OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS A

2825/01

Cosmology

Wednesday **26 JANUARY 2005** 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 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.
- 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	4	
2	14	
3	8	
4	7	
5	15	
6	11	
7	11	
8	20	
TOTAL	90	

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

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,	$n = \dfrac{1}{\sin C}$
capacitors in series,	$\dfrac{1}{C} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \ldots$
capacitors in parallel,	$C = C_1 + C_2 + \ldots$
capacitor discharge,	$x = x_0 e^{-t/CR}$
pressure of an ideal gas,	$p = \frac{1}{3}\dfrac{Nm}{V}<c^2>$
radioactive decay,	$x = x_0 e^{-\lambda t}$
	$t_{\frac{1}{2}} = \dfrac{0.693}{\lambda}$
critical density of matter in the Universe,	$\rho_0 = \dfrac{3H_0^2}{8\pi G}$
relativity factor,	$= \sqrt{(1 - \frac{v^2}{c^2})}$
current,	$I = nAve$
nuclear radius,	$r = r_0 A^{1/3}$
sound intensity level,	$= 10 \lg\left(\dfrac{I}{I_0}\right)$

Answer **all** the questions.

1 **(a)** In 1543 Copernicus proposed a new model for the solar system.

Outline briefly the main features of the solar system as proposed by Copernicus. Include in your answer the shape of the path he proposed for the orbit of the planets.

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....

....

.... [2]

(b) The model proposed by Copernicus was revised by Kepler. State **two** changes made by Kepler to the Copernican model.

1. .... [1]

2. .... [1]

[Total: 4]

For Examiner's Use

2 (a) (i) State the equation that represents Newton's law of gravitation, defining all symbols.

....

....

....

.... [1]

(ii) Why did Newton believe that the Universe must be infinitely large?

....

.... [1]

(b) The period and average orbital radius of two Earth-orbiting research satellites are given in Fig. 2.1.

satellite	period / h	orbital radius / km
A	1.63	7010
B	48.1	67100

Fig. 2.1

(i) Satellite **B** has the larger orbital radius. Using Newton's law of gravitation, explain why the satellites have such different periods.

....

....

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.... [2]

(ii) Using data from Fig. 2.1, calculate the average orbital radius for a satellite with a period of 57.2 hours.

radius = ...km [3]

For Examiner's Use

(c) One of the satellites is used to observe a nova. This is a star which releases a large amount of energy but does not undergo a supernova explosion because its mass is too low. Its apparent magnitude increases rapidly.

(i) What is meant by the *apparent magnitude* of a star?

....

....

.... [1]

(ii) A particular nova has a maximum increase in apparent magnitude of 12. Calculate

$$\frac{\text{the intensity of light before the change in apparent magnitude}}{\text{the intensity of light just after the change in apparent magnitude}}.$$

answer = ... [3]

(d) Suggest **three** advantages that land–based telescopes have over those which are on satellites orbiting the Earth.

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.... [3]

[Total: 14]

For Examiner's Use

3 **(a)** The cosmic microwave background radiation is evidence for the way in which the Universe began. State a feature of the intensity of this microwave background radiation.

.... [1]

(b) The first stars are thought to have formed many years after the Universe came into being. What are the similarities and differences between the **composition** of the Sun and that of the very first stars?

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.... [3]

(c) The chemical composition of a star can be found from the light that it emits. Explain how some of the elements present in a star can be detected from a study of the spectrum of the star.

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.... [4]

[Total: 8]

For Examiner's Use

4 The Hertzsprung–Russell (H-R) diagrams in Fig. 4.1 show the pattern of stars within two galaxies of similar size.

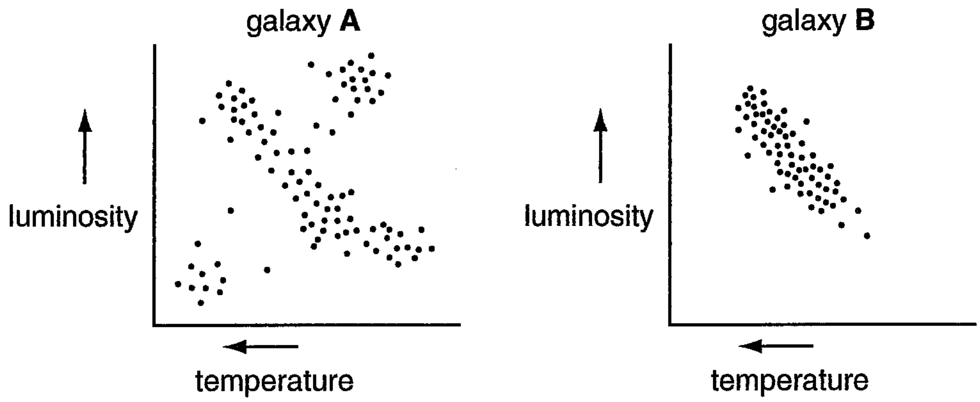

Fig. 4.1

(a) Label on the diagram for galaxy **A**

- the position of a high-mass star using the letter **M**
- the position of a white dwarf using the letter **W**. [2]

(b) **(i)** Describe in detail how the classes of star present in galaxy **A** are different from those in galaxy **B**.

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.... [3]

(ii) Galaxy **B** formed more recently than galaxy **A**. Explain how this may be deduced from the H-R diagrams.

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.... [2]

[Total: 7]

For Examiner's Use

5 **(a)** In 1929 Edwin Hubble showed that the Universe was expanding by studying the light from stars and galaxies. Explain how.

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.... [5]

(b) Suggest why many stars within our galaxy do not conform with Hubble's law.

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.... [2]

(c) Estimate the age of the Universe, giving your answer in seconds. Show your working and take the Hubble constant to be 75 km s^{-1} Mpc^{-1}.

age = ... s [3]

For Examiner's Use

(d) Describe how the fate of the Universe depends upon its mean density and explain why this ultimate fate is not yet known.

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.... [5]

[Total: 15]

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For Examiner's Use

6 **(a)** Observations made over many days show that the intensity of light from one particular star is not constant. The measurements of intensity and time are given in Fig. 6.1.

time / days	intensity / 10^{-12} W m^{-2}
0	11.0
4	17.5
7	32.0
8	39.0
9	50.0
11	49.5
12	38.5
14	24.0
17	14.0
21	8.0

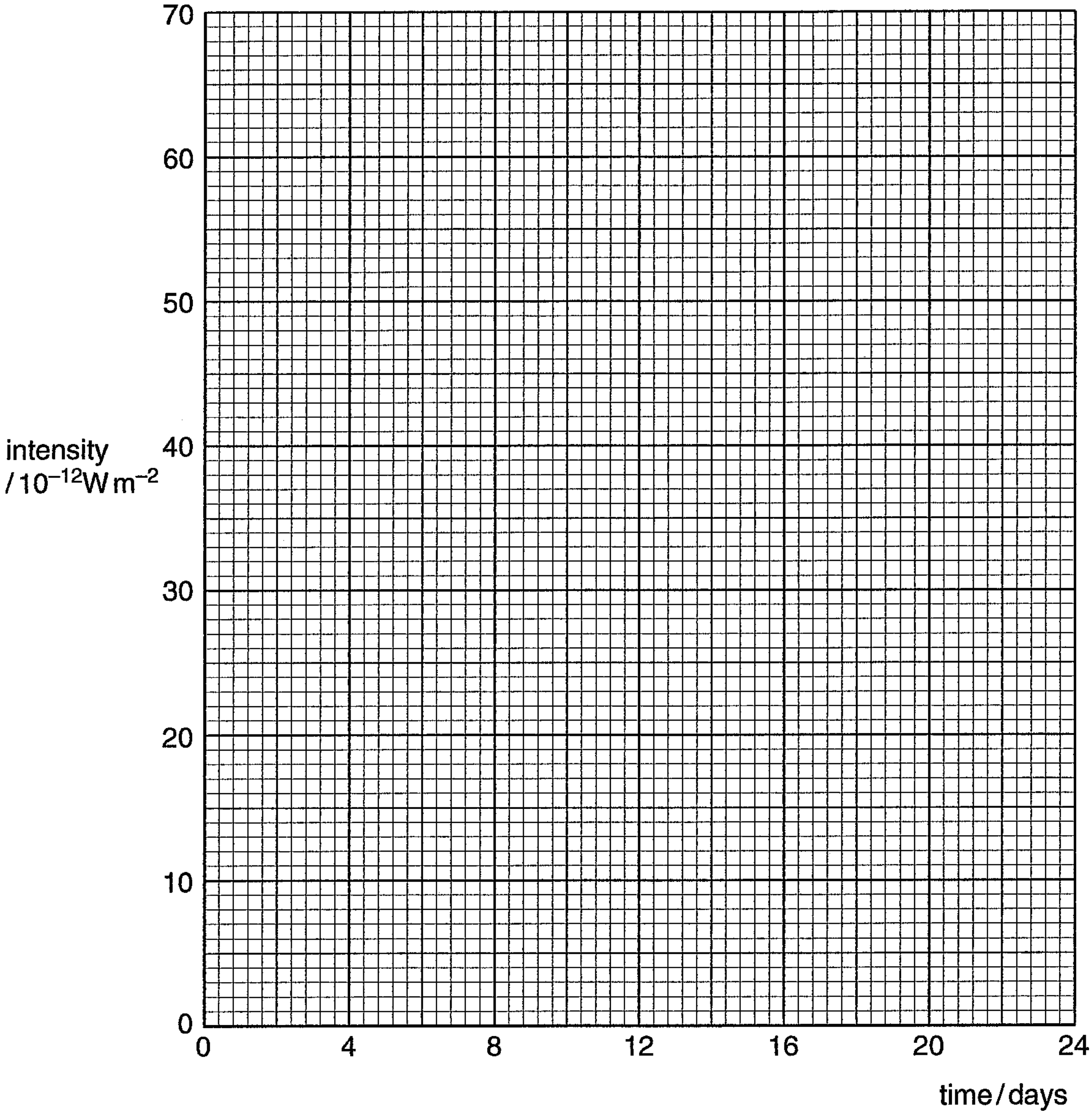
Fig. 6.1

(i) Plot the points on the grid in Fig. 6.2. [2]

(ii) Draw a curve through the points on Fig. 6.2. [2]

(iii) Estimate from the graph the time at which the intensity is greatest.

time = ... days [1]



intensity / 10^{-12} W m^{-2}
70
60
50
40
30
20
10
0
0
4
8
12
16
20
24
time / days

Fig. 6.2

For Examiner's Use

(b) The change of intensity is thought to be due to the influence of a black hole. As the Earth moves along its orbit, the line of sight between the Earth and the star passes over a black hole. Fig. 6.3 shows the star, the black hole and the path of the Earth.

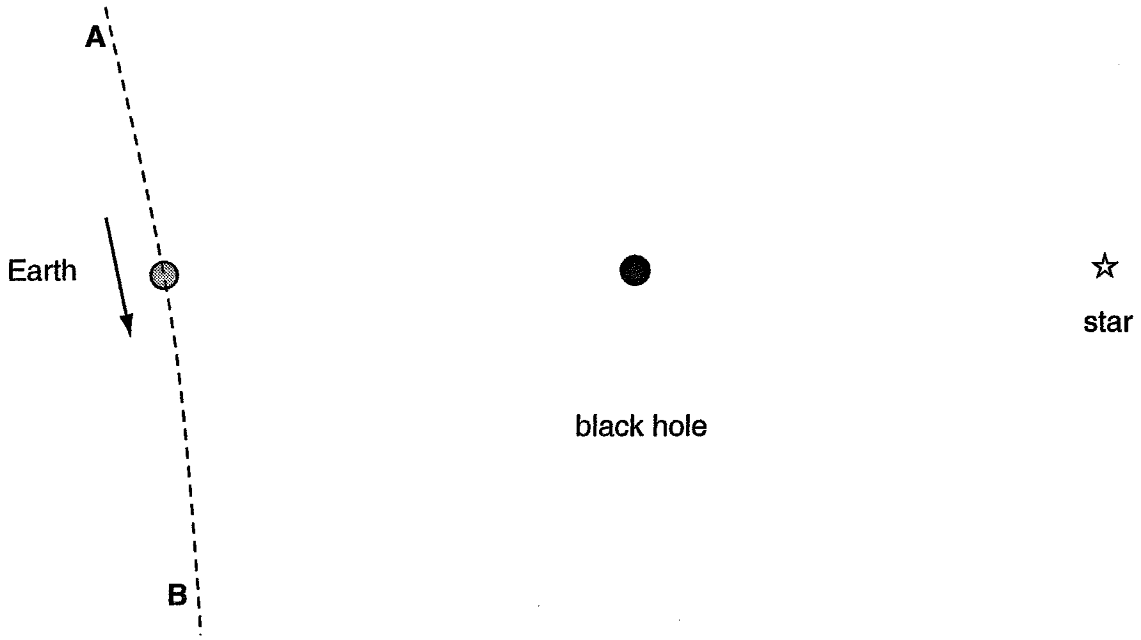


Fig. 6.3

(i) Draw **two** rays of light on Fig. 6.3 from the star to the Earth when they are in the positions shown. [2]

(ii) Explain the shape of the graph in Fig. 6.2 by reference to the Earth's motion along the path **AB**.

....

....

.... [2]

(c) Explain why the path of photons is affected by the influence of strong gravitational fields, such as those close to stars.

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....

.... [2]

[Total: 11]

For Examiner's Use

7 **(a)** Einstein's Special Theory of Relativity was first published in 1905. State the **two** postulates of the special theory.

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.... [2]

(b) Describe a thought experiment that illustrates length contraction.

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.... [5]

For Examiner's Use

(c) A pulsar is a rapidly spinning star that emits a strong continuous beam of radio waves. The beam rotates with the pulsar rather like the beam of light from a torch which is turned in a circle.
One such pulsar, represented in Fig. 7.1, is at a distance of 1000 ly (9.46×10^{18} m) from the Earth and its period of rotation is 1.49 s.

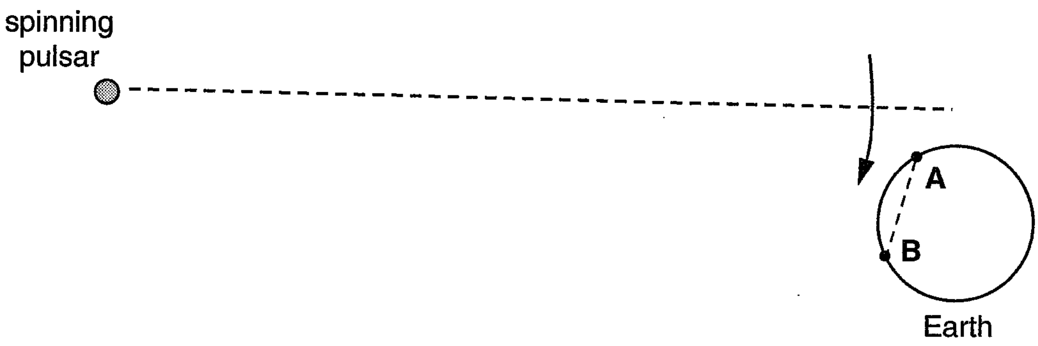

Fig. 7.1 (not to scale)

The radio beam is monitored by two observatories on Earth, **A** and **B**, which are a linear distance of 11 000 km apart. The beam sweeps past one observatory 2.73×10^{-13} s later than the other.

(i) Show that the speed at which the beam sweeps across the Earth is approximately $4.0 \times 10^{19}\ \text{m s}^{-1}$.

[1]

(ii) Comment on the value obtained in **(i)**.

....

....

....

.... [2]

(iii) Show that the data in **(i)** is consistent with the pulsar being at a distance of 9.46×10^{18} m from Earth.

[1]

[Total: 11]

For Examiner's Use

8 Although the idea for the airbag was first suggested more than fifty years ago, it has only been a compulsory safety feature in the modern motor car since 1998. When a car experiences a serious head-on collision, the seat belt is designed to restrain the driver's body. However, without the cushioning effect of an airbag, the inertia in the driver's head will cause it to carry on moving at the speed of the car until it is stopped by the steering wheel or the windscreen. When activated, the airbag must be fully inflated before the driver's head reaches it so that the head hits a soft target.

One early system stored the gas for the airbag in a cylinder under the driver's seat. When the deceleration of the car was sufficiently large, a sensor caused an electrical circuit to operate and open a valve so that the compressed gas could rush into the airbag on the steering wheel.

The sensor used a steel ball and spring in a cylinder as shown in Fig. 8.1.

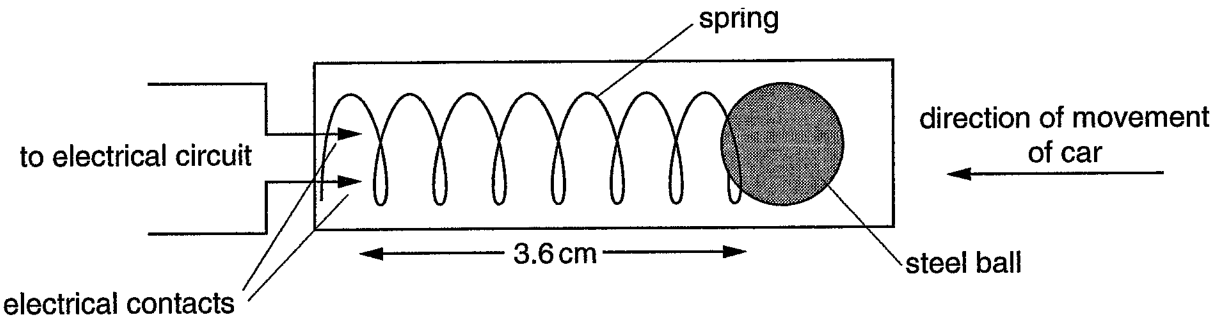

Fig. 8.1

When the car was being driven normally, the spring kept the steel ball apart from the two electrical contacts inside the cylinder. But if the deceleration became large enough, the inertia of the free ball compressed the spring and the ball touched the two contacts, thus activating the electrical circuit.

The method of storing compressed gas in a cylinder was not very reliable because some cylinders slowly leaked gas and so all had to be checked regularly.

The modern method of inflating an airbag is to generate the gas chemically by activating an electrical heater or detonator in an explosive chemical mixture. The heating starts a very rapid chemical reaction which produces nitrogen for the airbag. This means that the folded airbag along with chemicals and heater can all be located together in a compact container and positioned anywhere inside the car.

Consider the following data for a car running head-on into an immovable object.

initial velocity of car	$= 54\,\text{km hr}^{-1}$
final velocity of car	$= 0$
car front crumple distance	$= 1.25\,\text{m}$
distance from head to windscreen	$= 0.96\,\text{m}$

(a) Show that the car's speed in m s^{-1} just before hitting the object is $15\,\text{m s}^{-1}$.

[2]

(b) Calculate

(i) the deceleration of the car during the collision (assumed to be constant)

deceleration = ... m s^{-2} [2]

(ii) the time taken for the car to crumple to rest.

time = ... s [2]

(c) The data for a ball and spring sensor is given below.

mass of ball	$= 0.12\,\text{kg}$
spring constant	$= 30\,\text{N m}^{-1}$
distance to be compressed	$= 3.6\,\text{cm}$

Calculate

(i) the force necessary to compress the spring by 3.6 cm

force = ... N [2]

(ii) the deceleration which the force in **(c)(i)** would cause in a mass of 0.12 kg.

deceleration = ... m s^{-2} [1]

For Examiner's Use

(d) When the airbag was fully inflated from a storage cylinder, the bag had a volume of 0.060 m^3, with the gas inside at a pressure of 250 kPa. If the storage cylinder had a volume of 3.0×10^{-4} m^3, calculate the stored gas pressure, assuming the gas was ideal and at constant temperature.

pressure = ... Pa [2]

(e) Suppose that the pressure inside the cylinder dropped by 20% over a period of 4 weeks. Assuming the mean temperature of the cylinder is 17 °C, calculate the average number of gas molecules leaving per second during this time.

number leaving per second = ... [4]

(f) The data for a modern airbag is given below.

energy required for reaction to start	= 0.96 J
heater wire cross sectional area	= 2.75×10^{-8} m^2
heater wire length	= 2.2 cm
resistivity of heater wire	= 1.5×10^{-6} Ω m
battery voltage	= 12 V

(i) Show that the resistance of the heater filament is 1.2 Ω.

[2]

(ii) Hence calculate the time taken for the heater to start the chemical reaction.

time to start = ... s [3]

[Total: 20]

END OF QUESTION PAPER