OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS
Advanced GCE

PHYSICS A 2825/01

Cosmology

Friday **1 FEBRUARY 2002** Afternoon 1 hour 30 minutes

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

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.
- You may use an electronic calculator.
- You are advised to show all the steps in any calculations.

FOR EXAMINER'S USE		
Qu.	Max.	Mark
1	4	
2	8	
3	8	
4	6	
5	8	
6	5	
7	12	
8	13	
9	6	
10	20	
TOTAL	90	

This question paper consists of 19 printed pages and 1 blank page.

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[Turn over

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

For Examiner's Use

Answer **all** the questions.

1 In 1543, Copernicus proposed a model of the Universe based upon circular orbits, with the Sun at the centre of the Solar system.

(a) Explain how this new heliocentric model simplified our understanding of the observed motion of the planets.

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.....[2]

(b) Suggest why this model of the universe did not gain general acceptance until after the work of Kepler and Galileo.

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.....[2]

[Total : 4]

2 **(a)** State Newton's law of Gravitation.

[1]

(b) Show that the radius r of the circular orbit of a planet around the Sun is given by

$$r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$$

where M is the mass of the Sun and T is the orbital period of the planet.

[4]

(c) Venus has an orbital period of 0.62 years. Calculate the mean radius of its orbit about the Sun. Mass of Sun = 2.0×10^{30} kg.

mean radius = ... m [3]

[Total : 8]

[Turn over

3 Fig. 3.1 is an outline of the Hertsprung-Russell diagram.

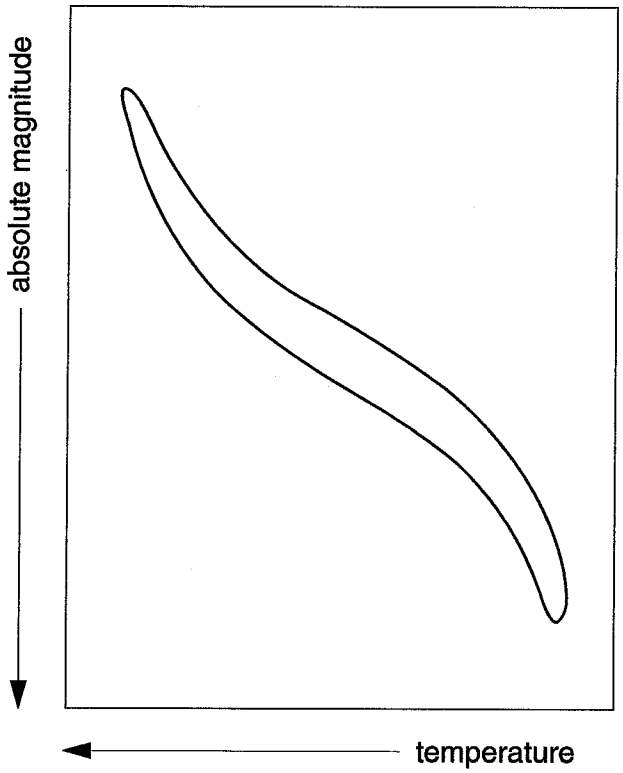

Fig. 3.1

(a) On Fig. 3.1, mark and label the position of

(i) a low mass main sequence star,

(ii) a high mass main sequence star,

(iii) a red giant,

(iv) a white dwarf.

[4]

(b) State and explain **two** differences between the evolution of high and low mass stars.

1. .....

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2. .....

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[4]

[Total : 8]

4 **(a)** Explain what is meant by

(i) *apparent magnitude* of a star,

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.....

(ii) *absolute magnitude* of a star.

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.....[2]

(b) The inverse square law may be used to derive the relation between apparent magnitude and absolute magnitude

$$m - M = 5 \lg (r/10).$$

(i) State the inverse square law relating the observed intensity of light I to the distance r between source and observer.

(ii) The star Procyon has an apparent magnitude of +0.4 and an absolute magnitude of +2.7. Calculate its distance from Earth. State an appropriate unit for the distance.

distance = ... [4]

[Total : 6]

[Turn over

5 **(a)** State Hubble's law.

.....

.....[1]

(b) A line in the spectrum of calcium has a wavelength of 396.8 nm when measured from a stationary laboratory source. The same spectral line is observed in five galaxies, resulting in the data shown in Fig. 5.1.

galaxy	distance /Mpc	λ_{obs}/nm	recession velocity/km s^{-1}
A	25	398.2	1058
B	300	416.6	14970
C	430	427.2	22980
D	750	448.1	38790
E	1200	476.9	60560

Fig. 5.1

(i) Explain how the recession velocities have been calculated from the wavelengths.

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.....[2]

(ii) On Fig. 5.2, plot a graph of recession velocity against distance. [3]

(iii) Using your graph, show that the data are consistent with a value for the Hubble constant H_o of approximately 50 km s^{-1} Mpc^{-1}.

[2]

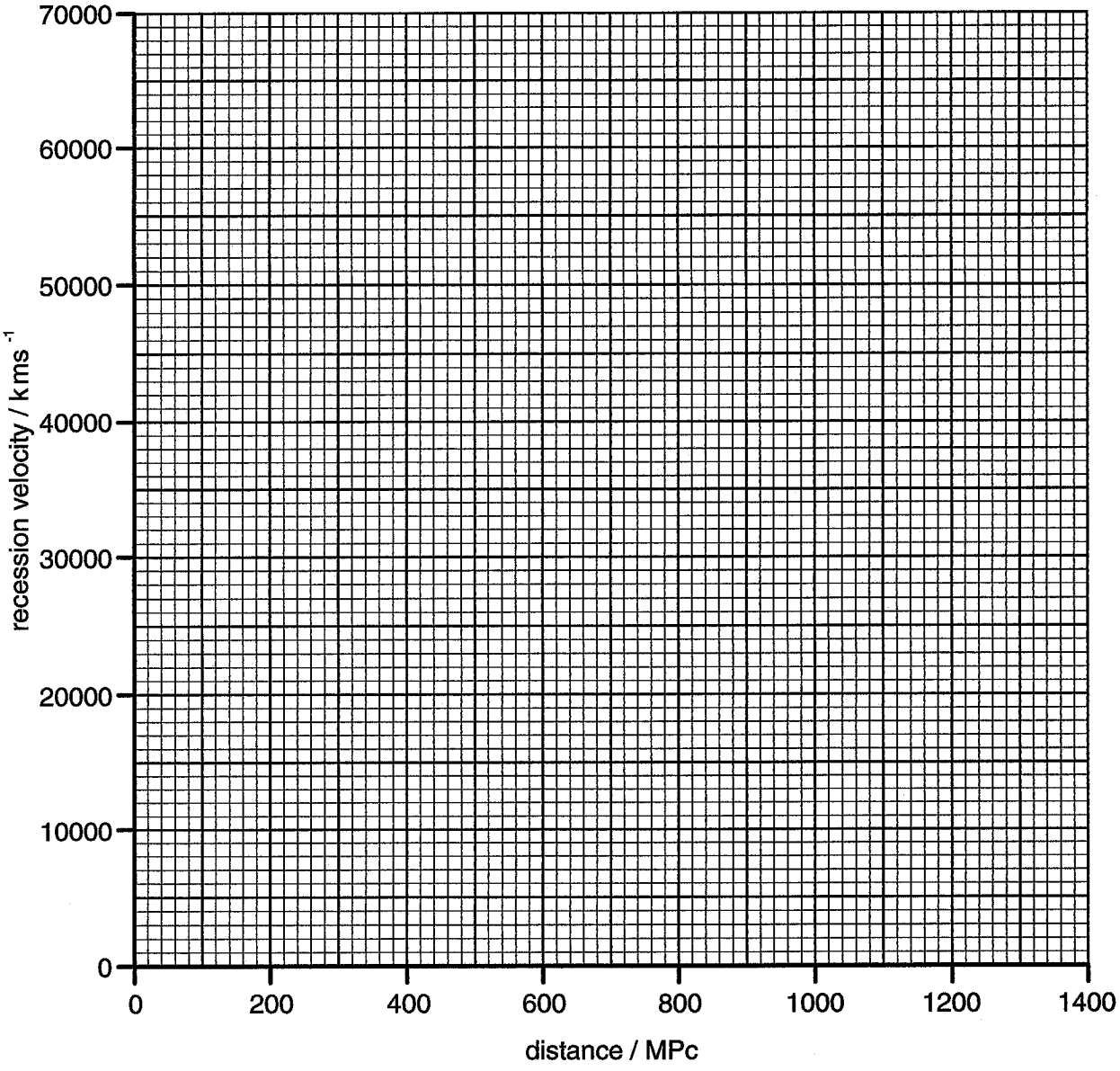

Fig. 5.2

[Total : 8]

6 The first stars were not formed until some time after the Big Bang.

(a) Outline how the first main sequence stars formed from clouds of gas.

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.....[3]

(b) The first stars are believed to have consisted solely of hydrogen and helium.

(i) State the origin of the helium.

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(ii) State **one** major difference in chemical composition between the 'first' stars and the Sun.

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.....

[2]

[Total : 5]

7 The critical density of the Universe can be shown to be given by the equation

$$\rho_0 = \frac{3H_0^2}{8\pi G}.$$

(a) State **two** assumptions made in the derivation of this equation.

1. .....

.....

2. .....

.....

[2]

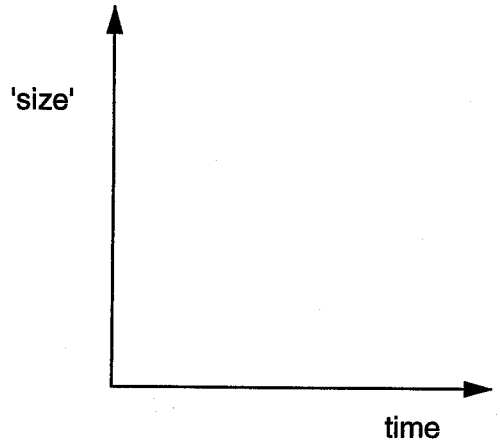
(b) Calculate the critical density of the Universe, giving your answer in hydrogen atoms per cubic metre. Hubble constant $H_0 = 1.6 \times 10^{-18}\,s^{-1}$, and the mass of a hydrogen atom = 1.7×10^{-27} kg.

Critical density = ... hydrogen atoms per cubic metre [4]

For Examiner's Use

(c) Theory suggests that the Universe may have three possible fates, referred to as *open*, *flat* and *closed*. Describe each of these and illustrate the evolution of the Universe in each case by a suitable sketch graph.

1. Open



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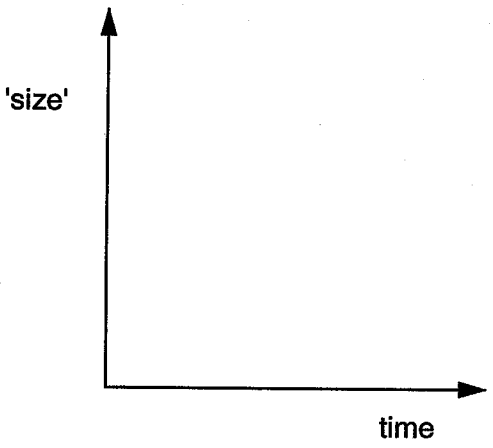
2. Flat



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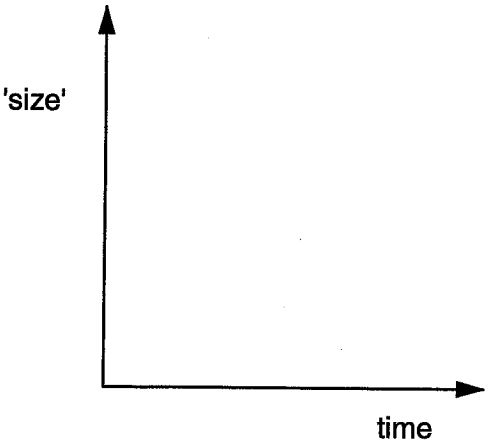
3. Closed



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[6]

[Total : 12]

8 **(a)** **(i)** One of the two postulates of Special Relativity states that '*The laws of physics are the same for all inertial observers*'. Explain the meaning of the term *inertial observer*.

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.....

(ii) State the other postulate of Special Relativity.

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[2]

(b) Describe a thought experiment to illustrate length contraction.

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.....[4]

(c) The star alpha Centauri is 4.2 light years from Earth. A spaceship travels at 0.98*c* from Earth to alpha Centauri.

(i) Calculate the time taken for the journey, according to observers on Earth.

time = ... years [2]

(ii) Show that the distance between Earth and alpha Centauri, according to the astronauts, is about 0.8 light years.

[3]

(iii) Calculate the time taken for the journey, as measured by the astronauts.

time = ... years [2]

[Total : 13]

9 **(a)** When examined in detail, the orbit of a planet is not perfectly elliptical. Explain how other planets are responsible for this effect.

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.....[2]

(b) The American astronomer Simon Newcomb made a detailed study of planetary orbits. By 1898 he had concluded that the orbit of Mercury showed a *perihelion shift* of 43 seconds of arc per century which is not entirely due to the presence of other planets.

(i) Draw a labelled diagram to show what is meant by the term *perihelion shift*.

[3]

(ii) Why is Newcomb's discovery one of the key pieces of evidence in support of the General Theory of Relativity?

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.....[1]

[Total : 6]

10 A couple who find modern life too stressful decide to move to a Scottish island which has no mains electricity supply.

There are two ways in which they could provide a power supply. One method is to lay a long-distance supply cable from another island which has mains electricity. The other method is to equip themselves with an aerogenerator and rechargeable batteries.

One disadvantage of using a long-distance supply cable is that the potential difference available at the user's end of the cable is less than the p.d. at the supply end of the cable. Because of this and the cost of laying a sufficiently thick cable, they decide to use an aerogenerator and batteries.

Rechargeable 12 V batteries are available and these will provide a reservoir of energy which can be increased by adding extra batteries. However, a battery will deliver only 80% of the energy stored in it.

The island is usually windy so they plan to keep the batteries charged by means of the aerogenerator. This consists of a rotating propeller of diameter 1.5 m, which drives a generator. The overall efficiency of the aerogenerator is 40%. It works by converting into electrical energy some of the kinetic energy of the air passing through the propeller. The average wind speed on the island is 8.0 m s^{-1}. This means that all the air inside a cylinder 8.0 m long, of diameter 1.5 m, passes through the propeller in 1 second. This is illustrated in Fig. 10.1.

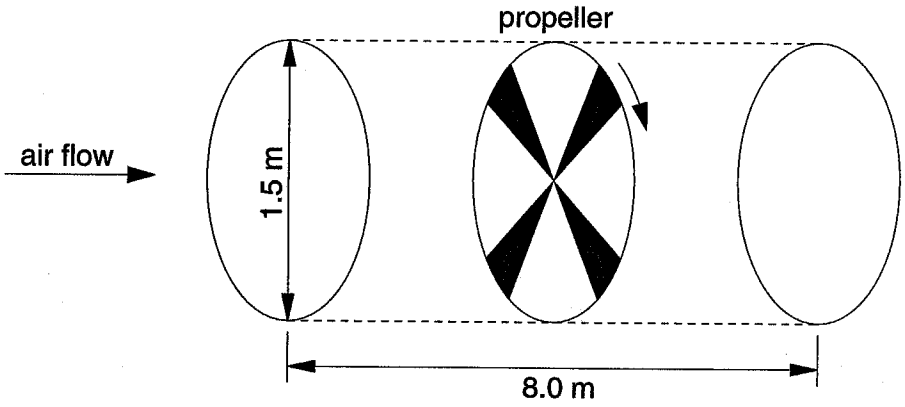

Fig. 10.1

Although the island is normally windy, there are periods of calm. Meteorological information suggests that the longest such period would be 40 hours. The couple estimate that their average power requirement during these periods would be 160 W.

Additional information:

amount of energy stored by one rechargeable battery	$= 7.0 \times 10^6$ J
density of air	$= 1.3$ kg m^{-3}

(a) Explain why the p.d. available to the user of a long mains cable would be less than the p.d. at the supply end of the cable.

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.....[3]

(b) Suggest why it is not possible for the aerogenerator to achieve an efficiency of 100%.

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.....[2]

(c) **(i)** Show that the mass of air contained in a cylinder of diameter 1.5 m and length 8.0 m is approximately 18 kg.

[2]

(ii) Calculate the kinetic energy of 18 kg of air travelling at 8.0 m s^{-1}.

energy = ... J [2]

(iii) Hence calculate the average power output of the aerogenerator.

power = ... W [1]

(d) Calculate the average time taken by the aerogenerator to recharge one battery fully.

time = ... s [2]

(e) **(i)** State what form of energy is stored by a battery.

.....[1]

(ii) Give **one** reason why the energy delivered by a battery is less than the energy input.

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.....[1]

(f) **(i)** Calculate the greatest amount of energy which needs to be delivered by the batteries during a 40 hour period of calm weather.

energy = ... J [2]

(ii) Calculate the total energy which the set of batteries must be capable of storing.

energy = ... J [2]

(iii) Calculate the minimum number of rechargeable batteries that will be needed.

[2]

[Total : 20]

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