Predictions in the Second Minimum Derived from a Valence Correlation Scheme

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Empirical systematic trends across nuclear shells have already been studied in the first minimum in the framework of 'valence correlation schemes' (VCS). A VCS is an approach that attempts to account for the systematic behaviour of nuclear observables in terms of a simple dependence on the numbers of valence nucleons. Underlying is the microscopical interpretation of vibrational states as due to particle-hole excitations produced by a vibrational field acting on a pair-correlated system of nucleons in the valence major shell. Thus the corresponding excitation energies simply depend on their collectivity, which in turn depends on the occupation of certain favoured shell model orbits, i.e. on the proton and neutron number, here represented by the sum of the valence nucleon numbers, $N_t = N_p + N_n$, where each number is counted relative to the nearest closed shell (valence particles or valence holes, depending on which is smaller) [1].

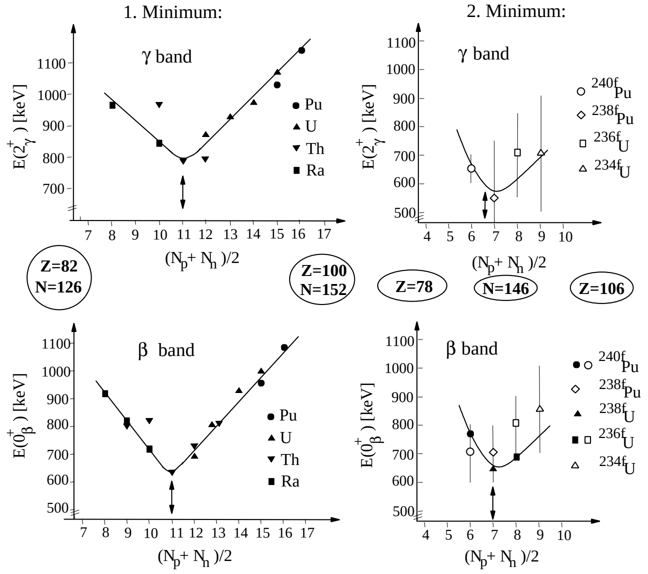

Fig. 1: Systematics of the experimental excitation energies of the β and γ vibrational band heads in the first minimum of actinide isotopes plotted versus the number of valence nucleon pairs.

Applying the concept of the N_t systematics to the actinide mass region results in the data shown in the left column of Fig. 1, where the excitation energies of the β and γ vibrational band heads (0^+ and 2^+ states, respectively) in the first minimum are plotted versus the number of valence nucleon pairs $(N_p + N_n)/2$. The systematics follows a characteristic trend with two almost linear branches and a distinct minimum. As expected, the minimum energies for both collective vibrational band heads show up exactly midway between closed shells, here between the spherical ^{208}Pb ($Z = 82, N = 126$) and the next higher-lying deformed shell closure near $Z = 100$ and $N = 152$, the latter derived from spectroscopic studies of heavy elements.

In case of the 0^+ levels this systematics even allows to distinguish between states with equal quantum numbers but different character of the wave function. This behaviour, reflecting the complex structure of 0^+ states, is illustrated in Fig. 2. Levels with strong E0 transitions (e.g. in ^{232}Th,^{232,234,238}U, ^{240}Pu) are located on a curve similar to the one displayed in Fig. 2 (labelled 'A'), while 0^+ states decaying mainly with weak or no E0 decay components group along separate systematic curves ('B', 'C').

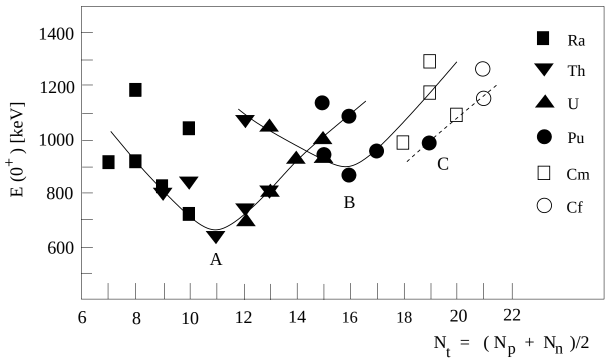

Fig. 2: Excitation energies of 0^+ states in the first minimum of actinide isotopes plotted versus the number of valence nucleon pairs. States decaying with strong ('A') and weak E0 decay contributions ('B'), respectively, are found to group along different systematic curves.

Given the clear systematic behaviour of β and γ vibrational phonon energies in the first minimum as visible in Fig. 1, it is tempting to transfer this approach also to the second minimum. Certainly much less experimental information is presently available in the second well, however, when considering the β band head energies, the U isotopes, differing from each other by one valence nucleon pair, reveal a rising trend from ^{238f}U to ^{234f}U, while the Pu isotopes show the opposite behaviour of a higher value of $E(0^+_\beta)$ for ^{240f}Pu compared to ^{238f}Pu. For deformed nuclei there are gaps in the single particle Nilsson energies that act like deformed shell closures. Having in mind the systematics found in the first minimum, a consistent arrangement can be found when assigning $Z = 78(106)$ as the lower (higher) deformed magic proton number, consistent with calculated shell correction energy minima. In this case the data points can be arranged in the N_t scheme as shown in the right-hand column of Fig. 1 around similar curves as in the first minimum with a distinct minimum at midshell. It should be emphasized that the data points originating from direct spectroscopic studies of the β vibration in ^{240f}Pu and ^{236f,238f}U result in highly accurate values of the first β phonon energy that justify the curve drawn in Fig. 1. On the other hand the additional experimental values emanating from transmission resonance studies complement these findings reflecting the general trend in good agreement with the precise spectroscopic data points within their larger uncertainties. Thus the rather simple empirical N_t systematics for the first time offers a possibility to predict β and γ vibrational phonon energies in the second minimum. Moreover, from the characteristic systematic trends visible in Fig. 1 additional predictions could be derived for new magic numbers in strongly deformed nuclei.

[1] P.G. Thirolf and D. Habs, Prog. Part. Nucl. Phys. **49** (2002) 325 and references therein