OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS A **2825/04**

Nuclear and Particle Physics

Monday **28 JUNE 2004** 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	11	
2	12	
3	11	
4	13	
5	13	
6	10	
7	20	
TOTAL	90	

This question paper consists of 20 printed pages.

Data

speed of light in free space,	$c = 3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$
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,	$n = \dfrac{1}{\sin C}$
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,	$p = \frac{1}{3}\dfrac{Nm}{V}<c^2>$
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,	$= \sqrt{(1 - \frac{v^2}{c^2})}$
current,	$I = nAve$
nuclear radius,	$r = r_0 A^{1/3}$
sound intensity level,	$= 10 \lg\left(\dfrac{I}{I_0}\right)$

*Answer **all** the questions.*

1 The radius r of an atomic nucleus is related to the radius r_0 of a nucleon (proton or neutron) by the equation

$$r = r_0 A^{\frac{1}{3}}. \qquad \textbf{equation 1}$$

(a) State the meaning of A.

....

....[1]

(b) On Fig. 1.1, sketch a graph to show the relation between r and A. Label the axes.

[2]

Fig. 1.1

For Examiner's Use

(c) **(i)** Show that the equation

$$\left[\frac{4}{3}\pi r^3\right] = \left[\frac{4}{3}\pi r_0^{\ 3}\right]A$$

can be derived directly from **equation 1**.

[2]

(ii) State the significance of the expressions in square brackets.

$\left[\frac{4}{3}\pi r^3\right]$ ....

$\left[\frac{4}{3}\pi r_0^{\ 3}\right]$ ....[2]

(d) Write an equation relating the mass m of a nucleus to the mass m_0 of a nucleon. Assume that both the proton and the neutron have the same mass m_0.

....

....[1]

(e) Using your answers to **(c)** and **(d)**, discuss whether the density of a nucleus depends on the value of A. State and explain what this implies about the spacing of the nucleons in nuclei of different sizes.

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....[3]

[Total: 11]

For Examiner's Use

2 **(a)** Distinguish between a nuclear *decay* and a nuclear *fission*.

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....[2]

(b) Natural uranium is a mixture of uranium-235 ($^{235}_{92}U$) and uranium-238 ($^{238}_{92}U$).
Write a nuclear equation to show how **one** of these nuclides can absorb a neutron, forming uranium-239.

....

....[1]

(c) Write nuclear equations to show how uranium-239 can undergo **two** beta decays, forming plutonium-239 ($^{239}_{94}Pu$).
The proton number for neptunium (Np) is 93.

....

....

....

....[2]

(d) Plutonium-239 is fissile but it is also radioactive and decays with a half-life of 2.41×10^4 years.

(i) State the particle that is emitted when plutonium-239 decays.

....[1]

(ii) Show that the decay constant of plutonium-239 is about $9 \times 10^{-13}\,s^{-1}$.

[2]

(iii) A particular fuel rod contains 0.25 kg of plutonium-239.
Calculate the activity of this plutonium. Give an appropriate unit for your answer.

activity = ... unit .... [4]

[Total: 12]

For Examiner's Use

3 (a) Explain the working of the prototype (JET) fusion reactor. Your account should include a nuclear equation for the energy-generating reaction. It should also state the conditions necessary for the reaction to proceed and describe how these conditions are achieved. You need not draw a sketch.

....[6]

For Examiner's Use

(b) A later version of this reactor may be able to generate useful electrical energy. Describe and explain how this could be done.

....

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....[3]

(c) State **two** possible advantages of nuclear fusion compared with other energy-generating processes.

....

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....

....

....[2]

[Total: 11]

For Examiner's Use

4 This question is about nuclear fusion inside the Sun.

(a) Describe the conditions inside the Sun and explain how they favour nuclear fusion. Your account should explain why the material inside the Sun is in the plasma state and how the plasma is confined.

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....[5]

(b) One process by which hydrogen nuclei fuse is called the carbon cycle. The following equations represent the reactions which make up this cycle.

$${}^{12}_{6}C + {}^{1}_{1}H \longrightarrow {}^{13}_{7}N$$

$${}^{13}_{7}N \longrightarrow {}^{13}_{6}C + {}^{0}_{1}e$$

$${}^{13}_{6}C + {}^{1}_{1}H \longrightarrow {}^{14}_{7}N$$

$${}^{14}_{7}N + {}^{1}_{1}H \longrightarrow {}^{15}_{8}O$$

$${}^{15}_{8}O \longrightarrow {}^{15}_{7}N + {}^{0}_{1}e$$

$${}^{15}_{7}N + {}^{1}_{1}H \longrightarrow {}^{12}_{6}C + {}^{4}_{2}He$$

(i) Why is this called the carbon cycle?

....

....[1]

For Examiner's Use

(ii) Summarise the carbon cycle by reducing the six equations above to a single equation, in its simplest form.

[2]

(iii) The binding energy per nucleon of $^{4}_{2}$He is 7.1 MeV.

Show that the energy released in joules when one $^{4}_{2}$He nucleus is formed is about 4.5×10^{-12} J. By referring to your answer to **(b)(ii)**, give **one** reason why this is only an approximation.

....

....

....[3]

(c) It is estimated that 8×10^{37} helium nuclei are formed per second inside the Sun. Assuming that this is the only energy-generating process, calculate the total power emitted by the Sun.

power = ... W [2]

[Total: 13]

For Examiner's Use

5 This question is about the principles of operation of the synchrotron.
The main features of a particular synchrotron are illustrated in Fig. 5.1.

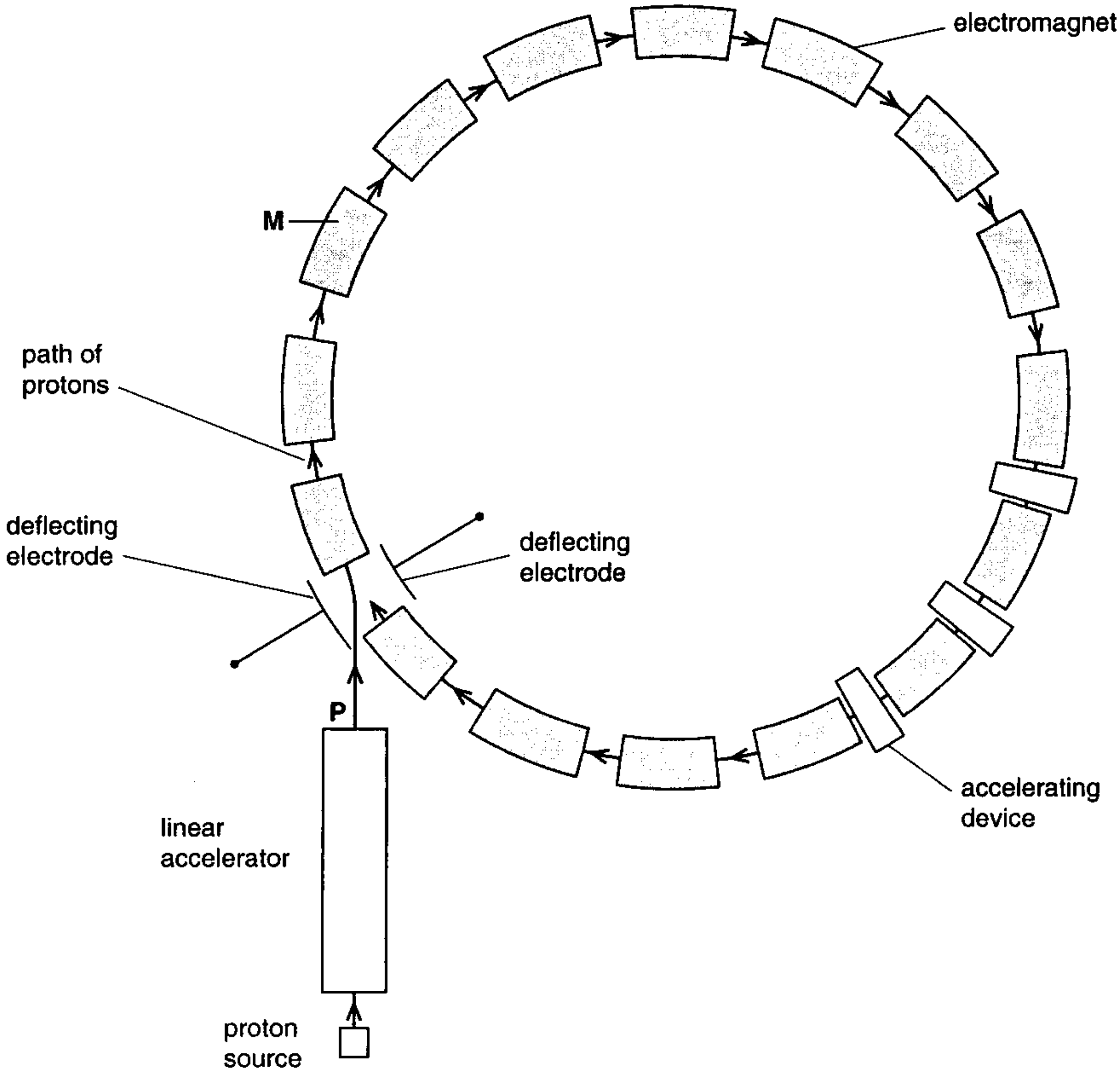

Fig. 5.1

(a) Protons from the source pass through the linear accelerator and emerge at **P** with energy 20 MeV per proton.

Calculate the speed of the protons at **P**.

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

For Examiner's Use

(b) The protons are then deflected into an approximately circular path by passing them into an electric field between two deflecting electrodes. They then follow a path of radius 800 m. They complete many revolutions before they reach their final speed.

(i) Mark the polarity of the electrodes on Fig. 5.1. [1]

(ii) Assuming that their change of speed during the first revolution is small, calculate the time taken for a proton to complete this revolution.

time = ... s [2]

(c) **(i)** The protons follow a circular path because of the magnetic field provided by the electromagnets.

1 Show by means of an arrow on Fig. 5.1 the direction of the force F on a proton when it passes through the electromagnet labelled **M**.

2 State, on the figure, the direction of the magnetic field due to **M**.

[2]

(ii) Show that the radius R of the circular path is related to the magnetic field strength B by the equation

$$R = \frac{mv}{qB}.$$

q and m are the charge and mass of the proton respectively and v is its speed.

State **one** assumption you have made.

....

....[3]

(iii) Using the equation in **(ii)**, explain why proton synchrotrons must have a large radius.

....

....[1]

For Examiner's Use

(d) When the protons have been accelerated to high energy by the accelerating devices, they are made to collide head-on with other high energy particles moving in the opposite direction.
When the other particles are anti-protons, these can be accelerated to the same speed inside the **same** ring as the protons.
When the other particles are electrons, they must be accelerated inside a **different** ring.
Explain this.

....

....

....

....[2]

[Total: 13]

6 **(a)** State the names of **two** classes of particle, each of which includes both the proton and the neutron.

1. ....

2. .... [1]

(b) It is thought that, in certain circumstances, the proton has a slight probability of decaying into a neutron, a positron and a third particle.

Write an equation to represent this reaction.

State the name of the third particle.

....

....[2]

(c) A free neutron is known to decay with a half-life of about 10 minutes.

In what situation are both neutrons and protons stable?

....[1]

For Examiner's Use

(d) (i) State the quark composition of

the proton ....

the neutron .... [2]

(ii) In the reaction

$$p^+ + p^+ \longrightarrow p^+ + n^0 + \pi^+$$

two quarks are created. These are a down quark (d) and an anti-down quark ($\bar{d}$).

Simplify this equation and using your answers to **(d)(i)**, write a quark equation.

[2]

(iii) Hence deduce the quark composition of the π^+ particle.

[2]

[Total: 10]

[Turn over

7 A student is concerned to keep fit and equally concerned to minimise the use of electricity from the national grid. The student decides to combine the two issues and designs the system shown in Fig. 7.1. The chain on the exercise bicycle turns a d.c. generator which passes a current through a heating coil immersed in a hot water tank. The idea is that the student exercises for a certain length of time and instead of simply "wasting" energy in pedalling, the energy is used to heat the water necessary for a shower when finished.

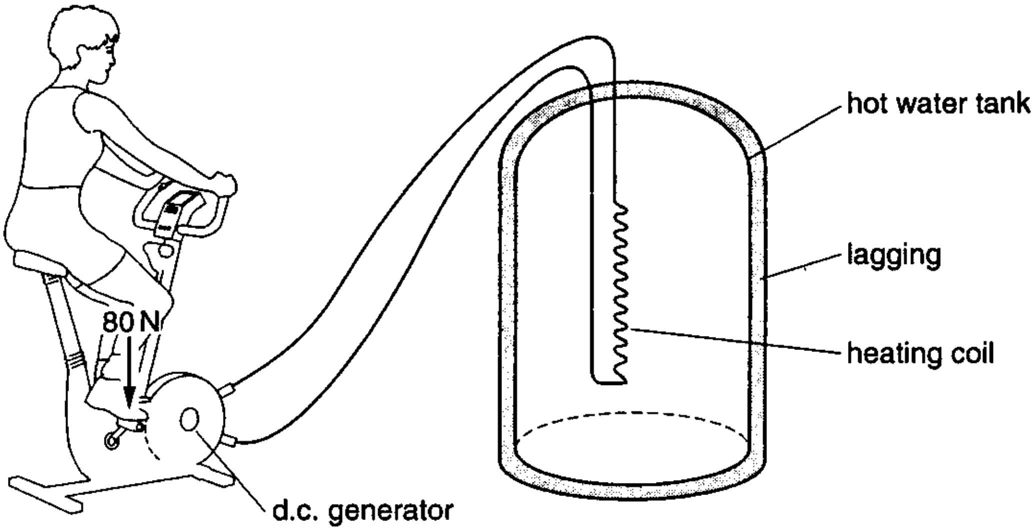

Fig. 7.1

The specific heat capacity of water = 4200 J kg^{-1} K^{-1}

(a) The water enters the hot water tank at a temperature of 8 °C and is required to be heated to 38° C for an acceptable shower. The shower lasts for 5 minutes during which time the water flows at a rate of 0.15 kg s^{-1}. Calculate

(i) the mass of water used during the shower

mass of water = ... kg [2]

(ii) the energy required to heat the water for the shower.

energy = ... J [2]

For Examiner's Use

(b) When pedalling on the exercise bicycle, each foot spends half the cycle doing work and the other half relaxing. While doing work, an average tangential force of 80 N is applied to each pedal. The pedal is positioned at a radius of 20 cm from the axle and the student maintains 1.3 revolutions per second.

(i) Show that the work done by the student during one revolution of the pedals is about 100 J.

[2]

(ii) Calculate the power produced by the student while pedalling.

power = ... W [1]

(iii) Calculate the total number of revolutions of the pedals required before the energy expended by the student equals that required to heat the water.

number of revolutions = ... [1]

(iv) Calculate the time for which the student must pedal in order to deliver the heat energy required.

time = ... hour [2]

For Examiner's Use

(c) The d.c. generator being driven by the exercise bicycle has an internal resistance of $1.2\,\Omega$ and produces an e.m.f. of 24 V while delivering a current of 5A.

(i) Show that the resistance of the heater element in the hot water tank is $3.6\,\Omega$.

[3]

(ii) Calculate the length of heater wire required if the element is made from resistance wire of resistivity $1.5 \times 10^{-7}\,\Omega\,m$ and cross-sectional area $0.32\,mm^2$.

length .... m [3]

(d) In practice, the student would have to pedal for an even longer time than your answer to **(b)(iv)**. By considering energy losses, give reasons for this. Include some calculations in your answer.

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....[4]

[Total: 20]