ONE HOUR THIRTY MINUTES

A list of constants is enclosed.

UNIVERSITY OF MANCHESTER

Introduction to Nuclear and Particle Physics

26th January 2010, 14:00-15:30

Answer **ALL** parts of question 1, **ONE** from Section A and **ONE** from Section B

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.

1. (a) The maximum energy of β particles emitted in the decay of ^{3}H is 18.61 keV. Estimate the *atomic* mass difference between ^{3}H and ^{3}He, stating clearly all the assumptions that you make. [5 marks]

(b) What is meant by the term *magic numbers*? Explain briefly how they arise in single-particle models of nuclei. [4 marks]

Use an independent-particle model to predict the spins and parities of the ground and first excited states in $^{49}_{20}$Ca. [4 marks]

The single-particle ordering beyond magic number 28 is: $2p_{3/2}, 2p_{1/2}, 1f_{7/2}, 1g_{9/2}$.

(c) Sketch quark flow diagrams for the associated production and subsequent decay of the K^0 and Λ^0 particles, stating the type of interaction involved at each stage.

The relevant processes are:

$$\pi^- p \to K^0 \Lambda^0$$

$$K^0 \to \pi^+ \pi^-$$

$$\Lambda^0 \to p \pi^-$$

The K^0 and Λ^0 particles have quark contents $(d\bar{s})$ and (uds) respectively.

[6 marks]

(d) Three hadrons, all with masses < 4 GeV/c^2, have the following quantum numbers $(Q, B, S, C) = (0, -1, 1, 0), (-1, 1, -3, 0)$ and $(-1, 0, 0, -1)$ respectively. Identify the quark contents of each hadron. [6 marks]

P.T.O.

SECTION A

Answer either Question A2 or Question A3

A2. The semi-empirical mass formula can be written as:

$$m(A,Z) = Zm_{1H} + (A-Z)m_n - a_v A + a_s A^{2/3} + a_c \frac{Z^2}{A^{1/3}}$$
$$+a_a \frac{(A-2Z)^2}{A} \mp a_p A^{-1/2}.$$

Explain briefly the physical origin of each of the terms. [10 marks]

For a chain of odd-A nuclei with constant mass, show that the binding energy of the ground states is a parabolic function of Z given by:

$$BE(A,Z) = \text{constant} - \left[\frac{a_c}{A^{1/3}} + \frac{4a_a}{A}\right] Z^2 + 4a_a Z.$$

[3 marks]

Show that the atomic number of the most bound nucleus in this isobar is given by:

$$Z_{min} = \frac{A}{2} \frac{1}{[1 + a_c A^{2/3}/4a_a]}.$$

Given the values of $a_c = 0.71$ and $a_a = 23.3$ MeV, show that the line of stability follows $N = Z$ for light nuclei, but favours a neutron excess in heavy systems. [7 marks]

The value of a_c given above is for spherical nuclei along the line of stability where the radius of the nucleus varies as $r_0 A^{1/3}$. Given that the electrostatic energy of a uniform sphere of charge Q and radius R is $\frac{3}{5}Q^2/4\pi\epsilon_0 R$, estimate the value of r_0. [5 marks]

P.T.O.

A3. The half life for α decay is found to vary very rapidly as a function of the decay Q value. Briefly explain this observation in terms of the mechanism of the decay process. Why does this phenomenon restrict the energies of commercially available α sources to around 5 MeV? [7 marks]

Natural samarium (average atomic mass 150.36 u) contains 15.1% of the radioactive isotope ^{147}Sm, which decays by α emission. A 1 g sample of natural Sm has an α particle activity of 89 per second. Estimate the half life of ^{147}Sm. [5 marks]

Natural samarium also contains another α-emitting isotope, ^{148}Sm, at a roughly similar isotopic abundance and a half life of 7×10^{15} years. Does the presence of this second α emitter affect your estimate of the half life of ^{147}Sm? Explain your answer. [2 marks]

Use the mass excess given below, to calculate the radioactive power generated per gram of natural samarium.
Mass Excesses: $\Delta(^{147}\text{Sm})=-79272.1$, $\Delta(^{143}\text{Nd})=-84007.4$ and $\Delta(^{4}\text{He})=+2424.9$ keV.

[5 marks]

Estimate the quantum number ℓ associated with the maximum angular momentum that can be carried off by an α particle from ^{147}Sm. [6 marks]

P.T.O.

SECTION B

Answer either Question B4 or Question B5

B4. Describe how the strong, electromagnetic and weak interactions can be explained in terms of exchange bosons. [7 marks]

Discuss the range of these interactions in terms of the properties of the relevant bosons.

[6 marks]

Indicate how each of these bosons couple to both leptons and quarks and, where appropriate, how they affect the properties of the leptons and quarks. [12 marks]

B5. Show how the simple 3-flavour quark model can be used to explain the baryon $J = 1/2$ octet and $J = 3/2$ decuplet. You do not need to identify the names of particles in each of these multiplets. [13 marks]

Show which quantum numbers of the $\Omega^-(sss)$ particle can be deduced from this simple model. [7 marks]

Show how this model can be used to predict the mass and lifetime of the Ω^-.

[5 marks]

END OF EXAMINATION PAPER