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UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

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

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(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 ${}^{14}_{6}C$ 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 ${}^{14}_{6}C$. What is the age of the iceman? The ${}^{14}C$ half life is 5730 years.

[4 marks]

Question 2

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(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 $^{33}_{16}S$ at its ground-state as predicted by the shell model.

[4 marks]

(d) Determine the spin and parities for the groundstates of the nuclei $^{4}_{2}He$, $^{6}_{3}Li$ and $^{15}_{7}N$

[7 marks]

(e) Discuss two possibilities for the first excited state of $^{17}_{8}O$ as predicted by the single particle shell model. State which one amongst the two is most likely.

[6 marks]

Question 3

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(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 dominat multipole assignments.

[10 marks]

(d) Write short notes on

(i) Non-conservation of parity

(ii) Alpha decay

[8 marks]

Question 4

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(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 ${}^{15}_{8}O$ and ${}^{15}_{7}N$,

(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 ${}^{15}O$ and ${}^{15}N$. 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 ${}^{4}_{2}He$ and the last proton in ${}^{16}_{8}O$.

[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 ${}^{4}_{2}He$ relative to ${}^{3}He$ and of ${}^{16}O$ relative to ${}^{15}N$?

[2 marks]

Question 5

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(a) Given the following radio-nuclides:

$$^{60}_{27}Co,\ ^{22}_{11}Na,\ ^{32}_{15}P$$

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

(a) $^3H \rightarrow {}_2He +$

[3 marks]

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

[3 marks]

(c) $\nu + {}^{13}C \rightarrow$

[3 marks]

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

[4 marks]

TABLE OF NUCLEAR PROPERTIES (ABRIDGED)

	Z	A	Atomic mass (u)	I^{π}	Abundance or Half-life
proton	1	1	1.007276		
neutron	0	1	1.008660		
H	1	1	1.007825	$\frac{1}{2}^{+}$	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	$\frac{1}{2}^{+}$	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	$\frac{1}{2}^{-}$	0.366%
		18	18.014081	1^{-}	0.63 s
O	8	15	15.003065	½-	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^{-})

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Fe	26	56	55.934439	0^+	91.8%
	26	60	59.934078	0^+	1.5 My
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	$3/2^+$	4.44h (β^-)

ELEMENT	MOL. WEIGHT(g)
Mg	24.305
Ca	40.08
Ru	102.91

Fundamental Constants and Conversion Factors

Charge of electron	e	1.602×10^{-19} C
Planck's constant	$\hbar$	6.58×10^{-16} eV.s
Fine structure constant	$e^2/4\pi\varepsilon_0$	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 = 3.7×10^{10} decays/s

1 b = 10^{-24} cm^2 Avogadro's number, $N_A = 6.023 \times 10^{23}$

Selection Rules

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(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
$\Delta\pi$ $\lvert \Delta J \rvert \le$	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

(C) Useful Information

PHYSICAL CONSTANTS 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

(D) Nuclear radius

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

CONVERSION FACTORS

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

$1 eV = 1.6022 \times 10^{-9}$ J

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

(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: