scaling of the normalization constant A, leaving the general pattern of scaling violation unchanged.

[14] The apparent discrepencies for the AF case at $x \simeq 0.20$ are not to be taken seriously as there is no reason for the theory to hold at such low q^2.

[15] D. J. Fox *et al.*, Phys. Rev. Lett. 33, 1504 (1974).

Evidence for Intermediate Structure in the Inelastic Scattering of Polarized Protons from ^{26}Mg and ^{27}Al†

C. Glashausser, A. B. Robbins, E. Ventura, F. T. Baker,* J. Eng, and R. Kaita
Department of Physics, Rutgers University, New Brunswick, New Jersey 08903

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Structure of variable widths from about 0.3 to 1.5 MeV has been observed in analyzing-power excitation functions for inelastic proton scattering from ^{26}Mg and ^{27}Al. Statistical tests and significant cross correlations show that it is very unlikely that this structure is the chance effect of random fluctuations. Thus these data are evidence for intermediate structure.

Since Block and Feshbach[1] and Kerman, Rodberg, and Young[2] suggested that simple modes of excitation of the nucleus might lead to structures with widths intermediate between those for the compound nuclear states and those for single-particle states, many attempts have been made to identify these states in nuclear reactions. Apart from isobaric analog resonances, however, only two isolated examples of intermediate structure in the elastic or inelastic scattering of protons are considered well-established.[3-5] The lack of selectivity in the (p,p') reaction mechanism presumably makes it difficult to observe definitively nonstatistical peaks in cross-section excitation functions, even when there is some evidence for intermediate structure.[6-8] In this Letter we report convincing evidence for intermediate structure in the elastic and inelastic scattering of low-energy protons from ^{26}Mg and ^{27}Al from measurements of analyzing-power excitation functions. The ease with which the structure is identified suggests that the method should have wide applicability.

The analyzing power A_y is a sensitive indicator of coherent structure; its magnitude depends on the interference between different partial waves. For direct reactions, A_y may be nonzero, but its value should vary smoothly over an energy region of several MeV. For compound reactions, the value of A_y averaged over a sufficiently large energy region should be zero because of the random phases of the contributing partial widths. In a region of high level density where the average width Γ of the compound states is much greater than the average spacing D, the value of A_y measured in small intervals should oscillate rapidly about zero in a manner characteristic of Ericson fluctuations. Intermediate structure is indicated by peaks in the excitation function of A_y which remain significant when the data are averaged over a region much larger than Γ.

The experiments were performed at the Rutgers FN tandem Van de Graaff accelerator, using the atomic-beam polarized-ion source. Solid-state detectors were mounted at symmetric angles on each side of the incident beam. Beam polarization was monitored continuously with a helium polarimeter. Targets were 0.5- to 1.0-mg/cm^2 self-supporting foils of ^{26}Mg and ^{27}Al. Data were recorded in 50-keV steps from 5.5- to 9.4-MeV incident proton energy for ^{26}Mg and in 50- and 100-keV steps from 6.1- to 12.0-MeV bombarding energy for ^{27}Al at several angles between 60° and 160°. Excitation functions of A_y for several final states in ^{26}Mg at 140° and for ^{27}Al at 145° are shown in Figs. 1 and 2.

The qualitative features that indicate intermediate structure are apparent from these figures. The raw data in 50-keV steps [e.g., Fig. 1(b)] show the expected Ericson fluctuations; a coherence width Γ of about 50 keV has been determined from previous cross-section measurements.[7,9] However, considerable structure remains when these fluctuations have been smoothed by averaging over larger intervals. The p_1 and p_2 data (p_i refers to the proton group leading to the ith state) for ^{26}Mg at 140° are probably the most striking. The p_1 data show two negative peaks about 750 keV wide separated by 1.5 MeV. The p_2 data reveal one positive bump of about the same width; the value of A_y rises to 0.7 at the peak compared to values close to zero everywhere else. The

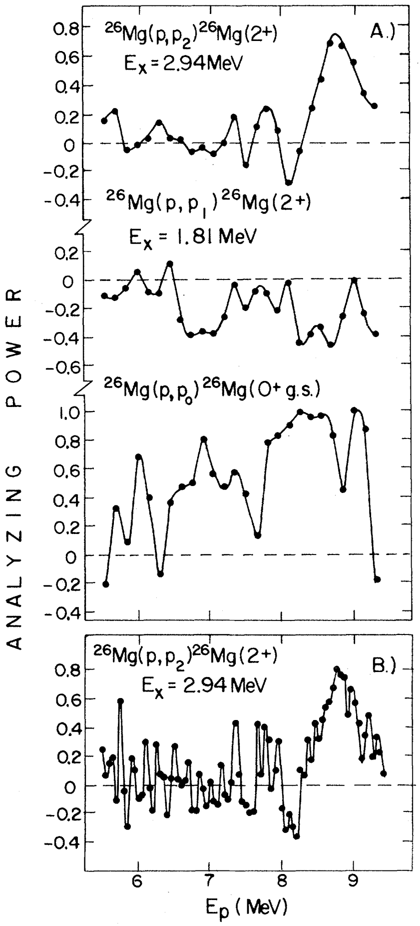

FIG. 1. (a) Measured analyzing powers as a function of incident proton energies for the reaction ^{26}Mg(p, p')^{26}Mg at θ_{lab}=140°. Each point shown is the average of three data points measured at 50-keV intervals. The solid lines are guides to the eye. (b) Measured analyzing powers as a function of incident proton energies for the reaction ^{26}Mg(p,p_2)^{26}Mg (2_2^+) at θ_{lab}=140°. The data shown were taken at 50-keV intervals.

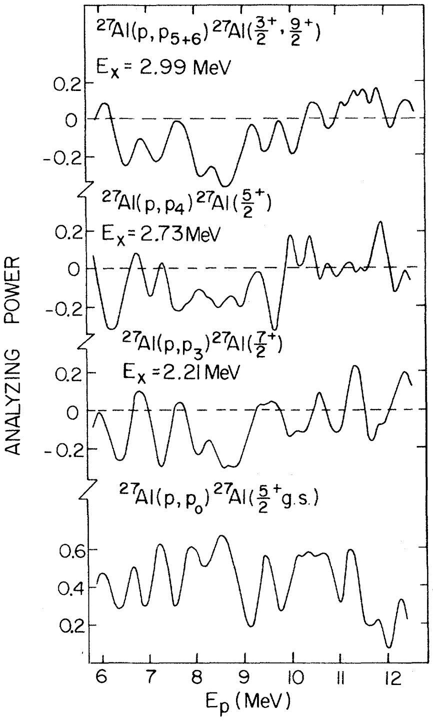

FIG. 2. Measured analyzing powers as a function of incident proton energy for the reaction ^{27}Al(p,p')^{27}Al at θ_{lab}=145°. The solid lines have been drawn through data points which have been smoothed over an interval $2\delta E$ of 300 keV.

structure in the ^{27}Al data has a greater variety of widths, and the smoothed values of A_y are not as large. Note, however, that the 1-MeV wide bump around 8.5 MeV appears in at least three of the four observed channels and that p_3 and p_{5+6} are generally strongly correlated.

Statistical tests of Baudinet-Robinet and Mahaux[5] indicate it is very unlikely that such structure can be the chance effect of random fluctuations.[10] The first test (IV.3. in Ref. 5) involves calculation of the *total number* of runs above and below an arbitrary reference value R. (A run is defined as a sequence of independent data points all of which are above or all of which are below R.) The second test (IV.5. of Ref. 5) is based on the length of the *longest* run observed both above and below R. Random data will generally consist of a relatively large number of mostly short runs. Note that these are only two of numerous possible tests. It is necessary to satisfy just one to indicate nonrandomness.

Values of A_y averaged over 2 to 3 times Γ and separated by 2 to 3 times Γ were considered independent.[11] In the absence of intermediate structure, the data points of Fig. 1(a) would thus fluctuate randomly about an average value defined by the direct-reaction contribution which is assumed to be constant. Test 1 indicates that it is less than 1% probable that either the ^{26}Mg p_1 data points or the ^{26}Mg p_2 data points in Fig. 1(a) constitute a set of independent random numbers. Test 2 indicates nonrandomness at the 1% level for the ^{27}Al p_{5+6} state at 145° and for the ^{26}Mg p_2 state at 140°.

These tests were applied to the entire range of data at once. Test 2 is more sensitive if it is applied successively to regions of data only slightly larger than the width of the apparent intermediate structure. The assumption of a flat direct-

TABLE I. Probability P that the data are random. The value listed is the smallest value obtained from the statistical tests described in the text.

		Angle			Angle
Reaction	120°	140°	160°	Reaction	145°
^{26}Mg(p,p_0)	>0.05	>0.05	>0.05	^{27}Al(p,p_0)	>0.05
^{26}Mg(p,p_1)	0.01	0.01	>0.05	^{27}Al(p,p_3)	0.01
^{26}Mg(p,p_2)	0.05	0.01	0.02	^{27}Al(p,p_4)	>0.05
				^{27}Al(p,p_{5+6})	0.01

reaction background is also essentially certain for a small energy range. The probability P of satisfying this modified Test 2 was calculated for computer-generated random numbers. Table I summarizes the results of all these tests. No nonstatistical structure was positively identified in forward-angle data. The p_1 and p_2 data for ^{28}Mg and the p_3 and p_{5+6} data for ^{27}Al are thus not in accord with the predictions of the statistical model. This statement remains true for all but the ^{27}Al p_3 state even if the "independent" averaged data points have a normalized correlation of about 0.30; the probability that the p_3 data are random would increase to about 7% in this case.

Calculations of normalized cross correlations $R^{\alpha\alpha'}$ between different channels α also indicate that the data are not random. Because we were searching for intermediate structure of width about 1 MeV, the correlations were calculated over an interval of 1.2 MeV for both actual and smoothed data. Since finite-range-of-data errors are not yet known for A_y correlations, the probability of obtaining large values of $R^{\alpha\alpha'}$ was calculated for computer-generated random numbers. Comparison of the values of $R^{\alpha\alpha'}$ for the actual data with the computed values for random numbers is thus another test of whether the averaged data are consistent with randomness. For ^{27}Al, the cross correlations between p_0-p_3, p_0-p_{5+6}, and p_3-p_{5+6} all appear to be nonstatistical, as expected from Fig. 2. For example, for 1.2-MeV intervals around all energies between 8.1 and 9.1 MeV, $|R(p_0\text{-}p_{5+6})|$ is greater than 0.6 for the unsmoothed data and greater than 0.8 for the smoothed data; this is less than 1% probable for random numbers. The correlations for ^{26}Mg are not as pronounced, but they also are very unlikely for random numbers.

This correlation analysis and the statistical tests of randomness clearly indicate nonstatistical structure. Is it possible that we are deceived? Of course, improbable events do occur. In addition, an unusually rapid variation with energy of the direct-reaction background, very different from the slowly varying predictions of the distorted-wave Born approximation, might distort the statistical analysis. Finally, an improbably large correlation between the "independent" data points of Fig. 1 would also increase the probability that they could arise from random nuclear amplitudes. According to Ericson fluctuation theory,[12] the normalized autocorrelation $C(\epsilon)$ is only 0.10 if ϵ is 3Γ, but this is not known for A_y. Thus a decisive test of our analysis would involve calculation of the probability distribution of A_y for inelastic scattering using random compound nuclear amplitudes. Haglund and Thompson[13] have begun to perform such calculations for elastic scattering where the number N of independent reaction channels is much smaller than for inelastic scattering. While initial indications are that A_y has somewhat larger correlations and fluctuations than the cross section, similar calculations of cross sections for $N=1$ show apparent structure which is quickly damped as N increases.[14] Even the $N=1$ structure would not appear nonrandom according to the statistical tests of Ref. 5.

The nature of the apparent intermediate structure is not yet understood. Previous analysis of cross-section data for ^{26}Mg indicated no significant deviations from the statistical model[9]; for ^{27}Al there are indications of nonrandom structure in the cross section but positive identification would be very difficult.[7,8] There is stronger evidence for structure in the (p,α) reaction on ^{26}Mg.[15] The relationship between the structure in the cross section and the structure observed here in A_y is not simple, but this is expected since peaks in the A_y excitation function must correspond to the interference of at least two entrance-channel partial waves.[16] The fact that so much structure is observed for both ^{26}Mg and ^{27}Al makes it likely that overlapping intermediate states are at least partly responsible in both cases. This could account for the fact that unusual structure is not clearly visible in cross-section data; it becomes visible in A_y data because of the sensitivity of A_y to interference.

Further clues to the origin of the observed structure are presently being sought by extending the measurements to higher energies (where we have now found further structure), and to neighboring nuclei, and by analyzing the angular distributions of A_y. It may be noteworthy that the structure observed here in A_y for ^{27}Al(p,p') is surprisingly similar to structure previously observed in the cross-section excitation function for the ^{27}Al(p,γ_0)^{28}Si capture reaction.[17] Explanations of the bumps in terms of more general doorway configurations such as particle-vibration coupling[8] may also be possible. In any case, the striking nature of the structure observed here in A_y, compared to the much more gentle average structure observed for so long in cross-section studies, suggests the importance of pursuing this investigation both theoretically and experimentally.

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*Present address: Department of Physics, University of Georgia, Athens, Ga. 30602.

[1] B. Block and H. Feshbach, Ann. Phys. (N.Y.) 23, 47 (1963).

[2] A. K. Kerman, L. S. Rodberg, and J. E. Young, Phys. Rev. Lett. 11, 422 (1963).

[3] G. M. Temmer, M. Maruyama, D. W. Mingay, M. Petrascu, and R. Van Bree, Phys. Rev. Lett. 26, 1341 (1971).

[4] W. Mittig, Y. Cassagnou, N. Cindro, L. Papineau, and K. K. Seth, Nucl. Phys. A231, 316 (1974).

[5] Y. Baudinet-Robinet and C. Mahaux, Phys. Rev. C 9, 723 (1974).

[6] J. Hellström, P. J. Dallimore, and W. F. Davidson, Nucl. Phys. A140, 378 (1970).

[7] R. V. Elliot and R. H. Spear, Nucl. Phys. 84, 209 (1966).

[8] T. Kozlowski, Z. Moroz, W. Ratynski, M. Szymczak, and J. Wojtkowska, Acta Phys. Pol. B6, 309 (1975).

[9] O. Häuser, A. Richter, W. vonWitsch, and W. J. Thompson, Nucl. Phys. A109, 329 (1968).

[10] Although these tests have been described as applicable only when a unique spin and parity of the compound nucleus contributes, they are in fact applicable here where many spins and parities are involved. This is because, according to Ericson fluctuation theory, any permutation of the sample of A_y or $d\sigma/d\Omega$ as a function of energy should have equal probability in the absence of intermediate structure.

[11] C. Mahaux, private communication.

[12] A. Richter, in *Nuclear Spectroscopy and Reactions*, edited by J. Cerny (Academic, New York, 1974), Part B, p. 343.

[13] R. F. Haglund, Jr., and W. J. Thompson, Bull. Am. Phys. Soc. 20, 693 (1975), and private communication.

[14] P. P. Singh, P. Hoffman-Pinther, and D. W. Lang, Phys. Lett. 23, 255 (1967), and private communication.

[15] B. W. Allardyce, P. J. Dallimore, I. Hall, N. W. Tanner, A. Richter, P. vonBrentano, and T. Mayer-Kuckuk, Nucl. Phys. 85, 193 (1965).

[16] H. L. Harney, Phys. Lett. 28B, 249 (1968).

[17] P. P. Singh, R. E. Segel, L. Meyer-Schutzmeister, S. S. Hanna, and R. G. Allas, Nucl. Phys. 65, 577 (1965).

Magnetic Moment of the 6_1^+ State in ^{42}Ca†

L. E. Young, R. Brenn,* S. K. Bhattacherjee,‡ D. B. Fossan, and G. D. Sprouse§
Department of Physics, State University of New York, Stony Brook, New York 11794

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The g factor of the 6_1^+ state at 3189 keV ($T_{1/2}=5.4$ nsec) in ^{42}Ca has been remeasured with a significant improvement in accuracy by a pulsed-beam time-differential method using an in-beam superconducting magnet at 61 kG. The g factor obtained is $g(6_1^+)=-0.415\pm0.015$. A $g(\nu f_{7/2})=-0.53\pm0.02$ is extracted from this result by use of the coexistence wave function due to Erikson; this value is in agreement with the single-particle value of -0.547 indicating a negligible orbital anomaly δg_l.

The study of the magnetic moments of nuclear states near doubly closed shells provides a useful probe into the magnetic properties of nucleons inside nuclear matter. Because of the structure of the bare $M1$ operator, there are no first-order core-polarization contributions to the single-particle magnetic moment from a core which is doubly closed in both L-S and j-j coupling, as for the ^{40}Ca nucleus. Recently there have been theoretical efforts[1-4] to understand the magnetic dipole moments of states in the Ca region in terms of effective $f_{7/2}$-nucleon moments and hence to test the additivity of $f_{7/2}$ magnetic moments in this region. The determination of whether there are anomalies in the orbital part of $f_{7/2}$-nucleon g factors, δg_l, due to mesonic effects[5] is of considerable interest. The magnetic moment of the 6_1^+ state in ^{42}Ca plays a pivotal role