OCR
RECOGNISING ACHIEVEMENT

**OXFORD CAMBRIDGE AND RSA EXAMINATIONS**

**Advanced GCE**

# PHYSICS A

# 2825/04

Nuclear and Particle Physics

Thursday **26 JANUARY 2006** 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 | 12 | |
| 2 | 12 | |
| 3 | 13 | |
| 4 | 13 | |
| 5 | 11 | |
| 6 | 9 | |
| 7 | 20 | |
| TOTAL | 90 | |

**This question paper consists of 16 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, | $\mathrm{u} = 1.66 \times 10^{-27}\ \mathrm{kg}$ |
| 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, | $= 10 \lg\left(\frac{I}{I_0}\right)$ |

For Examiner's Use

Answer **all** the questions.

**1** Fig. 1.1 shows two protons **A** and **B** in contact and at equilibrium inside a nucleus.

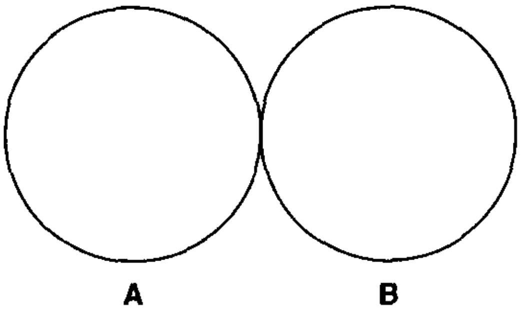


**Fig. 1.1**

Proton **A** exerts three forces on proton **B**. These are an electrostatic force $F_E$, a gravitational force $F_G$ and a strong force $F_S$.

**(a)** On Fig. 1.1, mark and label the three forces acting on proton **B**. Assume that every force acts at the centre of the proton. [2]

**(b)** Write an equation relating $F_E$, $F_G$ and $F_S$.

[1]

**(c)** The radius of a proton is $1.40 \times 10^{-15}$ m.
Calculate the values of

**(i)** $F_E$

$F_E$ = .................................... N [2]

**(ii)** $F_G$

$F_G$ = .................................... N [2]

**(iii)** $F_S$.

$F_S$ = .................................... N [1]

For Examiner's Use

**(d)** Comment on the relative magnitudes of $F_E$ and $F_G$.

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**(e)** Fig. 1.2 shows two **neutrons** in contact and at equilibrium inside a nucleus.

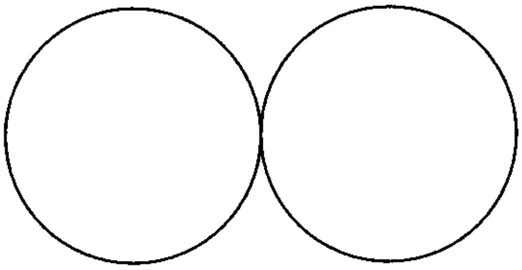

**Fig. 1.2**

Without further calculation, state the values of $F_E$, $F_G$ and $F_S$ for these neutrons.

**(i)** $F_E$ = ........................................................................ N [1]

**(ii)** $F_G$ = ........................................................................ N [1]

**(iii)** $F_S$ = ........................................................................ N [1]

[Total: 12]



[Turn over

**2** This question is about the production and use of plutonium-239 ($^{239}_{94}Pu$).
In a uranium fission reactor, uranium-238 ($^{238}_{92}U$) is bombarded with neutrons.
A nucleus of $^{238}_{92}U$ can absorb a neutron.
The product of this reaction then undergoes two decay reactions to produce $^{239}_{94}Pu$.

**(a)** Write nuclear equations for these three reactions.
Use X to represent any intermediate nuclide.

**(i)** absorption of a neutron

[1]

**(ii)** first decay reaction

[2]

**(iii)** second decay reaction

[1]

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

half-life = ....................................... y [1]

**(ii)** Calculate the decay constant λ of plutonium-239.

decay constant = .................................. $s^{-1}$ [2]

For Examiner's Use

(c) Plutonium-239 can be used (with uranium-235) in a different kind of reactor. A particular fuel rod for such a reactor has a mass of 4.4 kg, of which 5.0 % is plutonium-239.

(i) Show that the number of atoms of plutonium in this fuel rod is $5.5 \times 10^{23}$.

[2]

(ii) Calculate the activity of the plutonium in this fuel rod.
State the unit of your answer.

activity = ...................... unit........ [3]

[Total: 12]



[Turn over

**3** The Sun's energy is generated by fusion reactions.
Fusion is most likely to occur when reacting nuclei approach each other along the same straight line. Fig. 3.1 shows two protons which have the same initial speed.

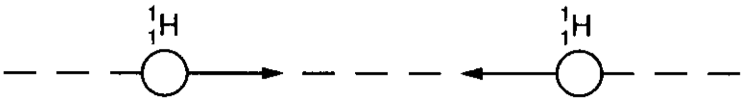


**Fig. 3.1**

**(a)** Describe the energy changes in this system as the protons approach each other and come to rest.

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**(b)** In order to fuse, the centres of the protons must reach a separation of $2.1 \times 10^{-15}$ m or less. Calculate the minimum initial kinetic energy of **each** proton for fusion to occur.
The total potential energy $E_P$ of **two** charges $Q_1$ and $Q_2$ at separation $r$ is given by

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

kinetic energy = .................................... J [2]

**(c)** Using the equation

$$E_K = 2.07 \times 10^{-23}\, T$$

calculate the temperature $T$ of a plasma such that the kinetic energy of the protons is equal to your answer to **(b)**.

temperature = .................................. K [1]

**(d)** Proton fusion occurs at a temperature of about $1.5 \times 10^7$ K. Suggest why this fusion can occur at a much lower temperature than your answer to **(c)**.

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**(e)** Two series of fusion reactions in the Sun are particularly important. One is the **hydrogen cycle** which consists of the following reactions. The energy outputs from each reaction are shown.

$$2\,({}^{1}_{1}H) \rightarrow {}^{2}_{1}H + {}^{0}_{1}e + {}^{0}_{0}\nu + 2.3 \times 10^{-13}\,J$$

$${}^{2}_{1}H + {}^{1}_{1}H \rightarrow {}^{3}_{2}He + 8.8 \times 10^{-13}\,J$$

$$2\,({}^{3}_{2}He) \rightarrow {}^{4}_{2}He + 2\,({}^{1}_{1}H) + 20.6 \times 10^{-13}\,J$$

The hydrogen cycle of reactions may be summarised in the equation

$$4\,({}^{1}_{1}H) \rightarrow {}^{4}_{2}He + 2\,({}^{0}_{1}e) + 2\,({}^{0}_{0}\nu) + E$$

**(i)** Calculate the value of $E$, the total energy output for this reaction.

$E$ = .................................... J [2]

**(ii)** Suggest why the amount of heat generated inside the Sun by the hydrogen cycle of reactions is less than would be expected from your answer to **(i)**.

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**(f)** Another series of reactions which occurs in the Sun is the **carbon cycle**. This involves the fusion of protons with carbon and nitrogen nuclei. It happens to a greater extent inside stars hotter than the Sun. Suggest why these reactions require higher temperatures than the hydrogen cycle.

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[Total: 13]

4 (a) Describe what is meant by **fixed target** and **colliding beam** experiments. Discuss the relative advantages of each.

*description* ..........................................................................................................

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*advantages* ..........................................................................................................

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For Examiner's Use

**(b)** A high-energy positron collides with a stationary electron, creating a ${}^{0}_{0}Z$ particle. The reaction may be represented thus

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

The incoming positron and the outgoing ${}^{0}_{0}Z$ particle both move at approximately the speed of light.

**(i)** Use the principle of conservation of momentum to compare the masses of the positron and the ${}^{0}_{0}Z$ particle.

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..........................................................................................................................[2]

**(ii)** The rest mass of the ${}^{0}_{0}Z$ particle is $1.6 \times 10^{-25}$ kg.

Calculate the ratio of the rest mass of the ${}^{0}_{0}Z$ particle to the rest mass of the positron.

ratio = ........................................ [1]

**(iii)** Explain why your answers to **(i)** and **(ii)** are **not** contradictory.

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**(c)** State why the method of creating a ${}^{0}_{0}Z$ particle described in **(b)** is not very productive.

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[Total: 13]

For Examiner's Use

5 This question is about the ways in which a gold isotope might undergo spontaneous decay.

Data.

| name | symbol | mass/u |
|---|---|---|
| gold-192 | $^{192}_{79}Au$ | 191.92147 |
| platinum-192 | $^{192}_{78}Pt$ | 191.91824 |
| mercury-192 | $^{192}_{80}Hg$ | 191.92141 |
| electron | $^{0}_{-1}e$ | 0.00055 |

A student suggests that $^{192}_{79}Au$ should undergo either $\beta^+$ or $\beta^-$ decay.

**(a)** Write nuclear equations for each of these suggested reactions.

$\beta^+$

$\beta^-$

[2]

**(b)** Deduce whether either of these reactions can take place.

[5]

**(c)** Calculate the maximum kinetic energy, in joule, of any emitted $\beta$ particle.

energy = ..................................... J [4]

[Total: 11]

For Examiner's Use

**6** **(a)** With particular reference to **two** kinds of hadron, discuss the stability or otherwise of hadrons.

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**(b)** Tritium-3 ($^{3}_{1}H$) decays to helium-3 ($^{3}_{2}He$) with the emission of a $\beta^{-}$ particle.

**(i)** Name the force responsible for this decay process.

..........................................................................................................[1]

**(ii)** Write a nuclear equation to represent this process.

[1]

**(iii)** Write a quark equation, in its simplest form, to represent this process.

[2]

[Total: 9]

7 This question is about the design and use of Christmas tree lights.

**Design of bulbs**

An engineer intends to design light bulbs for use in a set of Christmas tree lights to be powered by a 240 V mains supply.

Each bulb, when operating normally, will use 0.50 W and will have a filament 6.0 mm long, made of tungsten.

resistivity of tungsten at normal working temperature = $1.1 \times 10^{-6}\,\Omega\,m$

**(a)** State **one** advantage of connecting these bulbs in parallel, rather than in series.

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**(b)** Suppose the bulbs are connected in **parallel**. Calculate

**(i)** the current through each bulb

current = ........................................ A [2]

**(ii)** the resistance of each bulb filament

resistance = ........................................ Ω [2]

**(iii)** the radius of each bulb filament.

radius = ........................................ m [3]

**(iv)** Hence suggest why these bulbs are impractical.

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**Use of bulbs**

A householder has two sets of Christmas tree lights.

**Set A** consists of 24 bulbs, each of resistance 200 Ω, connected in series.

**Set B** consists of 48 bulbs, each of resistance 50 Ω, connected in series.

All bulbs fail when their power dissipation reaches 0.75 W.

**(c)** **Set A** is connected to a 240 V mains supply. Fig. 7.1 shows the wiring of four of these bulbs.

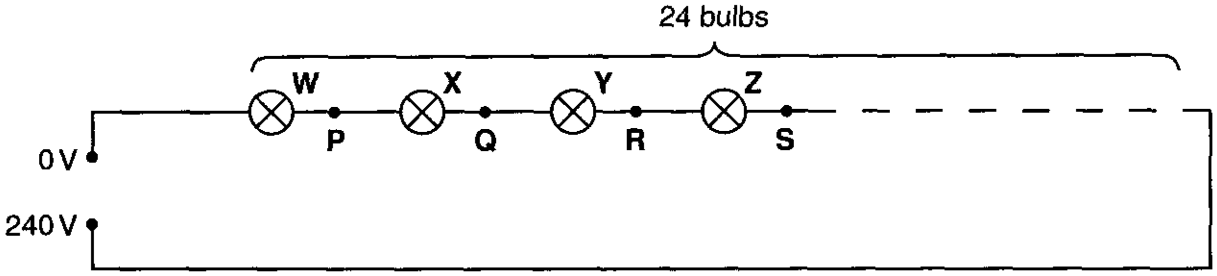


**Fig. 7.1**

During use, the filament of bulb **Y** fails and its resistance becomes infinite. In order to find which bulb has failed, the householder connects one terminal of a voltmeter to the 0 V terminal of the mains and notes the voltmeter reading when its other terminal is connected successively to points **P**, **Q**, **R** and **S**.
Enter in the table the voltmeter reading for each connection.
Explain your answer.

| connection | reading / V |
|---|---|
| **P** | |
| **Q** | |
| **R** | |
| **S** | |

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For Examiner's Use

(d) (i) The householder has no correct replacement bulbs for **Set A**. Each time a **Set A** bulb fails, it is replaced by a **Set B** bulb.
Explain why this is unsatisfactory and what will happen as more bulbs are replaced in this way.

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(ii) Calculate how many bulbs from **Set A** can be replaced by **Set B** bulbs before the system fails altogether.
Assume that the resistance of each bulb is independent of the current.

number = ................................................ [4]

[Total: 20]

**END OF QUESTION PAPER**