OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS B (ADVANCING PHYSICS)

Rise and Fall of the Clockwork Universe

2863/01

Friday **20 JANUARY 2006** Morning 1 hour 15 minutes

Candidates answer on the question paper.
Additional materials:
Data, Formulae and Relationships Booklet
Electronic calculator

Candidate Name

Centre Number

Candidate Number

TIME 1 hour 15 minutes

INSTRUCTIONS TO CANDIDATES

- Write your name in the space above.
- Write your Centre number and Candidate number in the boxes above.
- Answer **all** the questions.
- Write your answers, in blue or black ink, in the spaces provided on the question paper.
- Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure you know what you have to do before starting your answer.
- Show clearly the working in all calculations and give answers to only a justifiable number of significant figures.
- Do not write in the bar code. Do not write in the grey area between the pages.
- **DO NOT** WRITE IN THE AREA **OUTSIDE** THE BOX BORDERING EACH PAGE. ANY WRITING IN THIS AREA WILL NOT BE MARKED.

INFORMATION FOR CANDIDATES

- You are advised to spend about 20 minutes on Section A and 55 minutes on Section B.
- The number of marks is given in brackets [ ] at the end of each question or part question.
- There are four marks for the quality of written communication in 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.

FOR EXAMINER'S USE		
Section	**Max.**	**Mark**
A	**20**	
B	**50**	
TOTAL	**70**	

This question paper consists of 16 printed pages.

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[Turn over

Answer **all** the questions.

Section A

1 The nearest star, Proxima Centauri, is at a distance of 4.3 **light years** from Earth.

Calculate the distance to Proxima Centauri in metres.

$c = 3.0 \times 10^{8}\ \mathrm{m\,s^{-1}}$

1 year = $3.2 \times 10^{7}\ \mathrm{s}$

distance = ...m [2]

2 A process has an activation energy $E = 40\,\text{kJ mol}^{-1}$.

(a) Show that $40\,\text{kJ mol}^{-1}$ is about 7×10^{-20} J per particle.

The Avogadro constant (number of particles per mole) $= 6.0 \times 10^{23}\,\text{mol}^{-1}$.

[1]

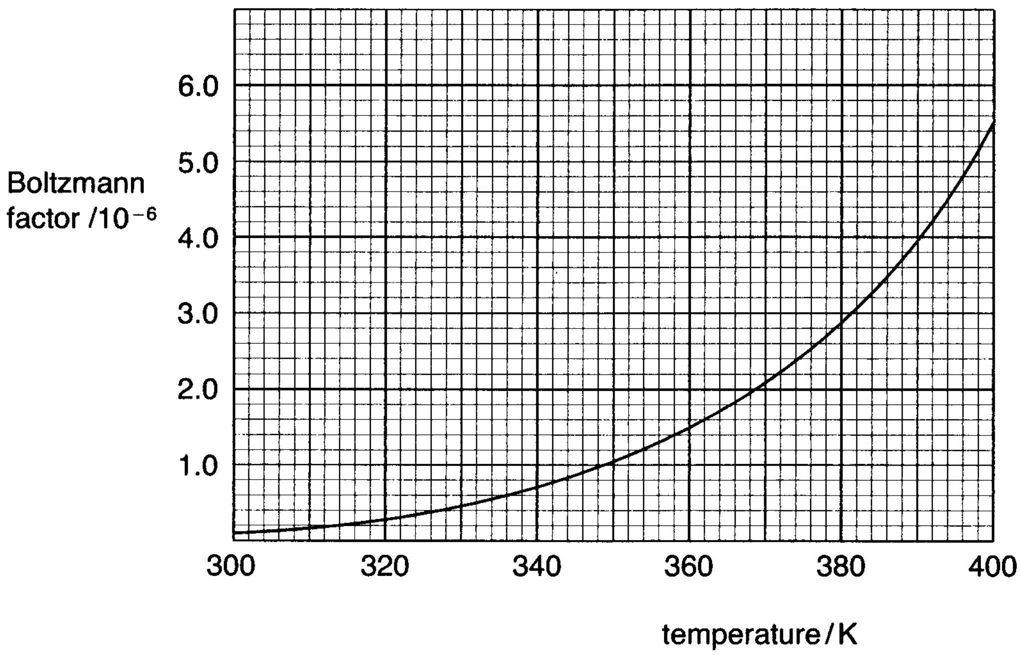

Fig. 2.1

(b) Fig. 2.1 shows the variation with temperature of the Boltzmann factor $f = e^{-E/kT}$ for this process.

(i) Describe how the Boltzmann factor varies with temperature over the range shown in the graph.

[2]

(ii) Sketch a second line on the graph showing how the Boltzmann factor would vary with temperature for a process with a slightly lower activation energy. [1]

3 An astronaut is using a 'manoeuvring unit' to propel herself during a spacewalk. A jet of nitrogen gas is ejected backwards to propel her forwards.

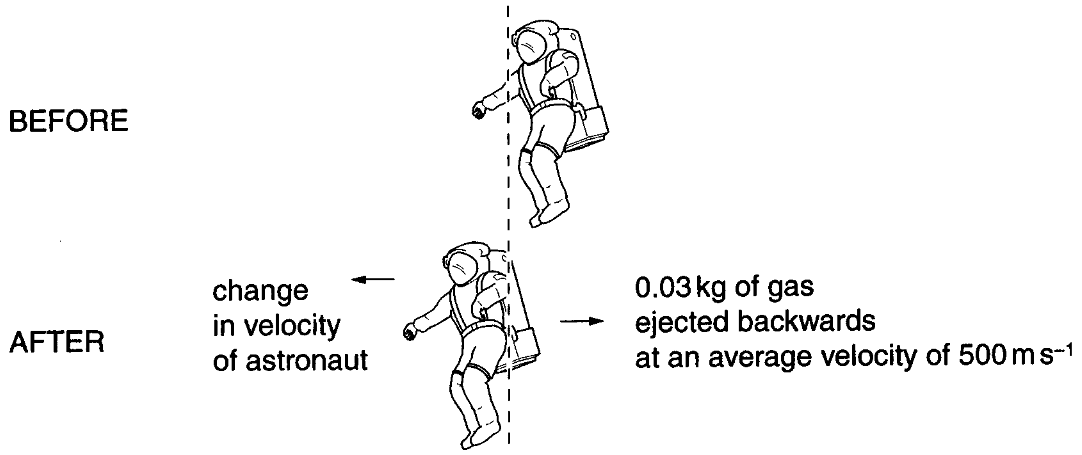

Fig. 3.1

The unit expels 0.03 kg of nitrogen gas at an average velocity of 500 m s^{-1}.

(a) Calculate the momentum of the expelled gas.

momentum = ... kg m s^{-1} [1]

(b) Calculate the change in velocity of the astronaut.

Mass of astronaut and manoeuvring unit after ejection of gas = 110 kg.

change in velocity = ... m s^{-1} [1]

4 A physics laboratory has a volume of $210\,m^3$.

(a) Calculate the mass of air in the laboratory.

density of air = $1.3\,kg\,m^{-3}$

mass of air = ...kg [1]

(b) Calculate the energy needed to raise the temperature of the air in the room from 15 °C to 22 °C.

specific thermal capacity of air = $1000\,J\,kg^{-1}\,K$

energy = ...J [2]

(c) Give a reason why the actual energy to warm the room is likely to be greater than suggested by this simple calculation.

[1]

5 A student produces a simple model of radioactive decay using the following equation

rate of decay of sample $\dfrac{\Delta N}{\Delta t} = -\lambda N$

where N is the number of nuclei present
λ is the decay constant
Δt is a small interval of time
ΔN is the number of nuclei decaying in time Δt.

The student chooses to set λ at $0.14\,\text{s}^{-1}$, the initial number of nuclei at 9.0×10^5 and the time interval Δt between calculations at 1.0 s. It is assumed that the rate of decay is constant over each time interval.

(a) Show that according to this model the number of nuclei remaining after 1.0 s is about 7.7×10^5.

[2]

(b) The student uses the model to calculate the number of nuclei remaining at successive one second time intervals for a period of 8 seconds. These results are shown in Fig. 5.1.

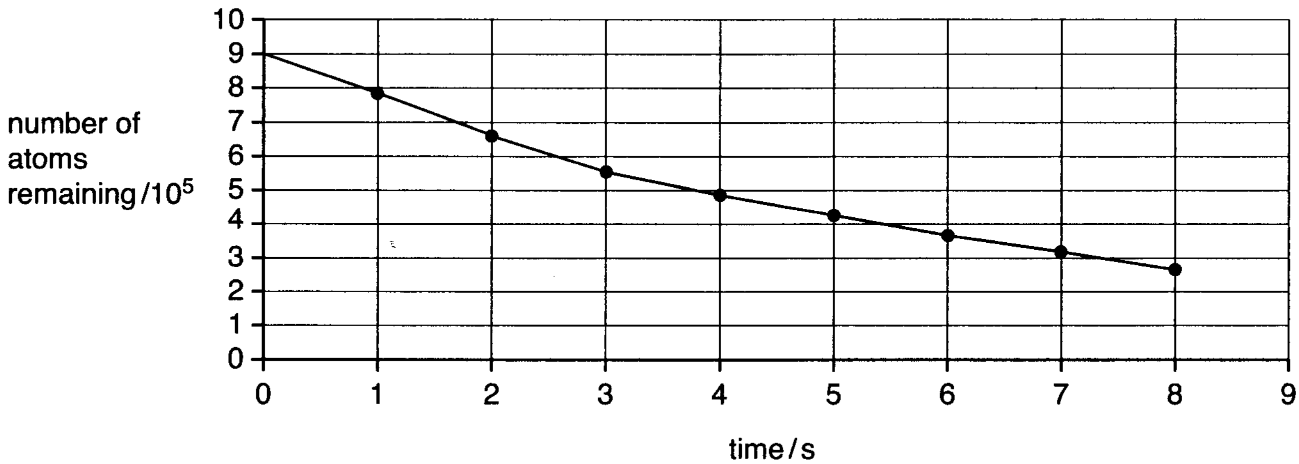

Fig. 5.1

(i) Show on the graph that the model gives a half-life of about 4.6 s. [1]

(ii) The actual half-life of an isotope with a decay constant of $0.14\,\text{s}^{-1}$ is 5.0 s. Account for the inaccuracy of the model and suggest how the model could be improved to give a closer match to reality.

[2]

6 Fig. 6.1 shows a diagram of the interior of the Sun.

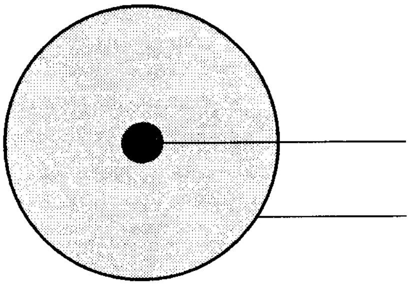

Fig. 6.1

(a) Estimate the typical energy of a gamma photon at a temperature of 10^7 K.

the Boltzmann constant, $k = 1.4 \times 10^{-23}\,\text{J K}^{-1}$

energy = ...J [1]

(b) Energy is transferred from the core at 10^7 K to the photosphere at 6000 K by a process of absorption and re-emission of photons.

Use these data to show that for every one gamma photon in the core about 2000 visible photons are emitted in the photosphere.

[2]

[Section A Total: 20]

Section B

In this section, four marks are available for the quality of written communication.

7 The 4700 μF capacitor shown in Fig. 7.1 is used as a part of a timing circuit.

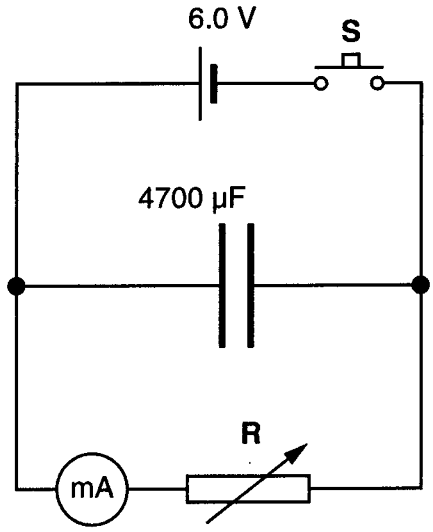

Fig. 7.1

The variable resistor **R** is initially set to a value of 12 kΩ.
The timing sequence is started by closing and opening the switch **S**.

(a) Whilst the switch **S** is closed, calculate

(i) the charge stored by the capacitor

charge = ...C [1]

(ii) the energy stored by the capacitor

energy = ...J [2]

(iii) the current in **R**.

current = ...unit .... [2]

(b) **(i)** Explain why the current will start to decrease as soon as **S** is opened.

[2]

(ii) Show that the time constant τ for this circuit is about 60 s.

[1]

(c) The experiment is repeated with the value of **R** reduced to 6.0 kΩ from its previous value of 12 kΩ.

State the new values of

(i) the current whilst the switch is closed

current = ... [1]

(ii) the time constant.

time constant = ...[1]

(d) With **R** set at 6.0 kΩ, a student briefly closes the switch **S** every 10 seconds. The voltage across the capacitor varies as shown in Fig. 7.2.

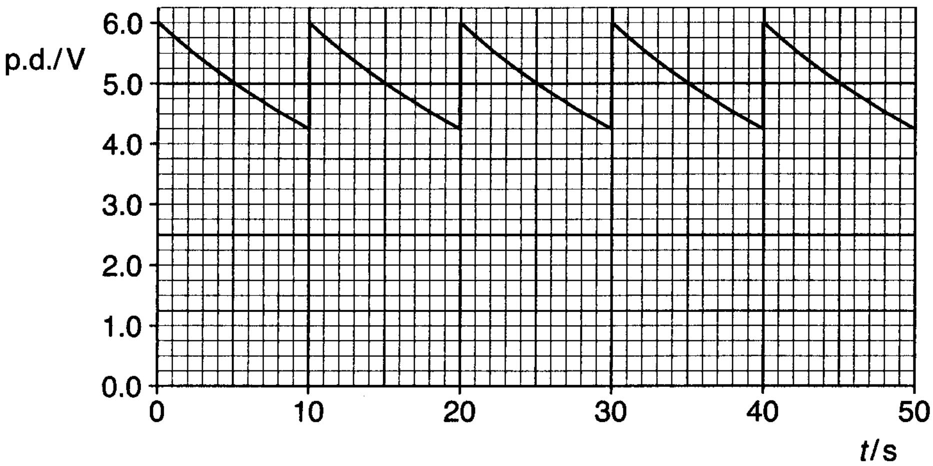

Fig. 7.2

State and explain **two** features of the graph.

feature 1:

explanation:

feature 2:

explanation:

[4]

[Total: 14]

8 This question is about a method of separating two forms of the gas uranium hexafluoride, UF_6.

Most UF_6 molecules are composed of fluorine and ^{238}U atoms . Some molecules have ^{235}U as their uranium component. As ^{235}U is useful in the nuclear industry, it is necessary to separate the two forms.

In **gaseous diffusion**, the gas is pumped into the high pressure chamber shown in Fig. 8.1. The $^{235}UF_6$ diffuses more quickly through the porous walls than the more massive $^{238}UF_6$.

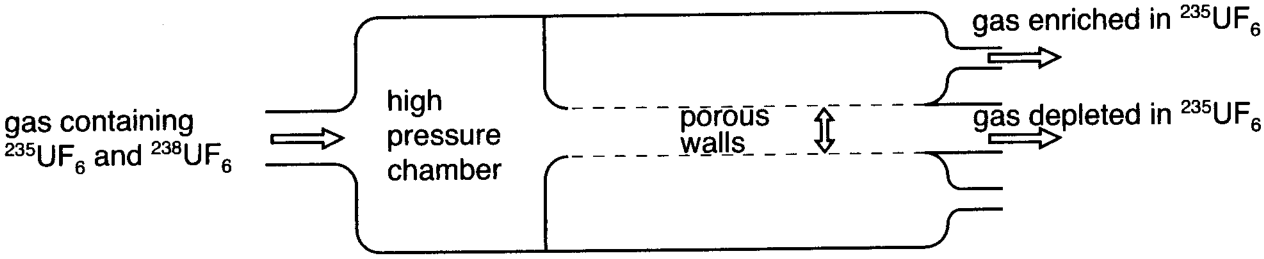

Fig. 8.1

(a) The average kinetic energy of a gas molecule of mass m at temperature T is given by the equation

$\frac{1}{2}mc^2 = \frac{3}{2}kT$ where c^2 is the mean square speed of the molecules.

(i) Explain why molecules of gas have a range of energies at any given temperature.

[1]

(ii) Calculate the root mean square (r.m.s.) speed c for molecules of $^{238}UF_6$ gas at 350 K.

mass of $^{238}UF_6$ molecule = 5.85×10^{-25} kg
$k = 1.38 \times 10^{-23}$ J K^{-1}

r.m.s. speed = ...m s^{-1} [2]

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(iii) Use $\frac{1}{2}mc^2 = \frac{3}{2}kT$ to show

$$\frac{\text{r.m.s. speed of molecule mass } m_1}{\text{r.m.s. speed of molecule mass } m_2} = \sqrt{\frac{m_2}{m_1}}$$

when both gases are at temperature T.

[2]

(iv) Hence calculate the r.m.s. speed of $^{235}UF_6$ molecules at 350 K.

mass of $^{235}UF_6$ molecule = 5.80×10^{-25} kg

r.m.s. speed = ... m s^{-1} [2]

(b) The process of gaseous diffusion involves molecules diffusing through tiny holes in the porous walls shown in Fig. 8.1.

Explain why the less massive $^{235}UF_6$ molecules will diffuse more quickly than $^{238}UF_6$ even though they are same size.

[2]

(c) The uranium hexafluoride passes through many diffusers before the proportion of $^{235}UF_6$ is high enough for use in the nuclear industry.

Explain why one pass through a diffuser will not fully separate the two forms of uranium hexafluoride.

[2]

[Total: 11]

9 Fig. 9.1 shows Spirit, a space probe approaching the planet Mars.

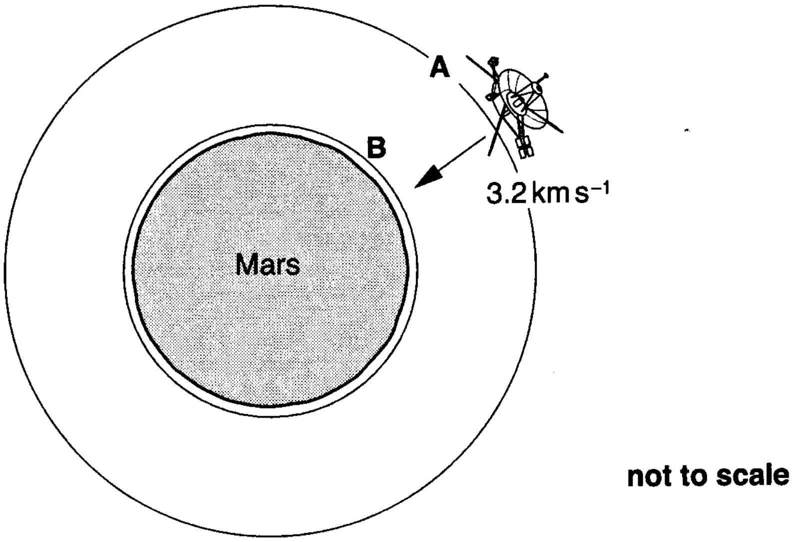

Fig. 9.1

At point **A**, Spirit is at a distance of 6×10^6 m from the planet's centre of mass travelling directly towards the planet at a speed of $3.2\,\text{km s}^{-1}$. Its engines are turned off.

(a) Show that the gravitational potential at point **A** is about $-7 \times 10^6\,\text{J kg}^{-1}$.

$G = 6.7 \times 10^{-11}\,\text{N m}^2\,\text{kg}^{-2}$
mass of Mars, $M = 6.4 \times 10^{23}\,\text{kg}$

[2]

(b) At point **B**, a height of 128 km above the surface, Spirit enters the upper atmosphere of Mars at a speed of $4.5\,\text{km s}^{-1}$. Its engines have been turned off since reaching point **A**. The gravitational potential at point **B** is $-1.2 \times 10^7\,\text{J kg}^{-1}$.

Explain why the craft speeds up as it approaches the planet.

[2]

(c) A few minutes later, the Martian atmosphere has slowed the spacecraft's speed to $430\,\mathrm{m\,s^{-1}}$.

Explain how interaction with the particles of the Martian atmosphere removes energy from the craft.

[2]

(d) After deploying a parachute and some braking rockets, the vertical speed of the landing probe is reduced to $0\,\mathrm{m\,s^{-1}}$ at which point it simply drops the remaining 15 m.

(i) Show that the magnitude of the gravitational field strength at the surface of Mars is just less than $4\,\mathrm{N\,kg^{-1}}$. State the equation you use in your calculation.

radius of Mars, $r = 3.4 \times 10^{6}\,\mathrm{m}$

[3]

(ii) Calculate the speed of the craft as it hits the surface assuming it falls from rest for the last 15 m.

[2]

[Total: 11]

[Turn over

10 This question is about a mass oscillating on an elastic spring.
The spring constant k for the spring is $24\,\mathrm{N\,m^{-1}}$.

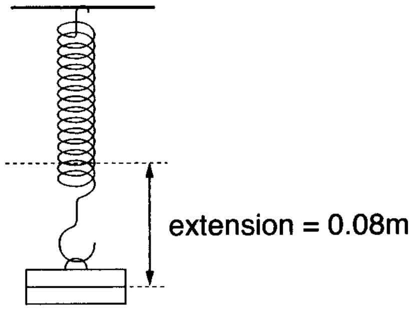

Fig. 10.1

(a) A mass of 0.20 kg is hung from the end of the spring and the system comes to rest.

(i) Show that the extension of the spring is about 0.08 m.

$g = 9.8\,\mathrm{N\,kg^{-1}}$

[1]

(ii) Calculate the elastic strain energy stored in the spring.

elastic strain energy = ... J [2]

(iii) Calculate the change in gravitational potential energy of the mass as it extends the spring by 0.08 m.

change in gravitational potential energy = ... J [2]

(iv) Explain why the energy stored in the spring is less than the change in gravitational potential energy.

[1]

(b) The spring is extended by a further 0.060 m and then released. The mass oscillates up and down.
The motion of the mass is recorded using a data logger. A short section of the trace is shown in Fig. 10.2.

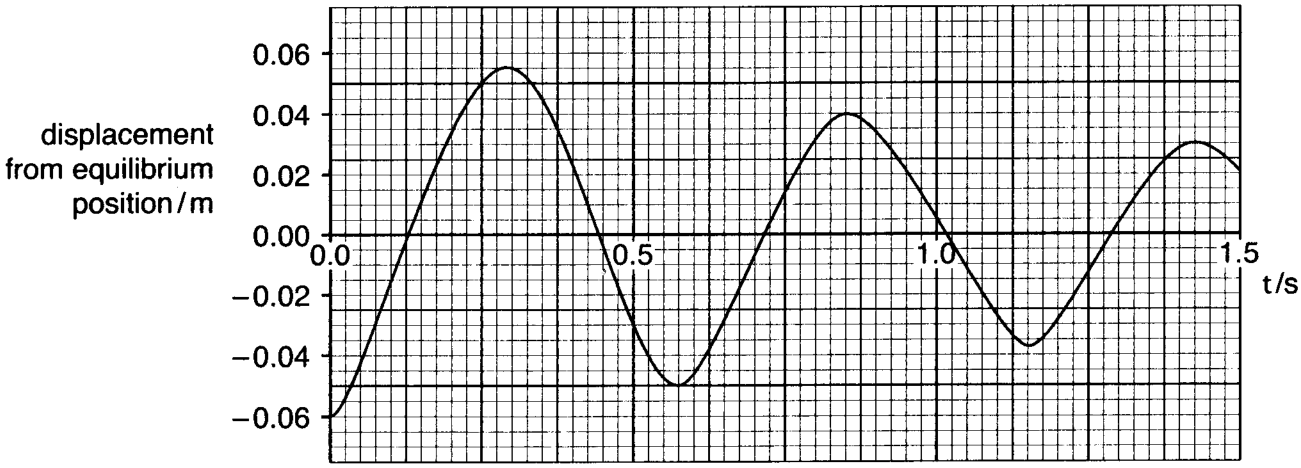

Fig. 10.2

(i) State how the graph shows that the velocity of the oscillating mass is zero when it is at maximum displacement.

[1]

(ii) Mark a point on the graph where the resultant force on the oscillating mass is zero. Label this point **X**. [1]

(c) The time trace of the oscillator over a large number of oscillations is shown in Fig. 10.3.

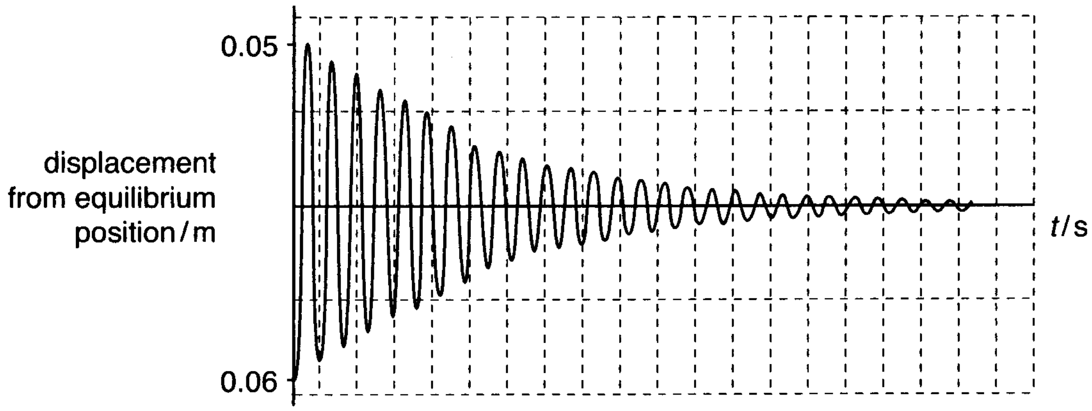

Fig. 10.3

Explain how the graph shows that the amplitude of the oscillation falls exponentially over time.

[2]

[Total: 10]

Quality of Written Communication [4]

[Section B Total: 50]

END OF QUESTION PAPER