OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE **2825/04**

PHYSICS A

Nuclear and Particle Physics

FRIDAY 25 JANUARY 2008 Morning

Time: 1 hour 30 minutes

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

CUP/T36531

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.
- Do **not** write outside the box bordering each page.
- 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 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 Nuclear and Particle Physics. The last question concerns general physics.

FOR EXAMINER'S USE		
Qu.	**Max.**	**Mark**
1	**10**	
2	**12**	
3	**13**	
4	**13**	
5	**10**	
6	**12**	
7	**20**	
TOTAL	**90**	

This document consists of **18** printed pages and **2** blank 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 forces between nucleons.
The graph of Fig. 1.1 shows the variation of the strong force between two nucleons with the separation of the centres of the nucleons. Over the range shown this graph is a straight line.

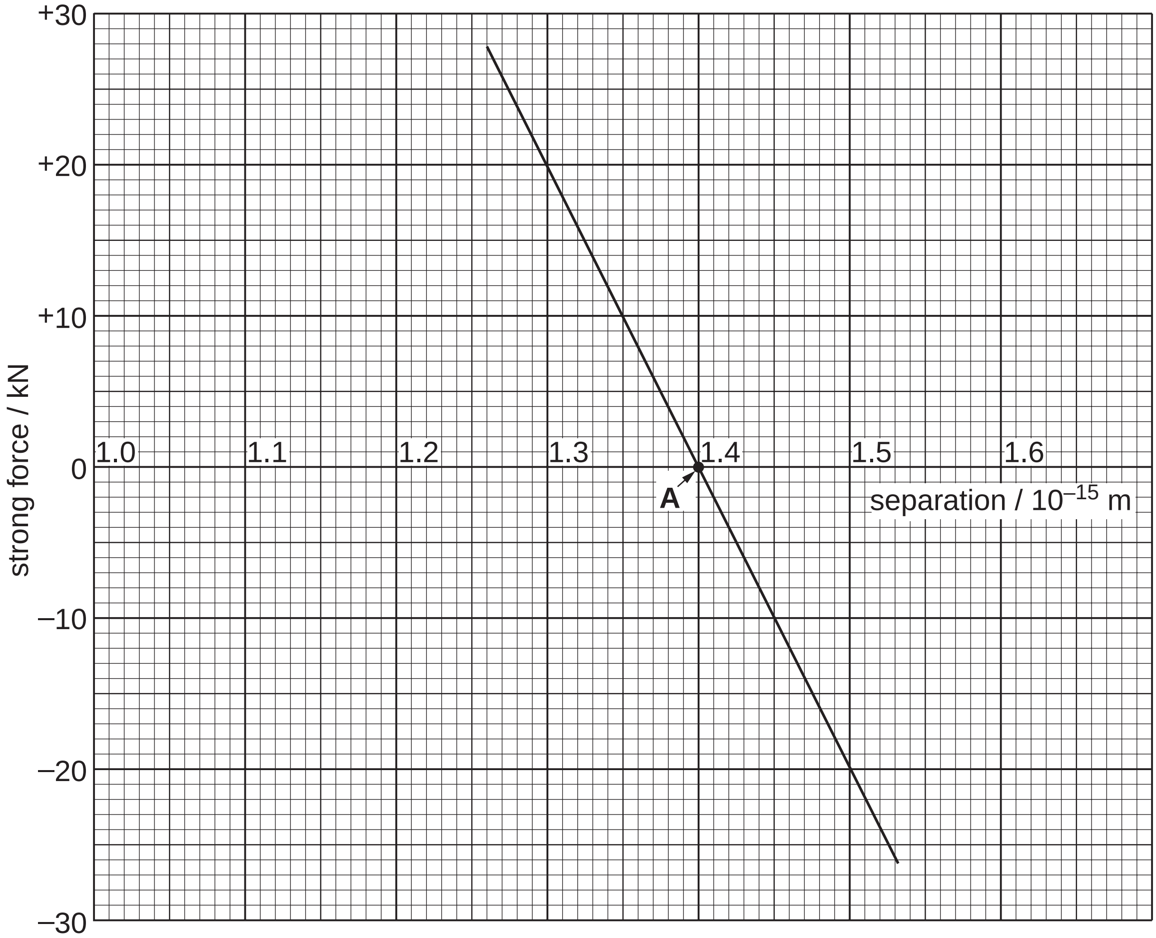

Fig. 1.1

(a) State and explain the significance of the point **A** in relation to two **neutrons**.

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....

....

.... [2]

(b) Find the gradient of the graph.

gradient = ...[2]

(c) Calculate the electrostatic force between two **protons** if their separation is equal to 1.40×10^{-15} m.

force = ... N [2]

(d) **(i)** State what must be true of the strong force and the electrostatic force for two adjacent protons to be in equilibrium.

....

....

....[1]

(ii) When two protons are at equilibrium their centres are at a separation **B**. Point **B** is very close to **A** but is **not** shown on Fig. 1.1.
Use the results from **(b)** and **(c)** to calculate the position of **B** in relation to **A**.
Explain your answer.

....

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....[3]

[Total: 10]

2 This question is about the formation and decay of plutonium-239, ${}^{239}_{94}Pu$.
Natural uranium is a mixture of the nuclides ${}^{235}_{92}U$ and ${}^{238}_{92}U$. When this natural uranium is exposed to neutrons, the heavier nuclei absorb a neutron. The resulting nucleus then undergoes two decay reactions, resulting in the formation of a ${}^{239}_{94}Pu$ nucleus.

(a) Write nuclear equations to represent these three reactions.
The nuclide formed in reaction 2 is an isotope of neptunium (Np).

reaction 1 ....

reaction 2 ....

reaction 3 ....
[4]

(b) A physicist prepares a sample of the neptunium isotope which decays to plutonium-239. She measures the activity of the sample over a period of 5.0 days. She then plots the graph shown in Fig. 2.1 of the variation with time of the activity of the sample.

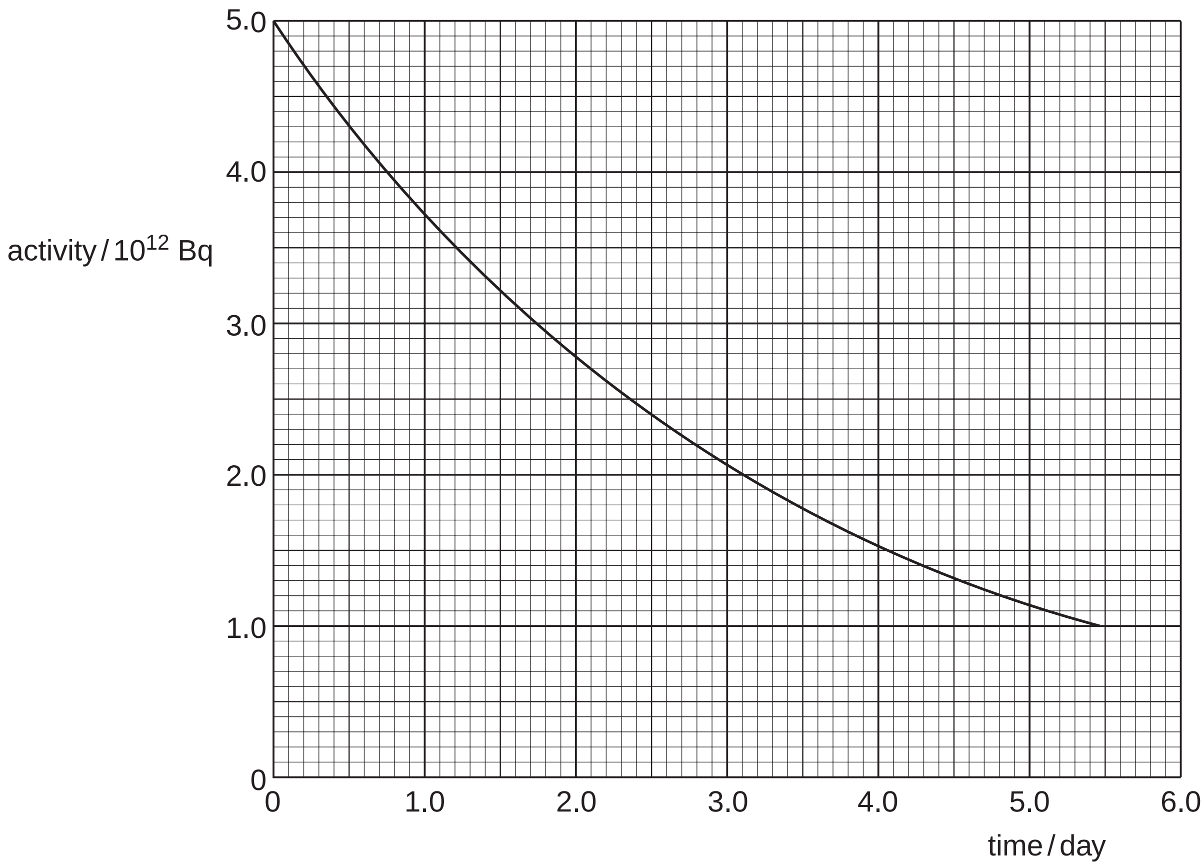

Fig. 2.1

(i) Find the half-life in seconds of the neptunium isotope.

half-life = ... s [2]

(ii) Show that the decay constant of the neptunium isotope is $3.4 \times 10^{-6}\ s^{-1}$.

[1]

(iii) Deduce the number of nuclei of the neptunium isotope which are present after 2.00 days.

number = ...[3]

(c) The physicist then measures the activity of a sample of plutonium-239 over the same period.

(i) State the half-life of plutonium-239.

half-life = ... year [1]

(ii) On Fig. 2.2, sketch the shape of the graph which she might obtain. [1]

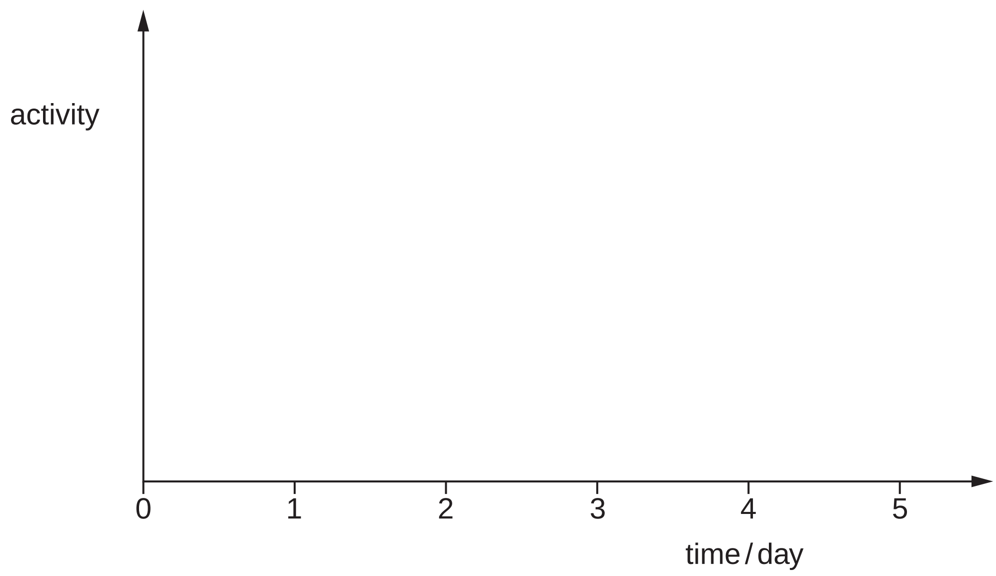

Fig. 2.2

[Total: 12]

[Turn over

3 This question is about particles and their antiparticles.

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

mass = ... kg charge = ... C [2]

(b) State where an antiproton might be found.

....[1]

(c) When a proton and an antiproton meet, γ-photons are produced.

(i) Describe these photons as fully as you can for a **slow-moving** proton-antiproton collision. No calculation is required.

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....[3]

(ii) A proton and an antiproton are moving with almost the same high speed and in the same direction. Each possesses 8.00×10^{-11} J of kinetic energy. The two particles meet. Calculate the frequency of the γ-photons produced.

frequency = ... Hz [4]

(iii) Discuss qualitatively how the photons generated as described in **(ii)** would differ from the photons generated in **(i)**. Illustrate your answer with a diagram.

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....[3]

[Total: 13]

4 This question is about the generation of energy from the fusion of deuterium and tritium.

Deuterium and tritium in the plasma state are raised to a high temperature inside the JET experimental fusion reactor.

A nucleus of deuterium ${}^{2}_{1}H$ fuses with a nucleus of tritium ${}^{3}_{1}H$ and a neutron ${}^{1}_{0}n$ is released. This neutron carries, on average, 80% of the energy generated in the fusion reaction.

data:	mass of ${}^{2}_{1}H$	2.0141 u
	mass of ${}^{3}_{1}H$	3.0160 u
	mass of ${}^{4}_{2}He$	4.0026 u
	mass of ${}^{1}_{0}n$	1.0086 u

(a) Write a nuclear equation for the fusion of a deuterium nucleus with a tritium nucleus.

....[1]

(b) Calculate how much energy in joule is released when a deuterium nucleus fuses with a tritium nucleus.

energy = ... J [4]

(c) Calculate the mean kinetic energy of the neutron emitted in this reaction.

kinetic energy = ... J [1]

(d) Explain why the neutron carries most, but not all of the energy released. State what happens to the remaining 20% of the energy released.

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....[4]

(e) Explain how the energy of the neutrons can be turned into heat energy.

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....[3]

[Total: 13]

5 A certain carbon (C) nuclide and a certain oxygen (O) nuclide each decay to form the same nitrogen (N) nuclide. These two decay reactions are represented by the arrows on Fig. 5.1.

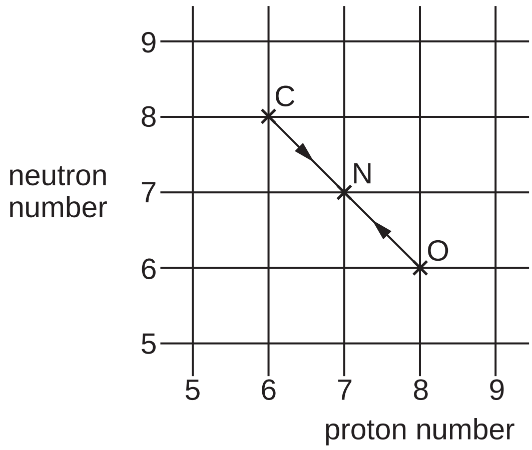

Fig. 5.1

(a) Write the symbols for the nuclei of each of these nuclides.

carbon .... oxygen .... nitrogen .... [2]

(b) Write nuclear equations for each of the decay reactions.

carbon decay ....

oxygen decay ....[2]

(c) Use your answers to **(b)** to deduce, **in their simplest form**, the quark equations which occur in these decay reactions.
Show all the steps in your deduction. Do not neglect leptons in your equations.

carbon decay

oxygen decay

[4]

(d) The axes shown in Fig. 5.2 can be used to plot a graph of the variation of nuclear mass with proton number. The nuclear mass scale does **not** start from zero.

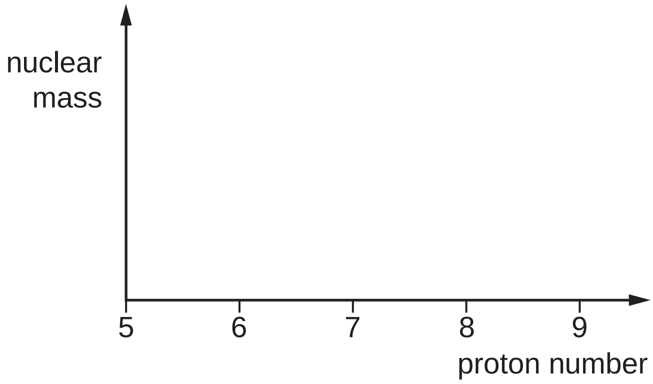

Fig. 5.2

Mark points showing possible positions for the carbon, oxygen and nitrogen nuclei, shown in Fig. 5.1, on this graph. Label your points **C**, **O** and **N** respectively.
Explain how you arrived at your answer.
Assume that the mass of the electron is negligible.

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....[2]

[Total: 10]

6 Describe the process of uranium fission inside a nuclear power station.
Your account should include

- a description of a self-sustaining fission reaction
- the meaning and significance of thermal neutrons
- a description of the distribution of nuclides among the fission products
- the principles of the extraction of useful energy from a fission reactor.

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....[12]

[Total: 12]

7 The normal temperature of a healthy human body is 37 °C. When an adult person at this temperature is at rest, energy from food is required to maintain normal internal body activity (the basal metabolic rate). On average this energy is supplied to the body at the rate of 75 W. When involved in physical activity, extra energy from food is used. 20% of this extra energy is needed to do mechanical work; the remaining 80% heats the body and has to be dissipated. The energy available from 1 g of food in the form of carbohydrate is about 1.7×10^4 J.

(a) A meal provides a person with 250 g of carbohydrate.

(i) Estimate the period of rest in hours which is provided for by this intake of food.

period of rest = ... hour [2]

(ii) Suggest why the temperature of the person's body remains steady during this period.

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....[2]

(b) A mountaineer of mass 70 kg climbs a mountain to a vertical height of 800 m above the starting point in 1.5 hours. Calculate

(i) the gain in potential energy of the mountaineer

potential energy gain = ... J [2]

(ii) the mass of carbohydrate used to provide this gain in potential energy

mass = ... g [1]

(iii) the minimum total mass of carbohydrate used by the mountaineer.

mass = ... g [3]

(c) A marathon runner, of mass 65 kg, competes on a day when the temperature of the environment is 40 °C. The rate of heating of the runner's body is 900 W.

(i) Calculate the rate of temperature rise of the runner's body. Assume that the body has a specific heat capacity of 4200 J kg^{-1} K^{-1}.

rate of temperature rise = ... K s^{-1} [2]

(ii) Explain why the runner's body cannot lose heat to the surrounding air by the processes of conduction, convection and radiation.

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....[2]

(iii) The runner maintains normal body temperature by using heat from the body to evaporate water (sweat) from the surface of the skin. The heat required to vaporise 1 kg of water is 2.4×10^6 J. Calculate the mass of water evaporated from the skin in 2.5 hours of running.

mass = ... kg [2]

(iv) To minimise harm to the body **during the race**, state and explain **two** precautions the runner should take.

1. ....

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2. ....

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....[4]

[Total: 20]

END OF QUESTION PAPER

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