UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

SUPPLEMENTARY 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:
(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)

(i) Define half-life and mean lifetime. [2]

(ii) Consider a simple decay process in which the initial number N_0 of radioactive nuclei of type A decay to stable nuclei of type B. In a time from t to t+Δt, how many decays will occur? [5]

(C) Explain the principle behind nuclear dating technique. [4]

(D) Write short notes on [9]
(i) Fluorescent radiation.
(ii) Auger process.
(iii) Internal Conversion.

Q.2. Semi-empirical formula for binding energy is given by

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

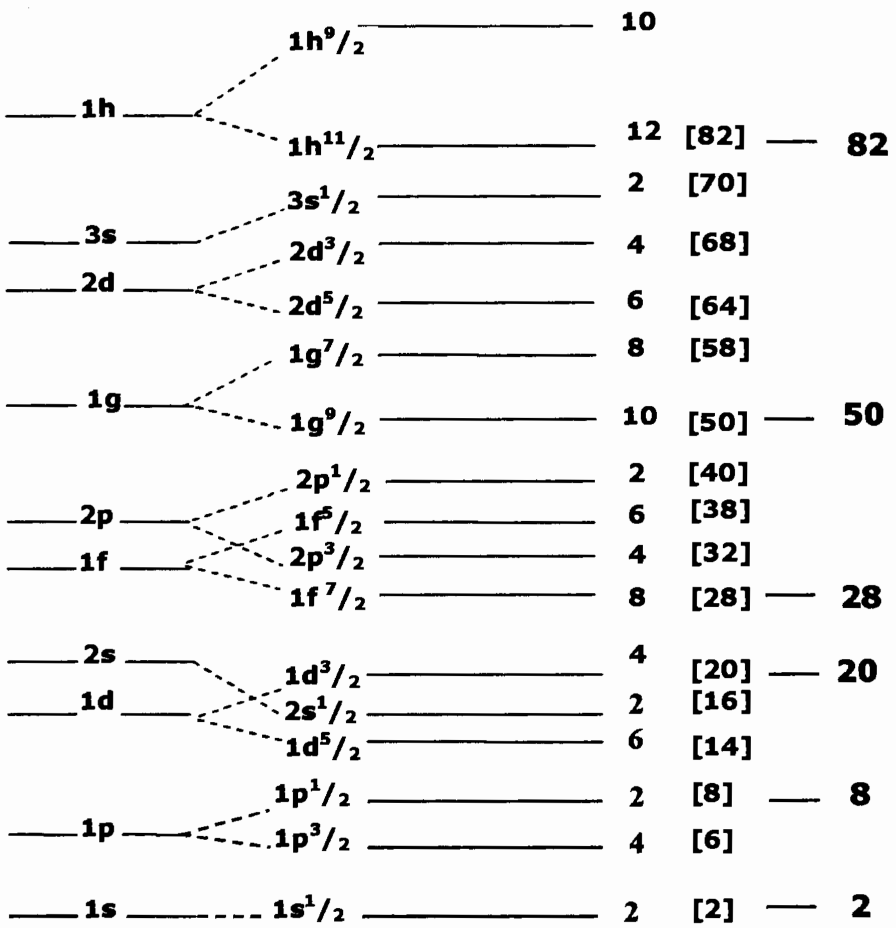
with a = 15.835 MeV , b = 18.33 MeV , s = 23.20 MeV, d = 0.714 MeV and
δ = 11.2 MeV for odd-odd or even -even
= 0 for odd-even or even-odd.

(i) Use the above formula to derive an expression for Q value for α-particle emission, where [15]

$$Q = B({}^4_2He) + B(Z-2, A-4) - B(Z,A)$$

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

Q.3. (A) Following diagram gives the energy levels calculated using a realistic potential with spin-orbit interaction according to shell model:



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

(ii) Give the expected shell-model spin and parity assignments for the ground states: [10]

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

(B) It has been found that the α -emission of the Thorium isotopes can be described by the relation [7]

$$log_{10}(\lambda) = 56.13 - \frac{105.07 \times 10^{7}}{v_{\alpha}}$$

where v_α is the velocity of α-particle in m/sec .
The α-energy in the case of ^{224}Th is 7.33 MeV.
What is the half life of ^{224}Th as estimated, from the above relation?

(C) (i) Define Q-value in a reaction [2]

$${}^{A}_{Z}X(p,d){}^{A'}_{Z'}X'$$

(ii) In ^{9}B(p,d)^{8}Be reaction, calculate Q-value. [4]

Given: Atomic masses: ${}^{9}_{5}B$ = 9.013329 a.u. , ${}^{8}_{4}Be$ = 8.005305 a.u.

${}^{2}_{1}H$ = 2.014102 a.u. , ${}^{1}_{1}H$ = 1.007825 a.u.

Q.4.

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

(ii) One of the processes that is most likely responsible for the production of neutrinos in the sun is the electron-capture decay of ${}^{7}_{4}Be$. Following is the disintegration process involving electron capture

$${}^{7}_{4}Be \rightarrow {}^{7}_{3}Li + \nu_e$$

Assume Be to be at rest and neutrino rest mass to be zero.

(a) Define electron capture energy E_c in terms of atomic masses of Be and Li. [2]
(b) Neglecting the binding energy of the captured electron, calculate the electron capture energy E_c. [2]
(c) Write down the equations relating to momentum conservation and energy conservation in the given process. [4]
Note: *For a zero rest mass particle,* ***kinetic energy = c p***, *where p is the momentum of the particle and c is the velocity of light.*
(d) Show that [6]

$$E_c = -c\, p_{Li} + \frac{p_{Li}^2}{2m_{Li}}$$

where p_{Li} = momentum of Li nucleus, m_{Li} = rest mass of Li.

Given: Atomic mass of $\;{}^{7}_{3}Li = 6.015121\,a.u. \quad and\ {}^{7}_{4}Be = 7.016928\,a.u.$

(iii) Classify the following decays according to degree of forbiddenness: [9]

(a) ${}^{26}_{13}Al(5^+) \rightarrow {}^{26}_{12}Mg^*(2^+)$

(b) ${}^{36}_{17}Cl(2^+) \rightarrow {}^{36}_{18}Ar(0^+)$

(c) ${}^{89}_{38}Sr(5/2^+) \rightarrow {}^{89}_{39}Y(1/2^-)$

Q.5.

(i) For the following γ transitions, give all permitted multipoles and indicate which multipole might be most intense in the emitted radiation. [7]

(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)

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

(b) By considering also internal conversion, what additional transitions would appear? [6]

@@@END OF EXAMINATION@@@

Appendix

Deuterium atom= 1876.14 MeV , Helium atom=3728.44 MeV

Mass excess for d = 13.136 MeV , Mass excess for p = 7.289 MeV

Selection Rules:

(A) β-decay:

Type of Transition		Spin Change ΔI	Parity Change
Allowed	**Fermi**	0	**No**
	GT	0, ± 1 (except 0 → 0)	**No**
1st Forbidden	**Fermi**	0 , ± 1 (except 0 → 0)	**Yes**
	GT	0 , ±1, ± 2 (except 0 → 0; 1/2→1/2; 0→ 1)	**Yes**
2nd Forbidden	**Fermi**	±1, ± 2 (except 1 → 1)	**No**
	GT	±2, ± 3	**No**
3rd Forbidden	**Fermi**	±2, ± 3	**Yes**
	GT	±3, ± 4 (except 0 → 0)	**Yes**

(B) γ- decay:

	E1	**E2**	**E3**	**E4**
$\Delta\pi$ $\lvert\Delta J\rvert \le$	**yes** **1**	**no** **2**	**yes** **3**	**no** **4**
	M1	**M2**	**M3**	**M4**
$\Delta\pi$ $\lvert\Delta J\rvert \le$	**no** **1**	**yes** **2**	**no** **3**	**yes** **4**

$\Delta\pi$ corresponds to parity change.

(C) Useful Information

PHYSICAL CONSTANTS [1] AND DERIVED QUANTITIES

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

USEFUL FORMULAE

$t_{\frac{1}{2}} = \frac{\ell n2}{\lambda} = \tau \, \ell n2$ where $t_{\frac{1}{2}}$ = 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:*

$\mathbf{v} = 1.389 \times 10^{7} [(E(MeV) / m(u)]^{1/2}$ 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) x 10^{-27} kg

$m_u c^2$ = 931.494 MeV

Electron	m_e	= 9.10938188(72) x 10^{-31} kg
	m_e/m_u	= 5.486 x 10^{-4} = 1/1823
	$m_e c^2$	= 0.510998902(21) MeV
Proton	m_p	= 1.67262158(13) x 10^{-27} kg
	m_p / m_u	= 1.00727647
	$m_p c^2$	= 938.272 MeV
Hydrogen atom	m_H	= 1.673533 x 10^{-27} kg
	m_H / m_u	= 1.007825
	$m_H c^2$	= 938.783 MeV
Neutron	m_n	= 1.67492716(13) x 10^{-27} kg
	m_n/m_u	= 1.00866491578(55)
	$m_n c^2$	= 939.565 MeV
Alpha particle	m_α	= 6.644656 x 10^{-27} kg
	m_α / 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