PC3322

ONE HOUR THIRTY MINUTES

A list of constants is enclosed.

UNIVERSITY OF MANCHESTER

Nuclear Physics

18th May 2001, 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.

1. (a) The semi-empirical mass formula contains four terms arising from a description of a nucleus as a charged liquid drop. It was found to be necessary to add a further term that is microscopic in origin. What is this term and describe its nature? Why was it introduced? [5 marks]

(b) Explain briefly why muonic X-ray energies are a useful probe of the nuclear charge distribution. [5 marks]

(c) What are the basic assumptions of the independent particle model? [5 marks]

(d) Many spherical, even-even nuclei have a relatively low-lying $J^{\pi} = 3^{-}$ level. What is the nature of such a state? [5 marks]

(e) The nucleus ^{168}Er is a prolate-deformed nucleus with a first excited 2^{+} state at 91.4 keV. What is the expected energy of the first excited 4^{+} state? [5 marks]

2. Describe briefly how the matter distribution of a nucleus can be determined. [6 marks]

Sketch a typical matter distribution calculated from experimental measurements. [4 marks]

Explain why there is a difference in the experimental precision of a measurement of the matter density and the charge density in the central region of a nucleus. [10 marks]

The rms proton and matter radii of $^{48}_{20}$Ca have been measured to be 3.407 fm and 3.541 fm respectively. Calculate the rms radius of the neutron distribution. Comment on the value of the rms radius of the neutrons compared to that of the protons. [5 marks]

3. (a) Describe three experimental observations that provide evidence for shell effects in nucleon single-particle orbitals. [9 marks]

Explain how the introduction of the spin-orbit potential leads to the correct reproduction of the known magic numbers.

[8 marks]

(b) The ground state of ^{17}O has $J^{\pi} = \frac{5}{2}^{+}$, and the first excited state, at an energy of 871 keV, has $J^{\pi} = \frac{1}{2}^{+}$. The mean lifetime of the 871 keV state is 259 psec. Estimate the strength of the γ ray transition from the 871 keV state in single-particle units, and comment on the result you obtain. [8 marks]

The single-particle estimates for γ-ray transition rates (in units of s^{-1}) are given by the following formulae, where E_γ is in units of MeV:

$$\begin{aligned} \lambda_{E1} &= 1.0\text{x}10^{14}\ A^{\frac{2}{3}}\ E_\gamma{}^3 & \qquad \lambda_{M1} &= 5.6\text{x}10^{13}\ E_\gamma{}^3 \\ \lambda_{E2} &= 7.3\text{x}10^{7}\ A^{\frac{4}{3}}\ E_\gamma{}^5 & \qquad \lambda_{M2} &= 3.5\text{x}10^{7}\ A^{\frac{2}{3}}\ E_\gamma{}^5 \\ \lambda_{E3} &= 34\ A^{2}\ E_\gamma{}^7 & \qquad \lambda_{M3} &= 16\ A^{\frac{4}{3}}\ E_\gamma{}^7 \end{aligned}$$

4. Give a brief description of the process of alpha decay. What binding energy condition must be satisfied for a nucleus (A,Z) to undergo alpha decay? [7 marks]

Discuss the factors that determine the decay rate for alpha emission. [6 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. [4 marks]

The nuclei $^{234}_{92}$U and $^{214}_{82}$Pb are members of a naturally occuring series of alpha emitters. Given that the binding energies per nucleon of $^{234}_{92}$U and $^{214}_{82}$Pb are 7.60 and 7.77 MeV respectively, estimate the average energy of alpha particles emitted in the part of the series that lies between $^{234}_{92}$U and $^{214}_{82}$Pb. Assume that all the alpha decays are to the ground state of the daughter nucleus. [8 marks]

(The binding energy of the alpha particle is 28.3 MeV)