Octupole modes of oscillation via analyzing power measurements

D. Ardouin
University of Nantes, Nantes, France

Ronald E. Brown, J. A. Cizewski, E. R. Flynn, and J. W. Sunier
Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87545

P. Alford and E. Sugarbaker
University of Colorado, Boulder, Colorado 80309
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Measurements of the analyzing power in the two-nucleon transfer reactions ^{70,72}Ge($\vec{t}$,p) have been carried out. This is a region where a shape transition has been previously proposed. Contrary to recent ($\vec{p}$,t) results, no strong interference effects between direct and two-step processes leading to the 2_1^+ states have been observed. However, a marked difference has been revealed for the 3_1^- octupole transition. A microscopic interpretation of this effect is proposed.

[NUCLEAR REACTIONS ^{70,72}Ge($\vec{t}$,p) measured $\sigma(\theta)$, A_y, DWBA analysis.]

The phase dependence of the interference between a direct process and inelastic multistep processes in two-neutron transfer reactions is known to be quite sensitive to the nuclear structure involved. Recent measurements with ($\vec{p}$, t) reactions, for instance, have revealed marked differences between the analyzing powers for the transitions leaving the residual nuclei in their first excited 2^+ (2_1^+) states.[1,2] These differences have been attributed to correlations due to the collective quadrupole oscillations as predicted in a microscopic description. In particular, there is almost a complete change of sign of the analyzing power A_y between the two isotones ^{114}Cd and ^{116}Sn, the latter being accepted as less collective than the former.

We have recently attempted to see if measurements of analyzing powers for the ($\vec{t}$, p) reaction would reveal similar effects and, therefore, could be used to investigate the microscopic structure of nuclear collective motion.[3,4] The present paper is a part of this work and focuses on the study of the Ge nuclei. A possible shape transition at N = 40–42 has been proposed from transfer experiments, particularly from the comparison of (p, t) and (t, p) reaction strengths[5,6] to 0^+ states. That the active shell model orbits are the same for the valence protons and neutrons has been shown to play a significant role in the onset of a shape instability in these nuclei. This appeared for instance in the observed neutron excess ($N-Z$) dependence of the octupole vibrational energies in this mass region[7] and in the occurrence of a splitting and reduction of the octupole-state strengths at $N=42$ in two-neutron transfer[6] and inelastic proton scattering[7,8] data.

The first purpose of this work is to look for the influence of nuclear structure effects on analyzing-power measurements in order to clarify the microscopic aspects of collective quadrupole or octupole oscillations. A further aim is to compare the sensitivity to the presence of interference effects of ($\vec{t}$, p) measurements with ($\vec{p}$, t) studies.

The analyzing powers and differential cross sections for (t, p) reactions leading to the ground-state (0_1^+), 2_1^+, and 3^- states of ^{72,74}Ge ($N=40$ and 42, respectively) were measured at $E_t = 17$ MeV. The beam was provided by the Los Alamos polarized triton source and FN tandem Van de Graaff accelerator. Typical polarizations of 0.75 were obtained with average beams of 60 nA. The emitted protons were analyzed with a quadrupole-three-dipole (Q3D) magnetic spectrometer and detected with a helical cathode proportional detector. A monitor detector served to provide relative normalizations as well as absolute cross sections based on optical model calculations. The ^{70}Ge and ^{72}Ge targets were enriched metallic oxides of 400 μg/cm^2 thickness. A more detailed description of the experimental apparatus is given in Ref. 9.

Angular distributions of differential cross sections and analyzing powers are shown in Figs. 1 and 2 for ^{72}Ge and ^{74}Ge, respectively. Examination of these two figures shows the two ground-state transitions to be quite similar. A slight tendency towards more negative values is observed for the $L=2$ A_y values in ^{74}Ge as compared to ^{72}Ge, while the two differential cross sections are very similar. A pronounced difference exists

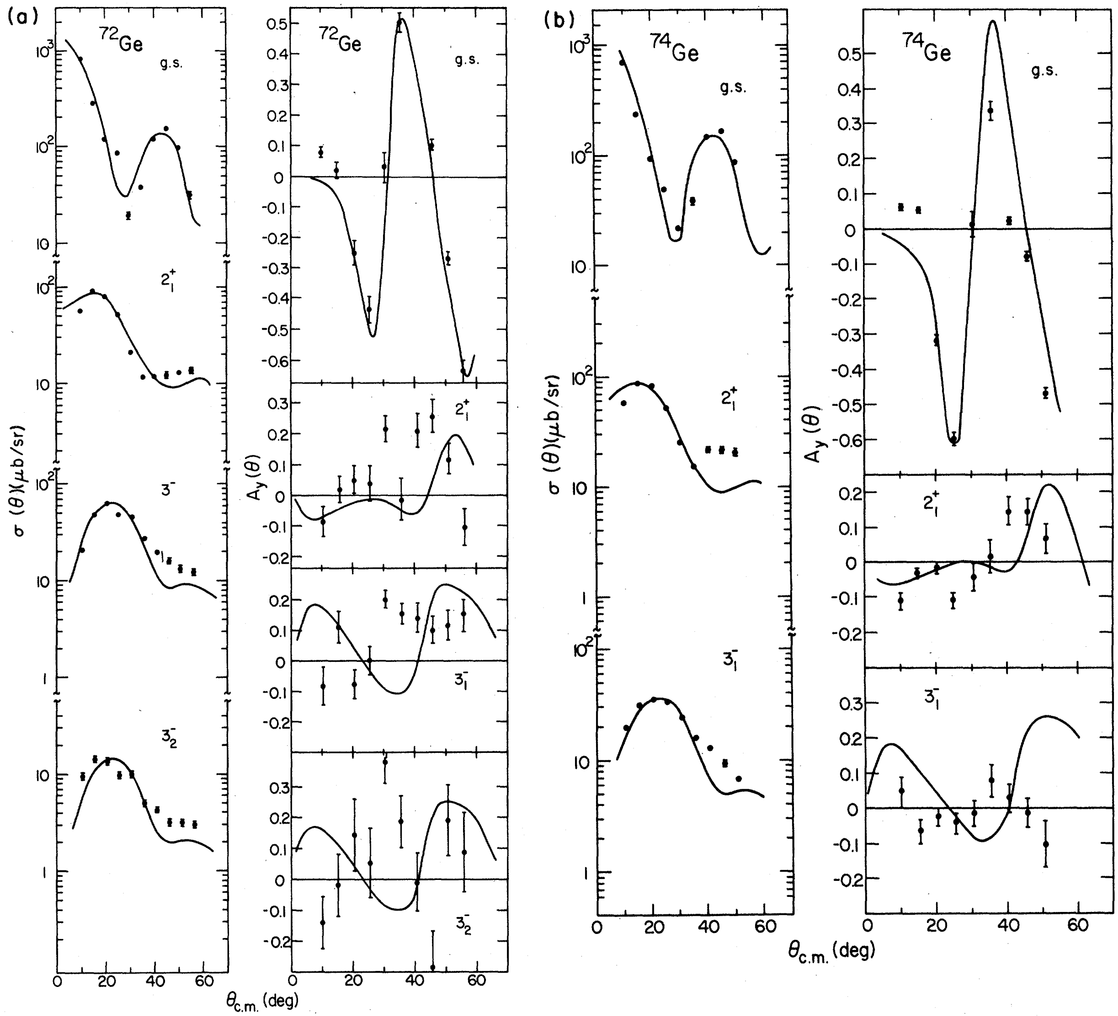

FIG. 1. (a) Analyzing power $A_y(\theta)$ and cross sections $\sigma(\theta)$ for the reaction $^{70}Ge(\vec{t},p)^{72}Ge$. Solid curves are DWBA calculations. (b) $^{72}Ge(\vec{t},p)^{74}Ge$ reaction. See caption for (a).

for the $L=3$ A_y values beyond 25° where the ^{72}Ge data exhibit positive values around 0.15, while zero or negative values appear for ^{74}Ge. A drop of about 40% is also observed in the 3_1^- state intensity leading to ^{74}Ge. Distorted wave calculations have been performed with the code DWUCK[10] using the triton potential taken from a survey of scattering data by Flynn *et al.*,[11] with an added spin-orbit potential from the polarized measurements of Hardekopf *et al.*[12] The analyzing-power calculations do show a greater sensitivity to the choice of the proton potential than do the differential cross sections. The best overall fit was obtained with the parameters of Picard[13] from a proton scattering analysis. These parameters are also very close to those used in the analysis of the Ni polarized data.[3] The quality of the fits is good for the ground-state A_y and cross sections. The position of the second maximum of A_y calculated for the 2_1^+ is shifted by about 6° as compared to the experimental data. A similar inadequacy of distorted-wave Born approximation (DWBA) calculations has already appeared in the analysis of Ni and Pd polarized data[3,4] to some extent, depending on the proton potential set. However, the present results show that DWBA calculations using the optical model parameters from the literature do reproduce the gross feature of the 2^+ data for the two Ge nuclei investigated and that there is no evidence for an out-of-phase behavior, as observed in the $(\vec{p},t)$ analysis of Yagi *et al.*,[1,2] between two nuclei of different shapes. Additionally, the corresponding 2_1^+ state cross sections measured by Yagi and co-workers also exhibited a different pattern and intensity. This behavior is not noted in the present $(\vec{t},p)$ data. The Ge (p,t)

2_1^+) state angular distributions of Guilbault *et al.*,[6] however, do show some discrepancies and a flatter structure than the standard DWBA $L=2$ shapes or higher 2^+ state angular distributions. That fact might also indicate, as suggested from the present analyzing-power measurements, that the phase change from interference between direct and indirect multistep processes[1,2] to the 2_1^+ states does not have the same sensitivity in stripping and pickup mechanisms.

The pronounced differences in analyzing power already mentioned for the $L=3$ transitions in ^{72}Ge and ^{74}Ge are emphasized by the DWBA calculations. Indeed the calculated analyzing power for ^{72}Ge is becoming out of phase with the data for the 3_1^- state transition. The same may also be true for the weakly populated state at 2.945 MeV which is known[6] to be the second 3^- state excited in the (t,p) reaction. This behavior at first appears quite surprising since the 3^- state is the strongest excited state of the Ge(t,p) data of Lebrun and co-workers,[6] and one should expect indirect processes to be small. The opposite situation revealed by our data must be correlated with the drop of the $L=3$ strength in ^{74}Ge and its splitting over two other states at 3.144 and 4.169 MeV (not studied here) in the two-neutron transfer data.[6] A similar splitting of the octupole transition in ^{74}Ge appears in the (p,p') data[8] correlated with a subsequent decrease of the ($BE3$: $0_1^+ \to 3_1^-$) value between ^{72}Ge and ^{74}Ge. The large $B(E3)$ value could initiate an inelastic process to the 3^- state resulting in a more significant two-step contribution in the ^{72}Ge nucleus. This behavior could also be responsible for a weak difference mentioned in the work of Lebrun *et al.*[6] between the ^{72}Ge and ^{74}Ge 3_1^- state angular distributions. A slight two-maxima pattern was noted in ^{72}Ge (and absent in ^{74}Ge) around 30°, precisely where the maximum of the A_y measurement is found (Fig. 1).

A key to understanding our data may come from examining the microscopic structure of octupole vibrations. The energy systematics of 3^- excitations in nuclei with $A \gtrsim 60$ can be correlated[14] with the spin-orbit interaction lowering $j+\frac{1}{2}$ orbitals, so that negative-parity states can be formed by excitations within the valence shell. For the Ge region the $g_{9/2}$ orbital is lowered into a negative-parity shell, so that low-lying 3^- states are expected to occur. The ($p_{3/2}$-$g_{9/2}$) proton transition inside the $Z=28-50$ major shell is expected to contribute much more to the lowest octupole excitations than the weak ($f_{5/2}$-$g_{9/2}$ or $p_{3/2}$-$d_{5/2}$) transitions according to pairing + octupole-octupole interaction calculations.[15,16] On the other hand, proton transfer data[17] have given strong evidence for a change in ordering of proton orbitals in this mass region. Between $N=40$ and 42 the $f_{5/2}$ state drops below the $p_{3/2}$ state which could explain the larger $B(E3)$ values in ^{72}Ge and, therefore, a favored inelastic indirect process in the ^{70}Ge$(t,p)^{72}$Ge transfer as revealed by our data. In addition, the splitting of the octupole strength observed experimentally at $N=42$ indicates a competition with other octupole modes of oscillation, such as neutron excitations[14,15] with the onset of the filling of the $g_{9/2}$ neutron orbital. This should also be connected to the (N-Z) dependence of the octupole vibration observed by Matsuki and coworkers[7] where the effects of adding two protons or two neutrons seem to cancel each other. The neutron-proton interaction has been proposed[18] to account for the onset of collectivity around $N=42$.

In conclusion, the analyzing-power measurements on octupole transitions, which in medium mass nuclei are known to be more intimately connected with the details of the individual orbits than are quadrupole transitions, appear as a very sensitive tool to investigate the microscopic structure of nuclear collective motion. In the present case an instability of the spherical shape (as suspected[6] in the ^{72}Ge ground state) with respect to octupole deformations has been revealed.

Other nuclei (^{128}Te, ^{150,152}Sm) are also known to exhibit a splitting of the octupole strength. It would be of interest to perform similar $(\vec{t},p)$ and $(\vec{p},t)$ measurements on these nuclei in order to explore more generally the effect of octupole instabilities on the reaction mechanism of two-neutron transfers.

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