Cambridge Pre-U

Cambridge International Examinations
Cambridge Pre-U Certificate

CANDIDATE NAME

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5244769891

PHYSICS (PRINCIPAL) **9792/03**

Paper 3 Part B Written Paper **May/June 2015**

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 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.

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 **38** printed pages and **2** blank pages.

DC (NH/CGW) 97090/4

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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	$\lambda = \dfrac{ax}{D}$	
Rayleigh criterion	$\theta \approx \dfrac{\lambda}{b}$	
photon energy	$E = hf$	
de Broglie wavelength	$\lambda = \dfrac{h}{p}$	
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	$F = \dfrac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$	
electrostatic potential energy	$W = \dfrac{Q_1Q_2}{4\pi\varepsilon_0 r}$	
gravitational force	$F = -\dfrac{Gm_1m_2}{r^2}$	
gravitational potential energy	$E = -\dfrac{Gm_1m_2}{r}$	
magnetic force	$F = BIl\sin\theta$	
	$F = BQv\sin\theta$	

electromagnetic induction	$E = -\dfrac{d(N\Phi)}{dt}$
Hall effect	$V = Bvd$
time dilation	$t' = \dfrac{t}{\sqrt{1-\dfrac{v^2}{c^2}}}$
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	$\dfrac{dN}{dt} = -\lambda N$
	$N = N_0 e^{-\lambda t}$
	$t_{\frac{1}{2}} = \dfrac{\ln 2}{\lambda}$
attenuation losses	$I = I_0 e^{-\mu x}$
mass-energy equivalence	$\Delta E = c^2\Delta m$
hydrogen energy levels	$E_n = \dfrac{-13.6\,\text{eV}}{n^2}$
Heisenberg uncertainty principle	$\Delta p\Delta x \geqslant \dfrac{h}{2\pi}$
	$\Delta E\Delta t \geqslant \dfrac{h}{2\pi}$
Wien's displacement law	$\lambda_{max} \propto \dfrac{1}{T}$
Stefan's law	$L = 4\pi\sigma r^2 T^4$
electromagnetic radiation from a moving source	$\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{\Delta f}{f} \approx \dfrac{v}{c}$

Section A

You are advised to spend about 1 hour 30 minutes answering the questions in this section.

1 (a) A body travels with constant speed v in a circle of radius r. The body moves from A to B in time δt and moves through an angle $\delta\theta$, as shown in Fig. 1.1.

Making use of a vector triangle, show that the acceleration a of the body is given by the equation

$$a = \frac{v^2}{r}.$$

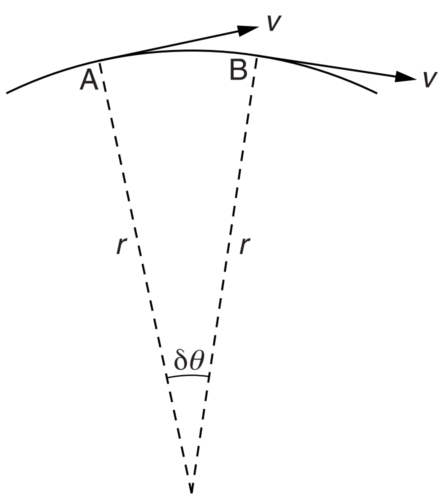

Fig. 1.1

[3]

(b) The Moon orbits the Earth in a circle of radius 3.84×10^8 m. The time it takes to complete one orbit is 27.3 days.

(i) Calculate the angular velocity of the Moon.

angular velocity = ... rad s^{-1} [2]

(ii) Calculate the acceleration of the Moon.

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

(c) Tides on the Earth have an effect on the speed of the Moon. The speed of the Moon is currently $1023\,m\,s^{-1}$. On average, the Moon loses 3.75×10^{12} J of kinetic energy every second as a result of this effect.

The mass of the Moon is 7.35×10^{22} kg.

(i) Calculate,

1. the kinetic energy of the Moon at present,

kinetic energy = ... J [2]

2. the kinetic energy of the Moon in a million years' time.

kinetic energy = ... J [2]

(ii) State and explain what will happen to the radius of the orbit of the Moon as a result of this loss of kinetic energy.

....

....

....

....

....

....

....[3]

[Total: 14]

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2 **(a)** State the conditions necessary for a body to undergo simple harmonic motion.

....

....

....[2]

(b) The cone of a loudspeaker moves with simple harmonic motion.

Give one other practical example of simple harmonic motion.

....

....[1]

(c) Fig. 2.1 shows how the displacement of a point on the cone of the loudspeaker in **(b)** varies with time. On Fig. 2.1, draw the corresponding graphs for the variation in velocity and acceleration, with time.

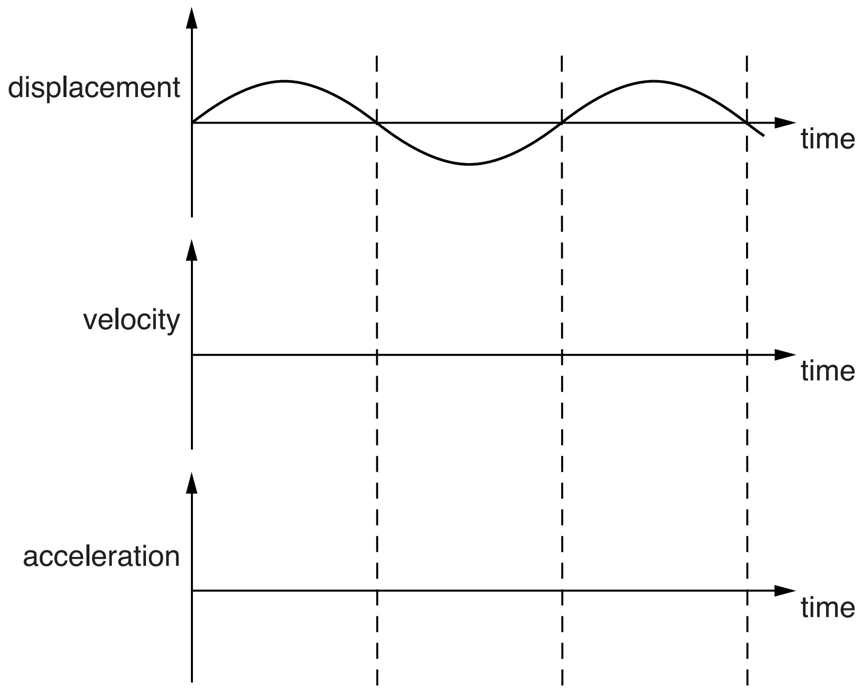


Fig. 2.1

[3]

(d) A loudspeaker produces sound of frequency 879 Hz.

(i) Calculate the angular frequency ω of the cone of the loudspeaker. Express your answer to an appropriate number of significant figures and give the unit.

angular frequency = ... unit ....[3]

(ii) The effective mass of the cone is 8.6 g and the mean amplitude of the vibration is 1.2 mm. Calculate the energy in one oscillation of the cone.

energy = ... J [2]

(iii) Assuming that 6% of the energy in one cycle is emitted in a sound wave and is replaced by energy from the amplifier, calculate the power output of the cone.

power output = ... W [2]

[Total: 13]

3 **(a)** A capacitor is made from two sheets of aluminium with an insulator between them. The separation between the plates is 2.6×10^{-4} m and the potential difference between the plates is 84 V.

Calculate the electric field between the plates.

electric field = ... NC^{-1} [2]

(b) Fig. 3.1 shows several capacitors connected to a battery in a circuit.

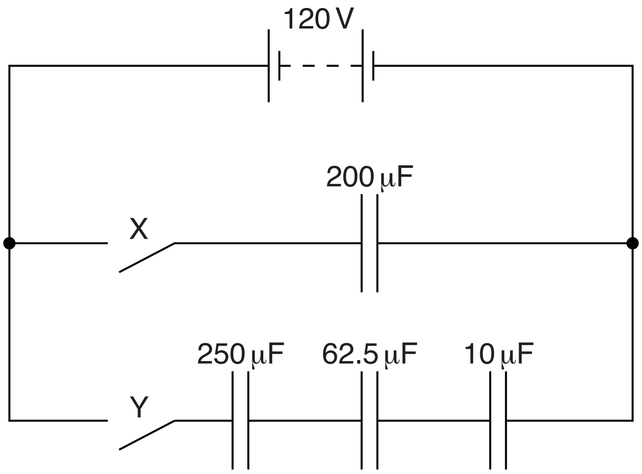


Fig. 3.1

(i) Switch X is closed and the 200 μF capacitor is fully charged.

Calculate,

1. the charge on the 200 μF capacitor,

charge = ... μC [1]

2. the energy supplied by the battery,

energy = ... J [1]

3. the energy stored in the 200 μF capacitor.

energy = ... J [1]

(ii) Explain how your answers to **(i) 2** and **(i) 3** are consistent with the conservation of energy.

....

....[1]

(iii) Switch Y is then closed and the other capacitors are fully charged.

Complete the table to show the charge, the potential difference and the energy stored by each of the three capacitors.

	capacitor		
	250 μF	62.5 μF	10.0 μF
charge / μC	1000		
p.d. / V		16.0	
energy / μJ	2000		

[1]
[2]
[2]

[Total: 11]

4 **(a)** Fig. 4.1 shows a thin slice of semiconductor material of width d and thickness t. The charge carriers are electrons in the material.

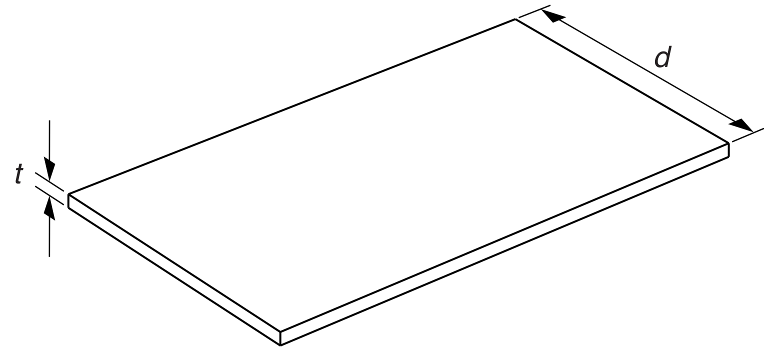


Fig. 4.1

The slice of semiconductor material is placed in a uniform magnetic field with a current in the slice so that a Hall voltage is produced between two opposite sides of the slice.

(i) On Fig. 4.1, indicate possible directions of the current and the magnetic field together with the polarity of the two sides across which the Hall voltage is produced. [3]

(ii) Explain how this Hall voltage is produced.

....

....

....

....[2]

(b) Fig. 4.2 shows a thin slice of semiconductor material in which there is a current.

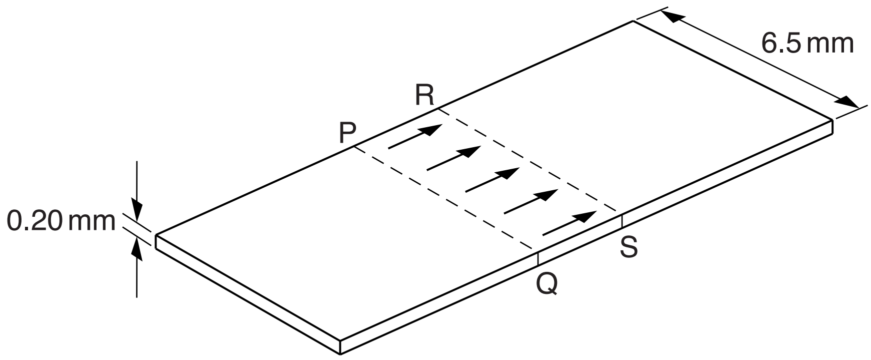


Fig. 4.2 (not to scale)

The charge carriers are electrons. This slice has width 6.5 mm and thickness 0.20 mm as shown. The current in the slice is 5.2 mA and, on average, electrons along the line PQ reach RS one second later. In the semiconductor the concentration of electrons free to move is $4.3 \times 10^{21}\,m^{-3}$.

(i) Calculate the number of electrons passing any point in the conductor in one second.

number of electrons in one second = ... [1]

(ii) Calculate the volume this number of moving electrons occupy in the semiconductor material.

volume = ... m^3 [1]

(iii) Calculate the mean speed of the electrons.

mean speed of electrons = ... $m\,s^{-1}$ [2]

[Total: 9]

5 **(a)** **(i)** The particle model of a gas of volume V at pressure p gives rise to the equation $pV = \frac{1}{3}Nm<c^2>$.

State the meaning of the following symbols in this equation.

N ....

m ....

$<c^2>$ ....[3]

(ii) **1.** Calculate the mean kinetic energy of a molecule of a gas at a temperature of 100 °C, using the equation mean kinetic energy = $\frac{3}{2}kT$.

mean kinetic energy = ... J [1]

2. Calculate, for oxygen and hydrogen at the same temperature, the ratio

$$\frac{\text{root mean square speed of a hydrogen molecule}}{\text{root mean square speed of an oxygen molecule}}.$$

mass of a hydrogen molecule = 3.34×10^{-27} kg
mass of an oxygen molecule = 5.31×10^{-26} kg

ratio = ...[3]

3. There is a considerable amount of oxygen in the Earth's atmosphere. Use your answer to **(a)(ii)2** to suggest why the Earth's atmosphere contains very little hydrogen.

....

....

....

....[2]

(b) Fig. 5.1 represents the proportion of molecules at different speeds in a fixed mass of nitrogen gas at temperatures of 300 K and 500 K.

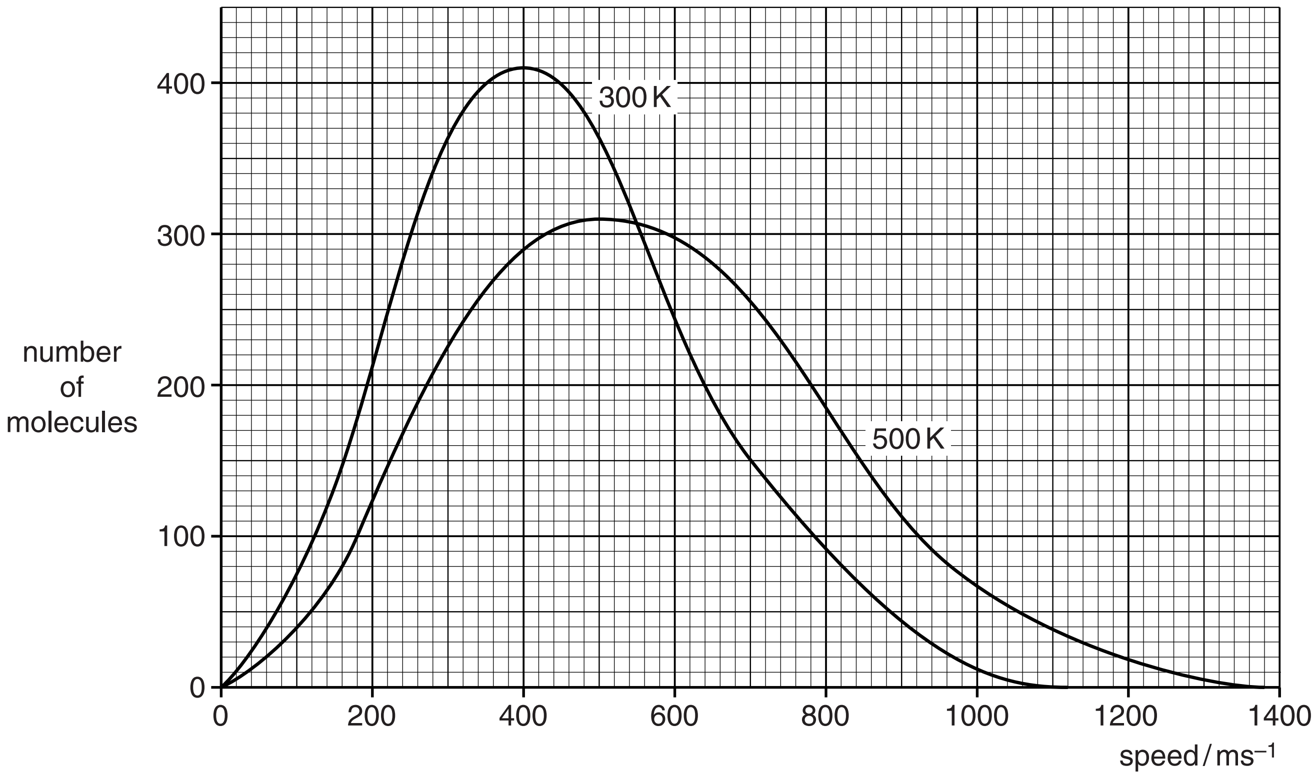


Fig. 5.1

(i) Calculate the ratio

$$\frac{\text{number of nitrogen molecules travelling at } 800\,\text{m s}^{-1} \text{ at } 500\,\text{K}}{\text{number of nitrogen molecules travelling at } 800\,\text{m s}^{-1} \text{ at } 300\,\text{K}}.$$

ratio = ...[1]

(ii) Explain why

1. the area beneath both graphs must be the same,

....

....

....[2]

2. the graph for 300 K has a higher maximum value than the graph for 500 K.

....

....[1]

[Total: 13]

6 **(a)** **(i)** Explain what is meant by the random nature of radioactivity.

....

....[1]

(ii) Show that the nature of radioactivity leads to the differential equation

$$\frac{dN}{dt} = -\lambda N,$$

where N is the number of radioactive nuclei and λ is a constant for the material undergoing decay.

[1]

(iii) Use the solution to this differential equation to determine the relationship between λ and the half-life $t_{\frac{1}{2}}$.

[3]

(b) **(i)** When a neutron collides with a nitrogen-14 nucleus, it can cause a radioactive carbon-14 nucleus to be formed. The proton numbers of nitrogen and carbon are 7 and 6 respectively.

Write an equation for this nuclear reaction.

[2]

(ii) Living things maintain a constant ratio of carbon-14 nuclei to carbon-12 nuclei by exchanging carbon with the environment. After death, the carbon-14 nuclei are not replaced. This is the basis for carbon dating of any archaeological specimen that was originally living. The fraction of carbon-14 nuclei to carbon-12 nuclei in living organisms is 1.0 to 1.3×10^{12}.

In one specimen it was found that the fraction of carbon-14 nuclei to carbon-12 nuclei was only 1.0 to 1.52×10^{12}.

The half-life of carbon-14 is 5730 years.

Calculate the length of time since this specimen was alive.

time = ... years [4]

(iii) Suggest a reason why a large uncertainty might be expected with carbon dating.

....

....[1]

[Total: 12]

7 The energy levels E_n in a hydrogen atom are given by the empirical equation

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

where n is an integer.

The four visible spectral lines P, Q, R and S in the hydrogen spectrum are illustrated in Fig. 7.1.

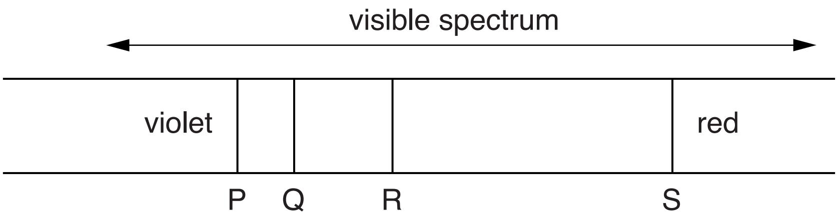


Fig. 7.1

The frequencies of three of these spectral lines are shown in the table.

spectral line	frequency / 10^{12} Hz
P	731
Q	f_Q
R	617
S	456

These frequencies are emitted when the energy level to which the electrons arrive is for $n = 2$.

(a) **(i)** Deduce the value of n for the energy level from which an electron has moved in order to produce spectral line S.

n = ... [3]

(ii) Determine the frequency of the spectral line Q.

frequency of line Q = ... $\times 10^{12}$ Hz [3]

(b) Light emitted from a distant star shows spectral line R shifted to a different frequency when measured on Earth. Its frequency has become 593×10^{12} Hz.
Calculate the speed of recession of the star.

speed of recession = ... $m\,s^{-1}$ [2]

[Total: 8]

Section B

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

8 Gravimeters are very sensitive instruments used to investigate the variation in gravitational field strength g close to the surface of the Earth.

(a) (i) State what is meant by the term *gravitational field strength*.

....

....[1]

(ii) Show that the gravitational field strength g_R, at a distance R, from the centre of the Earth is given by

$$g_R = -\frac{GM_E}{R^2},$$

where M_E is the mass of the Earth. R is greater than the radius R_E of the Earth. [3]

(iii) State the mathematical relationship between g_R and R^2.

....[1]

(iv) Fig. 8.1 is a graph of g_R against R.

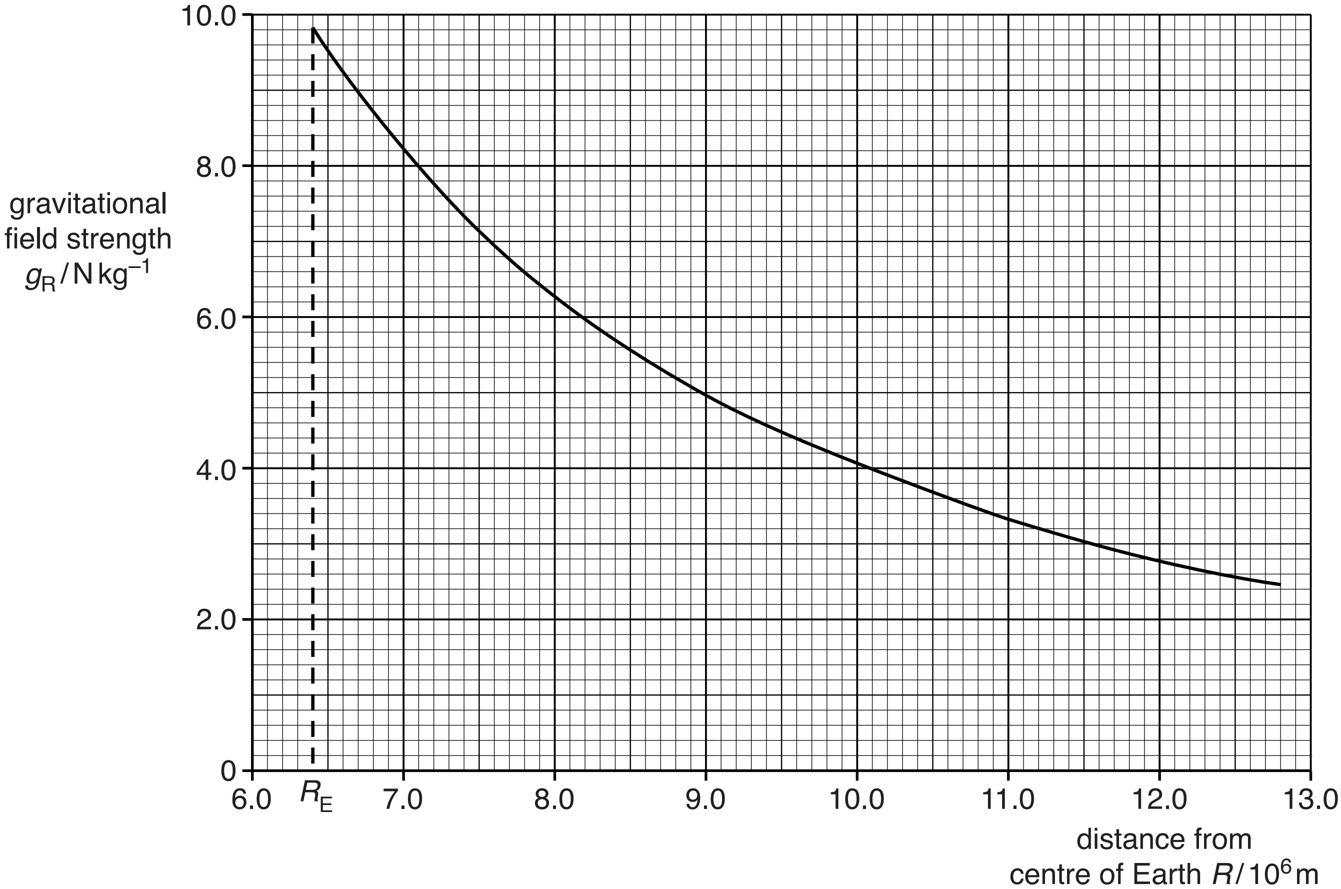


Fig. 8.1

Use data from the graph in Fig. 8.1 and the relationship in **(a)(ii)** to determine an average value for M_E, the mass of the Earth. Use two points on the graph and show your working.

mass of the Earth = ... kg [4]

(b) Gravimeters can detect localised reductions in gravitational field strength due to the presence of low density pockets of oil beneath the surface of the Earth.

Fig. 8.2 shows a spherical pocket of oil in the rock of the Earth's crust.

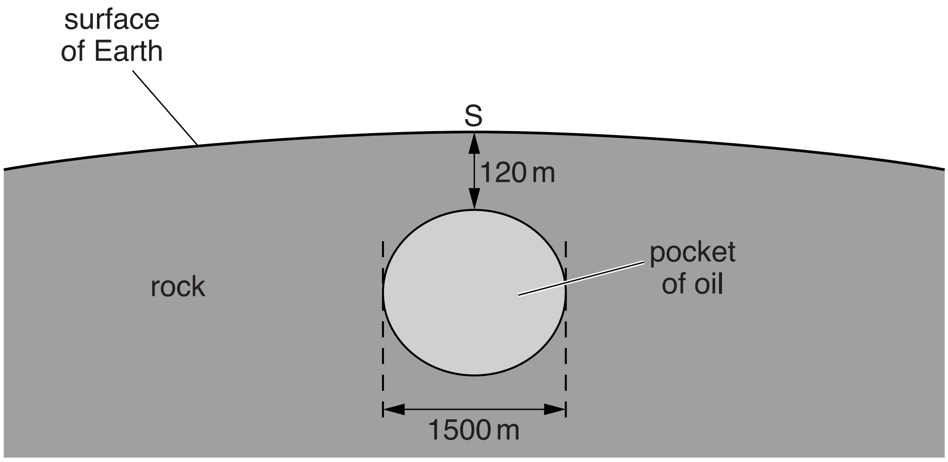


Fig. 8.2 (not to scale)

The pocket of oil has a diameter of 1500 m and the oil has a density of 830 kg m^{-3}.
The density of the surrounding rock is 2500 kg m^{-3}.

(i) Calculate the difference in mass between the pocket of oil and an equivalent volume of surrounding rock.

difference in mass = ... kg [3]

(ii) The top of the pocket of oil is 120 m directly below the point S on the Earth's surface.

Determine the difference in the Earth's gravitational field strength at point S and at a point on the Earth's surface above solid rock.

difference in gravitational field strength = ... N kg^{-1} [3]

(c) One design of gravimeter measures the change in the period T of oscillation of a mass m of a simple pendulum of length l.
Fig. 8.3 shows a simple pendulum.

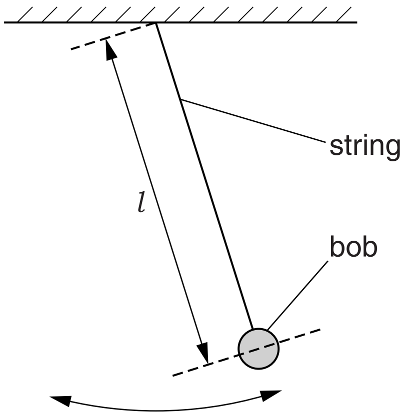


Fig. 8.3 (not to scale)

The period T is related to the length of the string by the equation

$$T = 2\pi\sqrt{\frac{l}{g}},$$

where g is the local value of the gravitational field strength.

(i) State the equation for g in terms of T and l.

[1]

(ii) By differentiating the equation given for T, determine how a fractional change, $\frac{\delta T}{T}$, in T, is related to a fractional change, $\frac{\delta g}{g}$, in g.

[3]

(iii) At a particular location, a pocket of oil produces a change in g, given by $\delta g = 0.000098\,\text{N kg}^{-1}$.

Calculate the change in period, δT, of a pendulum of period 2.0 s.

[1]

[Total: 20]

9 Fig. 9.1 shows a toy car on a track.

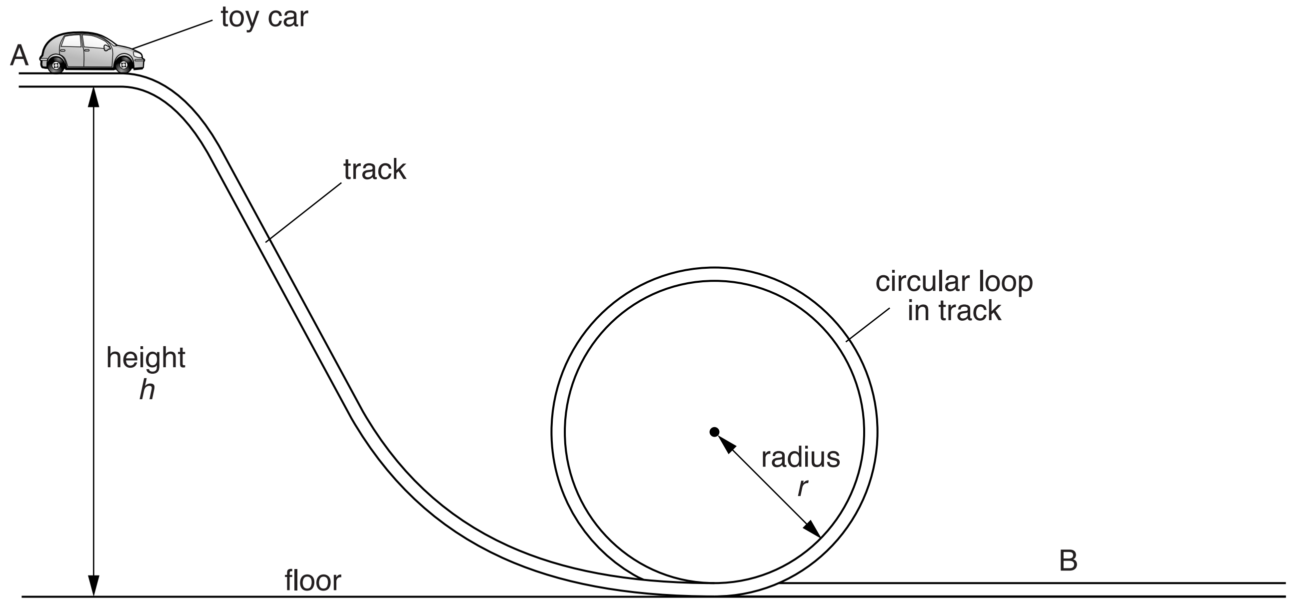
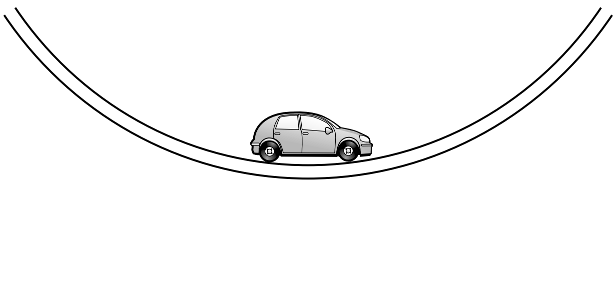


Fig. 9.1 (not to scale)

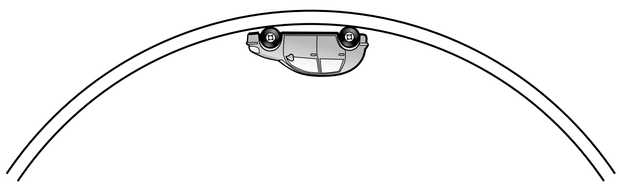
(a) The circular loop in the track has radius r. The car has mass m.

On Fig. 9.2a and Fig. 9.2b draw and label arrows to represent the relative magnitude **and** direction of the vertical forces acting on the car at the instant it passes

(i) the bottom of the loop,
(ii) the top of the loop.



bottom of the loop
Fig. 9.2a (not to scale)



top of the loop
Fig. 9.2b (not to scale)

[3]

(b) The toy car is released from rest from a point on the track height h above the floor. The radius of the circular loop of track is 15 cm. The car has speed v at the top of the circular loop.

(i) Calculate the minimum value of v that will enable the car to remain in contact with the track.

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

(ii) The height h of the track at end A is varied. There is a minimum height at which the toy car can complete the loop without losing contact with the track.

1. State the Principle of Conservation of Energy.

....

....

....[2]

2. Calculate the minimum height for the car to complete the loop without losing contact with the track. Ignore work done against friction.

minimum height = ... m [4]

(c) The car is replaced with a small ball of mass equal to that of the car. When released the ball rolls down the track without sliding. The minimum height for the ball to complete the loop, without losing contact with the track, is greater than the minimum height for the car.

Explain why the minimum height for the ball is greater.

....

....[2]

(d) **(i)** At B, the ball has a velocity of $1.7\,m\,s^{-1}$. The radius of the ball is 7.4 mm.

Calculate the angular velocity of the ball at B.

angular velocity = ... $rad\,s^{-1}$ [2]

(ii) The moment of inertia of the ball is $4.2 \times 10^{-6}\,kg\,m^2$.

Determine the rotational kinetic energy of the ball at B.

rotational kinetic energy = ... J [2]

(iii) A piece of paper sticks to the ball at B as it rolls along the track. The moment of inertia of the ball increases by $0.2 \times 10^{-6}\,kg\,m^2$.

Calculate the new angular velocity of the ball.

new angular velocity = ... $rad\,s^{-1}$ [2]

[Total: 20]

10 **(a)** Explain what is meant by the term *electric field.*

....

....[1]

(b) Fig. 10.1 shows part of a radial electric field.

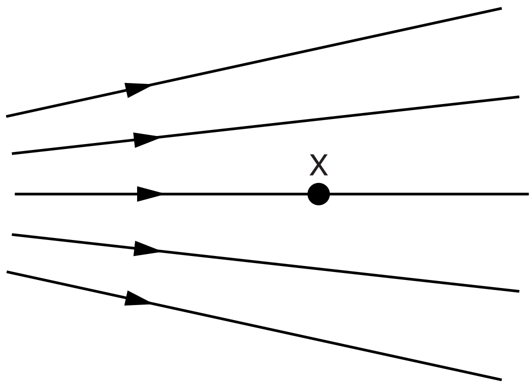


Fig. 10.1

(i) State and explain how the electric force on an electron placed at point X would compare with the electric force on a proton placed at point X.

....

....

....

....[3]

(ii) State and explain how the initial acceleration of an electron placed at point X would compare with the initial acceleration of a proton placed at point X.

....

....

....

....[3]

(c) Fig. 10.2 shows two protons placed at the points A and B of a right-angled isosceles triangle.

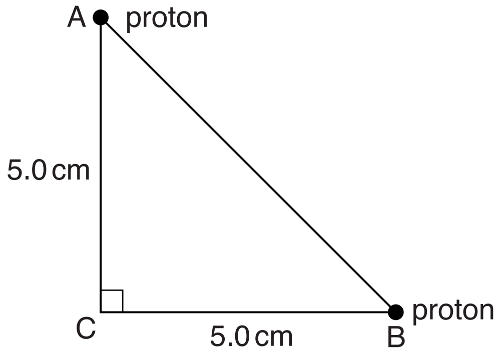


Fig. 10.2

Point C is 5.0 cm from both points A and B. Determine the electric field strength at point C on the triangle.

electric field strength = ... $N C^{-1}$ [4]

(d) Fig. 10.3 shows a point charge of $+Q_1$ and a nearby point charge of $+Q_2$. The two point charges are separated by a distance r.

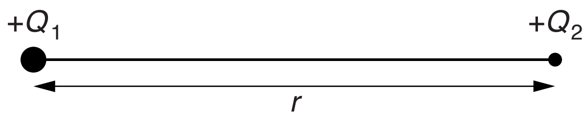


Fig. 10.3

(i) Use integration to derive the expression for the electric potential energy W of $+Q_2$ and explain the stages in your working.

You may wish to add details to Fig. 10.3 to help to clarify your working.

[4]

(ii) An alpha particle, ${}^{4}_{2}He$, is fired directly at a gold nucleus, ${}^{197}_{79}Au$, with an initial kinetic energy of 1.6×10^{-12} J, in a vacuum. The alpha particle is brought to rest close to the gold nucleus.

Assume that both particles are point charges.

Calculate the closest distance of approach of the alpha particle to the gold nucleus.

distance = ... m [3]

(iii) Determine the force of repulsion exerted on the alpha particle by the gold nucleus at the instant the alpha particle is brought to rest.

force = ... N [2]

[Total: 20]

11 In 2011, physicists claimed to have detected neutrinos travelling faster than the speed of light. The neutrinos travelled from CERN, in Switzerland, to the OPERA particle detector at the Gran Sasso laboratory in Italy.

The experiment that produced a result suggesting that neutrinos travel faster than the speed of light was repeated 15 000 times. It caused a sensation because this seemed to violate Einstein's theory of relativity. However, many physicists assumed that there must be a measurement error in the experiment. CERN called for other researchers to make independent checks of the result and four different experiments all showed that the neutrinos did not travel faster than the speed of light.

(a) State the postulates of Einstein's special theory of relativity.

....

....

....

....[2]

(b) Explain why a value of neutrino velocity v, greater than the speed of light c, would cause problems for the theory of relativity. Your answer should refer to Einstein's 'gamma-factor',

$$\gamma = \frac{1}{\sqrt{(1 - \frac{v^2}{c^2})}}.$$

....

....

....

....[2]

(c) **(i)** What is a neutrino?

....

....[1]

(ii) Explain how it is possible for neutrinos to travel from CERN to Gran Sasso through the crust of the Earth.

....

....

....

....[2]

(d) The neutrinos created at CERN were detected at Gran Sasso, 720 km away. The two key measurements which were made in order to calculate the speed of the neutrinos were:

- the distance between CERN and Gran Sasso,
- the time taken for the neutrinos to travel between the two laboratories.

(i) Explain how the distance measurement might be made and comment on how to achieve an accurate measurement.

....

....

....[2]

(ii) Explain how the time measurement might be made as accurately as possible.

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(e) In the experiment, neutrinos arrived at Gran Sasso 60 ns earlier than expected. The experimenters claimed an uncertainty in their time measurement of ± 8 ns and an uncertainty in their distance measurement of ± 20 cm.

(i) Show that the maximum uncertainty in the arrival time based on these measurement uncertainties is significantly less than 60 ns.

[3]

(ii) Explain why the measurement error in the original experiment must be a systematic error and not a random error.

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(f) The philosopher, Karl Popper suggested that the essential character of a scientific theory is that it is able to be tested by experiment. So, if it is incorrect, it can be shown to be so (it is in principle 'falsifiable'). The 'faster than light neutrinos' experiment shows how this works in practice.

Imagine that, at some time in the future, a research group claims to have shown that, in certain experiments, energy is not conserved. Describe the steps the scientific community should take to test this claim.

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[Total: 20]

12 Helium is unusual. It liquefies at –269 °C (4 K), but it cannot be solidified at ordinary pressures by lowering the temperature. It remains a liquid down to absolute zero (0 K) despite the fact that there is a small force of attraction between helium atoms when they are very close to one another.

(a) Describe an experiment that suggests that there is an absolute zero of temperature. Your explanation should include a labelled diagram of the apparatus used and an explanation of how the expected results lead to the idea of an absolute zero of temperature.

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(b) Use the kinetic theory to explain how the mean energy of a gas molecule changes with temperature as the temperature approaches absolute zero.

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(c) By referring to energy transfer and bonding, explain why we would expect a sample of liquid helium to solidify as it is cooled toward absolute zero.

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(d) The reason that helium does not solidify is related to the uncertainty principle.

(i) Explain why the uncertainty in an atom's position becomes smaller when a liquid solidifies.

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(ii) Show that the reduction in the uncertainty of its position leads to an increase in the uncertainty of its momentum, and hence in the uncertainty of its kinetic energy.

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(iii) Explain why, even as temperature approaches absolute zero, the helium atoms cannot have zero kinetic energy.

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(iv) The residual energy of a helium atom close to absolute zero is called 'zero-point energy'. Explain how 'zero-point energy' could prevent helium from solidifying.

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(v) All atoms in a lattice have a zero point energy, but all other elements can be solidified at ordinary pressures. Explain, by referring to energy and/or forces, what is unusual about helium.

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(e) Suggest reasons why it is possible to solidify liquid helium at extremely high pressures.

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[Total: 20]

13 Fig. 13.1 represents the structure of rubber.

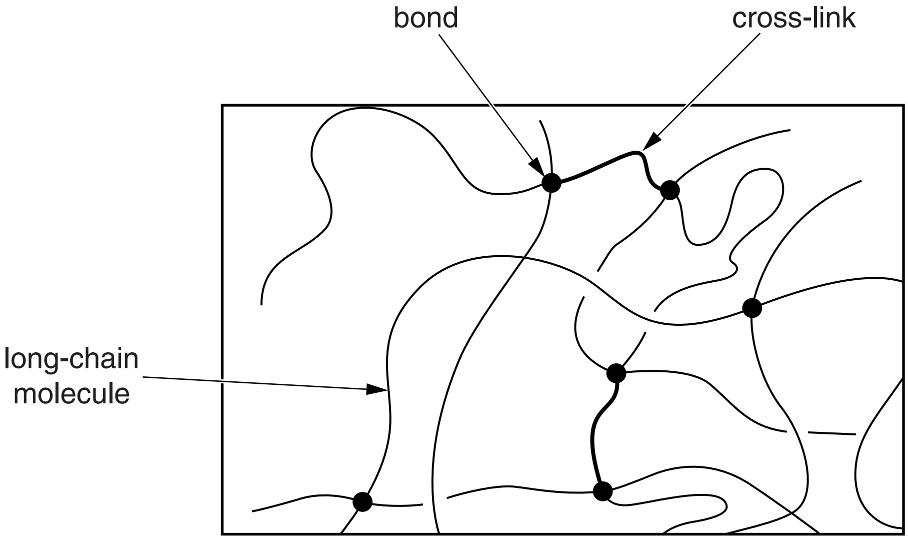

Fig. 13.1

Long chain molecules are linked by bonds at various points. The long chain molecules in rubber have the ability to coil up by rotating about their bonds.

(a) Use a diagram to help you explain why rubber can undergo large elastic strains.

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(b) The long chain molecules inside a rubber band consist of a large number of short sections joined together by bonds that can be rotated in any direction. This idea is shown in Fig. 13.2.

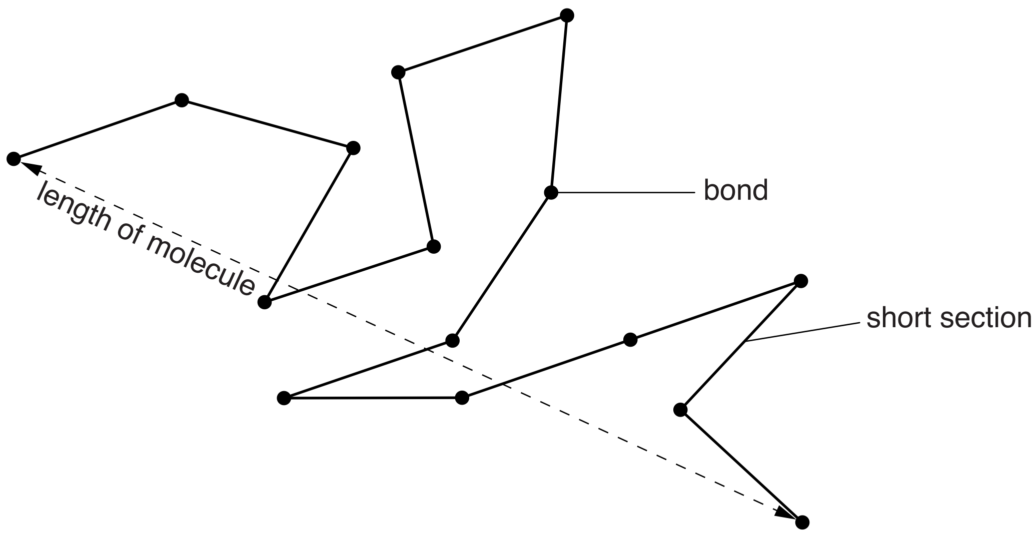

Fig. 13.2

A very simple model of such a molecule is shown in Fig. 13.3. It consists of just 4 sections, each of length l, joined together by hinges that are free to rotate only in the plane of the diagram.

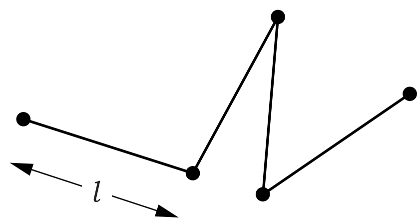

Fig. 13.3

(i) Draw a diagram to show how the molecule in Fig. 13.3 must be arranged to have a length of $4l$.

[1]

(ii) State the number of ways in which the molecule in Fig. 13.3 can be arranged to have a length $4l$.

....[1]

(iii) There are many ways for this molecule to have a length of $3l$. Draw labelled diagrams to show any **three** ways for the molecule to have a length of $3l$.

[2]

(c) **(i)** State how entropy is linked to the number of ways in which a system can be arranged.

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(ii) Sketch and label a graph to show how the entropy of a rubber band varies with its extension.

[2]

(iii) State the second law of thermodynamics.

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(iv) Use the second law of thermodynamics to explain why a rubber band must dissipate heat to its surroundings when it is stretched.

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(d) A curious experiment that is often demonstrated at science fairs is the rubber band heat engine. The apparatus is shown in Figs 13.4a and 13.4b.

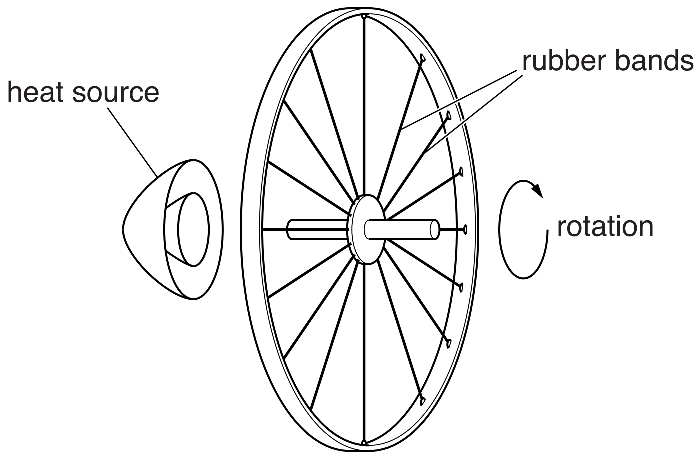

Fig. 13.4a

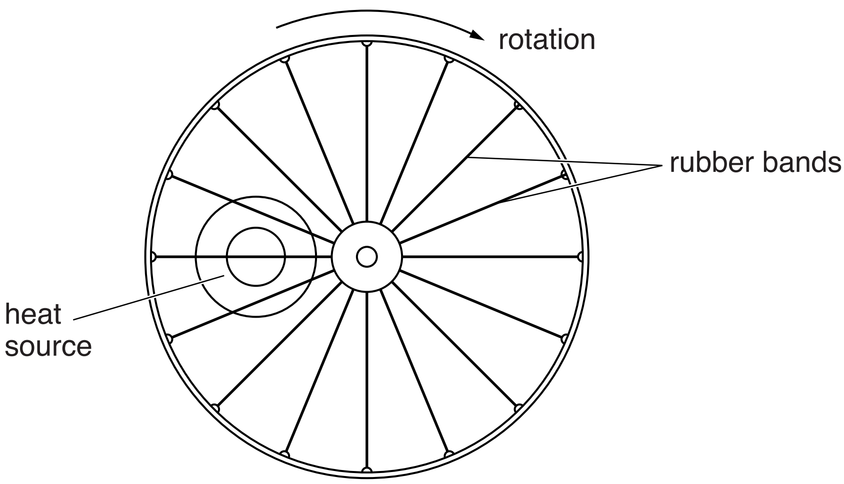

Fig. 13.4b

The spokes of a bicycle wheel have all been replaced by elastic bands under tension. When a heat source is placed off-centre, it heats the elastic bands to one side of the axle, and the wheel begins to rotate.

Use ideas about entropy, energy and moments to explain why this happens. You might find it useful to include a diagram.

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