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
22 August 2024
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** 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	/ 6
2	/ 9
3	/ 7
4	/ 12
5	/ 12
6	/ 14
7	/ 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/ºC + 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	=	$\frac{\mu_o I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\mu_o N I}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_o n I$
radioactive decay,	x	=	$x_o \exp(-\lambda t)$
decay constant,	λ	=	$\frac{\ln 2}{t_{½}}$

[Turn over

For Examiner's Use

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

1 **(a)** Distinguish between *precision* and *accuracy*.

....

....

....

.... [2]

(b) A simple pendulum consists of a mass attached to a light inextensible string of length L. The pendulum is secured to a fixed point and made to undergo oscillations when displaced by a small angle.

The acceleration of free fall g can be found by the following equation:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

where T is the period of oscillation.

The following data is given:
L = 50.0 ± 0.2 cm
T = 1.42 ± 0.01 s

(i) Determine g with its associated uncertainty. Give your answer to an appropriate number of significant figures.

g = ... ± .... m s^{-2} [3]

For Examiner's Use

(ii) When finding period *T* using a stopwatch, it is a good practice to time a large number of oscillations such that the total time taken is more than 20 seconds.

Explain why this should be done.

....

....

.... [1]

[Total: 6]

For Examiner's Use

2 A stone is projected vertically at a velocity of u from the edge of a building. The stone reaches a maximum height of 27 m above the top of the building and falls down to the ground below. Take the upward direction as positive.

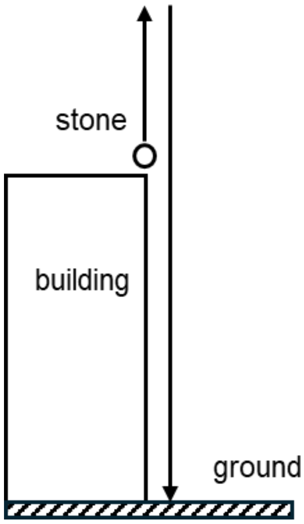

Fig. 2.1

(a) **(i)** Assume that air resistance is negligible.

1. Show that u is 23 m s^{-1}.

[2]

For Examiner's Use

2. The stone hits the ground after 6.0 s.

On Fig. 2.2, sketch the variation with time *t* of the velocity *v* from the time the stone is projected at *t* = 0 s until *t* = 6.0 s. Label the axes with appropriate values.

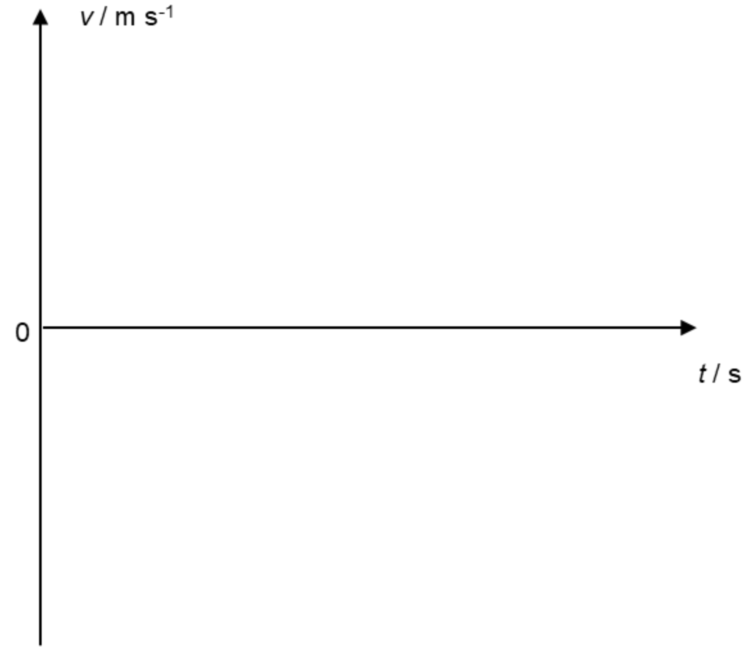

Fig. 2.2

[2]

(ii) In reality, air resistance is not negligible.

On Fig. 2.2, sketch the variation with time *t* of the velocity *v* of the stone till 6.0 s. Label the graph *R*. [2]

.

For Examiner's Use

(b) An elastic net is now placed on top of the ground to catch the stone, so that it does not hit the ground. To simplify the analysis, Fig. 2.3 shows two identical springs and a rigid container which are used to model the elastic net. Assume the masses of the springs and rigid container to be negligible. The stone hits the rigid container when the springs are at length x_0 and subsequently, the springs stretch by a maximum extension of x_s.

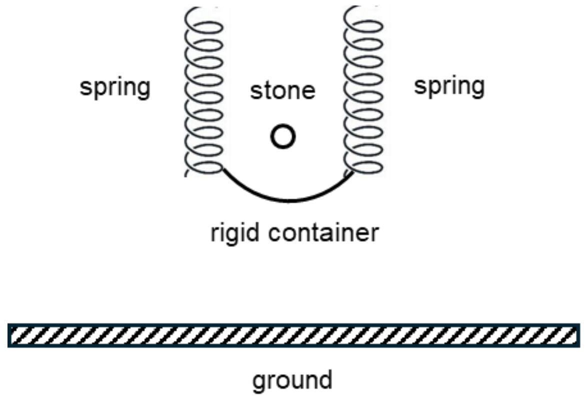

Fig. 2.3

On Fig. 2.4, sketch graphs of the following quantities to show the variation with extension *x* of the spring.

(i) The kinetic energy of the stone and container. Label this graph *K*.

(ii) The gravitational potential energy (GPE) of the stone and container. Take GPE to be zero at the lowest point of the motion. Label this graph *G*.

(iii) The elastic potential energy of the spring. Label this graph *E*.

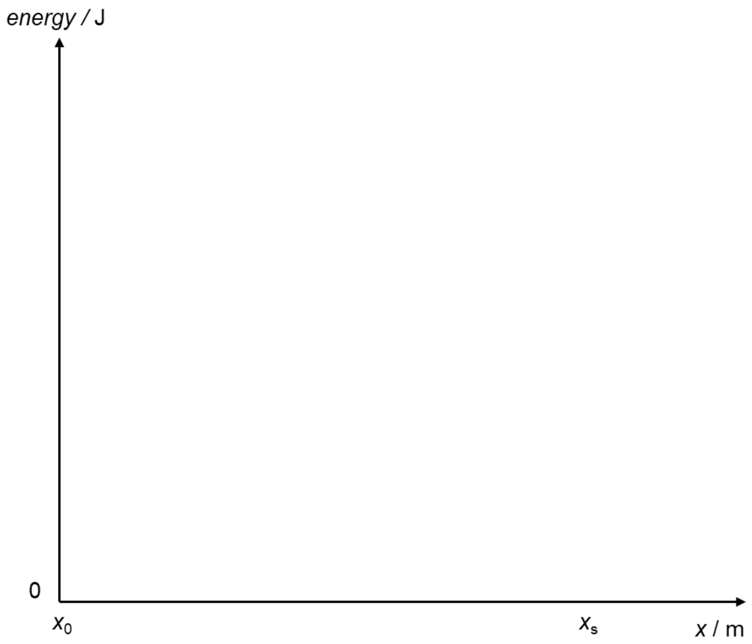

Fig. 2.4

[3]

[Total: 9]

For Examiner's Use

3 A uniform, rectangular canopy is 1.30 m wide. It is kept horizontal and in equilibrium by two steel cables. Fig. 3.1 shows the canopy fixed to the wall by a hinge.

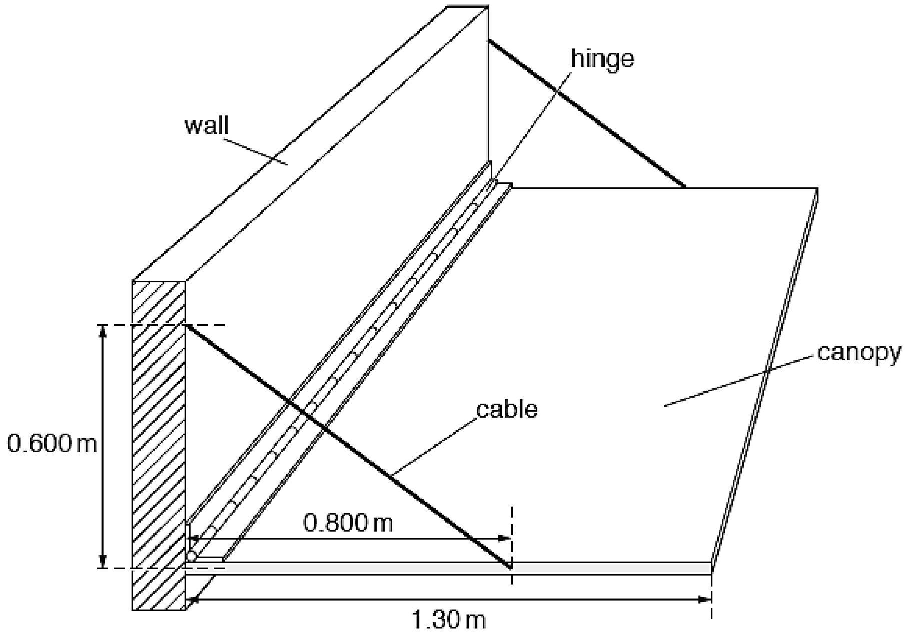

Fig. 3.1 (not to scale)

One end of each cable is attached to the canopy at a distance of 0.800 m from the wall. The other ends are attached to the wall at a distance of 0.600 m above the canopy.

The tension in each cable is 47.5 N.

(a) State the two conditions for an object to be in equilibrium.

1. ……………………………………………………………………………………………..

……………………………………………………………………………………………..

2. ……………………………………………………………………………………………..

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

(b) Determine the mass of the canopy.

mass = ………….………. kg [3]

[Turn over

For Examiner's Use

(c) Suggest and explain the direction of the force the hinge must exert on the canopy.

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

[Total: 7]

For Examiner's Use

4 **(a)** State *Newton's Law of Gravitation*.

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.... [2]

(b) A satellite of mass m orbits planet Mars of mass M in a circular path of radius r.

(i) Show that the kinetic energy of the satellite E_K is given by

$$E_K = \frac{GMm}{2r}.$$

[2]

(ii) Hence, show that the total energy of the satellite E_T is given by

$$E_T = -\frac{GMm}{2r}.$$

[1]

[Turn over

For Examiner's Use

(c) It was discovered that for every revolution of the satellite around Mars, Mars has rotated about its axis three times.

Data are given for the satellite and Mars in Table 4.1.

Table 4.1

duration of one day on Mars	24.6 hours
mass of Mars, *M*	6.39×10^{23} kg
mass of satellite, *m*	470 kg

(i) Determine the radius *r* of the circular orbit.

r = …………..……… m [3]

(ii) Determine the work done in bringing the satellite to an orbit with radius twice that of the original orbit.

work done = …………..……… MJ [2]

For Examiner's Use

(d) The satellite moves through a medium where a resistive force acts on it.

State and explain the effect on the speed of the satellite during its orbit.

…………………………………………………………………………………………………

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

[Total: 12]

[Turn over

For Examiner's Use

5 **(a)** Electromotive force (e.m.f.) and potential difference (p.d.) both have the volt as a unit.

(i) Define the *volt.*

……………………………………………………………………………………………

…………………………………………………………………………………… [1]

(ii) Using energy considerations, distinguish between e.m.f. and p.d.

e.m.f. ……………………………………………………………………………………..

……………………………………………………………………………………………..

p.d. ……………………………………………………………………………………….

…………………………………………………………………………………… [2]

(b) A battery of electromotive force (e.m.f.) 4.5 V and negligible internal resistance is connected to two filament lamps P and Q and a resistor R, as shown in Fig. 5.1.

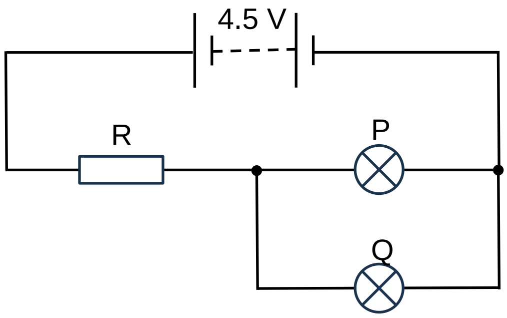

Fig. 5.1

For Examiner's Use

The current in lamp P is 0.15 A. The I–V characteristics of the filament lamps are shown in Fig. 5.2.

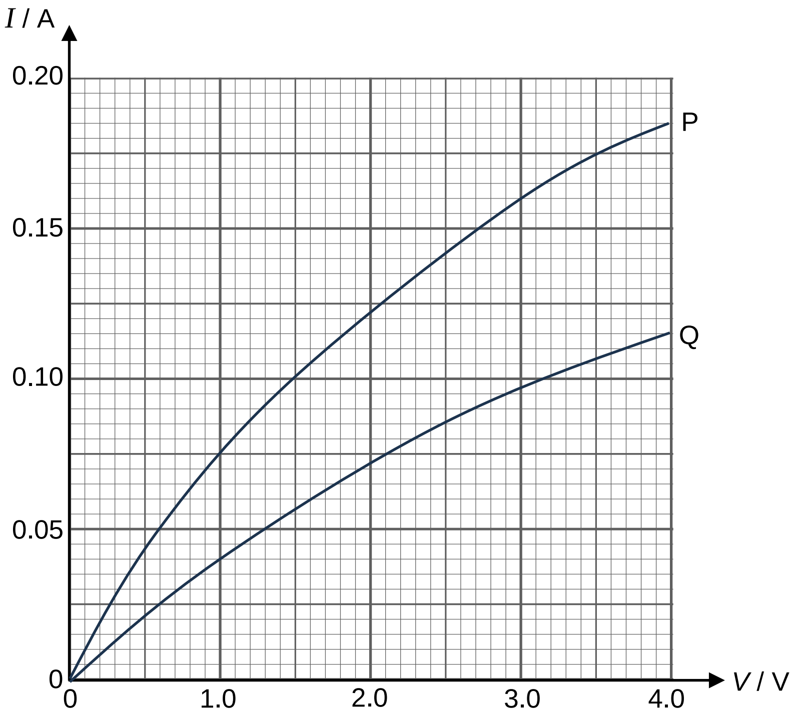

Fig. 5.2

(i) Using Fig. 5.2, determine the current in the battery. Explain your working.

current = ………….……… A [2]

(ii) Calculate the resistance of resistor R.

resistance = …………..……… Ω [2]

[Turn over

For Examiner's Use

(iii) The filament wires of the two lamps are made from material with the same resistivity at their operating temperature in the circuit. The diameter of the wire of lamp P is twice the diameter of the wire of lamp Q.

Determine the ratio

$$\frac{\text{length of filament wire of lamp P}}{\text{length of filament wire of lamp Q}}.$$

ratio = ………..……… [3]

(iv) The filament wire of lamp Q breaks and stops conducting.

Without further calculation, state and explain the effect on the resistance of lamp P.

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

…………………………………………………………………………………. [2]

[Total:12]

For Examiner's Use

6 **(a)** Radioactive decay is *random* and *spontaneous*.

Explain what is meant by random and spontaneous.

random: ……………………………………………………………………………………..

……………………………………………………………………………………………..

spontaneous: ………………………………………………………………………………

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

(b) A stationary polonium nucleus $^{210}_{84}\text{Po}$ decays to a lead (Pb) nucleus by emitting an alpha-particle.

(i) Write a nuclear equation to represent this emission.

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

(ii) Determine the ratio of $\dfrac{\text{kinetic energy of alpha-particle}}{\text{kinetic energy of lead nucleus}}$ after the nuclear reaction has occurred.

ratio = ………….……… [2]

(iii) A sample of polonium-210 has 4.2×10^{11} nuclei initially. The half-life of the nuclei is 138 days.

Calculate the activity of the source after 600 days.

activity = ………….……… Bq [3]

[Turn over

For Examiner's Use

(iv) A Geiger counter is used to measure the rate of decay after 600 days.

State and explain how the reading will differ from your answer in **(b)(iii)**.

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....

.... [1]

(c) Another nucleus, platinum-199, decays to gold-199 by emitting a beta particle. Fig. 6.1 shows the kinetic energy spectrum of the beta particles.

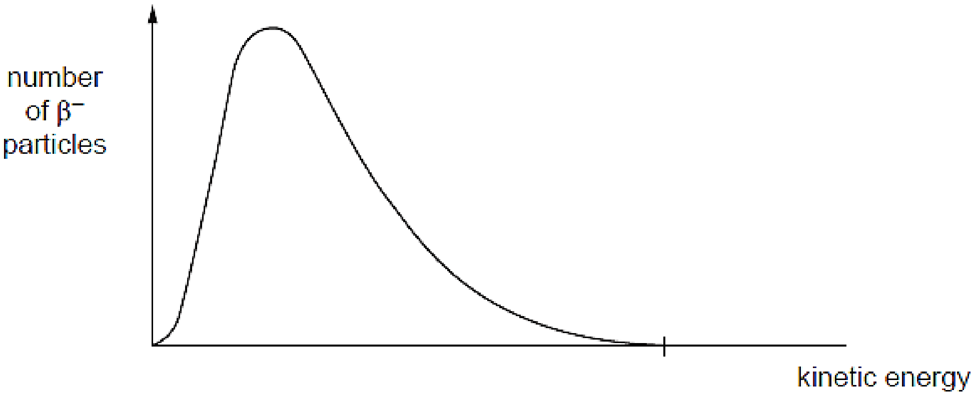

Fig. 6.1

(i) Explain how Fig. 6.1 predicts the existence of the neutrino.

....

....

....

.... [2]

For Examiner's Use

(ii) The nucleus of gold-199 is not stable and will decay further to mercury-199 which is a stable nucleus.

A sample of radioactive isotopes consists of only platinum-199 nuclei initially. The half-life of platinum-199 is 30.8 months and the half-life of gold-199 is 3.13 days.

After 30.8 months, suggest which nuclei would be of the smallest percentage. Explain your answer.

....

....

....

.... [2]

[Total: 14]

For Examiner's Use

7 Read the passage below and answer the questions that follow.

Invincible Class Submarine

The Republic of Singapore Navy (RSN) recently introduced the Invincible-class conventionally-powered attack submarines, replacing the ageing Challenger-class. Fig. 7.1 shows a submarine of similar configuration.

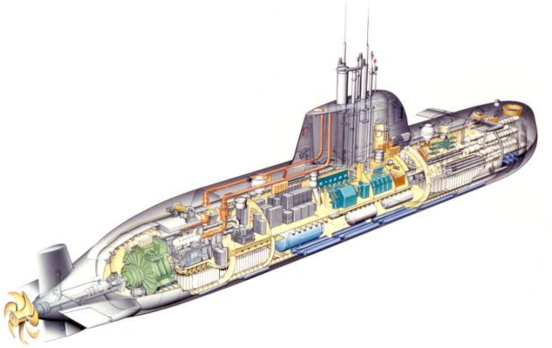

Fig. 7.1

Table 7.1 shows the basic information of the submarine.

Table 7.1

feature	quantity
length L / m	70.0
diameter d_0 / m	6.30
maximum speed (surface) / km h^{-1}	27.8
maximum speed (submerged) / km h^{-1}	37.0

The most efficient geometry for a submarine's pressure hull are circular cross-sections that transfer normal pressure loading to in-plane compressive forces i.e. hydrostatic pressure. Failures in the structure of a submarine could lead to an implosion. For simplicity, the hull can be analysed as a cylinder.

The hoop stress σ on a thin walled cylinder is given by

$$\sigma = \frac{d_0 P}{2t}$$

where P is the hydrostatic pressure acting normally at the hull, d_0 is the diameter and t is the wall thickness of the hull.

The compressive stress limit defines the maximum stress a metal can endure before experiencing permanent deformation and failure. Usually, the hull of a submarine is made of high-strength steel (HY-80) that has a compressive stress limit of 550 MPa.

For Examiner's Use

The cross-sectional view of the hull is shown on Fig. 7.2, illustrating the main stresses acting along the circumference of the hull.

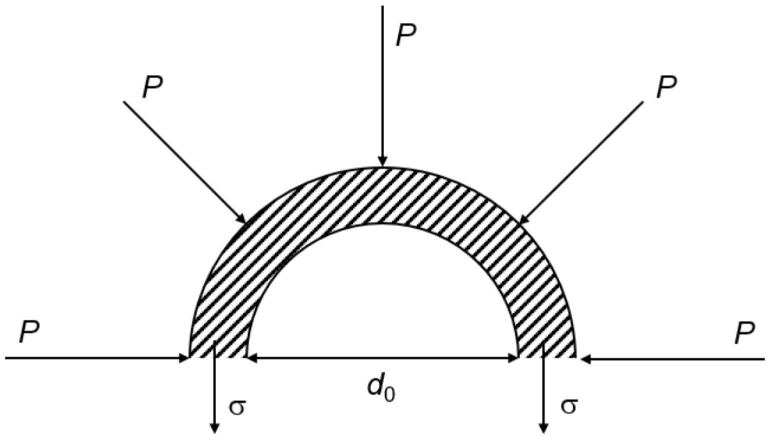

Fig. 7.2

Singapore is an international shipping hub where more than 1000 ships visit daily. To navigate safely underwater amidst the heavy traffic, submarines rely heavily on sonar. SONAR is the acronym for SOund Navigation And Ranging. Sonar uses sound waves to create a picture of the surroundings. This allows submarines to discreetly navigate, detect potential threats, and even communicate with other underwater vessels.

An active sonar transmits an acoustic signal, which propagates to a reflector and subsequently reflects the signal back to the sonar receiver. Phased array sonar is a type of active sonar that is typically used by military submarines. The equipment is made up of an array of transducers to transmit and receive sound waves. Phased array sonars can be used to create multiple beams at the same time, which can be useful for tasks such as tracking multiple targets or creating a three-dimensional image of an area.

Drag forces are a constant challenge for submarines navigating underwater. These arise from the friction between the submarine's hull and the surrounding water. This force is given by

$$F = \frac{1}{2} C_d \rho v^2 A$$

where ρ is the water density, v is the velocity of the submarine, A is the submarine's projected frontal area, and C_d is the drag coefficient of a dimensionless value representing the shape-dependent resistance of the object.

[Turn over

For Examiner's Use

(a) The new Invincible-class submarine is required to patrol the South China Sea periodically where it is deeper. The density, ρ, of seawater in this region is 1030 kg m^{-3}.

(i) Determine the pressure exerted by the seawater on the submarine's hull when it is 400 m in depth.

pressure = ………..……… MPa [2]

(ii) Hence, show that the required minimum mean thickness of the hull is 2.4 cm at this depth.

[2]

(iii) Explain why the submarine hull can be considered as a thin wall.

………………………………………………………………………………………..

………………………………………………………………………………………..

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

For Examiner's Use

(iv) The Young's modulus is a mechanical property of solid materials that is defined as the ratio of the stress applied to the object and the resulting deformation (compression) within Hooke's limit of proportionality.

Young's modulus E is given by

$$E = \frac{\sigma}{\left(\frac{d_x}{d_0}\right)}$$

where d_0 is the original diameter and d_x is the net compression of the diameter.

Determine the new diameter of the submarine when it is at 400 m depth and HY-80 has a Young's modulus, E of 205 GPa.

new diameter = …………..……… m [2]

(v) According to the hoop stress equation, when a submarine is required to travel in deeper waters, the design of its hull thickness must be increased.

State two limitations of this method.

1. ……..……………………………………………………………………………

…………………………………………………………………………………………

2. ……………………………………………………………………………………

………………………………………………………………………………… [2]

[Turn over

For Examiner's Use

(b) **(i)** Sonar uses seawater as a medium for the propagation of sound.

Describe how sound travels in the deep sea.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

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

(ii) Medwin's formula is a useful approximation for speed of sound in seawater:

$$c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.010T)(S - 35) + 0.016D$$

where c is the speed of sound, S is the salinity in parts per thousand (ppt), T is the temperature (°C), and D is the depth (m).

Table 7.2 shows the data about the seawater in the region.

Table 7.2

average salinity	33 parts per million (ppm)
average temperature	28 °C

Determine the speed of sound in the seawater at a depth of 400 m.

speed ………………………… m s^{-1} [2]

For Examiner's Use

(iii) The speed of sound in air is about 330 m s^{-1}.

Suggest why the speed of sound in the seawater is faster.

………………………………………………………………………………………………

………………………………………………………………………………………………

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

(iv) Fig. 7.3 shows a transmitter of the sonar transducer emitting a short sound pulse "ping" to detect a spherical object M, with cross-sectional area *S* underwater. The mean power of the transmitter is *P.* The transmitter can be taken to be a point source.

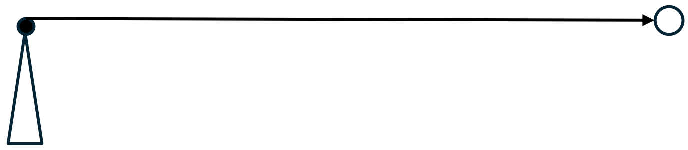

Fig. 7.3

The echo "ping" is received by M. Assume that there are no losses in the transmission and M reflects all the sound energy it receives over a hemispherical surface. The intensity of sound received at the transmitter from M is I_M.

Show that the distance, *d* of the object in terms of *P, S* and I_M is

$$d = \left[\frac{PS}{(I_M) 8\pi^2} \right]^{\frac{1}{4}}.$$

[3]

[Turn over

For Examiner's Use

(c) **(i)** The Invincible-class submarine is designed to be hydrodynamically efficient and the drag coefficient C_d can be assumed to be 0.1.

Determine the minimum engine power of the submarine so that it can move at its maximum constant speed underwater.

power = …………..……… W [2]

(ii) Suggest why in reality, the movement of the submarine will require more engine power than **(c)(i)** when traveling at the same constant speed.

……………………………………………………………………………………………

……………………………………………………………………………………………

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

[Total: 20]

End of Paper