SHAPE COEXISTENCE AND RADII OF TRANSITIONAL NUCLEI

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The dependence of the nuclear radius on the mass number is connected mainly with a change of the nuclear volume and deformation. The influence of the latter may be so intense that the mean square charge radius (RMS) increases with the decrease of the neutron number as in the Rb and Sr isotopes. The observed deviation of the RMS isotopic dependence on the volume in the conventional spherical nuclei of the Z=82 region requires a special explanation. The aim of the present work was to investigate the nuclear shape coexistence effect, viz. presence of low-lying states with various equilibrium deformation, on the isotopic dependence of the RMS in the nuclear ground state /1/.

At present it is ascertained that in the nuclei near the closed shells so-called intruder states from proton 2p—2h excitations are formed. In their energy spectrum there appear two branches of nuclear excitation typical for spherical and deformed nuclei. The neutron-deficient isotopes Pb, Bi and Tl give the best example of systematical behaviour of the intruder state properties. For the quadrupole interaction the excitation energies of the intruder states 0^+ in the even-even nuclei must exceed twice the intruder state energies in the neighbouring odd and odd-odd nuclei. In the Z=82 region this condition is well fulfilled, as one can see from the figure. Consequently, the effective neutron-proton interaction and the equilibrium deformation of the intruder state in these nuclei have a quadrupole origin.

In the two-level approximation the ortonormalized wave functions for the ground state

$$|1> = \sqrt{1-x}\,|s> + \sqrt{x}\,|d> \qquad (1a)$$

and intruder state

$$|2> = \sqrt{1-x}\,|d> - \sqrt{x}\,|s> \qquad (1b)$$

are superpositions of the unperturbed spherical |s> and deformed |d> states. The mixing parameter x determines the excitation energy of the intruder state

$$E = E_2 - E_1 = (1-2x)\,E_0 - 4V\sqrt{x(1-x)}, \qquad (2)$$

where E_0 is unperturbed energy and V is the matrix element of a residual neutron-proton interaction.

The neutron number independent part of the intruder state excitation energy $E_0 = 2(\varepsilon_p - \varepsilon_h) - \Delta E_p$ is considered as unperturbed energy. It is equal to 6.1 MeV in ^{208}Pb according to experimental data. Further, from systematics one may conclude that the excitation energy of the intruder 0^+ state is minimal in ^{190}Pb. It means the largest mixing, x=0.5, and from eq.(2) one obtains V=—0.33 MeV. The mixing parameters for other nuclei (see table) are determined by experimental values of the intruder 0^+ state energy.

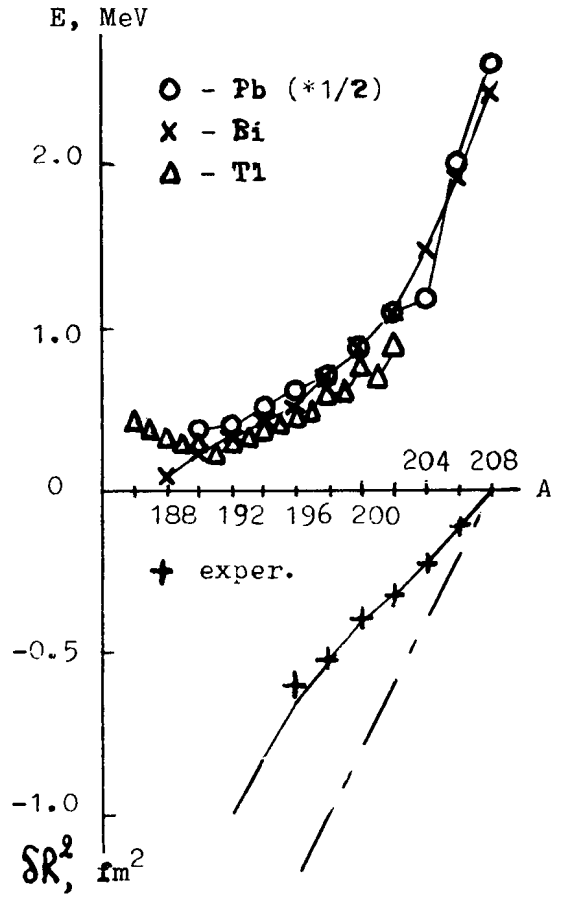

Fig. Intruder state energies and isotopic shifts (for Pb only)

Table

Deformation parameters, mixing coefficients and E0 transition rates

A	β	x	ϱ(E0)
208	—0.04	0.10	0.01
206	—0.06	0.21	0.03
204	—0.09	0.35	0.07
202	—0.10	0.38	0.10
200	—0.10	0.42	0.11
198	—0.11	0.44	0.12
196	—0.13	0.46	0.16
194	—0.13	0.48	0.17
192	—0.13	0.49	0.17

With the wave functions (1) the RMS for the ground state are calculated

$$R^2 = <1\,|r^2|\,1> = \frac{3}{5}R_0^2\{1 + \frac{5}{4\pi}x\beta^2 + \frac{10}{3}\sqrt{x(1-x)} < s|r^2|\,d>\} \quad (3)$$

and the E0 transition rate

$$\rho(E0) = <1|r^2|\,2> / R_0^2 = \frac{3}{4\pi}\sqrt{x(1-x)}\,Z\beta^2 + (1-2x) < s|r^2|d>, \quad (4)$$

where $R_0 = r_0 A^{1/3}$, β is the equilibrium deformation parameter. The latter is calculated by the shell correction method for the lowest proton 2p—2h configuration. The matrix element $<s|r^2|d>$ is calculated by the expansion of the deformed nucleus wave function on a spherical basis.

The values of the isotopic shifts of the RMS, $\delta R^2 = R^2(^A\text{Pb}) - R^2(^{208}\text{Pb})$, in this approach, obtained for the Pb isotopes, are compared with the volume shifts and experimental data /2/. The calculated values of the E0 transition rate for the intruder 0^+ state are given in the table. Unfortunately, there are no corresponding experimental data, except the estimate $\varrho(E0)_{exp} > 0.04$ for the nucleus ^{202}Pb /3/, which is in agreement with the calculated value.

These results show the significant role of the intruder states and the coexistence of shapes for the forming of the low-lying state properties in the transitional nuclei with a single-closed shell. A qualitatively correct description of the RMS isotopic shifts has been obtained. For a quantitative argeement with the experimental data it is necessary to receive new information about the E0 transitions in nuclei in the region of closed shells.

REFERENCES

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