ONE HOUR THIRTY MINUTES

A list of constants is enclosed.

UNIVERSITY OF MANCHESTER

Atoms and Nuclei

15th May 2002, 2.00 p.m. - 3.30 p.m.

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

---

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.

PC2302 June 2002 continued...

1. (a) Explain how the Stern-Gerlach experiment provided evidence for the existence of electron spin. [6 marks]

(b) Using the Semi-empirical Mass Formula to guide you, explain why heavy nuclei are unstable against fission. [6 marks]

(c) Estimate the radius of $^{208}_{82}$Pb and the Coulomb barrier for the interaction of protons with $^{208}_{82}$Pb. [6 marks]

(d) Living organic matter contains 1 atom of ^{14}C per 10^{12} atoms of ^{12}C. A wood carving has been attributed by archaeologists to around 100 AD. What would be the ratio of ^{14}C to ^{12}C atoms measured now? The half-life of ^{14}C is 5730 years. [6 marks]

(e) For each thermal neutron absorbed in fission reactor fuel, an average number η of fast neutrons is produced. Give the reason why η is less than the number of neutrons produced in a fission reaction. How can the value of η be varied? [6 marks]

2. (a) What are the allowed values of orbital angular momentum of all the states of the hydrogen atom with principal quantum number n=4? What are the degeneracies of each of these states? For each of the states with n=4, give the allowed values of their total angular momentum when the intrinsic spin of the electron is taken into account. [8 marks]

(b) Draw a diagram of a typical central-field potential in a multi-electron atom, giving an explanation for its shape as a function of distance from the nucleus. How does this potential give rise to shell effects in electron orbitals? [12 marks]

Write down an expression for an estimate of the energies of K_α X rays. Justify the parameters that appear in the expression. Hence estimate the energy of the K_α X rays of aluminium (Z=13). [10 marks]

3. Outline the three stages of the process that can lead to biological damage as a result of exposure to radiation. [10 marks]

What is meant by the term *Linear Energy Transfer* (LET)? Sketch an LET curve for 50 MeV protons. Why is the use of high-energy protons seen as a better methodology for treating deep-lying tumours than the use of photons? [12 marks]

Calculate the absorbed, equivalent and effective doses if 50 μJ of energy is deposited in the liver using 10 MeV neutrons. The mass of the liver can be taken to be 1.5 kg, and it has a weighting factor of 0.05. [8 marks]

PC2302 June 2002 continued...

4. Give a description of the process of alpha decay, including a discussion of the factors that determine the decay rate for alpha emission. [12 marks]

What condition on the masses of the relevant nuclei must be satisfied for a nucleus (A,Z) to undergo alpha decay? [3 marks]

Calculate the kinetic energy of alpha particles emitted by $^{252}_{98}\text{Cf}$. The atomic masses of $^{252}_{98}\text{Cf}$, $^{248}_{96}\text{Cm}$ and $^{4}_{2}\text{He}$ are 252.081619, 248.072340 and 4.002603 u respectively. [7 marks]

A supplier's catalogue offers alpha-particle sources for sale with energies in the range 5 to 8 MeV. Explain why the range is so limited. [8 marks]

————————————

PC2302