OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS B (ADVANCING PHYSICS) 2863/01

Rise and Fall of the Clockwork Universe

Monday **14 JANUARY 2002** Morning 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 space above.
- Write your Centre number and Candidate number in the boxes above.
- Answer **all** the questions.
- Write your answers in the spaces 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 round answers to only a justifiable number of significant figures.

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets [ ] at the end of each question or part question.
- 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.
- You will be awarded marks for the quality of written communication in Section B.
- You are advised to spend about 20 minutes on Section A and 50 minutes on Section B.

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

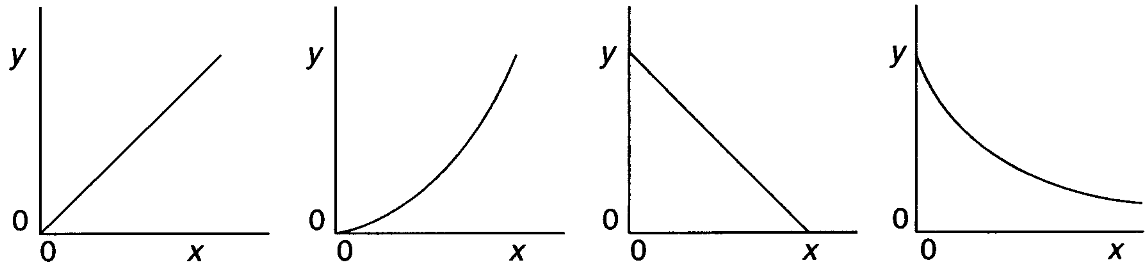
This question paper consists of 14 printed pages and 2 blank pages.

[Turn over

For Examiner's Use

Section A

1 Study the graphs **A, B, C, D**.



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

(a) Choose the graph that best shows the relationship between the charge stored on a capacitor (y) and potential difference across the capacitor (x).

answer ....

(b) Choose the graph that best shows the relationship between the rate of decay of a radioactive isotope (y) and time (x).

answer ....

[2]

2 Here is a list of astronomical phenomena,

A red shift of distant galaxies

B microwave background radiation

C stellar parallax

D black holes

From the list, choose the phenomenon that gives the **clearest** evidence that the universe has evolved from an initial hot, uniform, dense state.

answer .... [1]

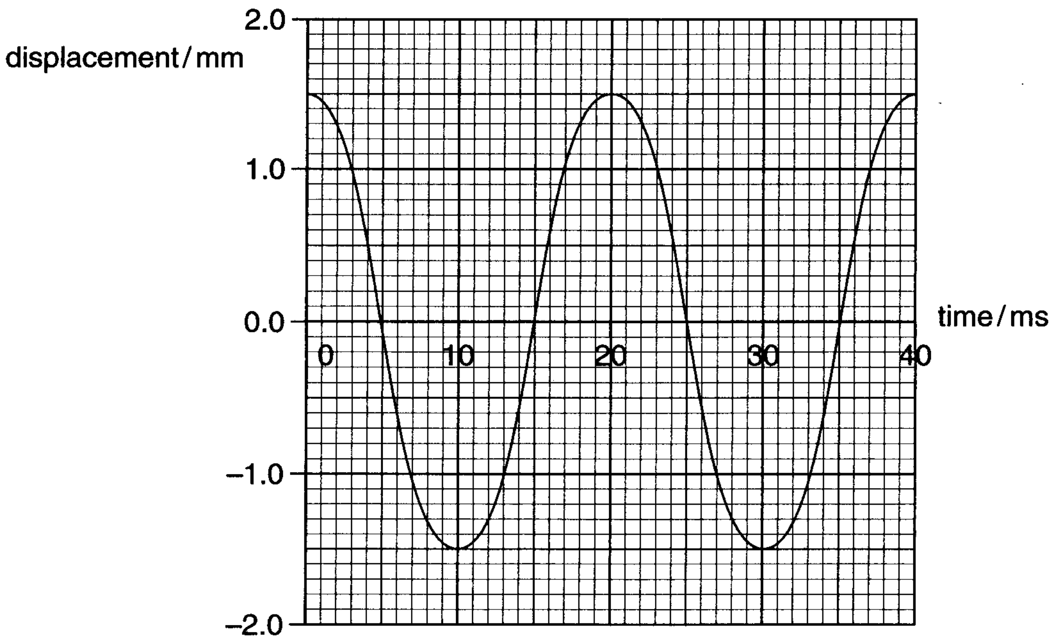
For Examiner's Use

3 Which of the following is currently the best estimate for the age of the Universe?

A 1.5×10^6 year **B** 1.5×10^8 year **C** 1.5×10^{10} year **D** 1.5×10^{12} year

answer .... [1]

4 The graph shows how the displacement of an oscillator varies with time.



Use the data on the graph to find,

(a) the amplitude of the oscillation

amplitude .... mm [1]

(b) the frequency of the oscillator.

frequency .... Hz [2]

[Turn over

5 The distance from Earth to a comet can be found by firing a pulse of radio waves at the comet and recording the time for the reflected pulse to return. On one occasion the pulse took 500 s to make the round trip.

(a) Show that the distance from Earth to the comet at the time of measurement was 7.5×10^{10} m.

[1]

(b) Describe how this technique could be used to find the speed of a comet which is directly approaching Earth.

[2]

6 The charge on a capacitor is 2.0×10^{-3} C when a potential difference of 4.5 V is applied across it.

Calculate the value of the capacitance.

value of capacitance .... F [2]

7 Show that the unit of capacitance, F, is equivalent to $C^2 J^{-1}$.

[2]

For Examiner's Use

8 The energy, ε, required for a water molecule to go from the liquid into the vapour is about 3×10^{-20} J.

(a) Calculate the Boltzmann factor, $e^{-\varepsilon/kT}$, for the vaporisation of water at 300 K.

Boltzmann factor = ... [2]

(b) State the units of the quantity kT.

units = ... [1]

9 A helium balloon has a volume of $5.0\,m^3$ at ground level on a summer's day. The temperature at ground level is 298 K and the pressure of the helium is 1.0×10^5 Pa.

The balloon rises to a height at which its volume is $10.8\,m^3$ and the temperature is 257 K.

Calculate the pressure of the helium in the balloon.

Assume that helium behaves as an ideal gas.

Pressure = ... Pa [3]

For Examiner's Use

Section B

Four marks in this section are awarded for quality of communication.

10 This question is about using radioactive carbon-14 to date organic material. Carbon-14 has a half-life of about 5 500 years.

Living matter has about 4×10^{10} atoms of carbon-14 in every gram of carbon. When an organism dies the carbon-14 is no longer replaced and so the number per gram falls as time passes.

(a) **(i)** Complete the table to show how the number of carbon-14 atoms in one gram changes over time.

time passed / years	number of carbon-14 atoms per gram
0	4×10^{10}
5 500	
11 000	
16 500	
22 000	

(ii) Use the data in the table to draw a curve on Fig. 10.1 showing how the number of carbon-14 atoms per gram in a sample decreases over time.

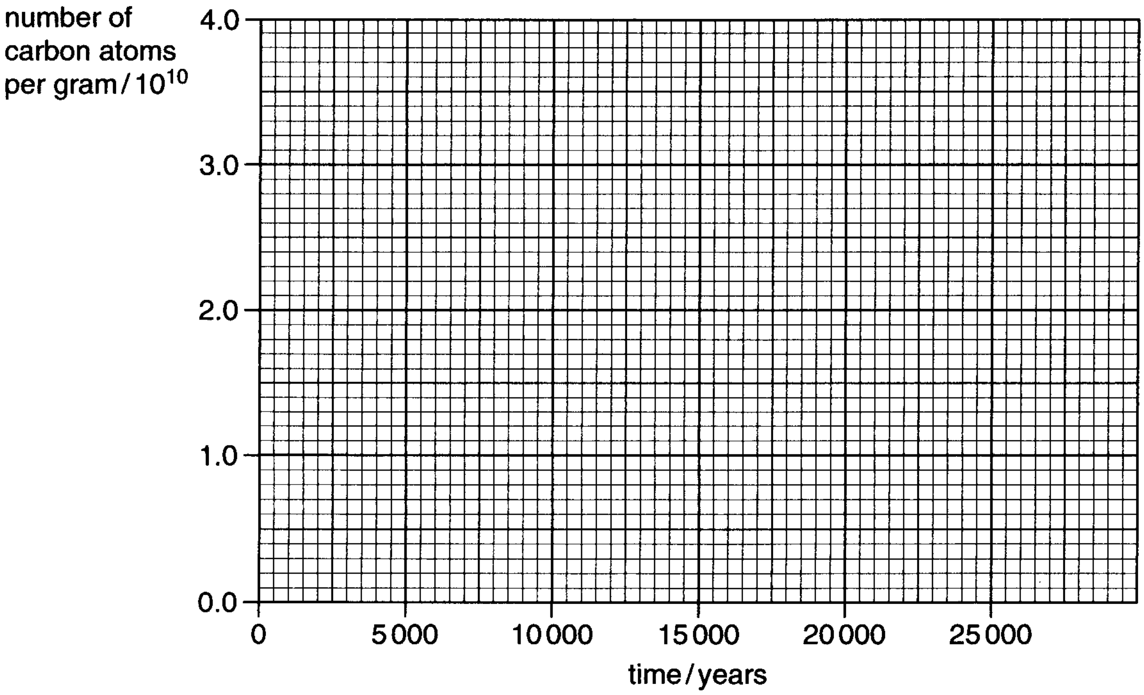


Fig. 10.1

[4]

(b) In 1983 a preserved body was discovered in a Cheshire bog. This has become known as the 'Lindow Man'.

The probability that a given atom of carbon-14 will decay in one second, λ, is $4.0 \times 10^{-12}\,s^{-1}$.

(i) Show that 2.5×10^{11} atoms of carbon-14 are needed to produce an average decay rate of 1.0 decay s^{-1}.

A sample containing 1.0 g of carbon was taken from a bog body. 65 atoms of carbon-14 in the sample were found to decay in 600 s.

(ii) Calculate the number of carbon-14 atoms present in the sample.

number of atoms of carbon-14 = ...

(iii) Use the graph in Fig. 10.1 to estimate the age of the sample.

age of sample = ... years

[3]

(c) Suggest reasons why this technique is not used in measuring the age of each of the following samples:

(i) meteorites and other material found elsewhere in the Solar System;

(ii) samples more than 100 000 years old;

(iii) samples less than 100 years old.

[3]

For Examiner's Use

11 This question is about a detector for neutrons and other sub atomic particles which works by measuring the temperature rise of a suitable liquid.

When neutrons enter the detector their kinetic energy can be shared amongst the particles within the detector. This results in a temperature rise of the liquid.

(a) Consider using water as the liquid in the detector.

Assume that each neutron passing through the detector transfers 3.5×10^{-16} J of energy to the water.

Show that 1.2×10^{19} neutrons would need to enter the detector to raise the temperature of 1 kg of water by 1 K.

Specific thermal capacity of water = 4.2×10^{3} J kg^{-1} K^{-1}

[2]

(b) Scientists are attempting to use this process to detect a new type of particle. This particle has a kinetic energy of 3.5×10^{-16} J but only interacts with matter very rarely. It is expected that only one of these particles would be absorbed per day by 1 kg of water.

Explain why the temperature rise of water cannot be used to detect such rare happenings.

[2]

For Examiner's Use

(c) A similar type of detector uses the temperature rise of very cold liquid helium-3 to detect the particles. When helium-3 is cooled to 1×10^{-4} K it has a specific thermal capacity of $7.0 \times 10^{-8}\,\mathrm{J\,kg^{-1}\,K^{-1}}$.

(i) The detector uses 8.0×10^{-6} kg of helium-3 at this temperature. Show that a particle transferring 3.5×10^{-16} J to the helium-3 will give a temperature rise of 6.3×10^{-4} K.

(ii) The smallest temperature change that can be detected is 0.5×10^{-6} K. Explain why it is unlikely that any particles will be detected if helium-3 absorbs the particles at a similar rate to water. Suggest how the apparatus can be adapted to make detection more likely.

[3]

12 This question is about using airbags and seat belts to improve driver safety.

In a test laboratory, a car travelling at $11.0\,m\,s^{-1}$ strikes a wall head-on and comes to rest in 0.1 s.

A crash test dummy of mass 75 kg is belted into the driver's seat of the car.

(a) Calculate the change of momentum of the dummy in the crash.

change of momentum = ... $kg\,m\,s^{-1}$ [2]

(b) In the crash, the dummy is brought to rest by the seat belt from a speed of $11\,m\,s^{-1}$, in a time of 0.14 s.

Show that the average force on the dummy is about eight times its weight.

[2]

The seat belt does not stop the head of the dummy moving forward. With no airbag the head could strike the steering wheel. Fig. 12.1 shows how the force on the head of the dummy changes over time if the head strikes a steering wheel.

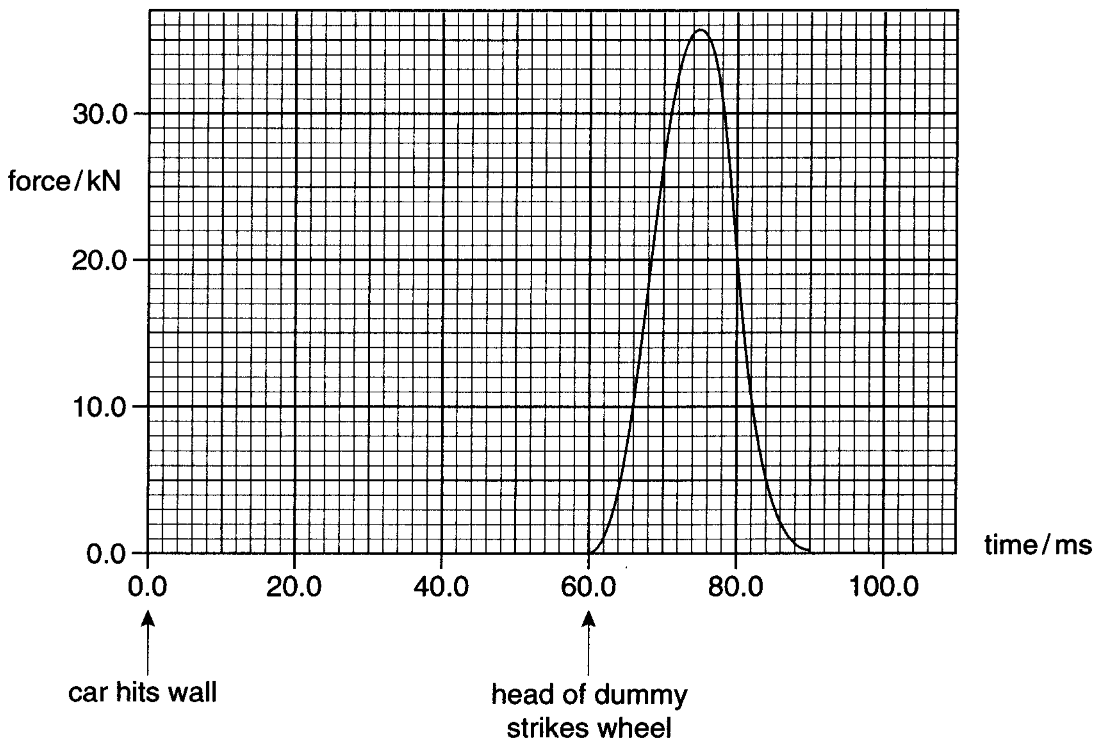


Fig. 12.1

If an airbag is installed it will begin to inflate from the steering wheel about 20 ms after the collision and takes a further 20 ms to fully inflate. 40 ms after the collision the bag begins to deflate.

(c) Suggest why airbags are most helpful if they are already deflating when the head strikes them.

[2]

(d) Draw a second graph on Fig. 12.1 to show how the force on the head changes if an airbag is present.

Explain how your graph shows,

(i) that the average force on the head is lower with an airbag

(ii) that the change of momentum of the head is the same in both cases.

[4]

13 This question is about the gravitational field around the Moon and the absence of any atmosphere around the Moon.

Fig. 13.1 shows lines representing equipotentials at different heights above the surface of the Moon.

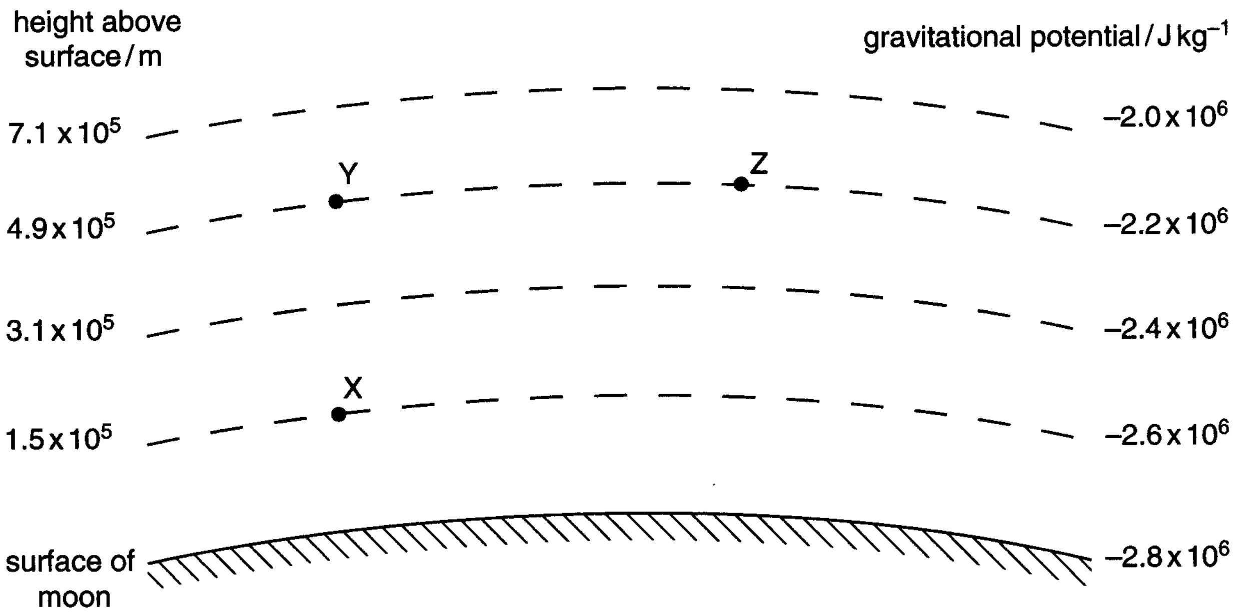


Fig. 13.1

(a) Explain why the energy required to move a mass from X to Y is the same as the energy required to move a mass from X to Z.

[2]

(b) (i) Show that about 78,000 J are required to move 28 gram of nitrogen molecules (one mole) from the surface of the Moon to a point far away from the surface.

[2]

Each nitrogen molecule has a mass of 4.7×10^{-26} kg. In one mole there are 6.0×10^{23} nitrogen molecules.

(ii) Show that the speed required for molecules at the surface of the planet to escape is about 2 400 m s^{-1}.

[3]

(c) Use the ideal gas law and $pV = \frac{1}{3}Nmc^2$ to show that the mean square speed of a molecule of an ideal gas at absolute temperature T is given by:

$$c^2 = \frac{3RT}{M_m}$$

where M_m is the mass of one mole of the gas.

[3]

(d) The mean surface temperature of the Moon is 290 K.

Calculate the root mean square speed of nitrogen molecules at 290 K.

[2]

(e) Explain why the moon has lost any nitrogen atmosphere it may have once possessed.

[2]

14 This question is about using the rate at which radiation emitted by stars (luminosity) is used to measure distances across the galaxy.

The luminosity of a type of star known as a 'Cepheid' oscillates periodically. The period of oscillation is related to the luminosity of the star.

(a) Study the data below.

Cepheid	period of oscillation of Cepheid / days	luminosity of Cepheid (Sun = 1)
A	1	200
B	5	1 500
C	10	10 000

Demonstrate how the data show that luminosity is **not** proportional to period.

[2]

(b) The *apparent* brightness of a star depends upon its luminosity and its distance from Earth. The relationship is described by

$$\textit{Apparent brightness} \quad \propto \quad \frac{\textit{luminosity}}{(\textit{Distance from Earth})^2}$$

Cepheid *A*, with a period of 1 day has the same apparent brightness as Cepheid *B* with a period of 5 days.

The more distant star is 1×10^{21} m away from Earth.

Calculate the distance from the Earth to the nearer star.

[3]

Quality of Written Communication [4]