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Abstract

A substantial simplification of the systematics in nuclear phase transition regions is obtained if the data are plotted against the product, $N_p \cdot N_n$, of the number of valence protons and neutrons instead of against N, Z, or A as is usually done. Such a scheme leads to a unified view of nuclear transition regions and to a simplified scheme for collective model calculations.

It is generally considered that the residual proton-neutron interaction is responsible for the onset of deformation [TAL62, FED77, CAS81] in nuclei. Since the total p-n strength should be simply related [CAS85, HAM65] to the number of interacting pairs of valence protons and neutrons, that is, to the product $N_p \cdot N_n$ (counted as valence holes past midshell), one might expect nuclear systematics to be much simpler if plotted against such a parameter. This is indeed the case, as seen for the A=130 region in Fig. 1 (top). To exploit this approach when significant shell or subshell closures are present requires careful counting of valence particles. Thus, for example, near A=150, the Z=64 gap is assumed to be active and thus the proton shell is Z=50-64 for N<90 but Z=50-82 thereafter. Likewise, near A=100 a realistic [FED77] proton shell is Z=38-50 for N<60 and Z=28-50 for N$\geq$60. $N_p \cdot N_n$ plots, subject to these definitions, are given in Figs. 1-2. They reveal that, again, a remarkable simplification results. Only the N=90 points in Fig. 1 deviate from a smooth curve: this simply reflects the fact that the Z=64 gap is still partly intact for N=90. Indeed, one can exploit the otherwise smooth systematics by shifting these N=90 points to this smooth curve and extracting effective valence proton numbers that reflect the evolving proton subshell structure.

$N_p \cdot N_n$ plots are useful in another way as well. Fig. 3 compares plots for <u>different</u> regions and reveals their nearly identical

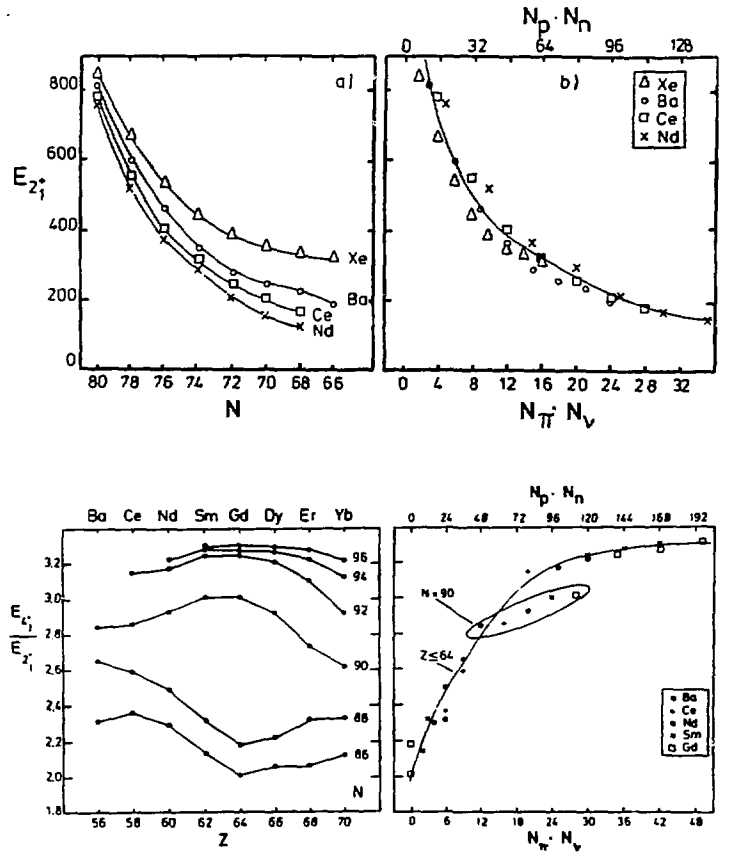


Fig. 1. N_pN_n and conventional plots for the A≈130 and 150 regions. For the latter region only the nuclei with $Z \leq 64$ are shown in the N_pN_n plot. The $Z \geq 66$ nuclei lie on a separate, parallel curve (see Fig. 3).

structure. In fact, three regions in Fig. 5 (A≈100, A≈150, Z<64, and A≈150, Z>66) have virtually the same slopes and the other two are only slightly different. The principal difference in the curves lies in their horizontal location. These findings are at first sight surprising since these regions were long thought to be widely different. However, simple estimates [CAS85, SOR84] of the p-n interaction in the highly overlapping orbits whose filling is crucial to the onset of deformation show that it is indeed roughly equal in the three regions of steeper slope in Fig. 3 and somewhat less for the other two regions. The horizontal shifts in Fig. 3 are also easily understood. In each region, a certain number of more or less inert orbits must be filled before the crucial, highly overlapping ones begin to fill. The horizontal position of a phase transition in an $N_p \cdot N_n$ plot reflects the number and degeneracy of such inert orbits.

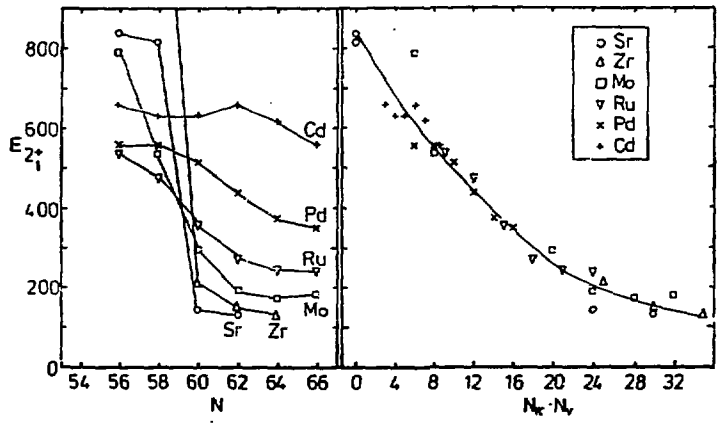
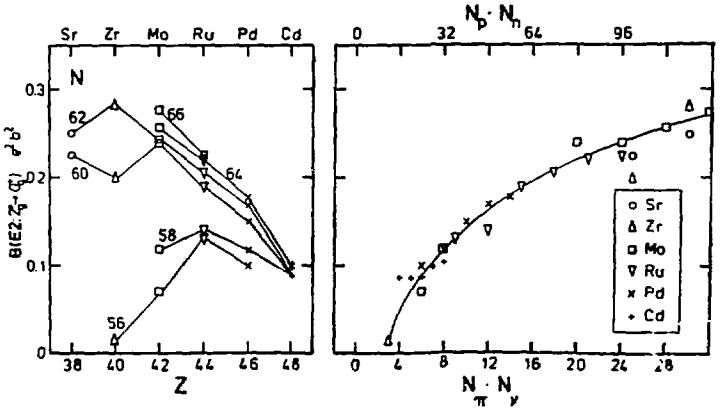


Fig. 2.
Examples of the simplification brought about in the N_pN_n scheme in the A=100 region.



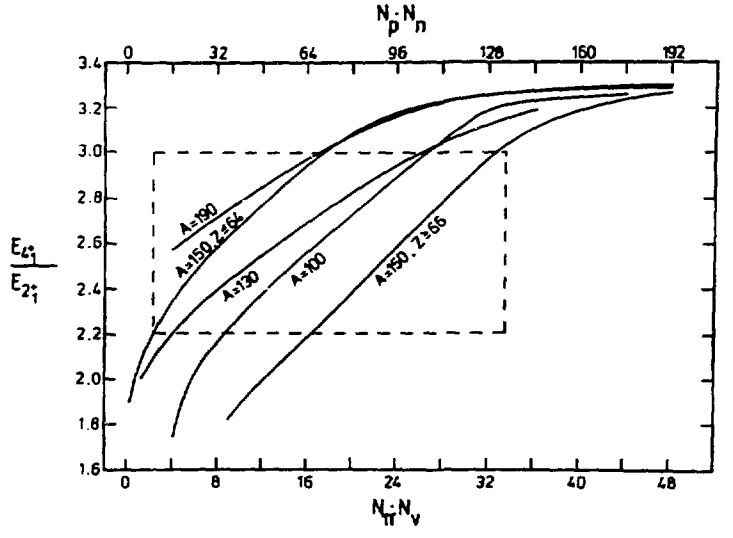


Fig. 3.
Comparison of smooth curves through the $E_{4^+_1}/E_{2^+_1}$ plots for five transition regions from A=100-200.

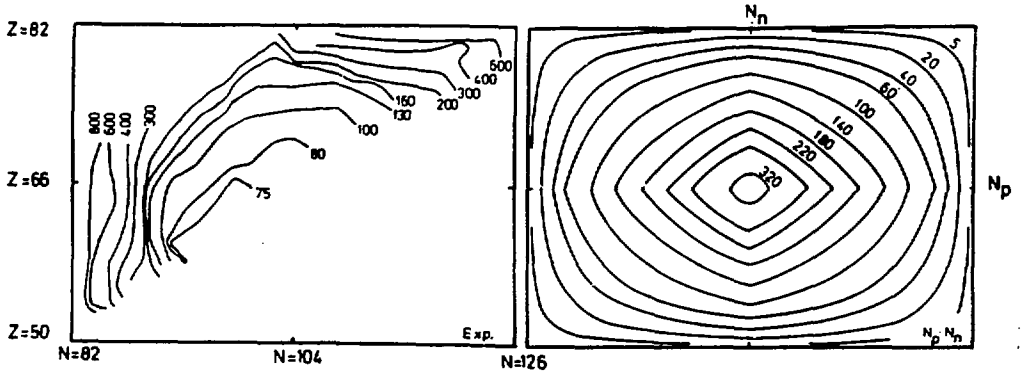


Fig. 4. Curves in the N-Z plane representing isodeformation contours: left, empirical contours of $E_{2^+_1}$ energies; right, contours of constant $N_p \cdot N_n$.

The fact that different $N_p \cdot N_n$ plots are so similar has two immediate consequences besides a unified interpretation of diverse regions. One is that such a plot gives greater confidence in extrapolation far off stability. This can be of use either in estimating the structure of such nuclei or in choosing particularly crucial nuclides for study. This point is highlighted in Fig. 4 which shows isodeformation contours [CAS85] for the A=150 region. The theoretical curves are those of constant $N_p \cdot N_n$ which define nuclei with the same structure. In an N-Z plot, then, such isodeformation curves will be hyperbolas which will have nearly vertical or horizontal contours at the edges of major shell regions. This behavior is in contrast to many typical collective model calculations (e.g., RAG74) which lead to roughly circular contours. It is remarkable that the data display just the features expected in the $N_p \cdot N_n$ scheme. However, it is also clear that this could be tested much more decisively by the addition of even the first 2^+ energy of a few neutron rich isotopes of Xe-Sm near A=150.

The other consequence is that $N_p \cdot N_n$ systematics offer a way to greatly simplify collective model calculations. Normally, such calculations are parameterized for each nucleus individually or for a set of isotopes. The $N_p \cdot N_n$ curves suggest that an entire region can be treated as a unit in which the collective parameters are taken as smooth functions of $N_p \cdot N_n$ only. Moreover, Fig. 3 suggests that the same set of parameters

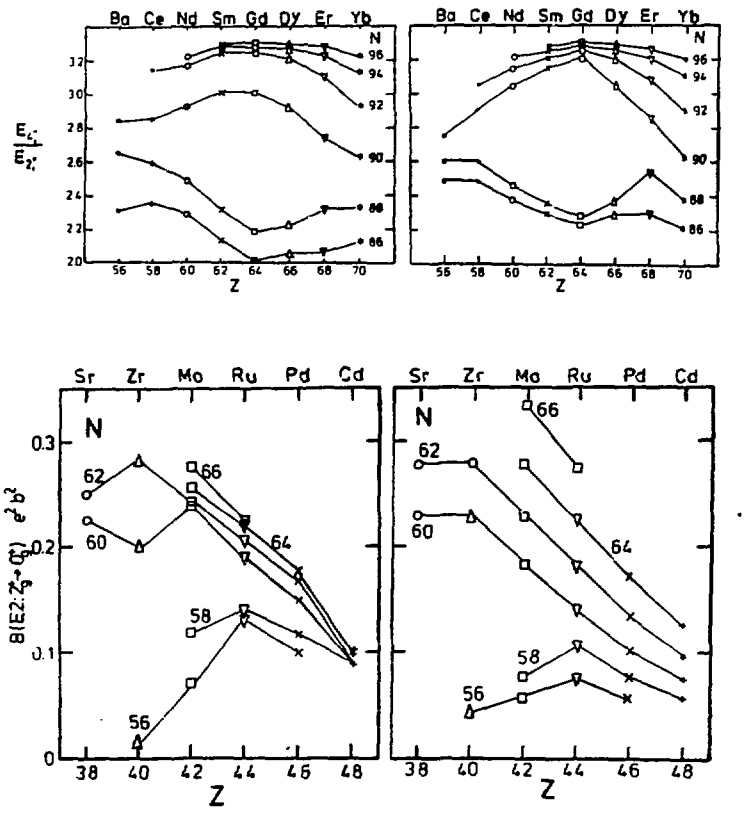


Fig. 5 Examples of empirical (left) and calculated (right) results for the A=150 and 100 regions.

could even be used for several regions of similar slope. This idea can be illustrated with an IBA calculation of ≈100 nuclei in the three vibrator → rotor regions of similar slope in Fig. 3 using the IBA-1 Hamiltonian

$$H = \varepsilon n_d - \kappa Q \cdot Q \qquad : \qquad \varepsilon = \varepsilon_0 \cdot e^{-\theta(N_\pi N_\nu - N_0)} = \varepsilon_0 e^{\theta N_0} e^{-\theta N_\pi N_\nu} \qquad (1)$$

where N_π,N_ν are boson numbers and where θ is related to the slope and N_0 to the horizontal displacement in an $N_p \cdot N_n$ plot. In Eq. (1), a vibrator to rotor transition is obtained by allowing ε to decrease as a function of $N_\pi \cdot N_\nu$. Eq. (1) contains five parameters: ε_0, θ, κ, χ (an internal parameter in Q), and N_0. To achieve the utmost economy of parameters ε, κ, θ, and χ are held constant for all 100 nuclei, and N_0 has a separate value for each of the three regions. This gives 7 parameters for ≈100 nuclei or, in fact, 6 parameters if one uses the second form for ε in Eq. (1) where ε_0

and N_0 are combined. Examples of the results [CAS85] are shown in Fig. 5. Given the highly constrained parameterization, the predictions are in remarkable agreement with the data. The overall trajectories of each transition region are closely reproduced and so are many of the detailed systematics. The reason for this agreement lies less in the specific features of the IBA as in the exploitation of the $N_p \cdot N_n$ scheme: therefore, one expects that similar simplifications might apply to other collective models.

Summary

1) The $N_p \cdot N_n$ scheme provides a major simplification of nuclear systematics, particularly in transition regions.
2) It provides information on evolving shell structure.
3) $N_p \cdot N_n$ plots show a remarkable similarity in transition regions previously thought to behave quite differently. $N_p \cdot N_n$ is an appropriate unit to measure the rapidity of different phase transitions. Moreover, this rapidity is primarily a function of the p-n interaction in certain crucial highly overlapping orbits.
4) $N_p \cdot N_n$ systematics are very useful for extrapolation far off stability and can be exploited to simplify collective model calculations.

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