OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS B (ADVANCING PHYSICS)

Rise and Fall of the Clockwork Universe

2863/01

Thursday **15 JUNE 2006** Morning 1 hour 15 minutes

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

Candidate Name

Centre Number

Candidate Number

TIME 1 hour 15 minutes

INSTRUCTIONS TO CANDIDATES

- Write your name, 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 diagrams and graphs 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 15 printed pages and 1 blank page.

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[Turn over

Section A

Answer **all** the questions.

1 Here is a list of energies.

0.34 J 3.4 J 34 J

Choose the value from the list that is the best approximation to

(a) the energy stored in a spring of stiffness constant $k = 2700\,\text{N m}^{-1}$ when extended by 50 mm

answer ……………….. J

(b) the energy stored on a 4700 μF capacitor when a p.d. of 12 V is applied across it.

answer ……………….. J
[2]

2 A guitar string vibrates at a frequency of 150 Hz with a maximum amplitude of 2 mm in the middle of the string. It is assumed to vibrate with simple harmonic motion.

Show that the magnitude of the maximum acceleration of the string is about $1800\,\text{m s}^{-2}$.

[2]

3 The speed of a comet approaching the Earth can be measured by reflecting radar pulses off the approaching body.

The tables give results from a pair of measurements to determine the speed of a comet directly approaching the Earth. The first measurement took place at 12:00 hours.

time pulse sent			time reflected pulse received		
hours	minutes	seconds	hours	minutes	seconds
12	00	00	12	00	55.0

time pulse sent			time reflected pulse received		
hours	minutes	seconds	hours	minutes	seconds
12	35	00	12	35	54.9

(a) Show that the distance to the comet at 12:00 hours was about 8.3×10^9 m.

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

[2]

(b) Use the data in the tables to calculate the average velocity of approach of the comet during the measurement period.

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

[Turn over

4 Fig. 4.1 shows the variation in volume *V* with pressure *p* of one mole of an ideal gas.

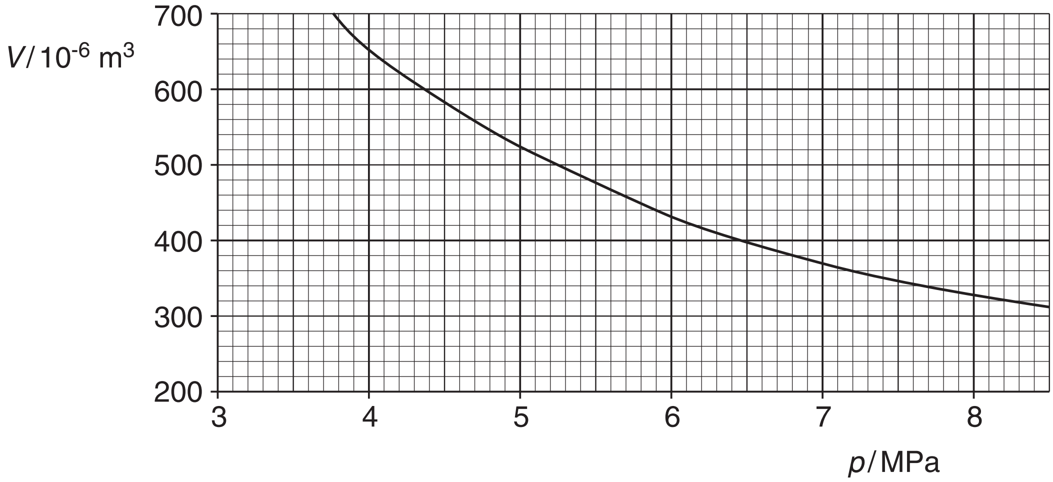

Fig. 4.1

(a) Use data from the graph to show that the gas was at a temperature of about 310 K. State the equation you use in your calculation.

$R = 8.3\,\text{J mol}^{-1}\,\text{K}^{-1}$

[3]

(b) The table below shows some data about the pressure and volume of the same gas at 250 K. Complete the table by calculating the missing value of *V*.

p / MPa	V / 10^{-6} m^3
4	520
8	

[1]

(c) On the axes of Fig. 4.1, sketch a graph of *V* versus *p* for the gas at a temperature of 250 K.

[1]

5 Hubble's Law states that the velocity of recession of a galaxy is proportional to the distance to the galaxy as measured from Earth. The further away a galaxy is, the faster it recedes from us.

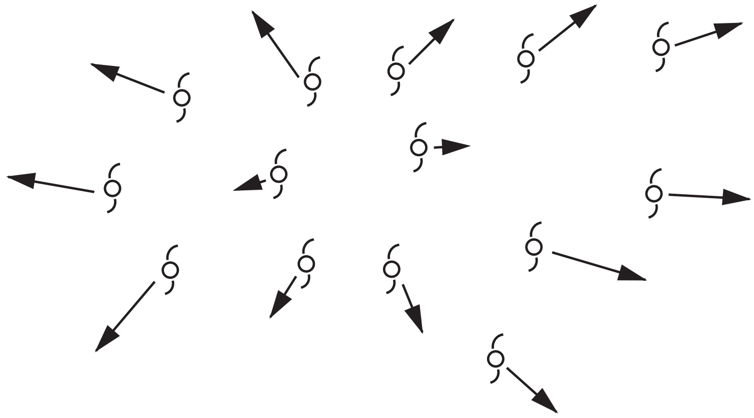

Fig. 5.1

Hubble's Law can be written as

$$v = H_0 d$$

where v is the velocity of recession
d is the distance from Earth
H_0 is the Hubble constant = 2.2×10^{-18} s^{-1}.

(a) State the observational evidence that supports Hubble's Law.

[1]

(b) The value of $1/H_0$ gives an estimate of the time passed since all the galaxies were close together. This gives an estimate of the age of the Universe.

Use the value of H_0 to estimate for the age of the Universe in years.
1 year = 3.2×10^7 s

[2]

(c) Suggest one reason why the age of the Universe may be larger than this value.

[1]

6 A 2200 μF capacitor is discharged through a 1.1 kΩ resistor.

(a) Show that the time constant τ of the circuit is about 2.4 s.

[1]

(b) A student models the discharge using a simple spreadsheet calculation. The model calculates the current at the start of each 1.0 s time interval.

The model keeps the current at a constant value for the duration of each 1.0 s interval. A graph of the results is given in Fig. 6.1.

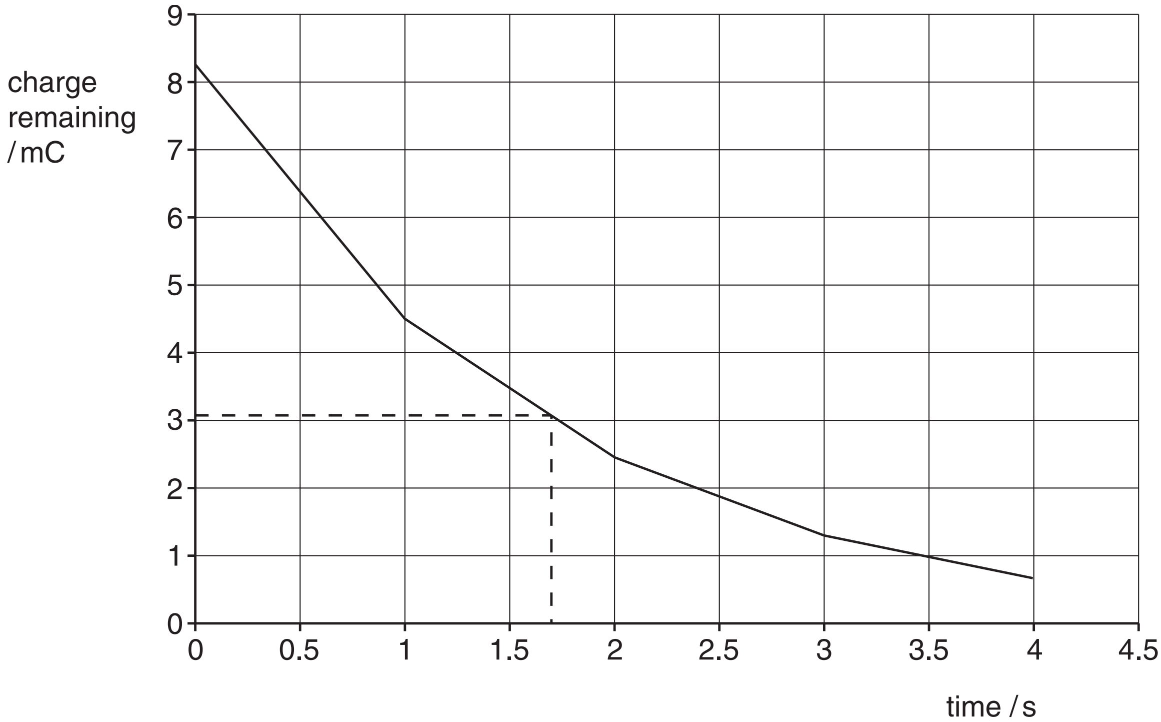

Fig. 6.1

This model suggests that the time constant is about 1.7 s.
Explain why the model predicts a more rapid rate of decay than is actually the case and suggest how the model could be improved.

[2]

[Section A Total: 20]

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Turn to page 8 for Section B.

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Section B

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

7 This question is about using a radioisotope of potassium to find the age of a rock.

(a) A sample of potassium-40 has a mass of 1.8×10^{-6} g.

(i) Calculate the number of potassium nuclei in the sample.

molar mass of potassium-40 = 40 g mol^{-1}
$N_A = 6.0 \times 10^{23}$ particles per mole

number of nuclei in sample = ... [2]

(ii) The activity of the sample is 0.48 Bq. Show that the decay constant λ for potassium-40 is about $1.8 \times 10^{-17}\,s^{-1}$.

[2]

(iii) Use the value of λ to calculate the half-life of potassium-40 in years.

1 year = 3.2×10^{7} s

half-life =.............. years [2]

(b) Potassium-40 decays into a stable isotope of argon.

A particular rock sample was found to contain numbers of potassium and argon nuclei in a ratio of 1 nucleus of potassium to 3 nuclei of argon.

It is assumed that all the argon in the rock has been produced from the decay of potassium, and that none has escaped.

(i) Calculate the age of the rock.

age of rock = ………………….. years [2]

(ii) In fact, some argon does escape. This means that the rock is older than the calculated value. Explain why the rock is older.

[2]

[Total: 10]

8 This question is about the relationship

force = rate of change of momentum.

The relationship is often written in the form $F = \dfrac{(mv - mu)}{t}$.

(a) A ball of mass 0.075 kg is fired at a wall. The velocity of the ball when it strikes the wall is $15\,\mathrm{m\,s^{-1}}$. It leaves the wall with a velocity of $-10\,\mathrm{m\,s^{-1}}$.

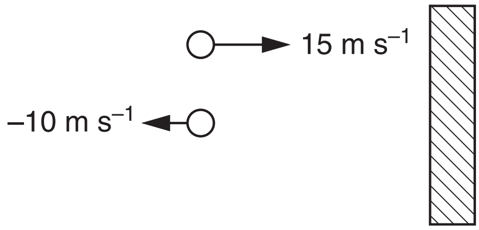

Fig. 8.1

(i) Show that the change of momentum of the ball is about $-1.9\,\mathrm{kg\,m\,s^{-1}}$.

[2]

(ii) The ball is in contact with the wall for 0.12 s.

Calculate the average force exerted on the ball during the collision.

average force on ball .... N [2]

(iii) State how the average force exerted on the **wall** during the collision compares with the average force on the **ball**.

[2]

(b) The behaviour of an ideal gas can be modelled as many particles in constant motion. The particles collide with the walls of the container without loss of energy.

Use the ideas about force and rate of change of momentum from **(a)** to explain why the **pressure** of a fixed mass of gas at constant volume increases as the temperature of the gas rises.

[3]

(c) When a nitrogen (N_2) molecule with a speed of $500\,m\,s^{-1}$ bounces off the wall of the container shown in Fig. 8.2, it experiences a maximum change of momentum of about $5 \times 10^{-23}\,kg\,m\,s^{-1}$.

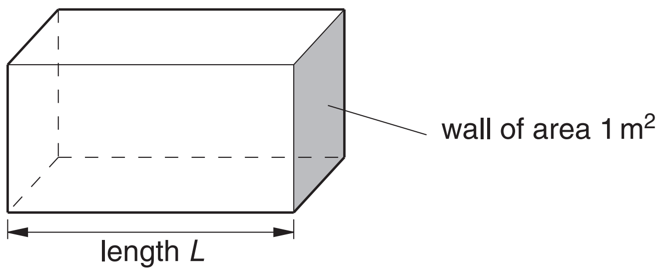

Fig. 8.2

Calculate the minimum number of collisions per second required for nitrogen molecules at a speed of $500\,m\,s^{-1}$ to exert a pressure of $1 \times 10^5\,N\,m^{-2}$ on a wall of area $1\,m^2$.

minimum number of collisions per second = ... [2]

(d) When the r.m.s. speed of N_2 is doubled, the maximum change of momentum of an N_2 molecule on collision with the wall is also doubled.

Explain why the pressure on the walls of the container in Fig. 8.2 **more** than doubles when the speed of the particles in the container doubles.

[2]

[Total: 13]

[Turn over

9 This question is about the gravitational field of the Sun.

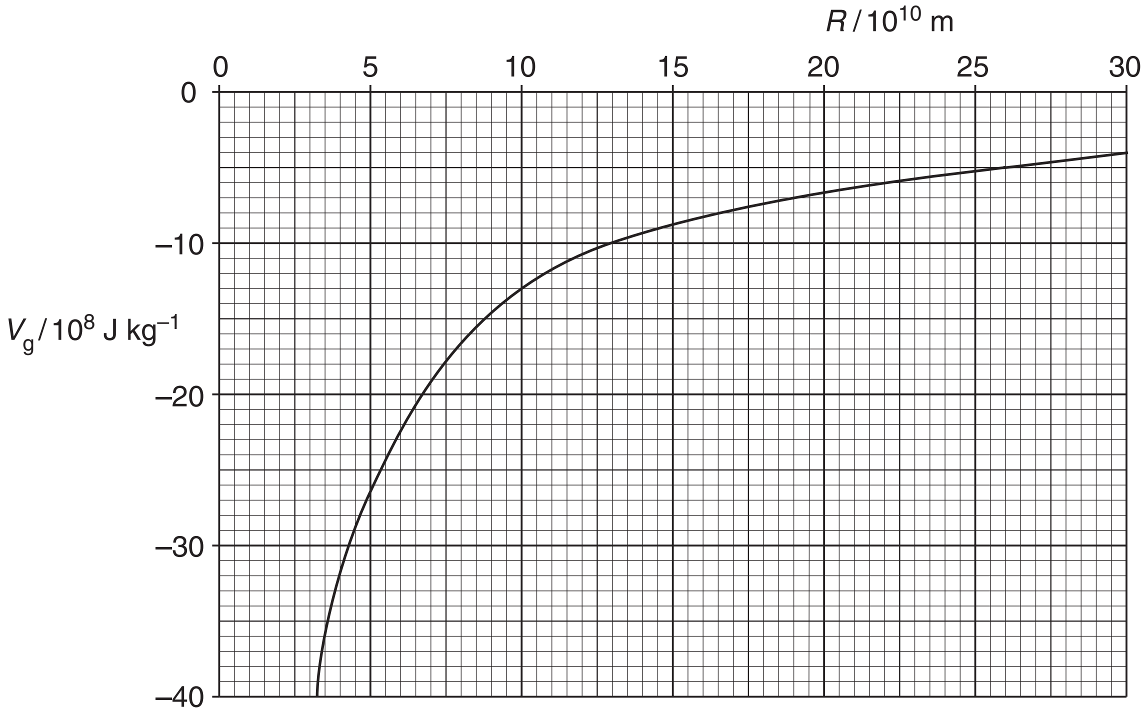

Fig. 9.1

The graph shows how the gravitational potential due to the mass of the Sun varies with distance from the centre of the Sun.

(a) (i) The Earth orbits the Sun at a mean distance of about 15 x 10^{10} m.

Use the graph to show that the gravitational potential energy of the Earth is about –5 x 10^{33} J.

mass of Earth = 6.0 x 10^{24} kg

[2]

(ii) Use the gradient of the graph to show that the magnitude of the gravitational field strength of the Sun at this distance is about 6 x 10^{-3} N kg^{-1}. Show your method clearly.

[2]

(iii) Hence calculate the force F_s exerted by the Sun on the Earth at this distance.

F_s = ……………….N [1]

(b) The answer to **(a) (iii)** is the value of the centripetal force acting on the Earth at a radius of orbit R.

(i) State the relationship giving the centripetal force F_s on a body of mass m orbiting the Sun at a radius R and speed v.

centripetal force F_s =

[1]

(ii) Use the relationship in **(b)(i)** to show that the kinetic energy of the Earth in orbit around the Sun can be given by the expression

kinetic energy = $\frac{F_s R}{2}$.

[1]

(c) Calculate the **total** energy of the Earth in orbit around the Sun.

mean radius of Earth orbit = 15 x 10^{10} m

total energy = ……………….J [2]

(d) If an orbiting body loses energy, for example by passing through a cloud of meteorites, it will settle into an orbit nearer the Sun. By considering changes in potential energy and kinetic energy, explain why an orbiting body would orbit with a **greater speed** when it settled into an orbit nearer the Sun.

[3]

[Total: 12]

10 This question is about the random thermal energy of motion of particles in the Sun.

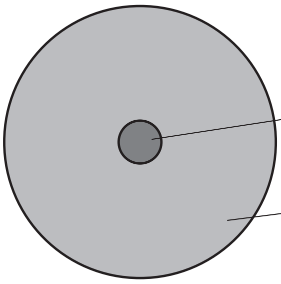

Fig. 10.1

The surface of the Sun is at a temperature of about 6000 K.

(a) **(i)** Show that the average energy of a particle at the surface of the Sun is about 8.0×10^{-20} J.

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

[1]

(ii) The energy needed to ionise a hydrogen atom by collision is of the order 10 eV. Show that this energy is about 20 times greater than the average energy of a particle at the surface of the Sun.

$1\ \text{eV} = 1.6 \times 10^{-19}$ J

[2]

(b) The particles in the Sun are in random thermal motion making frequent collisions with one another. The Boltzmann factor, $f = e^{-E/KT}$ gives an estimate of the fraction of collisions that have an energy of at least E.

(i) Suggest why some of the particles have an energy 20 times the average value.

[1]

(ii) Calculate the value of the Boltzmann factor when $\frac{E}{kT} = 20$.

Boltzmann factor = ... [2]

(iii) Each particle in the surface of the Sun makes about 10^9 collisions per second. Use this fact and the answer to **(b) (ii)** to explain why, in one second, most of the hydrogen at the surface of the Sun has experienced ionisation.

[2]

(c) In the core of the Sun, collisions between protons occasionally cause them to fuse to form ^2_1H. The energy *E* needed for this is about 1.5×10^{-13} J.
To have this average energy, the protons require a temperature of the order of 10^{10} K.

(i) The temperature of the core of the Sun is about 10^7 K.

Show that the ratio $\frac{E}{kT}$ for the fusion reaction is of the order of 10^3.

[1]

(ii) Suggest why this calculation indicates that stars like the Sun continue to shine for tens of billions of years. (e^{-1000} is too small to be computed on a calculator).

[2]

[Total: 11]

Quality of Written Communication [4]

[Section B Total: 50]

END OF QUESTION PAPER

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