OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE UNIT **2825/01**

PHYSICS A

Cosmology

FRIDAY 26 JANUARY 2007 Morning

Time: 1 hour 30 minutes

Additional materials: Electronic calculator

Candidate Name

Centre Number

Candidate Number

INSTRUCTIONS TO CANDIDATES

- Write your name, Centre Number and Candidate number in the boxes above.
- Answer **all** the questions.
- Use blue or black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure you know what you have to do before starting your answer.
- Do **not** write in the bar code.
- Do **not** write outside the box bordering each page.
- WRITE YOUR ANSWER TO EACH QUESTION IN THE SPACE PROVIDED. ANSWERS WRITTEN ELSEWHERE WILL NOT BE MARKED.

INFORMATION FOR CANDIDATES

- The number of marks for each question is given in brackets [ ] at the end of each question or part question.
- The total number of marks for this question 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	10	
3	8	
4	13	
5	15	
6	14	
7	20	
TOTAL	90	

This document consists of **17** printed pages and **3** blank pages.

[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, $n = \dfrac{1}{\sin C}$

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, $p = \frac{1}{3}\dfrac{Nm}{V}\langle c^2\rangle$

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, $= \sqrt{(1 - \dfrac{v^2}{c^2})}$

current, $I = nAve$

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

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

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Answer **all** the questions.

1 **(a)** **(i)** State the important observations made by Galileo of

1 the Earth's moon ....

....

2 the planet Jupiter. ....

.... [2]

(ii) How did these observations help develop our understanding of the Universe?

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.... [2]

(b) Explain how in the 19th century a close study of the motion of Uranus further improved our knowledge of the solar system.

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.... [3]

(c) The Universe contains bodies each having a wide range of size and mass. The masses shown in Fig. 1.1 are each quoted as a fraction of the mass of the Sun.

Complete the table by suggesting what the other 3 bodies may be.

$\frac{\text{mass of body}}{\text{mass of Sun}}$	body
1×10^{10}	
1	Sun
1×10^{-6}	
1×10^{-9}	

Fig. 1.1

[3]

[Total: 10]

2 Newton first showed that the gravitational force F between two bodies of mass m_1 and m_2 a distance r apart is given by

$$F = \frac{Gm_1 m_2}{r^2}.$$

(a) (i) A satellite of mass m_s moving with velocity v is in circular orbit about the Earth, of mass m_e.

By considering an expression for centripetal force show that the velocity of the satellite is given by

$$v^2 = \frac{Gm_e}{r}.$$

[1]

(ii) Hence show that the relationship between T, the period of the satellite, and r, the radius of its orbit is given by

$$T^2 = \frac{4\pi^2 r^3}{Gm_e}.$$

[2]

(b) The Global Positioning System (GPS) uses 24 satellites. They each orbit the Earth with a period of 11h 58min. Calculate the average orbital radius of the satellites.

mass of the Earth, $m_e = 5.98 \times 10^{24}$ kg

radius = ... m [3]

(c) (i) Give **two** reasons why atomic clocks on the satellites do not run at the same rate as those on the Earth's surface.

....

....

.... [2]

(ii) A correction factor is applied to make the atomic clocks on Earth remain in time with those in the satellites. The size of this correction varies between maximum and minimum values during each orbit. What does this suggest about the satellites' orbit? Explain your answer.

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.... [2]

[Total: 10]

3 (a) What is meant by the *Doppler Effect*?

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.... [2]

(b) Describe how Edwin Hubble used atomic spectra to establish the law that now bears his name. You should refer to

- the data required
- the calculation made using the data from the spectra
- the conclusions that can be drawn from Hubble's law.

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.... [6]

[Total: 8]

4 **(a)** The evolution of a star is divided into several separate stages. What are the characteristics of a *main sequence* star?

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.... [2]

(b) **(i)** Explain why the absolute magnitudes of two stars need to be used to compare their luminosity.

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.... [2]

(ii) A star at a distance of 158.5 pc from Earth has an **apparent** magnitude of 7.5. Calculate the **absolute** magnitude of the star.

absolute magnitude = ... [3]

(c) Subsequent observations showed the apparent magnitude of the star in **(b)** changed over a number of days. The table in Fig. 4.1 shows measurements of the apparent magnitude taken over several days.

apparent magnitude	time/days
+7.5	0
–3.0	0.5
–10.0	1.0
–12.5	1.5
–12.5	3.0
–10.5	4.5
–8.0	9.0
–6.5	13.0
–4.0	21.0

Fig. 4.1

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(i) Use the data in the table to plot a graph of the star's apparent magnitude against time on Fig. 4.2. [2]

(ii) Draw a curve through the points. [1]

(iii) Use the graph to find the apparent magnitude when the star is at its brightest.

apparent magnitude = ... [1]

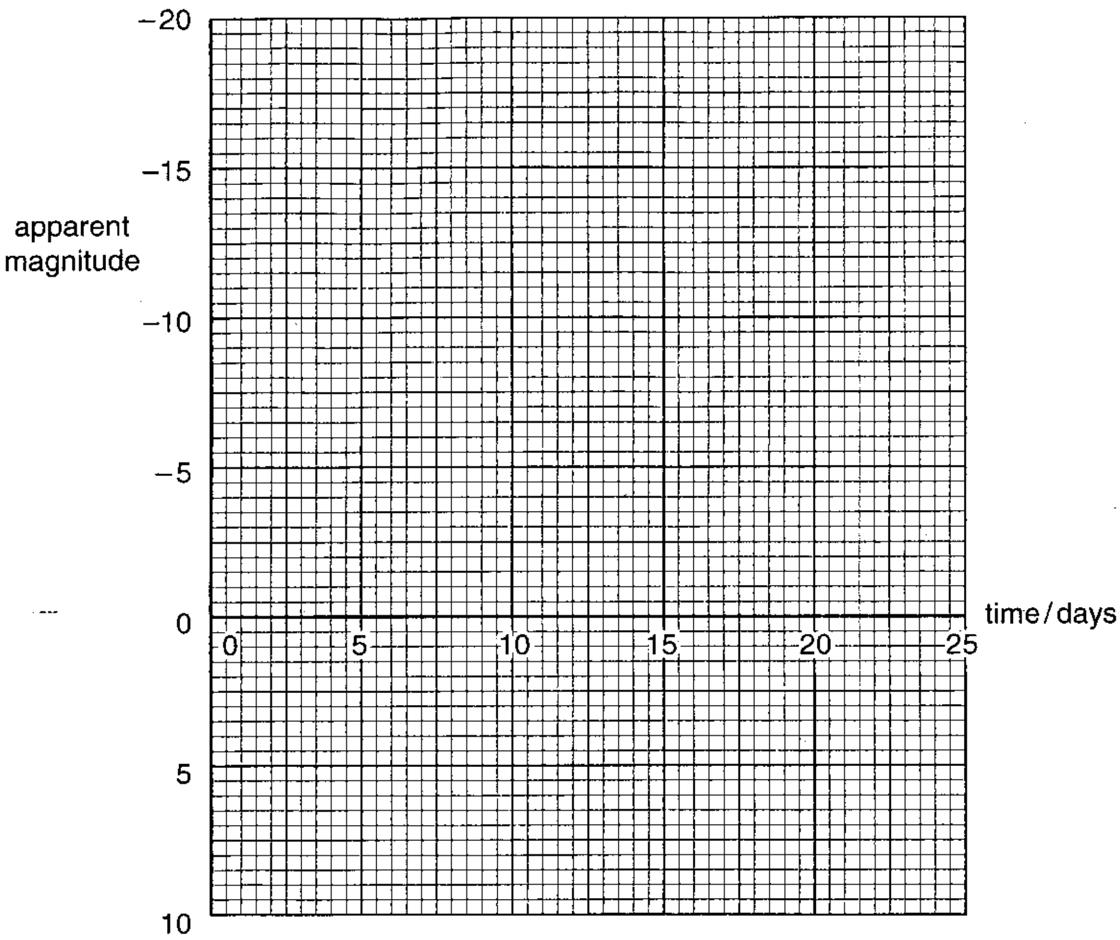

Fig. 4.2

(iv) Suggest and explain what event has taken place within the star.

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.... [2]

[Total: 13]

5 **(a)** Outline the evolution of the Universe from the Big Bang to the formation of the first atoms.

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.... [6]

(b) State **one** feature of the cosmic microwave background radiation and explain how it provides evidence for the Big Bang theory.

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.... [2]

(c) **(i)** Show that the average energy of a photon of the cosmic microwave background radiation is 1.8×10^{-22} J. Assume an average wavelength of 1.1 mm.

[2]

(ii) Show that the rest mass energy of a proton or neutron is about 1.5×10^{-10} J.

Assume the mass of either particle to be 1.7×10^{-27} kg.

[2]

(iii) It is thought that at present there may be as many as 1000 million photons from the cosmic microwave background radiation for each proton or neutron in the Universe. Calculate the ratio

$$\frac{\text{rest mass energy of 1 proton or neutron}}{\text{energy of 1000 million photons}}.$$

ratio = ... [1]

(iv) Explain how the value of this ratio might have been different when the Universe was much younger. Assume that the number of protons and neutrons has remained constant during this time.

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.... [2]

[Total: 15]

6 (a) What are the **two** conditions required by the special theory of relativity?

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... [2]

(b) Describe an experiment which uses muons to demonstrate time dilation.

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... [6]

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(c) A spacecraft travels at a constant speed of 0.99*c* from Earth to a star 6 light-years away. The craft carries a clock that is monitored from Earth.

(i) What is a light-year?

....

.... [1]

(ii) Calculate the time taken for the journey as measured by

1 a clock on Earth

time = ... *y*

2 the clock on the rocket when monitored from Earth.

time = ... *y*
[5]

[Total: 14]

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7 A champion BMX cyclist wishes to become a professional and seeks help from an A-level Physics student in creating an act. The student suggests two stunts; one involving a horizontal take-off on to a sloping ramp and the other involving a loop-the-loop manoeuvre.

(a) The student begins by finding out the maximum speed the cyclist can produce on level ground. Two flags are positioned 240 m apart on a flat road. The cyclist is told to accelerate to the first flag and to pedal as hard as he can until the second flag is passed. This is shown in Fig. 7.1.

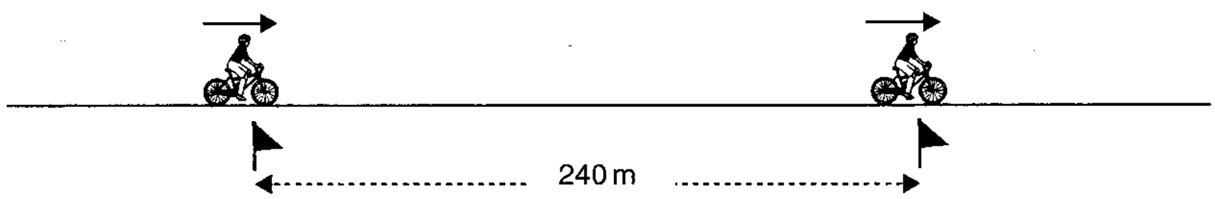

Fig. 7.1

The student gets the cyclist to repeat the test three times and records the following results:

14.8 s 17.2 s 15.6 s

Show that the mean speed the cyclist can maintain over the 240 m is about 15 m s^{-1}.

[2]

(b) The student designs the stunt shown in Fig. 7.2 where the cyclist must take off at 15 m s^{-1} from a horizontal launch pad and land smoothly just at the edge of a sloping ramp.

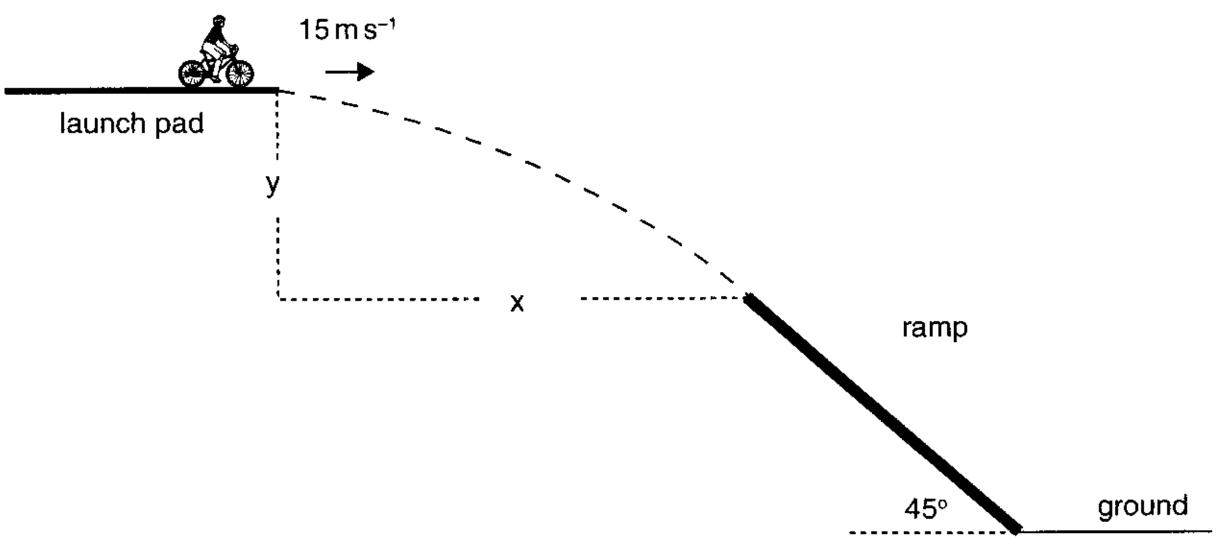

Fig. 7.2

The student reasons that in order to land smoothly, the direction of the velocity of the cyclist on reaching the edge of the ramp must be at the same 45° angle as the ramp itself.
Ignore air resistance in all calculations.

(i) Explain why the vertical component of the velocity on reaching the ramp must be $15\,\text{m}\,\text{s}^{-1}$.

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.... [1]

(ii) The student calculated the vertical fall y to the ramp to be about 11 m. Show how he arrived at this result.

[2]

(iii) The student calculated the horizontal jump x to the ramp to be about 23 m. Show how he arrived at this result.

[1]

(iv) The total mass of the cyclist and bike is 86 kg. Show that the kinetic energy of the cyclist on reaching the ramp is about 19 kJ.

[3]

(c) The student next designs a loop-the-loop stunt shown in Fig. 7.3. The cyclist must enter the circular runway at the same $15\,m\,s^{-1}$ speed in order to exit from it smoothly.

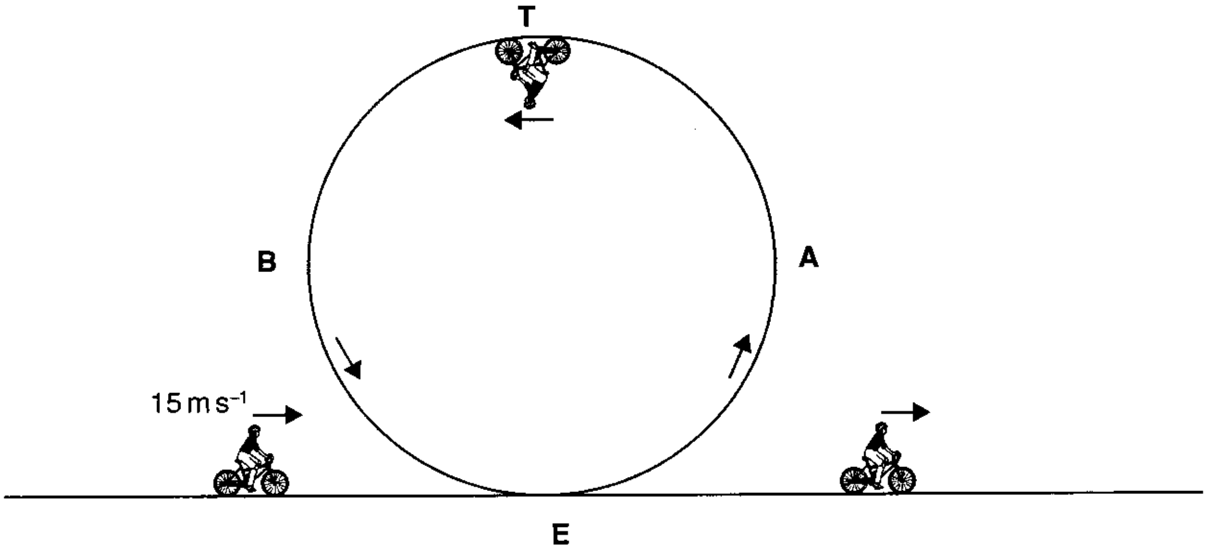

Fig. 7.3

In order to calculate the maximum diameter of loop in which the cyclist can safely execute the manoeuvre, the student makes the following assumptions

- the cyclist stops pedalling once he enters the loop at **E**
- the normal reaction of the runway on the tyre just becomes zero at the top of the loop **T**
- therefore the centripetal force at the top **T** is provided by the force of gravity only
- air resistance and runway friction can be ignored.

As a result, the student calculates the diameter of the track to be 9.17 m.

(i) Show that the speed of the cyclist at the top **T** of the loop should be $6.7\,m\,s^{-1}$.

[3]

(ii) The total mass of the cyclist and bike is 86 kg. Calculate

1 the kinetic energy of the cyclist at the top **T**

kinetic energy = ... J [2]

2 the gravitational potential energy of the cyclist at the top **T**. Take the gravitational potential energy at **E** to be zero.

potential energy = ... J [2]

(iii) Show that the sum of the kinetic and potential energies at the top **T** of the loop is equal to the kinetic energy of the cyclist as he enters the loop at **E**.

[2]

(iv) The cyclist suggests that removing the top half or semicircle of the loop from **A** to **B** would allow him to fly in a semi-circular arc through the air and thus make a more spectacular stunt. How should the student respond to this suggestion? Explain your reasoning.

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....

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.... [2]

[Total: 20]

END OF QUESTION PAPER

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