Candidate forename		Candidate surname	

Centre number						Candidate number				

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

ADVANCED GCE UNIT

G494

PHYSICS B (ADVANCING PHYSICS)

Rise and Fall of the Clockwork Universe

THURSDAY 27 JANUARY 2011: Afternoon

DURATION: 1 hour 15 minutes

SUITABLE FOR VISUALLY IMPAIRED CANDIDATES

Candidates answer on the question paper.

OCR SUPPLIED MATERIALS:

Data, Formulae and Relationships Booklet

OTHER MATERIALS REQUIRED:

Electronic calculator
Ruler (cm/mm)

READ INSTRUCTIONS OVERLEAF

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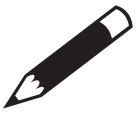
INSTRUCTIONS TO CANDIDATES

- **Write your name, centre number and candidate number in the boxes on the first page. Please write clearly and in capital letters.**
- **Use black ink. Pencil may be used for graphs and diagrams only.**
- **Read each question carefully. Make sure you know what you have to do before starting your answer.**
- **Write your answer to each question in the space provided. Additional paper may be used if necessary but you must clearly show your candidate number, centre number and question number(s).**
- **Answer ALL the questions.**

<u>INFORMATION FOR CANDIDATES</u>

- The number of marks is given in brackets [ ] at the end of each question or part question.
- The total number of marks for this paper is <u>60</u>.
- You are advised to spend about 20 minutes on Section A and 55 minutes on Section B.
- The values of standard physical constants are given in the Data, Formulae and Relationships Booklet. Any additional data required are given in the appropriate question.
-  Where you see this icon you will be awarded marks for the quality of written communication in your answer.

  This means for example, you should

  - ensure that text is legible and that spelling, punctuation and grammar are accurate so that the meaning is clear;
  - organise information clearly and coherently, using specialist vocabulary when appropriate.

Answer ALL the questions.

SECTION A

1 Here is a list of units.

$m\,s^{-1}$ $m^2\,s^{-2}$ $kg\,m^2\,s^{-2}$ $kg\,m\,s^{-1}$ $kg\,m\,s^{-2}$

(a) Which one is a correct unit for force?

_____________________ [1]

(b) Which one is a correct unit for root mean square speed?

_____________________ [1]

2 The graph of Fig. 2.1 shows how the gravitational field strength g of a planet varies with the distance r from its centre.

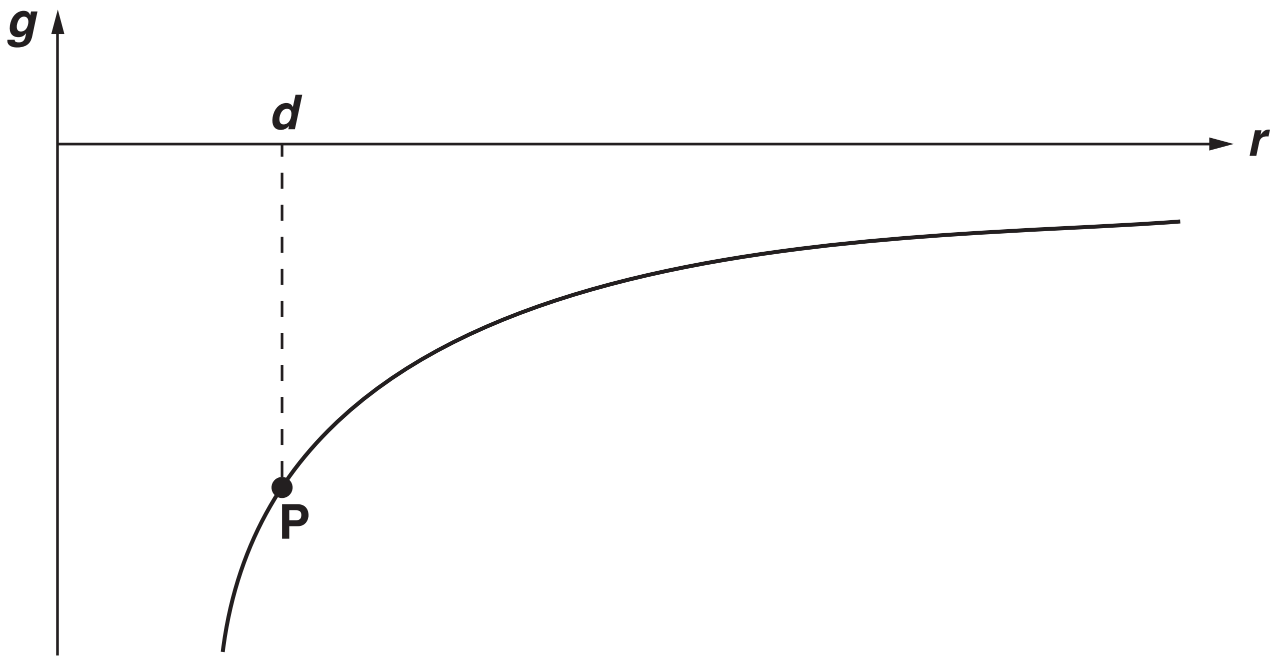


Fig. 2.1

Here are four suggested ways of using the graph to calculate the gravitational potential of a spacecraft at point P, when it is a distance d from the centre of the planet.

Put a tick (✓) in the box next to the correct calculation.

The gravitational potential is ...

... the gradient of the curve at P when $r = d$. ☐

... the reciprocal of the gradient of the curve at P when $r = d$. ☐

... the area between the curve and the r axis from $r = 0$ to $r = d$. ☐

... the area between the curve and the r axis from $r = d$ to $r = \infty$. ☐

[1]

3 In Fig. 3.1, there is a current in the resistor after the switch has been opened. The decay of charge Q on the capacitor can be modelled by the equation

$$\frac{dQ}{dt} = -\frac{Q}{RC}.$$

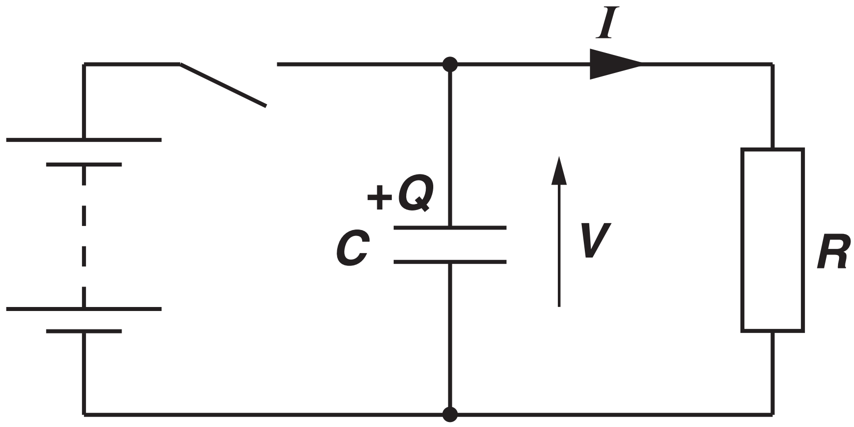


Fig. 3.1

(a) Write down an equation for the p.d. V across the capacitor of capacitance C when it stores a charge Q.

[1]

(b) Here are some equations for electric current.

Which one correctly links the current I in the resistor to the charge Q stored by the capacitor at time t after the switch has been opened?

Put a ring around the correct equation.

$I = -\frac{Q}{t}$ $\qquad$ $I = -\frac{dQ}{dt}$ $\qquad$ $I = +\frac{dQ}{dt}$ $\qquad$ $I = +\frac{Q}{t}$

[1]

(c) Use the equation $I = \frac{V}{R}$ to link your answers to (a) and (b) to show that

$$\frac{dQ}{dt} = -\frac{Q}{RC}.$$

[1]

4 The air in a football has a mass of 1.1×10^{-2} kg.

(a) Show that the ball contains about 2×10^{23} particles.

molar mass of air $M_{air} = 2.9 \times 10^{-2}\,\text{kg mol}^{-1}$

the Avogadro constant $N_A = 6.0 \times 10^{23}\,\text{mol}^{-1}$

[1]

(b) Calculate the mean square speed $\overline{c^2}$ of the particles in the football.

pressure of air in the ball = 1.7×10^5 Pa

volume of air in the ball = $5.4 \times 10^{-3}\,\text{m}^3$

$\overline{c^2}$ = ____________________ $\text{m}^2\,\text{s}^{-2}$ [2]

(c) The temperature of the air in the football increases during a game.

On the axes of Fig. 4.1, sketch a graph to show how the mean square speed $\overline{c^2}$ of air particles in the football varies with absolute temperature T.

Assume the air behaves as an ideal gas.

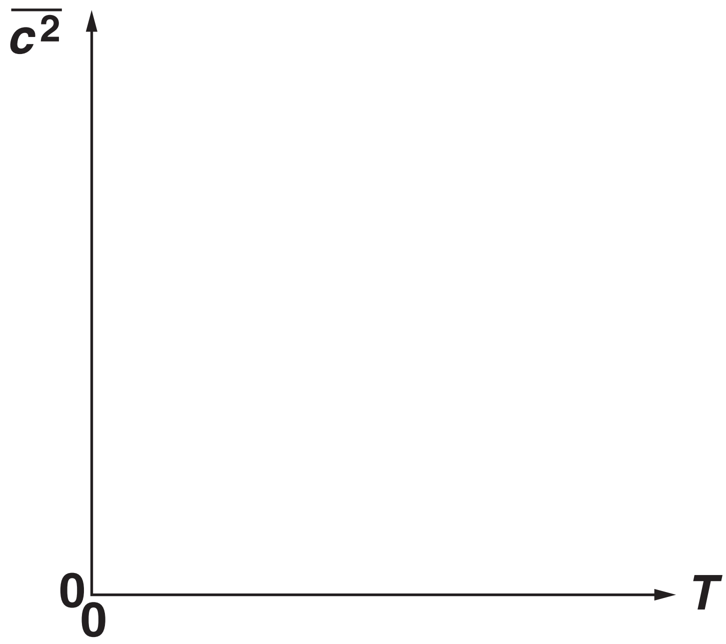


Fig. 4.1

[1]

5 **The Universe is believed to be expanding, starting from an original 'big bang'.**

One piece of evidence for this is provided by the cosmological red-shift of galaxies.

(a) **State what property of light is measured to determine the red-shift of a galaxy.**

[1]

(b) **Explain how cosmological red-shift provides evidence for an original 'big bang'.**

[2]

6 Which one of the graphs of Fig. 6.1 best shows how the Boltzmann factor $e^{-E/kT}$ varies with absolute temperature T?

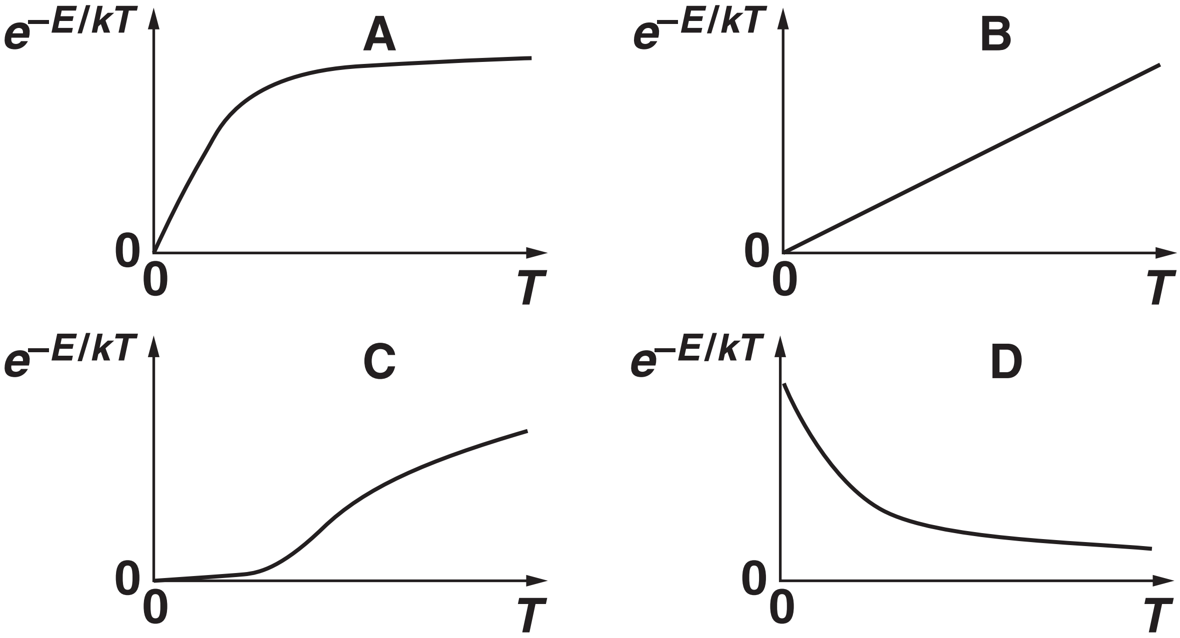


Fig. 6.1

answer ______________________ [1]

7 The energy ε required to change the state of water from liquid to gas is 6.9×10^{-20} J per particle.

(a) Calculate the ratio $\frac{\varepsilon}{kT}$ for a single water particle at $T = 300$ K.

$k = 1.4 \times 10^{-23}\,\mathrm{J\,K^{-1}}$

$\frac{\varepsilon}{kT}$ = ______________________ [1]

(b) Calculate the value for the Boltzmann factor of a water particle at 300 K.

Boltzmann factor = ______________________ [1]

(c) **Although the Boltzmann factor is very small, a puddle of water at 300 K evaporates over a space of a few hours.**

Two of the statements below, when taken together, provide an explanation for this.

The rate at which particles in the liquid collide with each other is very large.	☐
Only particles close to the surface of the liquid can escape.	☐
Each particle collides with others in the liquid many times.	☐
The temperature of the liquid rises as particles escape from it.	☐
The energy of a particle can change each time it collides with others.	☐

Put a tick (✓) in the box next to the each of the TWO statements required. **[1]**

8 The graph of Fig. 8.1 shows how the VELOCITY of an object in simple harmonic motion varies with time.

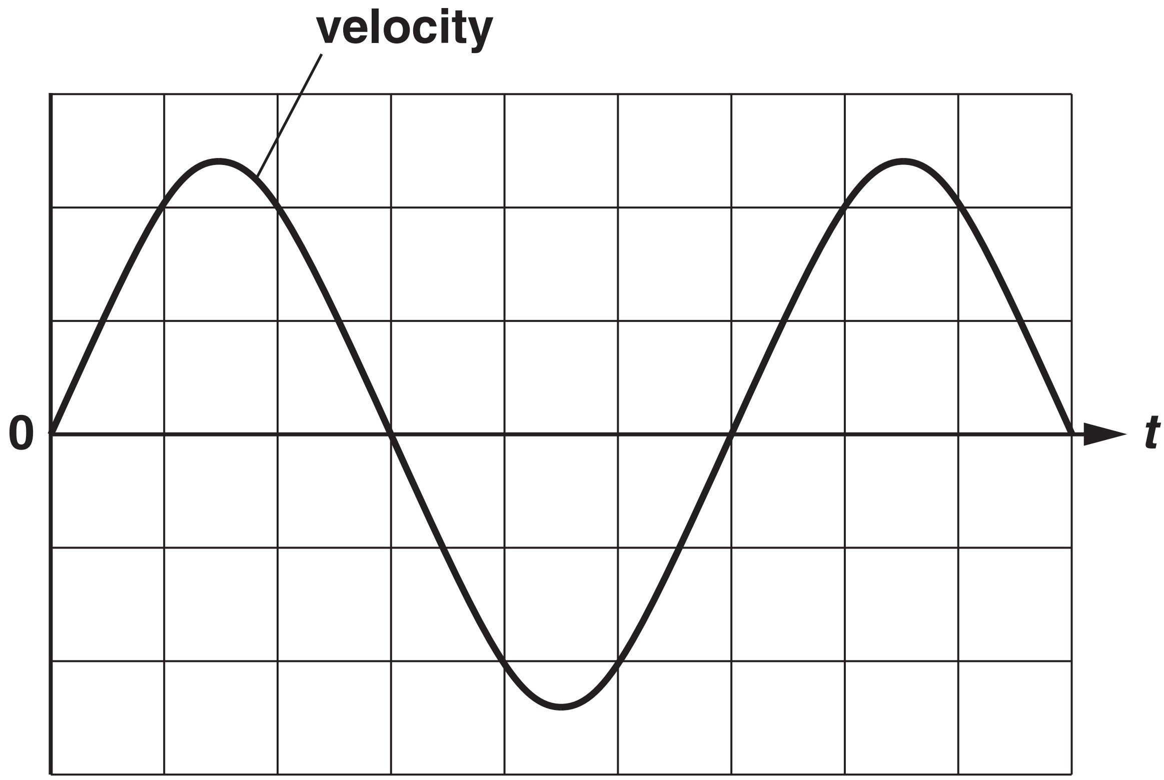


Fig. 8.1

On the axes of Fig. 8.1, sketch a graph to show how the DISPLACEMENT of the object varies with time. [1]

9 **A 4700 μF capacitor is charged by connecting it to a 20V power supply.**

(a) Show that this stores about 1 J of energy in the capacitor.

[1]

(b) The capacitor is subsequently discharged through a 10 Ω resistor, delivering an average heating power of 20W during the discharge time.

Put a ring around the average heating power when the capacitor, initially charged by a 20V power supply, is discharged through a 5 Ω resistor.

5W **10W** **20W** **40W**

[1]

[Section A Total: 20]

SECTION B

10 **This question is about the oscillations of a loudspeaker cone.**

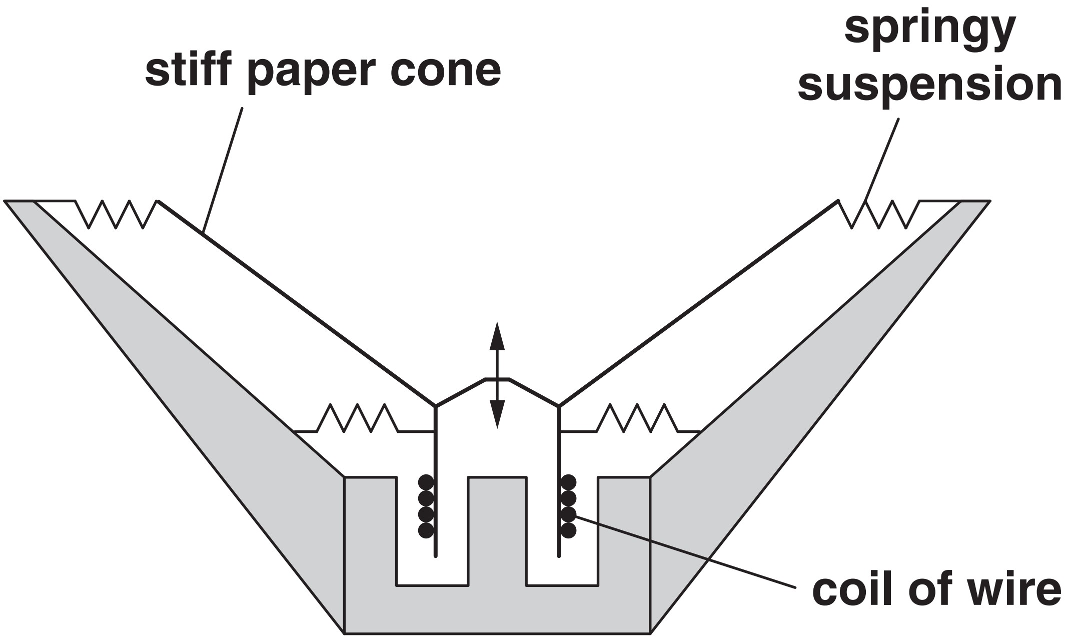


Fig. 10.1

Fig. 10.1 shows a cross-section through a loudspeaker. The stiff cone is made of paper, held in place by a springy suspension which allows the cone to move up and down.

(a) **The cone oscillates in simple harmonic motion.**

Describe how the force provided by the springy suspension varies as the cone is displaced from its equilibrium position.

[2]

(b) The cone and its suspension are modelled as a mass of 0.040 kg held in place by a spring of force constant $1.1 \times 10^3\,\mathrm{N\,m^{-1}}$.

(i) Show that the natural frequency of free oscillation for the system is about 30 Hz.

[2]

(ii) The loudspeaker coil is connected to a signal generator. This forces the cone to vibrate at the frequency of the current in the signal generator.

Describe how the amplitude of oscillation of the cone changes as the frequency of the signal generator is slowly increased from 20 Hz to 50 Hz.

[2]

(c) In use the loudspeaker is mounted on a box, as shown in Fig. 10.2.

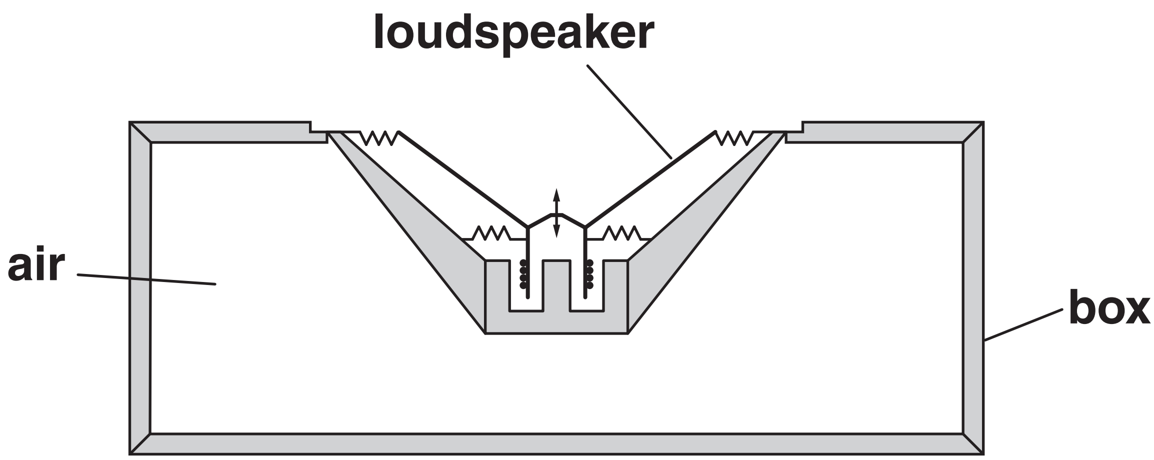


Fig. 10.2

The air in the box cannot escape. The air behaves as another spring acting on the cone.

Explain why the air acts like a spring and its effect on the frequency of free oscillations of the cone.

Your answer should use appropriate technical terms.

[4]

[Total: 10]

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11 This question is about placing a satellite in orbit around the planet Mars.

Fig. 11.1 shows the path followed by the satellite.

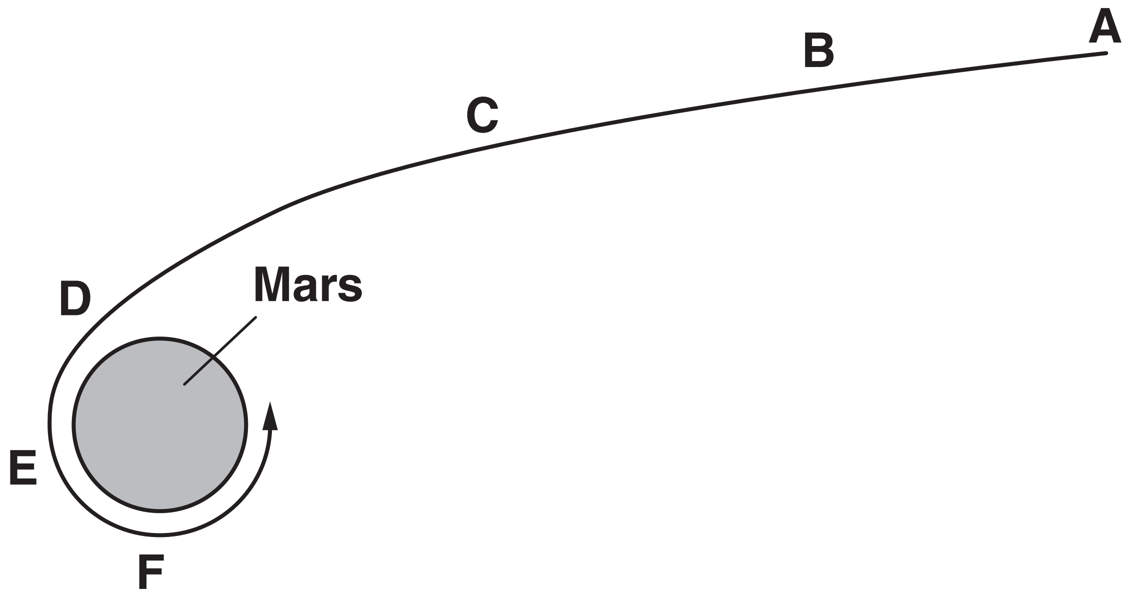

Fig. 11.1

The satellite falls freely from A to D with its rocket thrusters turned off.

The rockets are fired briefly at point D to slow the satellite down and place it in a circular orbit.

(a) The points labelled A to F on the path are separated by the same interval of time.

Use Fig. 11.1 to complete the sketch graphs of Fig. 11.2 for the variation with time of the kinetic energy and gravitational potential energy of the satellite. The graphs have been started for you. [4]

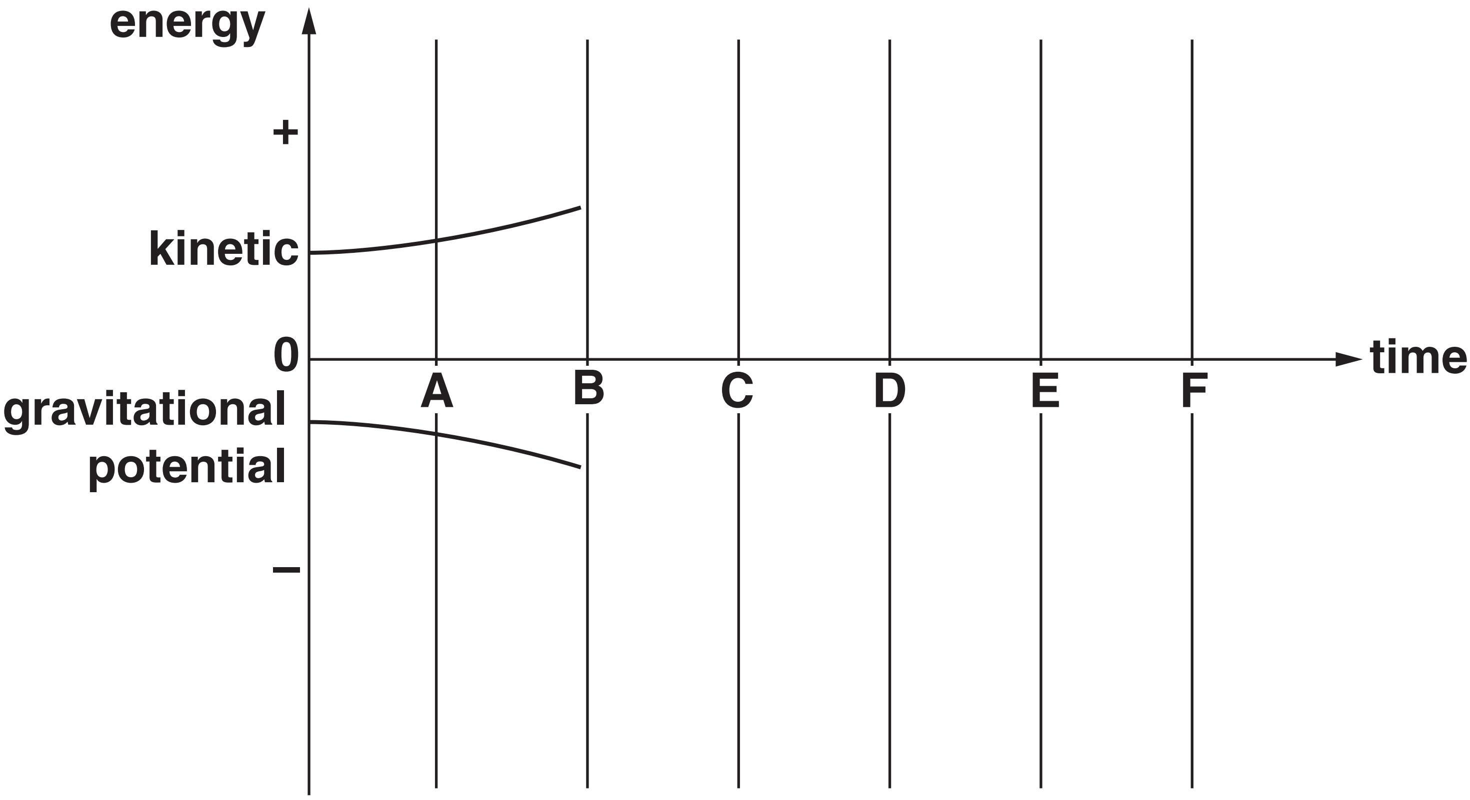

Fig. 11.2

(b) The speed of the satellite drops from $1.8 \times 10^3\,\mathrm{m\,s^{-1}}$ to $1.5 \times 10^3\,\mathrm{m\,s^{-1}}$ when the rockets are fired at point D. The mass of the satellite drops from $1.2 \times 10^3\,\mathrm{kg}$ to $9.5 \times 10^2\,\mathrm{kg}$ as the exhaust gases leave the rockets. The exhaust gases leave the rockets in the direction of the satellite's motion so that it slows down.

Calculate the average velocity of the exhaust gases.

Ignore any effects of the planet's gravity on the system.

average velocity of gases = ____________________ $\mathrm{m\,s^{-1}}$ [3]

(c) (i) By equating the gravitational force on a satellite with the centripetal force required for a circular orbit of radius r around a planet of mass M, show that r is given by

$$r = \frac{GM}{v^2}$$

where G is the gravitational force constant and v is the speed of the satellite.

[2]

(ii) Calculate the radius r of the satellite's orbit around Mars for an orbit speed of 1.5×10^3 m s^{-1}.
$G = 6.7 \times 10^{-11}$ N m^2 kg^{-2}
$M = 6.5 \times 10^{23}$ kg

r = ______________ m [1]

[Total: 10]

12 This question is about providing warm fresh air for people who work in large office buildings in winter.

It is recommended that the air in offices should be completely replaced once every hour.

(a) The air in an office has the following properties:

- **pressure of 1.0×10^5 Pa**
- **volume of 1.3×10^2 m^3**
- **temperature of 20° C**

Show that the office contains about 3×10^{27} particles of air.

$k = 1.4 \times 10^{-23}$ J K^{-1}

[2]

(b) The air in the office is replaced every hour. On its way into the room, the cold air at 5 °C is passed through a heater to raise its temperature to 20 °C.

Do calculations to estimate the power of the heater.

power = ______________ W [3]

(c) On its way through the heater, the cold air

- increases its temperature
- has no change to its pressure

Explain how the density of the air changes as it passes through the heater.

Your answer should clearly link the change of density to the behaviour of the air particles.

[4]

[Total: 9]

13 This question is about time dilation for particles called muons moving at high speed.

(a) Muons are short-lived particles which are created when protons collide with nuclei at high energy. They decay randomly into electrons and anti-neutrinos, with a half-life of 1.5 μs. The process can be modelled with the expression

$$\frac{\Delta N}{\Delta t} = -\lambda N.$$

(i) Explain the meaning of the decay constant λ in the expression.

[2]

(ii) Calculate the value of λ for the decay of a muon.

λ = ________________ s^{-1} [1]

(b) In a recent experiment, a beam of high-energy muons was created with a speed of almost $3.0 \times 10^8\,m\,s^{-1}$. They were trapped in a magnetic field so that they travelled in a circular path until they decayed into electrons. Non-relativistic calculations were made to estimate the time and distance for the muons to decay.

(i) Show that when only one-eighth of the original number of muons remain in the beam, they have travelled about 1.4 km.

The half-life of a muon is $1.5\,\mu s$.

[3]

(ii) On the axes of Fig. 13.1, sketch a graph to show how the proportion of muons still in the beam should vary with the distance that they have travelled, assuming the non-relativistic calculation of (i).

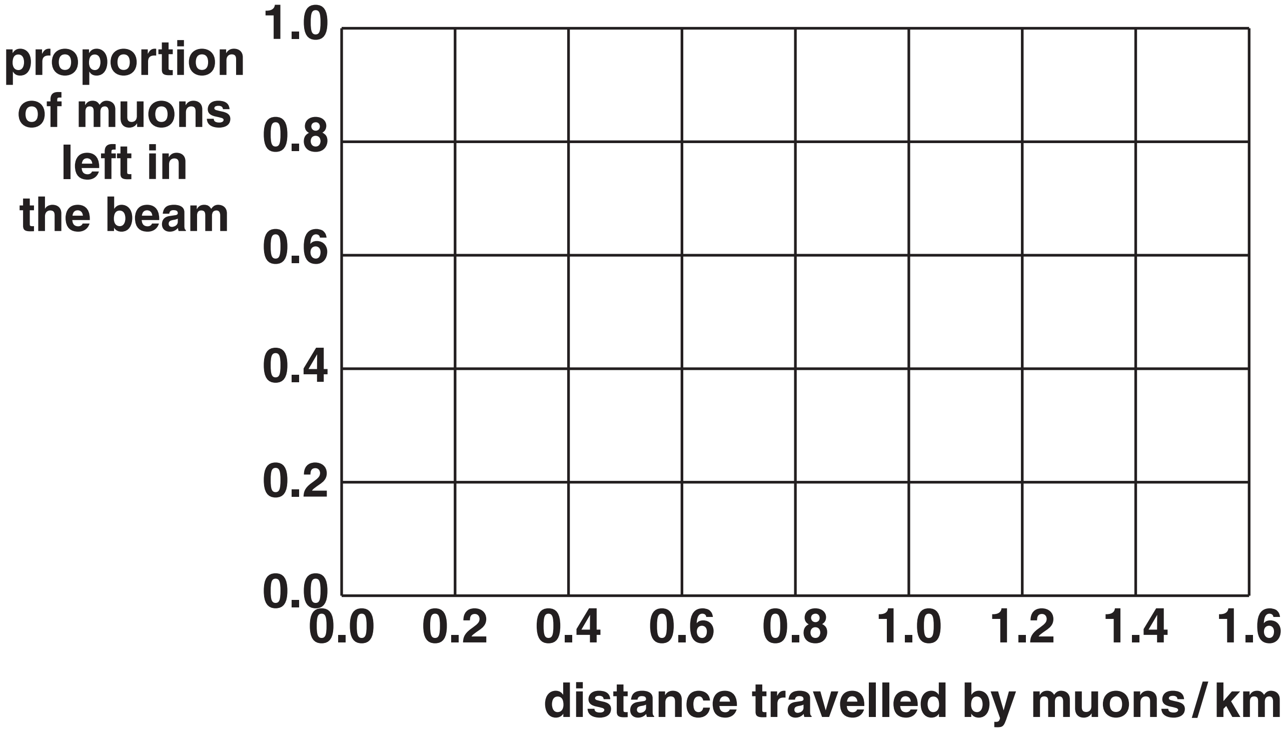

Fig. 13.1

[2]

(iii) The experiment shows that the non-relativistic calculation of (i) is wrong.

The muons in the beam are able to travel a distance of 4.0 km before only one-eighth of them are left undecayed. Use the formula

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

to help explain why this is different from your answer to (i).

Your answer should include a value for γ.

[3]

[Total: 11]

[Section B Total: 40]

END OF QUESTION PAPER

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