SOVIET PHYSICS JETP VOLUME 18, NUMBER 1 JANUARY, 1964

SPATIAL CORRELATION OF NUCLEONS IN LIGHT NUCLEI

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Submitted to JETP editor January 15, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **45**, 228-230 (August, 1963)

The Coulomb energy differences of isobaric triplets of light nuclei are considered. The values indicate a relatively large mutual Coulomb energy of the pair of external protons and hence an appreciable spatial correlation between them.

PAIR correlations of nucleons in nuclei are well known from the different energy variations on going from nuclei with an odd number of nucleons to nuclei with an even number. There is no doubt that energy pairing effects are connected with the spatial correlation of the paired nucleons. In the general case, this connection is complicated and multiple-valued. For one class of nuclei, however, the spatial correlation of the nucleons can be demonstrated quite clearly and convincingly.

We have in mind isobar triplets of nuclei of the type $A = 4n + 2$. In connection with the first determination of the energy of the ground state of Be^6 [1] we have already indicated that there exists a strong spatial correlation between nucleons in nuclei of the lightest isobar triplet He^6–Li^6–Be^6. Recently [2] more accurate measurements of the energy of Be^6 were made. More accurate data were also obtained on the energies of the other isobar triplets [3,4], in which the effect of spatial correlation of the nucleons is also clearly pronounced.

Let us consider four of the lightest isobar triplets of the type $A = 4n + 2$:

$$He^6 — Li^{6*} — Be^6, \qquad Be^{10} — B^{10*} — C^{10},$$
$$C^{14} — N^{14*} — O^{14}, \qquad O^{18} — Fe^{18*} — N^{18}.$$

For the central nuclei of each triplet (Li^6, B^{10}, L^{14}, and F^{18}) we have in mind the lowest excited state with isotopic spin $T = 1$ [4]. Then each three nuclei correspond to three projections of the isotopic spin $T = 0, \pm 1$. If the isotopic independence of the nuclear forces is satisfied exactly, then the energy of these isobars should differ only because of the difference in the Coulomb energy.

The Coulomb energy of the last isobar with charge $Z + 2$, in which both last nucleons are protons, can be represented in the form

$$Q(Z+2) = Q(Z) + 2Q(p, Z) + Q(p, p).$$

Here $Q(Z)$ is the Coulomb energy of the first isobar, $Q(p, Z)$ is the Coulomb energy of one proton in the field of a nucleus with charge Z, and $Q(p, p)$ is the mutual Coulomb energy of two protons. The value of $Q(p, Z)$ can be determined as the difference between the Coulomb energies of the second and first isobar nuclei

$$Q(p, Z) = Q(Z+1) - Q(Z).$$

The energy difference between the third and second isobar nuclei

$$Q(Z+2) - Q(Z+1) = Q(p, Z) + Q(p, p)$$

differs from the preceding one only in the mutual energy of the protons $Q(p, p)$. Thus, from the experimentally known masses of the nuclei of the isobar triplet and the corresponding Coulomb differences

$$\Delta Q_{21} = Q(Z+2) - Q(Z+1)$$

and

$$\Delta Q_{10} = Q(Z+1) - Q(Z)$$

we can determine separately the Coulomb energy of each proton in the field of a nucleus with charge Z, and the mutual energy of the pair of protons in the nucleus with charge $Z + 2$.

Were each of the pairs of external protons to be distributed over the volume of the nucleus in the same way as the Z preceding ones, that is, were the charge density at each point of the nucleus with charge $Z + 2$ greater by a factor $(Z + 2)/Z$ than the charge density in the nucleus with charge Z, then the following relation would apply

$$\gamma = ZQ(p, p)/Q(p, Z) = 1.$$

Actually $\gamma > 1$ in all the cases considered. This means that the Coulomb energy of the proton pair is relatively large, and consequently, the average distance between them is noticeably smaller than the average distance between each of them and the core nucleus.

The table lists the values of the Coulomb differences, calculated on the basis of the known

Difference in Coulomb energies of the isobars of type A = 4n + 2 (MeV)

A	Z	ΔQ_{21}	$\Delta Q_{10} = Q(p,Z)$	$Q(p, p)$	γ	
					experiment	theory
6	2—3—4	1.54±0.04	0.82±0.03	0.72±0.07	1.8	1.11
10	4—5—6	2.66±0.07	1.97±0.01	0.69±0.08	1.4	1.18
14	6—7—8	3.62±0.01	2.94±0.01	0.68±0.02	1.4	1.04
18	8—9—10	4.18±0.06	3.49±0.01	0.69±0.07	1.6	1.15

data[3,4] by the universally accepted method[5] with account of the mass difference n − H, and the quantity $\gamma = ZQ(p, p)/Q(p, Z)$, which can be called the coefficient of spatial correlation of the pair of last nucleons.

The value of γ reliably exceeds unity in all cases, and consequently the spatial correlation of the pairs of external nucleons in the nuclei of the type A = 4n + 2 is quite large. The deviation of γ from unity is, generally speaking, not surprising if the distribution over the volume of the nucleus is not the same for the protons in different states. The absolute value of γ depends on the specific model.

Even-odd variations of the Coulomb energy are observed also in pairs of mirror nuclei[5]. An analysis of these variations, based on different models, is the subject of several theoretical papers[6,7].

In the last column of the table is given the value of γ following from the work of Carlson and Talmi[8], in which the nucleon pairing effect is calculated for a spherical oscillator potential.

Wackman and Austern[9] analyzed the structure of nuclei with mass A = 6 and gave the energies of the ground states of all three isobars calculated on two assumptions. The values obtained for γ are 1.26 and 1.46, and although they exceed the values given by Carlson and Talmi, they are still much lower than the experimental value 1.8.

The fact that $\gamma > 1$ can be explained also without assuming spatial correlation of the nucleons, by assuming, however, violation of the rules of charge symmetry or isotopic invariance of the nuclear forces, which leads either to a relative lowering of the energy level of the middle isobar, or to an increase in the level of the third isobar.

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Translated by J. G. Adashko
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