Cambridge International Examinations
Cambridge Pre-U Certificate

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

3143760435

PHYSICS (PRINCIPAL) **9792/03**

Paper 3 Written Paper **May/June 2017**

3 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, candidate number and name on all the work you hand in.
Write in dark blue or black pen.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
DO **NOT** WRITE IN ANY BARCODES.

Section 1
Answer **all** questions.
You are advised to spend about 1 hour 30 minutes on this section.

Section 2
Answer any **three** questions. All six questions carry equal marks.
You are advised to spend about 1 hour 30 minutes on this section.

Electronic calculators may be used.
You may lose marks if you do not show your working or if you do not use appropriate units.

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 Examiner's Use	
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11	
12	
13	
Total	

The syllabus is approved for use in England, Wales and Northern Ireland as a Cambridge International Level 3 Pre-U Certificate.

This document consists of **40** printed pages.

DC (ST/SG) 131998/5

Data

gravitational field strength close to Earth's surface	$g = 9.81\,\text{N kg}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19}\,\text{C}$
speed of light in vacuum	$c = 3.00 \times 10^{8}\,\text{m s}^{-1}$
Planck constant	$h = 6.63 \times 10^{-34}\,\text{J s}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\,\text{F m}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11}\,\text{N m}^2\,\text{kg}^{-2}$
electron mass	$m_e = 9.11 \times 10^{-31}\,\text{kg}$
proton mass	$m_p = 1.67 \times 10^{-27}\,\text{kg}$
unified atomic mass constant	$u = 1.66 \times 10^{-27}\,\text{kg}$
molar gas constant	$R = 8.31\,\text{J K}^{-1}\,\text{mol}^{-1}$
Avogadro constant	$N_A = 6.02 \times 10^{23}\,\text{mol}^{-1}$
Boltzmann constant	$k = 1.38 \times 10^{-23}\,\text{J K}^{-1}$
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8}\,\text{W m}^{-2}\,\text{K}^{-4}$

Formulae

uniformly accelerated motion

$$s = ut + \tfrac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

$$s = \left(\frac{u+v}{2}\right)t$$

heating

$$\Delta E = mc\Delta\theta$$

change of state

$$\Delta E = mL$$

refraction

$$n = \frac{\sin\theta_1}{\sin\theta_2}$$

$$n = \frac{v_1}{v_2}$$

diffraction

single slit, minima $n\lambda = b\sin\theta$

grating, maxima $n\lambda = d\sin\theta$

double slit interference $\lambda = \frac{ax}{D}$

Rayleigh criterion $\theta \approx \frac{\lambda}{b}$

photon energy $E = hf$

de Broglie wavelength $\lambda = \frac{h}{p}$

simple harmonic motion $x = A\cos\omega t$

$v = -A\omega\sin\omega t$

$a = -A\omega^2\cos\omega t$

$F = -m\omega^2 x$

$E = \frac{1}{2}mA^2\omega^2$

energy stored in a capacitor $W = \frac{1}{2}QV$

capacitor discharge $Q = Q_0 e^{-\frac{t}{RC}}$

electric force $F = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$

electrostatic potential energy $W = \frac{Q_1Q_2}{4\pi\varepsilon_0 r}$

gravitational force $F = -\frac{Gm_1m_2}{r^2}$

gravitational potential energy $E = -\frac{Gm_1m_2}{r}$

magnetic force $F = BIl\sin\theta$

$F = BQv\sin\theta$

electromagnetic induction $E = -\frac{\mathrm{d}(N\Phi)}{\mathrm{d}t}$

Hall effect $V = Bvd$

time dilation $t' = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$

length contraction $l' = l\sqrt{1-\frac{v^2}{c^2}}$

kinetic theory $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$

work done on/by a gas $W = p\Delta V$

radioactive decay $\frac{\mathrm{d}N}{\mathrm{d}t} = -\lambda N$

$N = N_0 e^{-\lambda t}$

$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

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

mass-energy equivalence $\Delta E = c^2\Delta m$

hydrogen energy levels $E_n = \frac{-13.6\,\mathrm{eV}}{n^2}$

Heisenberg uncertainty principle $\Delta p\Delta x \geqslant \frac{h}{2\pi}$

Wien's displacement law $\lambda_{\max} \propto \frac{1}{T}$

Stefan's law $L = 4\pi\sigma r^2T^4$

electromagnetic radiation from a moving source $\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$

Section 1

Answer **all** questions in this section.
You are advised to spend about 1 hour 30 minutes on this section.

1 **(a)** Derive the expression, in terms of the mass *M* of the Earth and its radius *r*, for the relationship between the gravitational constant *G* and the gravitational field strength *g* near the Earth's surface.

[2]

(b) Fig 1.1 is a graph of gravitational field strength *g* plotted against distance from the centre of the Earth.

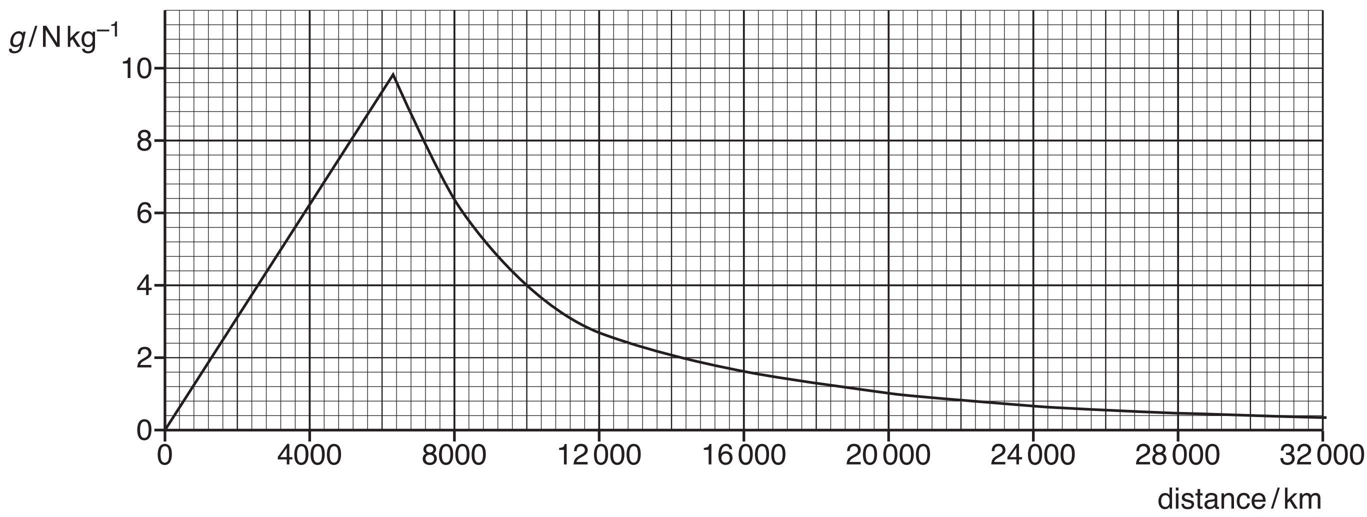

Fig. 1.1

(i) Use data from the graph to determine

1. the radius of the Earth,

radius of the Earth = ... km [1]

2. the gravitational force on a man-made satellite of mass 20 000 kg at a distance of 8200 km from the centre of the Earth.

gravitational force = ... N [2]

(ii) Calculate the speed of the satellite in **(b)(i)2** for it to be circling the Earth at constant speed.

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

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

....

....[1]

(ii) Use Fig. 1.1 to estimate the gravitational potential at a distance of 10 000 km from the centre of the Earth.

gravitational potential = ... $J\,kg^{-1}$ [4]

[Total: 13]

2 A cycle of changes in pressure, volume and temperature of gas inside a cylinder of a petrol engine is illustrated in Fig. 2.1. The gas is assumed to be ideal.

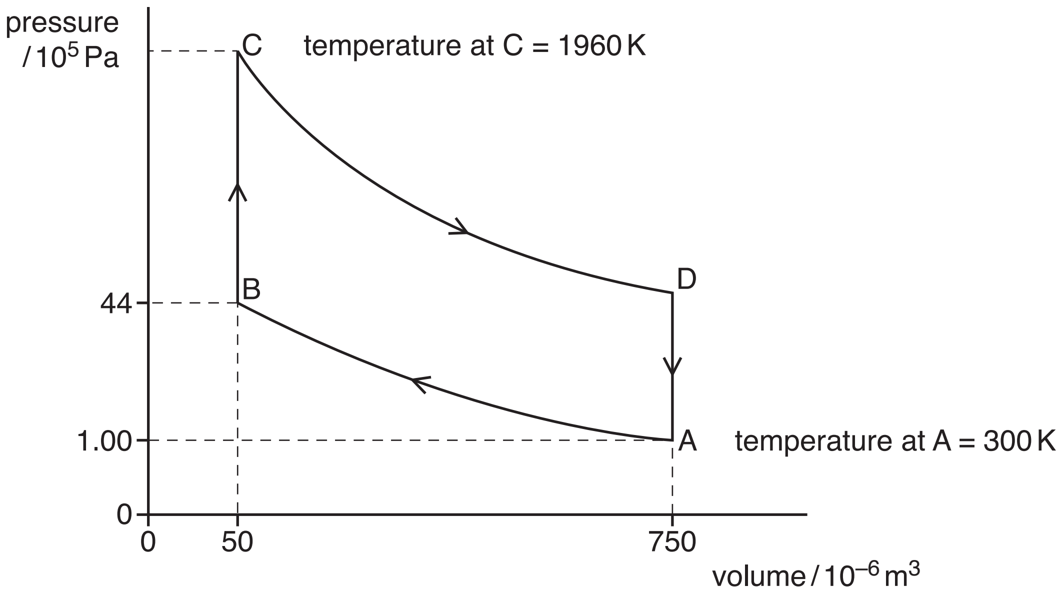

Fig. 2.1 (not to scale)

There are four stages in the cycle.

stage	description
A to B	Rapid compression of the gaseous petrol/air mixture with the temperature rising from 300 K at A and the pressure rising to 44×10^5 Pa at B.
B to C	The petrol/air mixture is exploded, resulting in an almost instant rise in pressure. At C the temperature has risen to 1960 K.
C to D	Rapid expansion and cooling of the hot gases.
D to A	Return to the starting point of the cycle.

(a) **(i)** Use the values on the graph at A to determine the number of moles present in the gases in the cycle.

number of moles = ... mol [2]

(ii) Calculate the temperature of the gas at B.

temperature = ... K [2]

(iii) Calculate the pressure of the hot gas at C.

pressure = ... Pa [2]

(iv) State

1. the work done by the gas during stage B to C,

....[1]

2. what is represented by the area ABCD enclosed by the graph.

....

....[2]

(b) Complete the table showing the work done on the gas, the heat supplied to the gas and the increase in the internal energy of the gas, during the four stages of one cycle.

stage	work done **on** gas /J	heat supplied **to** gas /J	**increase** in internal energy of gas /J
A to B	+ 360	0	
B to C		+ 670	
C to D		0	– 810
D to A			

[4]

(c) Calculate the efficiency of this cycle.

efficiency = ... % [2]

[Total: 15]

3 **(a)** **(i)** State what is meant by the terms *electric field* and *electric field strength*.

electric field ....

....

electric field strength ....

.... [2]

(ii) Determine the electric field strength at a distance of 25 cm from a point charge of $+5.2 \times 10^{-7}$ C. Give a unit for electric field strength with your answer.

electric field strength = ... unit .... [3]

(b) Fig. 3.1 shows three electric charges of value $+2 \times 10^{-6}$ C at X, -3×10^{-6} C at Y and $+4 \times 10^{-6}$ C at Z. These charges are at the corners of an equilateral triangle.

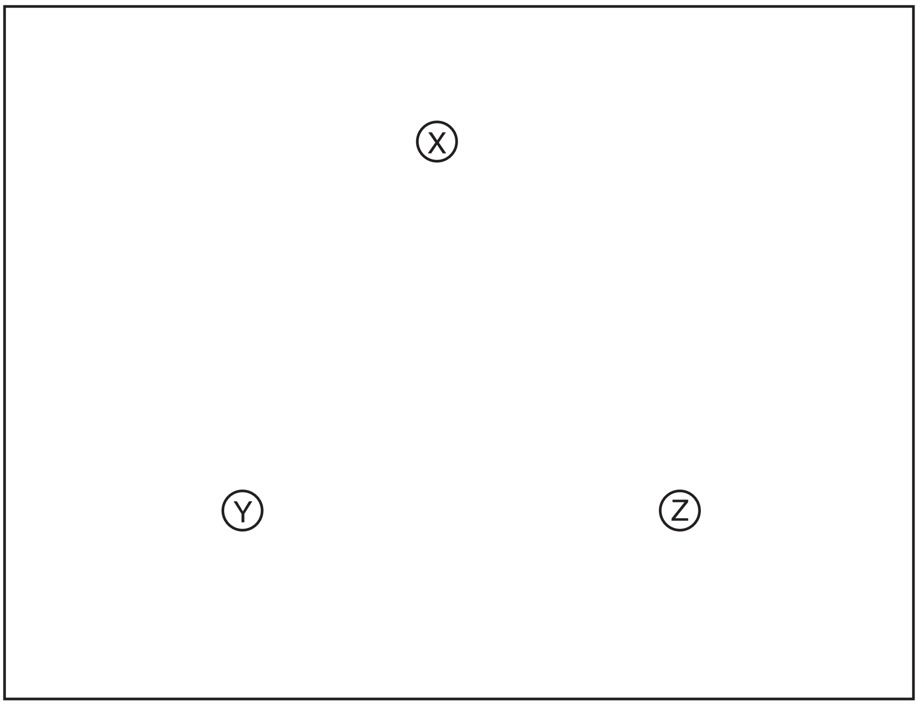

Fig. 3.1

Without making any calculations, draw on Fig. 3.1 a field diagram, indicating its main characteristics, within the whole area of the rectangle given. [4]

[Total: 9]

4 **(a)** Two coils are wound on a ring of soft iron, as shown in Fig. 4.1. The number of turns on each coil can be varied.

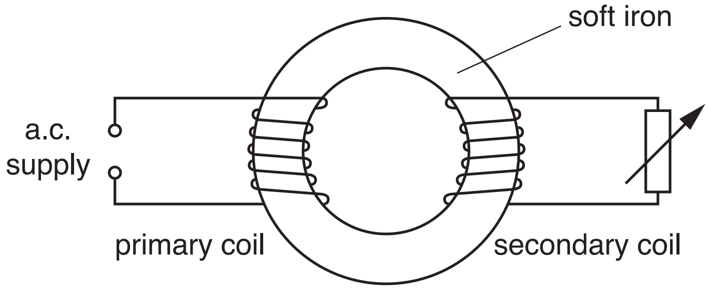

Fig. 4.1

The primary coil is connected to an alternating current supply of variable frequency. The secondary coil is connected to a variable resistor.

State **four** factors that could increase the magnitude of the alternating current through the variable resistor.

....

....

....

....

....

....[4]

(b) A small bar magnet is allowed to fall freely through a plastic tube on which a solenoid is wound. The solenoid, which is much longer than the length of the magnet, is connected to a sensitive centre-zero galvanometer, as shown in Fig. 4.2a.

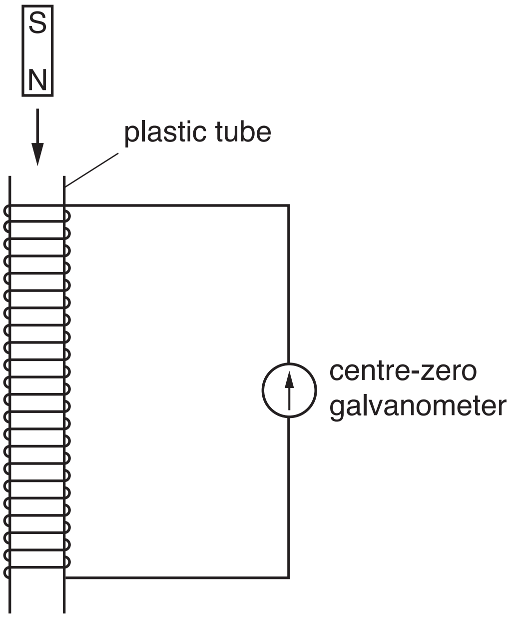

Fig. 4.2a

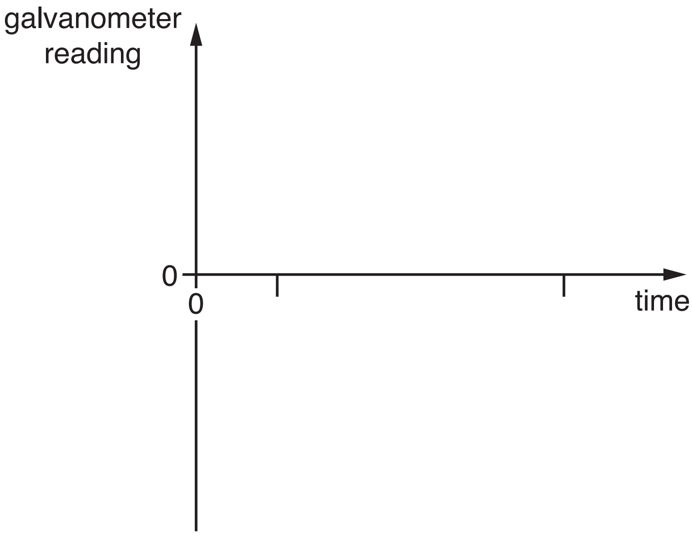

Fig. 4.2b

The two markers on the *x*-axis of Fig. 4.2b show the times when the magnet starts to enter the solenoid and when it starts to leave the solenoid.

On Fig. 4.2b, sketch a graph to show how the galvanometer reading will vary with time. [3]

[Total: 7]

5 **(a)** Define *capacitance*.

....

....[1]

(b) A capacitor of capacitance 56 μF is charged from a battery of electromotive force 12.0 V and negligible internal resistance. The capacitor is charged through a resistor of resistance 66 kΩ, as shown in Fig. 5.1.

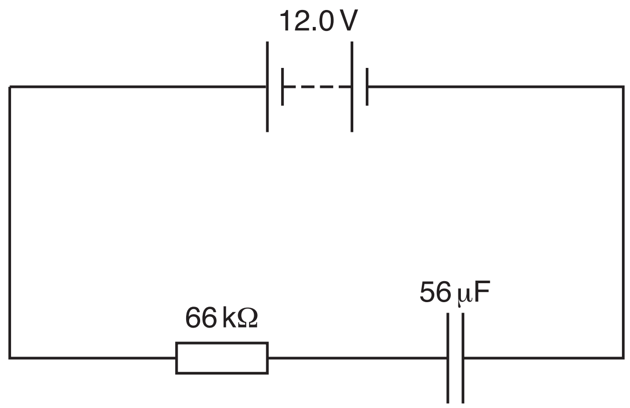

Fig. 5.1

(i) Calculate the charge on the capacitor when it is fully charged.

charge = ... C [2]

(ii) Calculate the energy stored in the capacitor when it is fully charged.

energy = ... J [2]

(iii) Show that the unit of the quantity *CR* is the second.

[2]

(iv) The quantity *CR* is called the time constant of the charging circuit. The charge *Q* on a capacitor at time *t* is given by the equation

$$Q = Q_0(1 - e^{-\frac{t}{RC}})$$

where Q_0 is the final charge.

1. Calculate the ratio of $\frac{Q}{Q_0}$ after one time constant.

$\frac{Q}{Q_0}$ = ...[2]

2. Calculate the time taken for the capacitor shown in Fig. 5.1 to reach 99% of its final charge.

time = ... s [4]

[Total: 13]

6 **(a)** Fig. 6.1 represents the experiment with alpha particles and gold atoms that first suggested that the positive charge on an atom was concentrated in a very small nucleus.

Complete the diagram to show subsequent paths of the three alpha particles fired towards a gold nucleus.

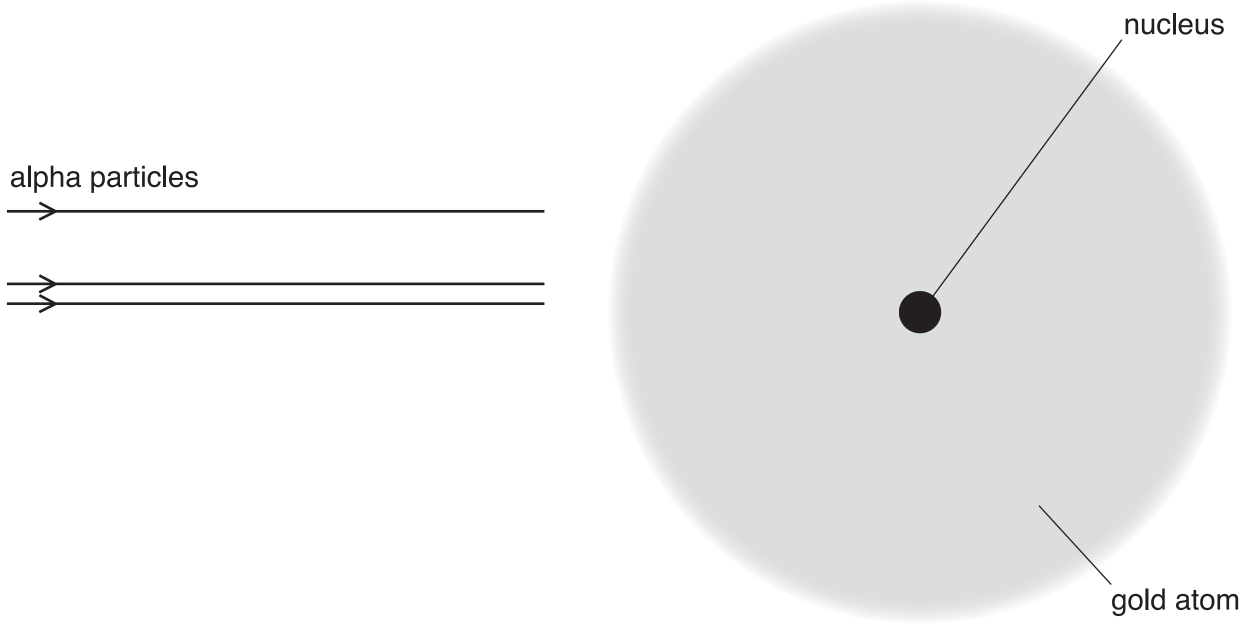

Fig. 6.1 (not to scale)

[2]

(b) An alpha particle has a speed of $1.30 \times 10^{7}\,\mathrm{m\,s^{-1}}$.

(i) Calculate the kinetic energy of the alpha particle.

kinetic energy = ... J [2]

(ii) An alpha particle is aimed directly at a gold nucleus, proton number 79. It will stop at the distance of closest approach *r* when all of its kinetic energy is converted into electrical potential energy.

Calculate the distance of closest approach *r*.

r = ... m [4]

[Turn over

(iii) Estimate the volume of a gold atom Au-197.

volume = ... m^3 [2]

(iv) Use your answer to **(b)(iii)** to determine the ratio

$$\frac{\text{volume of gold atom}}{\text{volume of gold nucleus}}.$$

ratio = ... [2]

[Total: 12]

7 **(a)** A star known to be at a distance of 3.80×10^{17} m from the Earth provides a spectrum of light as shown in Fig. 7.1.

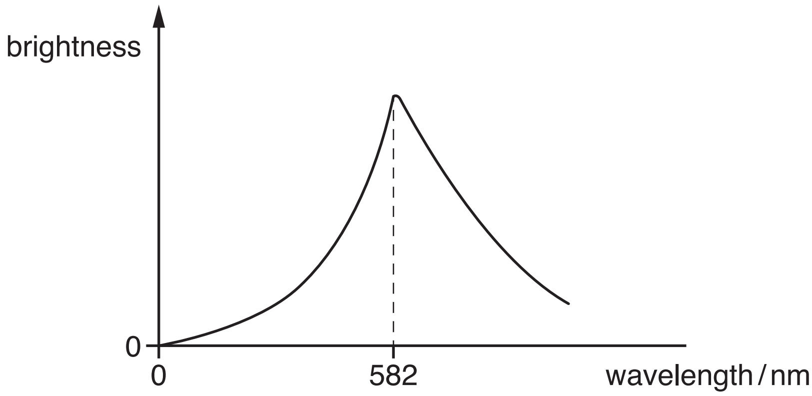

Fig. 7.1

(i) Use Wien's displacement law to determine the surface temperature of the star. The constant of proportionality in Wien's displacement law is 2.90×10^{-3} m K.

temperature = ... K [2]

(ii) This star provides an intensity of radiation at the Earth of 2.38×10^{-8} W m^{-2}.

Calculate the radius of the star.

radius = ... m [4]

(b) Describe how the wavelength of a spectral line from a light source could be measured in a school laboratory.

....

....

....

....

....

....

....

....

....

....[5]

[Total: 11]

Section 2

Answer any **three** questions in this section.
You are advised to spend about 1 hour 30 minutes on this section.

8 Fig. 8.1 shows a roundabout. The roundabout consists of a horizontal disc from which the chairs are suspended by ropes. The disc is rotating about a central column. The chairs travel in a horizontal circular path at constant speed.

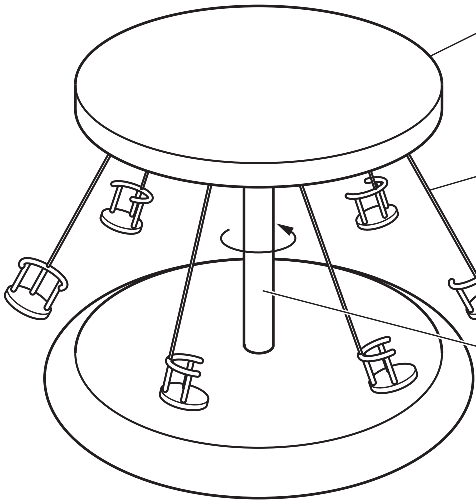

Fig. 8.1 (not to scale)

(a) Ignoring air resistance, discuss with reference to the forces acting on one chair, whether the chair is in a state of equilibrium

(i) vertically, ...

....

....

(ii) horizontally. ....

....

....

[4]

(b) Fig. 8.2 shows the rope supporting each chair making an angle of 49° to the vertical when the roundabout has an angular speed of 1.33 rad s^{-1}.

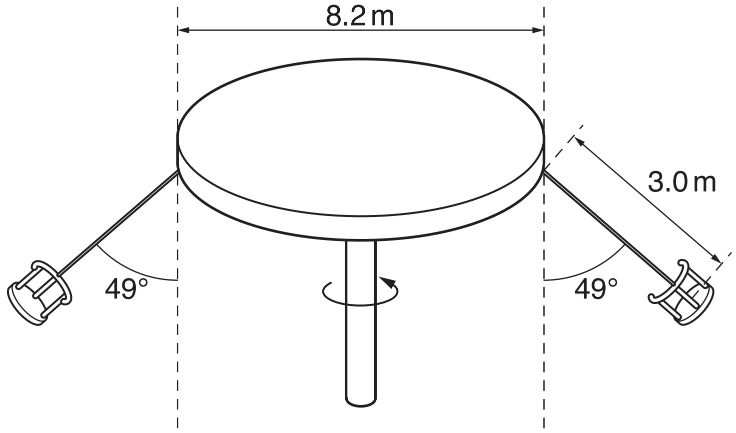

Fig. 8.2 (not to scale)

The diameter of the rotating disc is 8.2 m. The centre of mass of a chair is 3.0 m from the point of suspension.

Calculate the centripetal acceleration of a chair.

acceleration = ... m s^{-2} [3]

(c) Fig. 8.3 shows a plan view of a thin disc of uniform density ρ, radius R, thickness t and mass M.

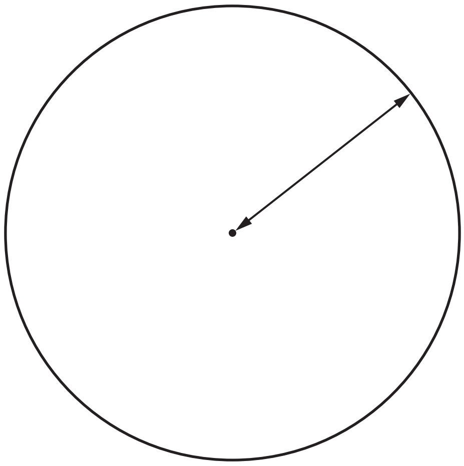

Fig. 8.3

Use integration to derive an expression for the moment of inertia I of the disc about its central axis. Add to Fig. 8.3 to support your answer and define any symbols you introduce in your derivation.

[4]

(d) The equations for rotational motion can be determined by direct analogy with the equations for linear motion. Complete the table by inserting the corresponding word equation for rotational motion.

linear motion	rotational motion
force = mass × acceleration	
linear momentum = mass × velocity	
kinetic energy = ½ mass × (velocity)^2	

[3]

(e) The horizontal disc, with no seats attached, has a moment of inertia of 12 000 kg m^2. The angular velocity now increases uniformly from rest to an angular velocity of 1.34 rad s^{-1} in 30 s.

Determine

(i) the number of revolutions of the roundabout in 30.0 s,

number of revolutions = ...[3]

(ii) the rotational kinetic energy of the disc at an angular velocity of 1.34 rad s^{-1}.

rotational kinetic energy = ... J [1]

(f) When passengers are riding on the roundabout they start with a slow rotation. As the rate of rotation increases, the total moment of inertia of the passengers and the roundabout increases. Explain why.

....

....

....[2]

[Total: 20]

9 **(a)** A body's oscillatory motion is defined as simple harmonic motion when

$$a = -(2\pi f)^2 x.$$

(i) State what a and f represent in this equation.

a ....

f .... [1]

(ii) Explain the significance of the minus sign in the equation.

....

....[1]

(b) An alternating current in a wire causes electrons within the wire to oscillate with simple harmonic motion.

The instantaneous displacement x of the electron is given by the equation

$$x = A\cos(2\pi ft)$$

where A is the amplitude of the oscillation.

(i) Use differential calculus to derive an expression for the instantaneous velocity v of the electron at time t.

[1]

(ii) The period of oscillation of the electron is 0.02 s and its amplitude is 8.0 μm.

Calculate the magnitude of the maximum velocity of the electron.

maximum velocity = ... $m\,s^{-1}$ [3]

(iii) Fig. 9.1 is a graph of the displacement of the electron against time for one complete oscillation.

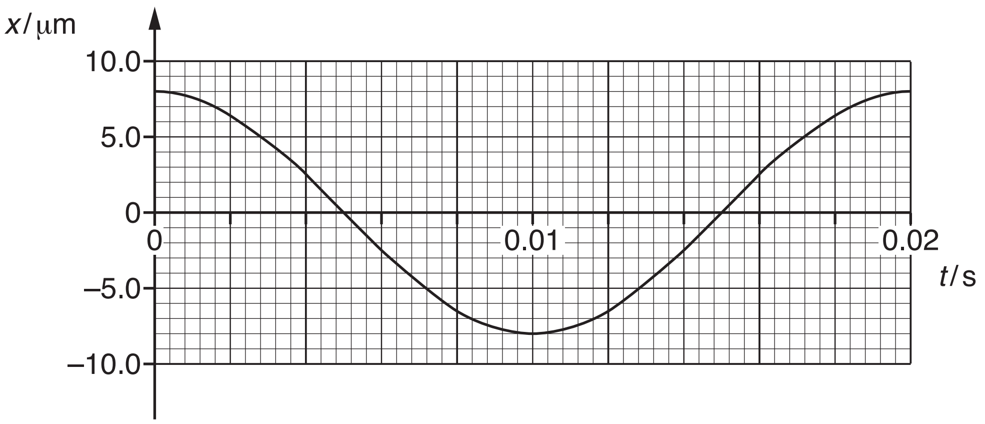

Fig. 9.1

1. Calculate the value of the maximum acceleration of the electron.

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

2. On Fig. 9.2, sketch the graph of acceleration against time for the electron. Label the *y*-axis with the maximum acceleration.

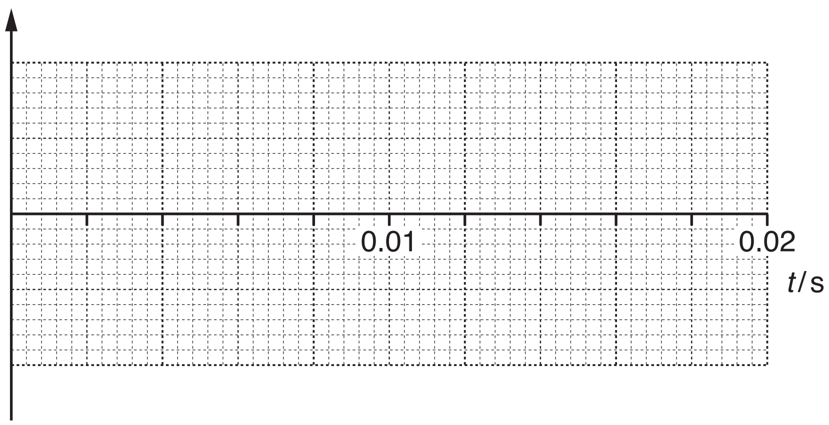

Fig. 9.2

[3]

(iv) State the phase difference between the displacement and the acceleration. Give the unit.

phase difference = ... unit .... [1]

(c) Fig. 9.3 shows a vertical rod which is oscillating in water.

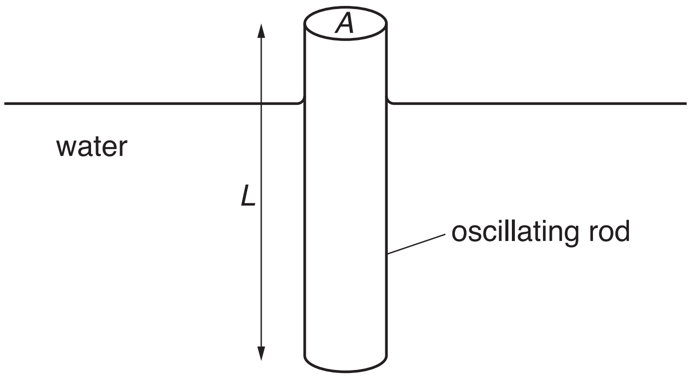

Fig. 9.3

The rod has mass m, length L and cross-sectional area A. It has uniform density ρ. The density of the water is σ.

The period T of the oscillations of the rod is given by the equation

$$T = 2\pi\sqrt{\frac{m}{A\sigma g}}$$

where g is the acceleration of free fall.

(i) Derive an expression for g in terms of numerical constants and ρ, σ, L and T.

[3]

(ii) The rod is given a small vertical displacement and then released. It oscillates, but damping soon causes it to come to rest after a few oscillations in the water.

State why the damping causes the oscillations to stop.

....

....[1]

(iii) Information from Fig. 9.4 can be used to verify that the damping on the rod is exponential.

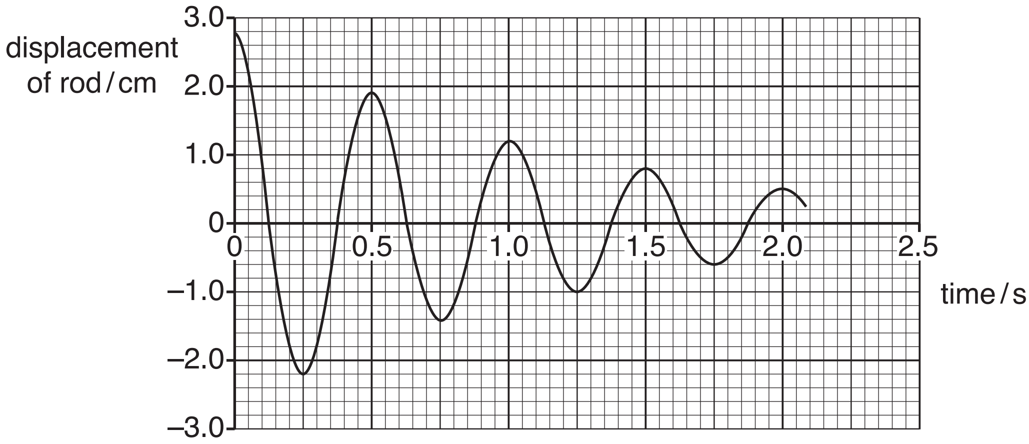

Fig. 9.4

1. Use Fig. 9.4 to complete the second column in the table of Fig. 9.5 to record the displacement at the times stated. [2]

2. Use the data to show that the damping is exponential. [1]

3. Use the axes in Fig. 9.6 to sketch a graph that illustrates your answer. [2]

time / s	displacement / cm	
0.0		
0.5		
1.0		
1.5		
2.0		

Fig. 9.5

Fig. 9.6

[Total: 20]

10 Fig. 10.1 shows the horizontal path of an electron travelling in a vacuum.

The electron leaves the electron gun with a constant speed v. The electron of mass m and charge e then enters a region of uniform magnetic field of flux density B.
The electron follows a circular path of radius r within the magnetic field.

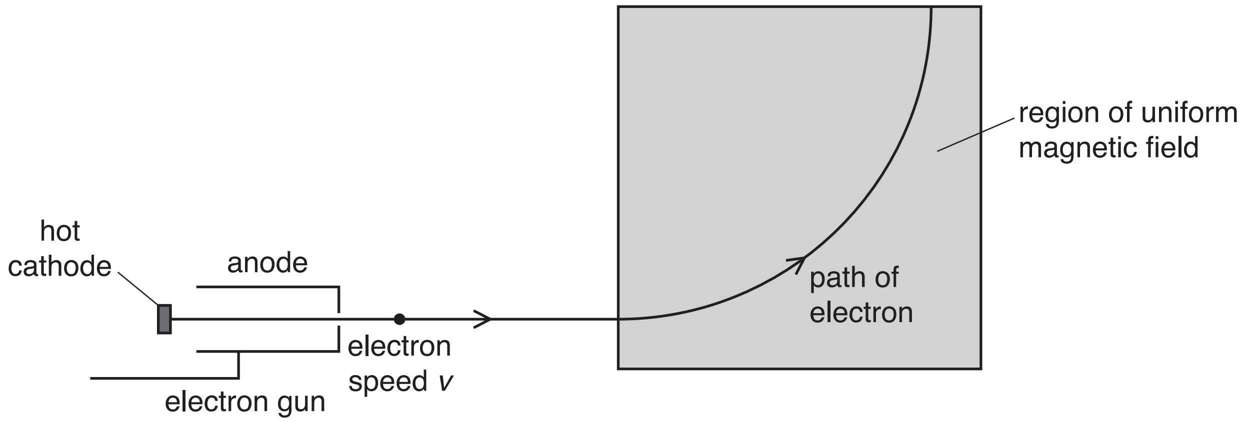

Fig. 10.1 (not to scale)

(a) **(i)** State the direction of the magnetic field.

....[1]

(ii) **1.** State the expression for the magnetic force on the electron in terms of the magnetic flux density B.

[1]

2. Derive an expression for the speed of the electron.

[2]

3. Derive a formula for the charge per unit mass e/m on the electron.

[2]

(b) The electron gun produces the electron by emission from the hot cathode. The electron is then accelerated from rest to speed v by the electric field between the anode and the cathode, where there is a potential difference of V.

(i) Give the equation relating the gain in kinetic energy of the electron and the work done on it by the electric field.

[1]

(ii) The charge per unit mass of an electron e/m is called its specific charge. Its numerical value is $1.76 \times 10^{11}\,\mathrm{C\,kg^{-1}}$.

Determine the radius of the circular path of an electron in Fig. 10.1 when the magnetic field has flux density 5.00 mT and the magnitude of the potential difference between the anode and the cathode is 576 V.

radius = ... m [3]

(c) Explain why the speed of the electron remains constant as it moves through the arc of a circle.

....

....

....[2]

(d) A uniform magnetic field, over a small area, can be produced using two identical flat vertical circular coils aligned on the same horizontal axis. There is an electric current in each coil.

Fig. 10.2 shows two such coils, G and H, each of *n* turns, separated by a distance equal to their radius *R*.

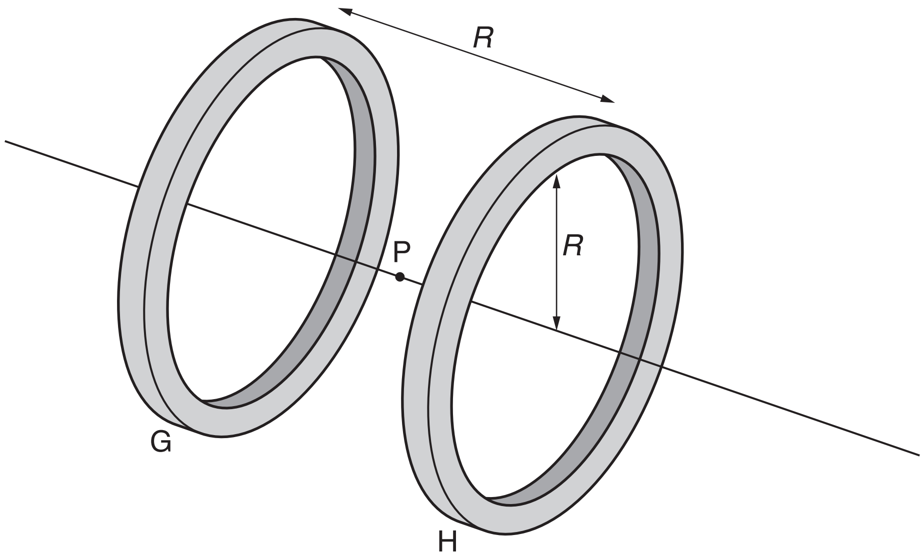

Fig. 10.2

Point P lies on the common horizontal axis at equal distance from coils G and H. For each coil there is a component of the magnetic field, acting in the same direction, along the common horizontal axis.

(i) Suggest why this arrangement of coils is often used to produce the magnetic field that deflects the electron in the experiment outlined in Fig. 10.1.

....

....

....

....[2]

(ii) The component $B(x)$ of the magnetic flux density at a point along the axis for a **single loop of wire** is given by

$$B(x) = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{\frac{3}{2}}},$$

where

I is the current in the loop,
R is the radius of the loop,
x is the distance on the axis from the centre of the loop,
μ_0 is the permeability of free space, $4\pi \times 10^{-7}\,\mathrm{H\,m^{-1}}$.

For the arrangement of coils in Fig. 10.2, show that the total component of the magnetic flux density B, at point P, along the axis is

$$B = \frac{\gamma \mu_0 n I}{R},$$

where n is the number of turns of wire on each coil and γ is a constant with an approximate value of 0.7.

[3]

(iii) Each coil in Fig. 10.2 consists of 280 m of wire producing 500 turns. The current through each coil is 0.28 A.

Calculate the value of the magnetic flux density B along the axis at P.

flux density = ...[3]

[Total: 20]

11 In 1814 the French philosopher and scientist Pierre Simon Laplace made the following comments about the nature of a Universe governed by Newton's laws.

'We may regard the present state of the universe as the effect of its past and the cause of its future. Imagine an intellect, which at a certain moment knows all forces that set nature in motion, and all positions of all items of which nature is composed. Imagine also that this intellect is vast enough to submit this data to analysis. Then the intellect would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.'

Pierre Simon Laplace, *A Philosophical Essay on Probabilities* (1814)

(a) State Newton's second law of motion.

....

....

....[1]

(b) During Laplace's lifetime, Newton's law of gravitation and Newton's second law of motion were thought to always hold true.

Explain why both laws are needed in order to describe the future motions of the planets.

....

....

....

....

....[2]

(c) (i) A physicist wishes to use Newton's laws to predict the path of an object in the Solar System.

State the information this physicist would need in order to make the prediction as precise and accurate as possible.

....

....

....

....

....

....

....

....[3]

(ii) Explain why, in practice, even if Newton's laws are absolutely correct, there will still be some uncertainty in the predicted path.

....

....

....

....

....[2]

(d) (i) State what is meant by a *deterministic* theory.

....

....

....[1]

(ii) Discuss whether a world governed by Newton's laws is a deterministic world.

....

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....

....[2]

(e) **(i)** State what the second law of thermodynamics predicts about the future of the universe.

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....

....[1]

(ii) Explain, by referring to 'number of ways', how the second law of thermodynamics allows us to predict that a drop of ink will eventually spread out uniformly when it has fallen into a glass of water.

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....

....[2]

(iii) Discuss how the kind of prediction made in **(e)(i)** and **(e)(ii)** differs from the kind of prediction that could be made by Laplace's imaginary intellect.

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....[2]

(f) Quantum theory was developed in the twentieth century and it undermined the Newtonian view of physical reality. Einstein was never entirely comfortable with this. In particular he thought that quantum theory was **non-local** and **incomplete**.

(i) Give an example of a non-local process in a quantum mechanical experiment.

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....[2]

(ii) Explain why quantum theory can be considered as being incomplete.

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....[2]

[Total: 20]

12 (a) One of the postulates of Einstein's special theory of relativity is that the speed of light is a constant independent of the speed of the source or of the observer.

A theory in the early twentieth century suggested that light waves are vibrations in an aether at rest in an absolute space. Explain how this theory is undermined by experiments that suggest that the speed of light *c* is a constant for a moving observer.

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....[4]

(b) A consequence of the special theory of relativity is that nothing can travel faster than the speed of light. Imagine a spacecraft travelling away from the Earth at 0.70 c relative to an observer on the Earth as shown in Fig. 12.1.

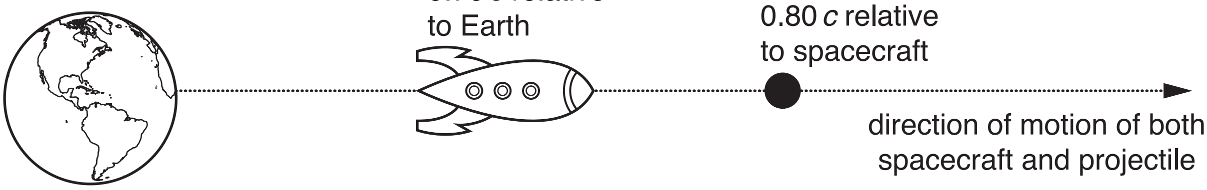

Fig. 12.1 (not to scale)

The spacecraft emits a projectile that travels forwards at 0.80 c relative to the spacecraft. Observers on the spacecraft and on the Earth both measure the speed of the projectile.

(i) State the speed of the projectile relative to the spacecraft as measured by the observer on the spacecraft.

speed = ...[1]

(ii) Calculate the speed of the projectile relative to an observer on the Earth if Newton's idea of absolute space was correct.

speed = ...[1]

(iii) When the observer on Earth measures the speed of the projectile, he gets a value which is just less than c.

Explain what this implies about measurements of distance and time made in the reference frames of the spacecraft and of the Earth.

....

....

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....[2]

(iv) The relativistic formula for calculating the speed of the projectile relative to the Earth is

$$w = \frac{(v+u)}{\left(1+\frac{uv}{c^2}\right)},$$

where

w is the speed of the projectile relative to an observer on the Earth,
u is the speed of the spacecraft relative to an observer on the Earth,
v is the speed of the projectile relative to an observer on the spacecraft.

1. Use this equation to calculate the speed of the projectile as measured by the observer on Earth.

speed = ...[1]

2. The spacecraft then emits a laser pulse in the same direction in which it is travelling.

Show that the equation above gives a speed of c for the laser pulse relative to an observer on Earth.

[2]

3. Show that the relativistic formula for relative speed reduces to the Newtonian equation ($w = v + u$) if either v or u or both are small compared to c.

[2]

(c) Astronauts are travelling from the Earth to a planet orbiting a star 100 light years from Earth. They are in a spacecraft moving with velocity 0.99 *c* relative to the Earth.

(i) Calculate the time it takes for the astronauts to reach the planet as measured by observers on the Earth.

time = ... years [1]

(ii) Calculate the distance, in light years, between the Earth and the planet as measured by the astronauts in the moving spacecraft.

distance = ... light years [2]

(iii) Calculate the time taken for the astronauts to reach the planet as measured by clocks inside the spacecraft.

time = ... years [1]

(d) Fig. 12.2 shows two stationary clocks, A and B, a distance *d* apart. In order to synchronise the clocks they are started at the same time by sending a flash of light from the point half way between them.

Discuss whether an observer, travelling at velocity *v* relative to the two clocks in a direction parallel to AB, will agree that the clocks are synchronised.

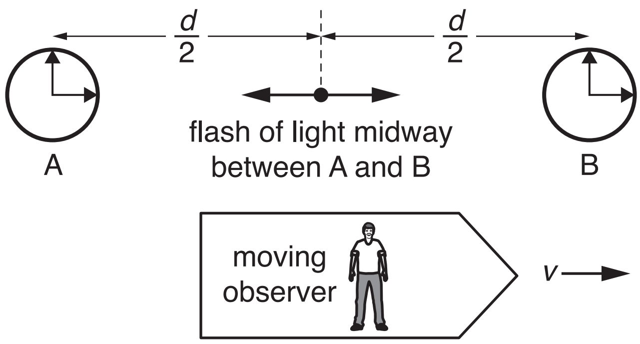

Fig. 12.2

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....[3]

[Total: 20]

13 (a) In the Bohr model of the hydrogen atom the electron moves in a circular orbit around the nucleus. In the ground state (n = 1) the orbit has a radius a_0 (the Bohr radius) and angular momentum $\frac{h}{2\pi}$.

(i) Use the de Broglie relation to show that the circumference of this orbit is equal to the de Broglie wavelength of the electron.

[3]

(ii) Explain how the fact that the circumference of this orbit is equal to the de Broglie wavelength of the electron is consistent with the idea that the ground state of the hydrogen atom represents a standing wave of the electron.

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....

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....[2]

(iii) Describe how the Bohr model of the hydrogen atom can be developed to account for excited states of the hydrogen atom ($n > 1$).

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....[3]

(b) In a more advanced quantum model the electron in a hydrogen atom is described in three dimensions by its wavefunction Ψ. Fig. 13.1 shows the magnitude of the electron wavefunction in the ground state of the hydrogen atom. This wavefunction is spherically symmetric.

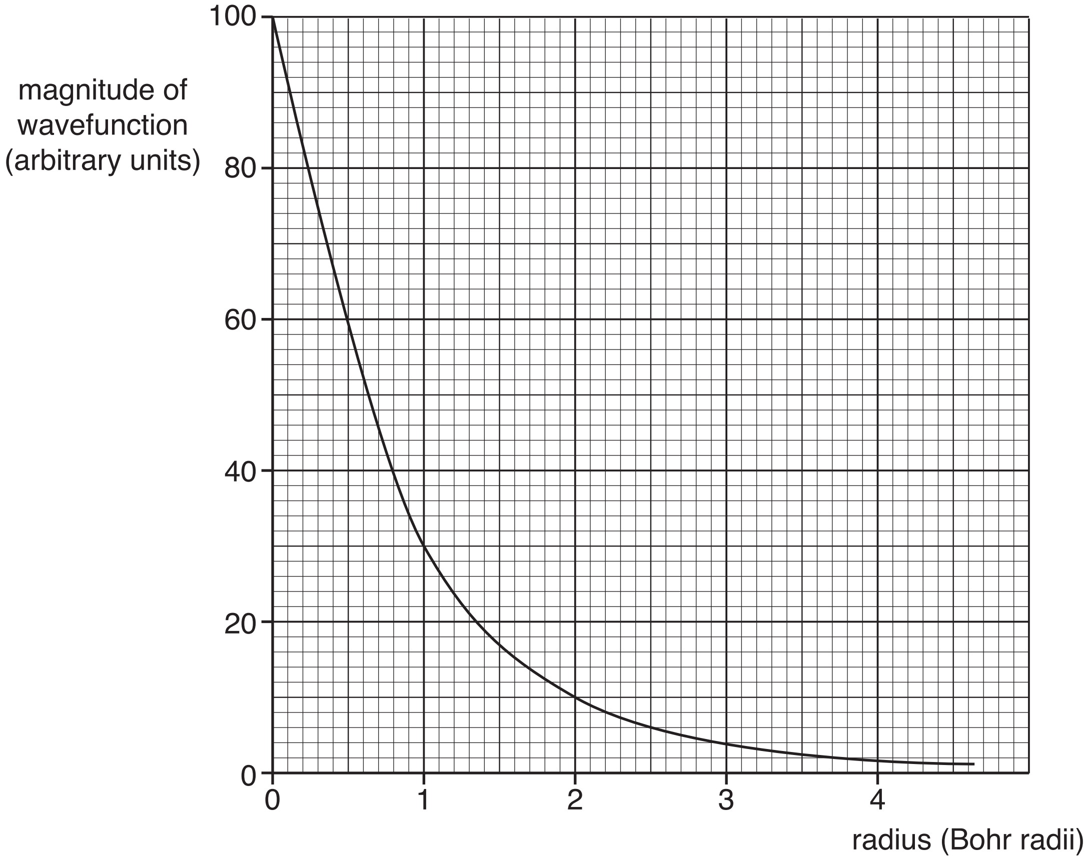

Fig. 13.1

According to the Copenhagen Interpretation of quantum theory, the probability per unit volume p of finding an electron at a particular location is proportional to $|\Psi|^2$.

(i) The value of p at one Bohr radius is p_1 and the value at two Bohr radii is p_2.

Calculate the ratio $\frac{p_2}{p_1}$.

$\frac{p_2}{p_1}$ = ... [2]

(ii) In order to calculate the probability of finding the electron in a spherical shell of small thickness δr and volume δV at a distance r from the centre of the atom $|\Psi|^2$ is multiplied by the volume δV of the spherical shell. Fig. 13.2 shows a cross-section of such a shell.

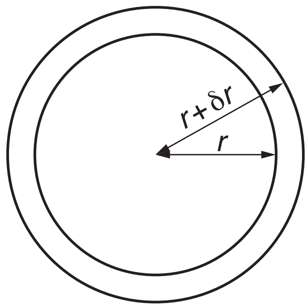

Fig. 13.2

1. Show that the volume δV contained in a spherical shell of small thickness δr at a distance r from the centre of the atom is given by $\delta V = 4\pi r^2 \delta r$.

[2]

2. On Fig. 13.3, sketch a graph to show the variation of δV with r.

Fig. 13.3

[1]

(iii) Calculate the ratio of the probability of finding the electron in a thin shell at two Bohr radii from the nucleus to the probability of finding it in a thin shell of the same thickness at one Bohr radius from the nucleus.

[4]

(iv) Fig. 13.4 shows how the probability of finding an electron in a thin shell of thickness δr varies with radius, where a_0 is the Bohr radius.

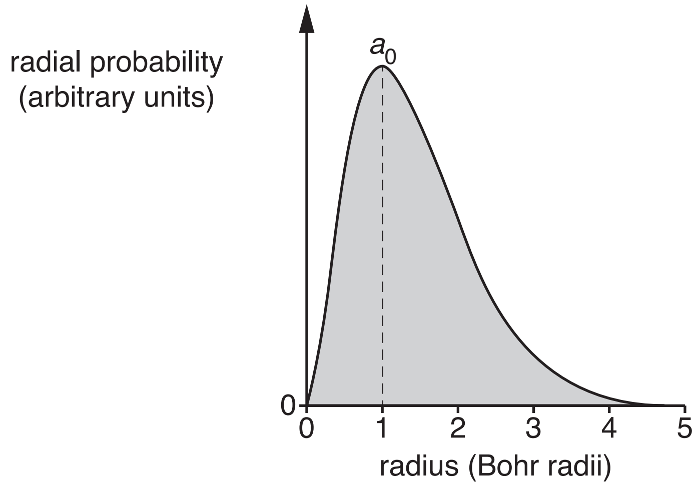

Fig. 13.4

Use your answers to **(b)(i)** and **(b)(ii)** to explain why

1. the radial probability approaches zero near the nucleus,

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....

2. the radial probability approaches zero at large distances.

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....

....

[3]

[Total: 20]