

NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

APPLIED PHYSICS DEPARTMENT

SPH 2205 ATOMIC AND NUCLEAR PHYSICS

SUPPLEMENTARY EXAMINATION

BSC HONOURS PART II : JULY 2001

DURATION : 3 HOURS

ANSWER **ALL** PARTS OF QUESTION IN SECTION A AND ANY **THREE** FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B CARRIES 60 MARKS.

SECTION A

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1. The expectation value of r in the hydrogen like atoms is given by;

$$\langle r \rangle = \frac{n^2 a_0}{Z} \left\{ 1 + \left[1 - \frac{\ell(\ell+1)}{n^2} \right] \right\}$$

- (a) (i) Identify all the quantities in this expression. [3]
- (ii) Compute $\langle r \rangle$ for all states with $n = 3$ and compare with the $\langle r \rangle$ found when $n = 1$. [4]
- (b) The L_1 - absorption edge in tungsten ($Z = 74$) is at 1.02 \AA . Assume that a K_α - photon is absorbed by one of the $2s$ - electrons in an Auger process. Determine the velocity of the ejected photo electron. [5]
- (c) Give the S-, L- and J- values for the terms $^1S_0, ^2S_{1/2}, ^1P_1, ^3P_2, ^3P_4, ^3F_4, \text{ and } ^1D_2$. [4]
- (d) (i) Write down the ground state electronic configuration of the element argon ($Z = 18$). [4]
- (e) Show that for positron emission to occur, the mass of the parent atom must exceed that of its daughter by two electron masses. [5]
- (f) The mass ratio of A to B atoms in a particular mineral sample is measured to be 0.02. If A has been produced solely by β - decay of B whose half-life is 4.68×10^{10} years, estimate the age of the mineral-bearing rock? [7]

(h) (i) Write down the ground state electronic configuration of Fluorine ($Z = 9$) [3]

(ii) Name one property of fluorine which is associated with its electronic Configuration. [5]

SECTION B

2 (a) State Pauli's Exclusion Principle for functions of multi-electron atomic system. [4]

(b) Set up an antisymmetric wave function for the $1s 2s$ configuration of the Helium atom. In doing this make use of the products of the spatial functions given in the provided table to functions of the one-electron atom. Also show that this wave function can be expressed as a determinant. [8]

Normalised eigenfunctions of the one-electron atom for $n = 1, 2,$ and 3 .
For hydrogen $Z = 1$

n	l	m_l	$\psi_{nlm_l}(r, \theta, \phi) = R_{nl}(r) \Theta_{lm_l}(\theta) \Phi_{m_l}(\phi)$			
1	0	0	$\frac{1}{\sqrt{\pi}} \left(\frac{Z}{a_0}\right)^{3/2} e^{-Zr/a_0}$	1	1	1
2	0	0	$\frac{1}{4\sqrt{2\pi}} \left(\frac{Z}{a_0}\right)^{3/2} \left(2 - \frac{Zr}{a_0}\right) e^{-Zr/2a_0}$	1	1	1
2	1	0	$\frac{1}{4\sqrt{2\pi}} \left(\frac{Z}{a_0}\right)^{3/2} \frac{Zr}{a_0} e^{-Zr/2a_0} \cos \theta$	$\cos \theta$	1	1
2	1	± 1	$\frac{1}{8\sqrt{\pi}} \left(\frac{Z}{a_0}\right)^{3/2} \frac{Zr}{a_0} e^{-Zr/2a_0} \sin \theta$	$\sin \theta$	$e^{\pm i\phi}$	$e^{\pm i\phi}$
3	0	0	$\frac{1}{81\sqrt{3\pi}} \left(\frac{Z}{a_0}\right)^{3/2} \left(27 - 18\frac{Zr}{a_0} + 2\frac{Z^2 r^2}{a_0^2}\right) e^{-Zr/3a_0}$	1	1	1
3	1	0	$\frac{\sqrt{2}}{81\sqrt{\pi}} \left(\frac{Z}{a_0}\right)^{3/2} \left(6 - \frac{Zr}{a_0}\right) \frac{Zr}{a_0} e^{-Zr/3a_0} \cos \theta$	$\cos \theta$	1	1
3	1	± 1	$\frac{1}{81\sqrt{\pi}} \left(\frac{Z}{a_0}\right)^{3/2} \left(6 - \frac{Zr}{a_0}\right) \frac{Zr}{a_0} e^{-Zr/3a_0} \sin \theta$	$\sin \theta$	$e^{\pm i\phi}$	$e^{\pm i\phi}$
3	2	0	$\frac{1}{81\sqrt{6\pi}} \left(\frac{Z}{a_0}\right)^{3/2} \frac{Z^2 r^2}{a_0^2} e^{-Zr/3a_0}$	$(3 \cos^2 \theta - 1)$	1	1
3	2	± 1	$\frac{1}{81\sqrt{\pi}} \left(\frac{Z}{a_0}\right)^{3/2} \frac{Z^2 r^2}{a_0^2} e^{-Zr/3a_0} \sin \theta \cos \theta$	$\sin \theta \cos \theta$	$e^{\pm i\phi}$	$e^{\pm i\phi}$
3	2	± 2	$\frac{1}{162\sqrt{\pi}} \left(\frac{Z}{a_0}\right)^{3/2} \frac{Z^2 r^2}{a_0^2} e^{-Zr/3a_0} \sin^2 \theta$	$\sin^2 \theta$	$e^{\pm 2i\phi}$	$e^{\pm 2i\phi}$

(c) Consider a three-electron system in an $2s 2p^2$ configuration. Write the total wave function in determinant form so that the wave function corresponds to

- 3 (a) $M_L = 1$ and $M_S = \frac{1}{2}$ [8]
 Show that a complete (n, ℓ) shell must necessarily have $L = 0, S = 0$. [4]

- (b) The energy levels of Helium-like atoms when one electron is in the Ground state ($n = 1$) could be expressed by

$$E = -RhcZ^2 - \frac{Rhc(Z-1)^2}{n^2}$$

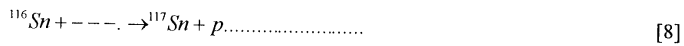
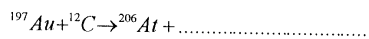
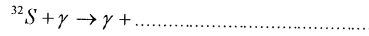
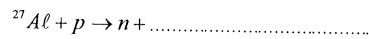
- (i) Discuss and explain the plausibility of these two terms of the energy. [8]
 (ii) Compare the energy levels for Helium when $n = 2, 3$ and 4 . [4]
 (iii) Why does the accuracy of the above expression for E increase when n increases? [4]

- 4 (a) Find the possible values of S, L and J for a configuration with three optically active electrons of quantum numbers $\ell_1 = 1, \ell_2 = 2, \ell_3 = 3$ for the same n value. [10]

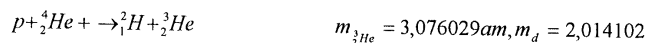
- (b) For each J value find the number of M_J values. [4]

- (c) Compose the spectroscopic terms for which the configuration has lowest and Highest energies. [6]

- 5 (a) Complete the following equations



- (b) (i) Calculate the Q - value of the reaction



$$m_p = 1,00782\text{amu}, \quad m_\alpha = 4,002603\text{amu} \quad [3]$$

- (ii) What is the condition for the reaction to take place? [3]

- 6 (a) Two identical particles move independently in a one-dimensional box length b , one being in the ground state and the other being in first excited state.

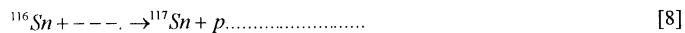
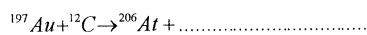
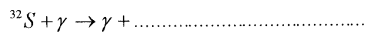
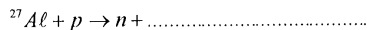
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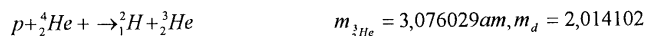
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