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II-16 The Measurement of the Quadrupole Moments of the First 2^+ States of ^{150}Sm and ^{194}Pt by the Reorientation Precession Technique

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Static quadrupole moments, Q, of a number of first 2^+ states in even nuclei have been measured in recent years with results of considerable significance to the understanding of the nuclear structure of these states.[1,2] The various techniques so far used measure the differential cross section for Coulomb excitation in such a manner that the diagonal quadrupole matrix element -a 2nd order effect- can be deduced from the data. Breit and his collaborators,[3] who suggested the bases for these methods, actually stressed a different approach for determining Q. They showed that the quadrupole interaction in the close collisions of heavy ions changes the sub-state population of the excited state, and that this reorientation is manifest in the angular distribution of the deexcitation gamma rays. Eichler and de Boer pointed out[1,4] that the perturbation discussed by Breit was in fact a precession (plus a breathing mode) of the angular distribution, (see Fig. 1) and that the turning angle with respect to the momentum transfer axis is linearly proportional to the quadrupole moment. We will call this the reorientation precession effect to distinguish it from the conventional techniques which for historic reasons continue to be called by the generic but misleading name of reorientation effect.

Eichler and de Boer emphasized that the reorientation precession technique is in principle a more reliable method than conventional reorientation techniques for measuring Q. It is a first order effect in contrast to the usual methods which require two independent measurements to deduce Q from a usually small correction to a large number. Moreover, the reorientation precession effect is much less sensitive to interferences involving higher order transitions which continue to confound and make ambiguous some of the results of conventional reorientation methods.

The precise angular distributions of the deexcitation gamma rays for a given experimental condition requires, at least, the full analysis of the de Boer-Winther Coulomb excitation computer program. It is useful, however, to have a first order estimate for the precession angle, Δ_{rp}, for a 2^+ state, based on the

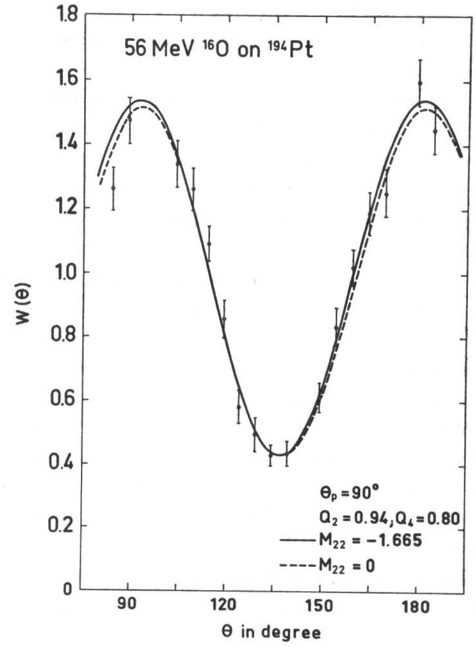

Fig. 1. The observed and expected angular distributions of deexcitation gamma rays from the first 2^+ state of ^{194}Pt in coincidence with oxygen projectiles scattered through a laboratory angle of 90°. The gamma ray angle, θ, is measured with respect to the beam direction. The theoretical curves were obtained from the de Boer-Winther program. Four levels 0^+, 2^+, 2^+, 4^+ in ^{194}Pt were taken into account. The dashed curve assumes $Q(21) = 0$. The solid curve assumes $Q(21)$ is oblate and of rotational strength.

classical quadrupole interaction,

$$\Delta_{rp} \simeq \frac{Z \text{ proj } QP}{5D^2\beta \text{ proj}}, \qquad (1)$$

where Q is in barns, D is the closest distance of approach in fermis, P is the polarization of the nucleus produced by the Coulomb excitation.[6] For oxygen projectiles scattered through 90° exciting a 2^+ state in

^{150}Sm having a quadrupole moment of 1 barn, one finds, $\Delta_{rp} \simeq 1.2°$, reasonable close to the results of the de Boer-Winther calculation given below. Furthermore the crude formulation, eq. (1), is also in reasonable agreement with the full calculation in predicting that for a given heavy ion projectile, the precession angle is only weakly dependent on either on the projectile energy or the scattering angle around 90° since the polarization factor, P, almost compensates the energy and scattering angle dependence of the denominator in eq. (1).

The smallness of the effect with the heavy ion beams available till now has deterred experimentalists. One investigation which sought the effect in ^{114}Cd excited by ^{16}O scattered through 90° had insufficient experimental accuracy to observe the expected 10 millirad rotation.[7]

We report here the unambiguous observation of the reorientation precession on the first 2^+ states of ^{150}Sm and ^{194}Pt excited by ^{16}O and ^{32}S beams. Both states have been studied by conventional reorientation techniques. The 334 keV state of ^{150}Sm is definitely prolate; the measured quadrupole moment[8] is about 25% larger than the rotational value based on the B(E2) value. The 328 keV State of ^{194}Pt has been determined to be oblate[9] confirming theoretical expectation.

The angular distribution of the deexcitation gamma rays in the scattering plane has the functional form

$$W(\theta_\gamma\theta_p) = N(\theta_p, X) + F(\theta_p, X) \cos 4(\theta_\gamma + \Delta) ,$$

where the coefficients N and F and the precession angle Δ are dependent on the quadrupole interaction as well as the usual Coulomb excitation parameters. The angle θ_γ is measured with respect to the recoil direction which is the symmetry axis for the correlation in first order perturbation theory when $Q = 0$. The Q dependence of N and F is weak and difficult to measure. The present experiments measured Δ.

The technique used for the results reported here was as follows:
Coincidence rates were measured between the particle detector, at θ_p with respect to the ^{16}O beam, and each of two NaI gamma detectors always separated by 45°. Runs were taken for a fixed θ_p varying the mean angle of the gamma detectors about the recoil axis. The particle detector was then turned to a scattering angle of $-\theta_p$ and the runs repeated with the gamma ray detectors in the appropriate positions about the new recoil axis. The anisotropy of the γ-particle coincidence rates as a function of mean gamma ray detector angle was fit by polynomials generated by the known functional form of the angular correlation. That form was checked in independently, Fig. 1.

The precessions angles for several scattering angles and for excitation by ^{16}O and ^{32}S are shown in Fig. 1. The results show unambiguously that the first 2^+ states of ^{150}Sm and ^{194}Pt are prolate and oblate respectively. The magnitudes of the quadrupole moments are in accord with previous reorientation results; they are somewhat larger than expected from a rotor model of the nuclear states. On the other hand the present results still contain sufficient uncertainty as to overlap with rotor values.

There are a number of effects of geometrical origin which produce spurious precessions. We summarize here some of the tests and consistency checks used; a detailed discussion will be presented elsewhere.

Rutherford scattering rates as a function of scattering angle were obtained prior to each run to check for misalignments of the particle detector with respect to the beam. Angular distributions of the gamma rays with respect to back scattered particles detected in a ring counter were run periodically to check for gamma ray detector misalignments. The alignment of the beam with respect to the turning axis of the target was checked at each run. Finally there was a consistency of precession results (within 0.2°) when the source to detector distances were increased from 2 to 6 cm and, when at 6 cm, the slits in front of the detector were changed from 2 to 6 mm.

There are also physical interactions other than the reorientation precession which produce precessions of the angular distribution.[10,11] One of these effects is the precession arising from the interaction of the nuclear quadrupole moment with the electric field gradient produced by an enhanced density of electrons scattered from the nucleus recoiling in the target. This effect, the subject of an accompanying paper,[11] is estimated to be less than 2 mrads in the experiments described here. More troublesome are quantal (orbit distorting) effects[12] especially in multiple Coulomb excitation[13] which cause rotations of the symmetry axis even in the absence of a quadrupole moment. The experimental values shown in Fig. 2 have been corrected for first order quantum mechanical effects according to the prescription of Smilansky.[12] These are small (0.1°) for the ^{16}O results, but are substantial (0.5°) for the ^{32}S results. Computer calculations show that these effects can be severe complications with heaviar ions or with states of larger B(E2) values.

Improvements in the experimental arrangement are

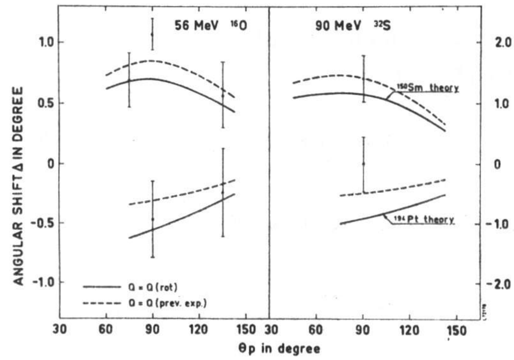

Fig. 2. The measured gamma ray distribution precession angles, Δ, for 56 MeV ^{16}O and 90 MeV ^{32}S beams exciting the first 2^+ states of ^{150}Sm and ^{194}Pt. The dashed curves are theoretically expected assuming the Q values are those measured in traditional reorientation experiments. (refs. 8 and 9) The solid curves use Q values derived from the B(E2) values assuming a pure rotor model. The angular shifts are with respect to the recoil axis and are opposite for the two states investigated.

now in progress to increase the counting rates by a factor of three and to decrease geometrical misalignments by a factor of 5. With these improvements we expect that the reorientation precession technique will be of practical use for states throughout the periodic table.

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