UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

MAIN EXAMINATION 2006/2007

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) Define mass defect , nuclear binding energy and separation energy. [6]

(ii) Compute mass defect, nuclear binding energy and neutron separation energy for ${}^{20}_{9}F$. [6]

Given: Atomic mass of ${}^{20}_{9}F$ = 19.999981 (u) .

${}^{19}_{9}F$ = 18.99840 (u).

(B) (i) Define radius of the nuclei. [2]

(ii) If we assume the charges to be discrete electrostatic energy for a nucleus of radius R and charge Ze is given by $\frac{3Z(Z-1)e^2}{20\pi\varepsilon_0 R}$.

(a) Show that for a mirror nuclei, the Coulomb energy difference is given by [2]

$|\Delta E| = \frac{6Ze^2}{20\pi\varepsilon_0 R}$ where Z referes to the nuclei of lower charge.

(b) Use this formula to estimate R in the case of ${}^{16}_{7}N$ (atomic mass=16.0061(u)) and ${}^{16}_{8}O$ (atomic mass=15.994915(u)). [3]

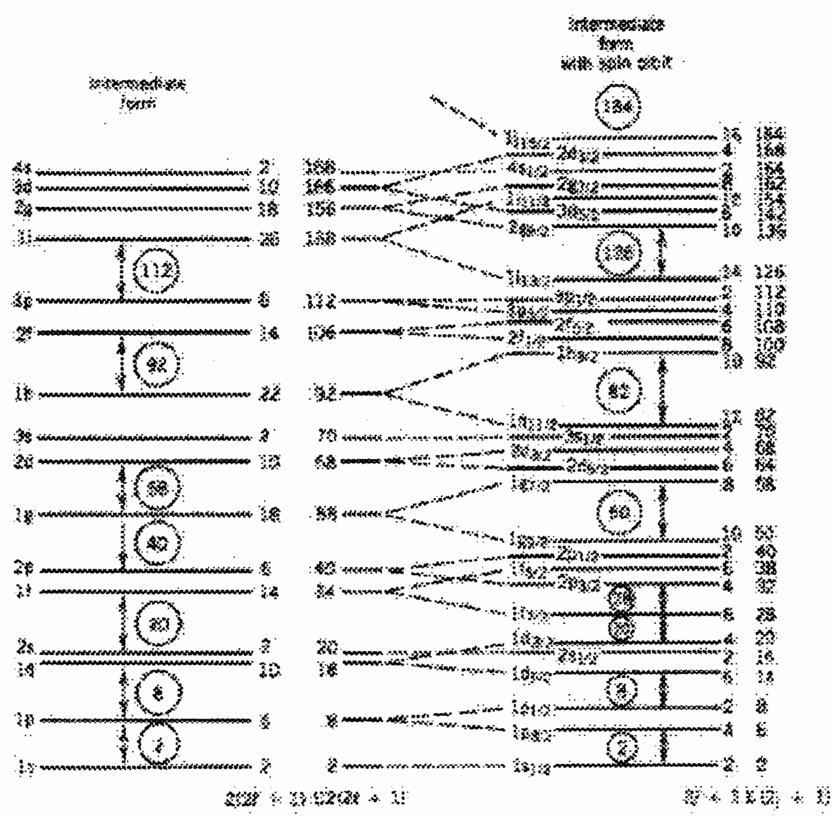
(C) Describe the processes:

(i) Nuclear Fission and Nuclear Fusion. [3]

(ii) Photoelectric effect and Auger process. [3]

Q.2. (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) 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.
Given: Assume the neutrino mass to be zero.
Nuclear mass of deuteron = 1875.611 MeV.

(C)

(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) Describe the significant processes through which the γ-rays in the energy range greater than 5 MeV primarily interact with matter. [6]

Q.3. (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) Assume following values of the parameters in the Semi-empirical mass formula:
a_v = 14.1 MeV , a_s = 13.0 MeV , a_c = 0.595 MeV and
a_a = 19.0 MeV
Neglect the pairing energy contribution.
Use the semi-empirical mass formula to calculate nuclear binding energy and neutron separation energy for ${}^{20}_{9}F$. [8]

(B) The α-decay of ${}^{253}_{99}Es$ (I =7/2, π= +) 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 and their dominant multi-pole assignments. [5]

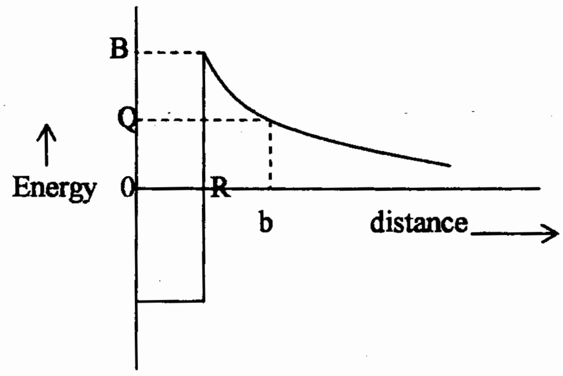
Note: *Most probable transitions are expected to be up to E2 and M2.*

Q. 4. (A) ${}^{137}_{55}Cs$ with its ground state $7/2^{+}$ decays by beta-decay to $11/2^{-}$ and $3/2^{+}$ states of ${}^{137}_{56}Ba$. What types of transitions are expected in each case? [4]

(B) The alpha-decay Q-value of $^{238}_{92}U$ is 4.268 MeV.

(i) Calculate the height B of the Coulomb barrier between the alpha-particle and the daughter nucleus, assuming that the nuclear potential has a sharp edge at a radius of $1.4A^{1/3}$ fm. [4]

(ii) Calculate the distance b beyond which the alpha-particle kinetic energy is positive. [5]



(C) $^{22}_{11}Na$ atom has mass of 20487.686 MeV and it decays, with half life of 2.6 years, from its 3^+ ground state by positron emission to ground state of Ne and by electron capture to the 2^+ first excited state of $^{22}_{10}Ne$ of atomic mass 20484.844MeV,

(a) Draw the energy level diagram. [2]
(b) Write down expressions for Q-values for the two types of decay, [2]
(c) Calculate the Q-values for the two types of decay in MeV. [4]
(d) What types of transitions are expected in each case? [4]

Q.5. (A) (i) A nuclear excited state decays by an E2 transition to the $3/2^+$ ground state. List the possible spin-parity assignments of the excited state. [3]

(ii) List all the possible multi-polarities for the following γ-transitions, indicating in each case, which is likely to be the most intense. [6]

(a) $3^- \rightarrow 2^+$, (b) $5/2^+ \rightarrow 9/2^+$.

(iii) Explain why transition from 0^+ to 0^+ will not allow any γ -radiation. [4]

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

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

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

(C) Supply the missing component(s) in the following processes: [2]

(i) $^{40}_{19}K \rightarrow \nu +$

(ii) $^{40}_{19}K \rightarrow \bar{\nu} +$

@@@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 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) x 10^{-34} J s = 0.65821 X 10^{-21} MeV s
$\hbar^2$ = 41.802 u MeV fm^2
$\hbar c$ = 197.327 MeV fm

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

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

Boltzmann constant k = 1.3806503(24) x 10^{-23} JK^{-1} = 0.8617 x 10^{-4} eV K^{-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	$= 1.67262158(13) \times 10^{-27}$ 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 1fm = 10^{-15} m

1 eV=1.6022 x 10^{-9} J

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

USEFUL FORMULAE

$t_{½} = \dfrac{\ell n2}{\lambda} = \tau\,\ell n2$ where $t_{½}$ = 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:*

$k \equiv 2\pi/\lambda = 0.21874\, [\, m(u) \times E(MeV)\,]^{½}$ fm^{-1}

Wave number for a photon of energy *E:*

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

---

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