OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS A

2825/04

Nuclear and Particle Physics

Monday **27 JUNE 2005** 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	10	
4	13	
5	11	
6	12	
7	20	
TOTAL	90	

This question paper consists of 20 printed pages.

Data

speed of light in free space,	$c = 3.00 \times 10^{8}\ \text{m s}^{-1}$
permeability of free space,	$\mu_0 = 4\pi \times 10^{-7}\ \text{H m}^{-1}$
permittivity of free space,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{F m}^{-1}$
elementary charge,	$e = 1.60 \times 10^{-19}\ \text{C}$
the Planck constant,	$h = 6.63 \times 10^{-34}\ \text{J s}$
unified atomic mass constant,	$u = 1.66 \times 10^{-27}\ \text{kg}$
rest mass of electron,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
rest mass of proton,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
molar gas constant,	$R = 8.31\ \text{J K}^{-1}\ \text{mol}^{-1}$
the Avogadro constant,	$N_A = 6.02 \times 10^{23}\ \text{mol}^{-1}$
gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{N m}^{2}\ \text{kg}^{-2}$
acceleration of free fall,	$g = 9.81\ \text{m s}^{-2}$

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

[Turn over

For Examiner's Use

Answer **all** the questions.

1 **(a)** The radius of a nucleon (proton or neutron) is r_0.

(i) Write an expression for the volume of a nucleon.

....[1]

(ii) A particular nucleus consists of A nucleons.
Using your answer to **(i)**, write an expression for the volume of this nucleus.

....[1]

(iii) The radius of this nucleus is r. Using your answer to **(ii)**, show that

$$r^3 = A r_0^{3}$$

[2]

(iv) On Fig. 1.1, draw a line to represent the variation of r^3 with A.

Fig. 1.1

State the gradient of this line.

....
[3]

For Examiner's Use

(b) **(i)** Use your answer to **(a)(ii)** to estimate the density of a gold nucleus ($^{197}_{79}Au$). Assume that the radius r_0 of a nucleon is 1.4×10^{-15} m.

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

(ii) Metallic gold has a density of 1.9×10^{4} kg m^{-3}. Estimate the percentage of the volume of the gold atom that is occupied by the nucleus. Explain your working.

percentage = ... % [2]

[Total: 12]

[Turn over

For Examiner's Use

2 (a) (i) State what is meant by *nuclear binding energy.*

....

....

....[1]

(ii) Fig. 2.1 shows the binding energy per nucleon for five nuclides, plotted against nucleon number.

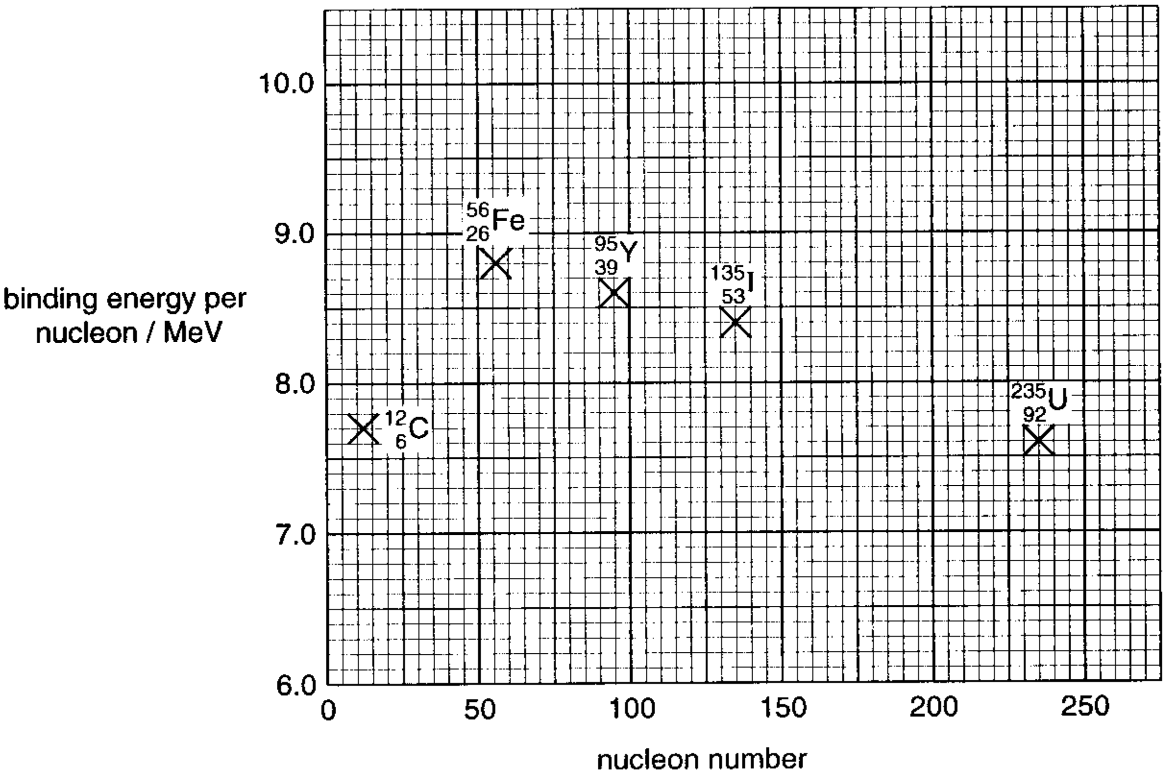

Fig. 2.1

$^{56}_{26}$Fe has the highest binding energy per nucleon. $^{12}_{6}$C and $^{235}_{92}$U have less binding energy per nucleon.
Explain how these values relate to the possibility of fission or fusion of the nuclides $^{56}_{26}$Fe, $^{12}_{6}$C and $^{235}_{92}$U.

....

....

....

....

....

....

....

For Examiner's Use

....

....

....

....[4]

(b) **(i)** A $^{235}_{92}U$ nucleus inside a nuclear reactor can absorb a thermal neutron. State what is meant by a *thermal neutron*.

....

....

....[1]

(ii) Write a nuclear equation for this reaction.

[1]

(iii) The resulting nucleus undergoes fission. Iodine-135 ($^{135}_{53}I$) and yttrium-95 ($^{95}_{39}Y$) are produced.
Write a nuclear equation for this reaction.

[1]

(iv) Use data from Fig. 2.1 to deduce how much energy in MeV is released when one nucleus of $^{235}_{92}U$ undergoes these reactions.

energy = ... MeV [4]

[Total: 12]

[Turn over

3 In the JET fusion experiment, a plasma consisting of a mixture of deuterium (^2_1H) and tritium (^3_1H) is confined within a magnetic field of high flux density.
The plasma is heated using two methods.

method 1 A very large current is passed through the plasma.
Fig. 3.1 shows the variation with time of this current.
The average electromotive force driving this current is 1.2 V.

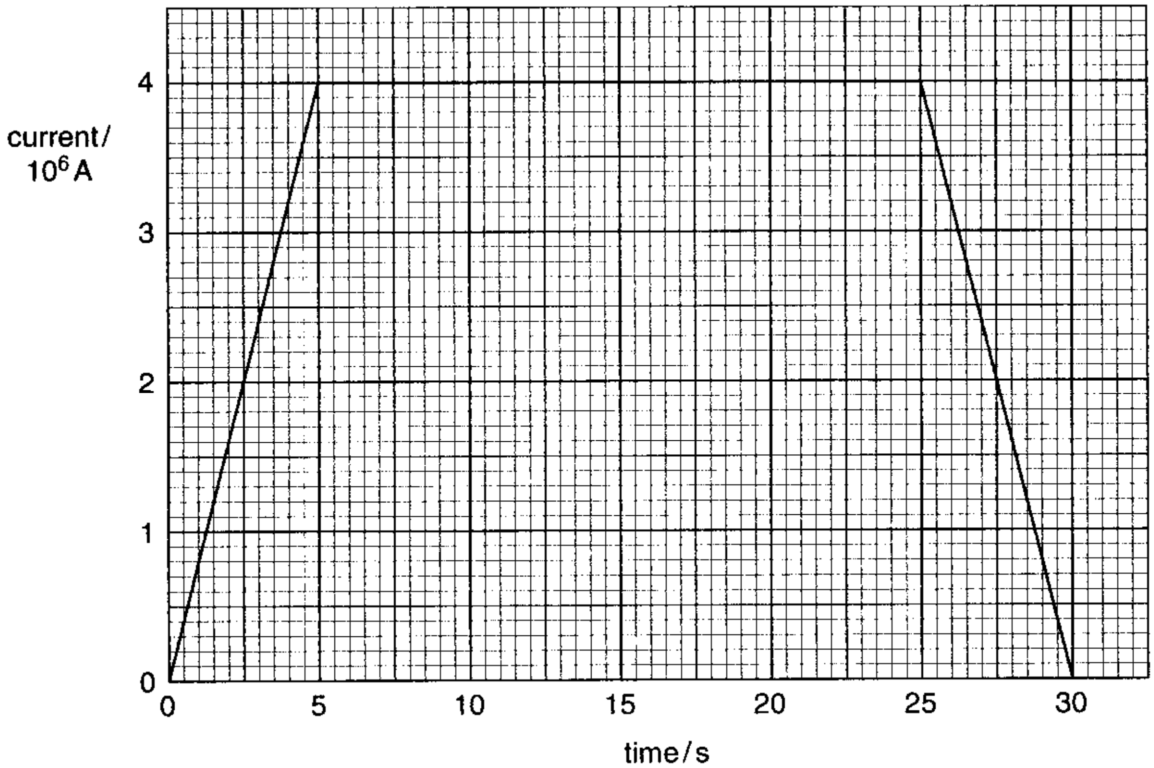

Fig. 3.1

method 2 Fast-moving deuterium atoms are injected into the plasma. The nuclei of the injected deuterium atoms collide with nuclei in the plasma and so transfer energy to it.

When the plasma temperature is high enough, deuterium and tritium nuclei fuse, producing a helium nucleus and a neutron. This reaction may be represented as follows.

$$^2_1H + ^3_1H \longrightarrow ^4_2He + ^1_0n + \text{energy}$$

The energy released is shared between the helium nucleus and the neutron, which move off in opposite directions.

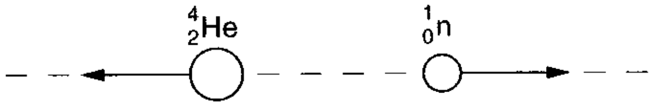

Fig. 3.2

For Examiner's Use

(a) For **method 1**, calculate the **total** energy input provided by the current source.

energy = ... J [4]

(b) Explain why in **method 2** a beam of neutral deuterium **atoms** is injected, rather than a beam of deuterium **nuclei**.

....

....

....

....

....[2]

(c) Show that the helium nucleus gains 20% of the total energy released in the fusion reaction, and the neutron gains 80% of the energy released.
You may assume that the initial momentum of the helium-neutron system is zero.

[4]

[Total: 10]

[Turn over

4 The linear accelerator or linac may be used for accelerating **protons** or **positrons**.
A particular linac consists of a source of charged particles and a series of cylindrical electrodes. These electrodes are attached alternately to the terminals of an alternating source of potential difference. The particles accelerate each time they cross the gap between two electrodes when the p.d. is 50 kV.

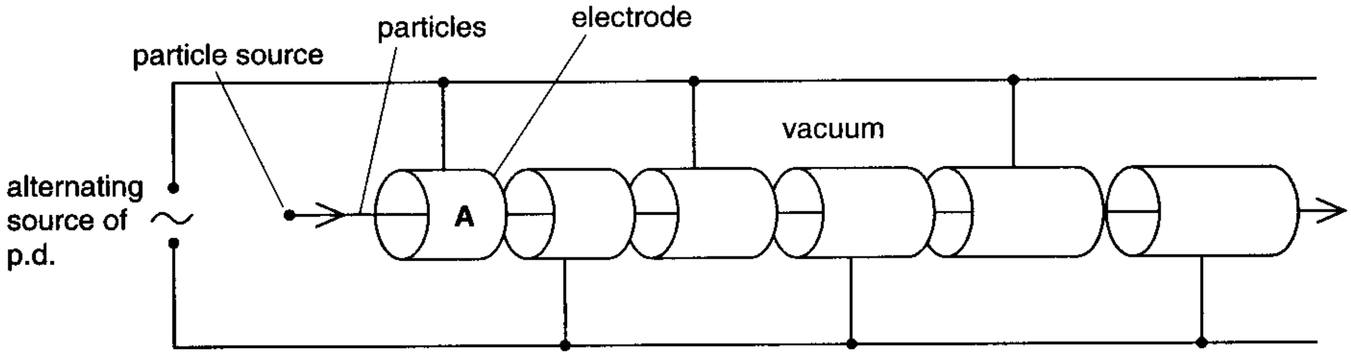

Fig. 4.1

Fig. 4.1 shows the first part of such a linac.

(a) **Protons** from the particle source enter electrode **A** with 30 keV of energy.

(i) State the energy of one of these protons after being accelerated 10 times.

energy = ... keV [1]

(ii) Calculate the speed of this proton.

speed = ... m s^{-1} [3]

(b) In a different linac, positrons are accelerated to the same energy. A student carries out a similar calculation to find the speed of these positrons. He calculates their speed to be $4.3 \times 10^8\,\mathrm{m\,s^{-1}}$.

(i) Explain why his answer cannot be correct.

....

....

....

....[2]

(ii) The lengths of the electrodes in a **proton** linac increase along the path of the particles (see Fig. 4.1). A high energy **positron** linac has electrodes which are all of the same length. Suggest why this is so.

....

....

....

....

....

....

....[3]

(c) A 0.65 MeV positron collides with a stationary electron. The two particles are annihilated and two γ-photons are produced. Calculate the frequency of one of these photons.

frequency = ... Hz [4]

[Total: 13]

For Examiner's Use

5 This question is about the theory of the cyclotron.

(a) Draw a sketch showing the principal features of a cyclotron. Show on your sketch a possible path of a proton inside the cyclotron.

[3]

For Examiner's Use

(b) Explain in words why a charged particle moving at right angles to a magnetic field of uniform flux density moves along a **circular** path.

....

....

....

....

....

....[3]

(c) A cyclotron having a magnetic field of uniform flux density B is used to accelerate particles of mass m and charge q.
Derive an equation for the frequency of the alternating source of potential difference in terms of B, q, and m.

[5]

[Total: 11]

[Turn over

6 This question is about the properties of **baryons** and **leptons**.

(a) Choose **two** examples of **baryons**

For each example discuss

- their composition
- their stability.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....[6]

For Examiner's Use

(b) Choose **two** examples of **leptons**

For each example discuss

- their composition
- the forces which affect them
- where they may be found.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....[6]

[Total: 12]

7 The London Eye, Fig. 7.1, is the largest observation wheel ever built. It has 32 egg-shaped capsules attached to the outside of the rim of the wheel. Each capsule holds up to 25 passengers and completes one revolution in 30 minutes.

The wheel of diameter 122 m, is driven by a drive system based on tyres gripping the edge of the wheel rim. 16 rubber tyres each supply a tangential force of 12.5 kN to the rim. The tyres are pressed against the rim by hydraulic cylinders.

The design engineers used computer simulations to predict all of the stresses on the structure. These programs modelled the effect of metal fatigue as well as wind and temperature changes over the whole structure. All of the 80 cables between the rim of the wheel and the hub (centre) remain under tension as the wheel rotates. The system acts like a large bicycle wheel suspended in the air.

As the wheel rotates, the tension in each cable changes. The wheel and support as a whole has a natural frequency of oscillation and it is important that the combination is not set in oscillation by the wind.

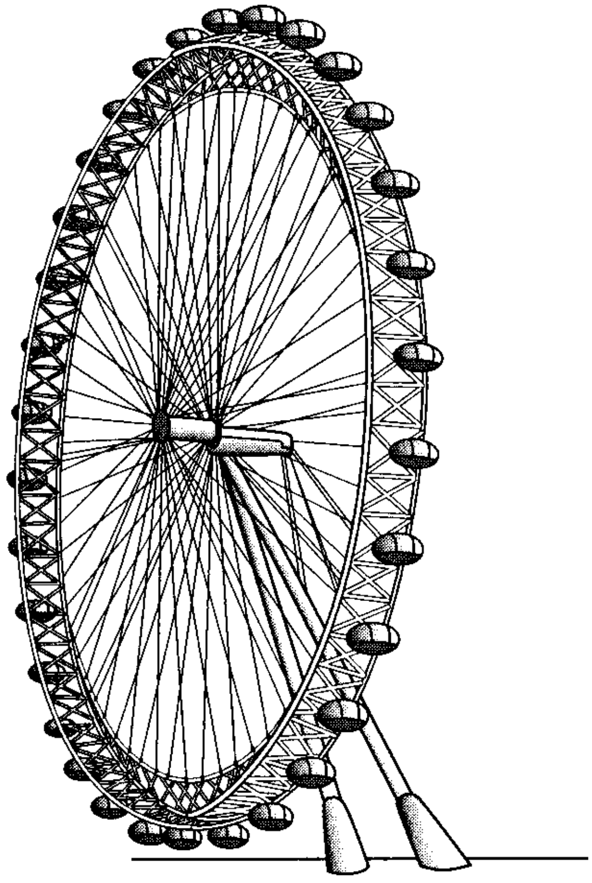

Fig. 7.1

For Examiner's Use

(a) **(i)** Calculate the linear speed of the wheel rim when it is turning normally.

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

(ii) Calculate the total force exerted by the drive system.

force = ... N [1]

(iii) Calculate the work done in moving the wheel through one revolution.

work done = ... J [2]

[Turn over

(iv) Calculate the useful power needed for the wheel to turn at the rate of one revolution every 30 minutes.

power = ... W [2]

(v) The wheel turns at a constant speed. Energy is converted as a result of

- friction in the bearings
- friction between the tyres and the rim
- electrical energy supplied to the motor.

Apply the conservation of energy for the rotating wheel and discuss which of the above produces useful work in rotating the London Eye.

....

....

....

....

....

....

....

.... [5]

(b) The London Eye behaves like a large bicycle wheel suspended in the air. Fig. 7.2(i) shows the front wheel and fork of a stationary bicycle wheel which is in contact with the ground. Fig. 7.2(ii) shows the front wheel and fork of the same bicycle when lifted off the ground.

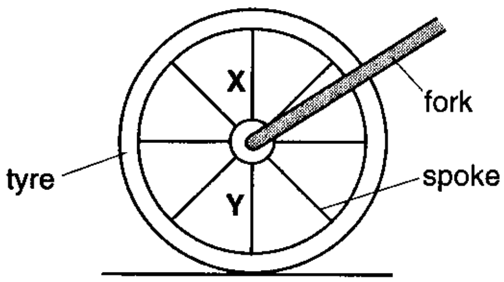

Fig. 7.2(i)

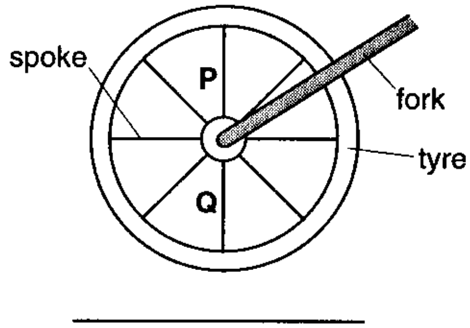

Fig. 7.2(ii)

Assume all spokes are always in tension.
Compare, giving a reason in each case, the magnitude of

(i) the tension in the spokes **X** and **Y**

....

....

(ii) the tension in the spokes **P** and **Q**.

....

....
[2]

(c) This question is concerned with the effect of the wind on the London Eye.

(i) In a storm the wind may exert a horizontal force of 1800 kN on the wheel support, causing it to deflect horizontally by 90 cm. Calculate a value for the spring constant k of the wheel support.

k = ...N m^{-1} [2]

[Turn over

For Examiner's Use

(ii) The natural frequency f of oscillation of the wheel is given by the equation

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

where m is the mass of the system.
Calculate the fundamental natural frequency f of oscillation of the wheel support when m is 9.5×10^5 kg.

f = ... Hz [2]

(iii) The wind may cause fluctuations at the frequency calculated in **(c)(ii)**. What problem might this cause and how may this problem be overcome?

....

....

....
[2]

[Total: 20]

END OF QUESTION PAPER