Nuclear Physics
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Self-evaluation sheet: α, β and γ decays

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

- Fermi's Golden Rule: theoretical derivation (as a non-relativistic perturbative expansion), spread of the energy levels in the presence of an external field, density of states for γ decays.
- γ decay: Derivation of the decay constant for the electric dipole field. Selection rules for electrical and magnetic transitions.
- β decay: Energy conditions, stability curves, density of states for three-body decays, kinematic aspects, Fermi theory, Fermi and Gamow-Teller transitions, wave functions for leptons and related multipole expansion, matrix elements, reduced average life, selection rules, Kurie plot and neutrino mass estimate, parity violation.
- α decay: Phenomenology, energy conditions, Geiger-Nuttal law, Gamow theory (WKB approximation), selection rules.

Exercises

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

1. Complete the following reactions
   - β^- decay of ^{8}Li
   - β^+ decay of ^{15}O
   - β^- decay of $^{32}_{15}$P
   - Electronic capture of $^{97}_{43}$Tc
   - α decay of $^{212}_{86}$Rn
   - α decay of $^{230}_{90}$Th
2. The decay scheme of ^{80}Br is shown in Fig. 1. Classify every decay channels available and provide an estimate for every decay constants.
3. Classify the following decays based on their degree of *forbiddenness*
   (a) ^{89}Sr$(5/2^+) \rightarrow {}^{89}Y(1/2^-)$
   (b) ^{36}Cl$(2^+) \rightarrow {}^{36}Ar(0^+)$
   (c) ^{26}Al$(5^+) \rightarrow {}^{26}Mg^*(2^+)$
   (d) ^{26}Si$(0^+) \rightarrow {}^{26}Al(0^+) \rightarrow {}^{26}$Mg (0^+)
   (e) ^{97}Zr$(1/2^+) \rightarrow {}^{97}Nb^*(1/2^-)$
   (f) ^{135}Xe$(3/2^+) \rightarrow {}^{135}Cs(7/2^+)$

4. For the following γ transitions, specify every allowed multipoles and indicate which multipoles may be the most intense in the emitted radiation

   (a) $9/2^- \rightarrow 7/2^+$
   (b) $1^- \rightarrow 2^+$
   (c) $4^+ \rightarrow 2^+$
   (d) $11/2^- \rightarrow 3/2^-$

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

Here are some calculations that will be illustrated in the classroom

1. ^{24}Ne ($t_{1/2}$ =3.38 min) β^--decays ^{24}Na ($t_{1/2}$=15 h), which in turn β^--decays in ^{24}Mg. Tell which levels are reachable by the beta decay and indicate the gamma de-excitation scheme (including the multipolarity of the transitions). The values of the masses are as follows: m(^{24}Ne)=22348.5 MeV/c^2, m(^{24}Na)=22346.05 MeV/c^2 and m(^{24}Mg)=22340.55 MeV/c^2 (Fig. 2).

2. ^{59}Fe emits two groups of β^- rays with maximum energy, respectively of 0.46 MeV (50%) and 0.26 MeV (50%). Gamma rays are then observed with energies of 1.30, 1.10 and 0.2 MeV. Tell what is the disintegration scheme. Being a β^- decay, the child nucleus is certainly ^{59}Co. The masses of the nuclides are: m(^{59}Fe)= 54894.1 MeV/c^2 and m(^{59}Co)=54892.54 MeV/c^2.

3. The ^{182}W level scheme, i.e. the arrival nucleus of a β^-decay of ^{182}Ta (g.s. 3^-) is shown in Fig. 3. Tell what are the possible beta and gamma decay patterns, specifying multipolarity and energies. m(^{182}Ta)=169472.0 MeV/c^2, m(^{182}W)=169471.3 MeV/c^2.

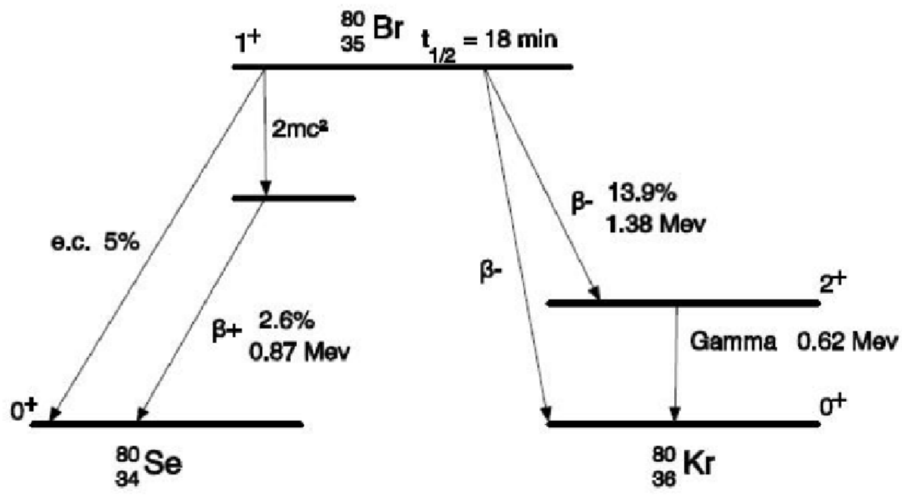

Figure 1: Decadimento β del ^{80}Br.

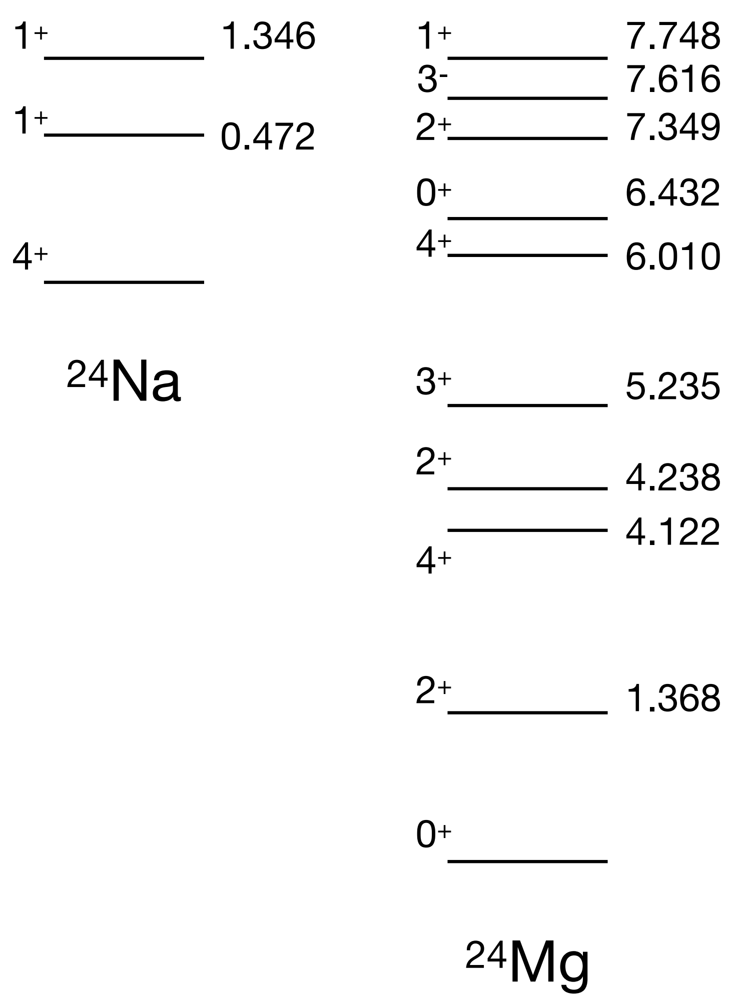
1+ 1.346
1+ 0.472
4+
24Na
1+ 7.748
3- 7.616
2+ 7.349
0+ 6.432
4+ 6.010
3+ 5.235
2+ 4.238
4+ 4.122
2+ 1.368
0+
24Mg

Fig. 2

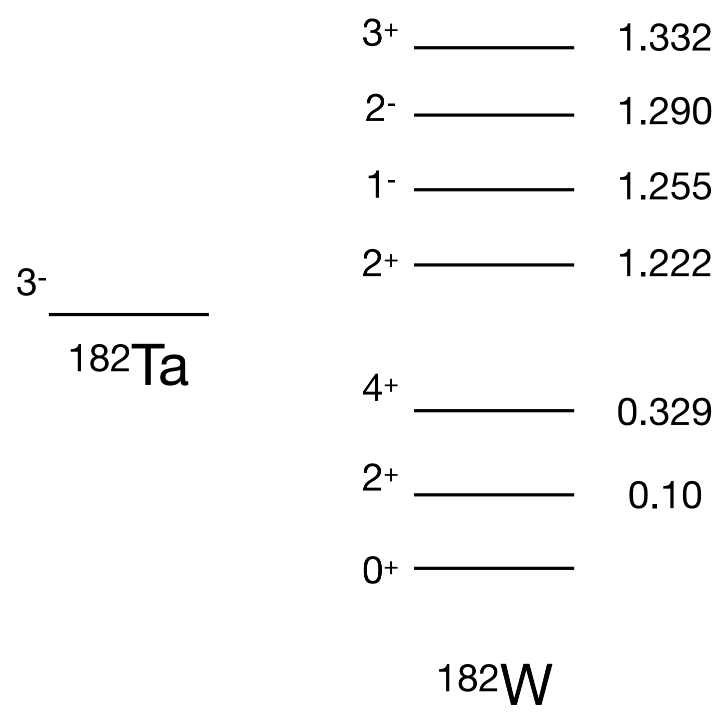
3-
182Ta
3+ 1.332
2- 1.290
1- 1.255
2+ 1.222
4+ 0.329
2+ 0.10
0+
182W

Fig. 3