Letters to the Editor

RESIDUAL np *INTERACTION IN HEAVY NUCLEI AND HIGH-LYING ISOMERIC STATES*

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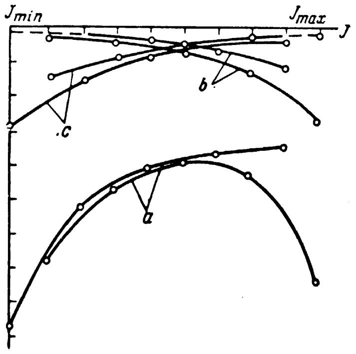
THERE is a large group of phenomena in nuclei, in which a vital part is played by residual np interaction between the nucleons of over-filled neutron and proton shells. It is obvious, for example, that the appearance of an isomeric level with spin $J = 9^-$ in the Bi^{210} nucleus, which has one neutron and one proton in excess of two filled shells, is caused by np forces. However, as we demonstrated in a previous paper [1], the appearance of an isomeric level $J = 16^+$ in the $Po^{212}(2n + 2p)$ nucleus is also due, in the final analysis, to np interaction. It has, therefore, become necessary on a general basis to study the main features of residual np interaction and the part it plays in the appearance of high-lying isomeric states in nuclei.

An analysis of the dependence of the value of the matrix elements of a configuration $\{j_1, j_2\}$ consisting of one neutron at level j_1 and one proton at level j_2 on the total spin J yielded the following results [2]: the variation of the matrix elements of the forces that are independent of the intrinsic nucleon spins (Wigner forces) is such that the matrix element is greatest for the state with total spin $J = J_{min}$, somewhat smaller for $J = J_{max}$ and smallest of all for $J = J_{max} - 1$. This dependence is represented in the figure by curves (a). The matrix elements of the forces that are dependent on the intrinsic nucleon spins (singlet forces) increase the increasing total spin J if the Nordheim number $N = l_1 + j_1 + l_2 + j_2$ of the configuration under consideration is even, and decrease if N is odd [curves (b) and (c)]. Direct calculation shows that in all these cases the points lie alternately on two smooth curves.

Since the residual np interaction contains both Wigner and singlet forces with parameters v_0 and v_1 respectively, in order to determine the over-all dependence of the matrix elements on the total spin J it is necessary to know the signs and values of these parameters. Theoretical analysis of the thoroughly investigated spectrum of the heavy Bi^{210} nucleus has shown that the parameters v_0 and v_1 must be of identical sign (attraction) and have approximately equal absolute values. Thus, for configurations $\{j_1, j_2\}$ whose Nordheim number is even, the J_{max} level will lie close to the J_{min} level, and this results in isomerism. For configurations with odd N, levels with intermediate spins are ranged between the J_{min} and J_{max} levels, so that in these cases isomerism does not take place. In the region of light nuclei ($A < 100$) the parameters v_0 and v_1 are of different sign, since the singlet forces become smaller than the triplet forces. The result is that isomerism of light nuclei will be observed in configurations whose Nordheim number is odd. For particle-hole configurations the parameter v_0 changes its sign, and this results in the matrix element being greatest for the state with spin $J = J_{max} - 1$, regardless of whether or whether or not the Nordheim number of the configuration under consideration is even.



General character of the dependence of the diagonal matrix elements of the operators of Wigner and singlet forces upon the integral spin J for the configuration: $\{j_1, j_2\}$: curves (a) – Wigner forces; curves (b) – singlet forces, even N; curves (c) – singlet forces, odd N.

A general examination of the matrix elements of the np interaction of configurations $\{j_1^2, j_2^2\}$ consisting of two neutrons and two protons shows that with even N the greatest matrix element corresponds in the region of heavy nuclei to the state in which the neutron and proton spins are aligned and $J = J_{max}$. Direct calculation of the diagonal matrix elements of np interaction in this region of nuclei gives a value for J_{max} that is approximately 500 keV higher than for the ground state. This is why the level $|g_{9/2}^2 8, h_{9/2}^2 8; 16\rangle$ in the Po^{212} nucleus is relatively low-lying (2.9 MeV), so that only levels with $J \le 8$ are below it. As a result, no γ transitions from the level $J = 16^+$ are detected, and only strongly forbidden α decay, with a hindrance coefficient 10^{13}, is observed [3].

From further analysis of the matrix elements of np forces it is possible to make an assumption regarding the isomeric nature of the levels which can be described in a diagonal approximation of the wave function $|j_1^{S_1} s_1 J_{1max}, j_2^{S_2} s_2 J_{2max}; J_{max}\rangle$

Isometric levels in the region of heavy nuclei

Nucleus	Configuration	Spin	Excitation energy (MeV)	Nucleus	Configuration	Spin	Excitation energy (MeV)
Bi^{210}	$\{g_{9/2}, h_{9/2}\}$	9	~0.25	At^{214}	$\{g^3_{9/2}, h^3_{9/2}\}$	21	~3.5
Bi^{211}	$\{g^2_{9/2}, h_{9/2}\}$	25/2	~0.8	Rn^{216}	$\{g^4_{9/2}, h^4_{9/2}\}$	24	~5.0
Po^{211}	$\{g_{9/2}, h^2_{9/2}\}$	25/2	~1.2	Ra	$\{i^2_{11/2}, f^2_{7/2}\}$	16	~3–4
Po^{212}	$\{g^2_{9/2}, h^2_{9/2}\}$	16	~2.9	Th	$\{i^2_{11/2}, i^2_{13/2}\}$	22	
Po^{214}	$\{g^4_{9/2}, h^2_{9/2}\}$	20	~4.0	U, Pu, Cu	$\{g^2_{7/2}, i^2_{13/2}\}$ $\{j^2_{15/2}, f^2_{5/2}\}$	18	~3–4

(s = seniority) for configurations whose Nordheim number is even (region of heavy nuclei). This is equally true for both odd-odd and even-even nuclei and for odd A nuclei. We note that the isomeric levels caused by np forces can be both low-lying and high-lying with respect to the ground state, from 100 keV to 5 MeV.

The following fact extends the region of the nuclei in which isomeric levels can be observed. Upon removal from the twice-filled shells the neutrons, as well as the protons separately, may be distributed simultaneously over two or more levels. If the nucleons at all these levels, except for one neutron level j_1 and one proton level j_2, are bound into states with zero angular momenta, then the splitting of the multiplet under the effect of the np forces is determined by the properties of the configuration $\{j_1^{n_1}, j_2^{n_2}\}$. In other words, the nucleons in states with zero angular momenta play no part in extending the configuration under consideration, and thus the assumption made above can be used to identify isomeric levels.

We must make special mention of isomerism in the region of transuranium elements. This region is characterized by the fact that several configurations, in which the nucleons are distributed over the levels in different fashion, will simultaneously be the lowest in energy. These configurations will also include those conducive to the formation of isomeric states. It is only if levels of other configurations with similar spin values should chance to be below this level that isomerism will not take place or will be attenuated. The table shows the isomeric levels in the region of heavy elements, their configurations, spins, and approximate excitation energies.

Thus, high-lying isomeric states must occur fairly frequently. The observation of isomeric levels in nuclei with short-lived ground states is of particular interest. In addition, the identification of these isomeric levels, and also the determination of their lifetimes, makes it possible for us to obtain more accurate knowledge of the nature of np interaction in nuclei.

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DIFFUSION LOSSES OF C^{11} NUCLEI IN PLASTIC FILMS ACTIVATED BY HIGH-ENERGY PROTONS

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IN many experiments [1] it is necessary to measure the intensity of the internal proton beam in an accelerator. Usually activated carbon-containing materials are used for this purpose. The intensity of the proton beam is determined from the number of produced β-active nuclei C^{11} ($C^{11} \rightarrow \beta^+ + B^{11} + \nu$). It was observed, however [2-4], that a definite part of the C^{11} nuclei in films made of polyethylene and other carbon-containing materials is lost upon irradiation in the accelerator, as a result of the diffusion of the gaseous products which are formed during the irradiation. Fuchs and Lindenberger [3] have shown that these losses are essentially due to realignment of the molecular