ON A POSSIBLE INTERPRETATION OF EXPERIMENTS ON INELASTIC SCATTERING OF FAST PROTONS ON LIGHT NUCLEI

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It is shown that the splitting of the level at ~ 20 MeV observed in inelastic scattering of protons on light nuclei can be explained by an anisotropic proton distribution in the nucleus.

THE experimental data of Tyrén and Maris [1] on the inelastic scattering of 180-MeV protons on light nuclei established that the level corresponding to an excitation energy ~ 20 MeV, which occurs in all investigated nuclei, undergoes splitting in some cases. This fact has not been explained in the published interpretations of these experiments. [2-4] In this note we indicate a possible cause for the splitting of the level at ~ 20 MeV.

From the angular distribution of the scattered protons, Tyrén and Maris assigned this level an angular momentum 1 and suggested that an E1 quantum is absorbed in its excitation. It is therefore reasonable to assume that this level is excited by a Coulomb interaction of the incident proton with the nucleus. (It is known that the nuclear interaction in the p state is suppressed.) The large kinetic energy of the scattered protons and the suggested Coulomb character of the interaction with the nucleons of the nucleus permit the calculation of the cross section for the inelastic scattering of protons on the nucleus in the Born approximation.

As is known, in this approximation the differential cross section for the excitation of the n-th level in the case of inelastic scattering of particles of mass M is

$$\frac{d\sigma_n}{d\Omega} = 4\left(\frac{e^2}{\hbar c}\right)^2\left(\frac{Mc}{\hbar q}\right)^2\frac{k_f}{k_i}|\langle n|d_z|0\rangle|^2. \qquad (1)$$

Here, k_i and k_f are the wave numbers of the incident and scattered protons, $\mathbf{q} = \mathbf{k}_i - \mathbf{k}_f$ is the momentum transfer; the sum $d_z = \Sigma z_\alpha$ runs over all protons in the nucleus (the z axis is directed along $\mathbf{q}$); the matrix element of d_z runs between the ground-state and n-th levels of the nucleus. For large energies of the incident proton and small scattering angles, we can set

$$k_f \approx k_i \approx k, \quad q^2 = k^2\vartheta^2 \qquad (2)$$

(ϑ is the scattering angle). Since $\hbar^2k^2 = 2ME$, we obtain

$$\frac{d\sigma_n}{d\Omega} = 2\left(\frac{e^2}{\hbar c}\right)^2\frac{Mc^2}{E}\frac{1}{\vartheta^2}|\langle n|d_z|0\rangle|^2. \qquad (3)$$

In the study of photonuclear reactions, it was established that the energies of all the E1 transitions in the nucleus are very close to one another, and that in the experiment only one rather broad giant resonance is observed. We therefore take the sum over all electric dipole transitions

$$\sum_n|\langle n|d_z|0\rangle^2 = \langle 0|d_z^2|0\rangle \qquad (4)$$

and we thus obtain

$$\frac{d\sigma}{d\Omega} = 2\left(\frac{e^2}{\hbar c}\right)^2\frac{Mc^2}{E}\frac{1}{\vartheta^2}\langle 0|d_z^2|0\rangle. \qquad (5)$$

This result is apparently unconnected either with the assumption of the Coulomb interaction of the incident proton with the nucleus or with the use of the Born approximation; Sakamoto [3] applied the t-matrix theory and assumed a nuclear interaction. He obtained the expression

$$d^2\sigma/d\Omega\, dE = \text{const}\cdot\vartheta^{-2}\sigma_{ph}(E_{exc})/E_{exc}$$

(σ_{ph} is the cross section for the absorption of the photon and E_{exc} is the excitation energy of the nucleus), which, with the aid of the summation rule

$$\int_0^\infty \sigma_{ph}(E)\,E^{-1}\,dE = 4\pi^2(e^2/\hbar c)\langle 0|d_z^2|0\rangle$$

leads to a form similar to (5):

$$d\sigma/d\Omega = \text{const}\cdot\vartheta^{-2}\langle 0|d_z^2|0\rangle.$$

We note that the cross section (5) contains, apart from terms directly measured in the experiments [1] ($d\sigma/d\Omega$, E, ϑ), only the characteristics of the nucleus, i.e., the mean value of the square of the dipole moment in the ground state, and is not connected with the cross sections for other processes.

It follows from (5) that an anisotropy in the proton distribution in the nucleus ($\langle 0 | d_z^2 | 0 \rangle \neq \langle 0 | d_x^2 | 0 \rangle$) leads to a splitting of the resonance—instead of one maximum, there are two or three—for axial and nonaxial nuclei. However, the splitting of the levels can be evidence of the deformation of the nucleus.

The data of Tyrén and Maris permit the determination of the size of the deformation of the nucleus

$$\Delta/E_0 = (a^2 - b^2)/R_0^2. \tag{6}$$

Here, Δ is the magnitude of the splitting, E_0 is the mean energy of the resonance, a and b are the ellipsoid semi-axes, R_0 is the radius of the perfect sphere. For the C^{12} and N^{14} nuclei, we obtain the values 0.146 and 0.234, respectively.

In favor of the suggestion that the splitting of the level is due to the deformation of the nucleus is also the fact that the splitting is not observed in nuclei with two filled shells (O^{16}, Ca^{40}); while in nuclei whose deformation is established (d-shell nuclei), the splitting occurs (F^{19}, Na, Mg) or an increase in the level widths is observed (Al, Si).

The high probability of E2 transitions in comparison with single-particle ones can also be explained qualitatively by the deformation of C^{12} and N^{14} nuclei. A quantitative estimate of the quadrupole moments corresponding to the deformations is difficult here, since the strong coupling approximation of the uniform model is inapplicable ($j = 1/2, 3/2$).

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