

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 Exam	iner's Use
Pap	per 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,	С	=	$3.00\times10^8~m~s^{-1}$
permeability of free space,	μ_{0}	=	$4\pi\times10^{-7}~H~m^{-1}$
permittivity of free space,	εo	=	$8.85 \times 10^{-12} \ F \ m^{-1}$
			$(1/(36\pi)) \times 10^{-9} \ F \ m^{-1}$
elementary charge,	е	=	$1.60 \times 10^{-19} \text{ C}$
the Planck constant,	h	=	6.63 × 10 ^{−34} J s
unified atomic mass constant,	и	=	$1.66 \times 10^{-27} \text{ kg}$
rest mass of electron,	me	=	$9.11 \times 10^{-31} \text{ kg}$
rest mass of proton,	m _p	=	$1.67 \times 10^{-27} \text{ kg}$
molar gas constant,	R	=	8.31 J K ⁻¹ mol ⁻¹
the Avogadro constant,	N _A	=	$6.02 \times 10^{23} \text{ mol}^{-1}$
the Boltzmann constant,	k	=	$1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant,	G	=	$6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
acceleration of free fall,	g	=	9.81 m s⁻²

Formulae					
uniformly accelerated motion,	S	=	$ut + \frac{1}{2}at^2$		
	V^2	=	u² + 2as		
work done on/by a gas,	W	=	$\rho\Delta V$		
hydrostatic pressure,	p	=	hogh		
gravitational potential,	ϕ	=	$-\frac{Gm}{r}$		
temperature,	T/K	=	T∕°C + 273.15		
pressure of an ideal gas,	p	=	$rac{1}{3}rac{Nm}{V}ig\langle C^2ig angle$		
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,	Ι	=	Anvq		
resistors in series,	R	=	$R_1 + R_2 + \dots$		
resistors in parallel,	$\frac{1}{R}$	=	$\frac{1}{R_1} + \frac{1}{R_2} + \dots$		
electric potential,	V	=	$\frac{Q}{4\pi\varepsilon_{o}r}$		
alternating current/voltage,	x	=	x _o sin <i>w</i> t		
magnetic flux density due to a long straight wire,	В	=	$\frac{\mu_o I}{2\pi d}$		
magnetic flux density due to a flat circular coil,	В	=	$\frac{\mu_o NI}{2 r}$		
magnetic flux density due to a long solenoid,	В	=	$\mu_o nI$		
radioactive decay,	x	=	$x_{\rm o} \exp(-\lambda t)$		
decay constant,	λ	=	$\frac{\ln 2}{t_{\frac{1}{2}}}$		

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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]

A non-uniform L-shaped beam of weight 10 N is attached to a wall using a hinge, as shown in Fig. 2.1. 2 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)	(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 <i>R</i> 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.





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





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

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

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 = $\dots \Omega$ [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.

[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]

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(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.

(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.





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.

(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} m².

(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 10³⁸ 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 10²⁸.

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

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:

 $4p \rightarrow He + 2e^+ + 2v + gamma$.

Given the mass of proton to be 1.007276u and mass of helium nucleus to be 4.002603u, 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,

•
$$\gamma = \frac{\sqrt{2m(U-E)}}{\hbar}$$

- *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 = $\frac{h}{2\pi}$.

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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