

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

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*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)** 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  $\beta^-$  and  $\beta^+$  decay.
- (v) nuclear fission and fusion.

**(C)** (i) Explain the principle behind nuclear dating technique.

[5]

(ii) The abundances of  $^{238}\text{U}$  and  $^{234}\text{U}$  in the present day natural uranium are 99.28% and 0.0058% respectively. The half life of  $^{238}\text{U}$  is  $4.498 \times 10^{10}$  yrs.

[5]

Calculate the half life of  $^{234}\text{U}$ .**Q.2.****(A)** Write brief notes on the following:

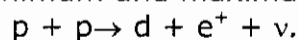
- (i) Scintillation detector. Explain why NaI crystal is doped with Tl .
- (ii) Internal Conversion.

[5]

[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]



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  $\nu$ = neutrino.

Note: Mass of proton=938.272 MeV,

Mass of deuteron =1875.611 MeV

Mass of  $e^+$  =0.511 MeV.Mass of neutrino  $\nu_e = 0$  (negligible).**(C)** Describe the significant processes through which the  $\gamma$ -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]

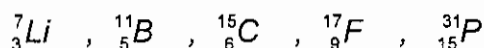
List the conservation laws in nuclear forces.

**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]

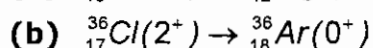
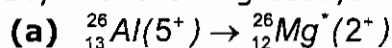
(iv) Determine the spin and parities for the ground state of the following nuclei by shell model considerations. [10]



*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  $\beta$ -decay. [2]

(ii) Classify the following decays according to degree of forbiddenness: [4]



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

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

with  $a = 15.835 \text{ MeV}$  ,  $b = 18.33 \text{ MeV}$  ,  $s = 23.20 \text{ MeV}$  ,  $d = 0.714 \text{ MeV}$  and  $\delta = 11.2 \text{ MeV}$  for odd-odd or even-even  
 $= 0$  for odd-even or even-odd.

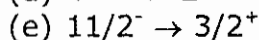
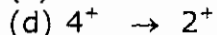
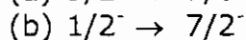
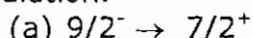
**(i)** Use the above formula to derive an expression for Q value for  $\alpha$ -particle emission, where

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

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

**Q.5.**

**(A) (i)** For the following  $\gamma$  transitions, give all permitted multipoles and indicate which multipole might be most intense in the emitted radiation. [5]



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

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

$$2^+(89\text{keV}), 4^+(288\text{keV}), 6^+(585\text{keV}), 0^+(1050\text{keV}), 2^+(1129\text{keV})$$

Draw an energy level diagram and show all reasonably probable  $\gamma$  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) $\beta$ -decay:

Type of Transition		$\Delta I$	Parity Change
Allowed	Fermi	0	No
	GT	$\pm 1$ or 0 (except $0 \rightarrow 0$ )	No
1 <sup>st</sup> Forbidden	Fermi	$\pm 1, 0$ (except $0 \rightarrow 0$ )	Yes
	GT	$\pm 2, \pm 1$ , or 0 (except $0 \rightarrow 0$ ; $1/2 \rightarrow 1/2$ ; $0 \rightarrow 1$ )	Yes
2 <sup>nd</sup> Forbidden	Fermi	$\pm 2$	No
	GT	$\pm 3$	No

##### (B) $\gamma$ - 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  $c = 2.99792458 \times 10^8 \text{ m s}^{-1} \sim 3.00 \times 10^{23} \text{ fm s}^{-1}$

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

Planck's constant  $h = 6.62606876(52) \times 10^{-34} \text{ J s}$   
 $\hbar = 1.054571596(82) \times 10^{-34} \text{ J s} = 0.65821 \times 10^{-21} \text{ MeV s}$   
 $\hbar^2 = 41.802 \text{ u MeV fm}^2$   
 $\hbar c = 197.327 \text{ MeV fm}$

Elementary charge  $e = 1.602176462(63) \times 10^{-19} \text{ C}$   
 $e^2/4\pi\epsilon_0 = 1.4400 \text{ MeV fm}$

Fine structure constant  $\alpha = \frac{e^2}{4\pi\epsilon_0\hbar c} = 1/137.036$

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

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

### USEFUL FORMULAE

$t_{1/2} = \frac{\ln 2}{\lambda} = \tau \ln 2$  where  $t_{1/2}$  = half life,  $\lambda$  = decay constant and  $\tau$  = mean life .

Energy width of a state of lifetime  $\tau$  :

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

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

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

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

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

Wave number for a photon of energy  $E$ :

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

### MASSSES AND ENERGIES

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

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

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

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

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

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

**CONVERSION FACTORS**

Fermi 1fm =  $10^{-15}$  m  
 1 eV =  $1.6022 \times 10^{-9}$  J

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

