OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS A

2825/01

Cosmology

Monday **28 JUNE 2004** Afternoon 1 hour 30 minutes

Candidates answer on the question paper.
Additional materials:
Electronic calculator

Candidate Name	Centre Number	Candidate Number

TIME 1 hour 30 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.

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets [ ] at the end of each question or part question.
- The total number of marks for this paper is 90.
- You may use an electronic calculator.
- You are advised to show all the steps in any calculations.
- The first six questions concern Cosmology. The last question concerns general physics.

FOR EXAMINER'S USE		
Qu.	**Max.**	**Mark**
1	10	
2	14	
3	13	
4	8	
5	14	
6	11	
7	20	
TOTAL	90	

This question paper consists of 20 printed pages.

Data

speed of light in free space,	$c = 3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$
permeability of free space,	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H\,m^{-1}}$
permittivity of free space,	$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F\,m^{-1}}$
elementary charge,	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
the Planck constant,	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
unified atomic mass constant,	$u = 1.66 \times 10^{-27}\ \mathrm{kg}$
rest mass of electron,	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
rest mass of proton,	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
molar gas constant,	$R = 8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
the Avogadro constant,	$N_A = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
gravitational constant,	$G = 6.67 \times 10^{-11}\ \mathrm{N\,m^{2}\,kg^{-2}}$
acceleration of free fall,	$g = 9.81\ \mathrm{m\,s^{-2}}$

Formulae

uniformly accelerated motion, $s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

refractive index, $n = \frac{1}{\sin C}$

capacitors in series, $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$

capacitors in parallel, $C = C_1 + C_2 + \ldots$

capacitor discharge, $x = x_0 e^{-t/CR}$

pressure of an ideal gas, $p = \frac{1}{3}\frac{Nm}{V}<c^2>$

radioactive decay, $x = x_0 e^{-\lambda t}$

$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$

critical density of matter in the Universe, $\rho_0 = \frac{3H_0^2}{8\pi G}$

relativity factor, $= \sqrt{(1 - \frac{v^2}{c^2})}$

current, $I = nAve$

nuclear radius, $r = r_0 A^{1/3}$

sound intensity level, $= 10\,\lg\left(\frac{I}{I_0}\right)$

For Examiner's Use

Answer **all** the questions.

1 **(a)** **(i)** Describe what is meant by the term *retrograde motion* as applied to the planets.

....

....

..........[2]

(ii) Explain why the observed retrograde motion presents difficulties for a geocentric model of the solar system.

....

....

..........[2]

(b) Describe the model of the Universe as proposed by Copernicus.

....

....

..........[2]

(c) Explain how the Copernican model resolved the problem of the retrograde motion of the planets.

....

....

..........[2]

(d) Give **two** reasons why the Copernican model was not immediately accepted.

1. ....

....

2. ....

..........[2]

[Total: 10]

For Examiner's Use

2 (a) Describe the main energy generation process taking place within a Main Sequence star.

....

....

....

....

....

....

....[3]

(b) Fig. 2.1 is a Hertzsprung-Russell (H-R) diagram for stars in our galaxy, showing the Main Sequence **M**.

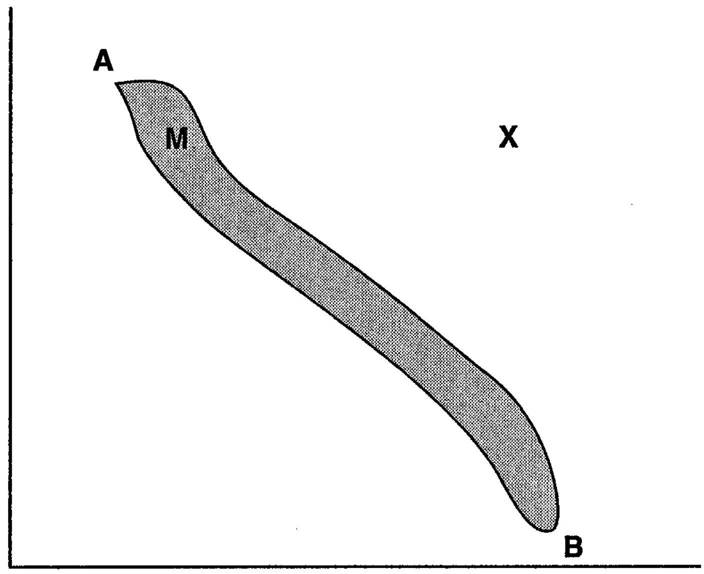


Fig. 2.1

(i) Label the axes, showing the directions in which numerical values increase. [4]

(ii) Indicate the present position of the Sun on the diagram. Label this position **S**. [1]

[Turn over

For Examiner's Use

(c) In time, the Sun will move to position **X** on Fig. 2.1. Suppose you were to observe this transformation from a safe distance outside the solar system.

(i) What differences would you notice in the appearance of the Sun?

....

....

....[2]

(ii) Explain what has happened to the energy generation processes inside the Sun.

....

....

....[2]

(d) Why are very few stars seen in regions **A** (top left) and **B** (bottom right) of the H-R diagram?

region **A** ....

....

region **B** ....

....[2]

[Total: 14]

For Examiner's Use

3 Fig. 3.1 shows a spectrum from a very distant quasar, PC 1247 + 3406.

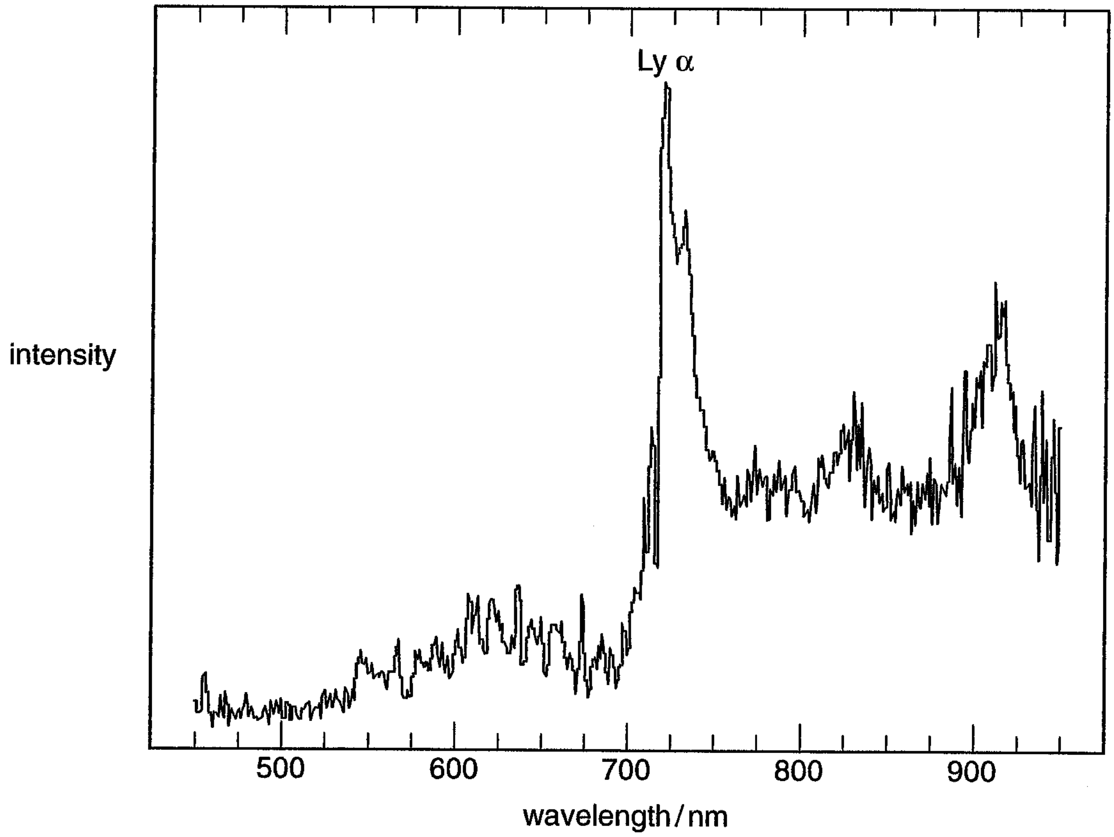


Fig. 3.1

The peak labelled Ly α is identified as the Lyman-alpha line of the hydrogen spectrum.

(a) What is the wavelength of the Ly α line in the quasar spectrum?

wavelength = ... nm [1]

(b) The wavelength of the Ly α line when measured using a hydrogen lamp in the laboratory is 121.6 nm. Explain how these measurements suggest that the Universe is expanding.

....

....

....[2]

[Turn over

For Examiner's Use

(c) The red-shift z is defined by the equation

$$z + 1 = \frac{\lambda'}{\lambda}$$

where λ' is the observed wavelength of radiation from the quasar and λ is that from the laboratory source. Show that the red-shift for this quasar is about 5.

[1]

(d) For radial velocities v, the relativistic Doppler effect gives the relationship between the red-shift z and the ratio v/c, where c is the velocity of light. This relationship is plotted in Fig. 3.2.

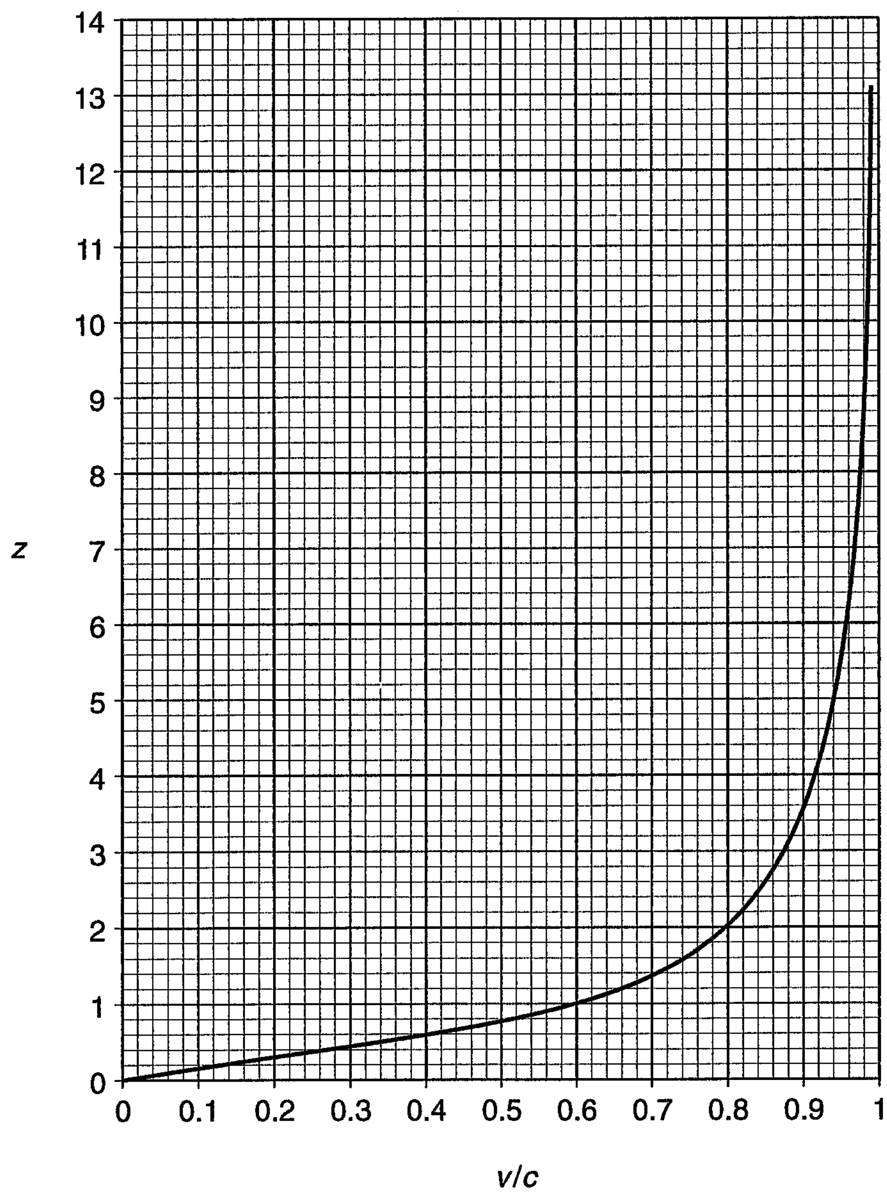


Fig. 3.2

(i) Using Fig. 3.2, calculate the radial velocity of quasar PC 1247 + 3406 for $z = 5$.

v = ... $m\,s^{-1}$ [2]

(ii) Calculate the distance of the quasar based on a Hubble constant of $70\,km\,s^{-1}\,Mpc^{-1}$.

Give your answer in light years.

distance = ... light year [3]

(iii) State **one** assumption you have made in obtaining your answer.

....

....[1]

(e) Explain the differences between terrestrial Doppler effects and cosmological red-shifts.

....

....

....

....

....

....[3]

[Total: 13]

For Examiner's Use

4 **(a)** Explain what is meant by the term *white dwarf*.

....

....

....

....[3]

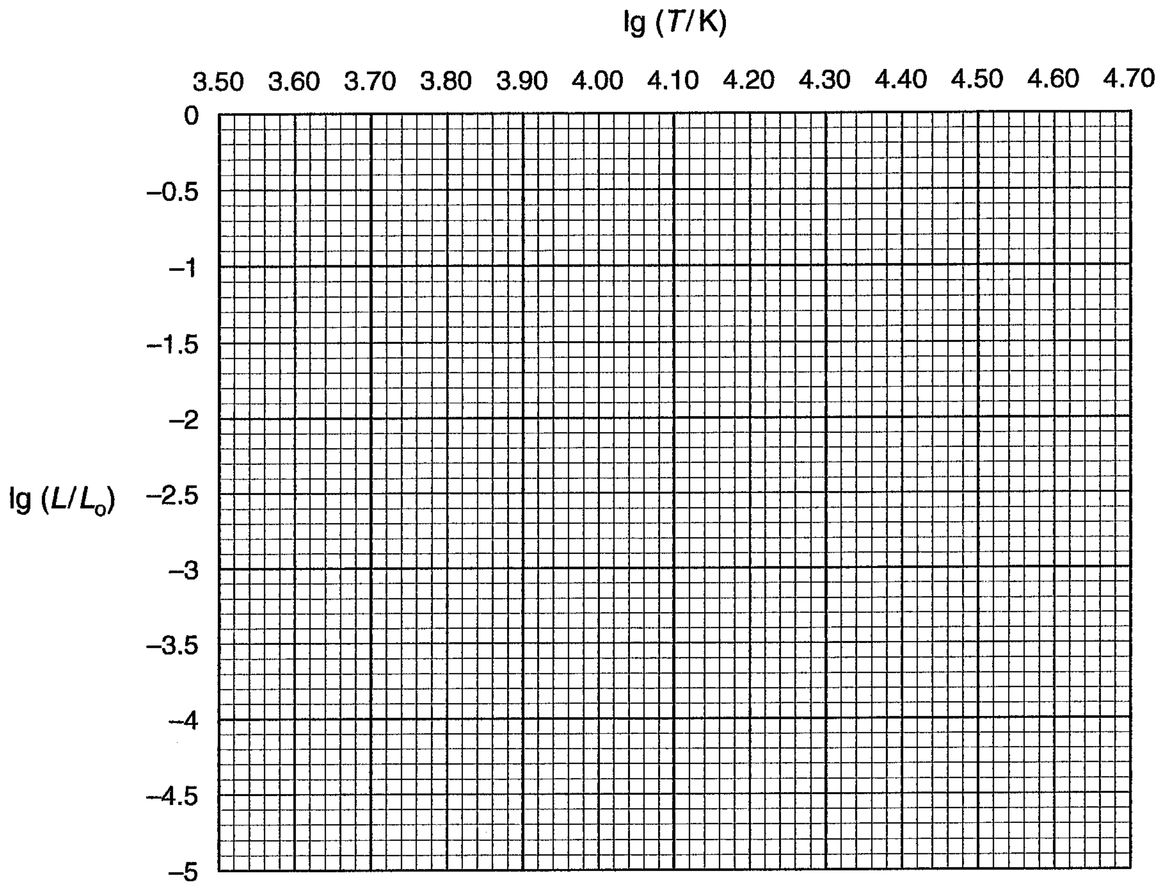
(b) A white dwarf gradually radiates away its energy, and so its temperature T and luminosity L fall. Fig. 4.1 shows temperature-luminosity data for white dwarfs. L is measured in multiples of L_0, the luminosity of the Sun.

lg (T/K)	lg (L/L_0)
3.60	−4.38
3.80	−3.75
4.00	−2.95
4.20	−1.93
4.40	−1.24
4.60	−0.58

Fig. 4.1

(i) Plot a graph of lg (T/K) against lg (L/L_0) on the grid provided.

Draw a line of best fit through the points. [2]



(ii) According to theory, the temperature and luminosity obey a relationship of the form

$$L = kT^n$$

where k and n are constants. Use your graph to find a value for n.

[3]

[Total: 8]

[Turn over

For Examiner's Use

5 (a) The hydrogen and helium atoms forming most of the visible matter in the Universe are believed to have been produced following the Big Bang. Discuss how this model explains the formation of these atoms.

....

....

....

....

....

....

....

....

....

....

....[6]

For Examiner's Use

(b) The future evolution of the Universe depends on the density parameter Ω, which is the ratio of the actual density of the Universe ρ to its critical value ρ_0,

$$\Omega = \frac{\rho}{\rho_0}.$$

Discuss how different values of Ω predict different possibilities for the future evolution of the Universe.

....

....

....

....

....

....

....

....

....

....

....

....

....

....[6]

(c) Some measurements on local galaxies give a value of $\Omega \approx 0.02$. Measurements of galaxy clusters and superclusters lead some cosmologists to believe that its value is exactly 1. Suggest why there is such a wide difference between these figures.

....

....

....[2]

[Total: 14]

For Examiner's Use

6 **(a)** Explain the effect of gravity on time in terms of a thought experiment based on the principle of equivalence.

....

....

....

....

....

....

....

....

....

....[5]

For Examiner's Use

(b) The effect of gravity on time produces a related effect called the gravitational red-shift. A photon of frequency f will undergo a decrease in frequency Δf as it moves against the direction of a gravitational field, given by

$$\frac{\Delta f}{f} \approx -\frac{g\Delta x}{c^2}$$

where Δx is the vertical distance moved by the photon. In 1960, Pound and Rebka measured this effect using 14.4 keV gamma rays moving vertically up a 22 m tower.

(i) Show that the frequency of a 14.4 keV gamma ray is approximately 4×10^{18} Hz.

[3]

(ii) Calculate the frequency shift.

frequency shift = ... Hz [2]

(c) Suggest a situation where the gravitational red-shift may be important.

....

....

....[1]

[Total: 11]

[Turn over

For Examiner's Use

7 A student is concerned to keep fit and equally concerned to minimise the use of electricity from the national grid. The student decides to combine the two issues and designs the system shown in Fig. 7.1. The chain on the exercise bicycle turns a d.c. generator which passes a current through a heating coil immersed in a hot water tank. The idea is that the student exercises for a certain length of time and instead of simply "wasting" energy in pedalling, the energy is used to heat the water necessary for a shower when finished.

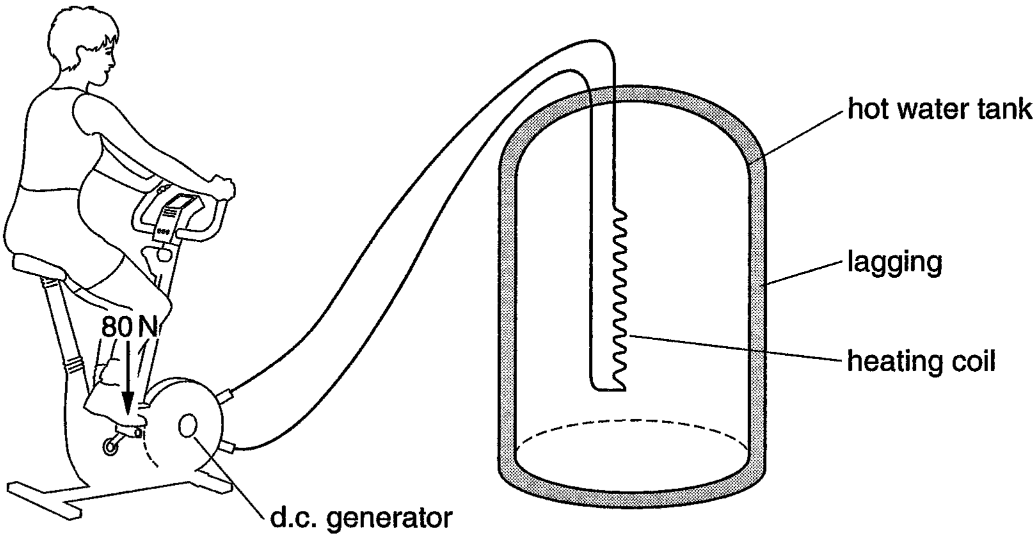


Fig. 7.1

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

(a) The water enters the hot water tank at a temperature of 8 °C and is required to be heated to 38° C for an acceptable shower. The shower lasts for 5 minutes during which time the water flows at a rate of 0.15 kg s^{-1}. Calculate

(i) the mass of water used during the shower

mass of water = ... kg [2]

(ii) the energy required to heat the water for the shower.

energy = ... J [2]

For Examiner's Use

(b) When pedalling on the exercise bicycle, each foot spends half the cycle doing work and the other half relaxing. While doing work, an average tangential force of 80 N is applied to each pedal. The pedal is positioned at a radius of 20 cm from the axle and the student maintains 1.3 revolutions per second.

(i) Show that the work done by the student during one revolution of the pedals is about 100 J.

[2]

(ii) Calculate the power produced by the student while pedalling.

power = ... W [1]

(iii) Calculate the total number of revolutions of the pedals required before the energy expended by the student equals that required to heat the water.

number of revolutions = ... [1]

(iv) Calculate the time for which the student must pedal in order to deliver the heat energy required.

time = ... hour [2]

For Examiner's Use

(c) The d.c. generator being driven by the exercise bicycle has an internal resistance of $1.2\,\Omega$ and produces an e.m.f. of 24 V while delivering a current of 5A.

(i) Show that the resistance of the heater element in the hot water tank is $3.6\,\Omega$.

[3]

(ii) Calculate the length of heater wire required if the element is made from resistance wire of resistivity $1.5 \times 10^{-7}\,\Omega\,\text{m}$ and cross-sectional area $0.32\,\text{mm}^2$.

length .... m [3]

(d) In practice, the student would have to pedal for an even longer time than your answer to **(b)(iv)**. By considering energy losses, give reasons for this. Include some calculations in your answer.

....

....

....

....

....[4]

[Total: 20]

END OF QUESTION PAPER