UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

MAIN EXAMINATION 2007/2008

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. Consider an isotope of atomic mass M(Z,A) where Z=atomic number, A= mass number =Z+N, and N = neutron number.

(i) Define mass defect. [1]

(ii) Define nuclear binding energy. [1]

Give an expression of the binding energy in terms of

(a) Nuclear masses. [1]

(b) Atomic masses. [1]

(iii) Define nuclear separation energy. [1]

Give an expression of separation energy in terms of relevant binding energies for

(a) Neutron separation energy. [2]

(b) Proton Seperation energy. [2]

(iv) Calculate

(a) Binding energy of ${}^{15}_{7}N$, ${}^{16}_{7}N$ *and* ${}^{16}_{8}O$. [6]

(b) Neutron separation energy in ${}^{16}_{7}N$ and proton separation energy in ${}^{16}_{8}O$. [4]

(v) Define radius of the nucleus. [2]

(a) For mirror nuclei , the Coulomb energy difference is given by the expression $|\Delta E| = \frac{6Ze^2}{5R}$, where Z corresponds to an isotope of smaller value between the two nuclei.

Use this expression to estimate R in the case of ${}^{15}_{7}N$. [4]

Given: ${}^{15}_{7}N$ (atomic mass=15.00011(u)) , ${}^{16}_{7}N$ (atomic mass=16.0061(u))

${}^{15}_{8}O$ (atomic mass= , ${}^{16}_{8}O$ (atomic mass=15.994915(u)).

Q.2.

(a) Define half life, mean life, decay constant. [3]

(b) Consider a piece of wood, weighing 50 gm, which has an activity of 320 disintegrations /minute for ${}^{14}_{6}C$. The corresponding activity in a living tree is 12 disintegrations/minute/gm. The half life of ${}^{14}_{6}C$ is 5730 yrs. Determine the age of the wood. [7]

(c) The abundances of ${}^{238}U$ and ${}^{234}U$ in the present day natural uranium are 99.28% and 0.0058% respectively. The half life of ${}^{238}U$ is 4.498 x 10^{10} yrs. Calculate the half life of ${}^{234}U$. [5]

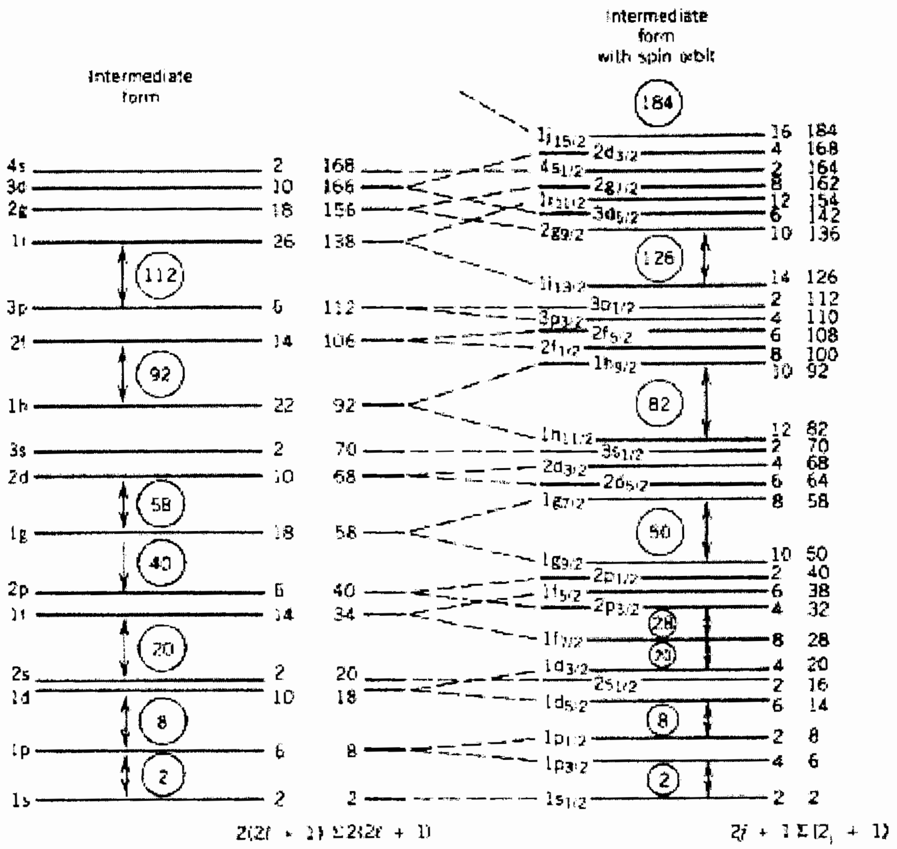
(d) Write brief notes on

(i) Flourescent radiation and scintillation detector. Explain why NaI crystal is doped with Tl . [5]

(ii) Semi-conductor detector. Is the detector suitable for high energy γ-radiation detection ? Explain your answer. [5]

Q.3. (A) Use the given shell model level scheme to determine the angular momentum and parity for the ground states of ${}^{17}_{8}O$ and ${}^{69}_{31}Ga$ without spin and with spin. [10]

What do you understand by the term " Magic Numbers" ?



Note: Refer to a better reproduction of the figure provided at the examination hall .

(B)

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

(ii) Among the possible interactions :

S(scalar),V(vector),T(Tensor),A(axial vector) and P(pseudo-scalar);

name the interactions which are the major contributors in Fermi type and GT-type β- transitions. [2]

(iii) Following the decay of ^{17}Ne a highly excited state in ^{17}F emits a 10.597 MeV proton in decaying to the ground state of ^{16}O.

(a) Draw the decay scheme diagram. [1]

(b) What is the maximum energy of the positrons emitted in the decay of the ^{17}F excited state? [6]

(iv) ^{137}Cs with its ground state $7/2^+$ decays by beta decay to $11/2^-$ and $3/2^+$ States of ^{137}Ba. What types of transitions are expected in each case? [4]

Q.4. (A) Semi-empirical mass formula is given by

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

where m(Z,A) corresponds to nuclear mass.

(i) Explain the origin of the various terms. [6]

(ii) Define the Q-value for the symmetric spontaneous fission. [2]

(iii) Using the given Semi-empirical mass formula and neglecting the pairing energy contribution , show that symmetric spontaneous fission depends only on surface energy and Coulomb energy contributions. [7]

(B) The α-decay of $^{253}_{99}Es$ $(I = 7/2, \pi = +)$ leads to a sequence of **negative-parity** states in $^{249}_{97}Bk$ with spin
3/2, 5/2, 7/2, 9/2, 11/2, 13/2 .

Assume that ground state of $^{249}_{97}Bk$ has spin $3/2^-$ and all other states are excited states according to the order given in the spin assignments.
The excited states decay by γ - transitions.

(a) For each state find the permitted values of ℓ_α [6]

(b) Draw an energy level diagram. [4]

Q.5. (A)

(i) $^{7}_{8}Li$ emits a 0.48 MeV , γ-ray in transition from $\frac{1}{2}^{-}$ to $\frac{3}{2}^{-}$. [5]
What are the possible choices for the multi-polarity and nature of emitted radiation.

(ii) Explain why transition from 0^+ to 0^+ will not allow any γ -radiation. [2]

(iii) ^{57}Co which has the spin-parity $\frac{7}{2}^{-}$, decays by an allowed GT-transition through K-Capture to an excited state of ^{57}Fe . [6]
The following γ-emissions are observed in ^{57}Fe .

E_γ (MeV)	Multipolarity
0.136	E2 (10%)
0.1216	M1 (90%)
0.0144	M1

The ground state of ^{57}Fe is $\frac{1}{2}^{-}$.
Construct a self-consistent energy level scheme for ^{57}Fe and assign spins and parities.

(B) List the conservation laws in Nuclear Reactions. [3]

(i) In a nuclear reaction involving a projectile of mass M_1 with kinetic energy E_1 and a stationary target of mass M_2 produces products of mass M_3 of kinetic energy E_3 and mass M_4 of kinetic energy E_4 .

Show that Q-value (in the lab.system) is given by [9]

$$Q = E_3\left(1+\frac{M_3}{M_4}\right) - E_1\left(1-\frac{M_1}{M_4}\right) - 2\frac{\sqrt{M_1 M_3 E_1 E_3}}{M_4}\cos\vartheta$$

where θ is the angle between the projectile direction and the outgoing nuclei M_3 .

@@@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 [1] AND DERIVED QUANTITIES

Speed of light $c = 2.99792458 \times 10^{8}\ \mathrm{m\ s^{-1}} \sim 3.00 \times 10^{23}\ \mathrm{fm\ s^{-1}}$

Avogadro's number $N_A = 6.02214199(47) \times 10^{26}$ molecules per kg-mole

Planck's constant $h = 6.626068\ 76(52) \times 10^{-34}\ \mathrm{J\ s}$

$\hbar = 1.054571\ 596(82) \times 10^{-34}\ \mathrm{J\ s} = 0.65821 \times 10^{-21}\ \mathrm{MeV\ s}$

$\hbar^2 = 41.802\ \mathrm{u\ MeV\ fm^2}$

$\hbar c = 197.327\ \mathrm{MeV\ fm}$

Elementary charge $e = 1.602176462(63) \times 10^{-19}\mathrm{C}$

$e^2/4\pi\varepsilon_0 = 1.4400\mathrm{MeV\ fm}$

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

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

USEFUL FORMULAE

$t_{1/2} = \dfrac{\ell n2}{\lambda} = \tau\,\ell n2$ where $t_{1/2}$ = half life, λ = decay constant and τ = mean life .

Energy width of a state of lifetime τ :

$\Gamma = 6.58212 \times 10^{-22} / \tau(\mathrm{s})\ \mathrm{MeV}$

Non-relativistic speed of mass m with energy E:

$v = 1.389 \times 10^{7}\ [(E(MeV)/m(u)]^{1/2}\ \mathrm{ms^{-1}}$

Non-relativistic wave number of mass m with energy E:

$k \equiv 2\pi/\lambda = 0.21874\ [\,m(u) \times E(MeV)\,]^{1/2}\ \mathrm{fm^{-1}}$

Wave number for a photon of energy *E:*

$$k \equiv 2\pi/\lambda = E/\hbar c = E\,(\mathrm{MeV})\,/\,197.327\ \mathrm{fm}^{-1}$$

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 1 fm = 10^{-15} m
1 eV = 1.6022×10^{-9} J
Million electron volts 1 MeV = 1.602176×10^{-13} J
1 MeV/c^2 = 1.783×10^{-30} kg

Cross section (barn) 1 b = $10^{-28}\ \mathrm{m}^2$

Year 1 y = 3.1536×10^7 s

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[1] Source: 1998 CODATA Recommended Values. Uncertainties are given in parentheses.