OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS
Advanced GCE

PHYSICS A 2825/04

Nuclear and Particle Physics

Friday **1 FEBRUARY 2002** Afternoon 1 hour 30 minutes

Additional materials:
Electronic calculator
Candidates answer on the question paper.

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 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.

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 19 printed pages and 1 blank page.

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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, $n = \frac{1}{\sin C}$

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

[Turn over

For Examiner's Use

Answer **all** the questions in the spaces provided.

1 The radius r of a nucleus consisting of A nucleons is given by the equation

$$r = r_0 A^{1/3}.$$

(a) What does r_0 represent?

.....[1]

(b) Fig. 1.1 illustrates this relationship.

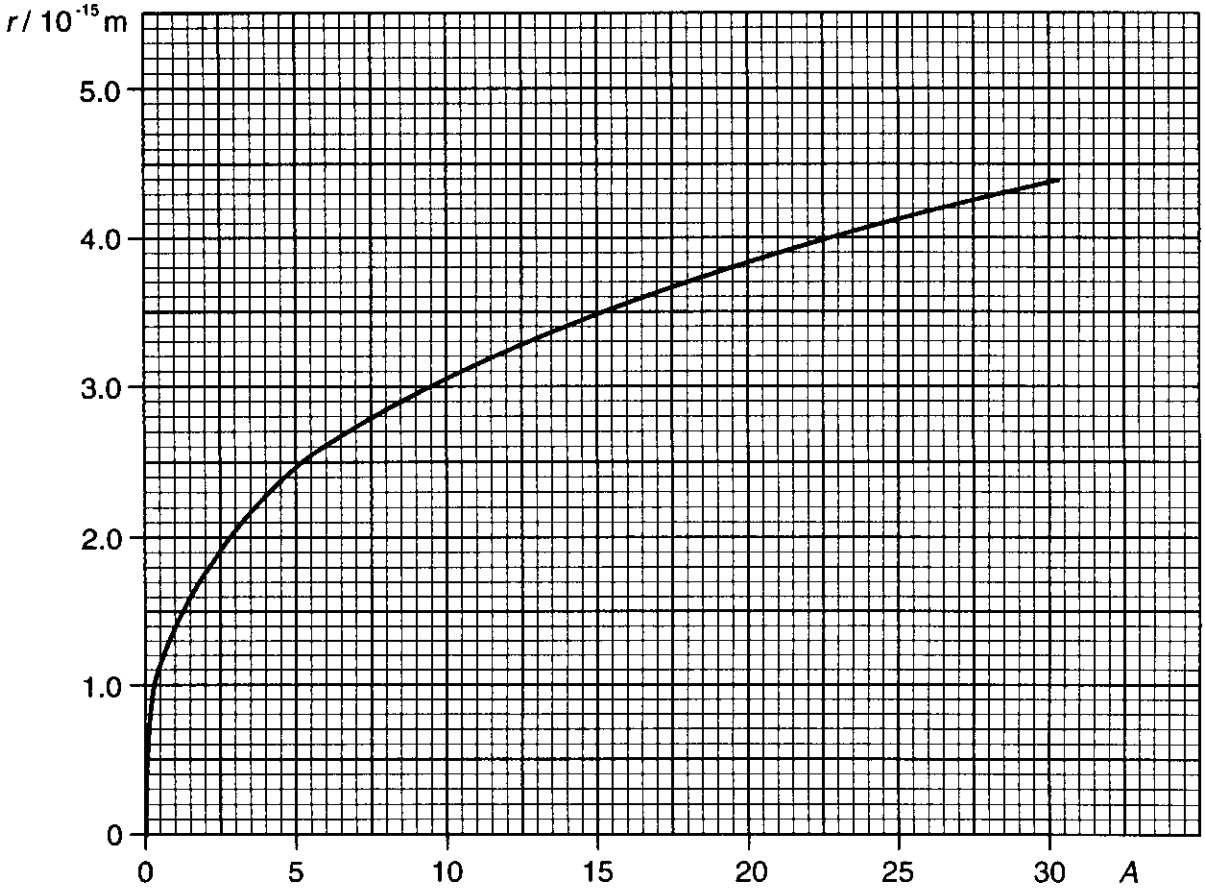

Fig. 1.1

(i) Use Fig. 1.1 to find the value of r when $A = 20$.

r = ... m

(ii) Use your answer to **(i)** to show that r_0 is equal to 1.4×10^{-15} m.

[2]

For Examiner's Use

(c) Hence estimate the density of the hydrogen ($^{1}_{1}$H) nucleus.
State an appropriate unit for your answer.

density = ... [3]

(d) Liquid hydrogen has a density of approximately 70 kg m^{-3}. Compare this with your answer to **(c)** and discuss what these values imply about the structure of the hydrogen atom.

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.....[4]

(e) **(i)** Assuming that the nuclei are spherical, deduce the relationship between the volume of the nucleus and the number of nucleons (A).

.....

.....

(ii) Suggest what your answer to **(i)** implies about the separation of the nucleons inside different nuclei.

.....

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[2]

[Total : 12]

[Turn over

For Examiner's Use

2 Two protons, travelling at the same speed, approach each other along the same straight line, as shown in Fig. 2.1.

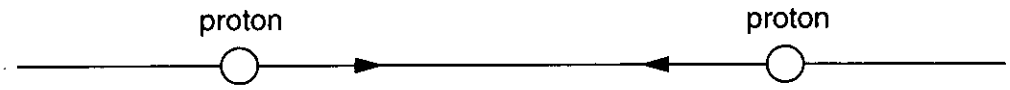

Fig. 2.1

(a) Assuming that no nuclear reaction takes place, describe (without calculation or explanation) the motion of these protons.

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.....[3]

(b) Describe the energy changes during this interaction.

.....

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.....[3]

(c) **(i)** The potential energy of such a system is given by the expression

$$E_P = Q^2 / (4\pi\varepsilon_0 r),$$

where Q = charge on proton
r = separation of protons
ε_0 = permittivity of free space.

In order to fuse, the particles must be at a separation of less than 2.0×10^{-15} m. Calculate the potential energy of the system when the protons are at this separation.

energy = ... J

For Examiner's Use

(ii) Hence show that, in order for fusion to occur, the initial kinetic energy of each proton must be at least 5.8×10^{-14} J.

[3]

(d) (i) Explain why protons in a plasma can fuse only when the plasma is at a high temperature.

.....

.....

(ii) The kinetic energy in joule, E_k, of a particle at temperature T in kelvin is given by the expression

$$E_k = 2 \times 10^{-23} T.$$

Estimate the minimum temperature at which protons will fuse.

temperature = ... K

[3]

[Total : 12]

3 This question is about collisions between protons and antiprotons.

(a) State the mass and charge of an antiproton.

mass = ... kg

charge = ... C

[2]

(b) High energy collisions can be used to investigate possible products of the reaction between a proton and an antiproton.

Method 1: A stream of antiprotons is fired at a stationary target containing protons.

Method 2: A stream of antiprotons is made to collide with a stream of protons travelling at the same speed, in the opposite direction.

Compare these two methods by stating and explaining one *disadvantage* of each method.

Method 1 .....

.....

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Method 2 .....

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[4]

For Examiner's Use

(c) In a particular interaction, the rest masses of a proton and an antiproton are annihilated and two γ-photons are created.

(i) Show that the total rest mass of the proton and antiproton is equivalent to 3.0×10^{-10} J of energy.

[3]

(ii) Calculate the minimum frequency of each γ-photon.

frequency = ... Hz [2]

(iii) State the circumstance in which this minimum frequency would occur.

.....

.....[1]

[Total : 12]

For Examiner's Use

4 This question is about the neutron.

(a) By putting ticks in the table of Fig. 4.1, indicate the classes of particle of which the neutron is a member.

	baryon	hadron	lepton	neutrino
neutron				

[1]

Fig. 4.1

(b) Complete Fig. 4.2 by entering appropriate values. The first row of the table has already been completed.

	baryon number	charge	strangeness
proton	1	+1	0
neutron			
up quark			
down quark			

[3]

Fig. 4.2

For Examiner's Use

(c) (i) State the composition of the neutron in terms of its constituent quarks.

.....

.....[1]

(ii) Write a numerical equation which shows that the total baryon number for these quarks is equal to the baryon number of the neutron.

Write equivalent equations for the charge and strangeness of the neutron.

charge.....

strangeness .....

[3]

(d) (i) The free neutron can decay, producing a proton, a β-particle and an anti-neutrino. Write an equation representing this decay process.

(ii) Describe this process in terms of the quarks in the neutron.

.....

.....

.....

[4]

[Turn over

For Examiner's Use

5 Natural uranium is a mixture of Uranium-235 and Uranium-238. Both isotopes are present in the fuel rods of a nuclear power station. The $^{235}_{92}U$ nuclei undergo *neutron-induced fission* when they absorb a *thermal neutron*. Absorption of neutrons by a $^{238}_{92}U$ nucleus eventually produces $^{239}_{94}Pu$ which does not undergo fission.

(a) Explain what is meant by

(i) *neutron-induced fission*,

.....

.....

.....

(ii) *thermal neutron*.

.....

.....

[3]

(b) **(i)** State the name and symbol of the nucleus which is formed when a $^{235}_{92}U$ nucleus absorbs a neutron.

.....

(ii) This nucleus then splits into two much less massive nuclei. By referring to the neutron/proton ratio of stable nuclei, discuss why the product nuclei are likely to be radioactive.

.....

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[3]

For Examiner's Use

(c) **(i)** Write an equation to represent the decay of a $^{239}_{94}Pu$ nucleus.

.....

.....

(ii) The half-life of this decay process is 24 000 years. Calculate the percentage of Plutonium-239 which decays in 1000 years.

percentage = ... %

[6]

[Total : 12]

[Turn over

6 The linear accelerator is a device which can be used to accelerate protons along a straight line. It consists of a long, evacuated tube fitted with a set of coaxial, hollow cylinders, the first few of which are shown in Fig. 6.1. Alternate cylinders are connected to opposite terminals of a source of alternating potential difference of constant frequency. The polarity of this p.d. reverses in the time taken by a proton to pass through each cylinder.

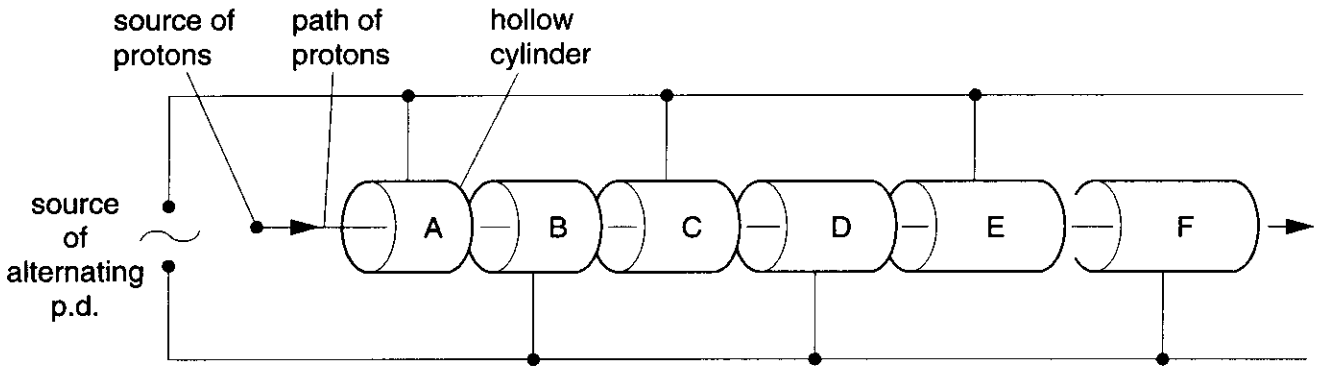

Fig. 6.1

When a proton passes from one cylinder to the next, it accelerates. It eventually emerges from the final cylinder (not shown) with high energy. The following are some of the quantities relating to the operation of a particular accelerator.

initial kinetic energy of a proton entering A	=	1.5 MeV
maximum p.d. between adjacent cylinders	=	500 kV
frequency of alternating p.d.	=	80 MHz
total number of cylinders	=	47

(a) Calculate the kinetic energy with which a proton emerges from the final cylinder.

energy = ... MeV [1]

For Examiner's Use

(b) Explain why a proton accelerates every time it passes from one cylinder to the next. Your answer should refer to the polarity of cylinders.

.....

.....

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.....[2]

(c) A proton travels at uniform speed while it is inside a cylinder. What does this show about the electric field inside a cylinder?

.....[1]

(d) Show that the speed of a proton entering cylinder A is $1.7 \times 10^7 \text{ m s}^{-1}$.

[2]

(e) A proton spends a time equal to half a cycle of the alternating p.d. inside each cylinder. Calculate the length of cylinder A.

length = ... m [3]

(f) Explain why each cylinder is longer than the one that precedes it.

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.....[1]

[Total : 10]

[Turn over

7 A couple who find modern life too stressful decide to move to a Scottish island which has no mains electricity supply.

There are two ways in which they could provide a power supply. One method is to lay a long-distance supply cable from another island which has mains electricity. The other method is to equip themselves with an aerogenerator and rechargeable batteries.

One disadvantage of using a long-distance supply cable is that the potential difference available at the user's end of the cable is less than the p.d. at the supply end of the cable. Because of this and the cost of laying a sufficiently thick cable, they decide to use an aerogenerator and batteries.

Rechargeable 12 V batteries are available and these will provide a reservoir of energy which can be increased by adding extra batteries. However, a battery will deliver only 80% of the energy stored in it.

The island is usually windy so they plan to keep the batteries charged by means of the aerogenerator. This consists of a rotating propeller of diameter 1.5 m, which drives a generator. The overall efficiency of the aerogenerator is 40%. It works by converting into electrical energy some of the kinetic energy of the air passing through the propeller. The average wind speed on the island is 8.0 m s^{-1}. This means that all the air inside a cylinder 8.0 m long, of diameter 1.5 m, passes through the propeller in 1 second. This is illustrated in Fig. 7.1.

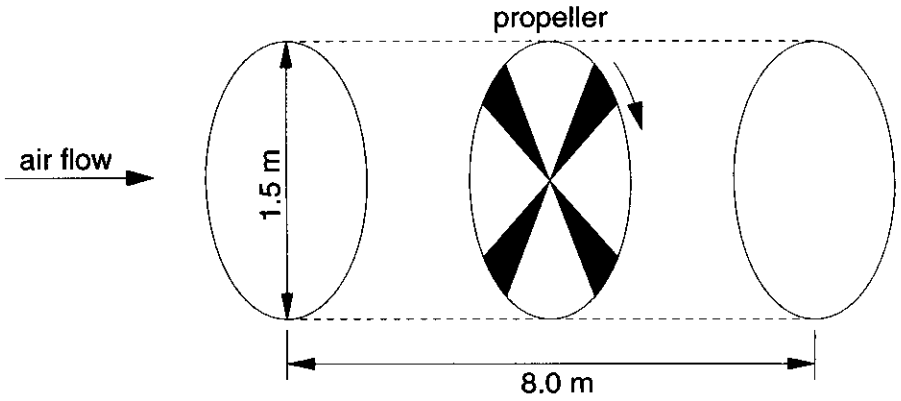

Fig. 7.1

Although the island is normally windy, there are periods of calm. Meteorological information suggests that the longest such period would be 40 hours. The couple estimate that their average power requirement during these periods would be 160 W.

Additional information:

amount of energy stored by one rechargeable battery	= 7.0×10^6 J
density of air	= 1.3 kg m^{-3}

For Examiner's Use

(a) Explain why the p.d. available to the user of a long mains cable would be less than the p.d. at the supply end of the cable.

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.....[3]

(b) Suggest why it is not possible for the aerogenerator to achieve an efficiency of 100%.

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.....[2]

(c) **(i)** Show that the mass of air contained in a cylinder of diameter 1.5 m and length 8.0 m is approximately 18 kg.

[2]

(ii) Calculate the kinetic energy of 18 kg of air travelling at 8.0 m s^{-1}.

energy = ... J [2]

(iii) Hence calculate the average power output of the aerogenerator.

power = ... W [1]

(d) Calculate the average time taken by the aerogenerator to recharge one battery fully.

time = ... s [2]

(e) **(i)** State what form of energy is stored by a battery.

.....[1]

(ii) Give **one** reason why the energy delivered by a battery is less than the energy input.

.....

.....

.....[1]

For Examiner's Use

(f) **(i)** Calculate the greatest amount of energy which needs to be delivered by the batteries during a 40 hour period of calm weather.

energy = ... J [2]

(ii) Calculate the total energy which the set of batteries must be capable of storing.

energy = ... J [2]

(iii) Calculate the minimum number of rechargeable batteries that will be needed.

[2]

[Total : 20]

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