OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE **2825/04**

PHYSICS A

Nuclear and Particle Physics

TUESDAY 17 JUNE 2008 Afternoon

Time: 1 hour 30 minutes

Candidates answer on the question paper
Additional materials: Electronic calculator

CUP/T44653

Candidate Forename

Candidate Surname

Centre Number

Candidate Number

INSTRUCTIONS TO CANDIDATES

- Write your name in capital letters, your Centre Number and Candidate Number in the boxes above.
- Use blue or black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure that you know what you have to do before starting your answer.
- Answer **all** the questions.
- Do **not** write in the bar codes.
- Write your answer to each question in the space provided.

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 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 Nuclear and Particle Physics. The last question concerns general physics.

FOR EXAMINER'S USE

Qu.	Max	Mark
1	10	
2	15	
3	11	
4	15	
5	10	
6	9	
7	20	
TOTAL	90	

This document consists of **20** printed pages.

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

Answer **all** the questions.

1 This question is about the *nuclear* and *atomic* densities of aluminium and gold.

(a) **(i)** Calculate the mass of the aluminium-27 nucleus $^{27}_{13}Al$.

You may assume that the proton and neutron each have a mass of 1.67×10^{-27} kg.

mass = ... kg [1]

(ii) Using the equation

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

calculate the volume of a $^{27}_{13}Al$ nucleus.

$r_0 = 1.40 \times 10^{-15}$ m

volume = ...m^3 [3]

(iii) Show that the density of the $^{27}_{13}Al$ nucleus is about 1.5×10^{17} kg m^{-3}.

[1]

(b) State the density of the gold-197 nucleus $^{197}_{79}Au$.
Explain in terms of nuclear structure how you arrived at this value.

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

....

....

....

.... [2]

(c) **(i)** The densities of aluminium and gold **metals** are:

aluminium 2.70×10^3 kg m^{-3}
gold 19.3×10^3 kg m^{-3}.

Show that the ratio

$$\frac{\text{mass of gold atom}}{\text{mass of aluminium atom}} \approx \frac{\text{density of gold metal}}{\text{density of aluminium metal}}.$$

State any assumption you have made.

....

....

....

.... [2]

(ii) Suggest what can be deduced from the relationship in **(i)**.

....

....

....

.... [1]

[Total: 10]

2 This question is about the products of nuclear fission.

(a) Explain how *nuclear fission* differs from *radioactive nuclear decay*.

....

....

....

....

.... [2]

(b) When a uranium-235 nucleus, $^{235}_{92}U$, is exposed to neutrons it may absorb a neutron and then undergoes fission. The percentage mass yield of the fission products varies with nucleon number as shown in Fig. 2.1.

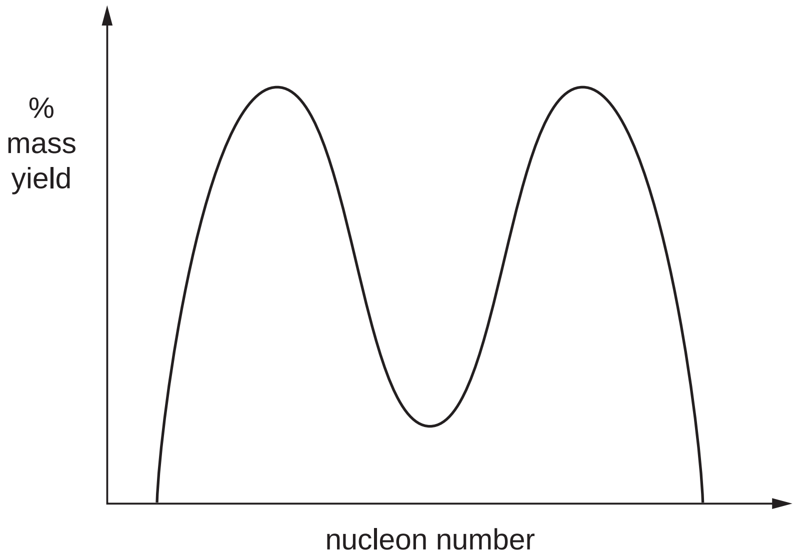

Fig. 2.1

(i) Explain why this graph is symmetrical.

....

....

....

....

.... [2]

(ii) In a few cases the fission results in the formation of two **identical** fission products.

State the proton number and nucleon number of **one** of these fission products.

Assume that no neutrons are produced in this fission reaction.

proton number = ... nucleon number = ... [1]

(c) In a particular fission reaction one of the fission products is iodine-140, ${}^{140}_{53}\mathrm{I}$.

State the proton number and nucleon number of the other product of this reaction.
Assume that two neutrons are produced in this fission reaction.

proton number = ... nucleon number = ... [1]

(d) A student suggests that the iodine-140 nucleus could decay by emitting **either** a neutron **or** a β^- particle.

The following are some relevant data:

mass of	${}^{140}_{53}\mathrm{I}$	139.9019 u
mass of	${}^{139}_{53}\mathrm{I}$	138.8969 u
mass of	${}^{140}_{54}\mathrm{Xe}$	139.8919 u
mass of	${}^{1}_{0}\mathrm{n}$	1.0087 u
mass of	${}^{0}_{-1}\mathrm{e}$	0.0006 u

(i) Write a nuclear equation for each of the suggested decay reactions.

neutron emission ....

beta emission .... [3]

(ii) Explain, **without** using numerical data, why the student might expect iodine-140 to decay in these two ways.

....

....

....

.... [2]

The relevant data given on page 7 is repeated here for your convenience:

mass of	$^{140}_{53}\mathrm{I}$	139.9019 u
mass of	$^{139}_{53}\mathrm{I}$	138.8969 u
mass of	$^{140}_{54}\mathrm{Xe}$	139.8919 u
mass of	$^{1}_{0}\mathrm{n}$	1.0087 u
mass of	$^{0}_{-1}\mathrm{e}$	0.0006 u

(iii) Use the numerical data to show whether the suggested decay reactions can actually occur.

neutron emission:

conclusion ....

....

beta emission:

conclusion ....

....
[4]

[Total: 15]

3 This question is about the possibility of fusion between two hydrogen nuclei, ${}^{1}_{1}H$, inside the Sun. Two ${}^{1}_{1}H$ nuclei approach each other along the same line, with equal kinetic energies. They will fuse if their separation becomes equal to or less than 2.0×10^{-15} m.

Fig. 3.1

(a) (i) Show that the potential energy E_p of two ${}^{1}_{1}H$ nuclei at a separation of 2.0×10^{-15} m is about 1×10^{-13} J. You may assume that the potential energy of two charges Q_1 and Q_2 at a separation of r is equal to

$$\frac{Q_1 Q_2}{4 \pi \varepsilon_0 r}.$$

ε_0 = permittivity of free space

[2]

(ii) The initial kinetic energy of each ${}^{1}_{1}H$ nucleus is E_k. They both come to rest at a separation of 2.0×10^{-15} m.

State the relationship between E_k and E_p.

relationship .... [1]

(iii) The mean kinetic energy, in joule, of the hydrogen nuclei in the Sun is $2.1 \times 10^{-23}\,T$, where T is the temperature of the Sun's interior.

Show that, for the mean kinetic energy to be equal to E_k, T must be more than 2.5×10^{9} K.

[2]

(iv) The Sun's interior is actually at a temperature of about 1.5×10^7 K.

Explain why ${}^1_1$H nuclei do fuse inside the Sun, even though its interior is at a much lower temperature than was deduced in **(iii)**.

....

....

....

....

....

....

.... [2]

Fig. 3.2 shows the binding energy per nucleon of the ${}^1_1$H and the ${}^4_2$He nuclei, plotted on a graph grid.

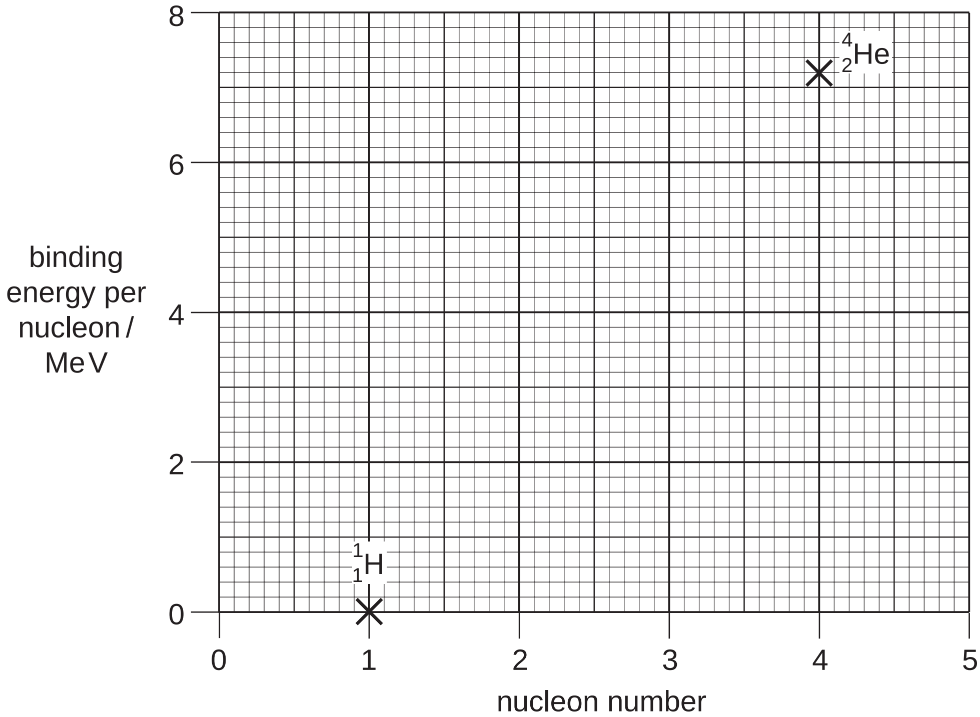

Fig. 3.2

(b) Explain why the binding energy per nucleon of the ${}^1_1$H nucleus is zero.

....

.... [1]

(c) In the hydrogen cycle of reactions which take place inside the Sun, four $^{1}_{1}H$ nuclei fuse to form a $^{4}_{2}He$ nucleus and two positrons.

(i) Write a nuclear equation which summarises this series of reactions.

.... [1]

(ii) Calculate how much energy in joule is released when one $^{4}_{2}He$ nucleus is created by fusion.

energy = ... J [2]

[Total: 11]

4 A cyclotron is designed for accelerating protons.

(a) **(i)** Show that the speed of a proton moving round a circle of maximum radius inside this cyclotron is about $6 \times 10^7\ \text{m s}^{-1}$.

data: radius of dees = 50.0 cm
flux density of magnetic field = 1.20 T

[3]

(ii) Show that the maximum kinetic energy which protons can have inside this cyclotron is about 17 MeV.

[3]

(b) Calculate the frequency of the source of potential difference which must be connected to the dees.

frequency = ... Hz [3]

(c) Calculate how many revolutions will be travelled by a proton inside this cyclotron.
Assume that the proton starts with zero energy.

data: accelerating potential difference = 80.0 kV

number = ... [3]

(d) **(i)** Explain why it is normally necessary for the magnetic field inside the dees of a cyclotron to be **uniform**.

....

....

....

....

.... [2]

(ii) As the proton's speed approaches the speed of light, its mass increases.

State briefly in what way the magnetic field in the dees would have to be non-uniform in order to compensate for this.

....

....

....

.... [1]

[Total: 15]

5 Name and describe fully the **three** forces which act between nucleons inside a nucleus. Your account should

- list the forces which act
- state which are long-range and which are short-range forces
- describe the way in which each force varies with particle separation
- state the relative size and importance of each force inside the nucleus
- state which type of particle experiences each type of force.

Illustrate your answer by sketching any relevant graph.

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.... [10]

[Total: 10]

6 **(a)** State the name of a group of particles which includes both the proton and the neutron.

name .... [1]

(b) Describe the stability of the proton

(i) when it is part of a nucleus

.... [1]

(ii) when it is free.

.... [1]

(c) A group of 500 neutrons are emitted simultaneously in a nuclear reaction and travel through space. Calculate how many of these neutrons will **not** have decayed after 200 s.

data: half-life of a free neutron = 613 s

number = ... [3]

(d) **(i)** Complete the table of Fig. 6.1 to show the charge and baryon numbers for the down quark and the neutron.

	charge	baryon number
up quark	$\frac{2}{3}$	$\frac{1}{3}$
down quark		
neutron		

[1]

Fig. 6.1

(ii) By considering the quark composition of the neutron, write **two** numerical equations to show how the charge and baryon number of the neutron are related to the charge and baryon number of its constituent quarks.

charge ....

baryon number .... [2]

[Total: 9]

7 A photo-voltaic cell is an electrical component which can generate a current proportional to the intensity of light incident on its light-sensitive surface. One type of solar panel uses a number of photo-voltaic cells in series to provide a sufficient voltage to power a practical device.

(a) The measured intensity of the solar radiation received on the upper atmosphere of the Earth is $1400\,\mathrm{W\,m^{-2}}$. The mean radius of the Earth's orbit round the Sun is $1.5 \times 10^{11}\,\mathrm{m}$.

(i) Show that

1 the surface area of a sphere of radius $1.5 \times 10^{11}\,\mathrm{m}$ is about $3 \times 10^{23}\,\mathrm{m^2}$

[1]

2 the Sun emits radiation with a total power of about $4 \times 10^{26}\,\mathrm{W}$ into the surrounding space.

[1]

(ii) Calculate the rate of conversion of mass to energy in the Sun.

rate of conversion = ... $\mathrm{kg\,s^{-1}}$ [2]

(b) Explain why, when the Sun is directly overhead at the equator

(i) the maximum intensity received on the surface of the Earth is less than $1000\,\mathrm{W\,m^{-2}}$

....

.... [1]

(ii) the maximum intensity decreases with distance North and South of the equator.

....

.... [1]

(c) An ornamental water fountain is driven by a pump powered by the electrical output of a solar panel. The following data is relevant to the operation of the system, which is arranged to give maximum solar power input.

area of light-sensitive surface of panel:	$0.080\,m^2$
solar intensity at the location of the panel:	$750\,W\,m^{-2}$
voltage output of panel:	17 V
current delivered to the pump:	270 mA
delivery rate of the fountain:	$0.50\,m^3$ per hour
efficiency of pump:	35%
density of water:	$1000\,kg\,m^{-3}$

Calculate

(i) the solar power input to the panel

power input = ... W [1]

(ii) the electric power generated by the panel

power generated = ... W [1]

(iii) the efficiency of the panel in converting solar power to electrical power

efficiency = ... [2]

(iv) the height of the fountain of water.

maximum height = ... m [5]

(d) A solar panel of greater area than the one in **(c)** supplies 80 W of electrical power to a heating coil immersed in water.

(i) Calculate the time required to heat 0.50 kg of water from 25 °C to 100 °C, assuming no loss of heat to the surroundings. The specific heat capacity of water is 4 200 J kg^{-1} K^{-1}.

time = ... s [3]

(ii) Suggest **two** reasons why this type of solar panel is unlikely to replace conventional mains-powered electric kettles as a means of boiling water, even when the solar power is a maximum.

1. ....

....

....

2. ....

....

.... [2]

[Total: 20]

END OF QUESTION PAPER

DO NOT WRITE ON THIS PAGE