PC2302

ONE HOUR THIRTY MINUTES

A list of constants is enclosed.

UNIVERSITY OF MANCHESTER

Atoms and Nuclei

7th June 2006, 2.00 p.m. - 3.30 p.m.

Answer **ALL** parts of question 1 and **TWO** other questions

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Electronic calculators may be used, provided that they cannot store text.

The numbers are given as a guide to the relative weights of the different parts of each question.

$$\mu_B = 5.8 \cdot 10^{-5} \text{ eV/T}$$
$$\hbar c = 197 \text{ MeVfm}$$

1. (a) State Moseley's Law for the frequency of X-rays and briefly describe its relevance. [5 marks]

(b) Sketch the dependence of the nuclear mass $M(A, Z)$ as function of the nuclear charge Z at a fixed mass number A for nuclei with odd and even A. What types of decays occur between the different states on the curve? [5 marks]

(c) Explain the main difference between the Bohr model's assumption about the ground state of hydrogen and the correct quantum mechanical description in terms of angular momentum.

In the Bohr model, give the velocity v/c of the electron in the ground state. [5 marks]

(d) Compare the binding energy of the deuteron to the typical binding energies per nucleon of heavier nuclei.

Give a process that can be used to measure the deuteron binding energy.

What is the total spin of the deuteron ground state ? [5 marks]

(e) Calculate the de Broglie wavelength of electrons with an energy of 2 GeV. Explain why these particles are useful for investigating the charge distributions of nuclei. [5 marks]

P.T.O.

2. (a) Describe the experimental setup, the results and the interpretation of the Franck-Hertz experiment. [8 marks]

(b) Sketch, using a polar plot, the square of the angular part of the wavefunction, $|\Theta(\theta)|^2$, for all hydrogen states with $n = 2$. What is the physical interpretation of $|\Theta(\theta)|^2$?

The associated Legendre Polynomials are given by $(m > 0)$

$$P_\ell^m(\cos\theta) = \frac{(-1)^m}{2^\ell \ell!}(1-\cos^2\theta)^{\frac{m}{2}} \frac{\mathrm{d}^{(\ell+m)}(\cos^2\theta - 1)^\ell}{\mathrm{d}\cos\theta^{(\ell+m)}}.$$

[5 marks]

(c) Explain the differences between orthohelium and parahelium and compare the energy level diagrams. [6 marks]

A helium atom has two electrons in the ground state $(n_1 = n_2 = 1)$. Estimate the total binding energy of the two electrons. [6 marks]

P.T.O.

3. (a) Describe and sketch the experimental setup, the results and the interpretation of the Stern-Gerlach experiment. [8 marks]

(b) Give the electron configuration for Potassium ($Z = 19$). [3 marks]

The total angular momentum L of Potassium is determined only by the angular momentum and the spin of the valence electron, since the angular momenta and spins of all other electrons add up to zero.

Assume the valence electron is in the $n = 4, l = 2$ state.

Give the allowed values for the total angular momentum quantum numbers j, calculate the magnitude of the total angular momentum $|\vec{j}|$ and give the term symbol $n^{2S+1}L_J$ for these states. [6 marks]

The potassium atom is placed in an external magnetic field $B = 10^{-4}$ T. Name and sketch the observed effect on the energy levels for both states. [4 marks]

Calculate the energy splitting ΔE between two adjacent energy levels (in eV) for one of the two states.

The Landé g-factor is given by

$$g_j = 1 + \frac{j(j+1) + s(s+1) - l(l+1)}{2j(j+1)}$$

[4 marks]

P.T.O.

4. (a) Sketch a potential $V(r)$ that is used to describe α decay. The thorium isotope ^{232}Th decays through α decay with $Q_\alpha = 4.08$ MeV. Give an approximate value of the kinetic energy of the α particle within the thorium nucleus, i.e. for r less than the nuclear radius. [5 marks]

(b) The thorium isotope ^{232}Th has a half life of $1.4 \cdot 10^{10}$ years. Its radioactive decay leads ultimately to the stable lead isotope ^{208}Pb. A piece of rock contains 3.65g of ^{232}Th and 0.75g of ^{208}Pb. What is the age of the rock as determined from the Th/Pb ratio? You can assume that all of the ^{208}Pb found in the rock is from ^{232}Th decays. [8 marks]

How many α particles are released in a single decay chain ? [2 marks]

(c) Calculate the energy of thermal neutrons (in units of eV) and compare it to the average kinetic energy of neutrons released in fission. [5 marks]

Describe how thermalisation of neutrons is achieved in a nuclear reactor and why thermal neutrons are needed.

Name the materials most commonly used for this purpose and give a qualitative comparison of their effectiveness. [5 marks]

END OF EXAMINATION PAPER