Cambridge Pre-U

UNIVERSITY OF CAMBRIDGE INTERNATIONAL EXAMINATIONS
Cambridge International Level 3 Pre-U Certificate
Principal Subject

CANDIDATE NAME

CENTRE NUMBER | CANDIDATE NUMBER

PHYSICS **9792/03**

Paper 3 Part B Written Paper **May/June 2012**

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 a pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.
DO **NOT** WRITE IN ANY BARCODES.

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

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

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	
1	
2	
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12	
13	
Total	

This document consists of **42** printed pages and **2** blank pages.

DC (NF/JG) 51121/5

UNIVERSITY of CAMBRIDGE International Examinations

Data

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

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
	$s = \left(\frac{u+v}{2}\right)t$
heating	$\Delta E = mc\Delta\theta$
change of state	$\Delta E = mL$
refraction	$n = \frac{\sin\theta_1}{\sin\theta_2}$
	$n = \frac{v_1}{v_2}$
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	$W = \frac{1}{2}QV$
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	$E = \frac{-d(N\Phi)}{dt}$
Hall effect	$V = Bvd$
time dilation	$t' = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$
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	$\frac{dN}{dt} = -\lambda N$
	$N = N_0e^{-\lambda t}$
	$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$
attenuation losses	$I = I_0e^{-\mu x}$
mass-energy equivalence	$\Delta E = c^2\Delta m$
hydrogen energy levels	$E_n = \frac{-13.6\,\text{eV}}{n^2}$
Heisenberg uncertainty principle	$\Delta p\Delta x \geqslant \frac{h}{2\pi}$
	$\Delta E\Delta t \geqslant \frac{h}{2\pi}$
Wien's 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 A

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

1 **(a)** An object is travelling with constant speed *v* on a circular path of radius *r*, as shown in Fig. 1.1.

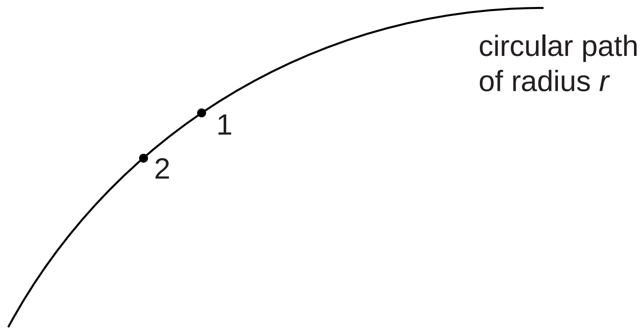

Fig. 1.1

The object moves from position 1 to position 2 in a short period of time. On Fig. 1.2, draw labelled lines to complete a vector diagram to show the change in velocity that takes place between position 1 and position 2. The velocity vector at position 1 is already drawn for you.

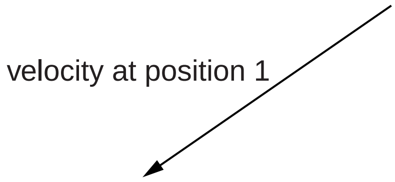

Fig. 1.2 [3]

(b) A roller-coaster ride in a theme park is illustrated in Fig. 1.3.

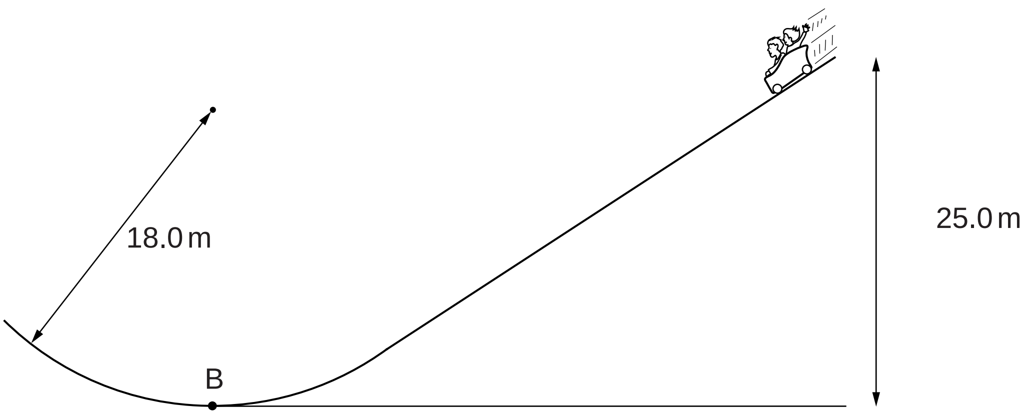

Fig. 1.3

The total mass of carriage and passengers is 560 kg. It has a speed of 10.0 m s^{-1} at the top of the descent. The height of the descent is 25.0 m. At point B, the bottom of the descent, the carriage is on a path of radius 18.0 m.

For Examiner's Use

(i) Calculate the speed of the carriage at B, the bottom of the descent, if 40 000 J is lost as frictional heating during the descent.

speed = ... m s^{-1} [5]

(ii) Calculate the magnitude of the two vertical forces on the carriage at B.

force 1 = ... N

force 2 = ... N

[3]

(iii) Draw a vector diagram showing the two forces from **(ii)**.

For Examiner's Use

[1]

(iv) State the type of each of the forces shown on your diagram in **(ii)**.

upward force ....

downward force ....

[2]

[Total: 14]

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2 **(a)** State what is meant by

(i) a *free* oscillation,

....

....

.... [1]

(ii) a *damped* oscillation,

....

....

.... [1]

(iii) a *forced* oscillation.

....

....

.... [1]

(b) A car component of mass 0.0460 kg rattles at a resonant frequency of 35.5 Hz.

Fig. 2.1 shows how the amplitude of the oscillation varies with frequency.

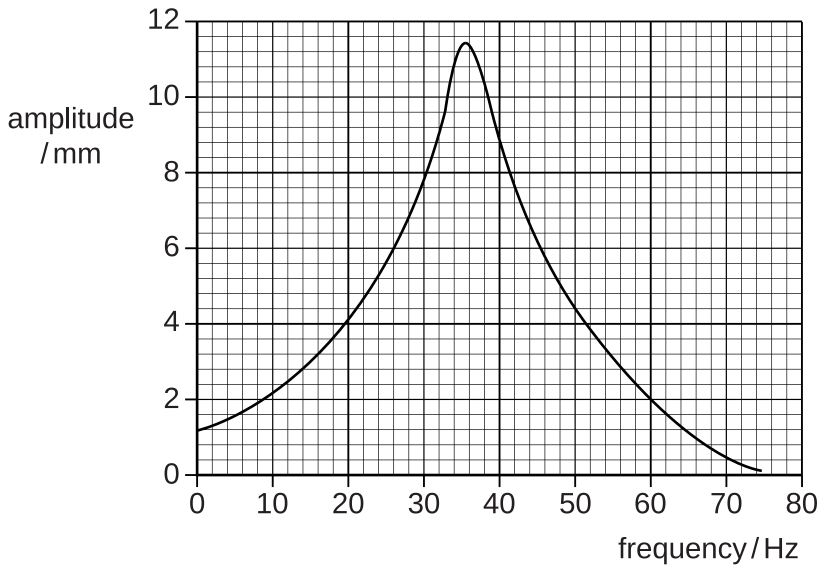

Fig. 2.1

For Examiner's Use

(i) Calculate the energy stored in the oscillation of the component when oscillating

1. at the resonant frequency,

energy = ... J [3]

2. at a frequency of 20.0 Hz.

energy = ... J [2]

(ii) On Fig. 2.1, draw a line to show the effect of supporting the component on a rubber mounting. [2]

[Total: 10]

For Examiner's Use

3 This question compares gravitational and electric potential.

(a) Fig. 3.1 is a map of an island showing contour lines, representing points of equal height, at intervals of 200 m.

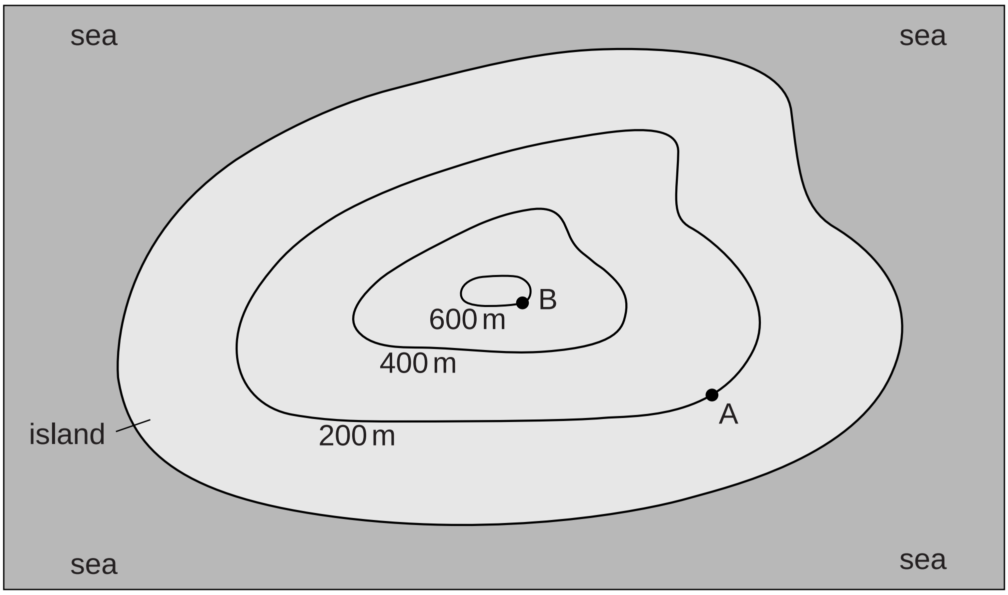

Fig. 3.1

(i) Calculate the minimum work required to be done to move an object of mass 50 kg from point A to point B.

work = ... J [1]

(ii) Calculate the change in the gravitational potential between points A and B on the map. State the unit of gravitational potential with your answer.

change in gravitational potential = ... unit .... [2]

(iii) On Fig. 3.1, draw 6 lines with arrows to show the direction that water could flow from the top of the island into the sea. [2]

For Examiner's Use

(iv) State why the gravitational field is not in the direction of the six lines you have drawn on Fig. 3.1.

....

....

.... [1]

(b) Fig. 3.2 is a similar diagram to Fig. 3.1 but now represents the electric potentials of a flat, positively charged, insulated object surrounded by a conductor at zero potential.

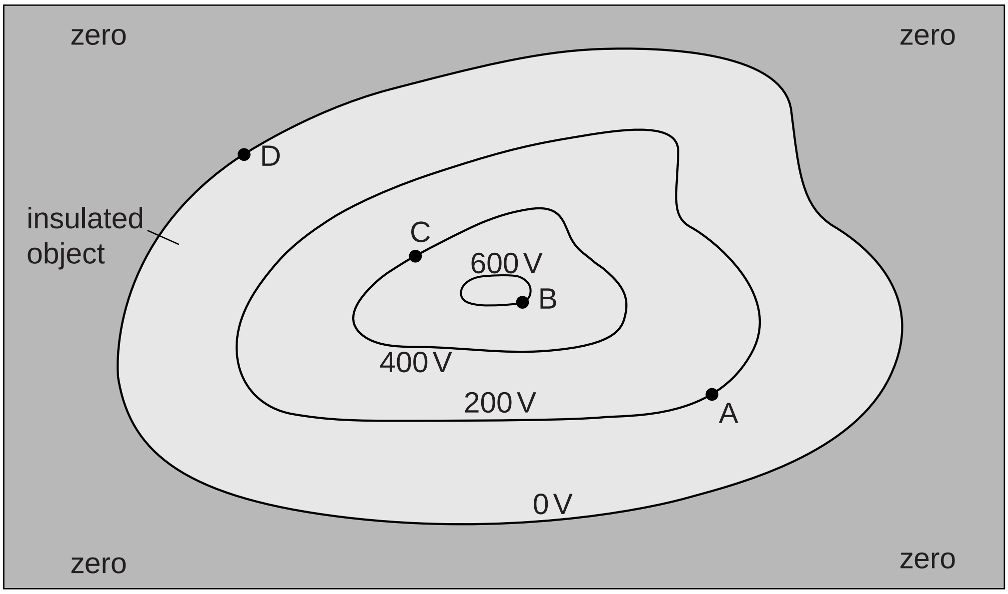

Fig. 3.2

(i) Draw 6 electric field lines on the object. [2]

(ii) Calculate the work done when a charge of 50 μC is moved

1. from A to B,

work done = ... J [2]

2. from C to D.

work done = ... J [1]

[Total: 11]

For Examiner's Use

4 **(a)** In a diesel engine a fixed amount of gas can be considered to undergo a cycle of four stages. The cycle is shown in Fig. 4.1.

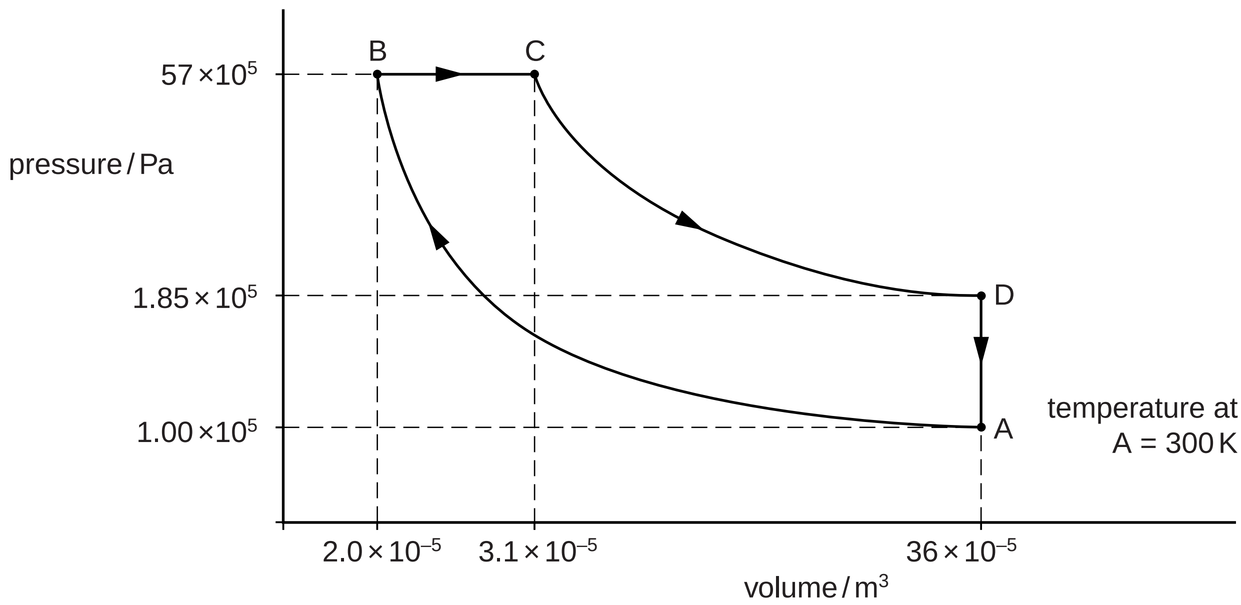

Fig. 4.1 (not to scale)

The four stages are

A → B a compression with a rise in pressure and temperature from an initial temperature of 300 K,
B → C an expansion at constant pressure while fuel is being burnt,
C → D a further expansion with a drop in both temperature and pressure,
D → A a return to the starting point.

Some numerical values of temperature, pressure and volume are given on Fig. 4.1. The values are for an idealised engine.

(i) Using Fig. 4.1, determine the work done **by the gas** during the stages

1. B → C,

work done = ... J [2]

2. D → A.

work done = ... J [1]

For Examiner's Use

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

temperature = ... K [3]

(b) Complete the following table for the four stages of the cycle given in **(a)**. Make use of two of your answers from **(a)**.

stage of cycle	heat supplied **to the gas** / J	work done **on the gas** / J	**increase** in the internal energy of the system / J
A → B	0	235	
B → C	246		
C → D	0	–333	
D → A			

[5]

(c) **(i)** Calculate the efficiency of this idealised engine.

efficiency = ... [1]

(ii) Suggest two reasons why, in practice, an engine such as this will have a lower efficiency than that calculated above.

1. ....

....

2. ....

....

[2]

[Total: 14]

For Examiner's Use

5 **(a)** An α-particle is emitted from a stationary polonium nucleus ${}^{210}_{84}\text{Po}$.

A lead (Pb) nucleus is produced. Write a nuclear equation to represent the emission.

[2]

(b) Use the laws of conservation of momentum and conservation of energy to deduce the values of the following ratios after the nuclear reaction has occurred.

(i) $\dfrac{\text{momentum of } \alpha\text{-particle}}{\text{momentum of lead nucleus}}$

ratio = ... [1]

(ii) $\dfrac{\text{speed of } \alpha\text{-particle}}{\text{speed of lead nucleus}}$

ratio = ... [2]

(iii) $\dfrac{\text{kinetic energy of } \alpha\text{-particle}}{\text{kinetic energy of lead nucleus}}$

ratio = ... [2]

For Examiner's Use

(c) The half life of polonium-210 nuclei is 138 days.

Calculate the time taken for the activity of a source of polonium-210 to decay from 24 000 Bq to 850 Bq.

time = ... days [3]

[Total: 10]

6 **(a)** The energy levels of electrons in gaseous hydrogen are described by the empirical equation

$$E_n = \frac{-13.6\,\text{eV}}{n^2}.$$

(i) Calculate the values of E_n for $n = 1$ to $n = 5$.

E_1 = ...eV, E_2 = ...eV, E_3 = ...eV, E_4 = ...eV, E_5 = ...eV. [2]

(ii) The line on Fig. 6.1 represents the energy level for a value $E_n = 0$ when $n = \infty$.

On Fig. 6.1, draw lines to represent the values obtained in **(i)**.

$n = \infty$ ———————————— $E_\infty = 0\,\text{eV}$

Fig. 6.1

[1]

For Examiner's Use

(b) On Fig. 6.1, show energy transitions from $n = 5$ to $n = 2$, from $n = 4$ to $n = 2$ and from $n = 3$ to $n = 2$. [1]

(c) (i) Use your values from **(a)** to calculate the photon energy of the light emitted by the transition from $n = 5$ to $n = 2$.

photon energy = ... eV [1]

(ii) Hence calculate the wavelength of the light emitted by a transition from $n = 5$ to $n = 2$.

wavelength = ... m [3]

(d) On Fig. 6.1, show an energy transition that could represent an infra-red emission. Mark this energy change 'infra-red'. [1]

(e) State the region of the electromagnetic spectrum in which a transition from $n = 5$ to $n = 1$ would lie.

.... [1]

[Total: 10]

For Examiner's Use

7 **(a)** The Earth's orbital motion around the Sun results in a small change in the apparent direction of a relatively close star X when seen against the background of very distant stars. This is shown, not to scale, in Fig. 7.1.

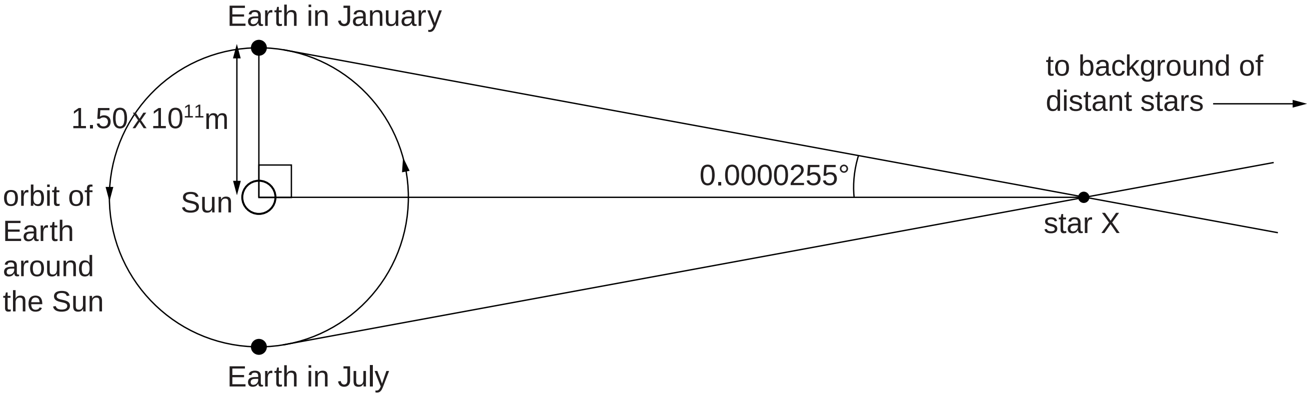

Fig. 7.1 (not to scale)

The distance of the Earth from the Sun is 1.50×10^{11} m and the angular change from January to July was measured to be 0.000051°. Half of this angle is shown on Fig. 7.1.

(i) Calculate the distance of star X from the Earth.

distance = ... m [2]

(ii) The luminous flux on the Earth from star X is $3.6 \times 10^{-9}\,W\,m^{-2}$.

Calculate the luminosity of X. Give the unit for luminosity.

luminosity = ... unit .... [3]

For Examiner's Use

(iii) Another star Y has the same luminosity as star X. The luminous flux on the Earth from Y is measured to be $8.3 \times 10^{-11}\,\mathrm{W\,m^{-2}}$.

Calculate the distance of Y from the Earth.

distance = ... m [3]

(b) Fig. 7.2(a) shows how the radiation intensity from the Sun, at a surface temperature of 5800 K, varies with wavelength.

Fig. 7.2(b) shows how the radiation intensity from Y varies with wavelength.

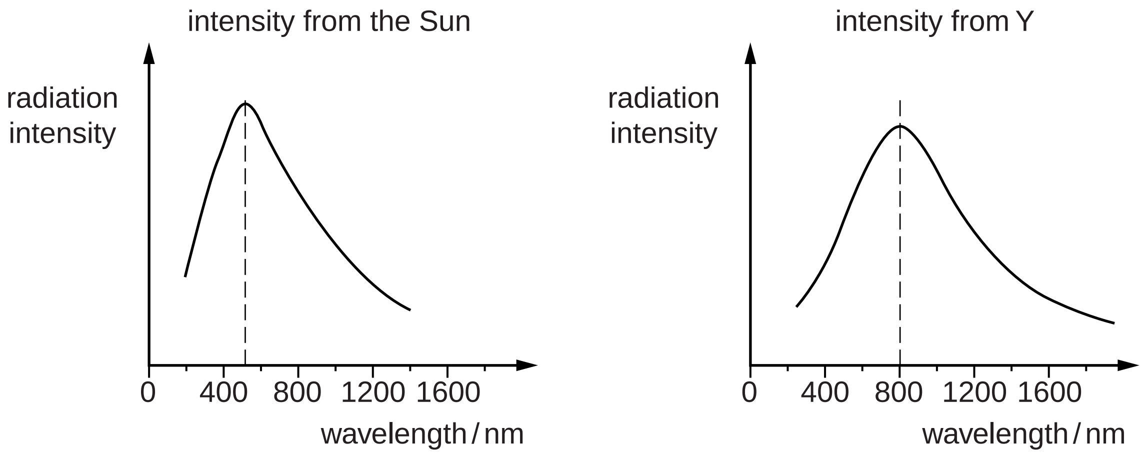

Fig. 7.2(a) **Fig. 7.2(b)**

Use Fig. 7.2(a) and Fig. 7.2(b) to determine the surface temperature of Y.

surface temperature of Y = ... K [3]

[Total: 11]

End of Section A

Section B

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

For Examiner's Use

8 Archaeologists use a variety of techniques to locate ancient buildings. One technique requires the measurement of electrical resistance. From this, measurements of resistivity may be determined.

(a) State the relationship between resistance and resistivity. State the meaning of any symbols that you use.

....

....

.... [2]

(b) Some resistors used in electronic circuits contain a thin film of carbon. Fig. 8.1 shows a square film of carbon of resistivity ρ. Current flows between the shaded faces.

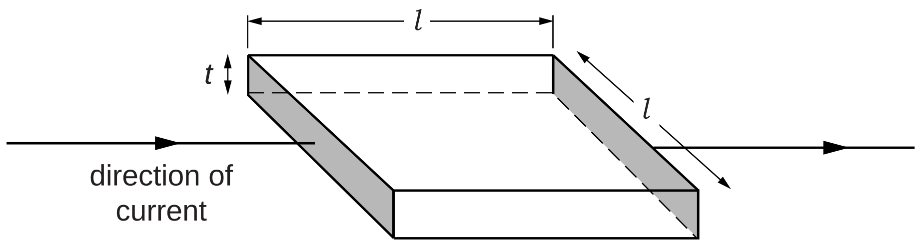

Fig. 8.1

Show that the resistance R of the square carbon film in Fig. 8.1 is independent of the length l of the sides of the square when the film has uniform thickness.

....

....

....

.... [2]

(c) An archaeologist places pairs of probes at regular intervals in the ground and measures the resistance of the soil. Different resistance values at different locations may indicate the presence of a prehistoric ditch. Fig. 8.2 illustrates this method.

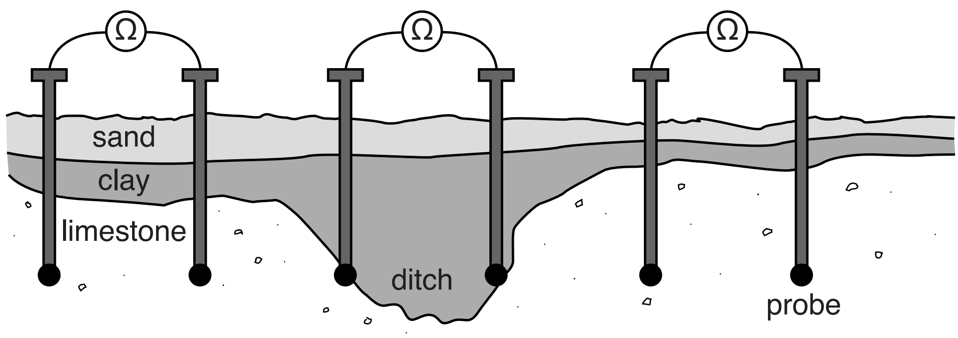

Fig. 8.2

Fig. 8.3 shows a block of clay. Fig. 8.4 shows a sample of clay and limestone incorporating the clay block shown in Fig. 8.3.

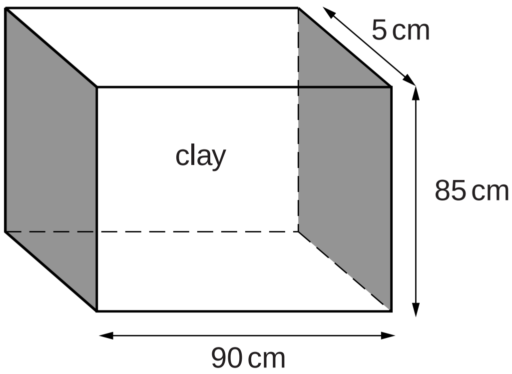

Fig. 8.3 (not to scale)

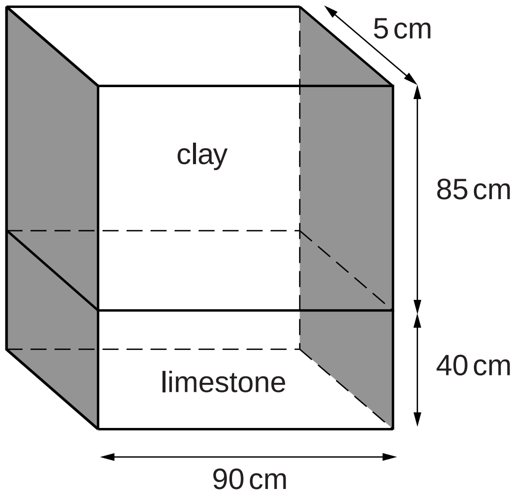

Fig. 8.4 (not to scale)

(i) The resistance between the shaded faces of the block of clay in Fig. 8.3 is 1650 Ω. The resistance between the shaded faces of the clay-limestone sample in Fig. 8.4 is 1600 Ω.

Calculate the resistance between the shaded faces of the limestone block.

resistance = ... Ω [3]

(ii) Determine the resistivity of this limestone.

resistivity = ... Ω m [2]

(d) Archaeologists also use an instrument called a geophone, as shown in Fig. 8.5, to detect man-made structures under the ground.

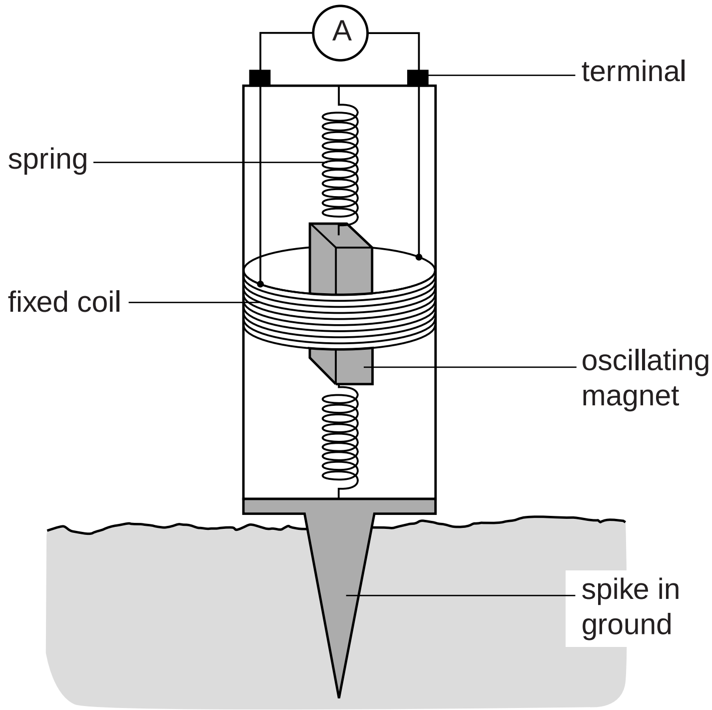

Fig. 8.5

The ground is made to vibrate. The magnet begins to oscillate within the insulated coil of wire fixed to the casing of the geophone. An e.m.f. is induced in the coil, producing a current which is measured by the ammeter.

(i) The coil has 60 turns. The maximum e.m.f. induced in this geophone is 84 mV.

Calculate the maximum rate of change of flux in the coil. Give units with your answer.

rate of change of flux = ... unit .... [3]

(ii) The relationship needed to answer part **(d)(i)** is a mathematical expression of Faraday's law.

State Faraday's law in words only.

....

....

....

.... [3]

(iii) Eventually the relative motion of the coil and magnet ceases due to damping.

Briefly explain how this damping effect is consistent with Lenz's law.

....

....

....

....

....

.... [2]

(e) On the axes of Fig. 8.6, sketch a graph of displacement *y* of the magnet against time *t* for 3 complete oscillations of the damped motion. Numerical values are not required.

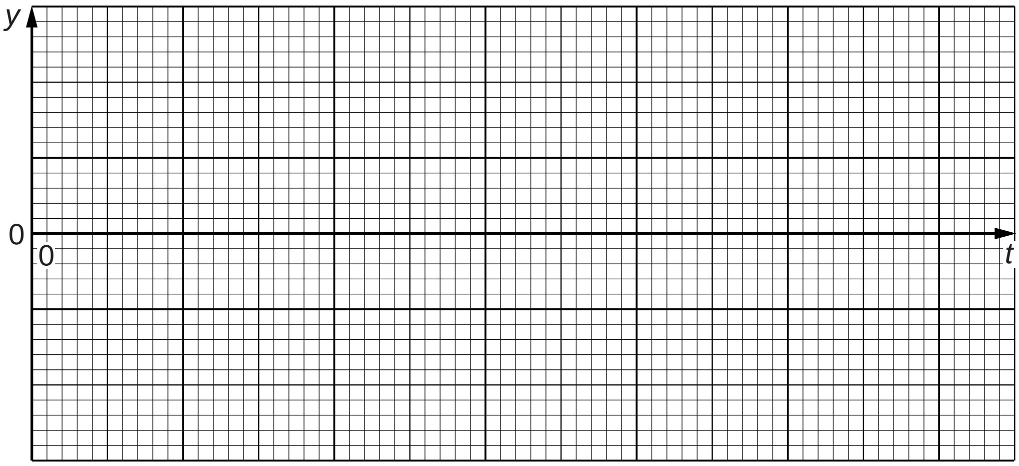

Fig. 8.6

[3]

[Total: 20]

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9 Galileo used a simple pendulum to time the motion of objects rolling down an inclined plane. Fig. 9.1 shows a simple pendulum.

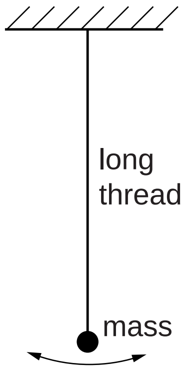


Fig. 9.1 (not to scale)

(a) A simple pendulum mass oscillates with simple harmonic motion.

State the general conditions necessary for simple harmonic motion.

....

....

....

.... [2]

(b) The displacement x of the mass at time t is given by the relationship

$$x = A \cos \omega t$$

where A is the amplitude of the oscillation and ω is the angular velocity.

This relationship is a solution to the differential equation that describes the condition for simple harmonic motion. State that equation.

.... [1]

For Examiner's Use

(c) The pendulum is displaced to one side and then released at time $t = 0$. Fig. 9.2 shows the positions of the mass at various times during a single oscillation.

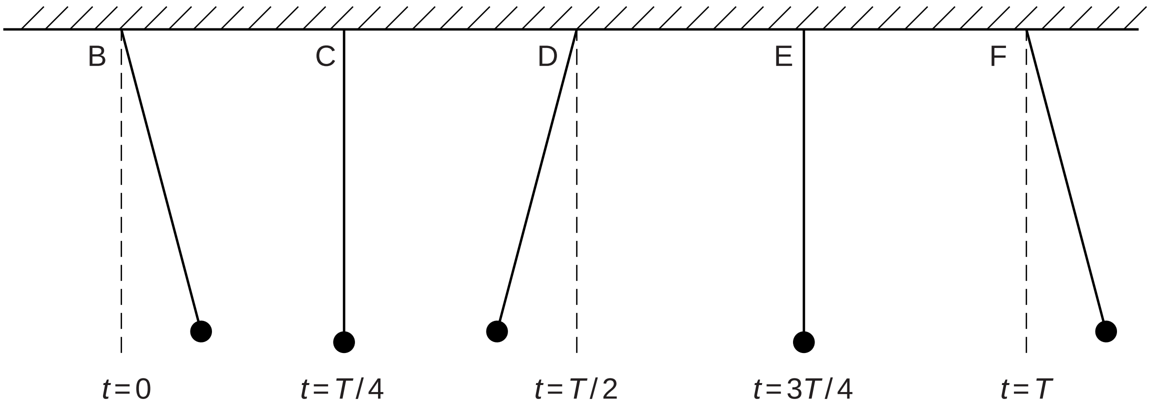


Fig. 9.2 (not to scale)

Complete the table below to describe the directions of the displacement, velocity and acceleration of the mass at times B to F using the symbols +, 0 and –.

Apply the convention that displacements, velocities and accelerations to the right are positive.

	B	C	D	E	F
displacement					
velocity					
acceleration					

[4]

(d) State the phase difference, for the pendulum in **(c)**, between

(i) the displacement and the velocity,

....

(ii) the displacement and the acceleration.

.... [2]

For Examiner's Use

(e) Fig. 9.3 shows the variation of displacement x with time t for a particular pendulum.

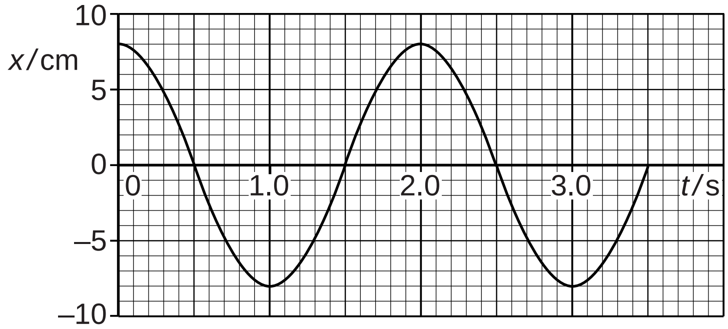


Fig. 9.3

(i) Use information from the graph to determine

1. the amplitude,

amplitude = ... cm

2. the frequency of oscillation.

frequency = ... Hz [1]

(ii) The mass m of the pendulum is 20 g.

1. Calculate the maximum force exerted on the mass.

maximum force = ... N [2]

2. On Fig. 9.4, sketch a graph to show how, for the time period given in Fig. 9.3, the force F varies with time t.

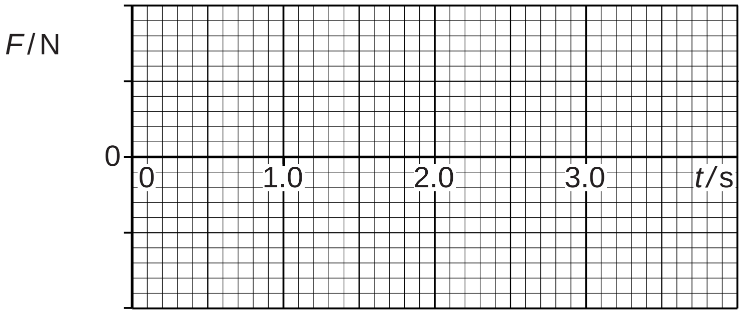


Fig. 9.4

[2]

(f) A rod is rolled down an inclined plane as shown in Fig. 9.5.

For Examiner's Use

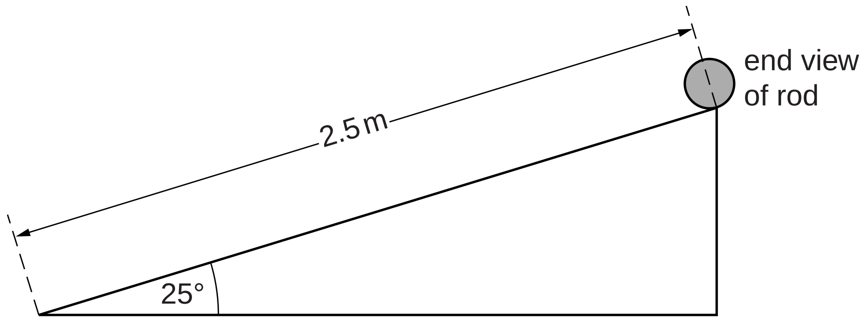
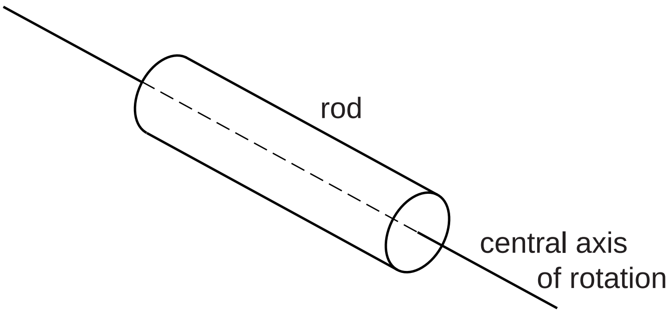


Fig. 9.5 (not to scale)

The plane of length 2.5 m is inclined at an angle of 25° to the horizontal.

(i) The rod has a radius R and a moment of inertia I about its central axis.

Briefly explain what is meant by the phrase *moment of inertia about its central axis*.
You may add to the diagram below to help illustrate your answer.



....

....

....

.... [2]

(ii) The rod has a mass M of 0.20 kg and its moment of inertia I is 0.10×10^{-4} kg m^2. It starts from rest and rolls down the inclined plane without slipping.

For Examiner's Use

Determine the angular speed ω of the rod at the bottom of the inclined plane where its linear speed v is 3.72 m s^{-1}.

angular speed = ... rad s^{-1} [4]

[Total: 20]

10 **(a)** The antiparticle of the electron is the positron.

State one similarity and one difference between an antiparticle and its particle pair.

similarity ....

....

difference ....

....
[2]

(b) An electron and a positron, both with negligible kinetic energy, annihilate. They produce two identical γ-ray photons.

Calculate

(i) the energy ΔE released, in joules,

ΔE = ... J [2]

(ii) the frequency f of each photon.

f = ... Hz [2]

(c) The graph in Fig. 10.1 shows the kinetic energy spectrum for β^- particles (electrons) emitted in the decay of platinum $^{199}_{78}Pt$ to gold $^{199}_{79}Au$.

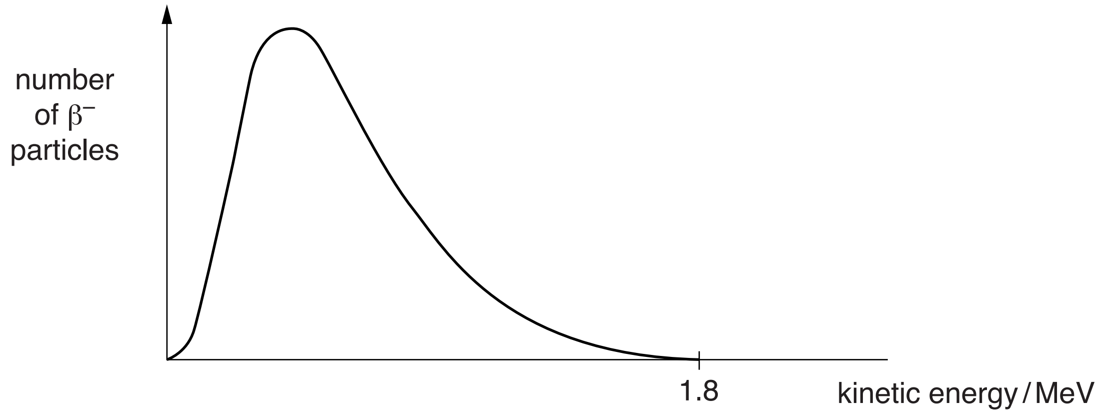


Fig. 10.1

Explain how a consideration of this kinetic energy spectrum and conservation of charge provided evidence for

(i) the prediction of the existence of the antineutrino,

....

....

....

....

....

(ii) the proton number of the antineutrino.

....

....

[4]

(d) Different thicknesses x of a metal ore are placed between a gamma source and a gamma radiation detector. Fig. 10.2 shows how the count rate of the detector decreases exponentially with thickness x as attenuation takes place.

For Examiner's Use

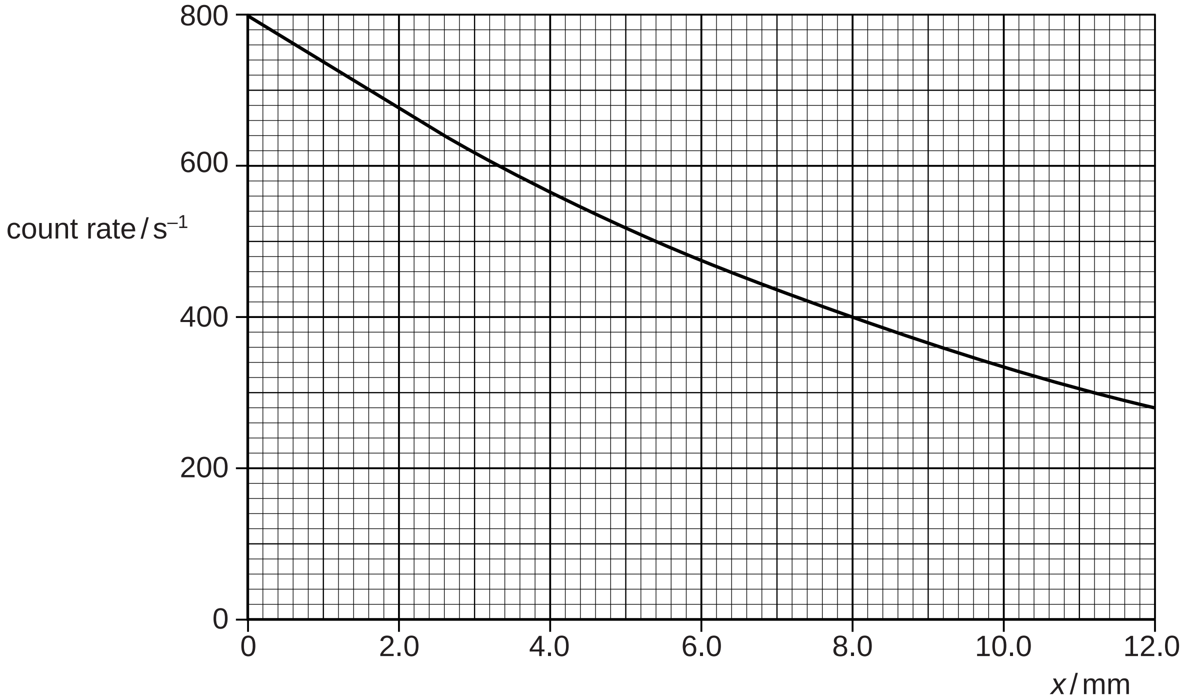


Fig. 10.2

The count rate is directly proportional to the intensity I of the gamma radiation.

Use data from Fig. 10.2 to determine the attenuation coefficient μ for the metal absorber. Give a unit with your answer.

μ = ... unit .... [4]

For Examiner's Use

(e) An electron has discrete energy levels within the hydrogen atom fixed by the principal quantum number *n*. The Bohr atom model uses the principal quantum number to describe the number of complete electron standing waves that fit the circumference of the atom and the quantum condition becomes

$$2\pi r = n\lambda \qquad \text{where } r \text{ is the orbital radius.}$$

(i) Derive an expression for the quantised angular momentum of an electron by also considering the de Broglie relation for λ.

....

....

.... [1]

(ii) Hence determine the angular momentum for $n = 4$. Give a unit with your answer.

angular momentum .... unit .... [2]

(iii) The ionisation energy E_I for the electron is given by the relationship

$$E_I = \frac{me^4}{8\varepsilon_0^2 h^2}$$

Use this relationship to determine the ionisation energy.

ionisation energy = ... J [3]

[Total: 20]

For Examiner's Use

11 (a) What does Einstein's special theory of relativity state about the Laws of Physics?

....

.... [1]

(b) What does Einstein's special theory of relativity state about the speed of light?

....

.... [1]

(c) In 1964, Filipas and Fox tested the special theory of relativity. They measured the speed of the γ-rays emitted when a sub-atomic particle, called a neutral pion, decays into a pair of identical γ-rays. The γ-rays are emitted in opposite directions. There are no other products of the decay.

(i) Explain why γ-rays are expected to travel at the speed of light.

....

.... [1]

(ii) Explain why a stationary pion could not decay to a single γ-ray photon.

....

....

....

.... [2]

(d) The pions used in the Filipas and Fox experiment in **(c)** were moving through the laboratory at about 0.20 *c*, and the γ-rays were emitted parallel to the motion. This is shown in Fig. 11.1.

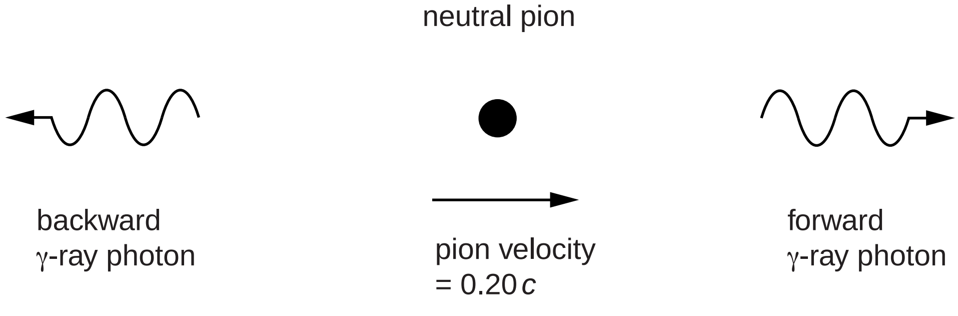


Fig. 11.1

For Examiner's Use

(i) The results of the experiment showed that the velocities of the photons relative to the laboratory were equal to *c* in both directions within the limits of experimental uncertainty.

State the conclusion that can be drawn from this.

....

....

.... [1]

(ii) State the velocity of the forward photon relative to the pion, as seen from a reference frame moving with the same velocity as the pion when it decays.

.... [1]

(iii) One consequence of the special theory of relativity is called time dilation.

Explain what is meant by *time dilation*.

....

....

....

.... [2]

(iv) The half-life for the decay of a neutral pion at rest in the laboratory is about 18.0 ns.

Calculate the expected half-life of the moving pions in the laboratory reference frame.

expected half-life = ... ns [2]

For Examiner's Use

(e) In 1971, Hafele and Keating decided to test the special theory of relativity by measuring the effects of time dilation on clocks. They did this by synchronising two atomic clocks at an air base and then sending one of them on a high-speed journey inside a jet aircraft. At the end of the journey they measured the time difference between the clocks and compared this with the expected time difference predicted by relativity. One part of this difference is caused by the relative motion of the two clocks as predicted by Einstein's time dilation formula.

(i) The average air speed of the jet aircraft was 300 m s^{-1} and the total time of flight, as measured on a clock at the airbase, was 50 hours.

Calculate the time dilation factor using the approximation:

$$\frac{t'}{t} = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \approx 1 + \frac{v^2}{2c^2}$$

time dilation factor = ... [2]

(ii) For the experiment described in **(i)**,

1. calculate the expected time difference between the two clocks at the end of the flight caused by special relativistic time dilation,

expected time difference = ...

2. state whether this time difference would increase or decrease the time measured by the clock on the aircraft as compared to the clock at the airbase.

....

[2]

For Examiner's Use

(iii) Hafele and Keating claimed that the measured time differences were within 10% of those predicted by the theory and so supported it.

However, even atomic clocks are not perfect time-keepers. An atomic clock at rest was known to gain or lose time by up to 5 ns per hour. One on board a plane might additionally gain or lose up to 100 ns per day.

The maximum predicted time differences for the Hafele and Keating experiment (including all relativistic effects) was about 275 ns.

Discuss whether Hafele and Keating were justified in claiming that their results supported Einstein's theory.

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.... [3]

(f) State and explain how special relativity affects the measured red shift of light from rapidly receding galaxies.

....

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....

....

.... [2]

[Total: 20]

For Examiner's Use

12 In 1919, Louis de Broglie suggested that electrons, like photons, might show wave-like properties, such as interference and diffraction. In the 1950s, Mollenstadt carried out interference experiments using electrons instead of light. The basic arrangement consisted of an electron point-source, a fine wire electrode connected to a positive potential, and a detecting screen. The arrangement is shown in Fig. 12.1.

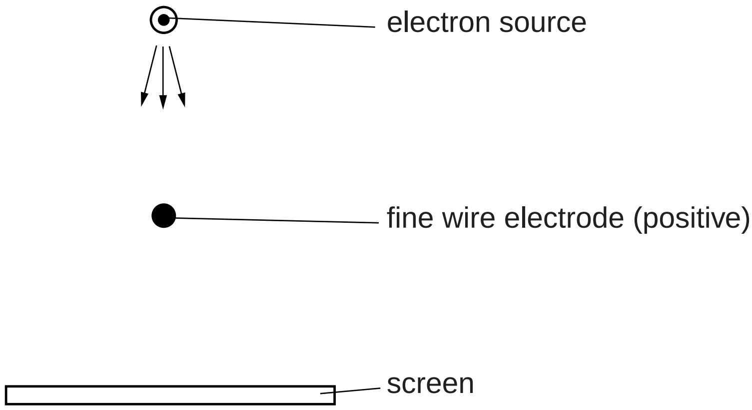

Fig. 12.1

(a) State one other piece of experimental evidence to support the idea that electrons can exhibit wave-like properties.

....

....

.... [1]

(b) The Copenhagen interpretation of Mollenstadt's experiment describes the electrons leaving the source as waves travelling outwards from a point. The effect of the fine wire electrode is to split the approaching wave into two converging wavefronts which superpose as they approach the screen. The arrival of electrons at the screen creates an interference pattern similar to the one shown in Fig. 12.2 below.

Fig. 12.2

The bright patches represent positions where small numbers of electrons arrive. The dark patches represent positions where large numbers of electrons arrive.

(i) The energy of the electrons leaving the source is increased. State and explain the effect on the spacing of the pattern.

....

....

....

.... [2]

(ii) The wavefunctions described by the Copenhagen interpretation are not observable. Explain how the theory uses wavefunctions to predict the pattern of maxima and minima.

For Examiner's Use

....

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....

.... [2]

(iii) Richard Feynman explained these patterns using a 'sum-over-histories' theory. Use his theory to explain how a minimum in the pattern is produced.

....

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....

.... [3]

(c) The rate at which electrons leave the source can be reduced, so that only one electron passes through the apparatus at a time. In a particular experiment, the rate of electron emission is one per millisecond, and the time taken to pass through the apparatus is less than 1 μs. The first electron leaves the source at t = 0 ms.

For Examiner's Use

The energy of the electrons and the voltage of the filament are exactly the same as were used to obtain Fig. 12.2.

(i) Fig. 12.3 shows part of the screen at different times. Complete Fig. 12.3 to show the screen at 10 ms, 50 ms, and 5 s. Use dots to show the detection of individual electrons and shading to show the detection of large numbers of electrons.

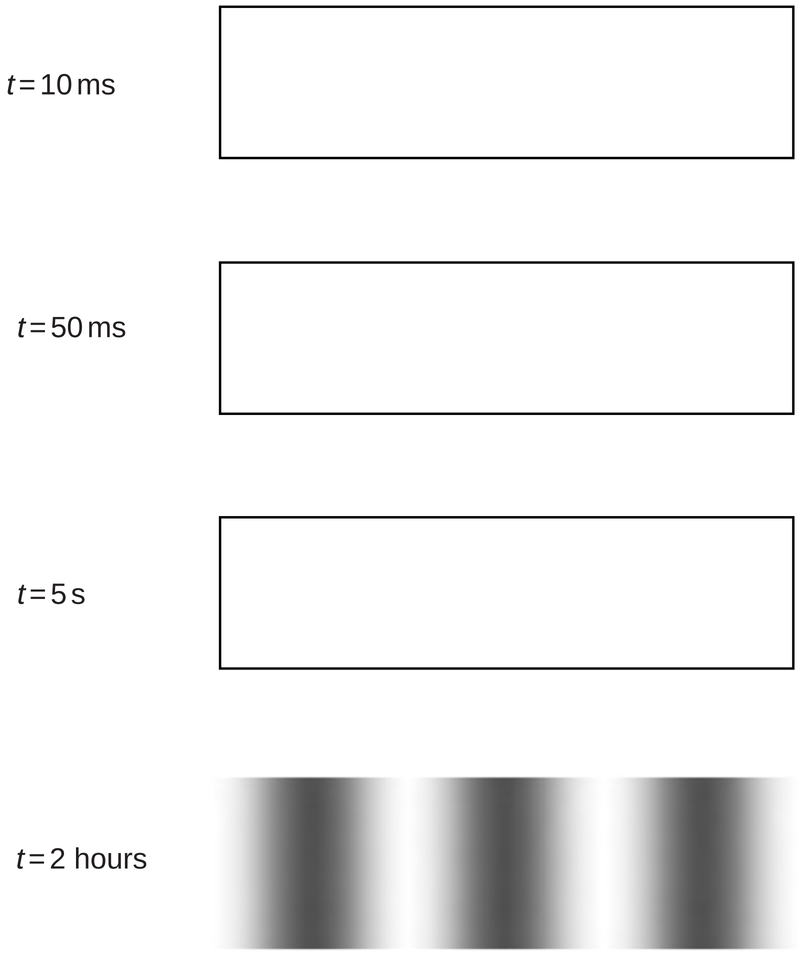

Fig. 12.3

[3]

(ii) A pattern emerges even though the electrons are passing through the apparatus one at a time. State two conclusions that can be drawn from this experiment.

1. ....

....

2. ....

....

[2]

(d) (i) Use the Copenhagen interpretation to describe what happens to the wavefunction of a single electron when it is observed at a particular point on the screen.

For Examiner's Use

....

....

....

.... [2]

(ii) Explain why the behaviour of the wavefunction, when an observation or measurement takes place, is a problem for the Copenhagen interpretation. This is often referred to as the 'Measurement Problem'.

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....

.... [1]

(iii) Describe how Everett's many-worlds interpretation explains what happens when a single electron travels through the apparatus from the source to the screen, and explain how this avoids the Measurement Problem.

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.... [4]

[Total: 20]

13 Some domestic refrigerators work by taking a fluid refrigerant around a cycle of changes that result in the inside of the refrigerator having a lower temperature T_{IN} than the outside environment T_{OUT}.

For Examiner's Use

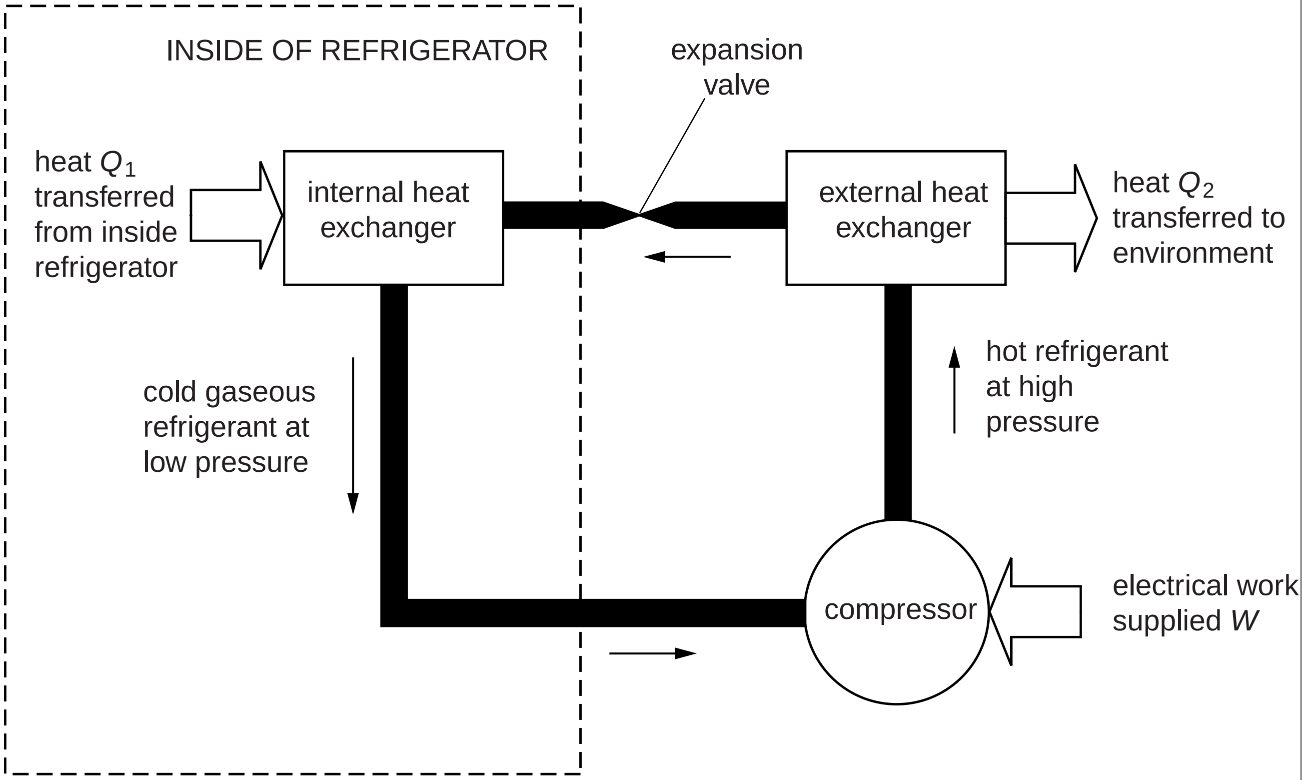

Fig. 13.1

The main steps of the process are:

1. A cold gaseous refrigerant is compressed by the compressor. Work W is done on the refrigerant.

2. The hot compressed refrigerant loses heat Q_2 to the environment and condenses to a liquid as it passes through an external heat exchanger (long series of narrow pipes outside the refrigerator).

3. The high pressure cool liquid passes through an expansion valve into a region of much lower pressure. It changes state to a gas, expands, and cools to a low temperature.

4. The cold gaseous refrigerant passes through an internal heat exchanger and absorbs heat Q_1 from the inside of the refrigerator.

5. The cold gaseous refrigerant returns to the compressor.

For Examiner's Use

(a) Use the 1st law of thermodynamics to explain why the temperature of a gas increases when it is compressed rapidly and decreases when it expands rapidly.

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.... [4]

(b) State the two energy changes that take place as the liquid refrigerant passes through the expansion valve.

1. ....

2. ....
[2]

(c) Explain why the heat exchanger inside the refrigerator extracts heat from the refrigerator.

....

.... [1]

(d) Explain what is meant by the entropy of the refrigerant.

....

....

.... [2]

(e) Explain why the entropy of the refrigerant increases when it is heated.

....

....

.... [2]

(f) The refrigerant returns to its original state once it completes the refrigeration cycle. State the change in entropy of the refrigerant over one complete cycle.

.... [1]

For Examiner's Use

(g) State whether each of the following parts of the refrigeration process, taken on their own, result in no change or an increase or a decrease of entropy:

(i) the cooling of the interior of the refrigerator and its contents,

....

(ii) the heating of the air next to the heat exchanger on the outside of the refrigerator.

....
[1]

(h) State what the second law of thermodynamics says about the entropy of the universe.

....

.... [1]

(i) Explain how a refrigerator obeys the second law of thermodynamics.

....

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.... [3]

(j) A domestic refrigerator in a closed kitchen is plugged into the mains supply and the door of the refrigerator is left open. State and explain what happens to the temperature in the kitchen.

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....

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.... [3]

[Total: 20]

End of Section B