ^{1}_{0}\text{n} \rightarrow ^{20}_{9}\text{F} + ^{37}_{17}\text{C}l$$

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

………………………………………………………………………………………… [2]

(b) A uranium-235 nucleus absorbs a neutron and becomes unstable. It then undergoes a fission reaction. One possible reaction is

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{142}_{54}\text{Xe} + ^{90}_{38}\text{Sr} + 4\,^{1}_{0}\text{n}$$

Table 7.1 shows the mass defects of the nuclei for this fission reaction.

Table 7.1

nuclei	mass defect / u
uranium-235 ($^{235}_{92}\text{U}$)	1.910
xenon-142 ($^{142}_{54}\text{Xe}$)	1.273
strontium-90 ($^{90}_{38}\text{Sr}$)	0.8405

Calculate the energy released from the fission of one nucleus of uranium-235.

energy = …………..……… J [2]

(c) Strontium-90 is unstable and decays into the isotope yttrium-90.

A sample initially contains only nuclei of strontium-90. The half-life of strontium-90 is 28.8 years. The ratio

$$\frac{\text{number of decayed nuclei of strontium-90}}{\text{number of undecayed nuclei of strontium-90}}$$

is equal to *R*.

Determine the value of *R* after 144 years.

R = ……………..……… [3]

(d) A power source contains 0.13 kg of strontium-90. Each nucleus of strontium-90 that decays emits 0.546 MeV of energy.

(i) Calculate the initial number N_0 of nuclei of strontium-90 in the power source.

N_0 = ……………..……… [1]

(ii) Determine the initial activity of the source.

activity = ……………..……… Bq [1]

[Turn over

For Examiner's Use

(iii) Hence, determine the initial power output from the source due to the decay of strontium-90.

power output = ……………..……… W [2]

[Total: 11]

For Examiner's Use

8 Read the passage and answer the questions that follow.

A common non-invasive medical imaging technique valued for its affordability, portability and minimal safety concerns is ultrasound. It is widely used in gynaecology and many cardiovascular applications.

Ultrasound waves are produced by a transducer as shown in Fig. 8.1. An oscillating voltage is applied to a piezoelectric element formed by a composite of lead zirconate titanate (PZT). The PZT element's thickness oscillates at the same frequency as the applied voltage. Placing the element in contact with a patient's skin transfers the mechanical motion into a pressure wave which is transmitted into the body.

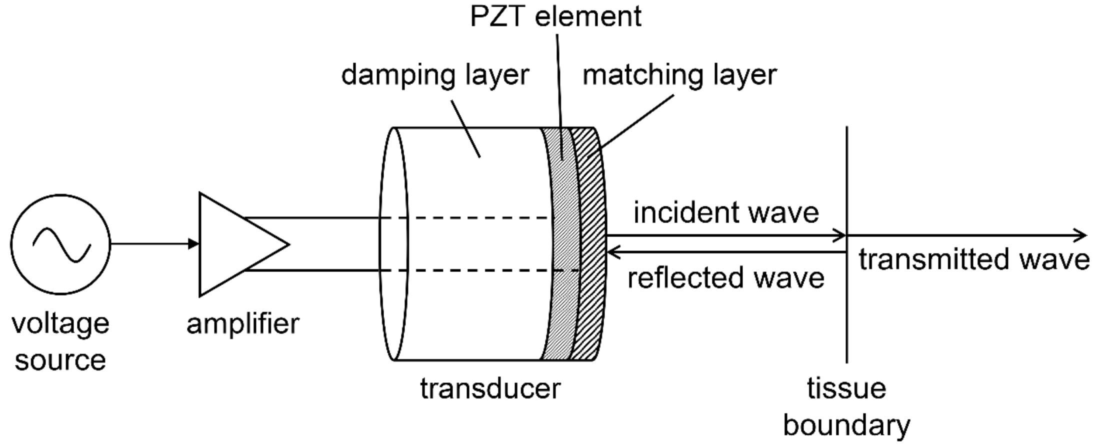

Fig. 8.1

At boundaries between tissues, a certain fraction of the wave energy is reflected back towards the transducer where it is detected to form the ultrasound image. The remainder is transmitted through the boundary deeper into the body.

The propagation of ultrasound energy through the body depends on the characteristic acoustic impedance *Z* of tissue. *Z* is determined by the physical properties of the tissue such as its density and compressibility. Table 8.1 shows the acoustic properties for air and some biological tissues.

Table 8.1

	acoustic impedance Z (10^5 g cm^{-2} s^{-1})	speed of sound v (m s^{-1})	density ρ (kg m^{-3})	compressibility κ (10^{11} cm g^{-1} s^2)
air	0.00043	330	1.3	71 000
bone	7.63	4000	1908	0.328
fat	1.34	1450	925	5.14
brain	1.58	1540	1025	4.11
muscle	1.71	1590	1075	3.68
liver	1.65	1570	1050	3.86
kidney	1.62	1560	1040	3.95

[Turn over

For Examiner's Use

The following equations relate the transmitted I_t and reflected I_r intensities to the incident intensity I_i at a boundary.

$$\frac{I_t}{I_i} = \frac{4Z_1Z_2}{(Z_1 + Z_2)^2}$$

$$\frac{I_r}{I_i} = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$$

where Z_1 and Z_2 are the acoustic impedances for the medium before and the medium after the boundary respectively.

As the acoustic impedance of the PZT element Z_{PZT} is large compared to that of skin Z_{skin}, a large amount of energy will be reflected from the patient's skin, preventing effective transmission of ultrasound waves from the transducer into the body. To improve this efficiency, a matching layer is attached to the PZT element. Its acoustic impedance is given by

$$Z_{\text{matching layer}} = \sqrt{Z_{PZT}Z_{skin}}$$

The thickness of this matching layer should be one-quarter of the ultrasound wavelength to maximise energy transmission through the layer in both directions.

Finally, to enhance the quality of the ultrasound image, contrast agents like microbubbles are injected into the patient. They are filled with compressible gas and respond to the ultrasound beam by compressing in high pressure regions and expanding in low pressure regions. They absorb energy during the compression and re-radiate them during expansion to produce a strong echo signal returning to the transducer.

For Examiner's Use

(a) Acoustic impedance Z is related to the density ρ and compressibility κ of tissues by the equation

$$Z = \rho^a \kappa^b$$

where a and b are constants.

By considering the units of Z, ρ and κ, determine the values of a and b.

a = ……………………

b = ……………………

[2]

(b) **(i)** Calculate $\frac{I_r}{I_i}$ when the ultrasound beam travels from muscle to bone.

$\frac{I_r}{I_i}$ = …………………… [2]

(ii) Hence, explain why in the imaging of the heart, the ultrasound must pass in between the ribs.

……………………………………………………………………………………

…………………………………………………………………………………… [1]

(iii) State the two biological tissues shown in Table 8.1 whose boundary is the hardest to detect by ultrasound.

…………………………………………………………………………………… [1]

[Turn over

For Examiner's Use

(c) As an ultrasound beam of initial intensity I_0 propagates through tissue, its intensity decreases exponentially. The transmitted intensity I depends on the frequency f of the wave, propagation distance x and the intensity attenuation coefficient μ of the tissue. The relationship is given by the equation:

$$I = I_0 e^{-\mu f x}$$

where μ for soft tissue is $0.23\ \text{cm}^{-1}\ \text{MHz}^{-1}$.

(i) Determine the distance at which the intensity of a 5.0 MHz ultrasound beam will be reduced by half when travelling through soft tissue.

distance = ………….……… cm [2]

(ii) Hence, state and explain whether high or low frequency ultrasound waves are used when imaging organs deeper in the body.

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………. [2]

(d) The PZT element in the transducer has an acoustic impedance of $30 \times 10^5\ \text{g cm}^{-2}\ \text{s}^{-1}$ while the corresponding value for skin is $1.7 \times 10^5\ \text{g cm}^{-2}\ \text{s}^{-1}$.

(i) Show that only 20% of the energy from the transducer is transmitted into the patient if the PZT element is in direct contact with the patient's skin.

[2]

For Examiner's Use

(ii) Hence, determine the efficiency in transmitting energy from the PZT element to a patient's skin when a matching layer is used.

efficiency = …………..……… % [4]

(iii) For a particular composite material used to make the matching layer, a 5.0 MHz ultrasound beam travels at a speed of 2500 m s^{-1} in it.

Calculate the thickness of the matching layer.

thickness = …………..……… m [1]

[Turn over

For Examiner's Use

(e) Fig. 8.2 shows the change in the shape of a microbubble as an ultrasound pressure wave passes through the tissue in which the microbubble is located.

Sketch the sinusoidal variation with time of pressure at this location.

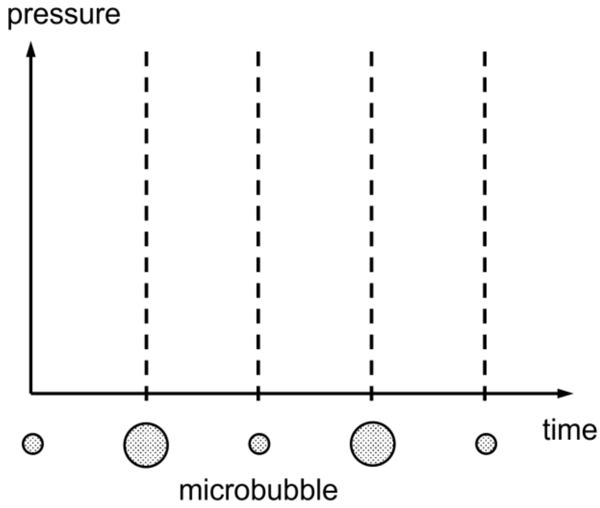

Fig. 8.2

[1]

(f) Ultrasound is the only imaging technique that is routinely used in pregnancy to assess the health of the foetus. It is preferred over X-rays as it does not involve ionising radiation.

Explain the indirect effect of ionising radiation on living tissues and cells.

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………………………………………………………………………………………………… [2]

[Total: 20]

End of Paper