ONE HOUR THIRTY MINUTES

A list of constants is enclosed.

UNIVERSITY OF MANCHESTER

Introduction to Nuclear and Particle Physics

24th January 2012, 2:00 p.m. - 3.30 p.m.

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) Describe three features of the strong force between two nucleons. [6 marks]

(b) In the independent particle model of the nucleus, the lowest single-neutron states are $1s_{1/2}$, $1p_{3/2}$ and $1p_{1/2}$. Explain what is meant by this notation. [3 marks]

Use this model to predict the ground-state spin and parity of ${}^{13}_{6}\mathrm{C}$. [4 marks]

(c) Two charged particles (a proton and an electron) are observed in the decay of a neutron. Sketch the distribution of the electron momentum and explain why this implies the existence of the undetected neutrino. What would the spectrum have looked like if the neutrino was not produced in the decay?

[7 marks]

(d) Show, using appropriate quark flow diagrams, how the W and Z bosons couple both to quarks and to leptons.

[5 marks]

P.T.O.

SECTION A

Answer either Question A2 or Question A3

A2. Explain what is meant by the terms *nuclear* mass m^N and *atomic* mass m. Write down an expression relating the two. [4 marks]

Hence show that the Q value for β^- decay can be written as:

$$Q_{\beta^-} = m_A - m_B$$

where m_A and m_B are the atomic masses of the parent and daughter nuclei. State clearly any approximations used. [4 marks]

The energies of electrons from β decay are typically of the order of 1 MeV. Use the uncertainty principle to explain why the electrons must be created in the decay process and cannot exist pre-formed inside the nucleus. [5 marks]

Nuclear β decay is often associated with the emission of γ rays and sometimes neutrons. Explain the origin of these radiations and the circumstances under which they can accompany β decay. [5 marks]

The process of β^+ decay is similar to β^- decay, but a positron is emitted instead of an electron and the Q value takes the form $Q_{\beta_+} = m_A - m_B - 2m_e$, where m_A and m_B are the atomic masses of the parent and daughter nuclei and m_e is the mass of an electron.

Describe another process that is often found to compete with β^+ decay and leads to the same daughter nucleus. [2 marks]

Use the following mass excesses to show that it is energetically possible for ^{152}Eu to decay by both β^+ and β^- decay.

Mass excesses: $\Delta(^{152}_{63}\text{Eu})=-72.894$, $\Delta(^{152}_{62}\text{Sm})=-74.769$ and $\Delta(^{152}_{64}\text{Gd})=-74.714$ MeV, and m_e=0.511 MeV

[5 marks]

P.T.O.

A3. Explain what is meant by nuclear binding energy and how it is related to nuclear masses.

[4 marks]

The trends in nuclear binding energies can be described using the semi-empirical mass formula, which can be written as:

$$BE(A,Z) = a_v A - a_s A^{2/3} - a_c \frac{Z^2}{A^{1/3}} - a_a \frac{(A-2Z)^2}{A} \pm a_p A^{-1/2}$$

where the coefficients have values of $a_v = 15.85$, $a_s = 18.34$, $a_c = 0.71$, $a_a = 23.21$ and $a_p = 12.0$ MeV.

Briefly describe the physical origin of each of the terms in this expression.

[10 marks]

Stating clearly any approximations used, show that the energy needed to remove a neutron S_n can be written as:

$$S_n(A,Z) \approx a_v - \frac{2}{3} a_s A^{-1/3} - a_a \left[1 - \frac{4Z^2}{A^2}\right]$$

[8 marks]

Hence show that the nucleus ${}^{28}_{9}$F is unbound with respect to neutron emission.

[3 marks]

P.T.O.

SECTION B

Answer either Question B4 or Question B5

B4. Give brief descriptions of the following properties and state the conditions under which each is conserved. For each case of non-conservation, briefly explain the process involved.

(a) Baryon number. [4 marks]

(b) Lepton flavour. [5 marks]

(c) Quark flavour. [4 marks]

(d) Hadron flavour. [4 marks]

(e) Quark colour. [4 marks]

(f) Hadron colour. [4 marks]

P.T.O.

B5. (a) Briefly discuss the concepts of *strangeness* and *isospin* as applied to both quarks and hadrons. [8 marks]

(b) Λ^0 particles can be produced by the **strong** $\pi^- p$ interaction. Explain why the Λ^0 particles have a lifetime of $\sim 10^{-10}$ s. [5 marks]

(c) A baryon of mass 1.2 GeV/c^2 has electric charge $Q = +2$ and orbital angular momentum $L = 0$. Deduce its quark content, its isospin partners and its angular momentum J. [6 marks]

(d) Λ^0 and Σ^0 baryons both have quark content uds and angular momenta $J = 1/2$, $L = 0$. The Σ^0 is part of an isospin triplet. Explain why the Λ^0 cannot have any isospin partners. [6 marks]

END OF EXAMINATION PAPER