OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS B (ADVANCING PHYSICS) 2863/01

Rise and Fall of the Clockwork Universe

Thursday **16 JUNE 2005** 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 the spaces provided on the question paper.
- 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.

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.
- Four marks are available for the quality of written communication in Section B.
- The values of standard physical constants are given in the Data, Formulae and Relationship Booklet. Any additional data required are given in the appropriate question.

FOR EXAMINER'S USE		
Section	Max.	Mark
A	21	
B	49	
TOTAL	70	

This question paper consists of 16 printed pages.

For Examiner's Use

Answer **all** the questions.

Section A

1 Fig. 1.1 shows a pendulum about to be released from point **P** at $t = 0$. The pendulum is made from a table tennis ball on the end of a length of thread.

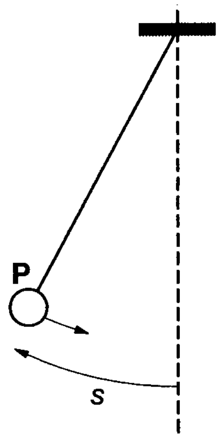
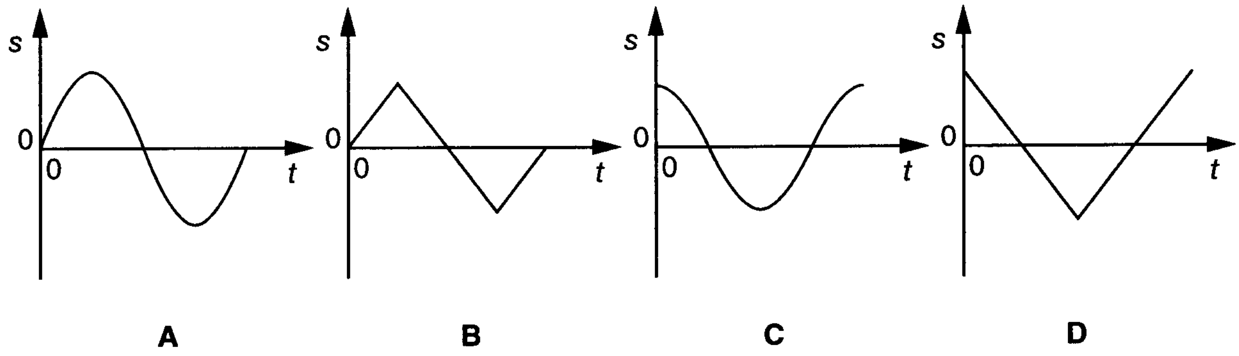


Fig. 1.1

(a) Choose which of the graphs showing the displacement s measured from the equilibrium position and time t best represents one oscillation of the ball released from point **P** at time $t = 0$.



The oscillation is best represented by graph .... [1]

(b) A glass block is placed at the centre of the oscillation as shown in Fig. 1.2. The ball bounces from the block.

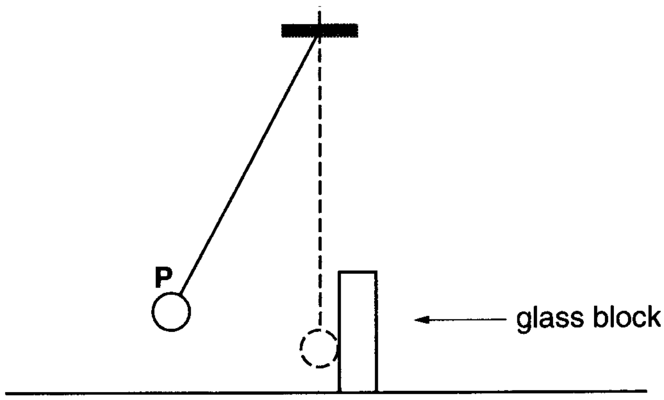
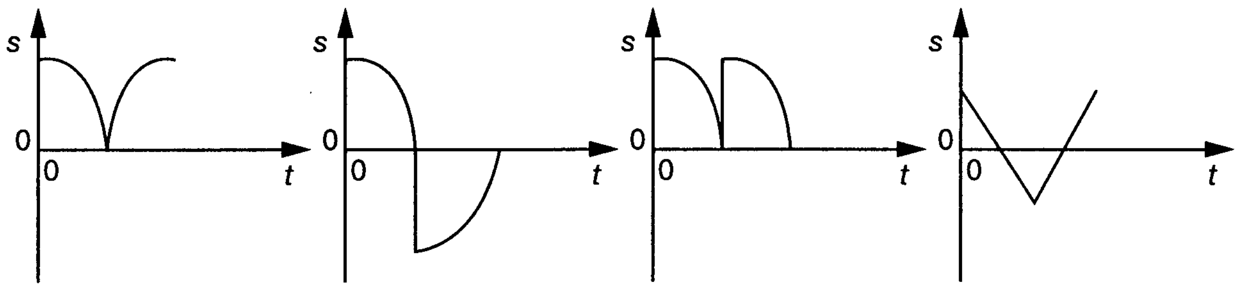


Fig. 1.2

Choose which of the graphs showing the displacement s and time t best represents one oscillation of the ball released from point **P**.



A **B** **C** **D**

The oscillation is best represented by graph .... [1]

2 The flash unit of a disposable camera contains a 470 μF capacitor. The potential difference across the charged capacitor is 270 V.

(a) Calculate the charge on the capacitor.

charge on capacitor = ... unit ....[3]

(b) Calculate the energy stored on the capacitor.

energy stored on capacitor = ... J [2]

For Examiner's Use

3 About three hundred thousand years after the Big Bang, the Universe was at a temperature of roughly 3000 K.

The photons emitted at that time are now observed to be at a temperature of around 3 K.

(a) Calculate the ratio $\dfrac{\text{energy of photons at 3 K}}{\text{energy of photons at 3000 K}}$

ratio = ... [1]

(b) Calculate the ratio $\dfrac{\text{wavelength of photons at 3 K}}{\text{wavelength of photons at 3000 K}}$

ratio = ... [1]

(c) Suggest why the answer to **(b)** gives a measure of how the radius of the Universe has changed since the photons were emitted.

[1]

4 The time constant τ of the discharge of a capacitance C through a resistance R is given by $\tau = RC$.

Show that the unit of the quantity RC is seconds.

[2]

5 Here are some data for one mole of ideal gas.

	pressure / Pa	volume / m^3	temperature / K
standard temperature and pressure (s.t.p)	1.01×10^5		273
room temperature and pressure (r.t.p)	1.01×10^5	2.45×10^{-2}	

(a) Show that the volume of one mole of an ideal gas at s.t.p. is about $2.2 \times 10^{-2}\,m^3$. Write down the equation you use to obtain your answer.

$R = 8.31\,J\,K^{-1}\,mol^{-1}$

[2]

(b) One mole of ideal gas at r.t.p. has a pressure of $1.01 \times 10^5\,Pa$ and a volume of $2.45 \times 10^{-2}\,m^3$.

Show that room temperature is about 25 °C.

[2]

6 Fig. 6.1 shows a method for heating water. A curved mirror focuses solar energy on to a tube carrying the water.

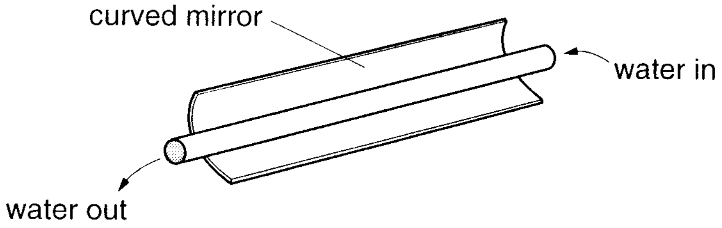


Fig. 6.1

When in operation, 900 J of solar energy strike the mirror each second.

Water flows along the tube at a rate of 0.020 kg s^{-1}.

Calculate the maximum possible temperature rise of the water flowing through the tube.

specific thermal capacity of water = 4200 J kg^{-1} K^{-1}

maximum possible temperature rise = ... K [2]

For Examiner's Use

7 It is important to monitor the mass of astronauts on long space missions. One method of measuring mass is shown in Fig. 7.1.

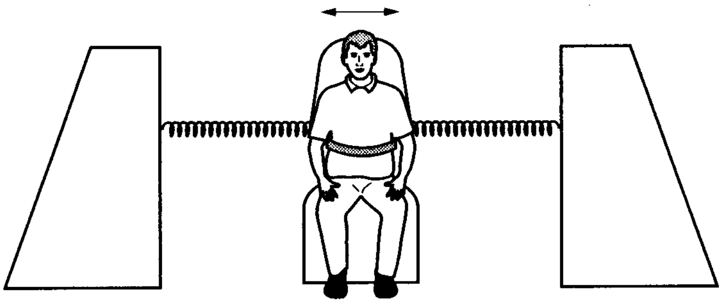


Fig. 7.1

The astronaut sits in the chair which is set oscillating in the direction shown.

Here are some data about the system.

stiffness constant k of spring system = $9.0 \times 10^3\,\mathrm{N\,m^{-1}}$

time period T of the oscillation = 0.60 s

mass of chair = 15 kg

Show that the mass of the astronaut is about 70 kg.

[3]

[Section A Total: 21]

For Examiner's Use

Section B

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

8 This question is about the behaviour of gases.

The average translational kinetic energy per molecule of gas $\frac{1}{2}m\overline{v^2}$ is related to the absolute temperature T by the relationship

$$\frac{1}{2}m\overline{v^2} = \frac{3}{2}kT$$

where k, the Boltzmann constant, is $1.4 \times 10^{-23}\,\mathrm{J\,K^{-1}}$.

(a) Show that the root mean square speed $\sqrt{\overline{v^2}}$ is proportional to $\frac{1}{\sqrt{m}}$ when T is kept constant.

[1]

(b) The table shows the root mean square (r.m.s.) speed of molecules for three gases at 293 K.

gas	mass / 10^{-27} kg	r.m.s. speed / m s^{-1}
helium	6.7	1400
neon	33	600
carbon monoxide	47	510

Propose and carry out an arithmetical test to decide whether the data in the table support the statement that the r.m.s. speed is proportional to $\frac{1}{\sqrt{m}}$ when T is kept constant.

proposed arithmetical test | calculation

conclusion:

[4]

For Examiner's Use

Fig. 8.1 shows the distribution of molecular speeds in a sample of oxygen gas.

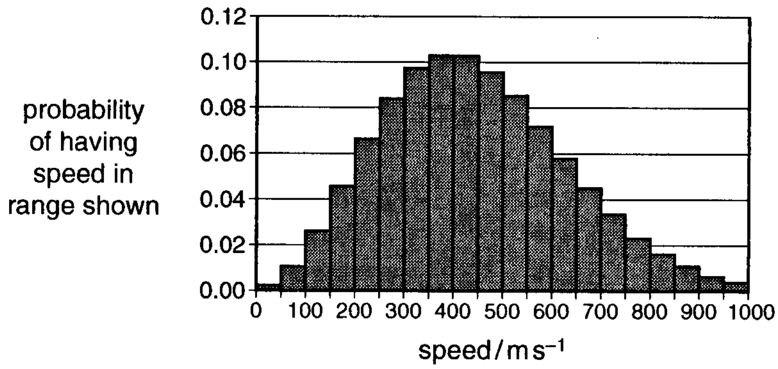


Fig. 8.1

The area of each bar is proportional to the fraction of molecules having a speed within that range. The chart shows that the molecules have a range of speeds.

(c) Use ideas from kinetic theory to explain why

(i) gas molecules have a range of speeds

[2]

(ii) gas molecules are very unlikely to have speeds **much** greater than the most common speed.

[2]

(d) (i) Fig. 8.1 shows that the most probable speed is 400 $m\,s^{-1}$.

Use the equation *root mean square speed = 1.2 × most probable speed*

to calculate the mean square speed of the molecules in the sample of the gas.

mean square speed = ... $m^2 s^{-2}$ [2]

(ii) Use your answer to **(d)(i)** to estimate the temperature of the gas.

mass of O_2 molecule = 5.3×10^{-26} kg.

temperature of gas = ... K [2]

[Total: 13]

[Turn over

9 This question is about the gravitational field around an asteroid.

It is assumed that the asteroid is spherical and of uniform density.

(a) **(i)** Fig. 9.1 shows some equipotential lines around the asteroid. There is a constant potential difference between each equipotential line.

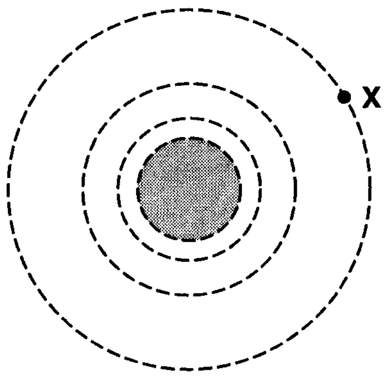


Fig. 9.1

State how the diagram shows that the gravitational field strength decreases as the distance from the surface of the asteroid increases.

[1]

(ii) Draw the gravitational field line through point **X**. [2]

(b) Here are some data about the asteroid.

radius = 1.25×10^5 m

mass = 4.5×10^{19} kg

(i) Show that the magnitude of the gravitational field strength on the surface of the asteroid is about $0.2\,\text{N kg}^{-1}$. Write down the equation you use to obtain your answer.

$G = 6.7 \times 10^{-11}\,\text{N m}^{-2}\,\text{kg}^{-2}$

[2]

(ii) It has been suggested that a space vehicle could land on the asteroid to search for valuable minerals.

Calculate the gravitational force on a vehicle of mass 3.0×10^2 kg on the surface of the asteroid.

force = ... N [1]

(c) The asteroid is spinning. The time for one rotation of the asteroid is five hours.

The space vehicle is on the equator of the asteroid at a distance 1.25×10^5 m from the centre.

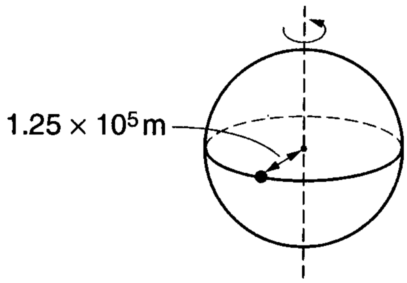


Fig. 9.2

(i) Show that the speed of a point on the surface of the asteroid is about 40 m s^{-1}.

[2]

(ii) Calculate the centripetal force needed to keep the vehicle on the surface of the asteroid at this point.

centripetal force = ... N [2]

(iii) Explain why the vehicle stays on the surface of the asteroid despite the rotation of the asteroid.

[2]

[Total: 12]

[Turn over

For Examiner's Use

10 This question is about a model of a liquid flow.

Water molecules are pictured as being 'caged in' by their neighbours, as shown in Fig. 10.1.

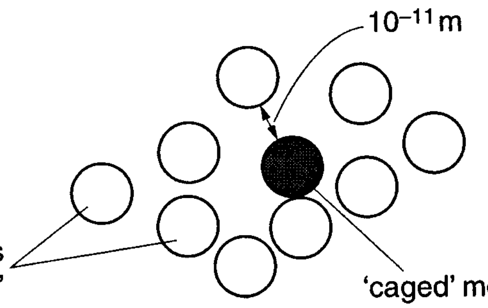


Fig. 10.1

For the water to flow, molecules must break free of their cages.
A molecule moves about 1×10^{-11} m between each collision with a wall of the 'cage'.

At 300 K, the average speed of water molecules is about 100 m s^{-1}.

On average, it takes a molecule 40 collisions ('breakout attempts') with the walls of the cage to break free. In this time, the molecule crosses the cage 40 times.

(a) Calculate the average time taken to break free.

time .... s [2]

(b) Estimate the energy of a water molecule at 300 K.

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

energy = ... J [2]

(c) The energy required by a molecule to break free is about 1.5×10^{-20} J.

Show that the Boltzmann factor for a water molecule breaking out of its cage at 300 K is approximately $\frac{1}{40}$.

[3]

For Examiner's Use

(d) Explain why a Boltzmann factor of $\frac{1}{40}$ supports the statement that on average it takes a molecule 40 breakout attempts to break free.

[1]

(e) The Boltzmann factor for water at the higher temperature 320 K is about 0.035.

(i) State the average number of collisions with the walls of the cage made by a water molecule at this temperature before it breaks free.

number of breakout attempts = ... [1]

(ii) Use your previous answers to suggest why water flows more quickly when warmer.

[2]

[Total: 11]

For Examiner's Use

11 This question is about the decay of a radioactive substance.

The rate of decay of a radioactive substance is described by the equation

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

where

λ is the probability of any single nucleus decaying in unit time
N is the number of undecayed nuclei present at time t.

(a) Explain how the equation shows that the activity will decrease over time.

[2]

(b) A sample with 1.0 g of $^{238}_{92}U$ contains 2.5×10^{21} uranium-238 nuclei.

Calculate the activity of the sample.

$\lambda = 5.0 \times 10^{-18}\,s^{-1}$

activity = ... s^{-1} [1]

(c) The graph in Fig. 11.1 shows how the natural logarithm of the number (ln N) of uranium-238 nuclei will change with time from an initial sample of 1.0 g of uranium-238.

$\ln 2.5 \times 10^{21} = 49.3$

$\ln 2 = 0.693$

For Examiner's Use

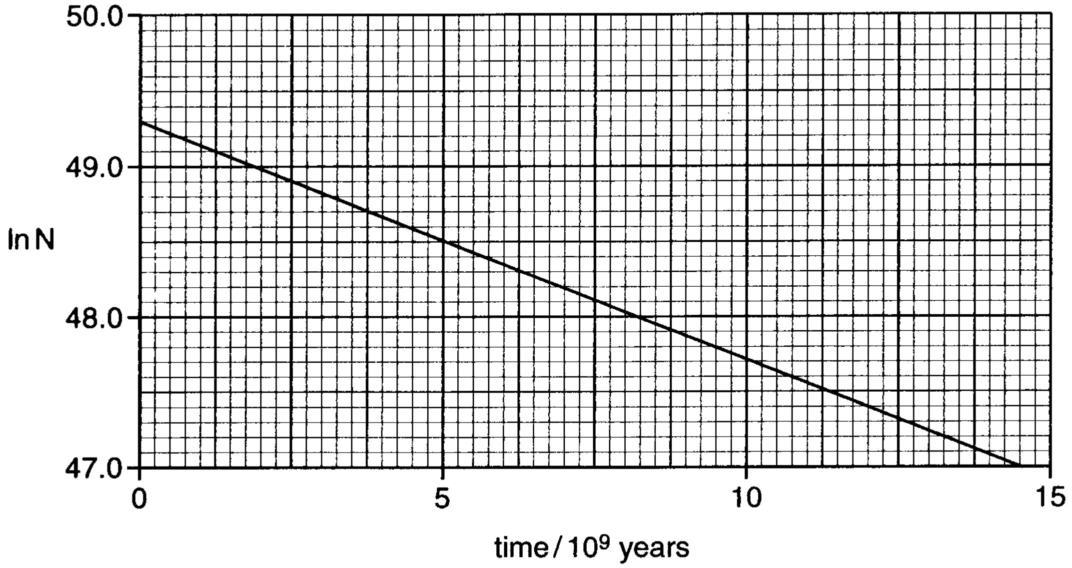


Fig. 11.1

(i) Explain how the graph shows that the half-life is about 4.5 billion years.

[2]

(ii) Explain why the activity of the sample of uranium-238 also falls to half its original value in this period.

[1]

(iii) Draw a line on the graph showing the decay of a 0.5 g sample of uranium-238. Label this line A. [2]

(d) The stable isotope lead-206 is formed only by the decay of uranium-238. The age of rocks can be estimated by measuring the ratio of lead-206 to uranium-238.

Suggest why rocks are never found with a lead-206 to uranium-238 ratio of more than about 1:1.

age of Earth = 4.6×10^9 years

[1]

[Total: 9]

[Quality of Written Communication 4]

[Section B Total: 49]