Nuclear Physics
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Self-evaluation Sheet: Basic topics in Nuclear Physics

In order to successfully take the exam, a student should know

- Definition of binding energy, binding energy as a function of A and Z, nuclear radii
- Valley of nuclear stability
- Semi-empirical mass formula and its theoretical justification, parabola of stability
- Non-interacting shell model and its theoretical justification, magic numbers and experimental evidences
- Isospin, isospin operators, total isospin for a nucleus, isospin multiplets and their properties
- Symmetry and antisymmetry of the nuclear wave function and consequent parity
- Nuclear isomers

Esercises

The student who is preparing to take the exam should be able to:

- determine spin and parity of the ground state of a nucleus with given A and Z
- interpret (if it is possible) the excited states of a nucleus using the shell model
- identify the components of a nuclear multiplet

In the following, some calculations that the student should be able to deal with

1. Consider the nuclei: ^{17}F, ^{39}K, ^{41}K, ^{87}Rb, ^{171}Yb. Give a realistic prediction for the ground-states based on the shell model.
2. Light nuclei in the shell model. Describe the ground states of the nuclei with $A \leq 4$ specifying the quantum numbers L, S, J and T and parity
   (a) For the nucleus of ^{4}He what excited states are expected within a quantum of oscillation?
   (b) What decay modes are available for these nuclei?
   (c) Which of the previous states are possible for ^{4}H? and which ones for ^{4}Be?
3. Show the energy spectrum (with spin and parity) for the five lower energy levels of the ^{210}Pb and explain the reason.
4. Using the shell model, provide spin and parity of the ground state of the following nuclei: ^{7}Li, ^{6}Li, ^{1}H, ^{2}H, ^{3}H, ^{11}B, ^{10}B,^{13}C, ^{12}C, ^{141}Pr, ^{4}He, ^{3}He, ^{14}N, ^{31}P.

5. Explain the following empirical evidences using the shell model:

   (a) Zirconium (Zr) is an excellent material for coating fuel elements, as it is able to stop the fission fragments but transparent to the paths of neutrons.
   (b) Nuclides, especially the heavy ones, tend to decay by emitting α particles rather than other combinations of neutrons and protons.
   (c) The ^{6}Li has a very high absorption cross section at thermal energies while the ^{7}Li does not, in fact the ^{6}Li is used to produce tritium in the DT fusion reactors through the reaction ^{6}Li(n,α)^{3}H.
   (d) ^{10}B is an excellent element for the control bars, while the ^{11}B is not.
   (e) In fission reactors charged with UO_2, one does not have to worry about oxygen in neutron reactions.
   (f) Despite having an anomalous Z/N ratio, in 1999 some experimental physicists were able to produce ^{48}Ni nuclei.
   (g) ^{9}Be has a cross-section for reactions (n, 2n) with an unexpectedly low threshold energy for neutron emission. In fact, beryllium is used as a neutron multiplier.

6. Identify the lowest energy levels of the ^{14}C, ^{14}N e ^{14}O nuclei that correspond to the iso-multiplets $I = 0$ and $I = 1$ (see Fig.1).

   Note: Personally I suggest to solve the exercises by forming small working groups

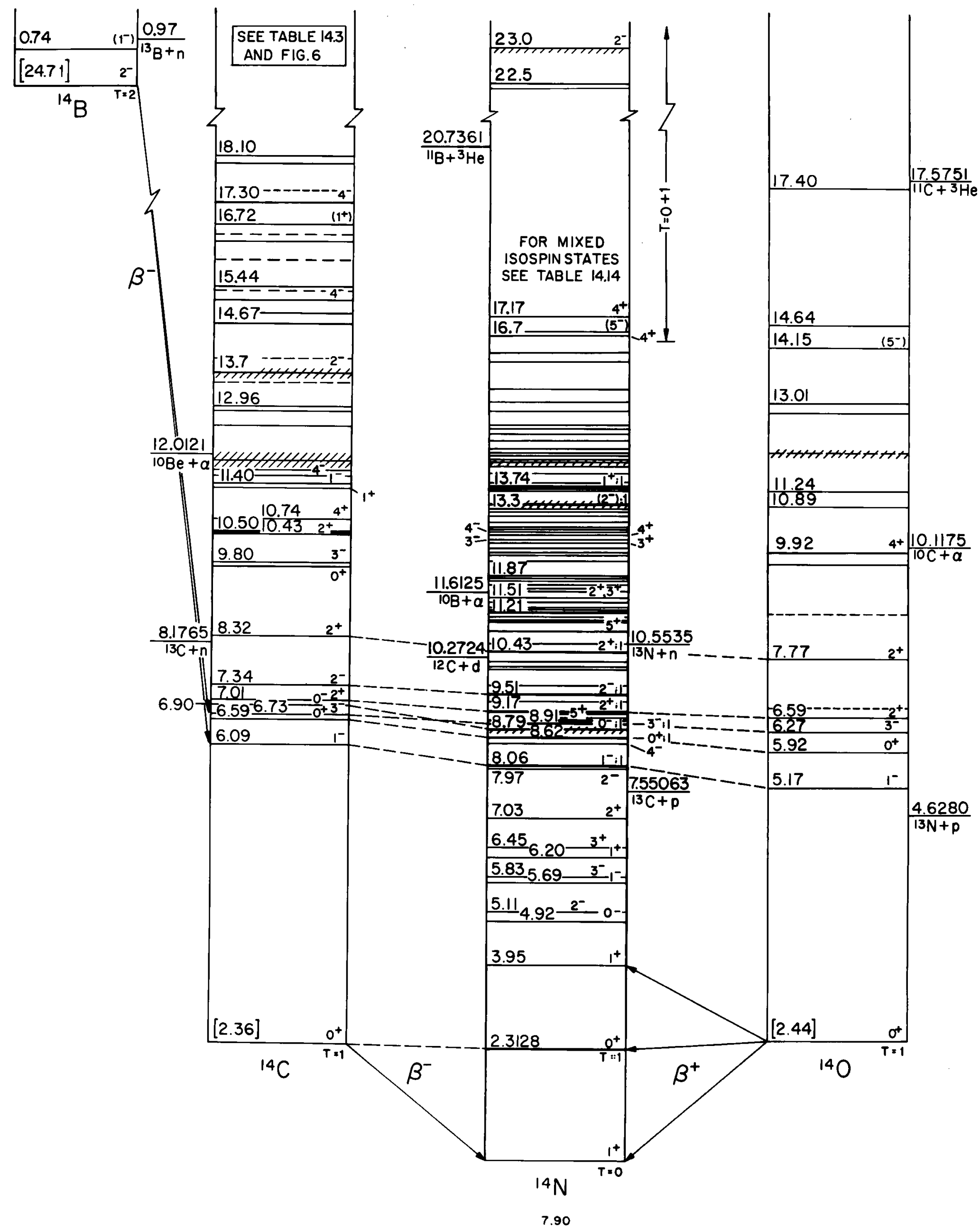

Figure 1: Energy levels for isobaric nuclei with $A = 14$.

B = Solids Hg = Liquids Kr = Gases Pm = Not found in nature

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H 1.00794																	2 He 4.002602
3 Li 6.941	4 Be 9.012182											5 B 10.811	C 12.0107	7 N 14.00674	8 O 15.9994	9 F 18.9984032	10 Ne 20.1797
11 Na 22.989770	12 Mg 24.3050											13 Al 26.581538	14 Si 28.0855	15 P 30.973761	16 S 32.066	17 Cl 35.4527	18 Ar 39.948
19 K 39.0983	20 Ca 40.078	21 Sc 44.955910	22 Ti 47.867	23 V 50.9415	24 Cr 51.9961	25 Mn 54.938049	26 Fe 55.845	27 Co 58.933200	28 Ni 58.6534	29 Cu 63.545	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.92160	34 Se 78.96	35 Br 79.504	36 Kr 83.80
37 Rb 85.4678	38 Sr 87.62	39 Y 88.90585	40 Zr 91.224	41 Nb 92.90638	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.90550	46 Pd 106.42	47 Ag 107.87	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.90447	54 Xe 131.29
55 Cs 132.90545	56 Ba 137.327	71 Lu 174.967	72 Hf 178.49	73 Ta 180.94.79	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.078	79 Au 196.56655	80 Hg 200.59	81 Tl 204.3833	82 Pb 207.2	83 Bi 208.58038	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	103 Lr (262)	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 Ds (269)	111 Rg (272)	112 Cn (277)	113 Uut (277)	114 Uuq (277)	115 Uup (277)	116 Uuh (277)		118 Uuo (277)

57 La 138.9055	58 Ce 140.116	59 Pr 140.50765	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.92534	66 Dy 162.50	67 Ho 164.93032	68 Er 167.26	69 Tm 168.93421	70 Yb 173.04
89 Ac 232.0381	90 Th 232.0381	91 Pa 231.035888	92 U 238.0289	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)