PC3322

ONE HOUR THIRTY MINUTES

A list of constants is enclosed.

UNIVERSITY OF MANCHESTER

Nuclear Physics

3rd June 2004, 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.

Useful data

$\hbar c = 197$ MeV fm   u=931.5 MeV c^{-2} Nuclear radius = $1.2A^{1/3}$ fm

1. (a) Explain how the finite size of the nucleus affects the energy of atomic electron levels. [5 marks]

(b) List *three* pieces of experimental evidence that suggest the nucleus has a shell structure. [5 marks]

(c) Sketch the lowest five states of (i) a vibrational, even nucleus, and (ii) a deformed rotational even nucleus. Label the states with their spin and parity. In each case indicate the ratio of energies of the second excited to first excited state. [5 marks]

(d) Use the binding energy formula of the semi-empirical mass formula:

$$E_B(A,Z) = a_v A - a_s A^{2/3} - a_c Z^2 A^{-1/3} - a_{sym}\frac{(A-2Z)^2}{A} \pm \delta$$

to explain why there can be more than one stable isobar in an even-A isobar chain. [5 marks]

(e) Sketch the general shape of (i) the β^- kinetic energy spectrum of a light neutron-rich nucleus; (ii) the α-particle kinetic energy spectrum of a heavy, even nucleus in a region of strong deformation. [5 marks]

2. Describe with the aid of a sketch the main features of the nuclear charge density distribution for a medium-mass nucleus. [4 marks]

How does the matter density distribution compare with the charge distribution in (i) a stable nucleus, and (ii) a neutron-rich nucleus in the same mass region. [2 marks]

State one experimental method for studying either the charge or matter distribution in radioactive nuclei. [2 marks]

In elastic electron scattering the electric form factor at low momentum transfer is given by the approximation

$$F(q) = 1 - \frac{q^2}{6}\langle r^2\rangle.$$

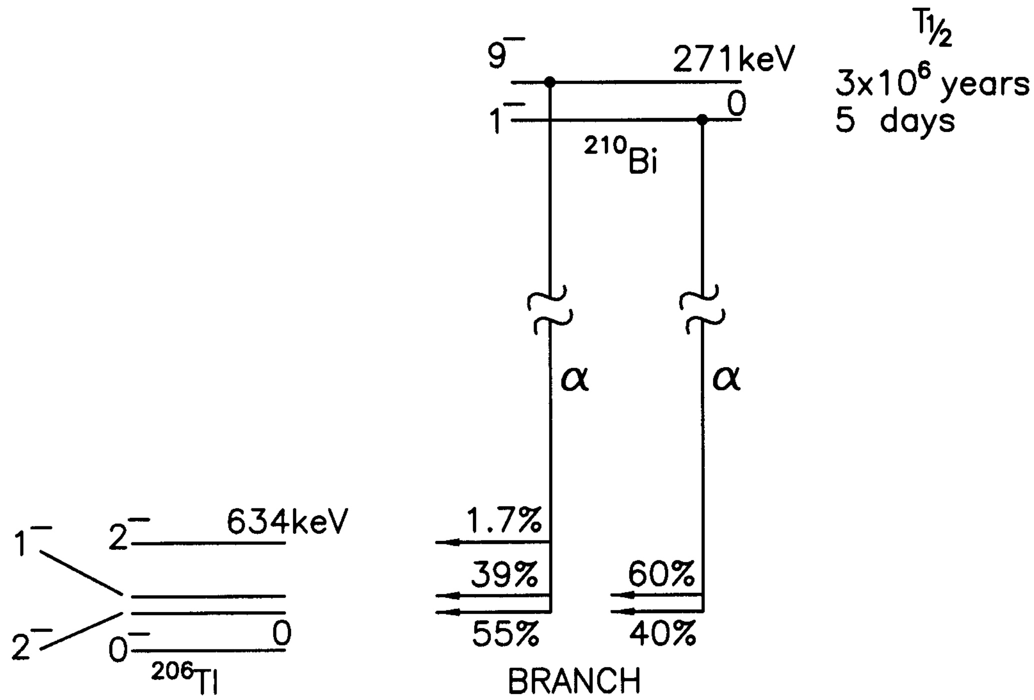
Explain the factors in this equation and express q in terms of the electron momentum and scattering angle. Why is it a useful parameter for compiling plots of experimental data? [8 marks]

Briefly describe how $F(q)$ is obtained experimentally. [3 marks]

Relativistic electrons of energy 100 MeV are scattered from a target of ^{208}Pb. Calculate the scattering angle at which the elastic scattering cross-section differs by 10% from the theoretical value for a point nucleus. [6 marks]

3. Describe a simple theory that can account for the main features of α-decay. [8 marks]

The α-decay branches for the ground state and an isomeric state of ^{210}Bi are shown in the figure below.



(i) State the approximate energy you would expect for α-particles from a long-lived heavy nucleus such as this. [2 marks]

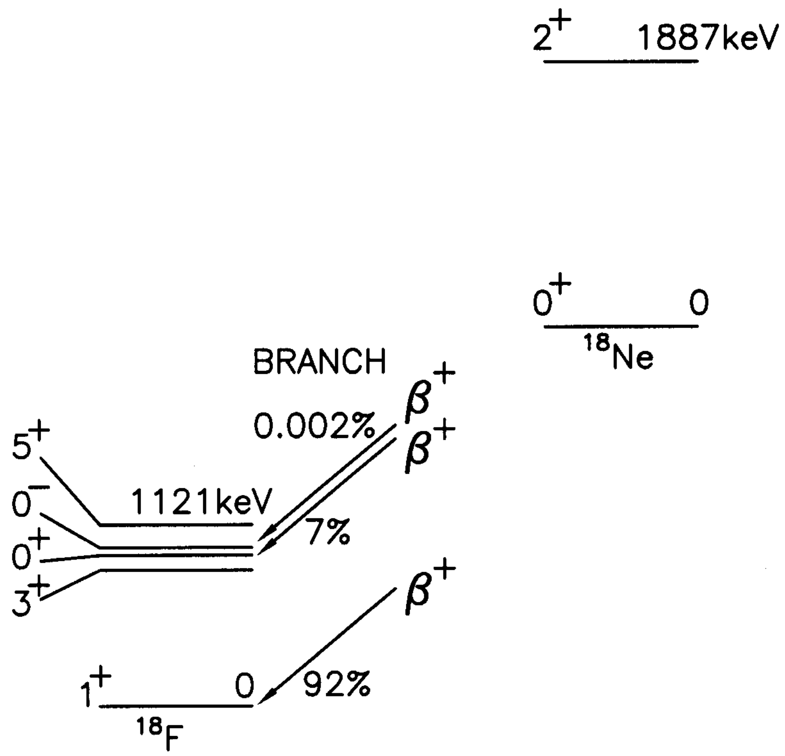
(ii) Explain why there is no α-branch to the ^{206}Tl ground state from either of the ^{210}Bi states. [4 marks]

(iii) How could your model account for the different branching ratios from the 9^- state in ^{210}Bi? [4 marks]

(iv) Make an estimate of the maximum angular momentum that the α-particle could remove from the nucleus. What factors are responsible for the large difference in half-life for the two states in ^{210}Bi. [7 marks]

4. Sketch the single-particle level scheme for a realistic nuclear potential. Label the levels with their appropriate quantum numbers and show how the magic numbers 2, 8 and 20 arise. [5 marks]

The β^+–decay branches from the ground state of $^{18}_{10}$Ne are shown in the figure below.



(i) Give the probable shell model configurations for the ground state of ^{18}Ne and the low-lying positive-parity states of ^{18}F. [5 marks]

(ii) Describe the process of β^+–decay, and calculate the end-point kinetic energy of the β^+ spectrum [Atomic masses: ^{18}F = 18.000937 u; ^{18}Ne = 18.005710 u]. [5 marks]

(iii) Give the classifications of the three β^+-decays indicated. Why are decays to the other states not observed? [5 marks]

(iv) On a sketch, show the main γ-ray transitions you would expect to observe from each of the four excited states of ^{18}F. Label the transitions with their character and multipolarity (σL). [5 marks]