RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS B (ADVANCING PHYSICS) 2863/01

Rise and Fall of the Clockwork Universe

Friday **20 JUNE 2003** Afternoon 1 hour 10 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 10 minutes

INSTRUCTIONS TO CANDIDATES

- Write your name in the spaces 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 50 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 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 14 printed pages and 2 blank pages.

For Examiner's Use

Answer **all** the questions.

Section A

1 Fig. 1.1 shows three possible paths, **A**, **B** and **C**, of a spacecraft moving near the Earth but well above the atmosphere.

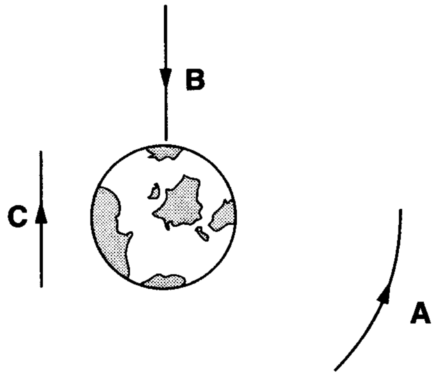

Fig. 1.1

(a) Which path follows a gravitational field line of the Earth ?

answer ....[1]

(b) Which path follows a gravitational equipotential line of the Earth?

answer ....[1]

2 Fig. 2.1 shows how the displacement of a simple harmonic oscillator varies with time.

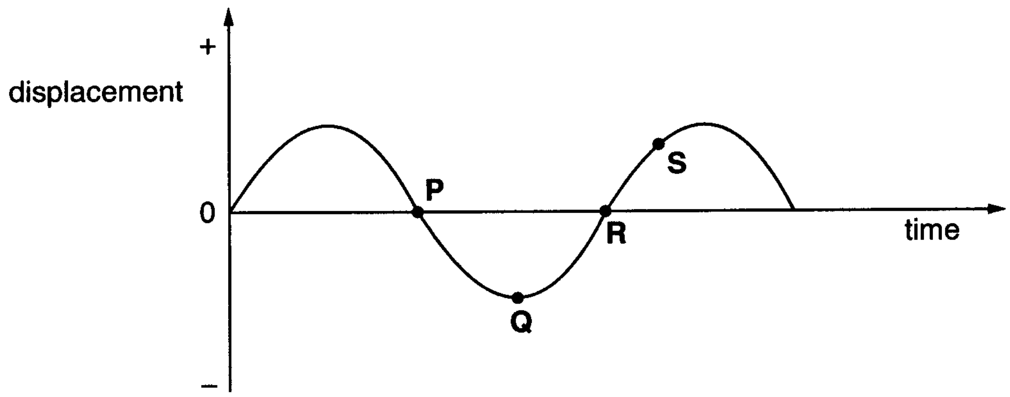

Fig. 2.1

(a) At which point, **P**, **Q**, **R** or **S**, is the acceleration the greatest?

answer ....[1]

(b) At which point, **P**, **Q**, **R** or **S,** is the velocity of the oscillator at its greatest positive value?

answer ....[1]

3 Here is a list of units.

JC^{-1} Cs^{-1} s s^{-1}

Which is the unit of λ, the radioactive decay constant?

answer ....[1]

4 A student makes and calibrates the simple water clock shown in Fig. 4.1.

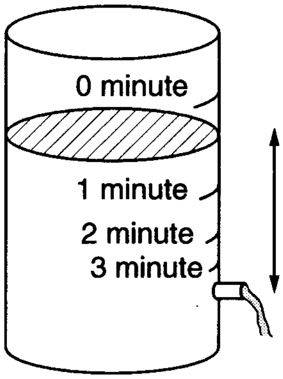

Fig. 4.1

(a) Explain how the marked time scale shows that the relationship between level of water and time passed is **not** linear.

[1]

(b) The rate of change of height of water $\frac{dh}{dt}$ is related to the instantaneous height h of water by the equation

$$\frac{dh}{dt} = -kh$$

where k is a constant.

(i) Describe, in words, the meaning of the equation $\frac{dh}{dt} = -kh$.

[2]

(ii) Suggest a physical factor that might affect the value of k.

[1]

5 At temperature T, the average energy of a particle is of the order kT where k is the Boltzmann constant.

(a) Show that the average energy of a particle, kT, at 300 K is about 4×10^{-21} J.

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

[1]

(b) Water molecules are held to the surface of the liquid by an average of two hydrogen bonds. It requires an energy of about 3.2×10^{-20} J to break each bond.

Show that the average energy required for a water molecule to break free from the surface of the liquid at 300 K is about 15 kT.

[1]

(c) Puddles of water can evaporate quickly on a warm summer's day even though the average energy of the molecules is less than that required to break free from the surface. Explain why this happens.

[2]

6 A player serves a ball in a game of tennis with a racket of mass 0.35 kg. The racket moves with velocity 22 m s^{-1} as it strikes the ball.

(a) Show that the momentum of the racket is about 8 kg m s^{-1}.

[1]

(b) In a typical serve, about 25% of the momentum of the racket is transferred to the ball. The racket strikes a stationary tennis ball of mass 0.050 kg.

Estimate the velocity of the ball when it leaves the racket.

[2]

7 A plastic duck hangs from a long spring as shown in Fig. 7.1. The duck oscillates vertically with a time period of 2.4 s.

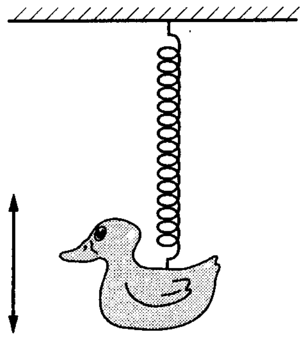

Fig. 7.1

(a) Calculate the frequency, *f*, of the oscillation.

frequency = ... Hz [2]

(b) The displacement x of the duck at time t is given by the equation

$$x = A \cos (2 \pi f t)$$

where $A = 0.20$ m.

Calculate the displacement of the duck when $t = 2.0$ s.

displacement = ... m [2]

[Section A Total: 20]

[Turn over

For Examiner's Use

Section B

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

8 This question is about choosing a capacitor to act as a back-up power supply for a digital clock display. The back-up supply must be able to store at least 30 J of energy and maintain a voltage of over 2 V for at least 12 hours.
Fig. 8.1 shows the basis of the system.

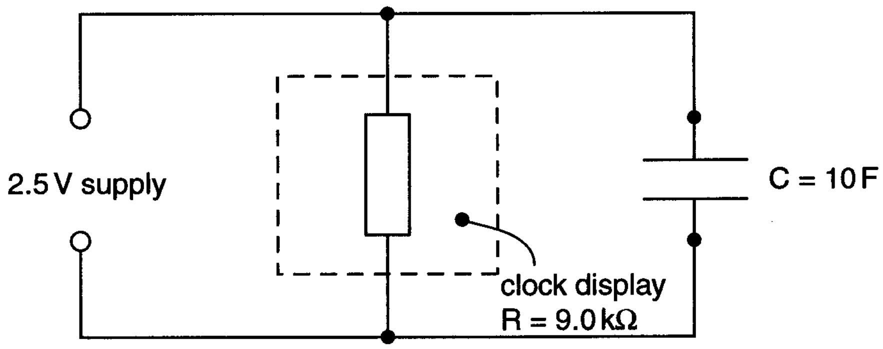

Fig. 8.1

When the 2.5 V supply fails, the capacitor begins discharging through the digital clock display system.

Specifications: capacitor rating = 10 F
operating voltage = 2.5 V
clock display = 9.0 kΩ

It is required that the capacitor can store at least 30 J of energy when at an operating voltage of 2.5 V.

(a) **(i)** Show that the 10 F capacitor meets this requirement.

[2]

(ii) The power supply in the circuit shown in Fig. 8.1 is disconnected.

Show that the time constant *RC* of the circuit is more than one day.

[2]

(b) When the supply fails, the voltage across the capacitor falls to $\frac{1}{e} = 0.37$ of its original value after one time constant *RC*.

(i) Complete the table below.

time	time passed / hour	potential difference across capacitor / V
0	0	2.5
RC	25	
2 *RC*	50	
3 *RC*	75	0.13

[2]

(ii) Draw a graph of these data on the axes of Fig. 8.2.

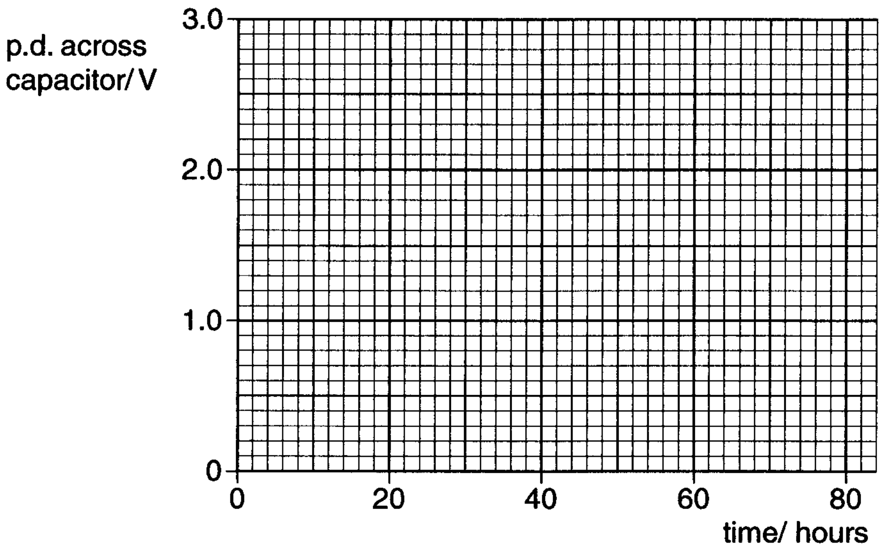

Fig. 8.2

[2]

(iii) Use the graph to decide whether the capacitor will be able to maintain a voltage greater than 2.0 V for twelve hours, as required. Show your method clearly.

[1]

[Total: 9]

For Examiner's Use

9 This question is about neutron stars.

Neutron stars are the remnants of huge stars that have exploded as supernovae.
One such neutron star has about the same mass as the Sun but its radius is only of the order of 10 km. Such a dense object has a very high gravitational field strength at its surface.

(a) (i) Write down an expression for g, the gravitational field strength at the surface of a star of mass M and radius r.

[1]

(ii) For a spherical star of average density ρ, the magnitude of g at its surface is given by

$$g = \tfrac{4}{3}G\pi\, r\rho$$

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

Use this expression to show that the units of g are $\mathrm{N\,kg^{-1}}$.

[2]

(iii) Show that the gravitational field strength at the surface of the star is about $1 \times 10^9\,\mathrm{N\,kg^{-1}}$.

$\rho_{star} = 4.0 \times 10^{14}\,\mathrm{kg\,m^{-3}}$

[2]

(b) A remarkable property of neutron stars is that they spin about their axes at a very great rate. The radiation from these stars is observed as regular pulses. This gives rise to the name 'pulsars'.

This particular neutron star of radius 10 km rotates 50 times every second.

(i) Show that the speed of a point on the equator of the star is about one percent of the speed of light.

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

[2]

(ii) Calculate the magnitude of the centripetal acceleration at a point on the equator of the star. Include units in your answer.

acceleration .... unit .... [3]

(c) Neutron stars can spin at a great rate without flying apart because the gravitational field strength is high enough to keep material on the surface of the star.
Explain how this statement is supported by your answers to **(a)(iii)** and **(b)(ii)**.

[3]

[Total: 13]

[Turn over

10 This question is about the speed of molecules in a gas.

The mass of one mole of nitrogen molecules N_2 is 2.8×10^{-2} kg.

There are 6.0×10^{23} molecules in one mole of nitrogen.

(a) Show that the mass of one molecule is about 5×10^{-26} kg.

[1]

(b) The relationship between the kinetic energy of a gas molecule and absolute temperature T is given by

$$\tfrac{1}{2}mv^2 = \tfrac{3}{2}kT$$

Show that the typical speed of nitrogen molecules at 300 K is about 500 m s^{-1}.

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

[2]

(c) When perfume from an air freshener is released into a room, it gradually diffuses through the volume of the room.

(i) Assuming the molecules of perfume move at about 500 m s^{-1}, show that it would take a molecule about 0.015 s to travel the length of a room 7.0 m long.

[2]

(ii) In fact, it takes very much longer than 0.015 s for the perfume to travel 7.0 m. Use ideas about diffusion to explain why this is the case.
A diagram may help your answer.

[3]

(d) The perfume molecules are much larger than nitrogen molecules.
Suggest how the rate of diffusion of perfume molecules compares with that of nitrogen molecules. Justify your answer.

[3]

[Total: 11]

[Turn over

For Examiner's Use

11 This question is about measuring distances and velocities in the Universe.

Distances and velocities of planets and asteroids within the Solar System can be measured by radar pulses from Earth reflected from the distant objects.

(a) A radar pulse from Earth was aimed at an asteroid. The time interval between the pulse leaving the transmitter and the detection of the reflected pulse was 40.2 s.

Show that the distance to the asteroid at the time of measurement was about 6×10^9 m. State any assumption you make.

$c = 3.00 \times 10^8 \text{ m s}^{-1}$

[2]

(b) The measurement was repeated 14 minutes later. The time interval was then 40.0 s.

(i) Show that the change in distance between the Earth and the asteroid was about 3×10^7 m during the period the measurements were taken.

[2]

(ii) Calculate the average velocity of approach of the asteroid at the time of the measurements.

average velocity = ... m s^{-1} [2]

(c) This radar-ranging method is impractical for measuring the distance or velocity of a star such as Sirius which lies about 7 light years from Earth.
Suggest **two** reasons why this is so.

[2]

For Examiner's Use

(d) Distant galaxies are observed to be receding (moving away) from the Earth at high velocities. The velocity of a galaxy in deep space is calculated from its redshift. The distance d to the object can be determined from its velocity of recession v using the relationship

$$v = H_0 d$$

where H_0 is the Hubble constant.

(i) Galaxy Y is observed to be receding at a velocity of $1.0 \times 10^6\,\text{m}\,\text{s}^{-1}$.

Show that the distance from the Earth to galaxy Y is about $4.5 \times 10^{23}\,\text{m}$.

In the year 2001, $H_0 = 2.2 \times 10^{-18}\,\text{s}^{-1}$.

[1]

(ii) Observations of distant galaxies show how the galaxies appeared millions of years ago.

Use your answer to **(d)(i)** to explain why this is so.

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

[2]

(e) The value of H_0 given in **(d)(i)** as $H_0 = 2.2 \times 10^{-18}\,\text{s}^{-1}$ is often given in the alternative form $H_0 = 70\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$.

One megaparsec (Mpc) is an astronomical unit of distance equal to $3.1 \times 10^{22}\,\text{m}$.

Show that the value $70\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$ is approximately equivalent to $2.2 \times 10^{-18}\,\text{s}^{-1}$.

[2]

[Total: 13]

Quality of Written Communication [4]

[Section B Total: 50]