Direct measurements of the sign of the deformation of nuclei by the Blair phase-shift method

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The surface shapes of the nuclei ^{12}C and ^{24}Mg were measured, for the first time, by determining the deviations from the Blair phase rule in inelastic scattering of α particles.

In 1966, Inopin and Shebeko predicted the Blair phase shift effect.[1] The attractive aspect of the phenomenon was the possibility of obtaining the sign of the nuclear deformation in the equilibrium state directly from experiment, without reducing the experimental data by means of a nuclear model.

We have observed the predicted effect in two strongly-deformed nuclei, ^{12}C (deformation parameter $(\beta) = 0.30$) and ^{24}Mg ($(\beta) = 0.61$). The gist of the phase-shift phenomenon is that the diffraction oscillations of the cross section, upon excitation of the ground state of the spherical nucleus ($\beta = 0$) and of the first-excited 2^+ level by α particles, are exactly in counterphase; if the nucleus is deformed ($\beta \neq 0$), then oscillations of the inelastic-scattering cross sections shift towards larger angles θ_{cms} for an oblate nucleus (sign $\beta < 0$), and small θ_{cms} for a prolate nucleus (sign $\beta > 0$), the angle shift being proportional to the value of the deformation, $\Delta\theta = -0.09\ \beta\theta$.[1]

For the measurement of the phase shift $\Delta\theta$ we chose the nucleus ^{12}C and ^{24}Mg, whose equilibrium shapes were thoroughly investigated theoretically, namely, ^{12}C is assumed to be oblate and ^{24}Mg prolate. Consequently we expected the Blair phase shift $\Delta\theta = \theta(2^+) - \theta(0^+)$ to occur on opposite sides of the extremum for 0^+ in these nuclei, and to have opposite signs

$$\mathrm{sign}[\Delta\theta(^{12}\mathrm{C})] = -\,\mathrm{sign}[\Delta\theta(^{24}\mathrm{Mg})]. \tag{1}$$

The experiment was performed with the α-particle beam of the isochronous cyclotron of our Institute at energies 39.0 and 50.5 MeV, using a procedure in which the angular resolution of the α spectrometer was improved in comparison with the usual diffraction measurements.[2] The experimental results are shown in the figure, from which it follows that the Blair phase shift does indeed take place. In fact, as expected for the ^{12}C nucleus, the oscillations of the cross section upon excitation of the 2^+ level are shifted towards larger angles, and towards smaller angles in the case of ^{24}Mg, i.e., relation (1) is confirmed. The sign and magnitude of the shifts agree with the theoretically expected $\Delta\theta(^{12}\mathrm{C}) = +5.6 \pm 0.3°$ and $\Delta\theta(^{24}\mathrm{Mg}) = -2.8 \pm 0.2°$.

We have analyzed the mechanisms competing with nuclear deformation and capable of causing an analogous phase shift of the diffraction oscillations at the cross section. The analysis shows that these phase-shift mechanisms can be neglected in the case of ^{12}C and ^{24}Mg.

Thus, the obtained values of $\Delta\theta$ lead to the conclusion that ^{12}C is oblate, i.e., has a negative nuclear deformation ($\beta(^{12}\mathrm{C}) = -0.30$), while ^{24}Mg is prolate and has a positive deformation ($\beta(^{24}\mathrm{Mg}) = +0.61$). We do not regard this experiment to be a fully reliable proof of the Blair phase shift effects, and the pressing problem now is to use the method to measure the signs of the equilibrium deformations of atomic nuclei.

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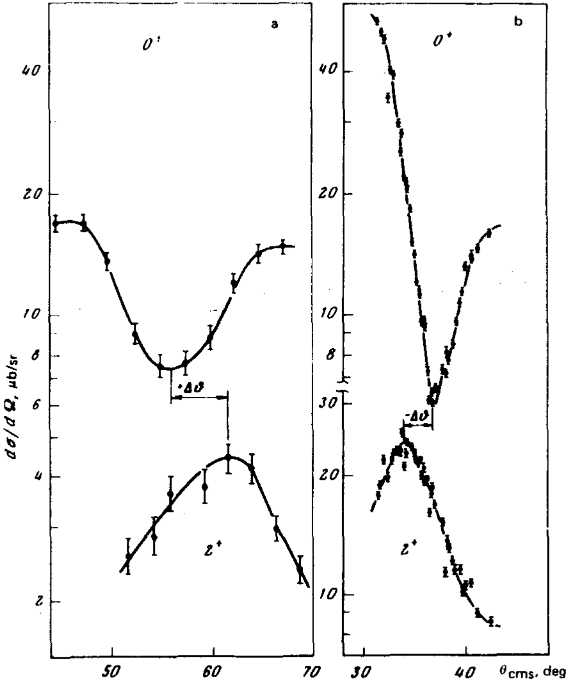

Shift of Blair phases for the strongly-deformed nuclei ^{12}C and ^{24}Mg, demonstrating that ^{12}C is an oblate nucleus and ^{24}Mg is prolate in the equilibrium state; a) angular distributions of elastic (0^+) and inelastic (2^+) scattering of 39.0-MeV α particles from ^{12}C; b) the same for 50.5-MeV α particles scattered from ^{24}Mg.

[1] E. V. Inopin and A. V. Shebeko, Zh. Eksp. Teor. Fiz. 51, 1761 (1966) [Sov. Phys.-JETP 24, 1189 (1967)]

[2] A. V. Yushkov and N. N. Pavlova, Yad. Fiz. 19, 729 (1974) [Sov. J. Nucl. Phys. 19, 370 (1974)]