EASTERN UNIVERSITY OF SRI LANKA
SPECIAL DEGREE EXAMINATION IN SCIENCE (PART II– 2006)
PH406 Advanced Nuclear Physics

Answer all questions **Time: Two hours**

$\frac{e^2}{4\pi\varepsilon_0}$ = 1.44×10^{-15} MeV.m

Mass of proton (m_p) = 938.28 MeV/c^2

Mass of neutron (m_n) = 939.59 MeV/c^2

Mass of electron (m_e) = 0.51 MeV/c^2

1. (a) What are mirror nuclei?

   (b) Assuming that the Coulomb energy of a nuclei is given by $E_C = \frac{3}{5}\frac{Z^2e^2}{4\pi\varepsilon_0 R}$ and that the nuclear force is charge symmetric, show that the maximum kinetic energy of β^+ particle emitted in a transition involving two mirror nuclei is given by $T_{max} = \left(\frac{3}{5}\frac{e^2}{4\pi\varepsilon_0}\frac{1}{R_0}\right)A^{2/3} + (m_p - m_n - m_e)c^2$, where the notations have their usual meaning.

   (c) The nuclide $_8O^{15}$ decays into $_7N^{15}$ with the emission of a β^+ particle. The maximum kinetic energy of the β^+ particle is found to be 1.68 MeV. Find the nuclear unit radius.

2. The following is the semi-empirical mass formula for the binding energy B of a nucleus according to the liquid drop model:

   $B = a_v A - a_s A^{2/3} - a_c\frac{Z^2}{A^{1/3}} - a_a\frac{(N-Z)^2}{A} + \delta$, where the notations have their usual meaning.

   (a) Discuss briefly the physical origin of the various terms in the equation for B.

   (b) The variation of B with atomic number Z for isobars of odd A can be represented by $B = \alpha + \beta Z + \gamma Z^2$. Derive expressions for α, β and γ.

   (c) Show that the most stable nucleus of mass number A should have Z given by:

   $$\frac{Z}{A} = \frac{2a_a}{4a_a + a_c A^{2/3}}$$

   (d) Calculate the Z value of the most stable nucleus of mass number A=77.

   You may find the following information useful:

   a_v=15.835 MeV, a_s=18.33 MeV, a_c=0.714MeV and a_a=23.20 MeV,

Turn over

3. In the shell model the sequence of energy level is as follows:

$1s_{1/2}, 1p_{3/2}, 1p_{1/2}, 1d_{5/2}, 2s_{1/2}, 1d_{3/2}, 1f_{7/2}, 2p_{3/2}, 1f_{5/2}, 2p_{1/2}, 1g_{9/2}, \ldots\ldots\ldots\ldots$

(a) Find the spin and parity of the ground state of ${}_{14}Si^{31}$, ${}_{8}O^{16}$, and ${}_{19}K^{40}$.

(b) The ground nuclear magnetic moment of a nucleus with an unpaired nucleon is given by

$$\mu = \left[\left(j - \frac{1}{2}\right)g_l + \frac{1}{2}g_s\right]\mu_N \qquad \text{when } j = l + \frac{1}{2}$$

$$= \left\{\left[1 + \frac{1}{2(j+1)}\right]jg_l - \frac{j}{2(j+1)}g_s\right\}\mu_N \quad \text{when } j = l - \frac{1}{2}$$

where the notations have their usual meaning.

Derive expressions for the nuclear magnetic moment of

(i) a nucleus having an unpaired neutron and

(ii) a nucleus having an unpaired proton.

(c) Estimate the ground state nuclear magnetic moment of

(i) ${}_{14}Si^{31}$, and

(ii) ${}_{19}K^{41}$

You may find the following information useful:

$g_l = 0, g_s = -3.826$ for neutron.

$g_l = 1, g_s = 5.586$ for proton.

4. (a) What is meant by beta decay and gamma decay of radioactive nuclei?

(b) State the selection rules for

(i) the allowed and first forbidden beta transition, and

(ii) the gamma decay

of radioactive nuclei.

(c) Classify the following β decay as allowed, first forbidden, Fermi or Gammow-Teller transitions

(i) ${}_{2}He^{6}(0^+) \rightarrow {}_{3}Li^{6}(1^+)$

(ii) ${}_{8}O^{14}(0^+) \rightarrow {}_{7}N^{14}(0^+)$

(iii) ${}_{16}S^{35}\left(3/2^+\right) \rightarrow {}_{17}Cl^{35}\left(3/2^+\right)$

(iv) ${}_{17}Cl^{36}(2^-) \rightarrow {}_{18}A^{36}(0^+)$

(v) ${}_{35}Br^{76}(1^-) \rightarrow {}_{34}Se^{76}(0^+)$

(b) The spins and parities of ground state, first excited state and second excited state of ${}^{152}_{62}Sm$ are (0, even), (2,even) and (1,odd) respectively. Determine the types of radiation between these states.

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