RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS A

2825/01

Cosmology

Thursday **22 JUNE 2006** 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 seven questions concern Cosmology. The last question concerns general physics.

FOR EXAMINER'S USE		
Qu.	Max.	Mark
1	6	
2	6	
3	14	
4	9	
5	11	
6	10	
7	14	
8	20	
TOTAL	90	

This question paper consists of 18 printed pages and 2 blank 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, $p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$

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 Discuss the **shape** of planetary orbits according to the ideas of Copernicus and Kepler. How does Newton's work on gravity support Kepler's model?

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

.... [6]

[Total: 6]

2 The elliptical path of a planet **P** which orbits a star is shown in plan view in Fig. 2.1. The period of the orbit is 80 years. The planet's current position and direction of motion are shown.

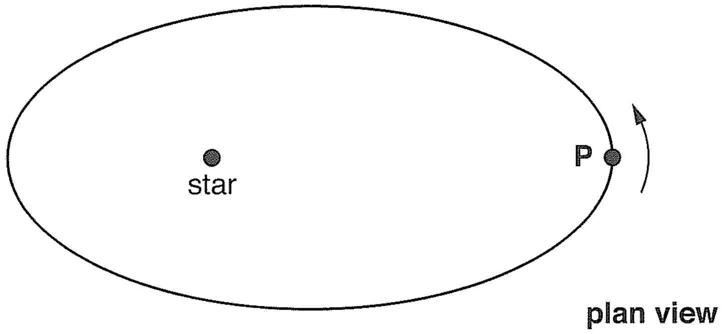


Fig. 2.1

(a) **(i)** Use one of Kepler's laws of planetary motion to find the approximate position of the planet after a further 20 years. Mark this position on Fig. 2.1 with an X. [1]

(ii) State which law you used and explain how you used it to locate the approximate position.

....

....

.... [2]

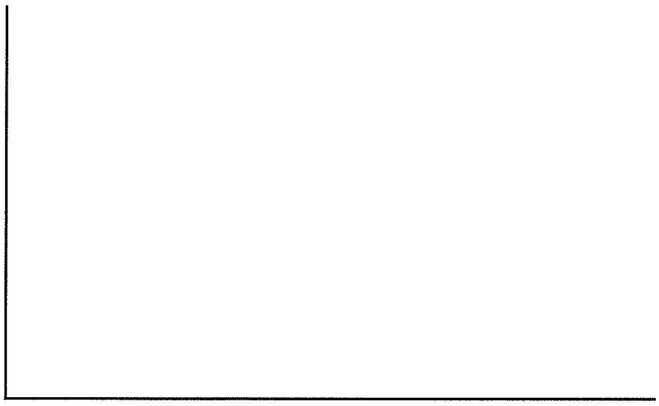
(b) A second planet orbiting the same star has an average orbital radius of 0.4 × the average orbital radius of **P**. What is its orbital period?

period = ... years [3]

[Total: 6]

For Examiner's Use

3 **(a)** On Fig 3.1, sketch a Hertzsprung-Russell (H-R) diagram showing the positions of Main Sequence stars (M), red giants (R) and white dwarf stars (W). Label the axes.



[5]

Fig. 3.1

(b) When a star ceases to be Main Sequence, it may evolve in several different ways. Explain the circumstances which will lead to the formation of a neutron star.

....

....

....

....

....

....

....

....

....

....

....

....

....

.... [4]

For Examiner's Use

(c) **(i)** A star of mass 7×10^{30} kg becomes a neutron star of radius 10 km. Calculate the average density of the neutron star, assuming that 50% of the original star's mass has been lost.

density = ... $kg\,m^{-3}$ [3]

(ii) State how the density of a neutron star compares to that of materials commonly found on Earth.

....

....

.... [2]

[Total: 14]

For Examiner's Use

4 (a) (i) Explain the terms *apparent magnitude* and *absolute magnitude*.

....

....

.... [2]

(ii) Explain **one** advantage of using absolute magnitude as a scale of brightness.

....

....

.... [1]

(b) (i) Two stars of apparent magnitude m_1 and m_2 are at distances r_1 and r_2 respectively from the Earth. They have the same absolute magnitude. Use the relation between apparent and absolute magnitudes to show that

$$m_1 - m_2 = 5\lg(r_1/r_2).$$

[2]

(ii) The Sun has an apparent magnitude of –26.7 and is 1.5×10^8 km from Earth. Calculate the apparent magnitude of a star which is identical to the Sun and at the galactic centre, a distance of 2.7×10^{17} km from Earth.

apparent magnitude = ... [2]

For Examiner's Use

(iii) Suggest reasons why, in practice, the apparent magnitude may be less than that calculated.

....

....

.... [2]

[Total: 9]

5 (a) Some stages in the early evolution of the Universe are represented in Fig. 5.1.

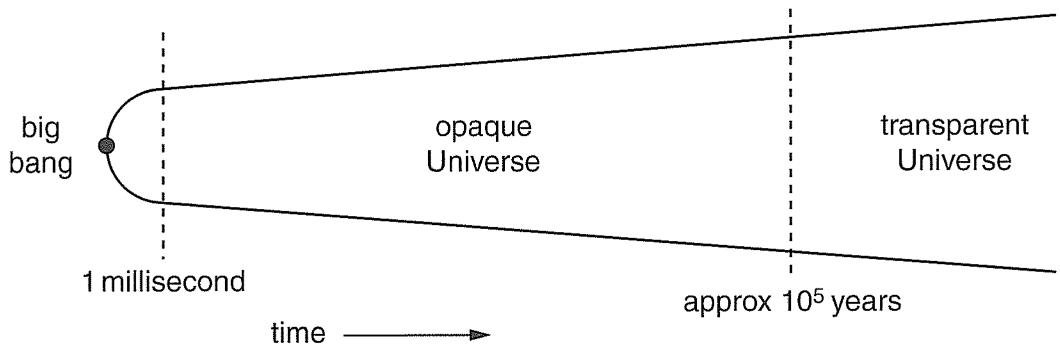


Fig. 5.1

(i) What limits our understanding of events in the first millisecond?

....

.... [1]

(ii) State and explain how the temperature of the Universe has changed after the first millisecond.

....

....

.... [2]

(iii) Explain how the Universe became *transparent*.

....

....

....

.... [3]

[Turn over

For Examiner's Use

(b) Describe and explain **two** pieces of evidence which suggest that the Universe did in fact begin with a big bang.

....

....

....

....

....

....

....

....

....

....

.... [5]

[Total: 11]

For Examiner's Use

6 **(a)** What is meant by the *cosmological principle*?

....

.... [2]

(b) The ultimate fate of the Universe is not yet clear. Fig. 6.1 shows a graph where the size of the Universe is represented from the big bang **B** to the present day **P**. The graph has been extended into the future by the dotted line (– – – – –).

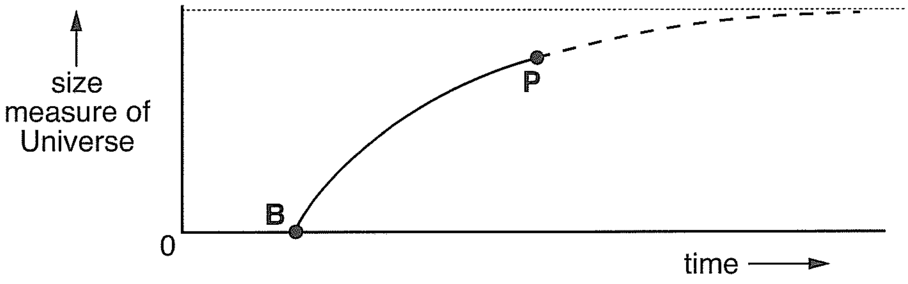


Fig. 6.1

(i) Calculate a value for the age of the Universe in years. Assume the Hubble constant to be 75 km s^{-1} Mpc^{-1}.

age = ... years [3]

(ii) Describe and explain what final fate for the Universe is represented in Fig. 6.1.

....

....

.... [2]

(iii) The mass of the Universe may be significantly greater than that assumed in **(b)**. Taking this to be case, sketch a second graph on Fig. 6.1 using the same scales to show the future evolution of the Universe. [2]

(iv) Comment upon the implications of your graph for the future of the Universe.

....

....

.... [1]

[Total: 10]

[Turn over

For Examiner's Use

7 **(a)** Explain how the concept of *time* is treated differently within the Special Theory of Relativity compared to its traditional use in Newtonian mechanics.

....

....

....

.... [2]

(b) Muons are unstable particles which pass down through the Earth's atmosphere at a speed of 0.994*c*. The number of muons per second *n* is measured at several places on a high mountain.
The number per second at the highest point is n_0 and *x* is the distance **below** this point. The results are given in Fig. 7.1.

x/m	n/n_0	$\ln(n/n_0)$
0	1.00	0
1000	0.85	–0.17
2000	0.72	–0.33
3000	0.61	–0.50
4000	0.52	
5000	0.44	

Fig. 7.1

(i) Complete the last column of the table in Fig. 7.1. [1]

For Examiner's Use

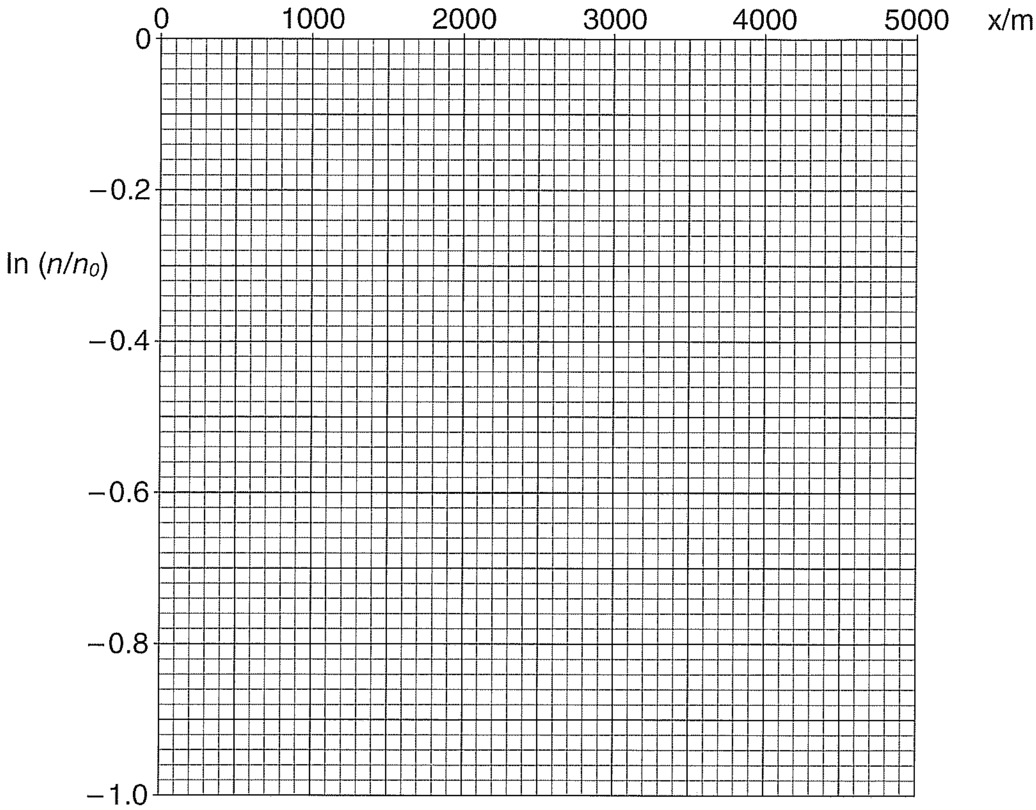


Fig. 7.2

(ii) Plot a graph of ln (n/n_0) against x on the axes in Fig. 7.2. [2]

(iii) Draw the best straight line through the points. [1]

(iv) n varies with x according to the equation

$$n/n_0 = e^{-kx}$$

Use your graph to show that the value of k is approximately $1.6 \times 10^{-4}\,m^{-1}$.

[2]

[Turn over

For Examiner's Use

(v) k is related to the half-life of the muons $T_{1/2}$ as measured by stationary observers on the mountain, by the equation

$$k = \frac{0.693}{cT_{1/2}}$$

where c is the speed of light.

Calculate the value of $T_{1/2}$.

$T_{1/2}$ = ... s [2]

(vi) The speed of the muons is 0.994c. Calculate the half-life of the muons as measured in their own frame of reference.

half-life in muon reference frame = ...s [3]

(vii) Suggest the significance of these measurements when they were first made.

....

.... [1]

[Total: 14]

For Examiner's Use

8 Most man-made objects launched into space are satellites placed in a particular orbit around the Earth to function as TV transmitters, telephone relays or weather stations. Some spacecraft have been launched, however, to travel into much deeper space to explore the outer planets of our solar system. All spacecraft, whether satellites or deep space probes, must communicate with Earth by transmitting a radio signal. The circuits producing the signal require battery power and batteries require recharging from an energy source.

Most satellites in orbit around the Earth derive their power from a panel of solar cells which convert sunlight into electrical energy. One such telecommunications satellite transmits a continuous 360 W signal powered from its battery for 24 hours per day. The battery is recharged from a solar panel which has an efficiency of 16% while in direct sunlight of light intensity 1.5 kW m^{-2}.

(a) Suggest what happens to the 84% of light energy which reaches the solar panel but is not converted to electrical energy.

....

.... [1]

(b) **(i)** Calculate the minimum surface area of solar panel required to produce the 360 W for the transmitter.

surface area = ... m^2 [2]

(ii) Give **two** reasons why the surface area would have to be much greater than your answer above.

1. ....

....

2. ....

.... [2]

For Examiner's Use

For a spacecraft launched into the outer regions of the solar system, it is not practical to have its battery recharged by solar panels. Such spacecraft use a Radioisotope Thermoelectric Generator (RTG). This generator has no moving parts and contains two different metals joined to form a closed electric circuit. When the two junctions between these metals are kept at different temperatures, an electric current is produced. One junction is cooled by space while the other is heated by the decay from a radioactive isotope. RTGs are very reliable sources of power.

Nowadays, RTGs use plutonium-238 which is an alpha emitter with a half-life of 88 years. Each alpha particle is emitted with a kinetic energy of 5.0 MeV.

(c) State **one** reason why solar panels are not practical in deep space.

....

.... [1]

(d) Suppose such a spacecraft transmits for 120 minutes each day from a 12 V circuit which draws a current of 5.0 A while transmitting back to Earth. During the rest of the day, the transmitting circuit is shut down. The battery charging, however, carries on continuously.

(i) Show that the energy required per day for transmission is about 0.4 MJ.

[2]

(ii) The overall efficiency in the RTG battery charging system is 25%. Show that the steady power output required from the RTG is about 20 W.

[2]

(iii) Calculate the minimum activity of the source (i.e. the number of 5 MeV alpha particles emitted per second) required to generate this power.

activity = ... Bq [2]

For Examiner's Use

(e) **(i)** Show that the decay constant λ of Pu-238 is $2.5 \times 10^{-10}\ s^{-1}$.

[2]

(ii) Calculate the number N of nuclei of Pu-238 required to generate the activity calculated in **(d)(iii)**.

N = ... [2]

(iii) Calculate the mass of Pu-238 corresponding to this number of nuclei.

mass = ... kg [2]

(f) Plutonium is one of the most dangerous chemical poisons known, as well as being a radioactive hazard. It has been estimated that 1 kg of this substance, suitably distributed, would be enough to kill everyone on Earth. Comment on the risks involved in using plutonium as a fuel for spacecraft.

....

....

....

.... [2]

[Total: 20]

END OF QUESTION PAPER