UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

SUPPLEMENTARY EXAMINATION 2009_10

TITLE OF THE PAPER: NUCLEAR PHYSICS

COURSE NUMBER : P442

TIME ALLOWED : THREE HOURS

INSTRUCTIONS:

- ANSWER ANY **<u>FOUR</u>** OUT OF **FIVE** QUESTIONS.
- EACH QUESTION CARRIES **<u>25</u>** 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) State whether each of the following statements is true or false. Give reasons, where applicable. [5]

(i) Electron do not feel the nuclear force at all..

(ii) At short distances the nuclear force is stronger than Coulomb force.

(iii) The fact that there are no bound states of the di-neutron and di-proton means that the nuclear force between a neutron and a proton is much stronger than that between two neutrons or between two protons.

(iv) Shape of the nucleus is always spherical.

(v) Even-Odd or Odd-Even nuclei in their ground states always have the angular momentum zero.

(B) Define the following: [10]

(i) mass defect and nuclear binding energy.
(ii) radius of the nuclei.
(iii) half life, mean life and decay constant.
(iv) the Q value for β^- and β^+ decay.
(v) nuclear fission and fusion.

(C) (i) Explain the principle behind nuclear dating technique. [5]

(ii) 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. [5]
Calculate the half life of ^{234}U.

Q.2.

(A) Write brief notes on the following:
(i) Scintillation detector. Explain why NaI crystal is doped with Tl . [5]
(ii) Internal Conversion. [5]

(B) Defining the Q value as $(m_i - m_f)\,c^2$, compute the range of neutrino energies (minimum and maximum) in the solar fusion reaction: [5]

$$p + p \rightarrow d + e^+ + \nu.$$

Assume the initial protons to have negligible kinetic energies.
Here m_i = initial masses and m_f = final masses.
symbols: p=proton. d = deuteron. e^+=positron, and ν= neutrino.

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) Describe the significant processes through which the γ-rays primarily interact with matter in the energy range less than 5 MeV. [5]

(D) Describe the nature of nucleon-nucleon force as derived from the of bound state of the deuteron and nucleon-nucleon scattering. at various energies. [5]
List the conservation laws in nuclear forces.

Q.3. (A) (i) What do you understand by the term " Magic Numbers" ? [2]

(ii) State the basic assumptions made in the single particle shell model. [3]

(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. [10]

$^{7}_{3}Li$, $^{11}_{5}B$, $^{15}_{6}C$, $^{17}_{9}F$, $^{31}_{15}P$

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

(B)(i) Explain why two types of selections rules (the Fermi and GT-selection rules) exist in β-decay. [2]
(ii) Classify the following decays according to degree of forbiddenness: [4]
(a) $^{26}_{13}Al(5^+) \rightarrow {}^{26}_{12}Mg^*(2^+)$
(b) $^{36}_{17}Cl(2^+) \rightarrow {}^{36}_{18}Ar(0^+)$

Q.4. Semi-empirical formula for binding energy is given by

$$B(Z,A) = aA - bA^{2/3} - s\frac{(A-2Z)^2}{A} - d\frac{Z^2}{A^{1/3}} - \delta\frac{1}{A^{1/2}}$$

with a = 15.835 MeV , b = 18.33 MeV , s = 23.20 MeV, d = 0.714 MeV and
δ = 11.2 MeV for odd-odd or even -even
= 0 for odd-even or even-odd.

(i) Use the above formula to derive an expression for Q value for α-particle emission, where

Q = B(^{4}He)+B(Z-2,A-4)-B(Z,A) [15]

(ii) Use the expression in (i) to find Q-value for for α-emission in $^{226}_{90}Th$. [10]

Q.5.
(A) **(i)** For the following γ transitions, give all permitted multipoles and indicate which multipole might be most intense in the emitted radiation. [5]
(a) $9/2^- \rightarrow 7/2^+$
(b) $1/2^- \rightarrow 7/2^-$
(c) $1^- \rightarrow 2^+$
(d) $4^+ \rightarrow 2^+$
(e) $11/2^- \rightarrow 3/2^+$

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

(iii) An even-Z,even-N nucleus has the following sequence of levels above its 0^+ ground state:

2^+(89keV), 4^+(288keV), 6^+(585(keV), 0^+(1050keV), 2^+(1129keV)

Draw an energy level diagram and show all reasonably probable γ transitions and their dominant multipole assignments. [10]

(B) Write short notes on : [8]

(a) Non-conservation of parity.

(b) Alpha decay .

@@@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**
$\Delta\pi$	**Yes**	**No**	**Yes**	**No**
$\|\Delta J\| \leq$	**1**	**2**	**3**	**4**
	M1	**M2**	**M3**	**M4**
$\Delta\pi$	**No**	**Yes**	**No**	**Yes**
$\|\Delta J\| \leq$	**1**	**2**	**3**	**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 $h = 6.626068\ 76(52) \times 10^{-34}$ J s

$\hbar = 1.054571\ 596(82) \times 10^{-34}$ J s $= 0.65821 \times 10^{-21}$ 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} $= 0.8617 \times 10^{-4}$ 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

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

Energy width of a state of lifetime τ :

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

Non-relativistic speed of mass *m* with energy *E*:

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

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

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

Wave number for a photon of energy *E*:

$k \equiv 2\pi/\lambda = E / \hbar c = E$ (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_α	$= 6.644656 \times 10^{-27}$ kg
	m_α / m_u	$= 4.001506175$
	$m_\alpha c^2$	$= 3727.379$ MeV

CONVERSION FACTORS

Fermi $1 fm = 10^{-15}$ 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: