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Shape coexistence and shape transitions in the even-A Ge nuclei

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A comparison of experimental data obtained in Coulomb excitation and two neutron transfer reaction measurements definitely assesses the existence of shape transitions and shape coexistence in the even-A germanium nuclei.

[NUCLEAR REACTIONS Comparison of two neutron transfer reactions and Coulomb excitation measurements. Shape coexistence and shape transitions in the Ge nuclei.]

The intriguing properties of nuclei around the $N=40$ region and more particularly of the even-A Ge nuclei have been made apparent by a number of experimental and theoretical investigations. The Ge nuclei are characterized by a complex nuclear system subjected to a variety of nuclear interactions which make these nuclei very shape unstable. Indeed, anomalies in transfer reactions strongly suggest both the existence of a shape transition (from spherical to weakly deformed) between $N=40$ (^{72}Ge) and $N=42$ (^{74}Ge) and a coexistence of different types of deformation.[1–5] However, recent Coulomb excitation measurements have also shown the presence of a structural change between ^{70}Ge ($N=38$) and ^{72}Ge ($N=40$).

We wish to report here on a comparison between the behavior of the neutron transfer reactions $[(p,t);(t,p)]$ (Refs. 2–5) and the results deduced from Coulomb excitation experiments.[6] It will be shown that all these data definitely support the existence in the Ge nuclei, both of a gentle shape transition from oblate to spherical to prolate, and of a coexistence of different types of deformations. To have a better understanding of the problems to be

From the assumption that the neutron transfer reactions within similar (different) nuclear struc-

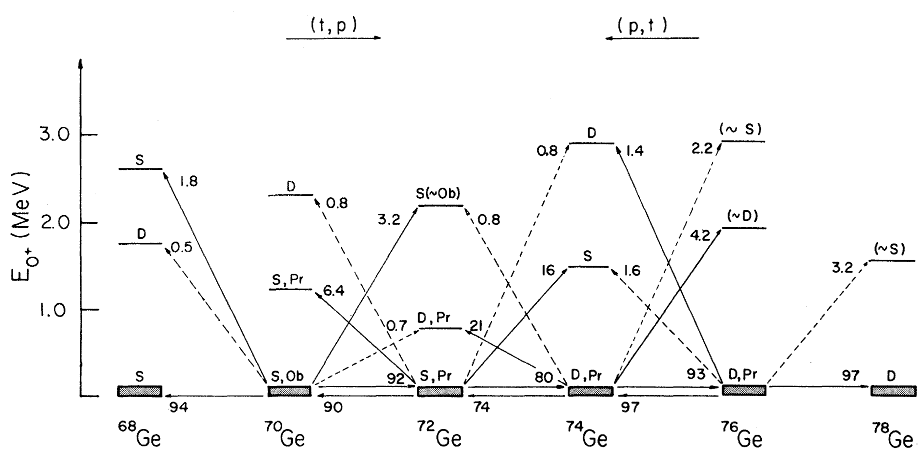

FIG. 1. Interpretation of the behavior of the (p,t) and (t,p) reaction versus Q_{2^+} measurements in the A-even Ge isotopes (see text).

tures are strongly favored (unfavored), the solid lines represent the "normal" $L=0$ transfer reactions within 0^+ states with similar shapes; the dotted lines represent $L=0$ transfer reactions with "anomalous" shapes.[3] The numbers on the lines give the relative intensity of population of the levels expressed in the percentage of the total cross section. From our Q_{2^+} and $B(E2)$ values[6] one could assign an almost spherical nature to the ground and low-energy excited states of ^{70}Ge and ^{72}Ge with the exception of the $0^{+\prime}$ and $0^{+\prime\prime}$ levels. On the other hand, the same states in ^{74}Ge and ^{76}Ge could be considered as having a moderately deformed nature. These properties are supported by the behavior of the $^{72}\mathrm{Ge}(0^+)\leftrightarrow{}^{74}\mathrm{Ge}(0^+)$ and $^{74}\mathrm{Ge}(0^+)\leftrightarrow{}^{76}\mathrm{Ge}(0^+)$ $L=0$ transfer reactions. In fact, the transition strength between the ground state of ^{74}Ge and ^{76}Ge (which have similar natures) is larger than that between the ground states of ^{72}Ge and ^{74}Ge which show the alleged shape change. Then the letters S (spherical) and D (deformed) shown in Fig. 1 indicate the shape characterizing each of the 0^+ levels and deduced from the intensity of the normal or anomalous $L=0$ transfer reactions. From an inspection of Fig. 1, it is evident that 0^+ states of different nature (or deformation) coexist in the same nucleus. For instance, the shape of the $0^{+\prime}$ levels of ^{72}Ge and ^{74}Ge must be identified to the shape of the ground state of ^{74}Ge and ^{72}Ge, respectively. Thus D and S characteristics are assigned to the $0^{+\prime}$ states of ^{72}Ge and ^{74}Ge, respectively. The above considerations are supported by the fact that a weak transition takes place between the deformed ground state of ^{76}Ge and the assumed spherical $0^{+\prime}$ excited state of ^{74}Ge. These results clearly show that a spherical to deformed shape transition takes place between the ^{72}Ge and ^{74}Ge nuclei and that these nuclei exhibit coexistent states of different nature (or deformation). The latter feature is also displayed in ^{68}Ge and to a lesser extent in ^{76}Ge and ^{78}Ge. The ^{70}Ge nucleus is somewhat anomalous within this framework. In fact, its ground state is relatively spherical, thus its first 0^+ excited level should be deformed. However, the observed behavior of the $L=0$ transfer reaction between the ground and the excited 0^+ states of $^{72}\mathrm{Ge}(0^+)$ and $^{70}\mathrm{Ge}(0^{+\prime})$, respectively, would agree more to a similar nature of these two states (i.e., to a spherical shape of the $0^{+\prime}$ level in ^{70}Ge). This feature is also supported by the much weaker $L=0$ transition from $^{72}\mathrm{Ge}(0^+)$ to $^{70}\mathrm{Ge}(0^{+\prime\prime})$ which would indicate that the $0^{+\prime\prime}$ state in ^{70}Ge is deformed. This apparently anomalous characteristic can be tentatively explained by considering the type of deformation [oblate (ob) or prolate (pr)] which takes place in the Ge nuclei and which can be obtained from our Q_{2^+} measurements.[6] Then, following the same trend of reasoning as above, oblate or prolate characteristics are attached to 0^+ ground and excited states in the Ge nuclei as shown in Fig. 1. This would remove the apparent anomaly in ^{70}Ge since oblate and prolate shapes may coexist in this nucleus, in agreement with several theoretical predictions.[1,7–10] With this in mind, the very weak transition between the 0^+ ground and $0^{+\prime}$ first excited states of ^{70}Ge and ^{72}Ge, respectively, may also be explained. In fact, in this case the $L=0$ transfer takes place not only between a spherical to a deformed state, but also between an oblate spheroid to a prolate deformed state. Obviously the same considerations should be valid for the $0^{+\prime\prime}$ levels in ^{70}Ge and ^{72}Ge (see Fig. 1).

The above interpretation seems particularly enticing because it would integrate harmoniously in a universal picture three hypotheses on the structure of the even-A Ge nuclei, that is: (1) the existence of a shape coexistence which has been suggested more or less explicitly by a plethora of theoretical investigations[1,4,5,7,10–13] and is supported by some experimental works[4–6]; (2) the presence of a spherical to deformed shape transition between $N=40$ and $N=42$. This feature has been predicted theoretically[1,3,5,8–10,14] and inferred experimentally[1,4,6]; (3) the existence of a gentle oblate to prolate shape transition between $N=38$ and $N=40$ which has been assessed both experimentally and theoretically.[1,6,10,15]

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