OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS A

2825/04

Nuclear and Particle Physics

Friday **31 JANUARY 2003** 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.
- You may use an electronic calculator.
- You are advised to show all the steps in any calculations.
- The first six questions concern Nuclear and Particle Physics. The last question concerns general physics.

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

This question paper consists of 20 printed pages.

SP (AT/SLC) S32591/5

[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, $p = \frac{1}{3}\frac{Nm}{V}<c^2>$

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 The graphs shown in Fig. 1.1 show the variation with separation *r* of **(i)** the electrostatic force F_E and **(ii)** the gravitational force F_G between two protons.

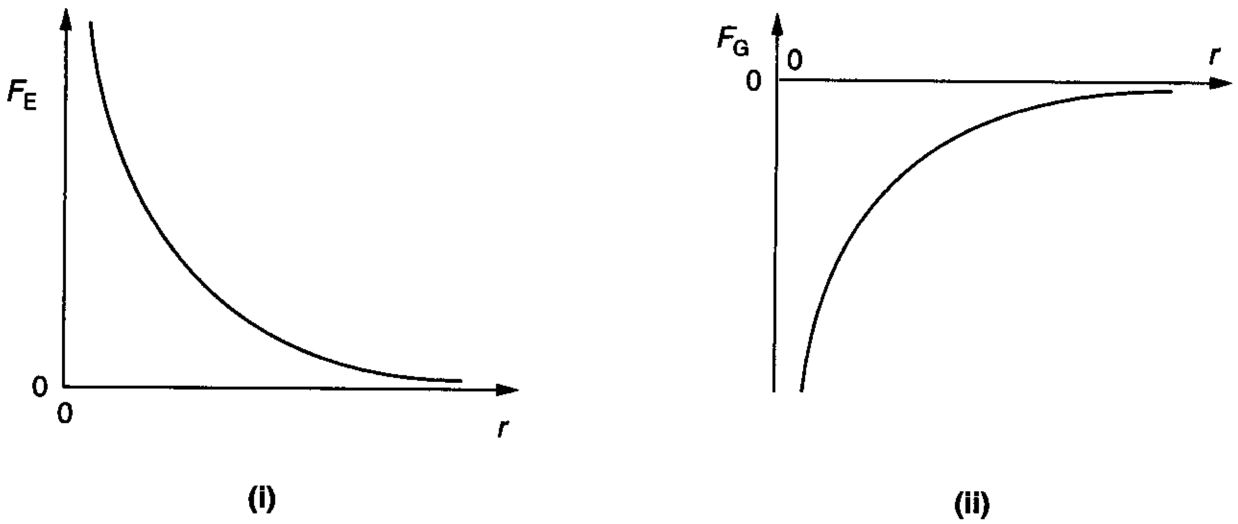

Fig. 1.1

(a) State the relation between

(i) F_E and *r*

....

....

(ii) F_G and *r*.

....

.... [2]

(b) Why is F_E positive, whereas F_G is negative?

....

....

.... [1]

(c) The range of values of *r* represented by each graph is the same.
State with a reason whether the F_E and F_G scales cover the same range of values.

....

....

.... [2]

(d) Fig. 1.2 shows how the strong force F_S varies with the separation r of two neutrons.

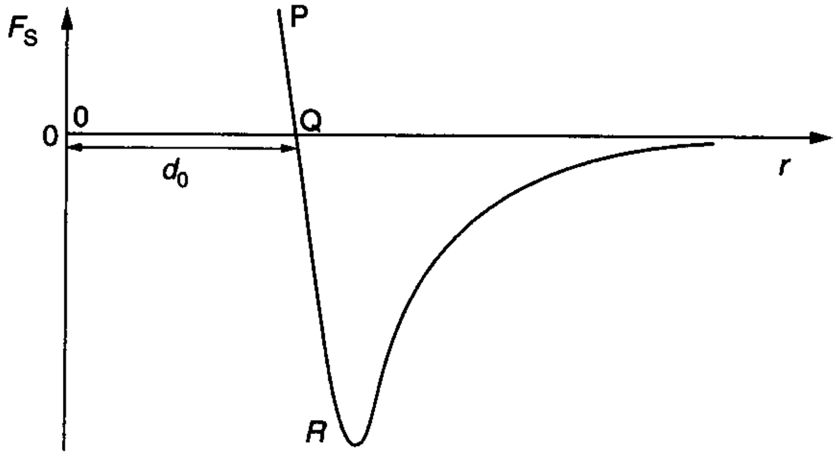

Fig.1.2

(i) State the significance of the separation d_0.

....

....[1]

(ii) State whether F_S is attractive or repulsive in regions PQ and QR.

PQ ....

QR ....

[1]

(iii) Explain how your answers to **(i)** and **(ii)** are related.

....

....

....[2]

(e) Calculate the density of a neutron. Assume that $d_0 = 1.4 \times 10^{-15}$ m and that the difference in mass between a proton and a neutron is negligible.
Give an appropriate unit for your answer.

density = ... unit ....[3]

[Total: 12]

For Examiner's Use

2 (a) Inside the fuel rods of a certain nuclear reactor, uranium-235 undergoes *neutron-induced fission*. This is stimulated by *thermal neutrons* which have entered the fuel rod. Explain what is meant by neutron-induced fission and thermal neutrons.

....

....

....

....

....

....

....[4]

(b) A $^{235}_{92}U$ nucleus undergoes the following reaction

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{146}_{57}La + ^{87}_{35}Br + 3^{1}_{0}n + \text{energy.}$$

The nucleus of $^{235}_{92}U$ has a binding energy of 1770 MeV. The binding energies of nuclei of $^{146}_{57}La$ and $^{87}_{35}Br$ are respectively 1210 MeV and 760 MeV.

Show that the energy released in this fission process is 3.20×10^{-11} J.

[3]

(c) Each fuel rod contains 4.20 kg of fuel. 3.00% of this mass is uranium-235.

(i) Show that the number of uranium-235 atoms in each fuel rod is about 3×10^{23}.

[2]

(ii) Calculate the total amount of energy available from this fuel rod.

energy = ... J [1]

(iii) Half of this energy is released in 3.00 years. Calculate the mean power generated by this fuel rod during this period.

1 year = 3.16×10^7 s

power = ... W [2]

[Total: 12]

[Turn over

For Examiner's Use

3 This is a question about nuclear fusion.

(a) In order to cause hydrogen nuclei to fuse, it is necessary to raise the temperature of the material so that it becomes a plasma. The plasma must be confined. Explain why the hydrogen must be at a high temperature in order for nuclei to fuse. State what is meant by a plasma and explain **two** ways in which a plasma may be confined.

....

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....[7]

(b) The following series of reactions occur inside the Sun.

(i) Two hydrogen-1 nuclei fuse to produce a hydrogen-2 (deuterium) nucleus and a positron.

(ii) The hydrogen-2 nucleus fuses with another hydrogen-1 nucleus to produce helium-3.

(iii) Two helium-3 nuclei then fuse to give helium-4 and two hydrogen-1 nuclei.

Write nuclear equations to represent these reactions.

(i) ....[1]

(ii) ....[1]

(iii) ....[1]

(c) Use your answers to **(i)**, **(ii)** and **(iii)** to deduce an equation which summarises the fusion of hydrogen-1 nuclei to form a helium-4 nucleus.

....

....

....

....

....

....

....[2]

[Total: 12]

For Examiner's Use

4 This question is about electrons and positrons in a synchrotron.

(a) Explain briefly a method of accelerating a charged particle from rest.

....

....

....[2]

(b) Describe and explain how a fast-moving charged particle can be made to follow a circular path.

....

....

....

....

....

....[3]

(c) In the Large Electron Positron collider (LEP), electrons and positrons reach a maximum speed of almost $3.0 \times 10^8\,\mathrm{m\,s^{-1}}$ and move in a circular orbit of radius 4.25 km.

(i) State the significance of this maximum speed.

....

....[1]

(ii) Calculate the time taken by an electron to complete one orbit.

time = ... s [2]

For Examiner's Use

(d) Positive and negative charges travel in circular paths in opposite directions when moving in a plane at right angles to the same magnetic field. Explain why this is so and give reasons why this technique is used in the LEP.

....

....

....

....

....

....

....

....

....

....[4]

[Total: 12]

5 (a) There are six quarks. In the list below, the first two have been named. Complete the list by naming the remaining **four**.

1. up
2. down
3. ....
4. ....
5. ....
6. ....

[2]

(b) State the quark composition of

the neutron ....[1]

the proton ....[1]

(c) (i) Distinguish between the two types of β-decay.

....

....[1]

(ii) Nitrogen-14 ($^{14}_{7}N$) can be formed as a result of two β-decay reactions.

1. β-decay of carbon-14 ($^{14}_{6}C$)

2. β-decay of oxygen-14 ($^{14}_{8}O$)

Write nuclear equations for these two reactions.

1. ....

....

2. ....

....

[2]

(iii) In each of the reactions in **(ii)**, state the name of the other particle which is produced.

1. ....

2. ....

[2]

For Examiner's Use

(iv) Show that reaction **1** in part **(ii)** is equivalent to the decay of a neutron into a proton and an electron.

....

....

....

....

....[2]

(v) Describe the decay reaction referred to in **(iv)** in terms of quarks.

....

....[1]

[Total: 12]

6 Rhodium-45 decays to palladium-46 by emitting an electron from the nucleus. Fig. 6.1 shows the proton number, neutron number and nuclear mass for these two nuclides.

	proton number	neutron number	nuclear mass / u
rhodium (Rh)	45	60	104.905 44
palladium (Pa)	46	59	104.904 83

Fig. 6.1

The electron has a mass of 0.000 55 u.

(a) Write a nuclear equation which represents the decay process.

....

....[1]

(b) Calculate the mass difference in u for this decay process.

mass difference = ... u [2]

(c) Calculate the energy equivalent in J of this mass difference.

energy = ... J [3]

(d) Assuming that the electron gains **all** of this energy in the form of kinetic energy, calculate the speed of the electron.

speed = ... $m\,s^{-1}$ [2]

(e) State **two** reasons why, in practice, the speed of the electron may be less than the value you have calculated in **(d)**.

1. ....

....

2. ....

....

[2]

[Total: 10]

7 A car in motion is subject to a number of forces. In particular, it usually experiences a motive force. It also experiences a drag force which is due to the effect of both friction (rolling resistance) and air drag. These forces are illustrated in Fig. 7.1.

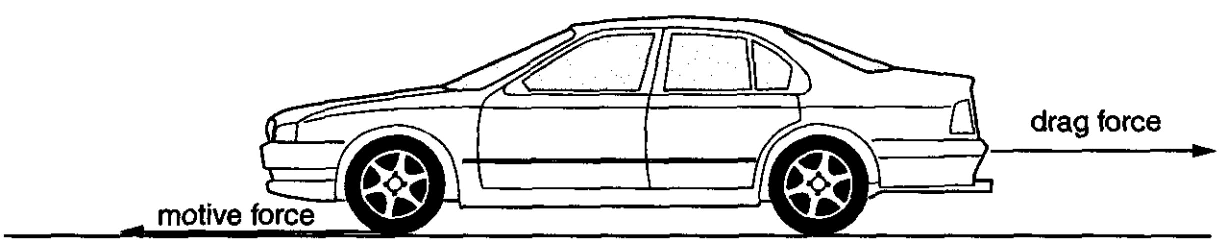

Fig. 7.1

The drag force depends on the shape and size of the car and its speed. The motive force can be varied by the driver using the accelerator pedal. Fig. 7.2 shows, for a particular car, the variation with speed of the *maximum* motive force at each speed. It also shows the variation with speed of the drag force.

Other data for this car:

mass of car	=	1100 kg
maximum braking force	=	9300 N
specific heat capacity of steel	=	$460\,J\,kg^{-1}\,K^{-1}$
effective mass of brakes	=	8.0 kg

The brakes may be assumed to be made entirely of steel.

For Examiner's Use

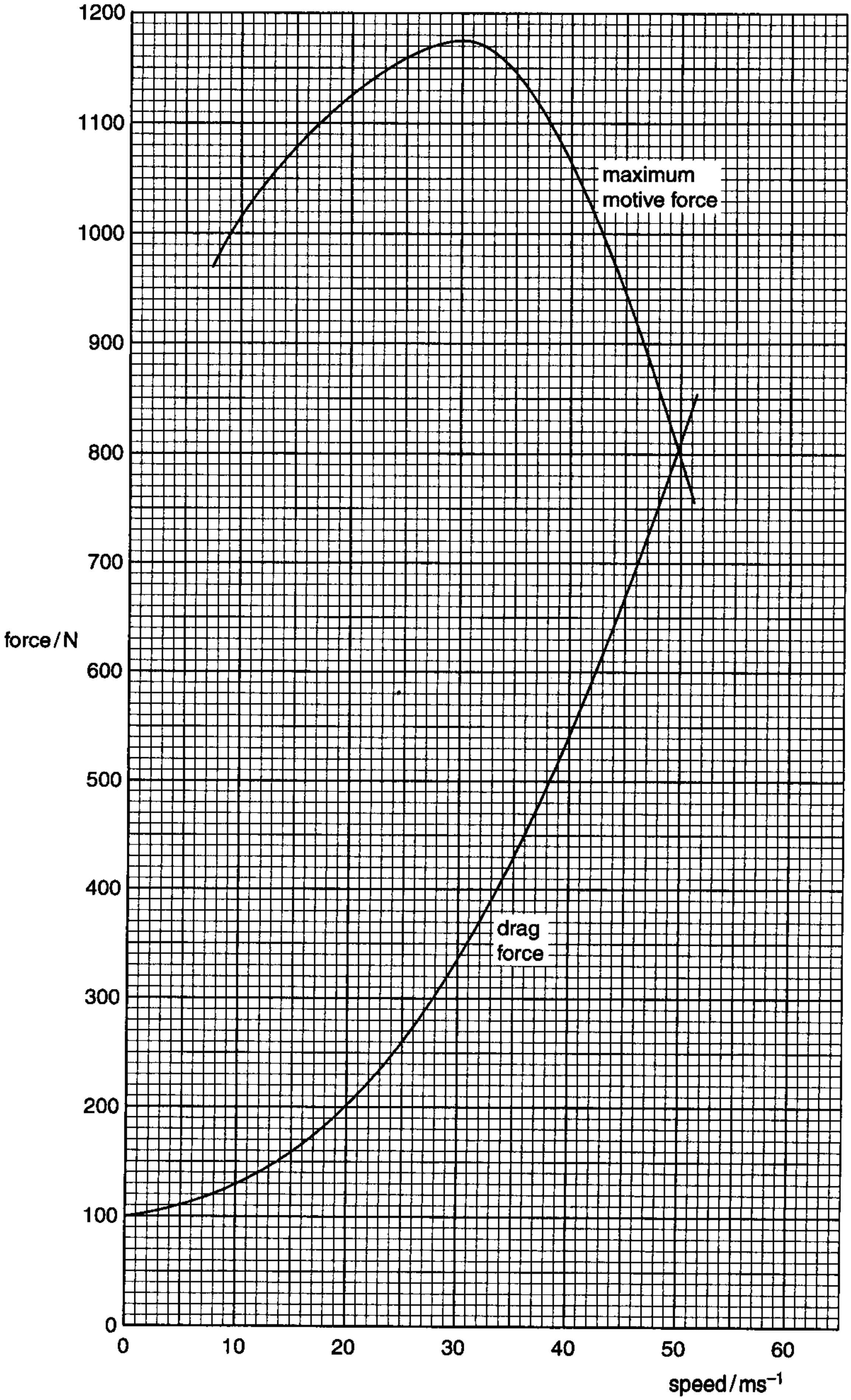

Fig. 7.2

(a) **(i)** What is the maximum motive force of this car at 10 m s^{-1}?

....

(ii) What is its drag force at 10 m s^{-1}?

.... [1]

(b) Find its maximum acceleration at 10 m s^{-1}.

acceleration = ... m s^{-2} [3]

(c) Find the speed at which its acceleration is greatest. Explain how you deduced this value, marking Fig. 7.2 as appropriate.

speed = ... m s^{-1}

....

....

....

.... [2]

(d) State the maximum speed of the car. Explain your reasoning.

maximum speed = ... m s^{-1}

....

....

.... [2]

For Examiner's Use

(e) On a motorway, the car normally travels at constant speed. To propel the car, the motive force must do work against the drag force. Show that the work done in moving the car through 1.00 km at a constant speed of 22 m s^{-1} is 2.2×10^5 J.

[3]

(f) Find the work done in moving the car through 1.00 km at a constant speed of 31 m s^{-1}.

work done = ...J [1]

(g) At 22 m s^{-1}, the car travels 16.0 km for each litre of fuel used. Calculate how far it can travel using 1.00 litre of fuel at 31 m s^{-1}.

distance = ...km [2]

(h) Show that the car's kinetic energy at 31 m s^{-1} is 5.3×10^5 J.

[1]

(i) The car is brought to rest from 31 m s^{-1} using its brakes, on a day when the temperature is 15°C. Calculate the final temperature of its brakes. State any assumption you have made.

temperature = ...°C

....

....

....[3]

(j) Calculate the shortest distance within which the car can be brought to rest from 31 m s^{-1}. State any assumption you have made.

distance = ...m

....

....

....[2]

[Total: 20]