PHYS30322

ONE HOUR THIRTY MINUTES

A list of constants is enclosed.

UNIVERSITY OF MANCHESTER

Nuclear Physics

23rd May 2007, 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.

P.T.O.

$$r = r_o A^{1/3}$$

1. (a) Sketch on a single plot, with appropriately labelled scales, the nuclear charge distribution as a function of radius for the following nuclei:

   (i) ^{6}Li

   (ii) ^{9}Li

   (iii) ^{11}Li.

   Briefly explain what is meant by the term "halo" nucleus. [5 marks]

   (b) Briefly explain what determines the stability of a particular nucleus with respect to beta decay. Why are large changes in spin between the parent and daughter nucleus not usually observed in beta decay? [5 marks]

   (c) State two pieces of experimental evidence which cannot be explained by the liquid-drop model of the nucleus. For the following nuclei, briefly explain the type of nuclear behaviour you would expect to form the low-lying excited states in; (i) ^{174}Hf (Z=72), (ii) ^{132}Sn (Z=50), and (iii) ^{124}Te (Z=52). [5 marks]

   (d) Use the Geiger-Nutall rule to explain why almost all commercial alpha sources emit alpha particles with energies in the range of 5 to 8 MeV? [5 marks]

   (e) Estimate the angle at which the first minimum occurs in the differential cross section for the elastic scattering of 420 MeV electrons from ^{16}O. Calculate the magnitude of the momentum transfer from the electron to the nucleus at this scattering angle. [5 marks]

P.T.O.

2. Write down an expression for the Woods-Saxon nuclear potential defining any symbols you use. Sketch this potential as a function of the nuclear radius. [4 marks]

Briefly explain what additional term is required in the Woods-Saxon potential to obtain the experimentally determined magic numbers. [4 marks]

Using this corrected Woods-Saxon potential, sketch the single-particle energy level diagram for the first 5 states. Label each of these states with their appropriate quantum numbers and indicate the position of the shell gaps. [7 marks]

Using your figure;

(i) For ^{16}O (Z=8) and ^{17}O briefly explain which nucleus you would expect to form the lowest-energy first excited state based on neutron excitation? [2 marks]

(ii) Make predictions for the spin and parity of the ground state for the following nuclei: (a) ^{13}C (Z=6), (b) ^{17}O (Z=8), (c) ^{4}He (Z=2), and (d) ^{24}F (Z=9). [6 marks]

(iii) Explain how it is possible to make a state of spin and parity 4^- for ^{24}F. [2 marks]

P.T.O.

3. Explain why in heavy-ion fusion-evaporation reactions the residual nuclei produced have their angular momentum aligned in a particular direction. Briefly explain how this information can be used to determine the spin of the states from gamma-ray emission. [10 marks]

Figure 1 shows the low lying nuclear states in ^{142}Tb. The branching ratio for the gamma-ray intensity is shown for the 5^+ state.

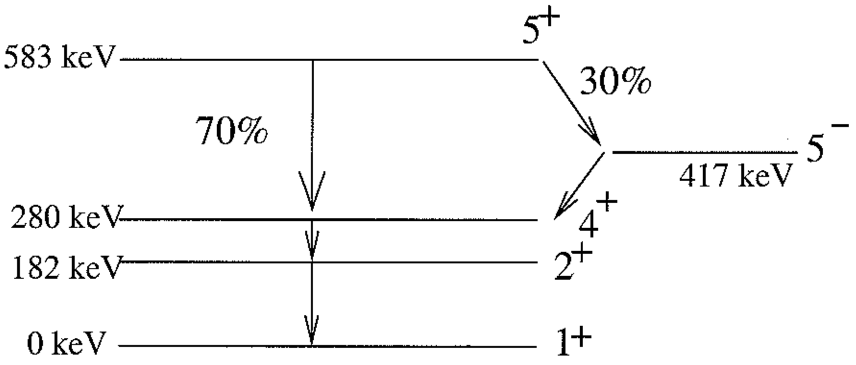

Figure 1: The low-lying level scheme for ^{142}Tb.

Calculate the half-life for the $5^+, 4^+, 5^-$ and 2^+ states in ^{142}Tb, assuming a single-particle description.

The single-particle Weisskopf estimates for transition multipolarities are:

$\lambda(E1) = 1.0 \text{ x } 10^{14} A^{2/3} E_\gamma^3$

$\lambda(E2) = 7.3 \text{ x } 10^{7} A^{4/3} E_\gamma^5$

$\lambda(M1) = 5.6 \text{ x } 10^{13} E_\gamma^3$

$\lambda(M2) = 3.5 \text{ x } 10^{7} A^{2/3} E_\gamma^5$

where E_γ is the transition energy in MeV and λ is in s^{-1}. [9 marks]

If 76% of the total transition intensity of the $4^+ \rightarrow 2^+$ decay takes place via electron conversion, calculate the electron conversion coefficient for this decay in ^{142}Tb. Calculate the half-life of the 4^+ state including the effects of electron conversion. [6 marks]

P.T.O.

4. Briefly discuss the modifications required to be made to the Coulomb potential of an electron moving in a nucleus with a non-point-like or extended-charge distribution. Sketch this modified potential for an electron as a function of the distance from the nucleus. [9 marks]

For a uniformly charged sphere of radius, R, the modified Coulomb potential can be approximated by

$$V(r < R) = \frac{-Ze^2}{4\pi\epsilon_o}\frac{1}{R}\left(\frac{3}{2} - \frac{1}{2}\frac{r^2}{R^2}\right).$$

Use first-order perturbation theory to calculate the shift in the electron energy for a 2s electron in a modified potential with wavefunction

$$\phi(r) = \frac{1}{2\sqrt{2}}\left(\frac{Z}{a_o}\right)^{\frac{3}{2}}\left(2 - \frac{r}{a_o}\right)\exp\left(\frac{-Zr}{2a_o}\right).$$

State any assumptions you make. [11 marks]

Briefly explain why in the analysis of nuclear rms radii, $\langle r^2\rangle$, the differences between neighbouring isotopes are often considered.

Evaluate the rms difference between the isotopes ^{142}Tb and ^{144}Tb (Z=67). The Bohr radius is given by 0.5×10^{-10}m. [5 marks]

END OF EXAMINATION PAPER