UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

MAIN EXAMINATION 2009_10

TITLE OF THE PAPER: NUCLEAR PHYSICS

COURSE NUMBER : P442

TIME ALLOWED : THREE HOURS

INSTRUCTIONS:

- ANSWER ANY **FOUR** OUT OF **FIVE** QUESTIONS.
- EACH QUESTION CARRIES **25** MARKS.
- MARKS FOR DIFFERENT SECTIONS ARE SHOWN IN THE RIGHT-HAND MARGIN.
- USE THE INFORMATION GIVEN IN THE ATTACHED **APPENDIX** WHEN NECESSARY.

THIS PAPER HAS **SIX** PAGES, INCLUDING THIS PAGE.

DO NOT OPEN THE PAPER UNTIL THE INVIGILATOR HAS GIVEN PERMISSION.

Q.1.

(A)

(i) For ${}^{16}_{7}N$ (atomic mass=16.0061(u)) and ${}^{16}_{8}O$ (atomic mass=15.994915(u)) compute the total binding energy and the binding energy per nucleon. [2]

(ii) Compute neutron and proton separation energies for ${}^{16}_{7}N$. [3]

Given: Atomic mass of ${}^{15}_{6}C$ = 15.0105993(u) and ${}^{15}_{7}N$ =15.000109(u).

(iii) Define radius of the nuclei. Explain the difference between nuclear matter radius and nuclear charge radius. [2]

(iv) For a nucleus of radius R and charge Ze, electrostatic energy is given by $\frac{3Z(Z-1)e^2}{20\pi\varepsilon_0 R}$.

if we assume the charges to be discrete . Using this for a mirror nuclei, the Coulomb energy difference is given by

$$|\Delta E| = \frac{6Ze^2}{20\pi\varepsilon_0 R}$$

where Z refers to the nuclei of lower charge.

Use this formula to estimate electrostatic radius R in the case of ${}^{15}_{7}N$ (atomic mass= 15.000109(u))and ${}^{15}_{8}O$ (atomic mass=15.0105993(u)). [4]

(B) Describe the principle involved in radioactive dating of rocks and organic specimens. [4]

(i) The radioactive decay of ${}^{232}_{90}Th$ (with half life 1.4 x 10^{10} yrs)leads eventually to stable ${}^{208}_{82}Pb$. A rock is determined to contain 3.65 gm of ${}^{232}_{90}Th$ and 0.75 gm of ${}^{208}_{82}Pb$. [5]

What is the age of the rock?

(ii) A living organisms has a constant activity due to ${}^{14}_{6}C$ decay of **0.23 Bq** for each gram of carbon. In 1991 a German tourist found an iceman in the Italian Alps who had become trapped in a glacier. One gram of the material found with the body was found to have an activity of about **0.121 Bq** due to the decay of ${}^{14}_{6}C$. [5]

What is the age of the iceman?

Q.2.

(A)(i) Define Q value for β^- , β^+ and electron capture. [3]

(ii) Can beta decay distinguish matter and anti-matter? Explain your answer. [2]

(iii) Explain why two types of selection rules (the Fermi and GT) exist in β-decay. [2]

(iv) In β^+ decay, positron emission is always accompanied by electron capture process and Auger electrons. Explain. [2]

(B) Consider the following fusion reaction

$$p + p \rightarrow d + e^+ + \nu_e$$

Assume the involved protons have negligible kinetic energy.

(i) Define Q-value in the reaction. [2]

(ii) Compute the range of neutrino energies (minimum and maximum). [2]

Note: Mass of proton=938.272 MeV, Mass of deuteron =1875.611 MeV

Mass of e^+ =0.511 MeV. Mass of neutrino ν_e = 0 (negligible).

(C) Classify the following decays according to the degree of forbidden ness

(i) $^{36}_{17}Cl(2^+) \rightarrow\ ^{36}_{18}Ar(3^+)$ [2]

(ii) $^{97}_{40}Zr(1/2^+) \rightarrow\ ^{97}_{41}Nb(1/2^-)$ [2]

(D) Write brief notes on any **two** of the following: [8]

(i) Scintillation detector. Explain why NaI crystal is doped with Tl .
(ii) Fission and Fusion.
(iii) Cyclotron and Synchrotron.

Q.3. Semi-empirical mass formula for nuclear mass *m(Z,A)* is given by

$$m(Z,A) = Zm_p + (A-Z)m_n - a_v A + a_s A^{2/3} + a_c Z^2 A^{-1/3} + a_a \frac{(A-2Z)^2}{A} + \delta\, A^{-1/2}$$

with a_v = 15.56 MeV , a_s = 17.23 MeV , a_c = 0.697 MeV , a_a = 23.20 MeV, and
δ = 11.2 MeV for odd-odd
= 0 for odd-even or even-odd.
= -11.2 MeV for even -even

(i) Explain the origin of various terms in the given semi-empirical mass formula. [6]

(ii) Define the Q-value for symmetric fission of a nuclei of mass m(Z,A). [2]
Show that possibility of the spontaneous symmetric fission depends on parameters a_s and a_c only. Neglect the contribution from pairing energy term. [8]

(iii) Define Q value for α-particle emission in terms of mass m(Z,A) of parent nucleus and m(Z-2,A-4) of daughter nucleus. [1]

(a) What is the relation between separation energy for α-particle and Q-value. [2]
(b) What is the relation between Q value and total kinetic energy involved in the α-decay. [1]

(c) Use the semi-empirical mass formula to derive an expression for the Q-value for α-particle emission. Neglect the contribution from pairing energy term. [5]

Q.4. (A) (i) What do you understand by the term " Magic Numbers" ? [2]

(ii) State the basic assumptions made in the single particle shell model. [4]

(iii) Explain how the spin and parities are determined using the single particle shell model for even-even, odd-even, even-odd and odd-odd nuclei. [4]

(iv) Determine the spin and parities for the ground state of the following nuclei by shell model considerations.

(a) $^{3}_{2}He$, $^{21}_{10}Ne$, $^{69}_{31}Ga$ and $^{209}_{83}Bi$. [4]

(b) $^{38}_{19}K$, $^{66}_{31}Ga$, and $^{82}_{37}Rb$. [6]

Note: Use the shell model level scheme given in the Appendix.

(B) Describe the significant processes through which the γ-rays in the energy range less than 1.0 MeV primarily interact with matter and its implication on the absorption of radiation in materials. [5]

Q.5. (A) $^{241}_{95}Am$ (5/2+) decays to series of states of $^{237}_{93}Np$ by α-decay. The ground state of $^{237}_{93}Np$ is (5/2 +) and following excited states of $^{237}_{93}Np$ are populated :

33.2(7/2+), 59.527(5/2-) , 103(7/2-) and 158.6 (9/2-) keV.

(i) Construct the decay scheme. [4]

(ii) For each state find the permitted values of ℓ_α . [5]

(iii) List all the possible multi-polarities of γ-transitions, indicating in each case most likely transition. [10]

Note: Do not consider E3 , M3 and higher transitions.

(B) Write short notes on : [6]

(a) Non-conservation of parity.

(b) Internal Conversion

@@@END OF EXAMINATION@@@

Appendix

Selection Rules:

(A) β-decay:

Type of Transition		ΔI	Parity Change
Allowed	**Fermi**	**0**	**No**
	GT	± 1 or 0 (except 0 → 0)	**No**
1st Forbidden	**Fermi**	± 1,0 (except 0 → 0)	**Yes**
	GT	±2, ± 1, or 0 (except 0 → 0; 1/2→1/2; 0→ 1)	**Yes**
2nd Forbidden	**Fermi**	± 2	**No**
	GT	± 3	**No**

(B) γ- decay:

	E1	**E2**	**E3**	**E4**
Δπ |ΔJ| ≤	**Yes** **1**	**No** **2**	**Yes** **3**	**No** **4**
	M1	**M2**	**M3**	**M4**
Δπ |ΔJ| ≤	**No** **1**	**Yes** **2**	**No** **3**	**Yes** **4**

(C) Useful Information

PHYSICAL CONSTANTS AND DERIVED QUANTITIES

Speed of light c = 2.99792458 x 10^8 m s^{-1} ~ 3.00 x 10^{23} fm s^{-1}
Avogadro's number N_A = 6.02214199(47) x 10^{26} molecules per kg-mole
Planck's constant h = 6.626068 76(52) x 10^{-34} J s

$\hbar = 1.054571\ 596(82) \times 10^{-34}$ J s = 0.65821×10^{-21} MeV s
$\hbar^2 = 41.802$ u MeV fm^2
$\hbar c = 197.327$ MeV fm

Elementary charge $e = 1.602176462(63) \times 10^{-19}$C
$e^2/4\pi\varepsilon_0 = 1.4400$MeV fm

Fine structure constant $\alpha = \dfrac{e^2}{4\pi\varepsilon_0 \hbar c} = 1 / 137.036$

Boltzmann constant $k = 1.3806503(24) \times 10^{-23}$ JK^{-1} = 0.8617×10^{-4} eV K^{-1}

Curie (1 Ci = 3.7×10^{10} dis/sec), is based upon the activity of one gram of radium.
Becquerel (Bq = 1 dis/sec)

USEFUL FORMULAE

$t_{1/2} = \dfrac{\ell n 2}{\lambda} = \tau\, \ell n 2$ where $t_{1/2}$ = half life, λ = decay constant and τ = mean life .

Energy width of a state of lifetime τ :
$\Gamma = 6.58212 \times 10^{-22} / \tau(\text{s})$ MeV

Non-relativistic speed of mass *m* with energy *E:*
$v = 1.389 \times 10^7\, [(E(\text{MeV}) / m(u)]^{1/2}$ ms^{-1}

Non-relativistic wave number of mass *m* with energy *E:*
$k \equiv 2\pi/\lambda = 0.21874\ [\,m(u) \times E(\text{MeV})\,]^{1/2}$ fm^{-1}

Wave number for a photon of energy *E:*
$k \equiv 2\pi/\lambda = E / \hbar c = E\,(\text{MeV}) / 197.327$ fm^{-1}

MASSES AND ENERGIES

Atomic mass unit m_u or u = $1.66053873(13) \times 10^{-27}$ kg
$m_u c^2 = 931.494$ MeV

Electron $m_e = 9.10938188(72) \times 10^{-31}$ kg
$m_e/m_u = 5.486 \times 10^{-4} = 1/1823$
$m_e c^2 = 0.510998902(21)$ MeV

Proton $m_p = 1.67262158(13) \times 10^{-27}$ kg
$m_p / m_u = 1.00727647$
$m_p c^2 = 938.272$ MeV

Hydrogen atom $m_H = 1.673533 \times 10^{-27}$ kg
$m_H / m_u = 1.007825$
$m_H c^2 = 938.783$ MeV

Neutron $m_n = 1.67492716(13) \times 10^{-27}$ kg
$m_n/m_u = 1.00866491578(55)$
$m_n c^2 = 939.565$ MeV

Alpha particle $m_\alpha = 6.644656 \times 10^{-27}$ kg
$m_\alpha / m_u = 4.001506175$
$m_\alpha c^2 = 3727.379$ MeV

CONVERSION FACTORS

Fermi 1fm = 10^{-15} m
1 eV=1.6022 x 10^{-9} J

Million electron volts 1 MeV = 1.602176 x 10^{-13} J
1 MeV/c^2 = 1.783 x 10^{-30} kg
Cross section (barn) 1 b = 10^{-28} m^2
Year 1 y = 3.1536 x 10^7 s

(D) Single particle shell model Level Scheme:
Following diagram gives the energy levels calculated using a realistic potential with spin-orbit interaction according to single particle shell model: