OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS
Advanced GCE

PHYSICS A 2825/01

Cosmology

Thursday **26 JUNE 2003** Morning 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 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 seven questions concern Cosmology. The last question concerns general physics.

FOR EXAMINER'S USE		
Qu.	Max.	Mark
1	5	
2	19	
3	9	
4	9	
5	9	
6	10	
7	9	
8	20	
TOTAL	90	

This question paper consists of 16 printed pages.

SP (AT/JB) S26044/8

Registered Charity Number: 1066969
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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, $p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$

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

Answer **all** the questions.

1 **(a)** Explain what is meant by a *heliocentric* model of the solar system.

.....

.....[1]

(b) State and explain how **two** of Galileo's astronomical discoveries provided support for the heliocentric world view proposed by Copernicus.

1. discovery .....

.....

explanation .....

.....

2. discovery .....

.....

explanation .....

.....[4]

[Total: 5]

2 A pair of stars, **X** and **Y**, form a binary system as shown in Fig. 2.1. The star **Y** moves around star **X** as shown.

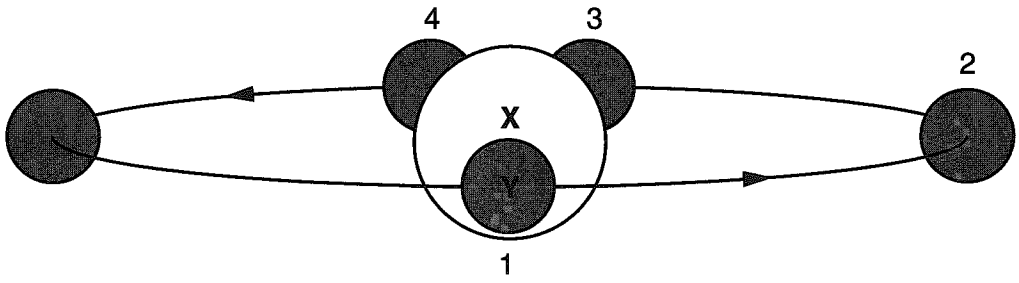

Fig. 2.1

Fig. 2.2 shows how the apparent magnitude of the pair, seen as an unresolved single star, varies with time.

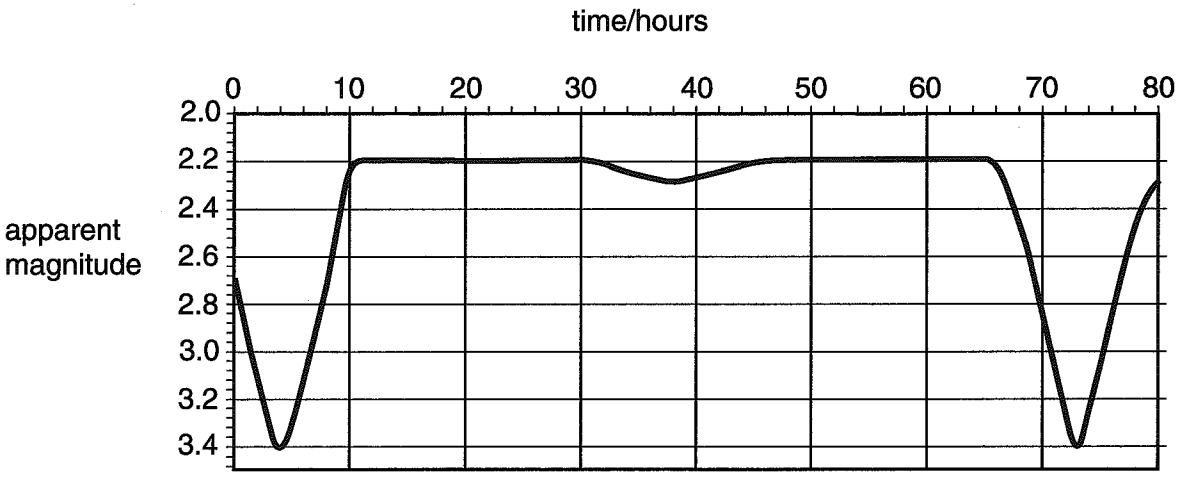

Fig. 2.2

(a) (i) Explain why the brightness of the binary system shows two different sized dips.

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.....[3]

(ii) **Y** is smaller and dimmer than **X**. For each of the positions 1 to 4 of **Y** on Fig. 2.1, indicate the corresponding points on the brightness curve of Fig. 2.2. [3]

(b) Light reaching us from binary stars is shifted in wavelength by the Doppler effect, and this may be used to obtain the velocities of the components of the system. Fig. 2.3 shows velocity data for **A** and **B** – two components of a binary star system.

time / hour	velocity of **A** V_A / km s^{-1}	velocity of **B** V_B / km s^{-1}	relative velocity $(V_A - V_B)$ / km s^{-1}
0	32	78	
2	150	29	
4	128	– 48	
6	– 12	– 80	
8	– 141	– 38	
10	– 139	39	
12	– 8	80	
14	130	46	
16	148	– 30	
18	28	– 79	
20	– 118	– 54	
22	– 154	21	
24	– 48	76	

Fig. 2.3.

(i) Complete the table by calculating the relative velocity at different times *t*. [2]

(ii) Using the axes provided in Fig. 2.4, plot a graph of relative velocity $(V_A - V_B)$ against time. [3]

For Examiner's Use

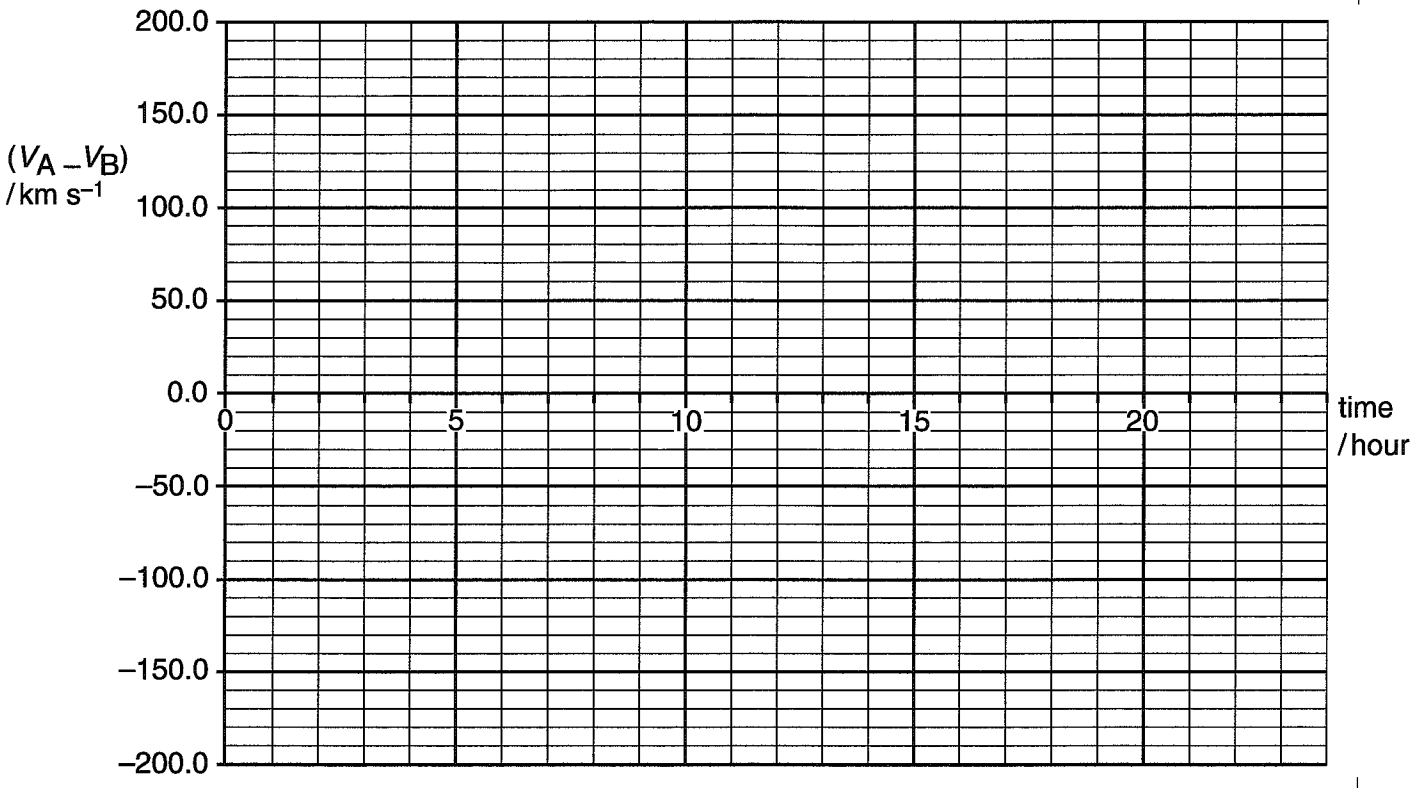

Fig. 2.4

(iii) Use the graph to determine the orbital period T of the system. Give your answer in seconds.

period = ... s [2]

(iv) The maximum relative velocity v_{max} is related to the orbital period T and orbital separation a by the equation

$$v_{max} = \frac{2\pi a}{T}$$

Calculate the orbital separation a of the two stars.

orbital separation = ... m [3]

(v) The total mass M of the two stars is related to their orbital separation a and their orbital period T by the equation

$$M = \frac{4\pi^2 a^3}{GT^2}$$

Calculate the total mass of **A** and **B**.

mass = ... kg [2]

(vi) Which of the two stars is the more massive, **A** or **B**? Justify your answer.

.....

.....

.....[1]

[Total: 19]

For Examiner's Use

3 **(a)** Explain briefly how the composition of a star is determined.

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.....

.....

.....[2]

(b) The distances to nearby stars may be determined by *parallax*, and are often quoted in *parsecs*.

(i) Explain the meaning of the term *parallax*.

.....

.....[2]

(ii) Explain how the *parsec* is defined. A diagram may be helpful.

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.....[2]

(c) The bright star Capella (α-Aurigae) has an apparent magnitude of 0.1 and is 4.3×10^{17} m from Earth. Calculate the absolute magnitude of Capella.

absolute magnitude = ...[3]

[Total: 9]

4 **(a)** Using the axes provided in Fig. 4.1, sketch and label a Hertzsprung–Russell diagram showing

(i) Main Sequence stars

(ii) red giants

(iii) white dwarfs

(iv) the present position of the Sun and a line indicating its likely future evolution. [5]

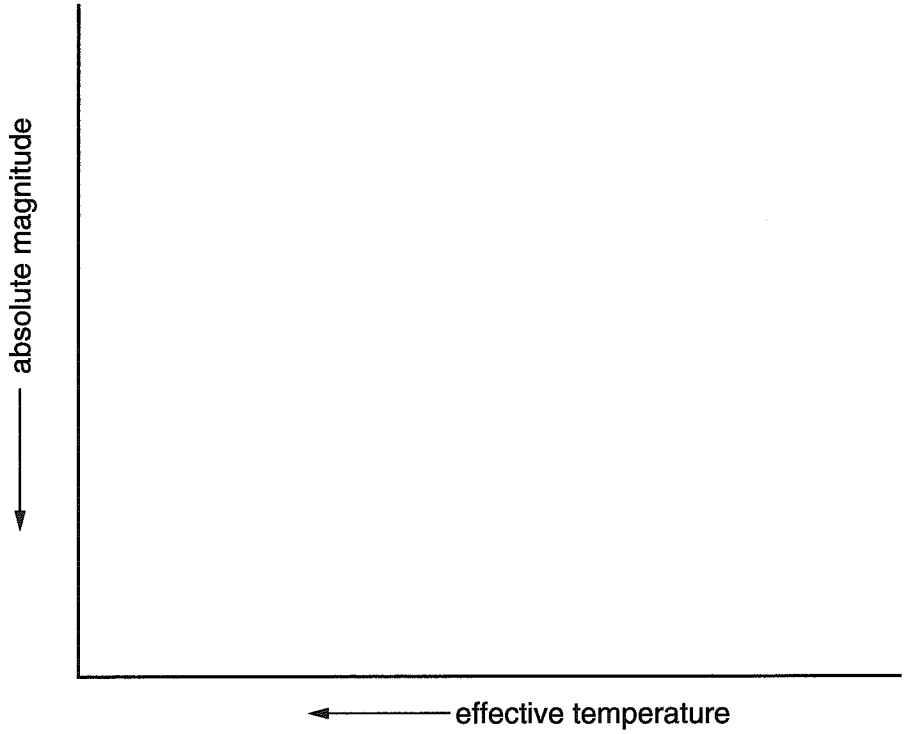

Fig. 4.1

(b) What are the requirements for a star to develop into a white dwarf, and how might this occur?

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.....[4]

[Total: 9]

For Examiner's Use

5 **(a)** State and explain the evidence in support of the big bang model of the Universe, including the microwave background radiation.

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.....[4]

(b) There is some evidence from observations of extremely distant *supernovae* that the expansion of the Universe may be accelerating so that the Universe is *open*.

(i) Describe what happens in a *supernova*.

.....

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.....[2]

(ii) What is an *open Universe*?

.....

.....

.....[2]

(iii) What effect would such an accelerating expansion have on the value of the Hubble constant?

.....

.....[1]

[Total: 9]

6 **(a)** **(i)** One of the postulates of the special theory of relativity states that the speed of light is *invariant*. Explain the meaning of the term *invariant*.

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.....[1]

(ii) State the other postulate of the special theory of relativity.

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.....[1]

(b) Give an account of a thought experiment which demonstrates the phenomenon of length contraction.

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.....[5]

(c) A spacecraft is travelling at a velocity of $0.8c$ relative to Bertha, a stationary observer. Albert, the occupant of the spacecraft, measures the length of his spacecraft to be 20.0 m. Calculate the length of the spacecraft as measured by Bertha.

length = ... m [3]

[Total: 10]

For Examiner's Use

7 **(a)** One form of the equivalence principle states that *inertial mass* and *gravitational mass* are identical. Explain the meaning of the terms

(i) *inertial mass*

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.....[1]

(ii) *gravitational mass.*

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.....[1]

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

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.....[5]

(c) The United States atomic standard clock is kept at the National Bureau of Standards at Boulder, Colorado at an altitude of 1646 m above sea level. It gains about 5 μs each year relative to a similar clock kept at the Royal Greenwich Observatory, at an altitude of only 24 m above sea level. Explain this result qualitatively.

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.....[2]

[Total: 9]

8 Electric vehicles offer many advantages over those powered by internal combustion engines. However, they suffer from one overwhelming problem – storing the energy. In spite of massive research into battery technology, the traditional lead-acid car battery is still best for storing energy. It can hold 20 times more energy per kg than its nearest competitor, the nickel-cadmium rechargeable cell.

A typical lead-acid battery has the following properties.

storage capacity = 0.75 kW h
volume = 7.0×10^{-3} m^3
mass = 16 kg
terminal voltage = 12 V

Petrol has the following properties.

energy available = 50 MJ kg^{-1}
density = 700 kg m^{-3}

(a) Suggest **two possible** advantages of electric vehicles over conventional petrol powered vehicles.

.....

.....

.....[2]

(b) The storage capacity of a battery is often quoted in ampere-hours. This is the number of hours for which a fully charged battery can supply a current of 1 A. Use the data to estimate the capacity in ampere-hours of a typical lead-acid battery.

capacity = ... ampere-hour [3]

(c) A bank of lead-acid batteries of total mass 960 kg is used to power a car.

(i) Calculate the total energy (in MJ) available.

energy = ... MJ [3]

(ii) The drag force on the car at $25\,m\,s^{-1}$ is 300 N. Estimate how far it could travel at this speed on a level road using the energy stored in these batteries.

distance = ... m [3]

(d) **(i)** Calculate the mass and volume of petrol that provides the same energy as the 960 kg of lead-acid batteries.

mass of petrol = ... kg

volume of petrol = ...m^3 [4]

(ii) The volume of petrol calculated in **(d)(i)** is very small.

Explain why, in practice, a greater volume of petrol is needed to travel the distance calculated in **(c)(ii)**.

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.....[2]

(e) Discuss the significance of your answers for the future adoption of electric vehicles rather than petrol vehicles.

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.....[3]

[Total: 20]