

UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

169

DEPARTMENT OF PHYSICS

MAIN EXAMINATION: 2010/2011

TITLE OF THE PAPER: NUCLEAR PHYSICS

COURSE NUMBER: P442

TIME ALLOWED: THREE HOURS

INSTRUCTIONS:

- ANSWER ANY FOUR OUT THE 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 10 PAGES, INCLUDING THIS PAGE.

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Question 1

170

- (a) Find the approximate density of nuclear matter in g/cm^3 . How does it compare to that of ordinary matter.

[7 marks]

- (b) A nuclear charge distribution can be described by a uniform distribution

$$\rho(r) = \begin{cases} \rho_0 & r < R_s \\ 0 & r > R_s \end{cases}$$

However a more realistic distribution is the Woods-Saxon distribution

$$\rho(r) = \frac{\rho_0}{1 + e^{(r-R)/a}}$$

- (i) Sketch the Woods-Saxon distribution $\rho(r)$ and compare it with the uniform distribution.

[3 mark]

- (ii) Find the value of a if the skin thickness $t = 2.3 fm$.

[6 marks]

- (iii) What is the significance of the parameter R ?

[2 marks]

- (c) Define the half life, mean life, and activity of a radioactive sample.

[3 marks]

- (d) A living organism has a constant activity due to ${}^{14}_6C$ decay of $0.23 Bq$ for each gram of carbon. In 1991 a German tourist found an iceman in the Italian Alps who had become trapped in a glacier. One gram of the body was found to have an activity of about $0.121 Bq$ due to the decay of ${}^{14}_6C$. What is the age of the iceman? The ${}^{14}_6C$ half life is 5730 years.

[4 marks]

Question 2

171

- (a) What do you understand by the term “magic numbers”?
[2 marks]
- (b) Explain how the spin and parities are determined using the single particle shell model for even-even, odd-even, and odd-odd nuclei.
[6 marks]
- (c) Draw the energy level configuration of the nucleus ${}_{16}^{33}\text{S}$ at its ground-state as predicted by the shell model.
[4 marks]
- (d) Determine the spin and parities for the groundstates of the nuclei ${}_{2}^{4}\text{He}$, ${}_{3}^{6}\text{Li}$ and ${}_{7}^{15}\text{N}$
[7 marks]
- (e) Discuss two possibilities for the first excited state of ${}_{8}^{17}\text{O}$ as predicted by the single particle shell model. State which one amongst the two is most likely.
[6 marks]

Question 3

192

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

(i) $\frac{9}{2}^- \rightarrow \frac{7}{2}^+$

(ii) $\frac{1}{2}^- \rightarrow \frac{7}{2}^-$

(iii) $1^- \rightarrow 2^+$

(iv) $4^+ \rightarrow 2^+$

(v) $\frac{11}{2}^- \rightarrow \frac{3}{2}^+$

[5 marks]

(b) Explain why a transition from 0^+ to 0^+ will not allow any γ radiation.

[2 marks]

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

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

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

[10 marks]

(d) Write short notes on

(i) Non-conservation of parity

(ii) Alpha decay

[8 marks]

Question 4

173

(a) State whether each of the following statements is true or false. Support your answer.

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

[2 marks]

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

[2 marks]

(b) From the known masses of ${}^{15}_8\text{O}$ and ${}^{15}_7\text{N}$,

(i) compute the difference in binding energy.

[5 marks]

(ii) If the difference arise from the difference in Coulomb energy, compute the nuclear radius of ${}^{15}_8\text{O}$ and ${}^{15}_7\text{N}$. Hint: The Coulomb energy of a charged sphere with homogenous distribution and total charge Ze is given by

$$U = \frac{3k_e(Ze)^2}{5R}$$

[5 marks]

(c) Binding energy of the last nucleon.

(i) Calculate the binding energy of the last neutron in ${}^4_2\text{He}$ and the last proton in ${}^{16}_8\text{O}$.

[7 marks]

(ii) How do these values compare with the experimental average binding energy per nucleon B/A ?

[2 marks]

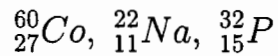
(iii) What does this tell you about the stability of ${}^4_2\text{He}$ relative to ${}^3\text{He}$ and of ${}^{16}_8\text{O}$ relative to ${}^{15}\text{N}$?

[2 marks]

Question 5

174

(a) Given the following radio-nuclides:



Show by actual calculation, which of these nuclides will decay by

(i) β^- emission

[4 marks]

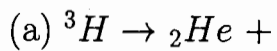
(ii) β^+ emission

[4 marks]

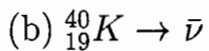
(iii) electron capture

[4 marks]

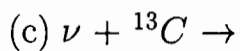
(b) Supply the missing particles in the following processes



[3 marks]



[3 marks]



[3 marks]

(c) The β decay of ${}_{76}^{191}\text{Os}$ leads only to an excited state of ${}_{77}^{191}\text{Ir}$ at an energy level of 171keV . Draw the decay scheme and compute the maximum kinetic energy of the β -spectrum.

[4 marks]

TABLE OF NUCLEAR PROPERTIES (ABRIDGED)

175

	Z	A	Atomic mass (u)	I ⁿ	Abundance or Half-life
proton	1	1	1.007276		
neutron	0	1	1.008660		
H	1	1	1.007825	1/2 ⁺	99.985%
He	2	4	4.002603	0 ⁺	99.99986%
He	2	6			
Li	3	7	7.016003	3/2 ⁻	92.5%
Be	4	11	11.021658	1/2 ⁺	13.8s(β ⁻)
B	5	11	11.009305	3/2 ⁻	80.2%
C	6	12	12.000000	0 ⁺	99.89%
N	7	15	15.000109	1/2 ⁻	0.366%
		18	18.014081	1 ⁻	0.63 s
O	8	15	15.003065	1/2 ⁻	122 s (ε)
		16	15.994915	0 ⁺	99.76%
	8	18	17.999160	0 ⁺	0.204%
F	9	18	18.000937	1 ⁺	110.0 min
Ne	10	20	19.992436	0 ⁺	90.51%
	10	22	21.991383	0 ⁺	9.33%
Na	11	22	21.994434	3 ⁺	2.60 y
Mg	12	22	21.999574	0 ⁺	3.86 s (ε)
Al	13	27	26.981539	5/2 ⁺	100.00%
Si	14	30	29.973770	0 ⁺	3.10%
	14	32	31.974148	0 ⁺	105y
P	15	30	29.978307	1 ⁺	2.50 m(ε)
	15	32	31.971725	1 ⁺	14.3d
S	16	32	31.972071	0 ⁺	95.02%
Cl	17	37	36.965903	3/2 ⁺	24.23%
Ar	18	37	36.966776	3/2 ⁺	35.0d
K	19	37	36.973377	3/2 ⁻	1.23 s
Ca	20	43	42.958766	7/2 ⁻	0.135%
Ca	20	47	46.954543	7/2 ⁻	4.54 d (β ⁻)
Sc	21	47	46.952409	7/2 ⁻	3.35 d (β ⁻)

Fe	26	56	55.934439	0 ⁺	91.8%	
	26	60	59.934078	0 ⁺	1.5 My	176
Co	27	60	59.933820	5 ⁺	5.27 y	
Ni	28	60	59.930788	0 ⁺	26.1%	
	28	64	63.927968	0 ⁺	0.91%	
	28	65	64.930086	5/2 ⁻	2.52 h (β ⁻)	
Cu	29	63	62.929599	3/2 ⁻	69.2%	
	29	64	63.929800	1 ⁺	12.7 h	
	29	65	64.927793	3/2 ⁺	30.8%	
Zn	30	64	63.929145	0 ⁺	48.6%	
Cs	55	137	136.907073	7/2 ⁺	30.2 y (β ⁻)	
Ba	56	137	136.905812	3/2 ⁺	11.2%	
Tl	81	203	202.972320	1/2 ⁺	29.5%	
Au	79	199	198.968254	3/2 ⁺	16.8%	
Os	76	191	190.960920	9/2 ⁻	15.4 d (β ⁻)	
Ir	77	191	190.960584	3/2 ⁺	37.3%	
Ru	44	104	103.905424	0 ⁺	18.7%	
Pd	46	105	104.905079	5/2 ⁺	22.2%	
Ru	44	105	104.907744	3/2 ⁺	4.44 h (β ⁻)	
ELEMENT			MOL. WEIGHT(g)			
Mg			24.305			
Ca			40.08			
Ru			102.91			

Fundamental Constants and Conversion Factors

Charge of electron	e	1.602x10 ⁻¹⁹ C
Planck's constant	ħ	6.58x10 ⁻¹⁶ eV.s
Fine structure constant	e ² /4πε ₀	1.44 MeV.fm
Electron rest energy		0.511 MeV/c ²
Neutron mass		1.008665 u
1 u = 931.5 MeV/c ²	1 Ci = 3.7x10 ¹⁰ decays/s	
1 b = 10 ⁻²⁴ cm ²	Avogadro's number, N _A = 6.023x10 ²³	

(A) β -decay:

177

Type of Transition		ΔI	Parity Change
Allowed	Fermi	0	No
	GT	± 1 or 0 (except $0 \rightarrow 0$)	No
1 st 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 nd 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 $c = 2.99792458 \times 10^8 \text{ m s}^{-1} \sim 3.00 \times 10^{23} \text{ fm s}^{-1}$

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

(D) Nuclear radius

$$R \cong r_0 A^{1/3}, \text{ where } r_0 = 1.2 \text{ fm}$$

CONVERSION FACTORS

Fermi $1\text{fm} = 10^{-15}\text{m}$

$1\text{eV} = 1.6022 \times 10^{-19}\text{J}$

178

Million electron volts $1\text{MeV} = 1.602176 \times 10^{-13}\text{J}$

$1\text{MeV}/c^2 = 1.783 \times 10^{-30}\text{kg}$

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

Year $1\text{y} = 3.1536 \times 10^7\text{s}$

(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:

