THIS IS A LEGACY SPECIFICATION

ADVANCED GCE

PHYSICS A

Nuclear and Particle Physics

2825/04

Candidates answer on the question paper

OCR Supplied Materials:
None

Other Materials Required:
- Electronic Calculator

Tuesday 27 January 2009
Morning

Duration: 1 hour 30 minutes

Candidate Forename		Candidate Surname	

Centre Number						Candidate Number				

INSTRUCTIONS TO CANDIDATES

- Write your name clearly in capital letters, your Centre Number and Candidate Number in the boxes above.
- Use 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, however additional paper may be used if necessary.

INFORMATION FOR CANDIDATES

- The number of marks 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.
- This document consists of **20** pages. Any blank pages are indicated.

FOR EXAMINER'S USE		
Qu.	**Max.**	**Mark**
1	**13**	
2	**13**	
3	**10**	
4	**12**	
5	**11**	
6	**11**	
7	**20**	
TOTAL	**90**	

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,	$\mathrm{u} = 1.66 \times 10^{-27}\ \mathrm{kg}$
rest mass of electron,	$m_\mathrm{e} = 9.11 \times 10^{-31}\ \mathrm{kg}$
rest mass of proton,	$m_\mathrm{p} = 1.67 \times 10^{-27}\ \mathrm{kg}$
molar gas constant,	$R = 8.31\ \mathrm{JK^{-1}\ mol^{-1}}$
the Avogadro constant,	$N_\mathrm{A} = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
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,	$= \sqrt{}\,(1 - \dfrac{v^2}{c^2})$
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 a nucleus is related to the nucleon number A of the nucleus by the equation

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

(a) Fig. 1.1 shows this relationship as a graph.

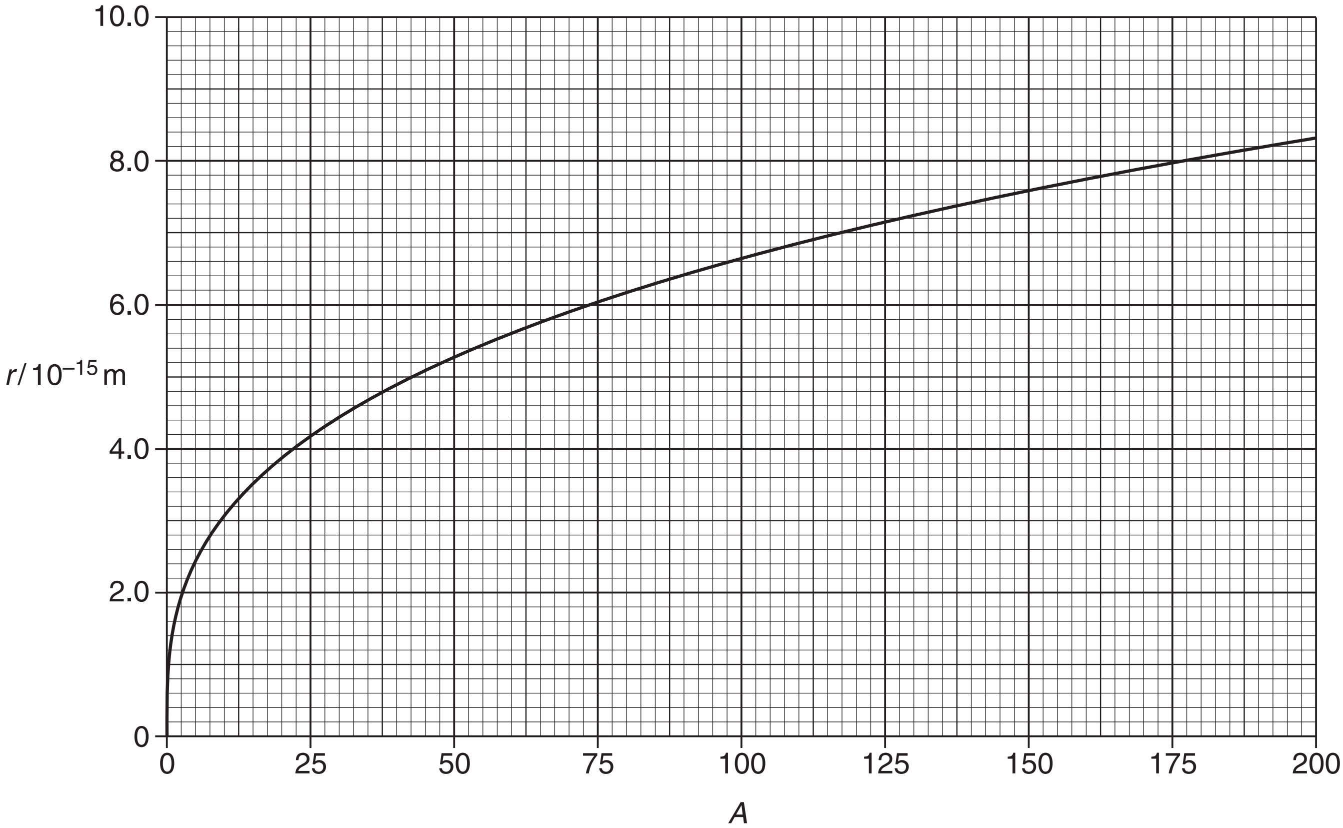

Fig. 1.1

Use information from Fig. 1.1 to calculate the value of r_0.

r_0 = ... m **[2]**

(b) **(i)** Show that the radius of a $^{235}_{92}U$ nucleus is about 9×10^{-15} m.

[1]

(ii) Show that the mass of a $^{235}_{92}U$ nucleus is about 4×10^{-25} kg.

Assume that proton mass = neutron mass = 1.67×10^{-27} kg.

[1]

(iii) Calculate the density of a $^{235}_{92}U$ nucleus.

density = ... $kg\,m^{-3}$ **[3]**

(iv) A nucleus of uranium-235 $^{235}_{92}U$ can absorb a neutron and undergo fission.

The products of a particular fission reaction are selenium-83 $^{83}_{34}Se$ and a cerium nuclide $^{X}_{Y}Ce$. A single neutron is emitted during this fission.

State the values of X and Y.

X = ... Y = ... **[2]**

(v) Calculate the ratio $\dfrac{\text{radius of cerium nucleus}}{\text{radius of selenium nucleus}}$.

ratio = ... **[2]**

(vi) Explain in words why both the selenium and the cerium nuclei have the same density as the $^{235}_{92}U$ nucleus.

....

....

....

.... **[2]**

[Total: 13]

2 This question is about neutron-induced fission reactions inside a nuclear reactor and a nuclear bomb.

In a **nuclear reactor**, uranium-235 nuclei undergo fission releasing neutrons having kinetic energy of about 2 MeV. In order to be absorbed by other uranium-235 nuclei these neutrons must have as little kinetic energy as possible and are then known as *thermal neutrons*.

(a) Why is it not possible for the neutrons to lose all their energy?

....

.... **[1]**

(b) The nuclei of uranium-238 which are also present can absorb neutrons which have more than 1 MeV of energy.

(i) Describe what happens after a uranium-238 nucleus has absorbed a neutron. Your description should state any processes that occur and name any nuclides that are formed.

....

....

....

.... **[2]**

(ii) Explain why it is important in nuclear reactors that the 2 MeV neutrons lose their energy **quickly**.

....

....

....

.... **[2]**

(c) In a particular fission reaction a uranium-235 nucleus absorbs a neutron and undergoes fission to a barium-141 nucleus and a krypton-92 nucleus. The reaction is as follows:

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{141}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3^{1}_{0}\text{n}$$

data: binding energies per nucleon for these nuclei are:

$^{235}_{92}\text{U}$ 7.6 MeV ; $^{141}_{56}\text{Ba}$ 8.4 MeV ; $^{92}_{36}\text{Kr}$ 8.6 MeV

(i) Show that the energy released when one $^{235}_{92}\text{U}$ nucleus undergoes fission in this way is about 200 MeV.

[3]

(ii) Calculate how much energy is released when 1.00 kg of uranium-235 undergoes fission. Assume that every fission generates the same amount of energy as the reaction stated above.

energy = ... J **[3]**

(d) A **nuclear bomb** can be created by pushing together several small masses of uranium-235 to make a larger mass. The uranium-235 then becomes very unstable and an explosion occurs.

Suggest why a larger mass of uranium-235 may explode even though a smaller mass does not.

....

....

....

....

.... **[2]**

[Total: 13]

3 This question is about choosing the most appropriate fusion reaction for generating useful energy.

(a) Use the ideas of kinetic energy and electric potential energy to explain why high temperatures are needed for fusion.

....

....

....

....

....

....

....

....

....

.... **[4]**

(b) The physicists designing the JET experimental reactor had to choose the best fusion reaction.

Two fusion reactions which could be used are:

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n \qquad \textbf{reaction 1}$$

$${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n \qquad \textbf{reaction 2}$$

data:

nuclide	atomic mass / u
${}^{2}_{1}H$	2.01410
${}^{3}_{1}H$	3.01605
${}^{3}_{2}He$	3.01603
${}^{4}_{2}He$	4.00260
${}^{1}_{0}n$	1.00866

Fig. 3.1

(i) In reaction 1 the mass defect is 0.00351 u.

Calculate the mass defect in reaction 2.

Hence explain which is the more suitable reaction for generating useful energy in the JET reactor.

mass defect = ... u

....

.... **[3]**

(ii) Fig. 3.1 states the masses of the **atoms** of these isotopes. Reaction 1 and reaction 2 are **nuclear** reactions.

Explain whether a more accurate answer in **(i)** could be obtained by allowing for the mass of the electrons in each atom.

....

....

.... **[1]**

(iii) Suggest why both fusion reactions occur at about the same temperature.

....

....

....

....

.... **[2]**

[Total: 10]

4 This question is about the creation of particles in collision reactions.

(a) Calculate the energy equivalence in GeV of the mass of a proton at rest.

$1\,\text{GeV} = 10^9\,\text{eV}$

energy = ... GeV **[4]**

(b) Calculate the percentage increase in the mass of a proton which has been accelerated through a potential difference of 6.00 GV.

percentage increase = ... % **[1]**

(c) When two protons (p) collide, the following reaction can take place.

$$p + p \rightarrow p + p + p + \bar{p}$$

(i) Show that this reaction requires an energy input of nearly 2 GeV.

[2]

(ii) When a high-energy proton collides with a **stationary** proton, it is found that the incoming proton must possess energy of at least 6 GeV in order for the reaction to occur.

Explain why this is much larger than your answer to **(i)** and state what happens to the energy which is not used in the reaction.

....

....

....

....

....

....

.... **[3]**

(iii) Briefly describe how the proton-proton collision could be carried out in order to create the proton-antiproton pair using an input energy of only 2 GeV.

Explain why this method would be successful.

....

....

....

....

....

.... **[2]**

[Total: 12]

5 Naturally occurring uranium consists of a mixture of uranium-235 $^{235}_{92}U$ and uranium-238 $^{238}_{92}U$. Both isotopes are radioactive and decay over time. They have different decay constants, so the ratio

$$R = \frac{\text{number of atoms of uranium-235}}{\text{number of atoms of uranium-238}}$$

has varied over the period of the Earth's history.

The proportions of these isotopes in uranium mined **at present** are:

uranium-235 0.72% ; uranium-238 99.28%.

(a) Calculate the value of R at present.

R = ... **[1]**

(b) The value of R decreases over time. Without numerical calculation, state how the half-life of uranium-235 compares with the half-life of uranium-238.

....

.... **[1]**

(c) It is estimated that the age of the Earth is 4.6×10^9 y.

R decreases exponentially and halves every 8.4×10^8 y.

Calculate R_0, the value of R when the Earth was first formed.

R_0 was .... **[3]**

(d) Fig. 5.1 shows how the number of atoms of uranium-238 has varied during the period since the Earth was formed.

On the same axes, sketch a graph to show how the number of atoms of uranium-235 has changed during the same period. **[2]**

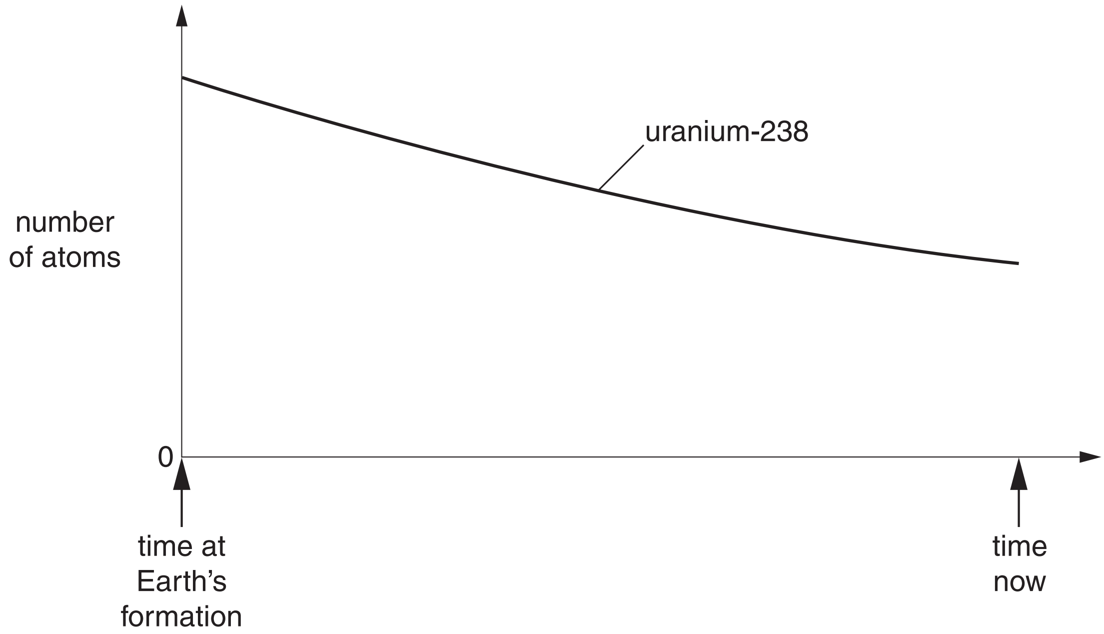

Fig. 5.1

(e) (i) State the effect on the proton number and the neutron number of the parent nucleus of an α-decay.

change in proton number .... change in neutron number .... **[1]**

(ii) State the effect on the proton number and the neutron number of the parent nucleus of a β^--decay.

change in proton number .... change in neutron number .... **[1]**

(iii) Starting from uranium-235, there is a *decay series* i.e. a series of nuclides, each of which decays to another nuclide. The series terminates with a nuclide which is stable.

Altogether in this series there are 7 α-decays and 4 β^--decays.

The initial nuclide is ${}^{235}_{92}U$.

Deduce the nuclear composition of the final, stable nucleus.

proton number .... neutron number .... **[2]**

[Total: 11]

6 **(a)** Describe the quark model of hadrons.

Your answer should, among other things, relate the properties of *either* the neutron *or* the proton to the properties of its constituent quarks.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

.... **[6]**

(b) Describe briefly the emission of leptons from nuclei.

Your answer should

- list **four** kinds of lepton
- state the force responsible for lepton emission
- give an example of a particular decay involving lepton emission.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

.... **[5]**

[Total: 11]

7 The speed with which a bullet emerges from the barrel of a gun can be measured by a number of different techniques. This question relates to **two** experiments performed using the same rifle and bullets.

Data:

- mass of rifle 4.3 kg
- mass of bullet 28 g
- length of rifle barrel 72 cm

(a) Fig. 7.1 shows the first experiment where the rifle fires the bullet into a measured distance *D* between two fast optical sensors each of which is connected to a timer.

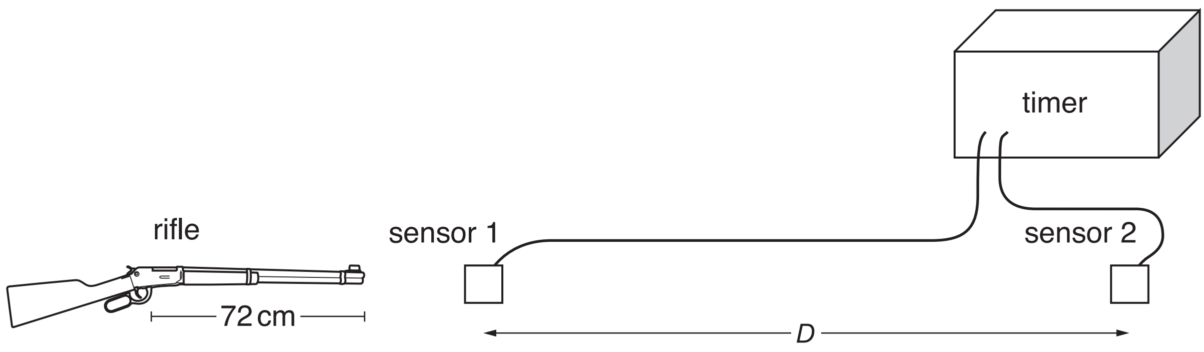

Fig. 7.1

When the bullet reaches sensor 1 the timer starts and when the bullet passes sensor 2 the timer stops.

distance *D* = 1.28 m
time *t* = 1.50 ms

(i) Show that the speed of the bullet is about 850 m s^{-1}.

[1]

(ii) The bullet accelerates as it travels along the rifle barrel. Show that the average acceleration in the barrel is about $5 \times 10^5\,\mathrm{m\,s^{-2}}$.

[2]

(iii) Calculate the average force on the bullet in the barrel.

average force on bullet = ... N **[2]**

(iv) Discuss the effect this force has on the rifle.

....

....

....

....

.... **[2]**

(b) Fig. 7.2 shows the second experiment where the same rifle fires the bullet horizontally into the middle of a block of lead resting on top of a vertical support.

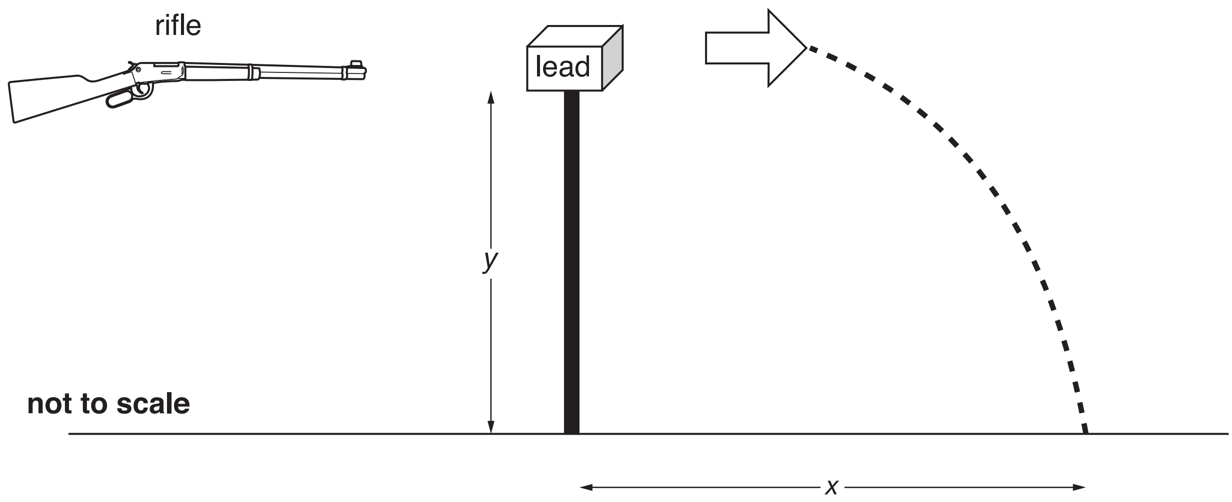

Fig. 7.2

When the bullet reaches the block it becomes embedded in the lead and the block is projected a horizontal distance *x* and falls a vertical distance *y* as shown. The following measurements are made;

mass of bullet	28 g
mass of lead block	3.60 kg
vertical distance *y*	2.41 m
horizontal distance *x*	4.60 m

(i) Show that the time taken for the block to fall through the vertical distance *y* is about 0.70 s.

[2]

(ii) Show that the horizontal projection speed of the block from the support is about 6.6 m s^{-1}.

[1]

(iii) Show that the speed of the bullet given by this collision experiment is also about 850 m s^{-1}.

[3]

(c) The initial kinetic energy of the bullet is transferred to the block as kinetic energy and thermal energy.

(i) Estimate the rise in temperature of the lead block. The specific heat capacity of lead is $126\,\mathrm{J\,kg^{-1}\,K^{-1}}$.

rise in temperature = ... K **[5]**

(ii) Explain **two** assumptions you made in this calculation.

....

....

....

....

....

.... **[2]**

[Total: 20]

END OF QUESTION PAPER

PLEASE DO NOT WRITE ON THIS PAGE