Cambridge Pre-U

CANDIDATE NAME			
CENTRE NUMBER		CANDIDATE NUMBER	

0123456789

PHYSICS **9792/03**

Paper 3 Written Paper **For examination from 2020**

SPECIMEN PAPER **3 hours**

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS
- Section 1: answer **all** questions.
- Section 2: answer **three** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

INFORMATION
- The total mark for this paper is 140.
- The number of marks for each question or part question is shown in brackets [ ].

This specimen paper has been updated for assessments from 2020. The specimen questions and mark schemes remain the same. The layout and wording of the front covers have been updated to reflect the new Cambridge International branding and to make instructions clearer for candidates.

For Examiner's Use	
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Total	

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

This document has **44** pages. Blank pages are indicated.

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	$n = \frac{\sin\theta_1}{\sin\theta_2}$
	$n = \frac{v_1}{v_2}$

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	$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$
electrostatic potential energy	$W = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$
gravitational force	$F = -\frac{Gm_1 m_2}{r^2}$
gravitational potential energy	$E = -\frac{Gm_1 m_2}{r}$
magnetic force	$F = BIl\sin\theta$
	$F = BQv\sin\theta$

electromagnetic induction	$E = -\frac{d(N\Phi)}{dt}$
Hall effect	$V = Bvd$
time dilation	$t' = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$
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	$\frac{dN}{dt} = -\lambda N$
	$N = N_0 e^{-\lambda t}$
	$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$
attenuation losses	$I = I_0 e^{-\mu x}$
mass-energy equivalence	$\Delta E = c^2\Delta m$
hydrogen energy levels	$E_n = \frac{-13.6\,\text{eV}}{n^2}$
Heisenberg uncertainty principle	$\Delta p\Delta x \geqslant \frac{h}{2\pi}$
Wien's displacement law	$\lambda_{\text{max}} \propto \frac{1}{T}$
Stefan's law	$L = 4\pi\sigma r^2 T^4$
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)** An object is travelling with constant speed v on a circular path of radius r, as shown in Fig. 1.1.

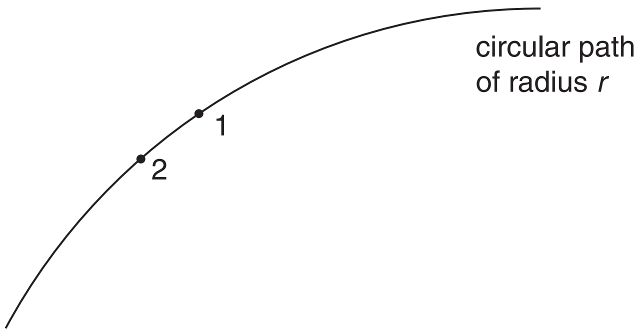

Fig. 1.1

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.

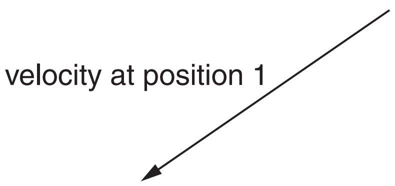

Fig. 1.2 [3]

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

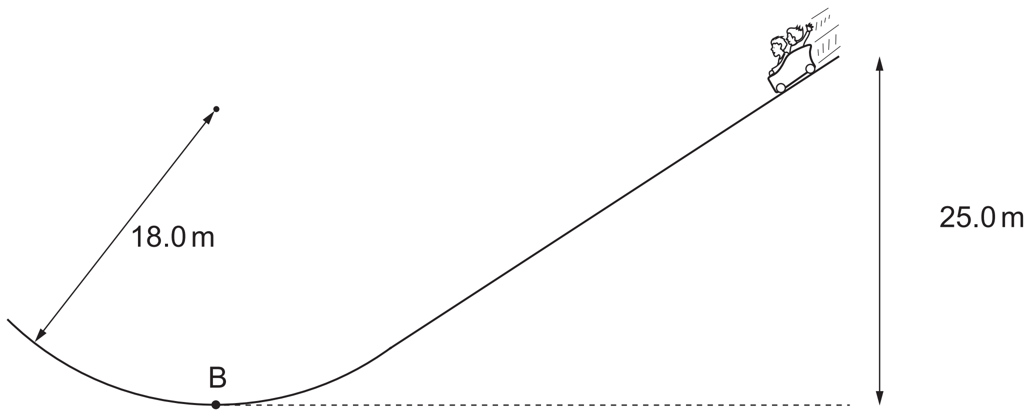

Fig. 1.3

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.

(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]

[Total: 11]

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 vibrates at a resonant frequency of 35.5 Hz.

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

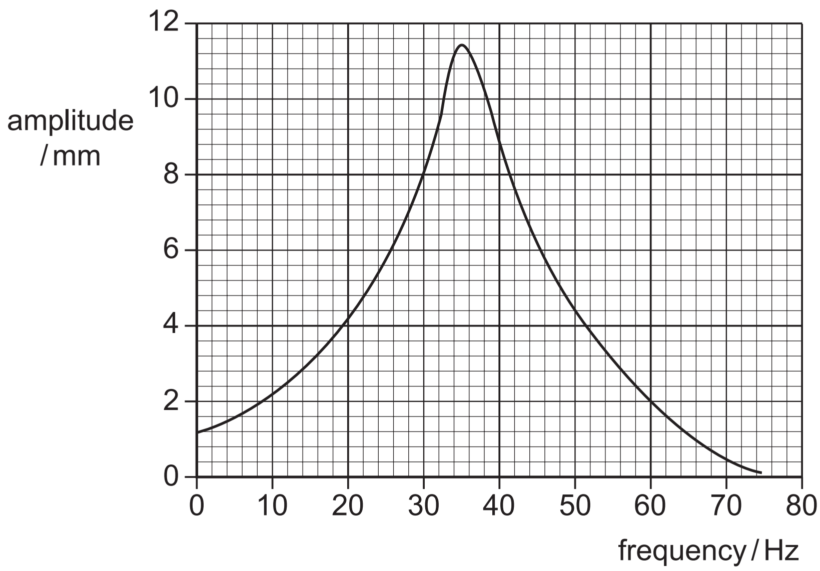

Fig. 2.1

Calculate the energy stored in the oscillation of the component when oscillating

(i) at the resonant frequency,

energy = ... J [3]

(ii) at a frequency of 20.0 Hz.

energy = ... J [2]

[Total: 8]

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.

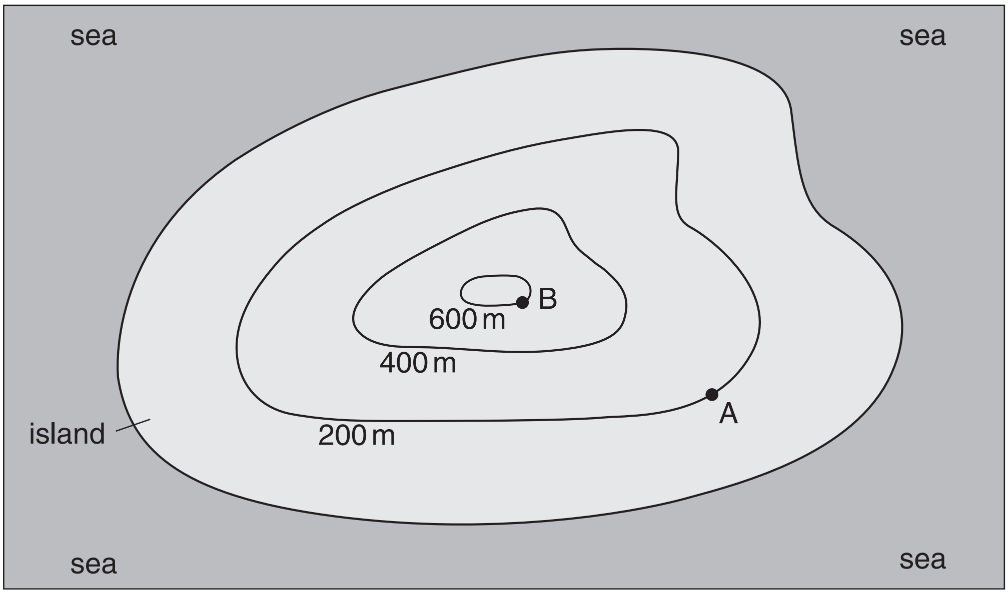

Fig. 3.1

(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]

(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.

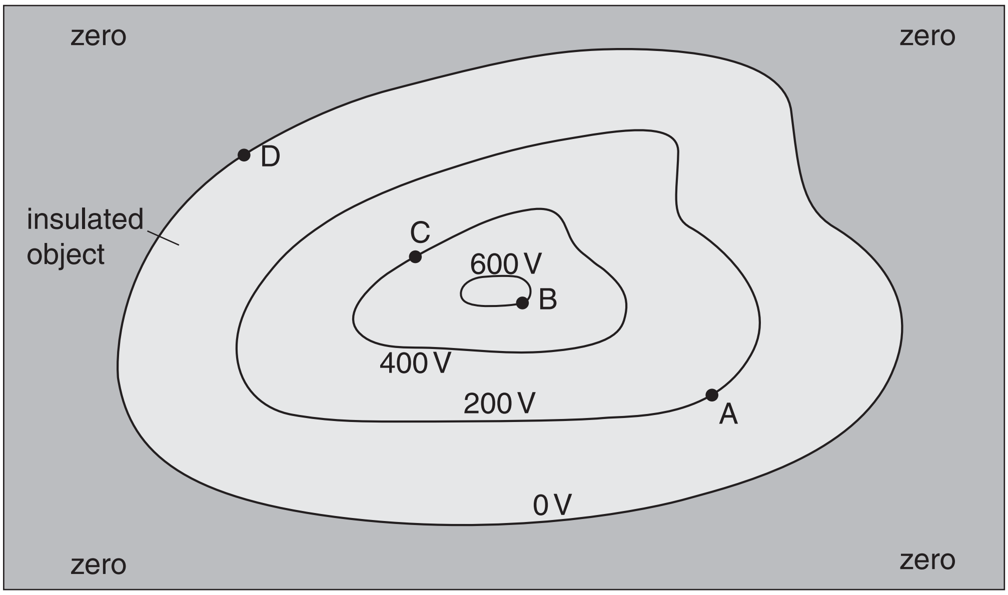

Fig. 3.2

(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: 10]

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.

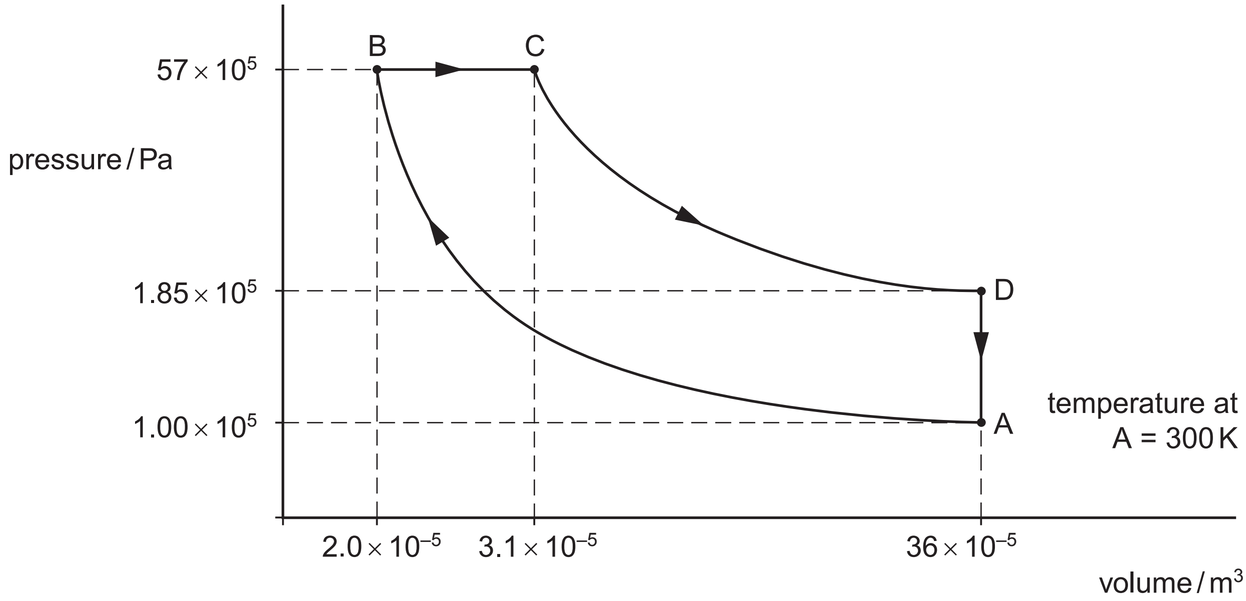

Fig. 4.1 (not to scale)

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 in 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]

(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) Calculate the efficiency of this diesel engine.

efficiency = ... [1]

[Total: 12]

5 **(a)** Theory suggests that the orbital period T for the moon of a planet should be related to its mean orbital distance r from the centre of the planet by an equation of the form

$$T = kr^n$$

where k is a constant.

The orbital periods and mean orbital distances for Saturn's five most massive moons are listed in the table. The table also includes values for log T (T / s) and log r (r / m).

Moon	Discovery Date	Discoverer	T / s	r / m	log (T / s)	log (r / m)
Iapetus	1671	Cassini	6 850 000	3 560 000 000	6.84	9.55
Titan	1655	Huygens	1 380 000	1 220 000 000	6.14	9.09
Rhea	1672	Cassini	390 000	527 000 000	5.59	8.72
Dione	1684	Cassini	236 000	377 000 000	5.37	8.58
Tethys	1684	Cassini	163 000	295 000 000	5.21	8.47

(i) Derive an expression for the gradient and the y-intercept of a graph of log (T / s) (y-axis) against log (r / m) (x-axis).

gradient = ...

y-intercept = ...

[3]

(ii) On Fig. 5.1 plot a graph of log (T/s) against log (r/m) on the grid and use it to determine a value for n.

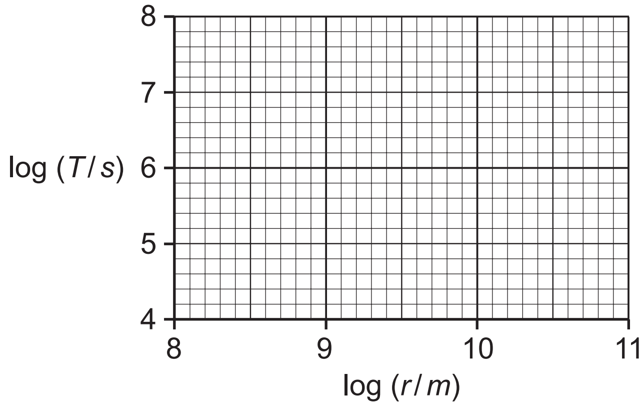

Fig. 5.1

n = ... [3]

(b) Theory suggests that k is equal to $\frac{2\pi}{\sqrt{GM}}$ where M is the mass of the planet around which the moons orbit and G is the gravitational constant.

When the graph in **(a)(ii)** is plotted on axes that start at (0, 0), the y-intercept is found to have a value of –7.49.

Calculate the mass of Saturn.

mass of Saturn .... kg [2]

[Total: 8]

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

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]

(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]

7 (a) Different terms may be applied to the magnetic field in a coil.

State the meanings of the three terms *magnetic flux density*, *magnetic flux* and *magnetic flux linkage*.

magnetic flux density ....

....

magnetic flux ....

....

magnetic flux linkage ....

....
[3]

(b) The magnetic flux density B in a long coil is given by the equation

$$B = \frac{\mu_0 N I}{l}$$

where μ_0 is a constant with the value $1.26 \times 10^{-6}\,\mathrm{Wb\,A^{-1}\,m^{-1}}$, N is the number of turns in the coil, l is the length of the coil and I is the current.

Determine the current required in a 2000 turn coil of length 0.22 m to produce a magnetic flux density of 1.2 T within the coil.

current = ... A [2]

(c) Fig. 7.1 shows a patient entering a magnetic resonance imaging (MRI) scanner.

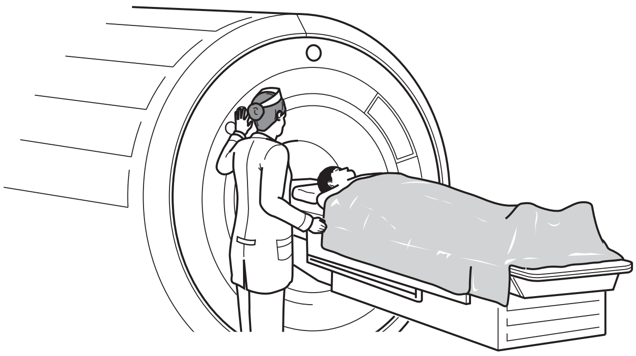

Fig. 7.1

The magnetic field in **(b)** has the magnitude required for an MRI scanner.

(i) Suggest why the coil in **(b)** would be impracticable for the current required by an MRI scanner.

....

.... [1]

(ii) Suggest two ways in which this problem could be avoided.

1. ....

....

....

2. ....

....

.... [2]

[Total: 8]

8 Experimental measurements of the gravitational constant G in different years are shown in the table.

Year	G / $m^3 kg^{-1} s^{-2}$
2000	$(6.674215 \pm 0.00009) \times 10^{-11}$
2007	$(6.67234 \pm 0.00014) \times 10^{-11}$
2009	$(6.67349 \pm 0.00017) \times 10^{-11}$

(a) State the year in which the measurement of G appears to be the most precise. Explain your answer.

....

.... [1]

(b) The value of G was determined in 2010 at the University of Zurich. The value was consistent with the value obtained in the 2007 experiment, but was not consistent with the values from 2000 or 2009. The experimenter who obtained the value for G in 2010 thinks that there is probably a systematic error in each of the other two experiments.

(i) Explain what is meant by a *systematic error*.

....

.... [1]

(ii) Explain why the most precise result may not be the most accurate.

....

....

.... [2]

(iii) Suggest two reasons why it is a good idea to determine the value of a fundamental constant by more than one method.

....

.... [2]

(iv) Suggest two reasons why it is difficult to make an accurate measurement of the universal gravitational constant *G*.

1. ....

....

2. ....

.... [2]

[Total: 8]

9 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. 9.1.

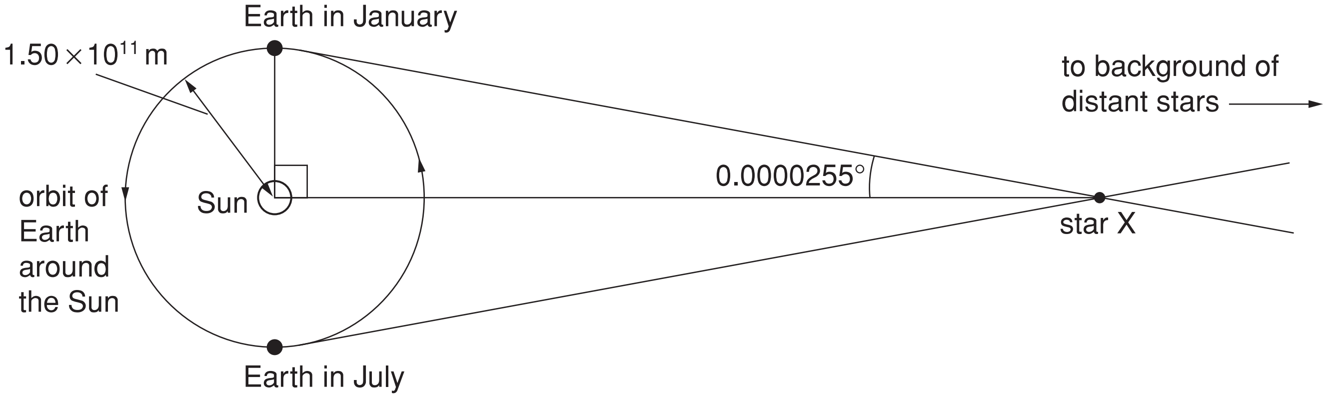

Fig. 9.1 (not to scale)

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. 9.1.

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

distance = ... m [2]

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

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

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

[Total: 5]

End of Section 1

Section 2

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

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 $^{199}_{79}Au$.

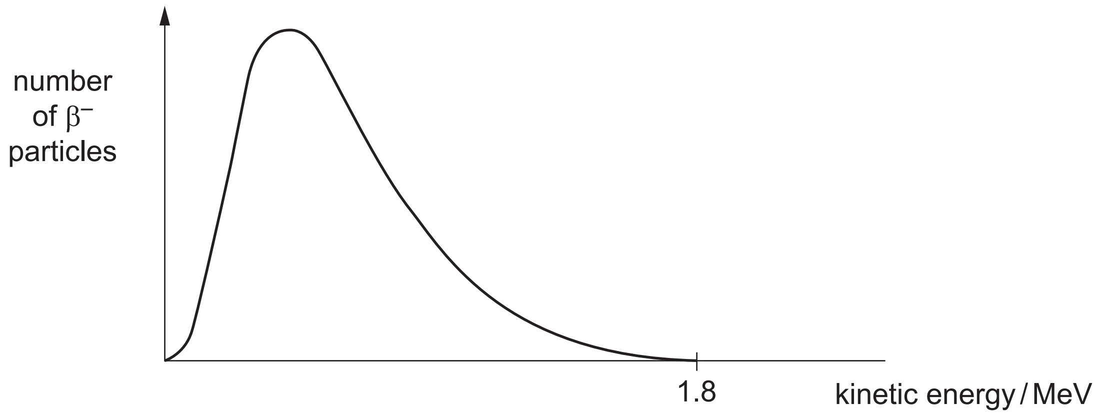

Fig. 10.1

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,

....

....

....

....

.... [3]

(ii) the proton number of the antineutrino.

....

.... [1]

(d) Different thicknesses x of a metal 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.

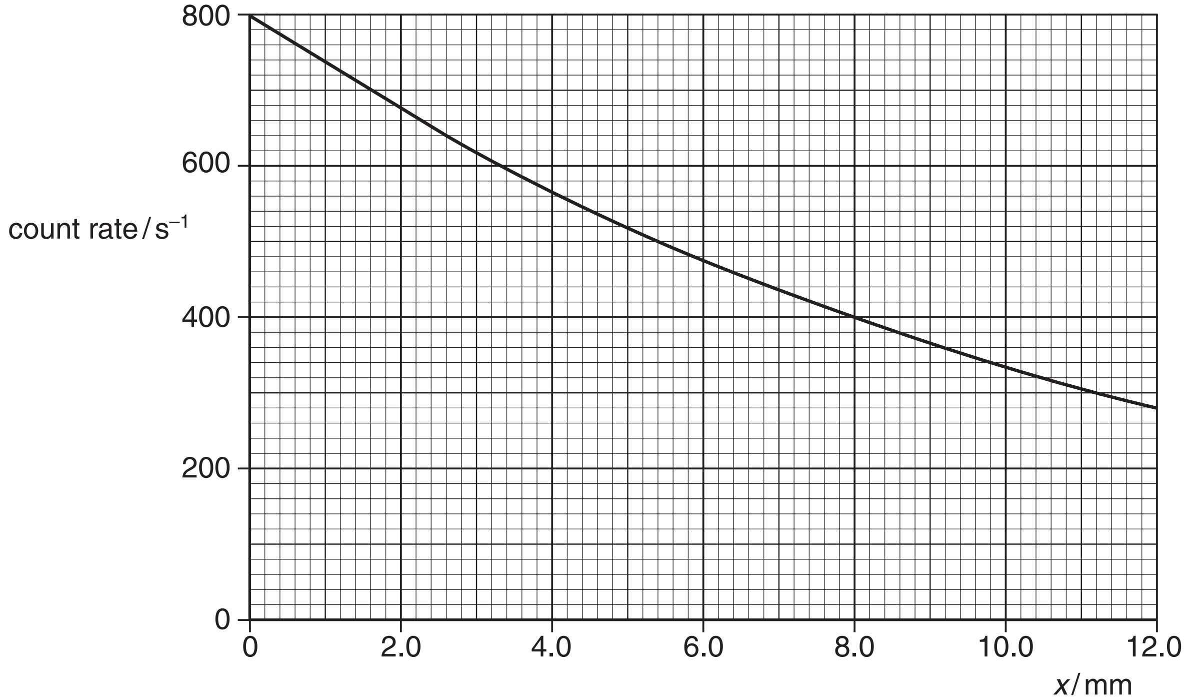

Fig. 10.2

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]

(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 of hydrogen is given by the relationship

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

Use this relationship to calculate the ionisation energy.

ionisation energy = ... J [3]

[Total: 20]

11 (a) An object moving in a circular path of radius r experiences an acceleration a even when travelling at constant speed v.

(i) Explain how it is possible for the object to accelerate and yet at the same time have constant speed.

....

....

....

....

.... [3]

(ii) State an expression for this acceleration.

....

.... [1]

(b) Fig. 11.1 shows the forces acting on a child who is riding backwards and forwards on a swing that follows a circular arc of radius r.

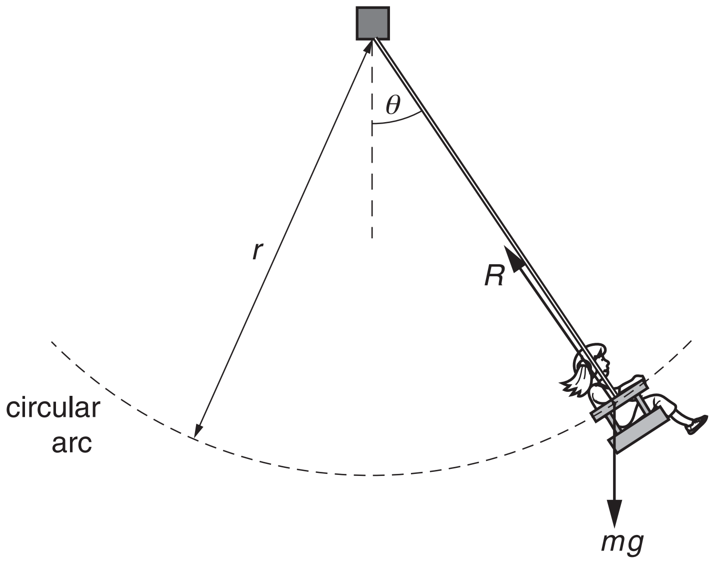

Fig. 11.1 (not to scale)

The child's weight is mg. R is the force of the seat on the child. As the instantaneous speed v of the child changes, R also varies.

As the child swings through the lowest point on the circular arc, $\theta = 0°$, her instantaneous speed is $4.7\,\text{m}\,\text{s}^{-1}$. The child weighs 200 N and the radius r is 2.8 m.

Calculate the value of R at this instant.

R = ... N [2]

(c) Fig. 11.2 shows a roundabout.

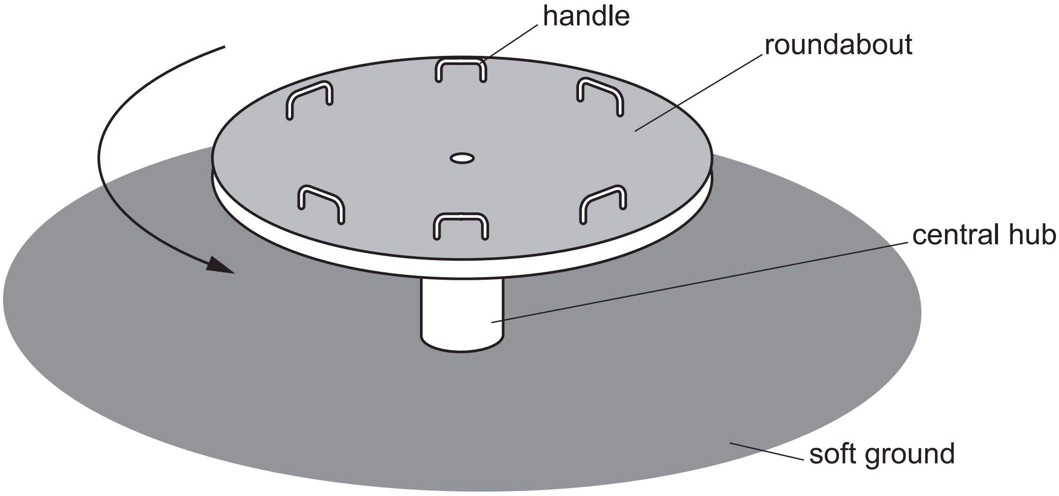

Fig. 11.2

The roundabout consists of a solid disc of mass *M* supported on a central hub.

(i) Use integration to derive an expression for the moment of inertia I of a thin uniform disc of radius *R* about its centre. You may annotate the diagram of the disc in Fig. 11.3 to define the terms you use.

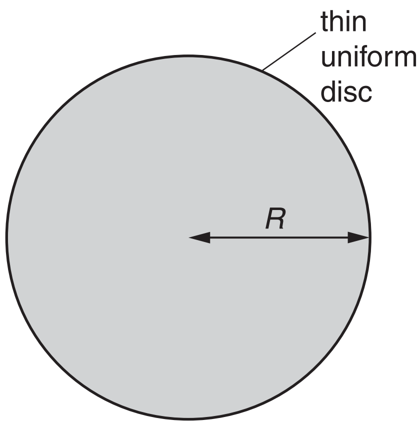

Fig. 11.3

[4]

(ii) The moment of inertia of the roundabout in Fig. 11.2 is 44.8 $kg\,m^2$. A torque of 10.1 N m is applied.

Show that the time taken to accelerate the disc from rest to 1.40 $rad\,s^{-1}$ is approximately 6 s.

[2]

(iii) Two teenagers of equal mass sit directly opposite each other on the roundabout. The moment of inertia of the roundabout and the teenagers is now 118 $kg\,m^2$.

Calculate how much longer than the time determined in **(c)(ii)** it will now take to accelerate from rest to 1.40 $rad\,s^{-1}$. Assume the same torque is applied as in **(c)(ii)**.

time increase = ... s [2]

(iv) The roundabout continues to rotate at 1.40 $rad\,s^{-1}$. The teenagers then lean outwards.

1 Explain why the period of rotation of the roundabout increases.

....

....

....

....

....

.... [3]

2 The period of rotation increases by 0.66 s.

Calculate the new moment of inertia.

new moment of inertia = ... $kg\,m^2$ [3]

[Total: 20]

12 Space rockets require thrust forces to change their motion in space. The thrust is exerted on the rocket by the fast moving exhaust gases that are ejected downwards.

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

....

....

.... [2]

(b) The mass of a rocket decreases as fuel is used up. The thrust F on a rocket of instantaneous mass m is given by the expression

$$F = V\,\frac{\mathrm{d}m}{\mathrm{d}t}$$

where V is the steady velocity of the exhaust gases, relative to the rocket.

The thrust on the rocket is 34.7 MN. The gas exhaust velocity is $2.6 \times 10^{3}\,\mathrm{m\,s^{-1}}$.

Calculate the rate of change of mass of the rocket.

rate of change of mass = ... $\mathrm{kg\,s^{-1}}$ [2]

(c) The rocket fires its engine and its mass decreases from its initial mass m_o to a mass m. The change in velocity Δv_r of the rocket depends upon the exhaust velocity V of the gases, m_o and m.

The ideal rocket equation gives the relationship:

$$\Delta v_r = V \ln\left(\frac{m_o}{m}\right)$$

(i) Show that the ratio $\left(\frac{m}{m_o}\right)$ is equal to $e^{\frac{-\Delta v_r}{V}}$.

[1]

(ii) Use the relationship in **(c)(i)** to complete the table below.

In this case V is $8.0 \times 10^3\,\mathrm{m\,s^{-1}}$.

$\Delta v_r / 10^3\,\mathrm{m\,s^{-1}}$	$\left(\frac{m}{m_o}\right)$
1.0	
2.0	0.78
3.0	0.69
5.0	0.54
6.0	0.47
	0.38
10.0	0.29
12.0	0.22

[2]

(iii) Fig. 12.1 is a graph of the mass ratio $\left(\frac{m}{m_o}\right)$ against the change in velocity Δv_r for a gas exhaust velocity V of $2.6 \times 10^3\,\mathrm{m\,s^{-1}}$.

On Fig. 12.1, draw a second graph plotting all the data from the table in **(c)(ii)**.

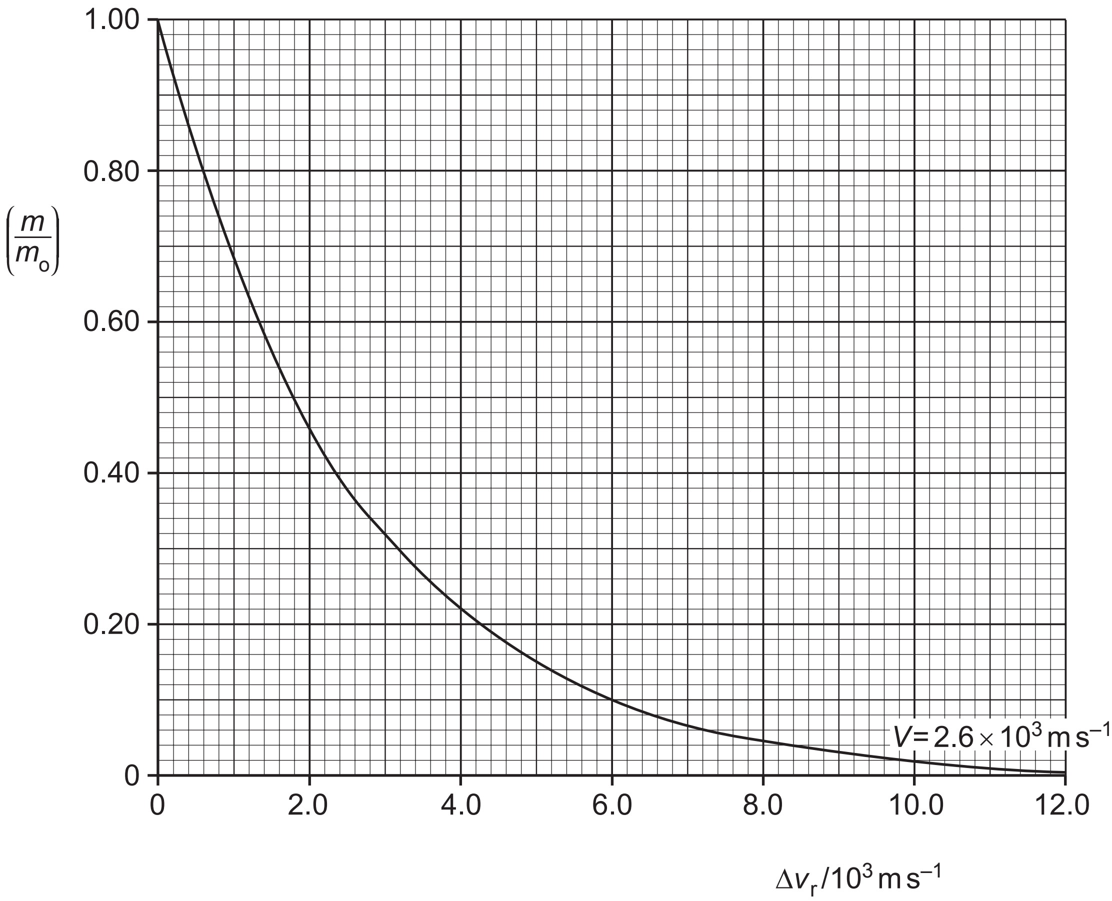

Fig. 12.1

[3]

(iv) The initial mass m_o of the rocket, including the fuel, is 2.04×10^6 kg.
The first burn of fuel gives $\Delta v_r = 5.0 \times 10^3\,\text{m}\,\text{s}^{-1}$.

Use the information from the graph in **(c)(iii)** to calculate the difference in the mass of fuel used to accelerate the rocket by the same change in velocity Δv_r if its gas exhaust velocity V is $8.0 \times 10^3\,\text{m}\,\text{s}^{-1}$ rather than $2.6 \times 10^3\,\text{m}\,\text{s}^{-1}$.

difference in mass = ... kg [3]

(d) A rocket launches a satellite, which orbits at a height h above the Earth's surface as shown in Fig. 12.2.

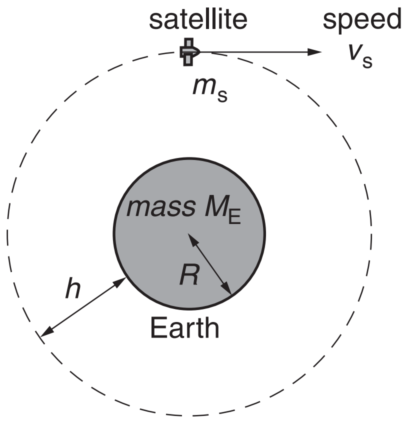

Fig. 12.2 (not to scale)

The satellite of mass m_s has speed v_s. The mass of the Earth is M_E and its radius is R.

(i) State the relationship for the gravitational potential energy E of the satellite in terms of relevant quantities given in Fig. 12.2.

[1]

(ii) Explain what is meant by the term *gravitational potential energy* of a mass such as a satellite.

....

....

.... [2]

(iii) Use the information given below to determine the height h of the satellite above the Earth's surface.

total energy of satellite	E_T	=	-4.5×10^9 J
mass of satellite	m_s	=	152 kg
speed of satellite	v_s	=	7.70×10^3 m s^{-1}
mass of the Earth	M_E	=	5.98×10^{24} kg
radius of Earth	R	=	6.36×10^6 m
gravitational constant	G	=	6.67×10^{-11} N m^2 kg^{-2}

height above Earth = ... m [4]

[Total: 20]

13 **(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) **(i)** One consequence of the special theory of relativity is length contraction.

Explain what is meant by *length contraction*.

....

....

.... [1]

(ii) Calculate the length of a 1.0 m rule moving at half the speed of light, relative to a stationary observer.

length = ... m [2]

(d) In 1960, Filipas and Fox tested the special theory of relativity. They measured the speed of γ-rays emitted when a sub-atomic particle, called a neutral pion, randomly decays into a pair of identical γ-rays only. In the experiment, the pions were moving through the laboratory at about 0.20 c. The rays are emitted in opposite directions as shown in Fig. 13.1

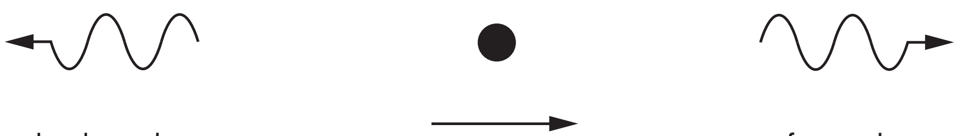

Fig. 13.1

(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]

(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 $300\,\text{m}\,\text{s}^{-1}$ 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 **(e)(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 = ... ns

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]

(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]

14 Albert Einstein and Niels Bohr made many contributions to the early development of quantum theory. Einstein's explanation of the photoelectric effect in terms of photon theory and Bohr's explanation of atomic spectra in terms of quantised energy levels are just two important examples. However, these two great physicists argued about the interpretation of quantum theory.

One of Einstein's arguments was that quantum theory could not be a complete description of physical reality because it did not allow particles, such as electrons, to have well defined properties of *both* position *and* momentum at any moment.

Bohr, on the other hand, thought that quantum theory contains all that can be known about reality, a view he developed in the Copenhagen Interpretation of quantum theory.

(a) Explain how Einstein's photon model of light differs from the classical description of light as an electromagnetic wave in the way it explains

(i) light intensity,

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....

.... [2]

(ii) the absorption of light energy by a metal surface.

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.... [2]

(b) Explain how the quantum model of the atom (Bohr's model) differed from the pre-quantum nuclear model (Rutherford's model) in the way electrons orbit the nucleus.

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.... [2]

(c) Explain, using a diagram, how Bohr's quantised atom and Einstein's photon theory can be used to explain why atoms of a cold gas absorb characteristic frequencies of electromagnetic radiation.

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.... [3]

(d) The Heisenberg Uncertainty principle (HUP) for position and momentum can be written in the form

$$\Delta p \Delta x \geqslant \frac{h}{2\pi},$$

where Δp is the uncertainty in momentum, Δx is the uncertainty in the position of a particle and h is the Planck constant.

(i) Use the uncertainty principle to explain Einstein's belief that quantum theory gives an **incomplete** description of the electron compared to the description given by Newtonian mechanics.

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.... [3]

(ii) Calculate the uncertainty in momentum when an electron of mass 9.11×10^{-31} kg travelling at 3.00×10^{7} m s^{-1} passes through a narrow slit of width 1.00×10^{-10} m (comparable to the spacing of atoms in a crystal).

uncertainty in momentum = ... kg m^{-2} [2]

(iii) Compare this uncertainty in momentum to the original momentum of the electron and state its significance.

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.... [2]

(e) The diagrams in Fig. 14.1 show what happens to two successive photons from a laser as they pass through a narrow slit and strike a light-sensitive screen.

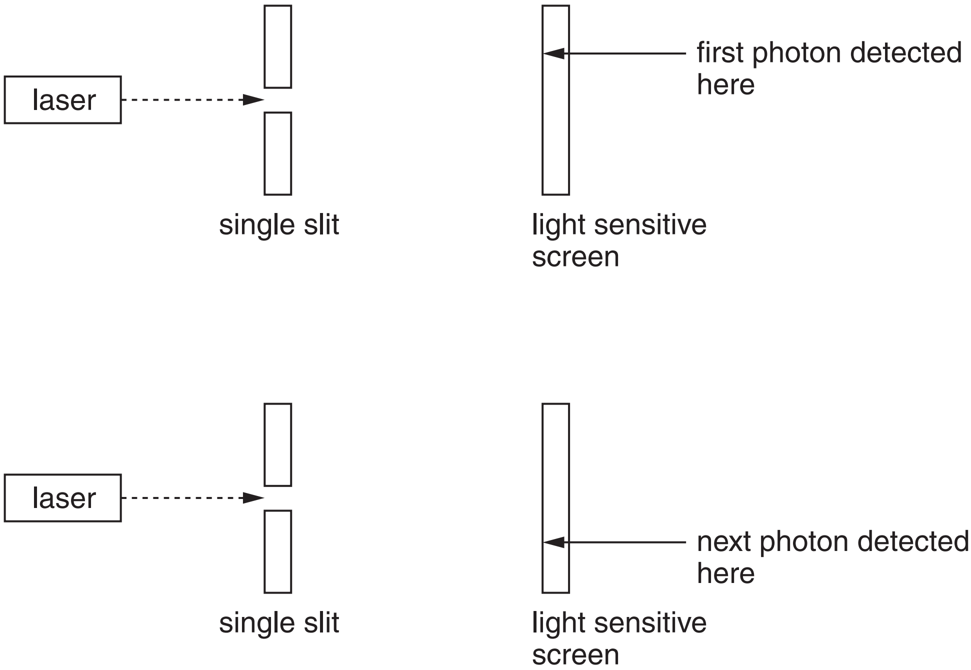

Fig. 14.1

Use the Copenhagen Interpretation of quantum theory to explain how two identical photons approaching the slit in the same way can end up striking the screen in two very different places.

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.... [4]

[Total: 20]

15 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}.

Fig. 15.1 represents the processes in a domestic refrigerator.

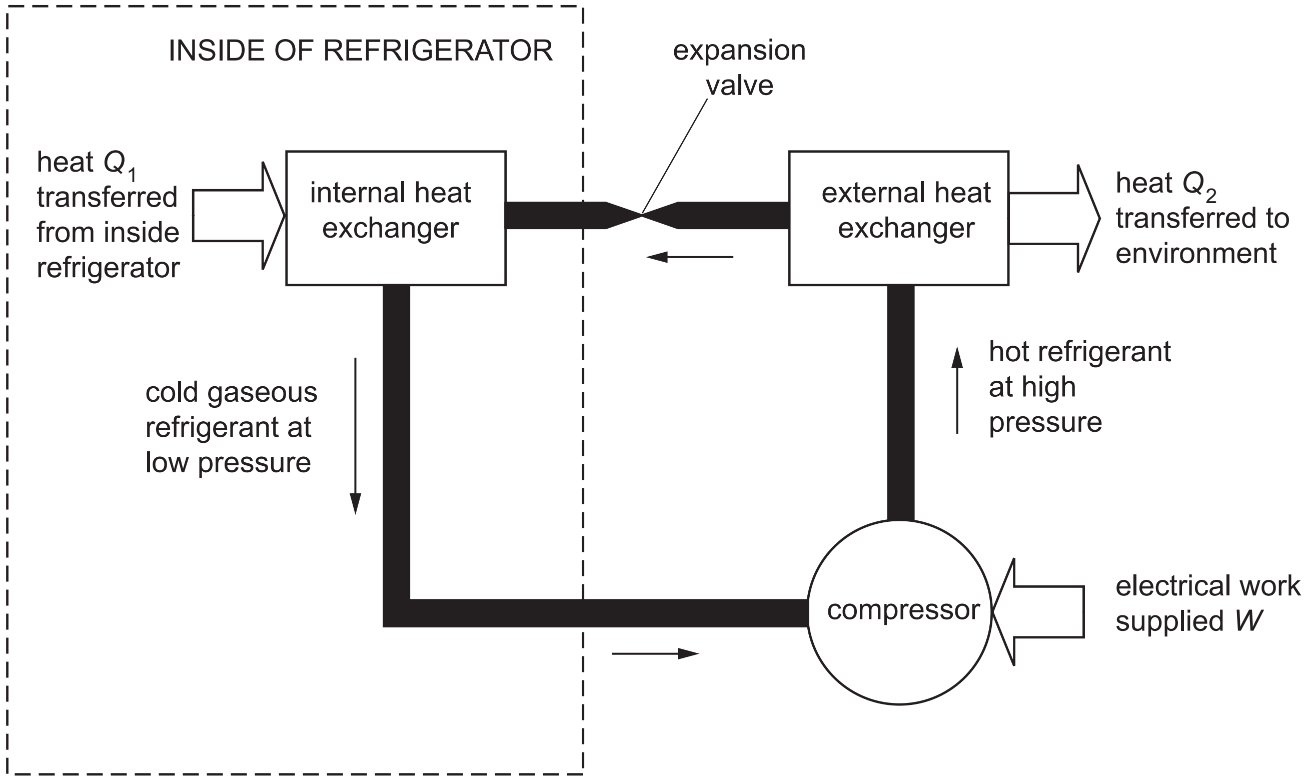

Fig. 15.1

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.

(a) Use the first 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 in Fig. 15.1.

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.

....

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.... [2]

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

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.... [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]

(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.

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.... [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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.... [3]

[Total: 20]

End of Section 2

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