RAFFLES INSTITUTION

2023 YEAR 5 PROMOTIONAL EXAMINATION

2 October 2023 Time: 2 hr 30 min

H2 PHYSICS

Section A

INSTRUCTIONS TO CANDIDATES

There are 3 sections in this paper.

Section A consists of **15** multiple-choice questions. For each question, four suggested answers are given. You are to choose the most appropriate one and shade your answer on the OMR form, using a soft pencil.

You are advised to attempt Section A first. The **OMR form will be collected at the end of the first 30 minutes**.

Section B consists of **5** structured questions. You are to write your answers in the spaces provided.

Section C consists of **2** longer structured questions. You are to write your answers in the spaces provided.

Attempt ALL the questions in Sections A, B and C.

This document consists of **10** printed pages.

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	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}

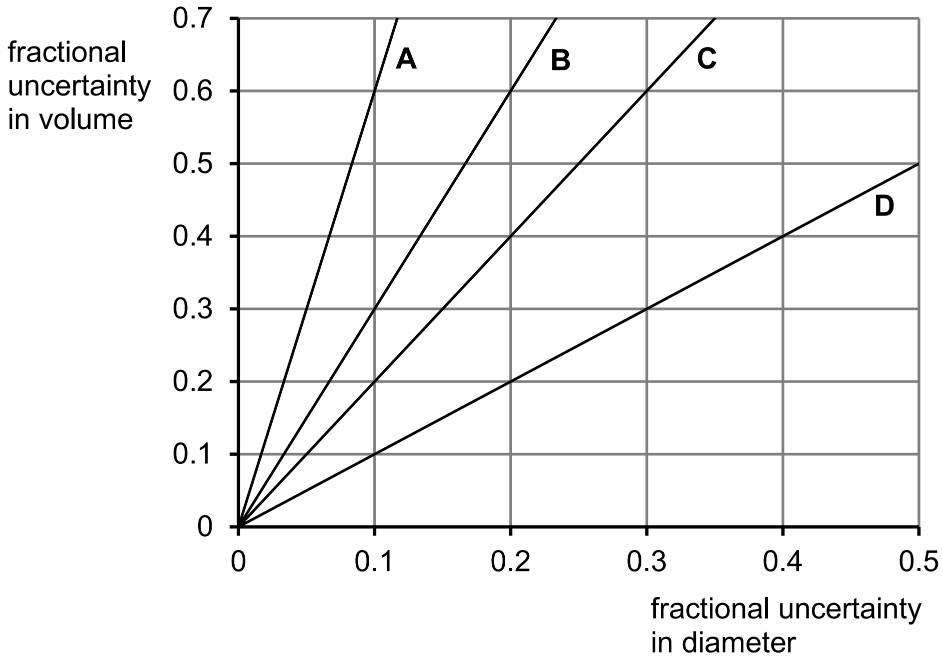
Formulae

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	=	ρgh
gravitational potential	ϕ	=	$-Gm/r$
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	=	$x_0 \sin\omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos\omega t = \pm\omega\sqrt{x_0^2 - x^2}$
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	=	$\frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	x	=	$x_0 \sin\omega t$
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	=	$\frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_0 nI$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\ln 2/t_{1/2}$

Section A (15 marks)

1 A spherical balloon is gradually inflated. Its diameter is measured at regular intervals and the uncertainty in the diameter is estimated. The volume of the balloon is then calculated at each interval using the diameter measured.

Which graph shows how the fractional uncertainty in the volume of the balloon varies with the fractional uncertainty in the diameter of the balloon?



2 Which sequence shows the unit prefixes in order of decreasing magnitude?

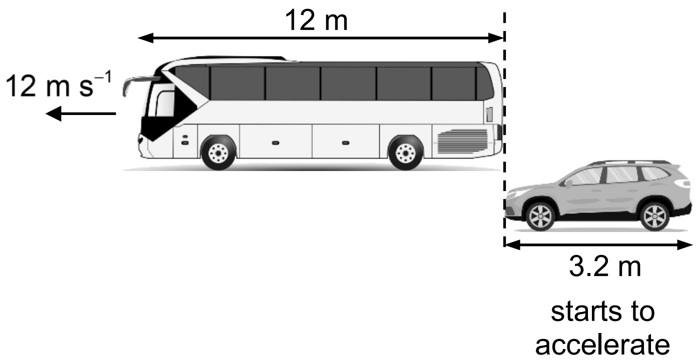
A kilo, giga, tera

B deci, mega, kilo

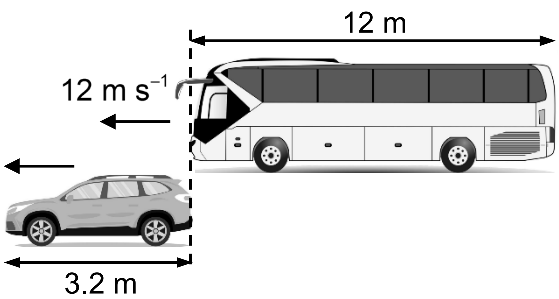
C centi, pico, nano

D milli, micro, nano

3 A car of length 3.2 m accelerates uniformly from rest as a bus of length 12 m passes its front at a constant speed of 12 m s^{-1} as shown.



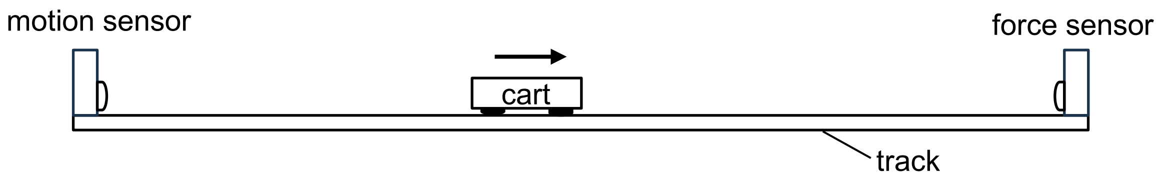
After 30 s, the car passes the front of the bus as shown.



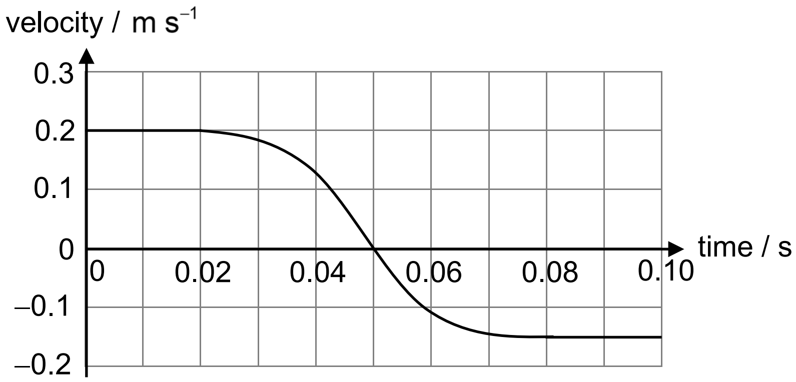
What is the acceleration of the car?

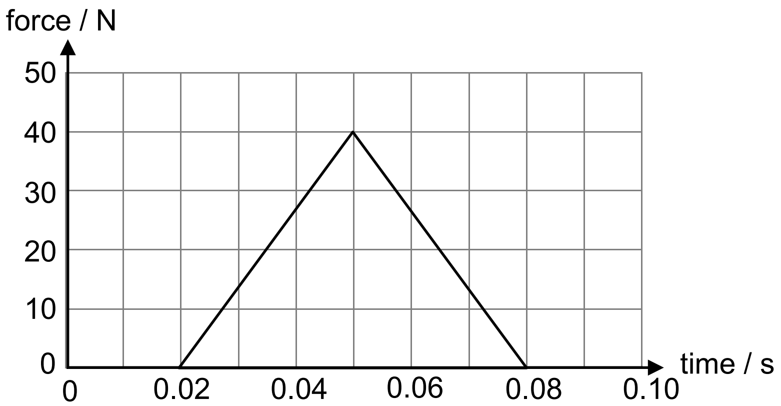
A 0.80 m s^{-2} **B** 0.81 m s^{-2} **C** 0.83 m s^{-2} **D** 0.86 m s^{-2}

4 A cart is placed on a horizontal track between a motion sensor and a force sensor. It is given a push such that it moves towards the force sensor and collides with it.



The variation with time of the velocity of the cart and the force on the sensor during the collision as measured by the motion sensor and force sensor respectively, are shown in the graphs.





What is the mass of the cart?

A 3.4 kg **B** 4.6 kg **C** 6.9 kg **D** 24 kg

5 Which statement about upthrust is always correct?

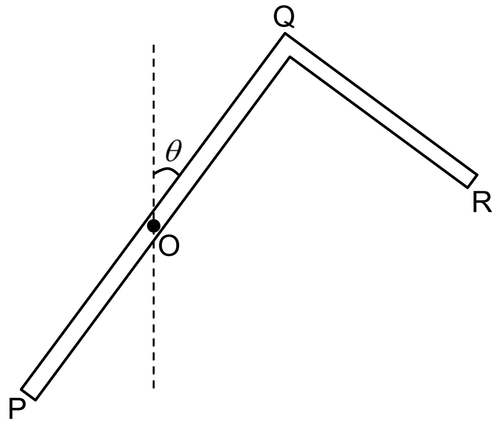
A The upthrust on an object is equal to the weight of the object.

B Two objects of the same mass will experience the same upthrust when fully submerged in the same type of liquid.

C The upthrust experienced by an object submerged in a liquid, is due to the fluid pressure at the bottom surface of the object.

D A solid metal sphere and a hollow plastic sphere with the same dimensions will experience the same upthrust when fully submerged in the same type of liquid.

6 The diagram shows a light, right-angle L-shaped rod PQR. Side PQ is twice the length of side QR. The rod is pivoted at point O, the midpoint of side PQ, such that it rotates freely in the vertical plane.

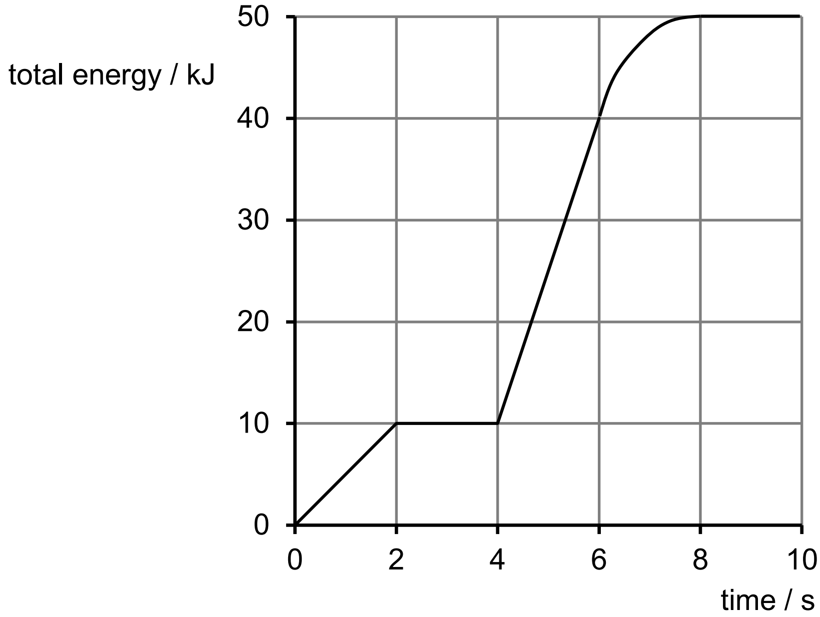


A small piece of clay of mass m is attached at R and another small piece of clay of mass $4m$ is attached at P. When the rod rests in equilibrium, PQ is at an angle θ to the vertical.

What is the value of θ?

A 7.1° **B** 14.0° **C** 18.4° **D** 26.6°

7 An electric crane is used to lift a container from the ground. The graph shows the variation with time of the total energy of the container.



If the efficiency of the electric crane is 65 %, what is the maximum electrical power supplied to the crane during the 10 seconds?

A 9.8 kW **B** 15 kW **C** 23 kW **D** 31 kW

8 The mean radius of the Earth's orbit around the Sun is 1.50×10^{11} m.

What is the mean speed of the Earth in its orbit around the Sun?

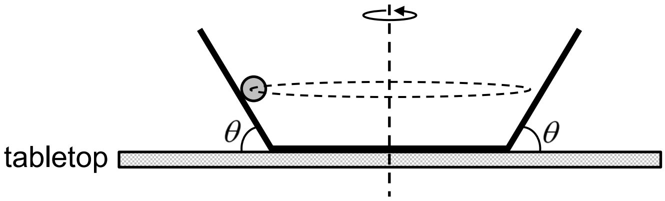
A 1.09×10^{7} m s^{-1}

B 2.99×10^{4} m s^{-1}

C 5.95×10^{-3} m s^{-1}

D 1.99×10^{-7} m s^{-1}

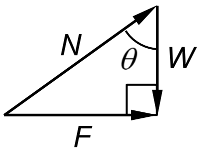
9 A small ball is made to move in a horizontal circle by rotating the bowl at a constant angular velocity about the vertical axis through its centre. The diagram shows the cross-section of the bowl.



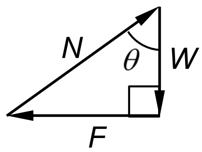
The sides of the bowl make an angle θ with the tabletop. Assume all resistive forces are negligible.

Which diagram shows the vector triangle of the weight of the ball *W*, contact force *N* and the centripetal force *F* on the ball at the instant shown above?

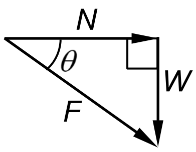
A



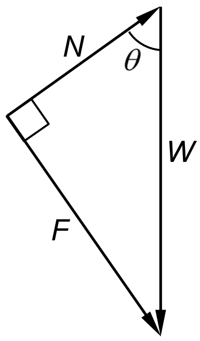
B



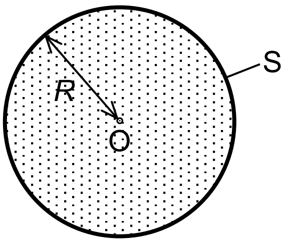
C



D



10 An astronomical spherical gas cloud has mass *M* and radius *R*. The gravitational potential on its surface S is $-\dfrac{GM}{R}$ and at its centre O is $-\dfrac{3GM}{2R}$.



A unit mass is moved at constant speed by an external force from S to O.

What is the work done on the mass by the gravitational force?

A $-\dfrac{5GM}{2R}$ **B** $-\dfrac{GM}{2R}$ **C** $\dfrac{GM}{2R}$ **D** $\dfrac{5GM}{2R}$

11 The escape speed of an object projected from the surface of the Earth is $11.2\ \text{km s}^{-1}$.

The radius of the Earth is 4 times that of the Moon and the ratio of the average density of the Earth to that of the Moon is $\frac{5}{4}$.

What is the escape speed of an object projected from the surface of the Moon?

A $2.50\ \text{km s}^{-1}$ **B** $3.13\ \text{km s}^{-1}$ **C** $5.01\ \text{km s}^{-1}$ **D** $20.0\ \text{km s}^{-1}$

12 Which of the following is an effect of a decrease in damping in a forced oscillation?

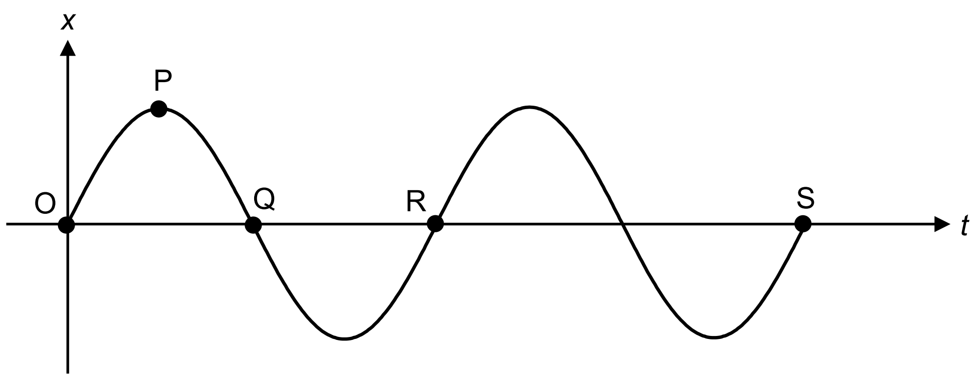
A All the energy from the driving system is transferred to the oscillating system.

B The total energy of the oscillating system decreases.

C The amplitude of the oscillation at resonance decreases.

D The period of the driving force at which resonance occurs decreases.

13 The graph shows the variation with time *t* of the displacement *x* of a particle on a progressive wave.



O, P, Q, R and S are points on the graph.

Which statement is correct?

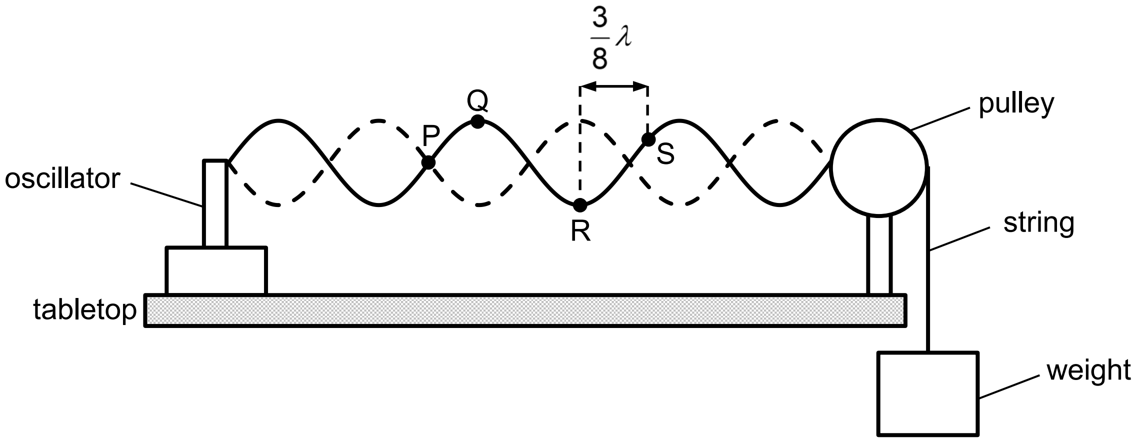
A At P, the acceleration of the particle is zero.

B The phase difference between P and Q is $90°$.

C OS represents two wavelengths.

D The kinetic energy of the particle is higher when it is at P than when it is at R.

14 A string is attached at one end to an oscillator and stretched by a weight over a pulley at the other end. When the oscillator is switched on, a stationary wave is formed on the string.



P, Q, R and S are points along the string. The wavelength of the incident wave is λ and the distance between points R and S is $\frac{3}{8}\lambda$.

Which statement is correct?

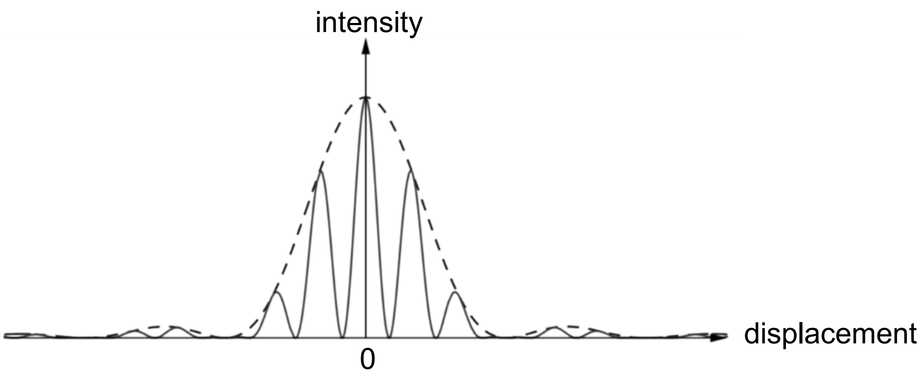
A The phase difference between R and S is $\frac{3}{4}\pi$ rad.

B Q and S are oscillating in phase with each other but have different amplitudes of oscillation.

C At P, the incident and reflected waves on the string always meet $\frac{\pi}{2}$ rad out of phase with each other.

D The distance between Q and R is $\frac{1}{2}\lambda$ and the amplitude of the incident wave is the same as the amplitude of Q.

15 Monochromatic laser light is incident on two narrow slits. The variation with displacement from the centre of the interference pattern of the intensity of the light captured on a screen at a large distance away is shown.



If the slit separation between the two slits is 0.60 mm, what is the width of each slit?

A 0.10 mm **B** 0.12 mm **C** 0.15 mm **D** 0.20 mm

END OF SECTION A

Name: ______________________ (   ) CT Group: 24S0 ______

RAFFLES INSTITUTION

2023 YEAR 5 PROMOTIONAL EXAMINATION

2 October 2023

H2 PHYSICS

Section B

INSTRUCTIONS TO CANDIDATES

Write your name, index number and CT Group.

Write your answers to Section B in the spaces provided on the question paper.

You are advised to write all your workings and answers clearly. Marks may be deducted for unclear workings.

For Examiner's Use		
Section A	MCQ	/ 15
Section B	1	/ 10
	2	/ 10
	3	/ 10
	4	/ 8
	5	/ 12
Section C	6	/ 15
	7	/ 15
Deductions		
Total		/ 95

This document consists of **14** printed pages.

Section B (50 marks)

1 A ball is kicked with an initial velocity u at an angle of 32.0° from the ground towards a vertical wall. The ball hits the top of the wall after a time of 1.40 s. The path of the ball, assuming negligible air resistance, is shown in Fig. 1.1.

The horizontal distance between the initial position of the ball and the base of the wall is 20.0 m.

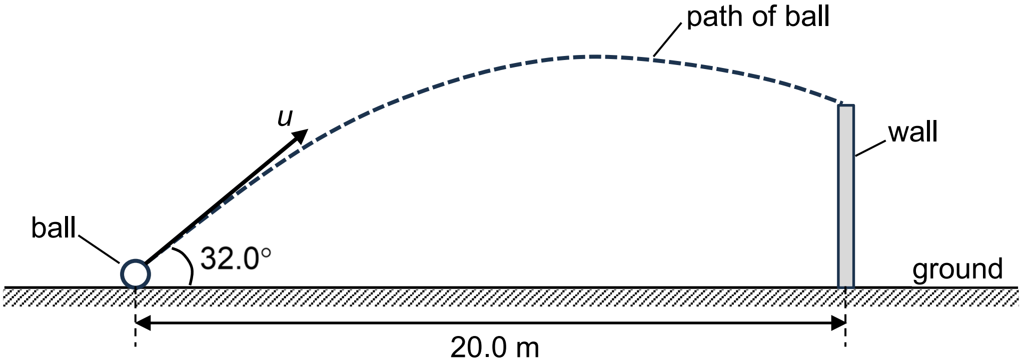


Fig. 1.1 (not to scale)

(a) Calculate the horizontal component of u.

horizontal component of u = ... m s^{-1} [1]

(b) Calculate the vertical component of u.

vertical component of u = ... m s^{-1} [1]

(c) Calculate the time for the ball to reach its maximum height above the ground.

time = ... s [2]

(d) **(i)** The ball is kicked at time $t = 0$ s.

On Fig. 1.2, sketch the variation with time t of the vertical component v_y of the velocity of the ball until it hits the wall at $t = 1.40$ s.

Include in your sketch, the values of the initial vertical velocity, the time at maximum height and the final vertical velocity of the ball when it hits the top of the wall.

Take direction upwards as positive.

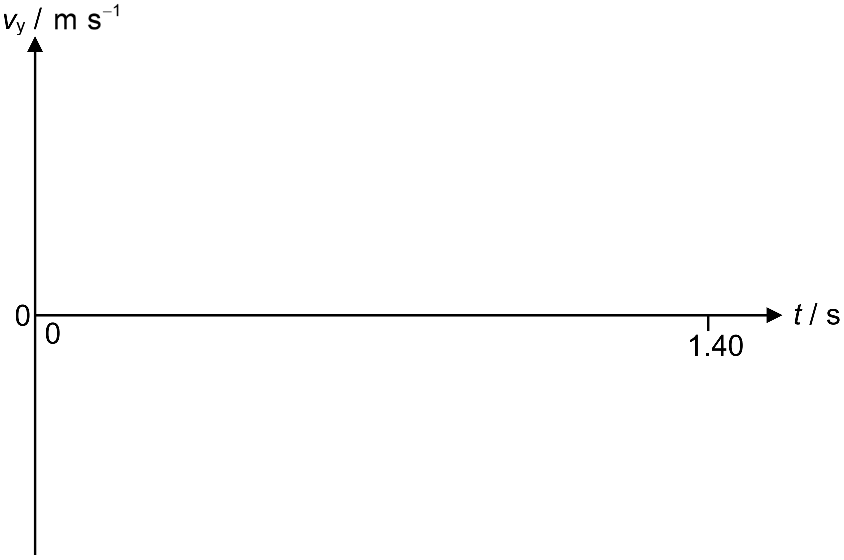


Fig. 1.2

[2]

(ii) Explain how the graph in Fig. 1.2 may be used to determine the height of the wall.

....

.... [1]

(e) In practice, air resistance is not negligible.

Describe qualitatively the effect, if any, of air resistance on the component of the velocity of the ball in

(i) the horizontal direction,

....

.... [1]

(ii) the vertical direction.

....

....

....

.... [2]

2 **(a)** A circular track is fixed horizontally on a smooth table. A spring, fixed at one end to a stand, is used to project a small ball along the frictionless track. Fig. 2.1. shows the top view of the setup.

The spring is compressed and the ball is placed next to it. When the spring is released, the ball goes round the track in a horizontal circle with uniform speed.

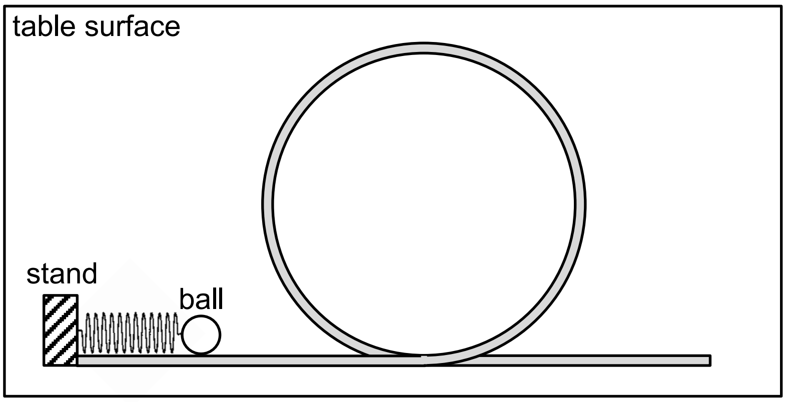


Fig. 2.1 (top view)

Explain how the kinetic energy of the ball can remain constant while a resultant force acts on the ball as it goes round the track.

....

....

....

.... [2]

(b) The circular track is now placed upright such that it forms a vertical circle of diameter 0.60 m. Point P is at the top of the track. Fig. 2.2 shows the front view of the setup.

The spring of force constant $80\ \text{N m}^{-1}$ is compressed again and the ball of mass 45 g is placed next to it. The spring is then released and the ball is projected horizontally onto the track.

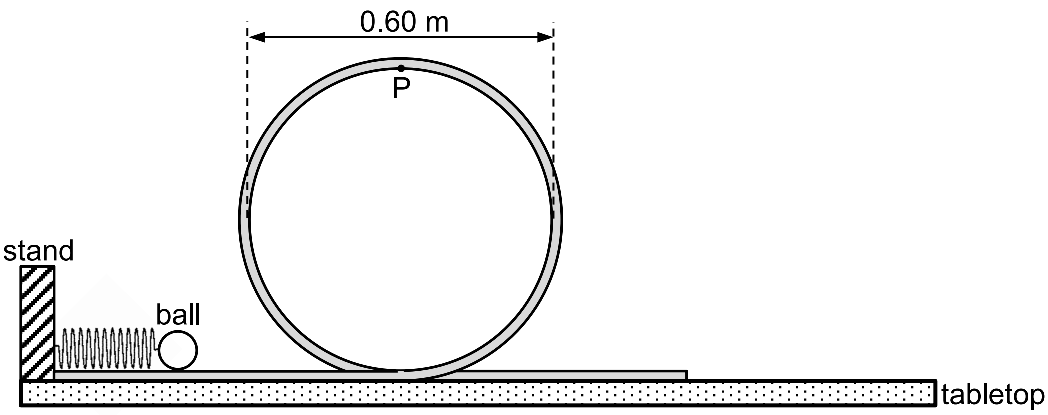


Fig. 2.2 (front view)

(i) **1.** Determine the minimum speed of the ball at point P such that it just completes the vertical circle without falling off the track.

Explain your working.

speed = ... m s^{-1} [3]

2. Calculate the initial compression of the spring for the ball to have the minimum speed at point P as determined in **(b)(i)1**.

compression = ... m [2]

(ii) If the ball is replaced with one of a greater mass, state and explain how this will affect your answers

1. in **(b)(i)1.**,

....

....

.... [1]

2. in **(b)(i)2**.

....

....

.... [1]

(iii) The initial compression of the spring is reduced and the ball leaves the track at point Q as shown in Fig. 2.3.

On Fig. 2.3, draw the path of the ball after it leaves the track at point Q.

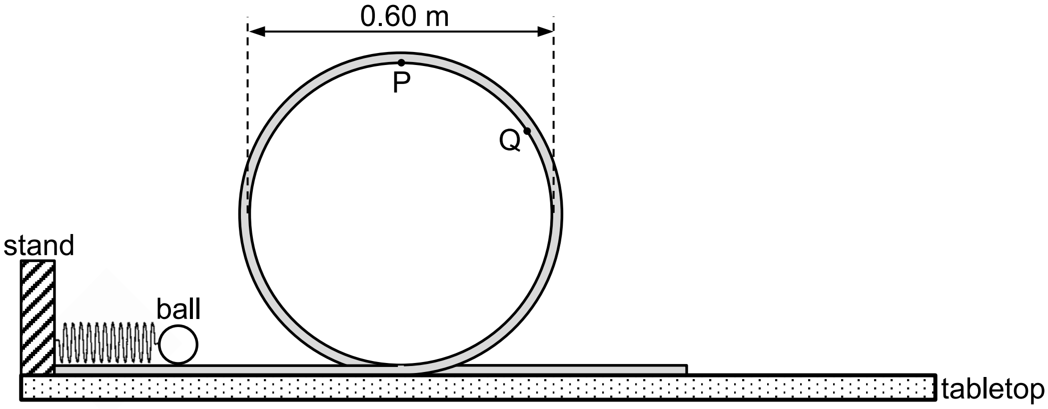


Fig. 2.3 (front view)

[1]

3 **(a)** A satellite of mass m orbits the Earth of mass M in a circular path as shown in Fig 3.1.

The Earth and the satellite may be considered to be point masses with their masses concentrated at their centres.

The satellite has speed v and the radius of its orbit about the Earth is r.

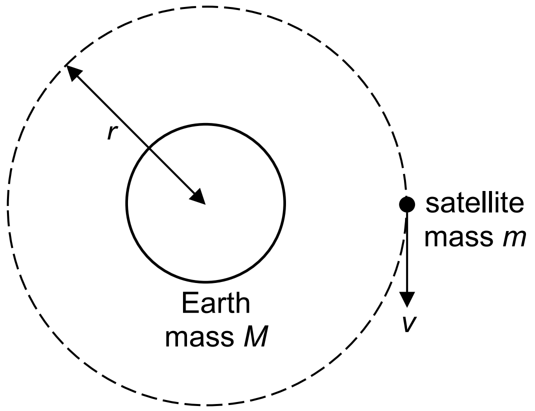


Fig. 3.1

(i) Show that the potential energy E_p and kinetic energy E_k of the satellite are related by the expression $E_p = -2E_k$. Explain your working.

[2]

(ii) The radius of the Earth is R_E. The kinetic energy of the satellite at $r = 4R_E$ is E.

On Fig. 3.2, sketch the variation with orbital radius r, from $r = R_E$ to $r = 4R_E$, of the satellite's

1. gravitational potential energy (label this graph E_p),

2. kinetic energy (label this graph E_k),

3. total energy (label this graph E_T).

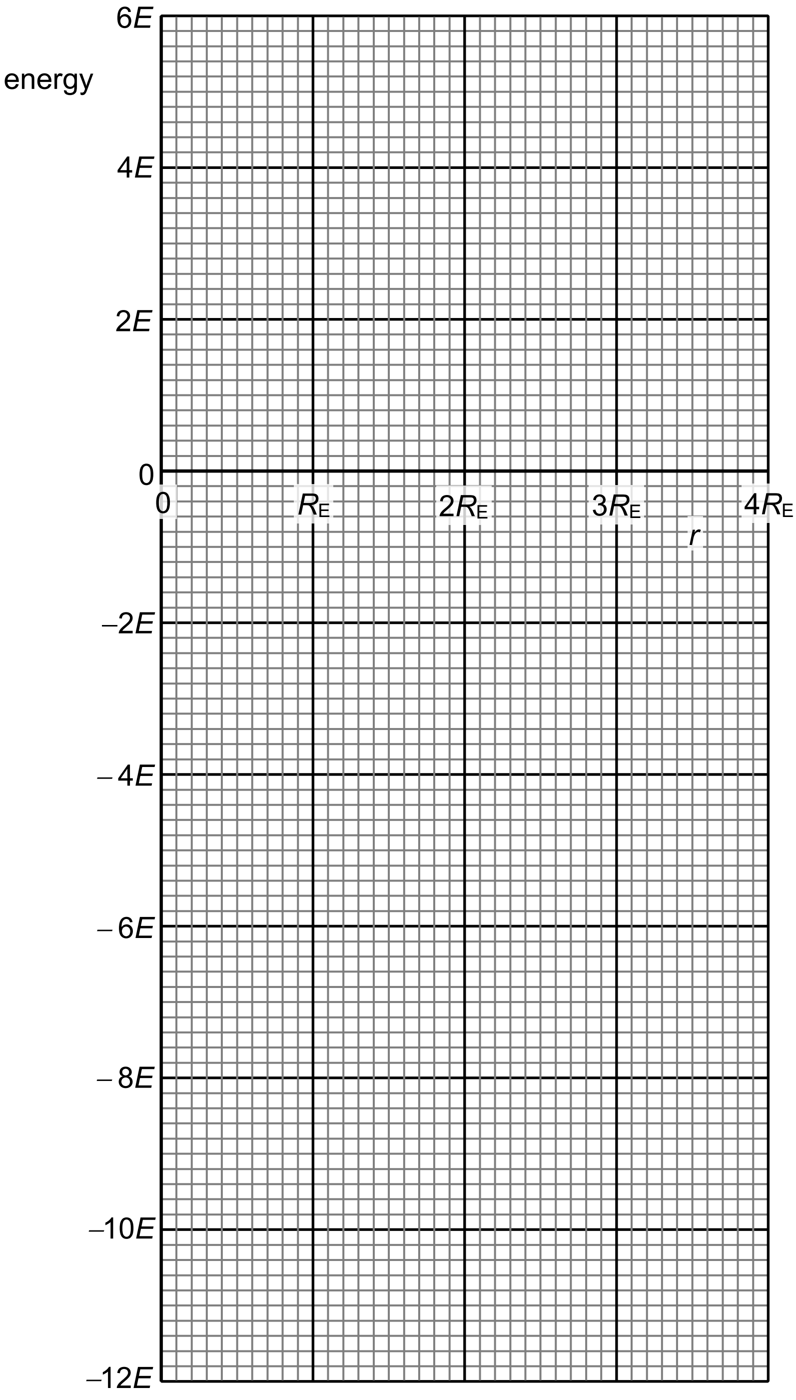


Fig. 3.2

[3]

(b) Launched on 24 November 1998, the International Space Station (ISS) serves as a cutting-edge facility dedicated to fostering collaborative scientific research. It revolves around the Earth in a circular orbit within the outermost layer of the Earth's atmosphere, at a height of 408 km above the Earth's surface.

The Earth has radius R_E of 6.37×10^6 m and mass M of 5.98×10^{24} kg.

(i) Determine, with appropriate calculations, whether the ISS could be in a geostationary orbit.

....

.... [3]

(ii) Explain why the ISS needs to fire its engine thrusters periodically to maintain its desired orbit.

....

....

....

.... [2]

4 **(a)** A point source of light of power 480 W emits light uniformly in all directions. A detector of diameter 6.0 cm is placed at a distance of 5.0 m from the point source, such that light falls normally on the detector.

Calculate the amount of light energy incident on the detector in 4.0 minutes.

energy = ... J [3]

(b) Three ideal polarising filters P_1, P_2 and P_3 are held in line with one another and with their transmission axes at different angles. A parallel beam of unpolarised light of intensity I_0 is directed towards the filters as shown in Fig. 4.1.

The light beam is incident on P_1 with its transmission axis vertical. The transmission axis of P_2 is at an angle θ to the vertical. The transmission axis of P_3 is at an angle 2θ to the vertical.

The intensity of the light beam emerging from P_3 is $\frac{I_0}{8}$.

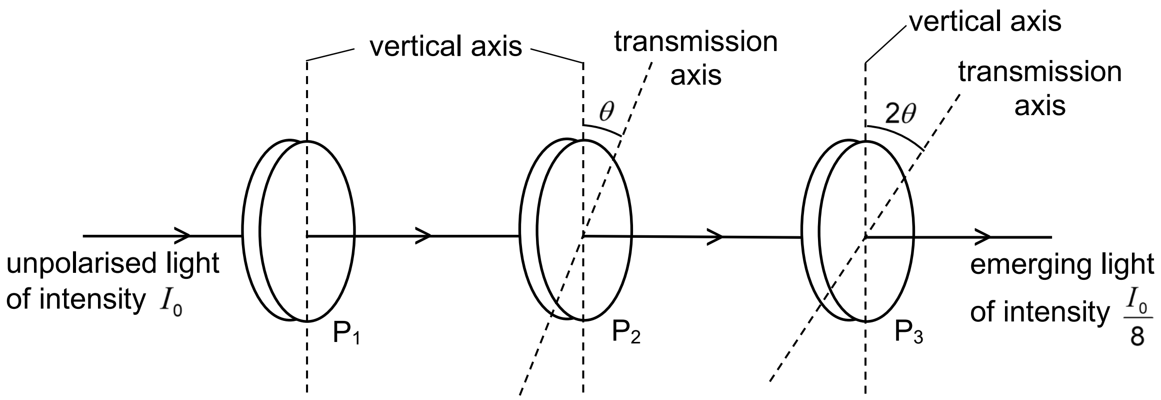


Fig 4.1

(i) Show, using Malus' law, that the value of θ is $45°$. Explain your working.

[2]

(ii) The transmission axis of polarising filter P_3 is rotated from its current position. The angle of rotation ϕ from its current position is as shown in Fig. 4.2.

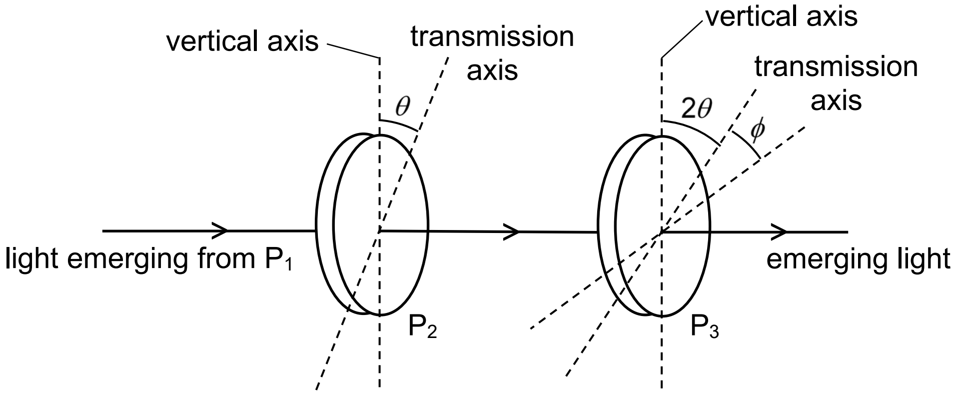


Fig. 4.2

1. Explain why the intensity of the light beam emerging from P_3 is zero when $\phi = 45°$.

.... [1]

2. On Fig. 4.3, sketch a graph to show the variation with ϕ of the intensity of the light beam emerging from P_3 from $\phi = 0°$ to $\phi = 360°$.

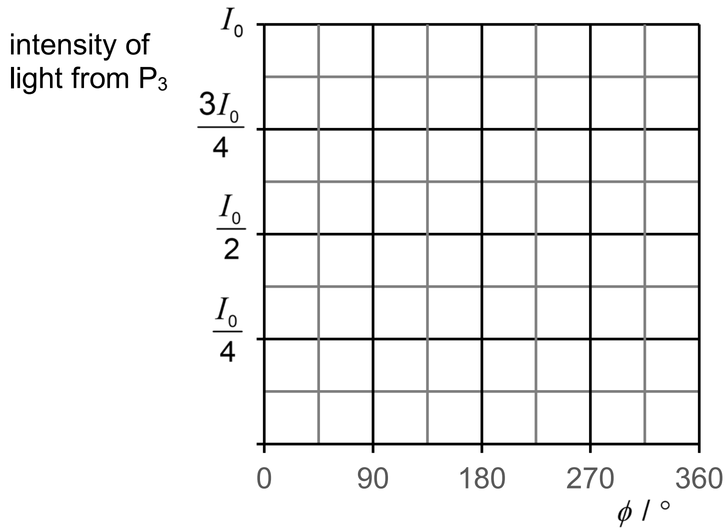


Fig. 4.3

[2]

5 **(a)** State the *principle of superposition*.

....

....

....

.... [2]

(b) Fig. 5.1 shows an experimental setup involving two coherent point sources of radio waves, S_1 and S_2, placed 50 cm apart from each other.

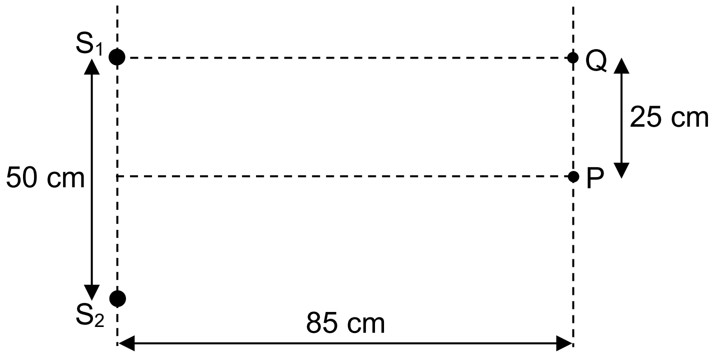


Fig. 5.1 (not to scale)

Points P and Q are at a horizontal distance of 85 cm from sources S_1 and S_2. Point P is equidistant from the two sources and point Q is directly in front of source S_1.

A receiver detects a high intensity signal at point P. The next high intensity signal is detected when the receiver is moved 25 cm upwards from point P to point Q.

(i) State what is meant by *coherent sources*.

....

.... [1]

(ii) State the phase difference between sources S_1 and S_2.

.... [1]

(iii) A student claims that the separation Δx between the consecutive high intensity signals detected by the receiver at points P and Q is given by the same formula as that for the fringe separation in a Young's double-slit experiment, which is

$$\Delta x = \frac{\lambda D}{d}$$

where $D = 85$ cm, $d = 50$ cm and λ is the wavelength of the radio waves emitted.

Explain, with reference to the data given, why the student's claim is incorrect.

....

....

....

....

.... [2]

(iv) Determine the wavelength λ of the radio waves.

λ = ... cm [2]

(v) The receiver is now moved horizontally from point Q to S_1 along the line QS_1. Along the way, the intensity of the signal detected by the receiver fluctuates.

Determine the number of high intensity signals detected by the receiver as it is moved from point Q to S_1, excluding the high intensity signal detected at point Q.

number of high intensity signals = ... [2]

(c) A narrow beam of monochromatic light of unknown wavelength is incident normally on a diffraction grating of 833 lines per millimetre. A large screen is placed parallel to the plane of the diffraction grating at a large distance away to observe the interference pattern.

The entire interference pattern consists of only five bright spots.

Determine the minimum possible wavelength of the light. Show your working clearly.

minimum wavelength .... nm [2]

END OF SECTION B

Name: ______________________________ (   )   CT Group: 24S0 ________

RAFFLES INSTITUTION

2023 YEAR 5 PROMOTIONAL EXAMINATION

2 October 2023

H2 PHYSICS

Section C

INSTRUCTIONS TO CANDIDATES

Write your name, index number and CT Group.

Write your answers to Section C in the spaces provided on the question paper.

You are advised to write all your workings and answers clearly. Marks may be deducted for unclear workings.

For Examiner's Use		
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This document consists of **8** printed pages.

Section C (30 marks)

6 A body of mass 2.6 kg is oscillating in simple harmonic motion between points P and Q. The variation with displacement *x* from point P of the kinetic energy of the body is shown in Fig. 6.1.

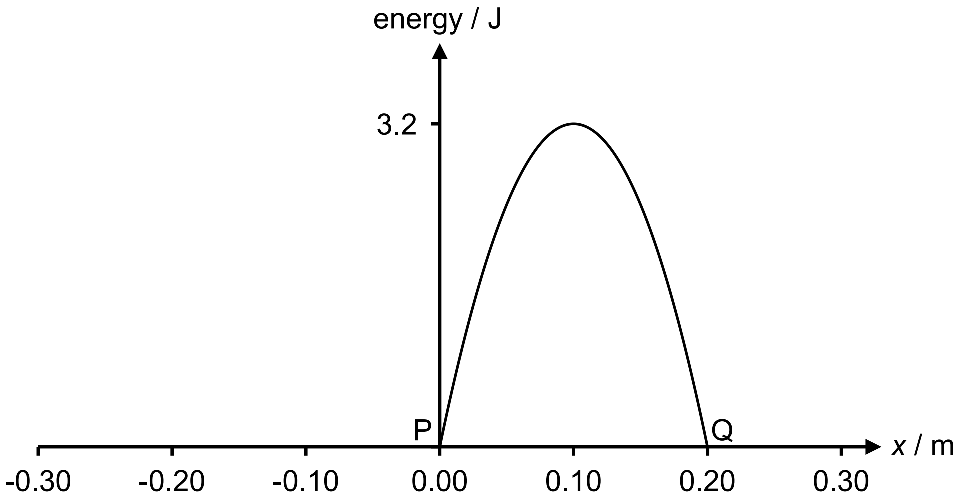

Fig. 6.1

(a) State the displacement *x* of the equilibrium position of the body.

.... [1]

(b) Calculate the maximum speed of the body.

maximum speed = ... m s^{-1} [2]

(c) Calculate the maximum acceleration of the body.

maximum acceleration = ... m s^{-2} [2]

(d) Calculate the period of the motion.

period = ... s [2]

(e) On Fig. 6.1, sketch the variation with x of the potential energy of the body. [1]

(f) The body is at point P at time $t = 0$ s.

On Fig. 6.2, sketch the variation with t of the potential energy of the body from $t = 0$ s to $t = 0.80$ s.

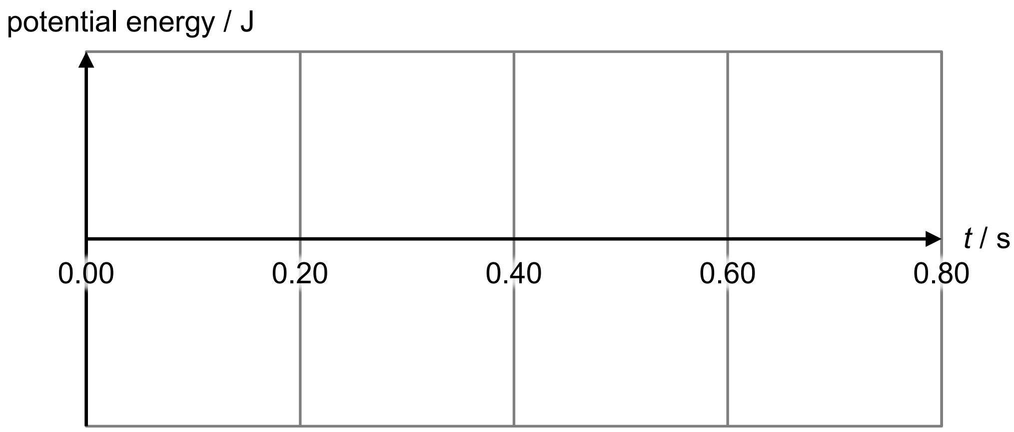

Fig. 6.2

[2]

(g) On Fig. 6.3, sketch the variation with x of the velocity v of the body.

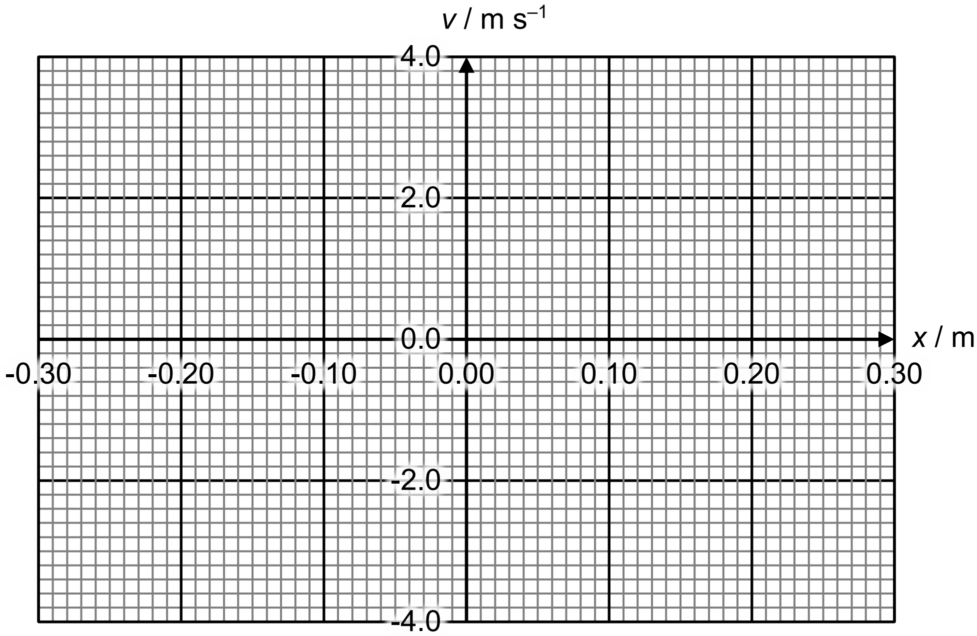

Fig. 6.3

[2]

(h) The body is now immersed in a beaker of water. The body is then released from point P and it undergoes oscillation.

(i) On Fig. 6.3, sketch the variation with x of v of the body for 2 cycles.

[1]

(ii) State and explain whether the body will attain maximum speed before it reaches the equilibrium position, at the equilibrium position or after it passes the equilibrium position from the time it is released.

....

....

....

....

....

.... [2]

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

Humans have ventured into space since the launch of Sputnik, the first artificial satellite to orbit the Earth. Space exploration has gone a long way since then, with milestone events like the first human to be in space, the first spacewalk and landing astronauts on the Moon. All these were possible by the advances made in rocket-propulsion design.

SpaceX, a privately-owned spaceflight company, specialises in rocket technology and design. The company is currently developing the Starship system, a fully reusable transportation system designed to carry both crew and cargo to low Earth orbit, the Moon, Mars and beyond.

The Starship system uses a two-stage rocket which burns liquid oxygen and methane that it carries on board as fuel. As the rocket operates, it continuously ejects burned fuel gases to create thrust. The gases are ejected in a direction opposite to the direction of travel of the rocket. The first stage of the rocket system, Super Heavy, is powered by 33 Raptor engines. The second stage of the system, Starship, is designed for long-duration space flight. Fig. 7.1 is a schematic sketch of the Starship system.

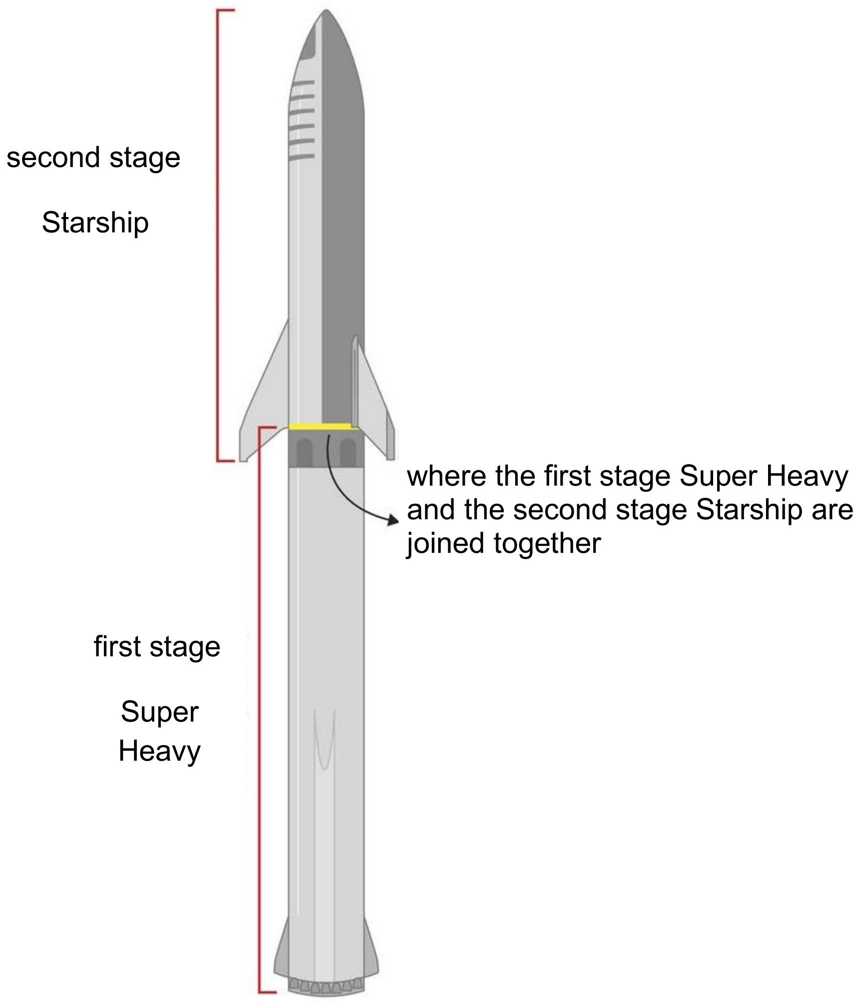

Fig. 7.1 (the Starship system)

During the first stage of the launch from Earth, the Raptor engines are powered for 162 s before the Super Heavy separates from the Starship and returns to Earth. The Raptor engines are then used for a controlled landing on land or water so that the Super Heavy can be reused for future missions.

The specific impulse I_s is a measure of how efficiently a rocket engine creates thrust. It can be calculated by the equation

$$I_s = \frac{F}{m_f}$$

where F is the thrust produced and m_f is the mass of the ejected gases flowing through the engine per second.

Data for specific impulse I_s measured at sea level and in vacuum for a single Raptor engine are shown in Table 7.1. The mass of the ejected gases per second m_f is also given.

Table 7.1

for a single Raptor engine	at sea level	in vacuum
I_s / m s^{-1}	3250	3560
m_f / kg s^{-1}	620	

(a) Using Newton's laws, explain how the rocket creates thrust.

....

....

....

....

....

.... [2]

(b) Determine the thrust produced by a single Raptor engine just after take-off.

thrust = ... N [2]

(c) Use Table 7.1 to determine if the Raptor engine works more efficiently at sea level or in vacuum. Explain your reasoning.

....

....

.... [2]

(d) The Super Heavy rocket still has some fuel remaining when it separates from the Starship. Suggest why it does not burn all its fuel before separating and returning to Earth.

....

.... [1]

(e) The Starship system has a total mass of 5.0×10^6 kg just after a vertical take-off.

2.0 minutes after take-off, the Starship system is still travelling vertically and the thrust is provided by all 33 Raptor engines working at the same time. It reaches an altitude of 30 km. The atmospheric pressure at this altitude is so low that the Starship system is effectively travelling in vacuum.

(i) Calculate the total thrust produced by the 33 Raptor engines.

thrust = ... N [1]

(ii) Determine the total mass of fuel consumed in 2.0 minutes.

Assume the rate of fuel consumption to be the same as the rate the gases are ejected from the 33 Raptor engines.

mass = ... kg [1]

(iii) Determine the acceleration of the Starship system 2.0 minutes after take-off.

Assume that the variation in the magnitude of the gravitational field strength can be neglected.

acceleration = ... $m\ s^{-2}$ [2]

(iv) Explain why the variation in the magnitude of the gravitational field strength can be neglected in **(e)(iii)**.

....

....

.... [1]

(f) A test flight of the Starship system was conducted in April 2023. The second stage Starship exploded after the Super Heavy rocket separated from it. It was found that the Starship, initially travelling upwards at $300\ m\ s^{-1}$, separated into three identical fragments immediately after the explosion. One fragment continued moving upwards at $360\ m\ s^{-1}$ while a second fragment moved to the right at $240\ m\ s^{-1}$.

By considering the conservation of momentum in the horizontal and vertical directions, determine the speed of the third fragment immediately after the explosion.

speed = ... $m\ s^{-1}$ [3]

END OF SECTION C