

CANDIDATE
NAME

CENTRE
NUMBER

--	--	--	--	--	--

CANDIDATE
NUMBER

--	--	--	--



PHYSICS

Paper 3 Part B Written Paper

9792/03

May/June 2014

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

1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
Total	

This document consists of **37** printed pages and **3** blank pages.

Data

gravitational field strength close to Earth's surface	$g = 9.81 \text{ N kg}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
speed of light in vacuum	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
electron mass	$m_e = 9.11 \times 10^{-31} \text{ kg}$
proton mass	$m_p = 1.67 \times 10^{-27} \text{ kg}$
unified atomic mass constant	$u = 1.66 \times 10^{-27} \text{ kg}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$	change of state	$\Delta E = mL$
	$v^2 = u^2 + 2as$	refraction	$n = \frac{\sin\theta_1}{\sin\theta_2}$
	$s = \left(\frac{u+v}{2}\right)t$		$n = \frac{v_1}{v_2}$
heating	$\Delta E = mc\Delta\theta$		

diffraction		electromagnetic induction	$E = -\frac{d(N\Phi)}{dt}$
single slit, minima	$n\lambda = b \sin \theta$	Hall effect	$V = Bvd$
grating, maxima	$n\lambda = d \sin \theta$	time dilation	$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$
double slit interference	$\lambda = \frac{ax}{D}$	kinetic theory	$\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT$
Rayleigh criterion	$\theta = \frac{\lambda}{b}$	work done on/by a gas	$W = p\Delta V$
photon energy	$E = hf$	radioactive decay	$\frac{dN}{dt} = -\lambda N$ $N = N_0 e^{-\lambda t}$ $t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$
de Broglie wavelength	$\lambda = \frac{h}{p}$	attenuation losses	$I = I_0 e^{-\mu x}$
simple harmonic motion	$x = A \cos \omega t$ $v = -A\omega \sin \omega t$ $a = -A\omega^2 \cos \omega t$ $F = -m\omega^2 x$ $E = \frac{1}{2}mA^2\omega^2$	mass-energy equivalence	$\Delta E = c^2\Delta m$
energy stored in a capacitor	$W = \frac{1}{2}QV$	hydrogen energy levels	$E_n = \frac{-13.6 \text{ eV}}{n^2}$
electric force	$F = \frac{Q_1 Q_2}{4\pi\epsilon_0 r^2}$	Heisenberg uncertainty principle	$\Delta p \Delta x \geq \frac{h}{2\pi}$ $\Delta E \Delta t \geq \frac{h}{2\pi}$
electrostatic potential energy	$W = \frac{Q_1 Q_2}{4\pi\epsilon_0 r}$	Wien's displacement law	$\lambda_{\max} \propto \frac{1}{T}$
gravitational force	$F = -\frac{Gm_1 m_2}{r^2}$	Stefan's law	$L = 4\pi\sigma r^2 T^4$
gravitational potential energy	$E = -\frac{Gm_1 m_2}{r}$	electromagnetic radiation from a moving source	$\frac{\Delta\lambda}{\lambda} \quad \frac{\Delta f}{f} \quad \frac{v}{c}$
magnetic force	$F = BIl \sin \theta$ $F = BQv \sin \theta$		

Section A

Answer **all** questions in this section.

You are advised to spend about 1 hour 30 minutes on this section.

- 1 A fairground ride called a Ferris wheel is a rotating vertical wheel. The ride carries a passenger who moves at constant speed in a circle of radius 16.0m. It takes 27.5s for one revolution of the wheel.

- (a) Calculate the following physical quantities for the passenger. Give the relevant SI unit for each quantity.

- (i) angular velocity

angular velocity = unit [2]

- (ii) speed

speed = unit [1]

- (iii) acceleration

acceleration = unit [1]

- (iv) rotational acceleration

rotational acceleration = unit [2]

- (b) At all times during the rotation of the wheel there are only two forces, neglecting air resistance, acting on the passenger.

W – the weight of the passenger

S – the force the seat exerts on the passenger

Newton's third law states that every force has an equal and opposite force acting on a different object. Describe the equal and opposite forces to the two forces acting on the passenger.

Weight of passenger.....

.....

.....

Force of seat on passenger.....

.....

.....

[3]

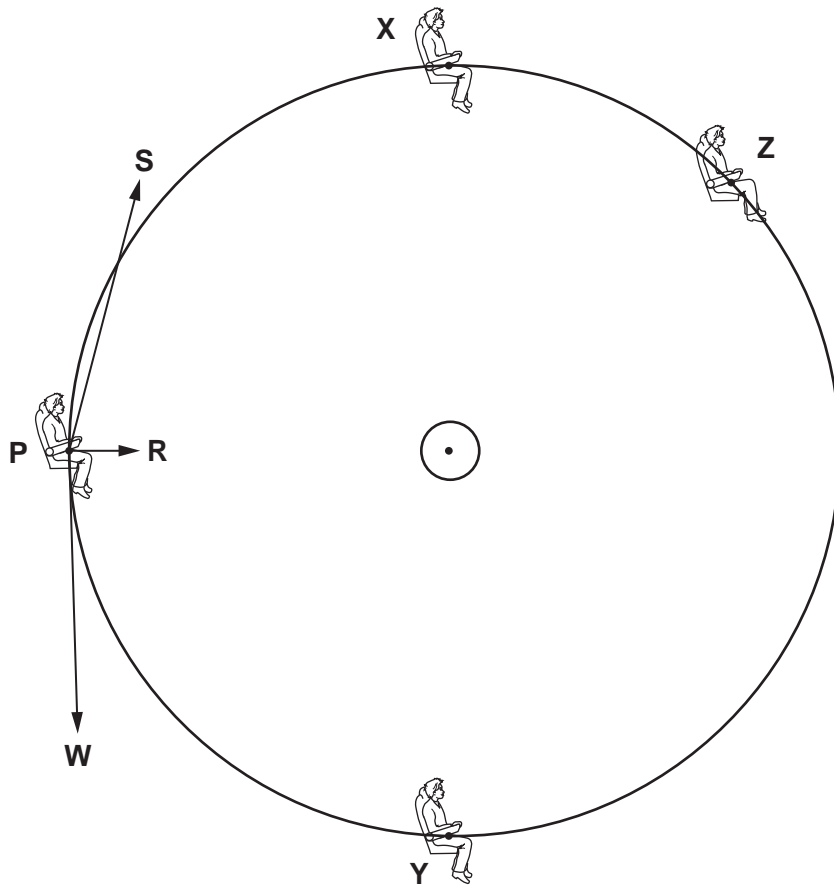
- (c) (i) The passenger has a mass of 62.4 kg. Use this and your answer to (a)(iii) to calculate the magnitude of the resultant of the two forces acting on the passenger at all times.

resultant force = N [2]

- (ii) Fig. 1.1 shows the passenger at different positions as the wheel rotates. At position **P** the two forces are shown, not to scale, together with their resultant force **R**.

For each of the positions **X**, **Y** and **Z** shown on Fig. 1.1, draw and label:

1. the resultant force vector **R**,
2. a vector to represent the weight **W**,
3. a vector to represent the force **S**.



[4]

Fig. 1.1 (not to scale)

- 2 In 1600 Kepler showed, from astronomical data obtained by Brahé, that the orbital period T of a planet is related to its distance r from the Sun by the expression

$$T^2 \propto r^3.$$

This is known as Kepler's third law.

In 1687 Newton stated his law of gravitation using the expression

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

where F is the force between two bodies separated by a distance r , G is the gravitational constant and m_1 and m_2 are the masses of the two bodies.

- (a) Use Newton's law of gravitation to derive an equation confirming Kepler's third law for a planet of mass m , in a circular orbit around the Sun of mass M .

[4]

- (b) Use the equation you derived in (a) to determine the mass of the Sun M . The distance between the Earth and the Sun is 1.50×10^{11} m.

mass of Sun = kg [3]

(c) Describe how you could use a similar method to (b) to determine the mass of the Earth.

.....
.....
.....
.....
.....
..... [2]

(d) Outline **one** application of Newtonian physics which indicates that the laws of physics apply universally and not just within our Solar System.

.....
.....
.....
.....
..... [2]

[Total: 11]

- 3 (a) Explain what is meant by the expression *electric field strength*.

.....

 [2]

- (b) In a crystal of sodium chloride, a sodium ion has a positive charge of $+e$. It is separated from its closest chlorine ion by a distance of 2.8×10^{-10} m. The chlorine ion has a charge of $-e$.

Assume that the ions are point charges.

- (i) Calculate the value of the electric field strength that one sodium ion creates at its closest chlorine ion.

electric field strength = N C^{-1} [3]

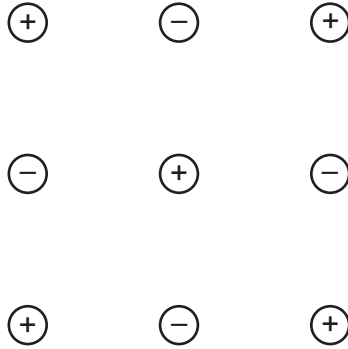
- (ii) Calculate the attractive force between the two ions.

force = N [2]

(c) The force calculated in (b)(ii) would result in the two ions accelerating towards each other. This does not happen because of the presence of other ions.

(i) Fig. 3.1 represents a plane of sodium and chlorine ions.

On Fig. 3.1, draw arrows to show the forces acting on the central sodium ion. Label the arrows to indicate whether these are forces of attraction (A) or repulsion (R).



[3]

Fig. 3.1

(ii) State the resultant force on the central ion.

resultant force [1]

(iii) When this central ion vibrates out of position, what must be the effect of the altered resultant force on the ion?

..... [1]

(iv) Suggest what determines the fixed distance between any two adjacent sodium and chlorine ions.

.....

 [2]

[Total: 14]

- 4 A capacitor of capacitance $2.4 \mu\text{F}$ is connected in the circuit shown in Fig. 4.1.

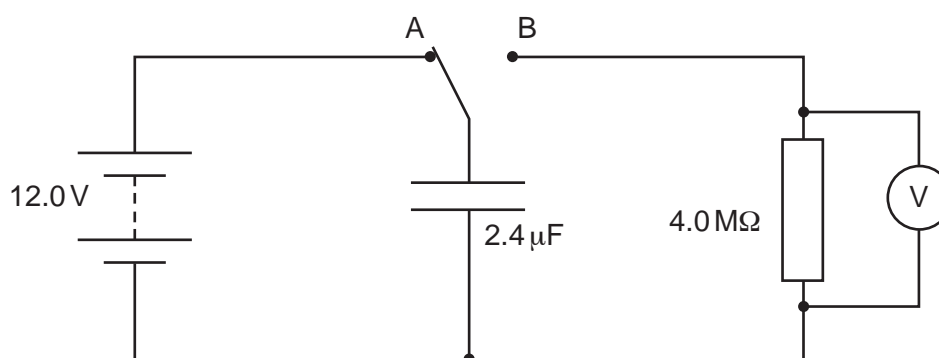


Fig. 4.1

The capacitor is first charged from a 12.0V battery with the switch in position A and then discharged through a $4.0 \text{ M}\Omega$ resistor by moving the switch to position B. A voltmeter of very high resistance is connected across the resistor. Readings are taken from the voltmeter every 10 seconds as the capacitor discharges, as shown in the table.

t/s	V/V	$\ln (V/V)$
0	12.0	
10	4.25	
20	1.09	
30	0.51	
40	0.19	
50	0.066	

- (a) Complete the table to show the values for natural logarithm $\ln (V/V)$.

[2]

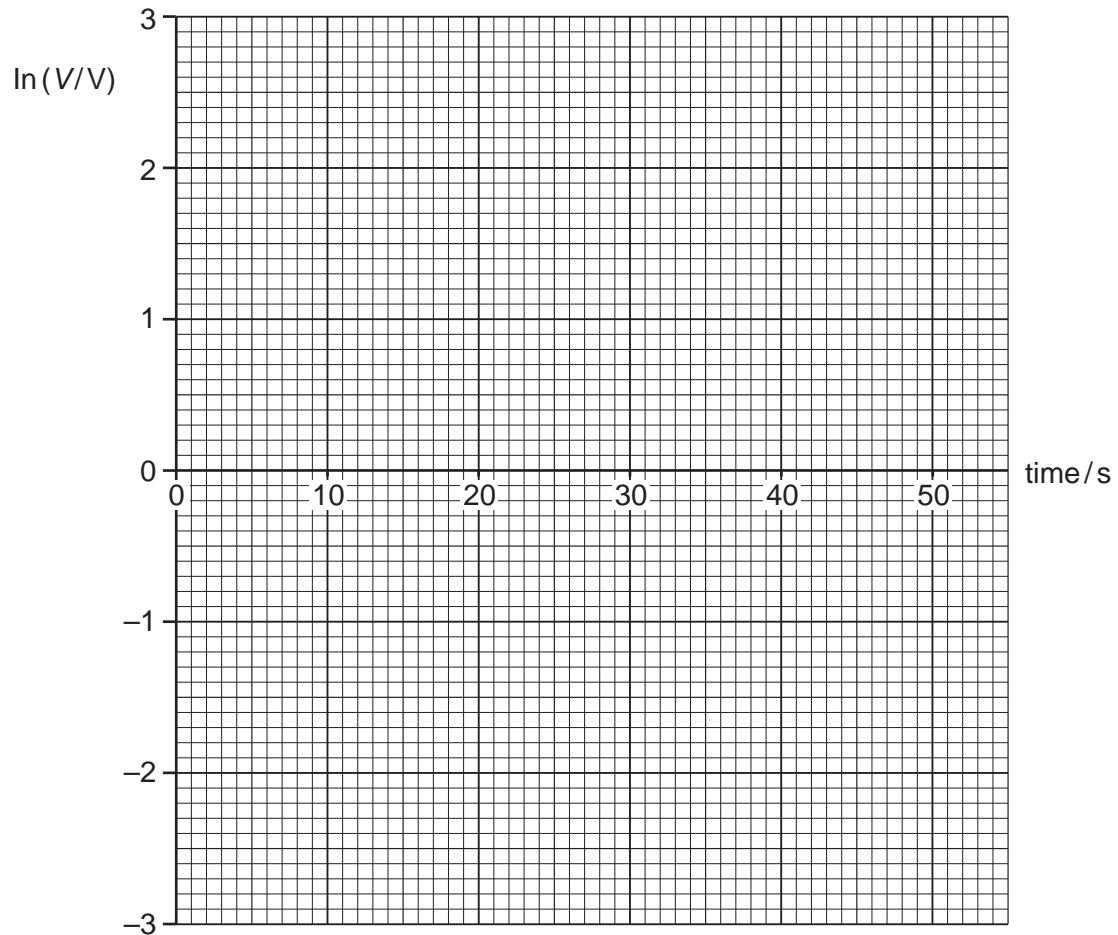


Fig. 4.2

- (b) On Fig. 4.2, plot a graph of $\ln(V/V)$ against time. [2]
- (c) On the graph, circle the anomalous data point. [1]
- (d) As the capacitor discharges, the potential difference across it decreases with time in the same way as the activity of a radioactive sample. Deduce the half-life for this decay.

half-life = s [2]

- (e) Estimate the charge remaining on the capacitor after a time of 100 s.

charge = C [4]

- (f) The time constant T for a capacitor of capacitance C when it discharges through a resistor of resistance R is given by the expression $T = CR$.

- (i) Show that the product **capacitance \times resistance** has the unit **second**.

[2]

- (ii) On Fig. 4.2, mark time constants T and $5T$ on the time axis.

[2]

[Total: 15]

BLANK PAGE

- 5 (a) A gas at a temperature of 306 K undergoes an expansion, from a volume of $4.2 \times 10^{-3} \text{ m}^3$ to a volume of $8.3 \times 10^{-3} \text{ m}^3$. The gas expands at constant pressure of $1.12 \times 10^5 \text{ Pa}$.
- (i) Calculate the final temperature of the gas.

temperature = K [2]

- (ii) Calculate the work done by the gas during the expansion.

work done = J [2]

- (b) Calculate the root mean square speed of four molecules with speeds 300 ms^{-1} , 400 ms^{-1} , 500 ms^{-1} and 1000 ms^{-1} .

root mean square speed = ms^{-1} [2]

(c) The mass of each molecule in the gas in (a) is 4.7×10^{-26} kg.

Calculate the root mean square speed of the molecules at

(i) 306 K,

root mean square speed = ms^{-1} [2]

(ii) the final temperature.

root mean square speed = ms^{-1} [1]

(d) Fig. 5.1 shows the random distribution of speeds in the molecules of the gas in (a) at a temperature of 306 K.

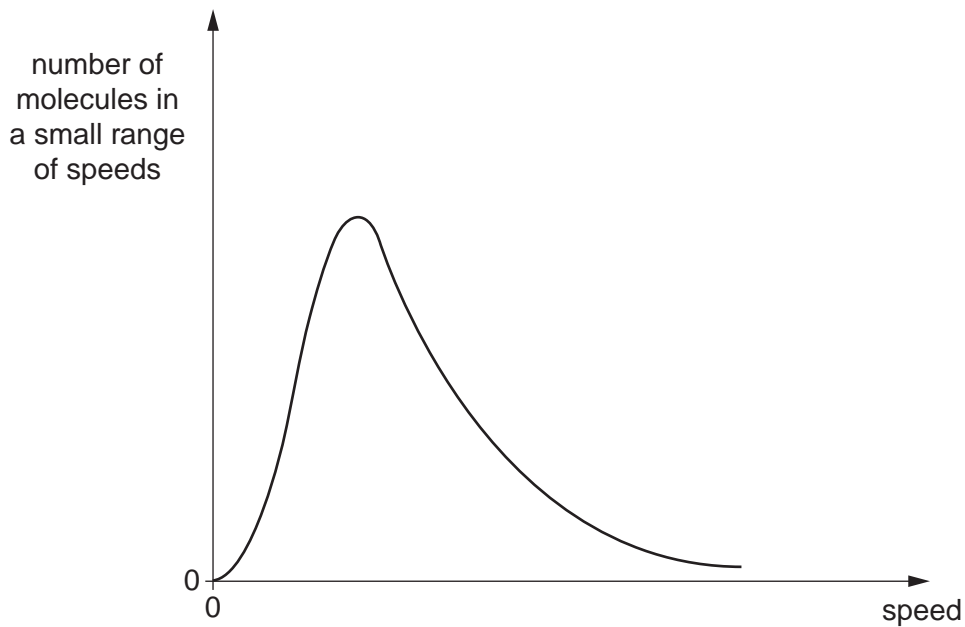


Fig. 5.1

On Fig. 5.1, draw the approximate shape of random distribution of speeds of molecules in the gas at the final temperature. [2]

[Total: 11]

- 6 (a) An alpha particle of charge Q_α , mass 6.6×10^{-27} kg and a speed of 3.0×10^7 m s⁻¹ approaches a stationary gold nucleus, head on. The gold nucleus has a charge Q_{Au} of $+79e$ and a mass about 50 times greater than the alpha particle. Assuming the gold nucleus remains stationary, when the alpha particle stops, all of its kinetic energy becomes electrostatic potential energy E between the two particles. This energy E can be found using the equation

$$E = \frac{Q_\alpha Q_{Au}}{4\pi\epsilon_0 r}$$

Assume both particles are point masses separated by a distance r .

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

kinetic energy = J [2]

- (ii) Calculate the distance separating the alpha particle from the gold nucleus when both particles are stationary.

distance = m [3]

- (b) Complete the table by putting in the heading the names of the three families into which the standard model classifies matter. Then put each of the following particles into the correct family.

down electron gluon neutrino photon up

	down	electron	gluon	neutrino	photon	up

[4]

[Total: 9]

- 7 The surface temperature of the Sun is 5800 K and light from the Sun has maximum intensity at a wavelength of 520 nm.

Light from a star emits maximum intensity at a wavelength of 480 nm. The luminosity of the star is 4.8×10^{29} W.

- (a) Calculate the peak surface temperature of the star.

temperature = K [2]

- (b) Calculate the radius of the star.

radius = m [3]

[Total: 5]

Section B

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

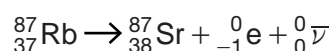
- 8 Samples of Moon rock were collected by Apollo astronauts.

Scientists measure the relative abundance of strontium isotopes in samples of Moon rock to determine the age of the rocks.

- (a) Define the term *isotope*.

.....
..... [2]

- (b) The isotope rubidium-87, found in Moon rock, is radioactive. It decays by beta emission. The nuclide decay equation is



- (i) There are no electrons in a nucleus.
Explain how it is possible for an electron to be emitted in beta decay.

.....
.....
..... [1]

- (ii) The decay constant of rubidium-87 is $1.44 \times 10^{-11} \text{ yr}^{-1}$.
Calculate, in years, the half life of rubidium-87.

half-life = yr [1]

- (c) When Moon rocks formed about 4.0×10^9 years ago they contained the isotopes rubidium-87, strontium-87 and strontium-86. The two strontium isotopes are stable. The rate at which strontium-87 atoms are created is equal to the rate of decay of the rubidium-87 atoms.

- (i) Use information given in (b)(ii) to show that this rate has remained almost constant over the age of the rock.

[3]

(ii) The ratio R of the strontium isotopes found in Moon rock is given by

$$R = \frac{\text{number of atoms } {}^{87}_{38}\text{Sr}}{\text{number of atoms } {}^{86}_{38}\text{Sr}}$$

On Fig. 8.1, sketch a graph to show how the ratio R has varied with time since the rock samples formed.



Fig. 8.1

[3]

(iii) Explain how a measure of the ratio R in (c)(ii) could be used to estimate the age of the Moon rock. State any additional information that would be required.

.....

.....

.....

.....

..... [3]

(iv) Suggest one reason that might make the method in (c)(iii) inaccurate.

.....

..... [1]

- (d) A mass spectrometer is used to determine the ratio R in a sample of Moon rock. Particles of rock are vaporised, releasing strontium ions that are then sent into the velocity selector of the spectrometer. The positive ions then pass through a magnetic field which makes them follow separate circular paths. Fig. 8.2 is a simplified diagram of a mass spectrometer.

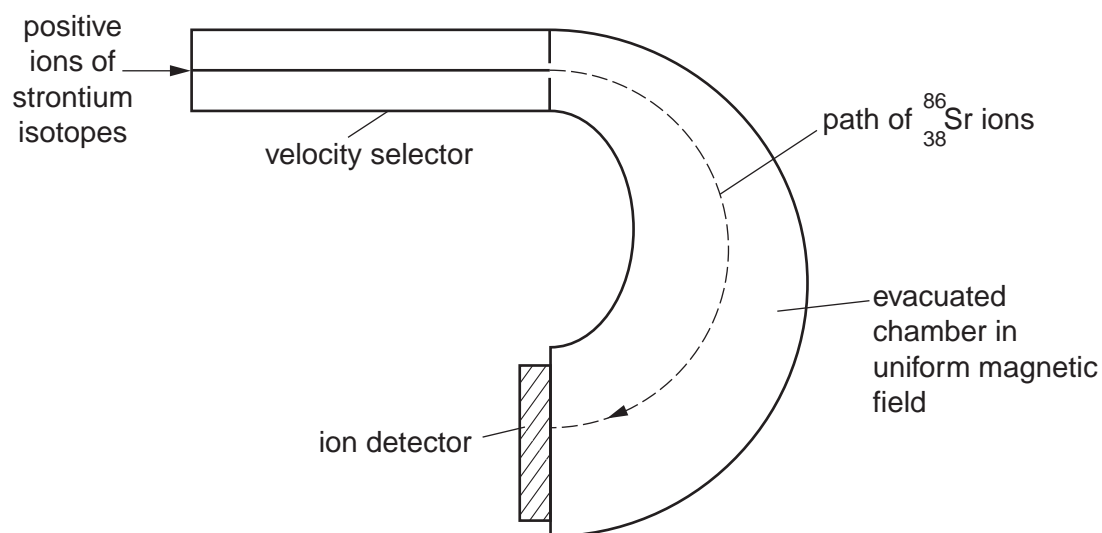


Fig. 8.2 (not to scale)

- (i) Ions of charge Q and mass m are deflected by a magnetic field of magnetic flux density B and follow a path of radius r when travelling at speed v .

Derive an expression for r in terms of Q , m , v , and B .

[2]

- (ii) The path of the strontium-86 ions is shown in Fig. 8.2.

On Fig. 8.2, sketch a possible path for the strontium-87 ions.

[1]

- (iii) The speed of the strontium ions, ${}_{38}^{87}\text{Sr}$ and ${}_{38}^{86}\text{Sr}$, is $7.6 \times 10^5 \text{ m s}^{-1}$. The magnetic flux density is 680 mT.

Determine the change in the magnetic flux density needed to make the ${}_{38}^{87}\text{Sr}$ ions follow the same path taken initially by the ${}_{38}^{86}\text{Sr}$ ions. Assume that the strontium ions have resulted from the loss of one electron from the corresponding strontium atoms.

change in magnetic flux density = T [3]

[Total: 20]

- (c) The terminals of coil B are connected to a data-logger which records the induced emf E as the magnet falls through the coil.

Fig. 9.2 is a graph showing how the emf varies with time.

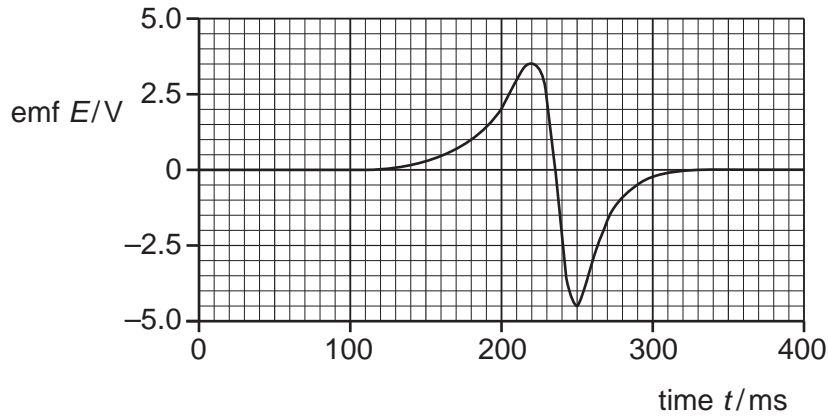


Fig. 9.2

- (i) The coil has 400 turns. Use data from the graph to determine the rate of change of flux at time $t = 200$ ms.

rate of change of flux = Wb s^{-1} [1]

- (ii) The peak emf values are + 3.5V and -4.5V.

Explain, in terms of the motion of the magnet, why these two values are different.

.....

.....

.....

..... [2]

- (d) Alternating currents may be generated by changing the magnetic flux linking a coil of wire. Fig. 9.3 shows the basic structure of an alternating current generator. It consists of a rectangular coil PQRS that is made to rotate about its horizontal axis in a uniform magnetic field.

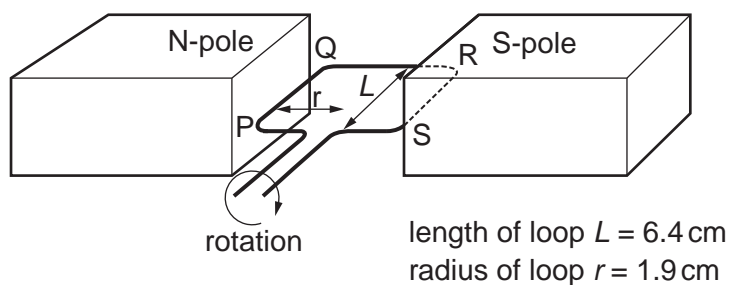


Fig. 9.3 (not to scale)

- (i) The coil has length 6.4 cm and radius 1.9 cm. It rotates with a frequency of 50 Hz. Show that the longer sides, PQ and RS, of the coil move at a speed of 6.0 ms^{-1} .

[2]

- (ii) The expression for the total magnetic flux linkage $N\phi$ with the coil at instant t is given by

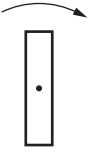
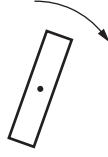
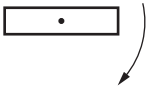
$$N\phi = BAN \cos(\omega t)$$

where N is the number of turns, A is the area of the coil, ω is the angular velocity of the coil and B is the magnetic flux density of the uniform magnetic field.

Use differentiation to derive an expression for the emf E in the rotating coil.

[1]

- (iii) The coil has 80 turns. The magnetic flux density of the uniform field is 2.8×10^{-2} T. The table gives values for the emf in the coil at different times during its rotation.

coil position			
time t /ms	0.0	1.8	5.0
emf E /V	0.0		1.7

Use the expression you derived in (d)(ii) to calculate the value of the missing emf in the table. Show your working. [3]

- (iv) On Fig 9.4, draw a graph of emf against time for one complete rotation of the coil.

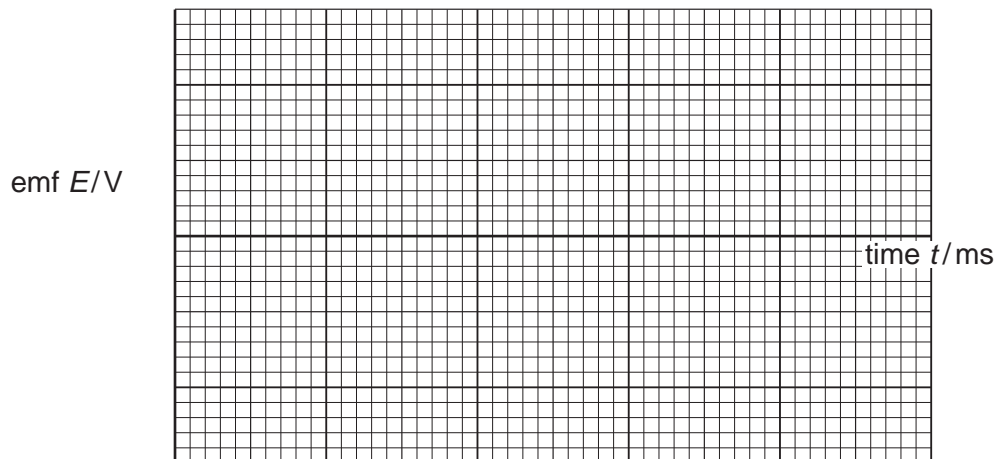


Fig. 9.4

[2]

- (v) Suggest why the emf is zero when the plane of the coil is vertical, but a maximum when the plane of the coil is horizontal.

.....

.....

.....

.....

..... [2]

[Total : 20]

- 10 (a) A particle moving with constant speed v in a circle of radius r experiences a force causing acceleration a towards the centre of that circle.

Fig. 10.1 shows the velocities v_1 and v_2 of the particle at two instants separated by the very short time interval t .

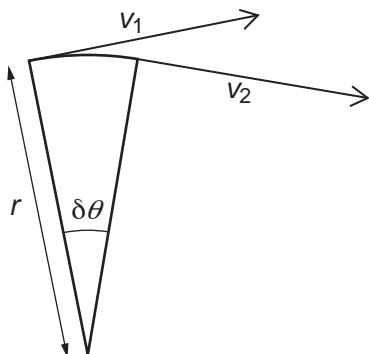


Fig. 10.1

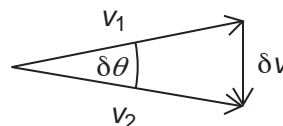


Fig. 10.2

Fig. 10.2 is a vector diagram showing the change in velocity δv that occurs in time δt where $\delta \theta$ is a very small angle.

Show that the acceleration a is related to v and r by the relationship

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

[3]

(b) Fig. 10.3 shows a racing car of mass m taking a bend at speed v .

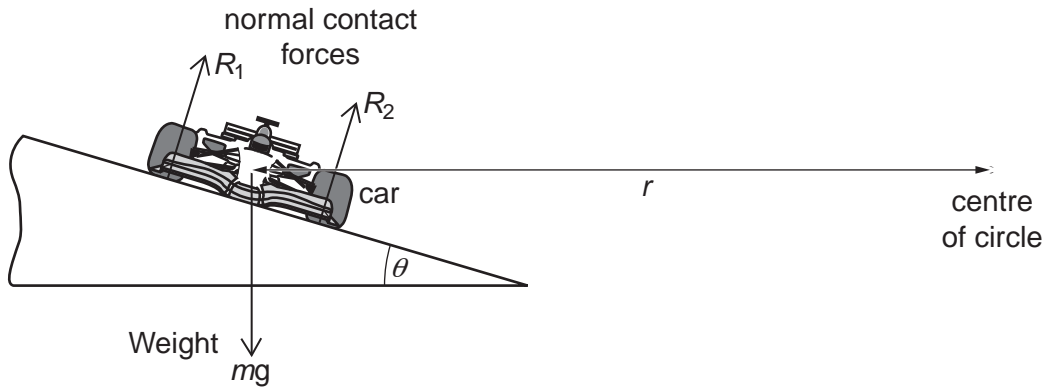


Fig. 10.3 (not to scale)

The track is banked at the bend. R_1 and R_2 are the normal contact forces on the wheels. Assume that these and the weight of the car are the only forces acting on the car. The car experiences a resultant centripetal force towards the centre of a circle of radius r . The track is at an angle θ to the horizontal.

(i) Derive an equation expressing the condition for no vertical acceleration.

..... [1]

(ii) Give the expression for the resultant horizontal centripetal force acting on the car in terms of R_1 , R_2 and θ .

.....
 [1]

(iii) Use your answers to **b(i)** and **b(ii)** to show that

$$\tan \theta = \frac{v^2}{rg}.$$

[1]

(c) Formula-1 racing cars are fitted with a Kinetic Energy Recovery System (KERS) so that the loss in kinetic energy of the decelerating car is given to a flywheel to increase its angular speed. When the car accelerates, rotational kinetic energy of the flywheel is transferred to the car.

(i) State the Principle of Conservation of Energy.

.....
 [2]

- (ii) Fig. 10.4 shows a simplified KERS flywheel. It consists of a solid cylinder of carbon fibre of mass M , radius R and length l .

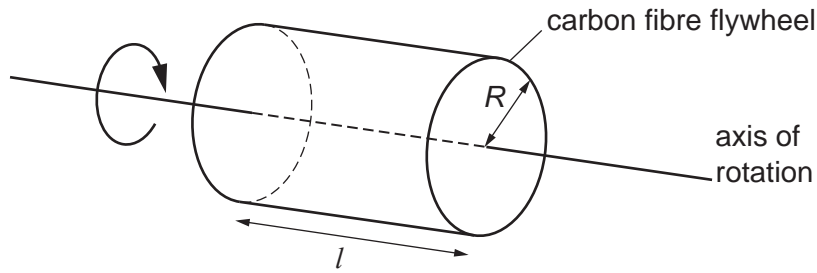


Fig. 10.4 (not to scale)

The volume V of the flywheel is given by $V = \pi R^2 l$ and its moment of inertia I about its axis of rotation is given by $I = \frac{1}{2} MR^2$.

Derive an expression for the density ρ of the carbon fibre in terms of I , R and l .

[2]

- (iii) The radius of the flywheel is 12.0cm and its length is 30.0cm. Its moment of inertia is 0.176 kgm².

Use your expression from (c)(ii) to calculate the density of the carbon fibre.

density = kgm⁻³ [2]

- (iv) The initial angular speed of the flywheel is 6700 rads⁻¹.

Determine the number of revolutions made by the flywheel each minute.

number of revolutions = min⁻¹ [1]

- (v) The racing car accelerates out of a bend. The angular speed of the flywheel decreases to 2880 rad s^{-1} in 6.67 s.

Determine the loss in rotational kinetic energy in the flywheel.

loss in rotational kinetic energy = J [3]

- (vi) Calculate the average power output of the flywheel during this time.

average power output = W [1]

- (vii) Determine the torque T on the flywheel that causes the reduction in angular speed. Give the unit.

torque = unit [3]

[Total: 20]

- 11 (a) Ernest Rutherford proposed a planetary model for the hydrogen atom. In the model, a single electron is treated as a point-like charged particle, moving in a circular orbit around a stationary proton (the nucleus) as shown in Fig. 11.1.

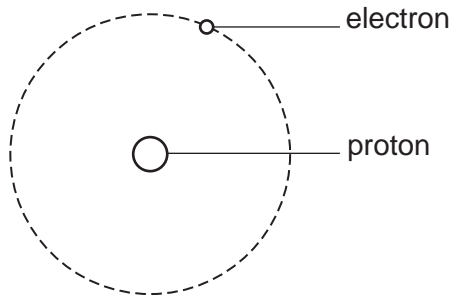


Fig. 11.1

- (i) State **two** forms of energy that the orbiting electron possesses and state whether each form is positive or negative.

.....
 [2]

- (ii) Explain why the total energy of the electron must be negative when orbiting the nucleus.

.....
 [2]

- (iii) State what a negative total energy implies about the relative sizes of the two forms of energy given in (a)(i).

.....
 [1]

- (c) Rutherford's planetary model allows any size for the electron orbits, but quantum theory puts a lower limit on the size of the hydrogen atom. To understand why this is the case, we can use the Heisenberg uncertainty principle for position and momentum.

$$\Delta p \Delta x \geq \frac{h}{2\pi}$$

- (i) State the meaning of the term Δp .

..... [1]

- (ii) State the meaning of the term Δx .

..... [1]

- (iii) State the changes in Δp and Δx when the atom is made smaller by reducing the radius of the electron orbit.

.....
 [1]

- (iv) Explain how the change in Δp affects the kinetic energy of the orbiting electron.

.....
 [2]

- (v) By considering your answers to (a)(ii) and (c)(iv), explain why there is a minimum radius for an electron orbit in the hydrogen atom.

.....

 [2]

- (d) In 1925, Erwin Schrödinger refined the quantum model for electrons in atoms. In 1933, Schrödinger received the Nobel Prize in physics for this work. In his acceptance speech he acknowledged that the quantum theory explanation for the atom is really a description of an **electron wave** captured by the nucleus.

- (i) State what the intensity of the electron wave inside an atom represents.

.....
 [1]

- (ii) Schrödinger's quantum model suggests that the idea of a distinct electron orbit is no longer valid. Some people describe electrons as 'clouds'. Suggest what an electron 'cloud' represents.

.....

 [2]

[Total: 20]

12 When Galileo was a student, he observed the lamps in Pisa cathedral swinging backwards and forwards. He noticed that the time period for these oscillations was almost independent of their amplitude. This led him to the idea that a simple pendulum could be used to control the ticking of a mechanical clock.

- (a) Two identical pendulum clocks keep time with one another when they are placed side by side, in the same laboratory.

Explain how you would expect their time periods to compare with one another if

- (i) one is at rest on Earth and the other is in a freely falling lift on Earth,

.....
.....
..... [2]

- (ii) one is at rest on Earth and the other is at rest on the Moon.

.....
.....
..... [2]

- (b) A hypothetical clock consists of two parallel mirrors separated vertically with a light pulse bouncing backwards and forwards between them. Suppose two such clocks keep time with one another when they are placed side by side, in a laboratory. One of the clocks now remains at rest in the laboratory while the other one moves through the laboratory at a constant velocity v .

Use a diagram to help explain why, when viewed from the laboratory reference frame, the time period of the moving clock is greater than that of the clock at rest.

.....
.....
.....
..... [4]

(c) A student suggests that time dilation effects can be measured directly by placing a 'light' clock inside a moving spacecraft alongside a wristwatch. He argues that the clock will lose more and more time with respect to the wristwatch. Discuss and explain whether or not this method would work.

.....
.....
.....
.....
..... [2]

(d) Idealised simple harmonic motion is time-reversible. This means that if time were to be reversed, the motion would look exactly the same. However, the oscillations of a real mass-spring oscillator are not time-reversible.

(i) Explain why the oscillations of the real mass-spring system are not time-reversible.

.....
.....
..... [2]

(ii) Explain how this illustrates the thermodynamic arrow of time.

.....
.....
..... [2]

- (e) In Schrödinger's thought experiment, a cat is confined within a box together with a deadly apparatus which will kill the cat if it is triggered by a radioactive atom. The radioactive atom has a 50% chance of decaying and triggering the apparatus in one hour. After one hour, the box is to be opened.

Explain how this system changes with time, from the moment the box is closed until just after it is opened, according to:

- (i) classical physics,

.....

.....

.....

.....

.....

.....

.....

- (ii) the Copenhagen interpretation of quantum theory,

.....

.....

.....

.....

.....

.....

.....

- (iii) the many-worlds interpretation of quantum theory.

.....

.....

.....

.....

.....

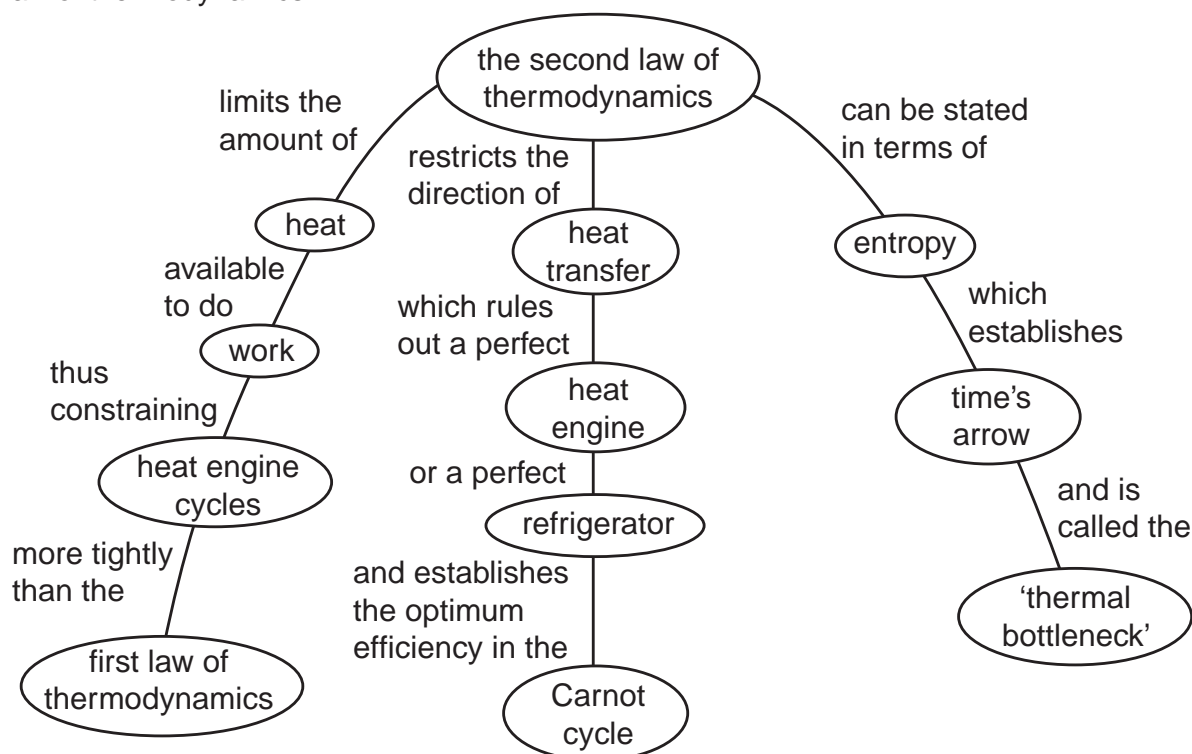
.....

.....

[6]

[Total: 20]

13 Fig. 13.1 is a diagram adapted from a physics website. It is a map of the implications of the second law of thermodynamics.



Heat engine: a device that is supplied with thermal energy and converts some of this into useful work (e.g. an internal combustion engine).

Carnot cycle: cycle of changes in a heat engine which leads to maximum theoretical efficiency.

Fig. 13.1

(a) (i) Describe, qualitatively, what is meant by the term *entropy*.

.....

 [2]

(ii) State the second law of thermodynamics in terms of entropy.

.....
 [1]

(iii) Explain, qualitatively, why the entropy of a constant volume of gas increases when it is heated.

.....

 [2]

- (b) An internal combustion engine in a car is an example of a heat engine. Fig. 13.2 shows the main energy transfers that take place during one cycle in such an engine.

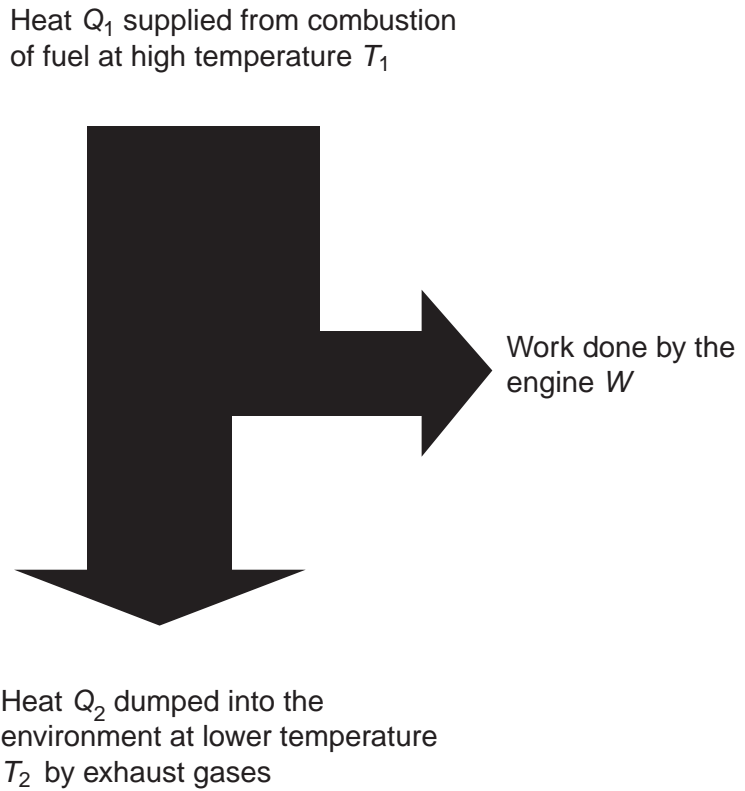


Fig. 13.2

- (i) The change in internal energy ΔU of the system is zero after completing one cycle. Use the first law of thermodynamics to write down an equation for the work done by the engine in one cycle of operation W , in terms of Q_1 and Q_2 .

..... [1]

- (ii) Write down an expression for the efficiency of the heat engine in terms of Q_1 and Q_2 .

..... [1]

- (iii) State the value of Q_2 that would result in an efficiency of 100%.

..... [1]

- (iv) Explain, in terms of entropy changes, why the efficiency of this engine must be less than 100%.

.....

 [3]

- (v) If the engine worked on an ideal thermodynamic (Carnot) cycle, the entropy change as a result of heat Q flowing in or out of the system at temperature T would be given by $\frac{Q}{T}$. The work done by the engine has no associated entropy change. Use this to calculate the maximum theoretical efficiency of this engine operating between temperatures $T_1 = 800\text{K}$ and $T_2 = 300\text{K}$.

[4]

- (c) (i) Explain why heat flows spontaneously from a hot object to a cold object, but not from cold to hot.

.....
.....
.....
.....
..... [2]

- (ii) Discuss the entropy changes that take place when water freezes.

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

[Total: 20]

Copyright Acknowledgements:

Question 13 © <http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/seclawcon.html>

Permission to reproduce items where third-party owned material protected by copyright is included has been sought and cleared where possible. Every reasonable effort has been made by the publisher (UCLES) to trace copyright holders, but if any items requiring clearance have unwittingly been included, the publisher will be pleased to make amends at the earliest possible opportunity.

Cambridge International Examinations is part of the Cambridge Assessment Group. Cambridge Assessment is the brand name of University of Cambridge Local Examinations Syndicate (UCLES), which is itself a department of the University of Cambridge.