YISHUN INNOVA JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME

CG

INDEX NO

PHYSICS

9749/02

Paper 2 Structured Questions

9 September 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 or graphs.
Do not use staples, paper clips, highlighters, glue or correction fluid/tape.

The use of an approved scientific calculator is expected, where appropriate.
Answer **all** questions.

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

For Examiner's Use	
Paper 2	
1	**/6**
2	**/6**
3	**/10**
4	**/12**
5	**/7**
6	**/8**
7	**/10**
8	**/21**
Penalty	
Paper 2 Total	
	/80

This document consists of **25** printed pages and **3** blank 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	=	$\rho g h$
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	=	$R_1 + R_2 + \ldots\ldots\ldots$
resistors in parallel,	$\frac{1}{R}$	=	$\frac{1}{R_1} + \frac{1}{R_2} + \ldots\ldots$
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	=	$\frac{\ln 2}{t_{\frac{1}{2}}}$

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

1 A girl falls vertically onto a trampoline, as shown in Fig. 1.1

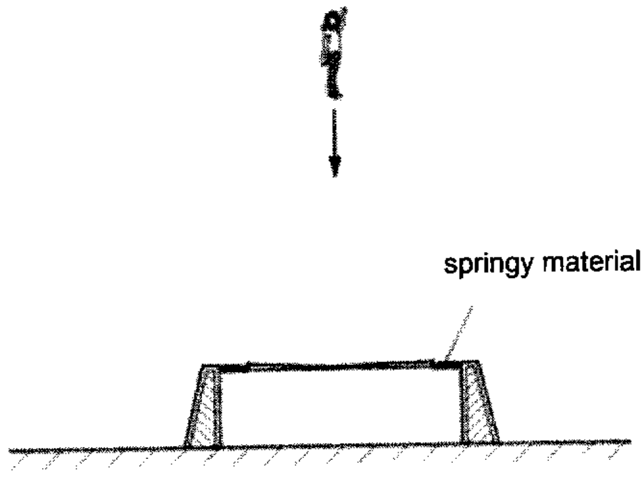

Fig. 1.1

The trampoline consists of a central section supported by springy material. At time $t = 0$, the girl starts to fall. The girl hits the trampoline and rebounds vertically. The variation with time t of velocity v of the girl is illustrated in Fig. 1.2.

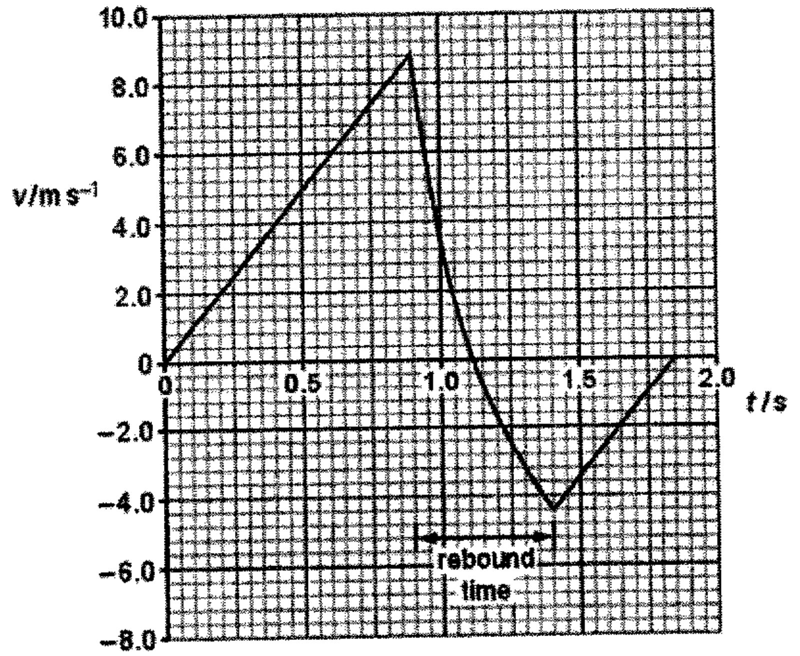

Fig. 1.2

(a) For the motion of the girl, calculate

(i) the distance fallen between time $t = 0$ and when she hits the trampoline,

distance = ... m [1]

(ii) the average acceleration during the rebound.

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

(b) (i) Explain, without calculation, how Fig. 1.2 shows that the acceleration of the girl before and after the rebound is the same.

....

....

.... [1]

(ii) Use Fig. 1.2 to compare, without calculation, the potential energy of the girl at $t = 0$ and $t = 1.85$ s. Explain your answer.

....

....

.... [2]

[Total: 6]

2 A non-uniform L-shaped beam of weight 10 N is attached to a wall using a hinge, as shown in Fig. 2.1. The beam is held at rest using a cord, such that the longer part of the beam is horizontal. The weight of the beam acts at a point on the beam that is at a horizonal distance of *x* away from the hinge. The tension in the cord is 5.0 N.

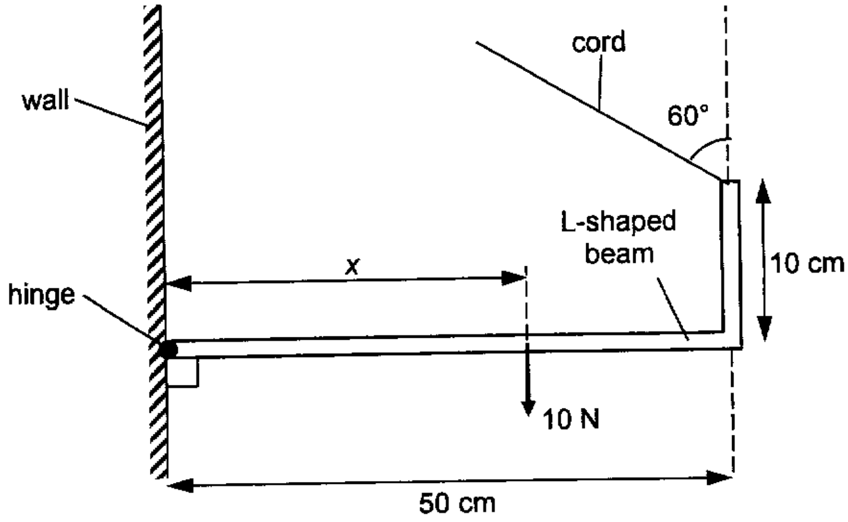

Fig. 2.1

(a) Determine the value of *x*.

x = ... cm [2]

(b) **(i)** On Fig. 2.1, draw and label

1. the tension *T* acting on the beam due to the cord, and [1]

2. the contact force *R* acting on the beam due to the hinge. [1]

(b) **(ii)** Show that the magnitude of *R* is 8.7 N.

[2]

[Total: 6]

3 A space technology company launches nanosatellites into space. The mass of each nanosatellite is 80 kg, and it is launched near Earth's equator to a height of 1.5×10^3 km above Earth's surface. The radius of Earth is 6.4×10^3 km and the mass of Earth is 6.0×10^{24} kg.

(a) **(i)** A nanosatellite is launched from Earth's surface using a propulsion system that supplies 3.0×10^9 J of energy to the nanosatellite.

Assuming that there is negligible air resistance and no loss of mass, calculate the kinetic energy of the satellite when it reaches a height of 1.5×10^3 km.

kinetic energy = ... J [3]

(ii) Another nanosatellite is currently in a circular orbit about Earth at the height of 1.5×10^3 km above Earth's surface.

Calculate the magnitude of centripetal force required for the nanosatellite to stay in this orbit.

centripetal force = ... N [2]

(b) Fig. 3.1 shows the variation of the gravitational potential with distance from the centre of Earth. The radius of Earth, R_E is indicated in Fig. 3.1.

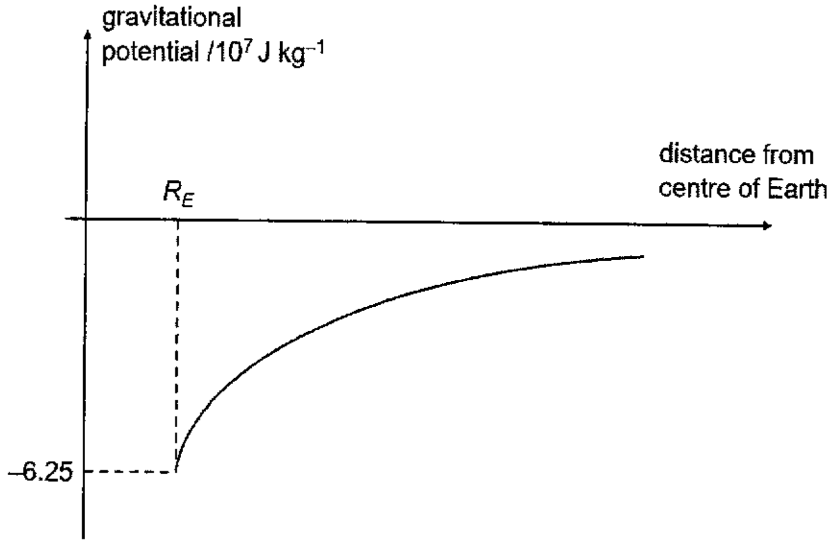

Fig 3.1

(i) State what is meant by *gravitational potential.*

....

....

.... [1]

(ii) Using Fig. 3.1, explain why the gravitational force acting on the nanosatellite due to Earth is an attractive one.

....

....

.... [2]

(iii) By referring to Fig. 3.1, calculate the escape velocity of the nanosatellite.

escape velocity = ………………... km s^{-1} [2]

[Total: 10]

4 (a) (i) For a progressive wave, state what is meant by

1. the wavelength, and

....

.... [1]

2. the phase difference.

....

.... [1]

(ii) When two similar progressive waves of wavelength λ arrive at a common point, the interference effect is related to the path difference Δx or the phase difference $\Delta\theta$ of the two waves.

State the relationship between the path difference and the phase difference using appropriate symbols.

[1]

(b) Fig. 4.1 shows the variation with time *t* of the displacement of two progressive waves P and Q passing the same point.

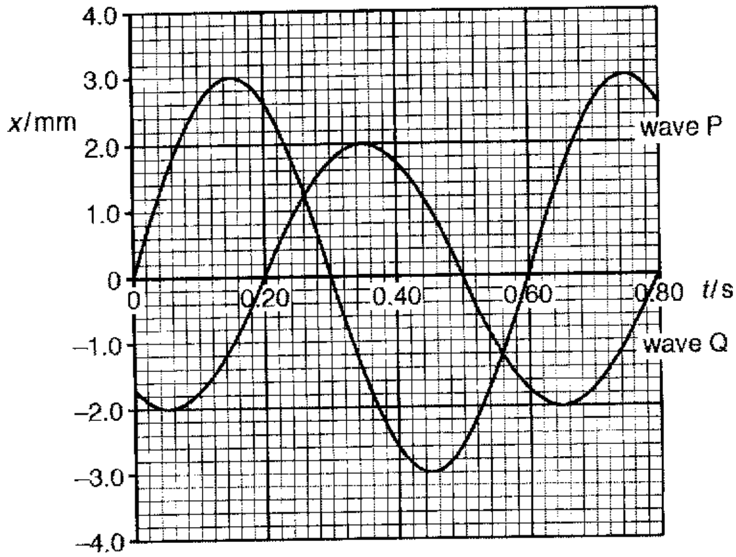

Fig. 4.1

The speed of the waves is 20 cm s^{-1}.

(i) Calculate the wavelength of the two waves.

wavelength = ... cm [2]

(ii) Determine the phase difference in degrees between the two waves.

phase difference = ... ° [2]

(iii) The two waves superpose as they pass the same point.

Use Fig. 4.1 to determine the resultant displacement at time t = 0.45 s.

displacement = ... mm [2]

(iv) Calculate the ratio

$$\frac{\text{intensity of wave Q}}{\text{intensity of wave P}}.$$

ratio = ... [2]

(v) The interference effect when the waves P and Q superpose can be observed because the two sources are coherent.

Explain what is meant by *coherent*.

....

.... [1]

[Total: 12]

5 A battery of electromotive force (e.m.f.) 12 V and negligible internal resistance is connected to a uniform resistance wire XY, a fixed resistor, and a variable resistor, as shown in Fig. 5.1.

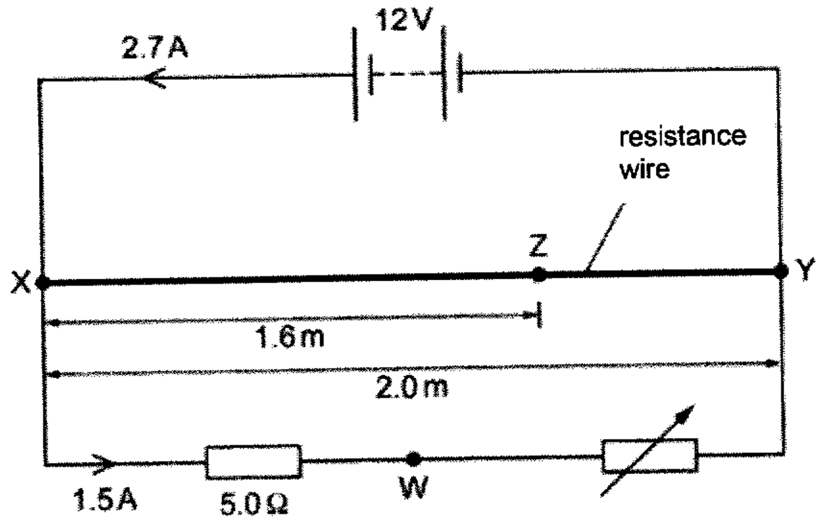

Fig. 5.1

The fixed resistor has a resistance of 5.0 Ω. The current in the battery is 2.7 A and the current in the fixed resistor is 1.5 A.

(a) Calculate the current in the resistance wire.

current = ... A [1]

(b) Determine the resistance of the variable resistor.

resistance = ... Ω [1]

(c) Wire XY has a length of 2.0 m. Point Z on the wire is at a distance of 1.6 m from point X.

Determine the potential difference between points W and Z.

potential difference = ... V [2]

(d) The resistance of the variable resistor is now increased.

State and explain whether the total power produced by the battery decreases, increases or stays the same.

....

....

....

....

.... [3]

[Total: 7]

6 A toroidal solenoid is used to determine the presence of alternating currents in cables without being electronically connected to it. It consists of a wire being wound on a plastic ring. The alternating current carrying cable is placed along the axis through the centre of the device as shown in Fig. 6.1.

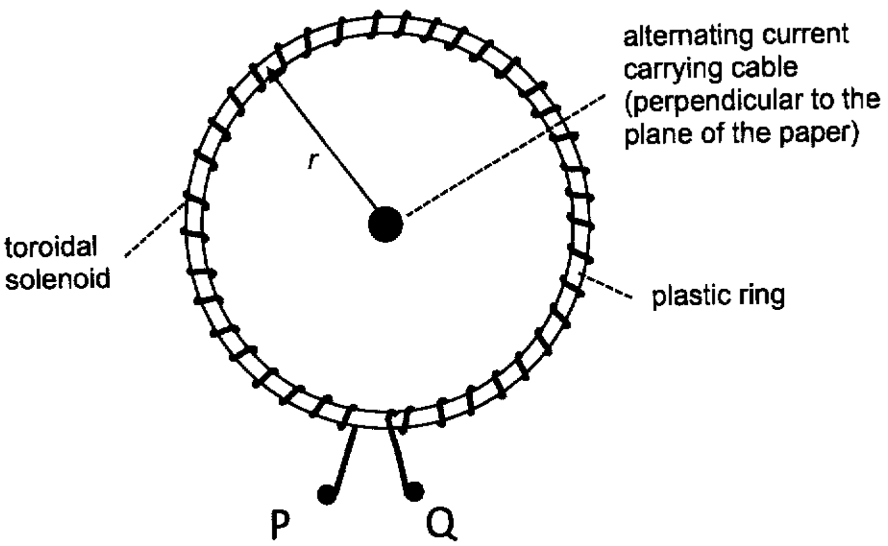

Fig. 6.1

The radius of the plastic ring r is 20 cm. The solenoid has a total of 1500 turns, and each turn has a radius of 0.50 cm.

The sinusoidal current I flowing in the cable is given by the expression $I = 1.2\sin 377t$, where time t is in seconds and current I is in amperes.

(a) **(i)** Determine the maximum magnetic flux density that is induced by the cable in the plastic ring. You may assume that the magnetic flux density in the plastic ring is uniform.

maximum magnetic flux density = ... T [2]

(ii) Hence, calculate the maximum magnetic flux linkage at the toroidal solenoid.

maximum magnetic flux linkage = ... Wb [2]

(b) The terminals P and Q are connected to a multimeter to measure the electromotive force, e.m.f., induced in the toroidal solenoid.

(i) Using the laws of electromagnetic induction, explain why there is an e.m.f. induced in the toroidal solenoid.

....

....

....

.... [2]

(ii) The multimeter usually measures the root-mean-square value of the e.m.f. when connected to an alternating voltage source.

Explain the significance of the root-mean-square value for the e.m.f. of the alternating voltage source in terms of energy considerations.

....

....

....

.... [2]

[Total: 8]

7 **(a)** Some energy levels for the electron in an isolated hydrogen atom are illustrated in Fig. 7.1.

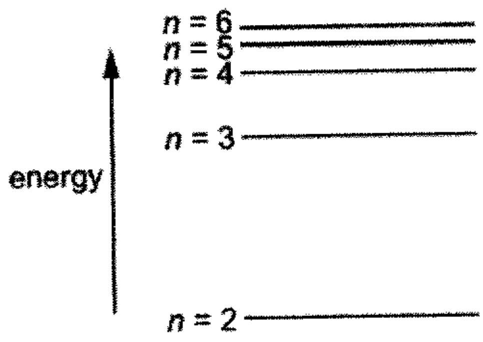

Fig. 7.1

Table 7.1 shows the wavelengths of photons that are emitted in the transitions to n = 2 from the other energy levels shown in Fig. 7.1.

wavelength / nm
412
435
488
658

Table 7.1

The energy associated with the energy level n = 2 is –3.40 eV.

Calculate the energy, in J, of energy level n = 3.

energy = ... J [3]

(b) A beam of red light of intensity 160 W m^{-2} is incident normally on a plane mirror, as shown in Fig. 7.2. The wavelength of light is 7.0×10^{-7} m.

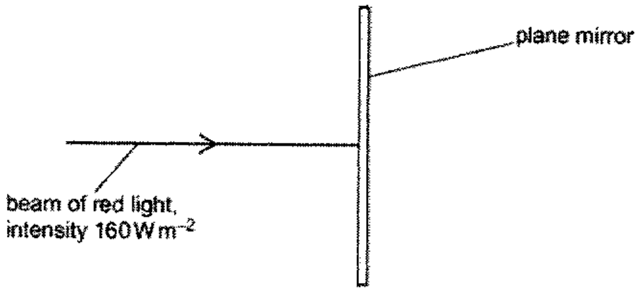

Fig. 7.2

All of the light is reflected by the mirror in the direction opposite to its original path.

The cross-sectional area of the beam is 2.5×10^{-6} m^2.

(i) Show that the number of photons incident on the mirror per unit time is 1.4×10^{15} s^{-1}.

[2]

(ii) Use the information in **(b)(i)** to determine the pressure exerted by the light beam on the mirror.

pressure = ... Pa [3]

(iii) The beam of red light in **(b)** is now replaced with a beam of blue light of the same intensity.

Suggest and explain whether the pressure exerted on the mirror by the beam of blue light is less than, the same as, or greater than the pressure exerted by the beam of red light.

....

....

....

.... [2]

[Total: 10]

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

The Sun Only Shines Because of Quantum Physics

The Sun delivers light and heat, over a distance of 150 million kilometres to Earth, making life possible. Each square metre of Earth receives about 1400 W of power from the Sun, enough to maintain liquid water. Like all stars, the Sun's energy comes from nuclear fusion in its core, enabled by the principles of quantum physics.

Starlight has been the primary energy source in the Universe since the Big Bang. Stars form from large clouds of hydrogen and helium that contract under gravity, heating their cores to extreme temperatures. In the Sun, nuclear fusion starts at about 4 million kelvins and requires densities higher than solid lead. However, classical physics calculations show that protons in the Sun's core don't have enough energy to overcome their mutual electrostatic repulsion, known as the Coulomb barrier.

Despite this, the Sun shines because of quantum mechanics. Inside the Sun, temperatures range from 4 million to 15 million kelvins. Protons (hydrogen nuclei) fuse into helium in a process that releases energy. This energy is transported as photons, which take around 100,000 years to reach the Sun's surface, and as neutrinos, which escape almost immediately.

The fusion process involves combining four protons to form a helium nucleus, releasing about 0.70% of the mass as energy according to $E = mc^2$. Each second, the Sun converts around 10^{38} protons into energy, producing a power output of 4×10^{26} Watts. Given the Sun's immense size, with a diameter 109 times that of Earth and a mass 300,000 times greater, this process occurs over a vast volume.

However, when you do your calculations, you find a shocking conclusion: there are zero collisions happening to lead to nuclear fusion. Zero. None at all. Here's where quantum mechanics, specifically quantum tunnelling and the Heisenberg Uncertainty Principle, come into play.

Furthermore, protons behave as waves, and their wavefunctions can overlap. When this happens, there's a finite probability that protons can "tunnel" through the Coulomb barrier, even without the required classical energy. The odds of fusion occurring during a proton-proton collision are about 1 in 10^{28}.

The Sun's energy output is a testament to the principles of quantum mechanics. Without quantum tunnelling and the uncertainty principle, the Sun would not shine, and Earth would be a cold, lifeless rock. Our very existence hinges on these quantum phenomena, highlighting the profound impact of quantum physics on the cosmos.

(a) Considering the Sun to be a point mass,

(i) show that the Sun emits a total power of 4.0×10^{26} W.

[2]

(ii) The Stefan-Boltzmann law states that the power P radiated by a black body is proportional to the fourth power of its temperature T and its surface area A,

$$P = \sigma A T^4,$$

where $\sigma = 5.7 \times 10^{-8}$ W m^{-2} K^{-4}.

1. Use SI base units to show that the equation is homogeneous.

[2]

2. Use your answer in **(a)(i)** to determine the effective surface temperature of the Sun. Radius of Earth = 6370 km.

temperature = ... K [2]

(b) **(i)** Given the range of the temperature in the Sun and considering that the proton behaves as an ideal gas, determine the maximum speed that a proton can move in the Sun.

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

(ii) Hence, determine the closest distance that two protons will come together, assuming that they are initially very far apart.

distance = ... m [2]

(iii) Explain why the value in **(b)(ii)** suggest that that the protons would not undergo fusion.

....

....

....

.... [2]

(iv) Suggest how Heisenberg Uncertainty Principle implies that the protons can still undergo fusion reaction.

....

....

....

.... [2]

(c) (i) The overall nuclear reaction can be summarised as:

$$4p \rightarrow He + 2e^{+} + 2\nu + \text{gamma}.$$

Given the mass of proton to be 1.007276*u* and mass of helium nucleus to be 4.002603*u*, determine the energy release in each nuclear fusion reaction.

energy = ... J [2]

(ii) The passage says that "The fusion process involves combining four protons to form a helium nucleus, releasing about 0.70% of the mass."

By making appropriate calculations, comment on the validity of this statement.

....

.... [2]

(d) **(i)** Quantum tunneling is a quantum mechanical phenomenon where particles can pass through a potential barrier that they classically should not be able to pass. This occurs because, at a quantum level, particles like protons can behave both as particles and as waves, described by a probability wavefunction.

The probability P of a particle tunneling through a barrier can be approximated using the relationship:

$$P \approx e^{-2\gamma d}$$

where

- d is the width of the barrier = 1.8×10^{-13} m,
- $\gamma = \dfrac{\sqrt{2m(U-E)}}{\hbar}$
  - m is the mass of the proton,
  - U is the height of the potential barrier = 10^{-13} J,
  - E is the energy of the particle = 10^{-16} J,
  - $\hbar$ is the reduced Planck constant = $\dfrac{h}{2\pi}$.

Determine the probability P of the proton tunneling through the potential barrier to undergo fusion.

probability = ... [2]

(ii) Despite the small probability that protons can tunnel through the potential barrier, the Sun still burns brightly.

Suggest a reason how this can happen.

....

.... [1]

[Total: 21]

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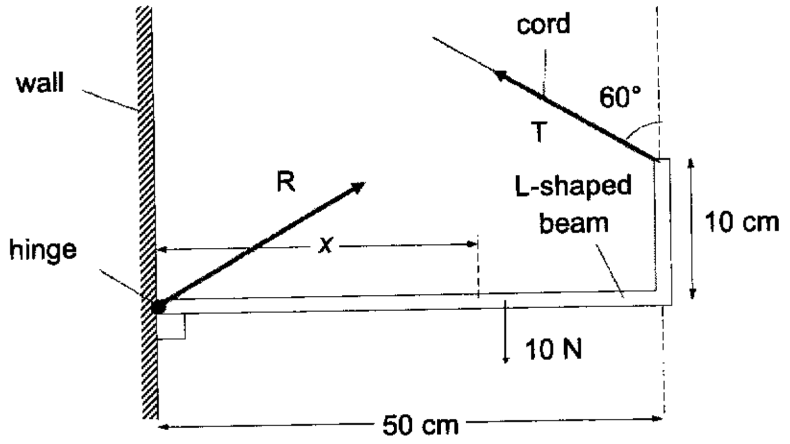
2024 JC2 Prelim Exam H2 Physics Paper 2 Solution

1	(a)	(i)	Distance = area under the $v-t$ graph $= \frac{1}{2}(8.8)(0.90) = 4.0$ m	B1
		(ii)	average acceleration $= \frac{\text{change in velocity}}{\text{time}}$ $= \frac{(-4.4-8.8)}{0.50}$ $= -26$ m s^{-2} *(Circle but not penalise for missing -ve sign)*	C1 A1
	(b)	(i)	The accelerations are the same as the gradients of the graph before and after the rebound are the same. (the girl is in a state of free fall before and after the rebound).	B1
		(ii)	The area under the lines represents height and the second area is smaller than the first area, hence, the rebound height is less than the initial height. Thus the GPE of the girl at t = 0 is larger than the GPE at t = 1.85 s. **OR** The kinetic energy (KE) of the girl at trampoline equals to the GPE at maximum height. The speed after rebound is smaller and hence the KE becomes smaller. Thus the gravitational potential of the girl after rebound is less.	M1 A1 (M1) (A1)

2	(a)		Using hinge as pivot: Clockwise moment due to weight = anti-clockwise moment due to tension Moment due to $T_y = T(\cos 60)50$ Moment due to $T_x = T(\sin 60)10$ $Wx = T(\cos 60)50 + T(\sin 60)10$ $10x = 5.0[50(\cos 60) + 10(\sin 60)]$ $x = 16.8 = 17$ cm Note: if either moment vertical/horizontal is not considered, max 1 mark.	M1 A1

	(b)	(i)	 Both vectors drawn and labelled 3 forces have common point	B1 B1
	(b)	(ii)	$R_x = T_x = 5.0\sin 60 = 4.33$ N $R_y + T_y = W$ $R_y = W - T_y = 10 - 5.0\cos 60 = 7.5$ N $\lvert R \rvert = \sqrt{R_x^2 + R_y^2} = \sqrt{4.33^2 + (-7.5)^2}$ $= 8.7$ N	M1 M1 A0

3	(a)	(i)	$GPE_{final} = -\dfrac{GM_{earth}(80)}{6.4\times10^6 + (1.5\times10^3)\times10^3}$ Total energy on Earth's surface = total energy at LEO $KE_i + GPE_i +$ energy supplied $= KE_f + GPE_f$ $\left(-\dfrac{GM_{earth}(80)}{6.4\times10^6}\right) + 3.0\times10^9 = KE_f + \left(-\dfrac{GM_{earth}(80)}{6.4\times10^6 + (1.5\times10^3)\times10^3}\right)$ $KE_f = 3.0\times10^9 + (6.67\times10^{-11})(6.0\times10^{24})(80)\left(\dfrac{1}{7.9\times10^6} - \dfrac{1}{6.4\times10^6}\right)$ $KE_f = 2.1\times10^9$ J	C1 C1 A1
		(ii)	Centripetal force is provided by gravitational force $F_c = F_G$ $F_C = \dfrac{GMm}{r^2}$ $F_c = \dfrac{6.67\times10^{-11}(6.0\times10^{24})(80)}{(7.9\times10^6)^2}$ $F_c = 510$ N (1m for both working and answer.)	B1 B1
	(b)	(i)	Gravitational potential at a point is the work done per unit mass by external agent in bringing a small test mass from infinity to that point.	B1

		(ii)	Since $F = -m\dfrac{d\phi}{dr}$, the negative of the gradient of the ϕ-r graph gives the force. Positive gradient means gravitational force (vector) is negative Since gravitational force is negative when displacement is positive, it is in the opposite direction as the displacement from Earth and hence is attractive. **OR** Potential decreases nearer to the Earth. Gravitational force must always be in direction of decreasing potential and points towards Earth and is attractive. **OR** The gravitational potential is always negative, so the external force points in the opposite direction to displacement from infinity to that point / points away from the earth. Hence, the gravitational force points opposite to the external force towards the earth and is an attractive one.	**M1** **A1** **(M1)** **(A1)** **(M1)** **(A1)**
		(ii)	$KE_{initial} + U_{initial} = KE_{final} + U_{final}$ $\frac{1}{2}mu^2 + m\phi_{initial} = \frac{1}{2}mv^2 + m\phi_{final}$ $\frac{1}{2}u^2 + \left(-6.25\times10^7\right) = 0 + 0$ $u = 11.2 \text{ km s}^{-1}$	 **M1** **A1**

4	**(a)**	**(i)1**	distance moved by wavefront/wave during one period / during one oscillation of a particle in that wave **OR** minimum distance between two wavefronts/crests/troughs/peaks **OR** minimum distance between two points which are in phase	**B1** **(B1)** **(B1)**
		(i)2	The phase difference between two particles refers to how much one particle lags or leads another with respect to a cycle. **OR** how one wave lags or leads another wave of the same wavelength.	**B1** **(B1)**
		(ii)	$\dfrac{\Delta\theta}{2\pi} = \dfrac{\Delta x}{\lambda}$ OR $\dfrac{\Delta\theta}{360°} = \dfrac{\Delta x}{\lambda}$	**B1**
	(b)	**(i)**	Using $v = \dfrac{\lambda}{T}$ or $v = f\lambda$ and $f = \dfrac{1}{T}$ From Fig. 4.1, T = 0.60 s $\lambda = vT = (20)(0.60)$ $= 12$ cm	 **M1** **A1**
	(b)	**(i)**	$\dfrac{\Delta\theta}{360°} = \dfrac{\Delta t}{T} = \dfrac{0.20}{0.60}$ $\Delta\theta = 120°$ (or $360° - 120° = 240°$) (Award M1 mark only if answers expressed in radians (2.09 rad).)	**M1** **A1**

		(ii)	At t = 0.45 s, using the principle of superposition, net displacement $= 1.00 + (-3.00)$ $= -2.00$ mm (Accept ±0.1mm)	M1 A1
		(iv)	Intensity ∝ (amplitude)^2 $\frac{I_Q}{I_P} = \left(\frac{A_Q}{A_P}\right)^2 = \left(\frac{2.0}{3.0}\right)^2$ $= 0.444$ (3sf)	M1 A1
		(v)	Two sources (waves) are said to be coherent when the phase difference is always the same OR there is a constant phase relationship at all times.	B1

5	(a)	Current = 2.7 – 1.5 = 1.2 A	B1
	(b)	p.d. across XY = 12 V = 1.5 (5.0 + R) Resistance R = 3.0 Ω	B1
	(c)	p.d. across XZ = (1.6/2.0)12 = 9.6 V p.d. across XW = 1.5(5.0) = 7.5 V potential difference = 9.6 – 7.5 = 2.1	C1 A1
	(d)	When the resistance of the variable resistor is now increased, the effective resistance of the circuit increases. For the same e.m.f. supply, the power dissipated in the effective resistor decreases since power is inversely proportional to the effective resistance. Thus the power supplied by the battery decreases. **OR** When the resistance of the variable resistor is now increased, the effective resistance of the 5.0 ohm and variable resistor increases, so the current in the variable resistor decreases. The current in the resistance wire is unchanged since the p.d. across the wire and the resistance remain the same. So, the current in the battery decreases (same e.m.f.) the power decreases.	B1 B1 B1 (B1) (B1) (B1)

6	(a)		$B_{max} = \frac{\mu_0 I_{max}}{2\pi d}$ $= \frac{(4\pi \times 10^{-7})(1.2)}{(2\pi)(20 \times 10^{-2})}$ $= 1.2 \times 10^{-6}$ T (2sf)	C1 A1
	(b)	(i)	$\Phi_{max} = NB_{max}A = NB(\pi r^2)$ $= 1500(1.2 \times 10^{-6})\pi(0.50 \times 10^{-2})^2$ $= 1.41 \times 10^{-7}$ Wb (3sf)	C1 A1

		(ii)	The alternating current in the cable induces an alternating (changing) magnetic field at the plastic ring / toroidal solenoid. This cuts the solenoid and thus there is an alternating (changing) magnetic flux linkage at the solenoid. Hence, by Faraday's law of electromagnetic induction, e.m.f. is induced in the solenoid.	B1 B1
		(iii)	The root-mean-square e.m.f. of the alternating voltage source is the equivalent to the value of steady direct current e.m.f. that dissipates the same power as the average amount of power dissipated by the alternating voltage. *(subtract 1m if average is not mentioned)*	B1 B1

7	(a)		$\frac{hc}{\lambda} = E_3 - E_2$ (identifying which two levels.) **OR** Uses wavelength of 658 nm $\frac{6.63\times10^{-34}\times3.00\times10^{8}}{658\times10^{-9}} = E_3 - (-3.40\times1.60\times10^{-19})$ $E_3 = -2.42\times10^{-19}$ J	C1 (C1) C1 A1
	(b)	(i)	Energy of each photon, $E = \frac{hc}{\lambda} = 2.84\times10^{-19}$ $\text{Power} = \text{intensity}\times\text{area}$ $\left(\frac{N}{t}\right)E = \text{intensity}\times\text{area}$ $\left(\frac{N}{t}\right) = \frac{\text{intensity}\times\text{area}}{E}$ number per unit time, $\frac{N}{t} = \frac{(160)(2.5\times10^{-6})}{2.84\times10^{-19}}$ $= 1.4\times10^{15}\ \text{s}^{-1}$	C1 M1 A0
		(ii)	$\text{Pressure} = \frac{\text{force}}{\text{area}}$ Pressure on the mirror by the light beam is equal to the total force of impact by the photons per unit area. Change of momentum for one photon after 'reflected' = 2*p* (where *p* = momentum of the photon) Total force exerted = Combоned rate of change of momentum $= 2\left(\frac{N}{t}\right)p = 2\left(\frac{N}{t}\right)\left(\frac{h}{\lambda}\right)$ $= 2(1.4\times10^{15})\left(\frac{6.63\times10^{-34}}{7.0\times10^{-7}}\right)(= 2.65\times10^{-12})$ $\text{Pressure} = \frac{2.65\times10^{-12}}{2.5\times10^{-6}}$ $= 1.1\times10^{-6}$ Pa	C1 C1 A1

		(iii)	For the same intensity, replacing the beam of red light with blue light that has a smaller wavelength will result in a decrease of $\frac{N}{t}$ ($\frac{N}{t}$ proportional to λ). Pressure is proportional to $\frac{N}{t}$ and inversely proportional to λ. Thus the pressure remains the **same**.	M1 A1

8	**(a)**	**(i)**	Let the power of the sun by P_{sun}. Considering the sun as a point source, the energy spreads out uniformly through space and the intensity is given by $\text{intensity} = \frac{P_{sun}}{4\pi r^2}$ $P_{sun} = 1400 \times \left[4\pi\left(150\times10^9\right)^2\right]$ $= 4.0\times10^{26}$ W	M1 M1 A0
		(ii)	$\text{Unit of power} = \frac{\text{unit of work done}}{\text{unit of time}} = \frac{\text{kg m}^2\text{ s}^{-2}}{\text{s}}$ $= \text{kg m}^2\text{ s}^{-3}$ $\text{Unit of } (\sigma A T^4) = (\text{kg s}^{-3}\text{ K}^{-4})(\text{m}^2)(\text{K}^4)$ $= \text{kg m}^2\text{ s}^{-3}$ Since the unit of P is the same as the unit of $\sigma A T^4$, the equation is homogeneous.	B1 B1 A0
		(iii)	$P = \sigma A T^4$ $4.0\times10^{26} = (5.7\times10^{-8})\left[4\pi\left(109\times6.37\times10^6\right)^2\right]T^4$ $T = 5830$ K	C1 A1
	(b)	**(i)**	Maximum speed is related to the maximum temperature Maximum temperature = 15 × 10^6 K Considering the protons to behave as ideal gases, $\text{KE of each proton} = \frac{3}{2}kT$ $\frac{1}{2}m_{proton}v^2 = \frac{3}{2}kT$ $\frac{1}{2}(1.67\times10^{-27})v^2 = \frac{3}{2}(1.38\times10^{-23})(15\times10^6)$ $v = 6.1\times10^5\text{ m s}^{-1}$	C1 A1
		(ii)	As the proton approaches each other, their initial kinetic energies equal the electric potential energy at the closest distance. By conservation of energy, $\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r} = 2\times\frac{1}{2}m_{proton}v^2$ $\frac{(1.6\times10^{-19})(1.6\times10^{-19})}{4\pi(8.85\times10^{-12})r} = 2\times\frac{1}{2}(1.67\times10^{-27})(6.1\times10^5)^2$ $r = 3.7\times10^{-13}$ m	C1 A1

		(iii)	The radius of nucleus is of the order of 10^{-15} m. The closest distance is much larger than the radius of the proton and thus the two protons will be too far apart for fusion to take place.	B1 B1
		(iv)	When protons are very close to each other, the uncertainty in their position Δx is small. According to the Heisenberg Uncertainty Principle, this results in a larger uncertainty in their momentum. Thus, the large uncertainty in momentum Δp means that there is a significant probability that some protons have much higher momentum (and thus kinetic energy) than the average to overcome the Coulomb barrier in those instances, allowing fusion reaction to take place.	B1 B1
	(c)	(i)	Mass difference = 4(1.007276u) – 4.002603u = 0.026501u Energy release = Δmc^2 = (0.026501) (1.66 × 10^{-27}) (3.0 × 10^9)^2 = 3.96 × 10^{-12}J	C1 A1
		(ii)	Energy release by 0.70% of the mass = (0.70/100)(4)(1.007276) (1.66 × 10^{-27})(3.0 × 10^8)^2 = 4.21 × 10^{-12}J Since the two values can be rounded to 4 × 10^{-12}J , the two values are close to each other and the statement is valid. **OR** Percentage difference = (4.21 ×10^{-12} – 3.96×10^{-12})/(3.96×10^{-12}) = 6.3% Since the percentage difference between the two values is less than 10%, the statement is valid.	M1 A1 (M1) (A1)
	(d)	(i)	$\gamma = \frac{\sqrt{2m(U-E)}}{\hbar} = \frac{\sqrt{2(1.67\times10^{-27})(10^{-13}-10^{-16})}}{6.63\times10^{-34}/2\pi} = 1.731\times10^{14}$ $P \approx e^{-2\gamma d} = e^{-2(1.731\times10^{14})(1.8\times10^{-13})} = 8.6\times10^{-28}$	C1 A1
		(ii)	The vast number of protons in the Sun of the order of more than 10^{38} suggests some protons will be able to tunnel through the potential barrier for fusion to occur.	B1