OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS A

2825/04

Nuclear and Particle Physics

Wednesday **26 JANUARY 2005** Morning 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	**12**	
4	**11**	
5	**12**	
6	**12**	
7	**20**	
TOTAL	**90**	

This question paper consists of 19 printed pages and 1 blank page.

SP (NF/SLM) S69608/4
 Registered Charity Number: 1066969 **[Turn over**

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,	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
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,	$= 10 \lg\left(\frac{I}{I_0}\right)$

For Examiner's Use

Answer **all** the questions.

1 This question is about the strong and electrostatic forces inside a nucleus.

Fig. 1.1 shows how the strong force (strong interaction) and the electrostatic force between two **protons** vary with distance between the centres of the protons.

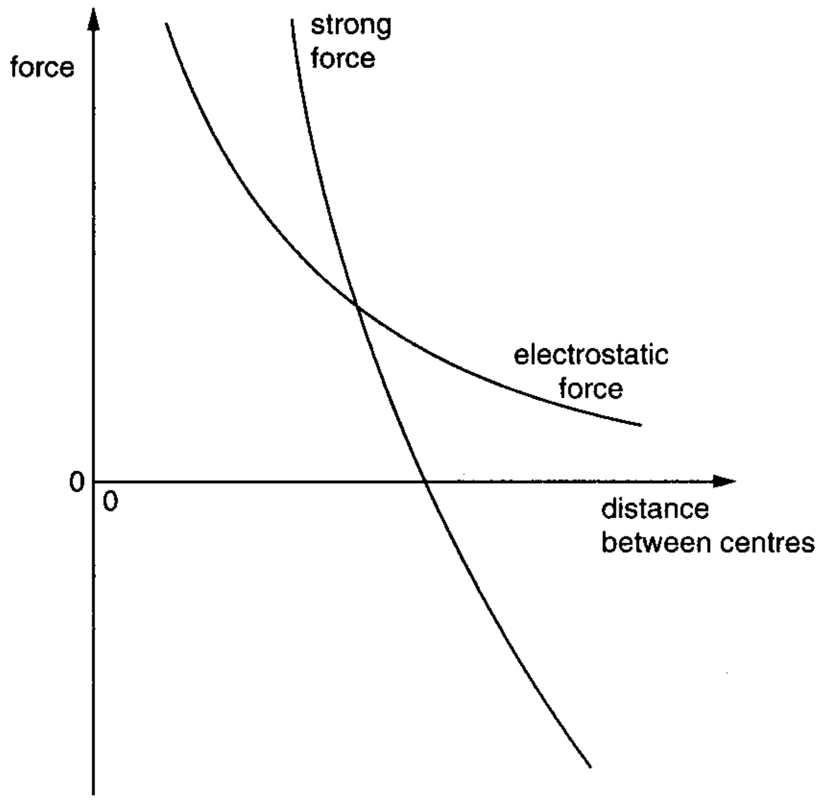

Fig. 1.1

(a) Label on Fig.1.1 the regions of the force axis which represent attraction and repulsion respectively. [1]

(b) **(i)** On Fig. 1.1, mark a point which represents the distance between the centres of two adjacent **neutrons** in a nucleus. Label this point **N**.

Explain why you chose point **N**.

....

....

....

....

....[2]

For Examiner's Use

(ii) On Fig.1.1, mark a point **P** which represents the distance between two adjacent **protons** in a nucleus.

Explain why you chose point **P**.

....

....

....

....[2]

(c) On Fig. 1.1, sketch a line to show how the **resultant force** between two **protons** varies with the distance between their centres. Pay particular attention to the points at which this line crosses any other line. [3]

(d) **(i)** Write an expression for the electrostatic force between two point charges Q which are situated at a distance x apart.

[1]

(ii) The electrostatic force between two protons in contact in a nucleus is 25 N. Calculate the distance between the centres of the two protons.

distance = ... m [2]

[Total: 11]

[Turn over

For Examiner's Use

2 This question is about two isotopes of plutonium.

(a) State briefly (without nuclear equations) how plutonium-239 can be produced.

....

....

....

....

....[2]

(b) **(i)** State what particle is emitted when plutonium-239 decays.

....[1]

(ii) Write a nuclear equation for the decay of plutonium-239 ($^{239}_{94}Pu$).

....

....[2]

(c) A sample contains 5.00×10^{20} atoms of plutonium-239 and 40.0×10^{20} atoms of plutonium-240.

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

....[1]

(ii) Show that after 9000 years there will be 3.85×10^{20} atoms of plutonium-239 left in the mixture.

[2]

For Examiner's Use

(d) After 9000 years, there will be 15.4×10^{20} atoms of plutonium-240 left in the mixture.

(i) State the ratio

$$\frac{\text{number of atoms of plutonium-240}}{\text{number of atoms of plutonium-239}}$$ after 9000 years.

ratio = ... to two significant figures only [1]

(ii) Use this ratio, together with the numbers of atoms in the original mixture, to deduce the **total** time (from the start) before the number of atoms of plutonium-239 and plutonium-240 are **equal**.

time = ... years [3]

[Total: 12]

[Turn over

For Examiner's Use

3 (a) Write an account of the conditions necessary for nuclear fusion to occur in a plasma.

- Describe the nature of a plasma.
- Explain why high temperatures are needed for fusion to take place.
- Explain why plasma confinement is necessary.
- Outline briefly **three** ways in which confinement can occur.

....
....
....
....
....
....
....
....
....
....
....
....
....
....
....
....
....
....
....
....
....
....
....

For Examiner's Use

....

....

....

....

....

....

....

....

....[9]

(b) When a helium nucleus ($^{4}_{2}He$) is produced by hydrogen fusion, 28.4 MeV of energy is released.

Calculate how much energy is released when 1.00 kg of $^{4}_{2}He$ nuclei is produced. Give your answer in joule.

energy = ... J [3]

[Total: 12]

[Turn over

For Examiner's Use

4 In the Sun there is a series of reactions called the hydrogen cycle.

(a) In one of these reactions, a hydrogen nucleus (^1_1H) fuses with a deuterium nucleus (^2_1H). Write an equation for this fusion reaction.

....

....[1]

(b) Fusion of a hydrogen nucleus and a deuterium nucleus is most likely when they approach each other along the same line. Fig. 4.1 illustrates this.

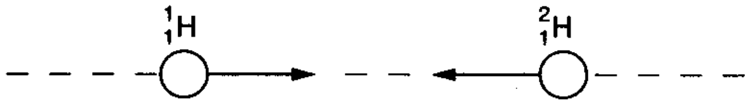

Fig. 4.1

In one such interaction, the two nuclei both decelerate and come to rest.

(i) Describe the energy changes which occur during this deceleration.

....

....

....

....[2]

(ii) The electric potential energy E_P of two particles carrying charges Q_1 and Q_2 at a separation r is given by

$$E_P = \frac{Q_1 Q_2}{4\pi \epsilon_0 r}$$

where ϵ_0 is the permittivity of free space.

The hydrogen and deuterium nuclei come to rest at a separation of 3.07×10^{-13} m. Show that their combined initial kinetic energy is 7.5×10^{-16} J.

[2]

For Examiner's Use

(iii) The deuterium nucleus has an initial speed v.
Show that the initial speed of the hydrogen nucleus is $2v$.

[2]

(iv) Using the answers to **(ii)** and **(iii)**, calculate the initial kinetic energies of the hydrogen nucleus and the deuterium nucleus.

kinetic energy of hydrogen nucleus = ... J

kinetic energy of deuterium nucleus = ... J
[4]

[Total: 11]

[Turn over

For Examiner's Use

5 **(a)** Outline the principles of operation of a synchrotron.

Your account should describe briefly the principal stages in the acceleration of particles and how they are made to move along a circular orbit.

You may illustrate your answer with a sketch.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

[5]

(b) In a series of experiments, positrons are made to collide with electrons in order to create a ${}^{0}_{0}Z$ particle. The reaction may be represented as follows.

$$ {}^{0}_{+1}e + {}^{0}_{-1}e \rightarrow {}^{0}_{0}Z $$

The rest mass of the ${}^{0}_{0}Z$ particle is 1.63×10^{-25} kg.

Show that the rest mass of the ${}^{0}_{0}Z$ particle is equivalent to about 92 GeV of energy.

[2]

(c) The reaction in **(b)** may take place in two ways.

process 1 • by means of a head-on collision between a beam of positrons and a beam of electrons of the same particle energy

process 2 • by directing a beam of positrons at electrons in a stationary target

(i) State the minimum particle energy needed to create a ${}^{0}_{0}Z$ particle by **process 1**. Explain your reasoning.

energy = ... GeV

....

....

....

....[3]

(ii) Explain why a beam of particles of energy about 92 GeV would **not** have enough energy to create a ${}^{0}_{0}Z$ particle by **process 2**.

....

....

....[2]

[Total: 12]

6 **(a)** The table of Fig. 6.1 shows four particles and three classes of particle.

	hadron	baryon	lepton
neutron			
proton			
electron			
neutrino			

Fig. 6.1

Indicate using ticks, the class or classes to which each particle belongs. [2]

(b) The neutron can decay, producing particles which include a proton and an electron.

(i) State the approximate half-life of this process.

....[1]

(ii) Name the force which is responsible for it.

....[1]

(iii) Write a **quark** equation for this reaction.

....

....[2]

(iv) Write number equations which show that charge and baryon number are conserved in this quark reaction.

charge ....

....

baryon number ....

....

[2]

For Examiner's Use

(c) Fig. 6.2 illustrates the paths of the neutron, proton and electron only in a decay process of the kind described in **(b)**.

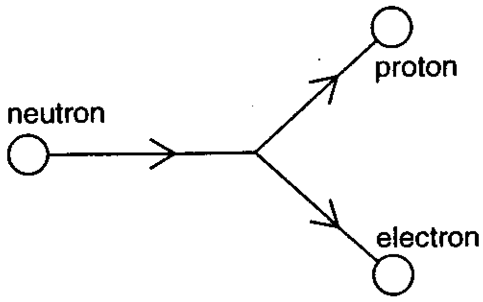

Fig. 6.2

Fig. 6.3 represents the momenta of the neutron, p_n, the proton, p_p and the electron, p_e on a vector diagram.

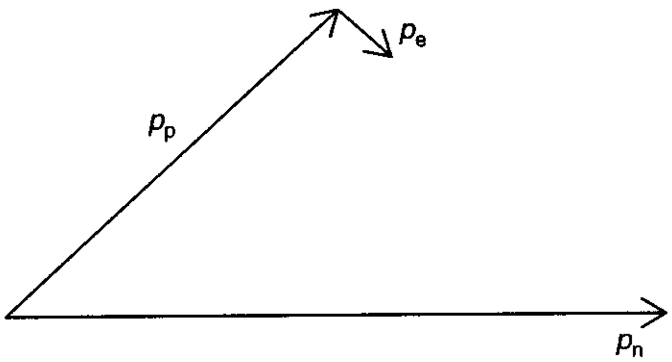

Fig. 6.3

(i) Draw and label a line on Fig. 6.3 which represents the resultant p_r of vectors p_p and p_e. [1]

(ii) According to the law of momentum, the **total** momentum of an isolated system remains constant.
Explain in as much detail as you can, why the momentum p_r is **not** the same as p_n.

....

....

....

....

....

....[3]

[Total: 12]

[Turn over

7 Although the idea for the airbag was first suggested more than fifty years ago, it has only been a compulsory safety feature in the modern motor car since 1998. When a car experiences a serious head-on collision, the seat belt is designed to restrain the driver's body. However, without the cushioning effect of an airbag, the inertia in the driver's head will cause it to carry on moving at the speed of the car until it is stopped by the steering wheel or the windscreen. When activated, the airbag must be fully inflated before the driver's head reaches it so that the head hits a soft target.

One early system stored the gas for the airbag in a cylinder under the driver's seat. When the deceleration of the car was sufficiently large, a sensor caused an electrical circuit to operate and open a valve so that the compressed gas could rush into the airbag on the steering wheel.

The sensor used a steel ball and spring in a cylinder as shown in Fig. 7.1.

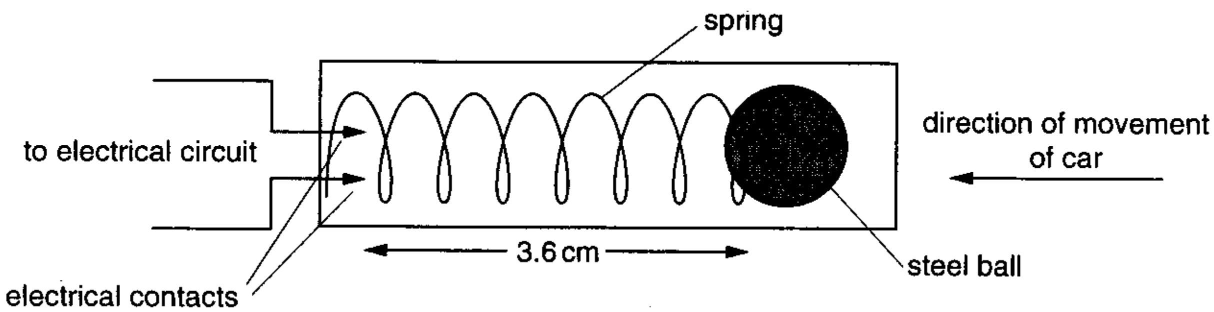

Fig. 7.1

When the car was being driven normally, the spring kept the steel ball apart from the two electrical contacts inside the cylinder. But if the deceleration became large enough, the inertia of the free ball compressed the spring and the ball touched the two contacts, thus activating the electrical circuit.

The method of storing compressed gas in a cylinder was not very reliable because some cylinders slowly leaked gas and so all had to be checked regularly.

The modern method of inflating an airbag is to generate the gas chemically by activating an electrical heater or detonator in an explosive chemical mixture. The heating starts a very rapid chemical reaction which produces nitrogen for the airbag. This means that the folded airbag along with chemicals and heater can all be located together in a compact container and positioned anywhere inside the car.

Consider the following data for a car running head-on into an immovable object.

initial velocity of car	$= 54\,\text{km hr}^{-1}$
final velocity of car	$= 0$
car front crumple distance	$= 1.25\,\text{m}$
distance from head to windscreen	$= 0.96\,\text{m}$

(a) Show that the car's speed in m s^{-1} just before hitting the object is $15\,\text{m s}^{-1}$.

[2]

(b) Calculate

(i) the deceleration of the car during the collision (assumed to be constant)

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

(ii) the time taken for the car to crumple to rest.

time = ... s [2]

(c) The data for a ball and spring sensor is given below.

mass of ball	= 0.12 kg
spring constant	= $30\,N\,m^{-1}$
distance to be compressed	= 3.6 cm

Calculate

(i) the force necessary to compress the spring by 3.6 cm

force = ... N [2]

(ii) the deceleration which the force in **(c)(i)** would cause in a mass of 0.12 kg.

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

(d) When the airbag was fully inflated from a storage cylinder, the bag had a volume of $0.060\,m^3$, with the gas inside at a pressure of 250 kPa. If the storage cylinder had a volume of $3.0 \times 10^{-4}\,m^3$, calculate the stored gas pressure, assuming the gas was ideal and at constant temperature.

pressure = ... Pa [2]

For Examiner's Use

(e) Suppose that the pressure inside the cylinder dropped by 20% over a period of 4 weeks. Assuming the mean temperature of the cylinder is 17 °C, calculate the average number of gas molecules leaving per second during this time.

number leaving per second = ... [4]

(f) The data for a modern airbag is given below.

energy required for reaction to start	= 0.96 J
heater wire cross sectional area	= $2.75 \times 10^{-8}\,m^2$
heater wire length	= 2.2 cm
resistivity of heater wire	= $1.5 \times 10^{-6}\,\Omega\,m$
battery voltage	= 12 V

(i) Show that the resistance of the heater filament is 1.2 Ω.

[2]

(ii) Hence calculate the time taken for the heater to start the chemical reaction.

time to start = ... s [3]

[Total: 20]

END OF QUESTION PAPER

BLANK PAGE