of unity on the spectroscopic factors is exceeded only for the state at 5.15 MeV. The sums of the $d_{3/2}$ and $s_{1/2}$ spectroscopic factors at the $f_{7/2}$ resonance are 1.83 and 1.51, respectively. The sum rule,

$$\sum_i S_{pp'}^{(i)}(Jj) = 2j + 1,$$

where j is the spin of the hole state, indicates that the sum of the $d_{3/2}$ spectroscopic factors should be 4.00, and that of the $s_{1/2}$ spectroscopic factors, 2.00. Only about one-half of the total $d_{3/2}$ hole strength is accounted for, as is expected, since only 3^- and 4^- spins have been analyzed at this resonance, and $d_{3/2}$ strength will be present in 2^- and 5^- states. The $s_{1/2}$ sum rule is, as expected, nearly satisfied. The situation is more complicated at the $p_{3/2}$ and $f_{5/2}$ resonances since at the $p_{3/2}$ resonance the data allowed analysis of only four out of nine particle-hole states, and at the $f_{5/2}$ resonance, only six out of ten particle-hole states.

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[1] P. A. Moore, P. J. Riley, C. M. Jones, M. D. Mancusi, and J. L. Foster, to be published.

[2] See, for example, S. A. A. Zaidi, L. J. Parish, J. G. Kulleck, C. F. Moore, and P. von Brentano, Phys. Rev. 165, 1312 (1968); G. C. Morrison, N. Williams, J. A. Nolen, Jr., and D. von Ehrestein, Phys. Rev. Letters 19, 592 (1967).

[3] A similar expression has been given previously by S. A. A. Zaidi, P. von Brentano, K. Melchior, P. Rauser, and J. P. Wurm, in Isobaric Spin in Nuclear Physics, edited by J. D. Fox and D. Robson (Academic Press, Inc., New York, 1968), p. 798.

[4] A. M. Lane and R. G. Thomas, Rev. Mod. Phys. 30, 257 (1958).

[5] D. D. Long and J. D. Fox, Phys. Rev. 167, 1131 (1968).

[6] S. A. A. Zaidi, private communication.

[7] S. A. A. Zaidi and S. Darmodjo, Phys. Rev. Letters 19, 1446 (1967).

MEASUREMENT OF THE STATIC QUADRUPOLE MOMENT OF THE FIRST EXCITED STATE IN ^{24}Mg

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The static quadrupole moment of the first excited $J^\pi = 2^+$ state in ^{24}Mg was measured to be $Q = -0.243 \pm 0.035$ b. The experimental technique developed for this measurement uses the reorientation effect in heavy ion Coulomb excitation and allows accurate determinations of static quadrupole moments to be made, particularly in light nuclei.

The low cross sections encountered in the Coulomb excitation of nuclei with $A < 40$ have until recently prevented measurements of the quadrupole moments of excited states in this mass region using the reorientation effect. However, ion beams provided by tandem accelerators with terminal voltages of about 10 MV have now made these experiments feasible. The interpretation of the data on the first excited 2^+ states in light even-even nuclei in terms of the reorientation effect is straightforward in principle, because the contribution of other low-lying excited states and of the giant-dipole states[1] to the population of the first excited state is altogether less than 1%.

The reaction kinematics in the Coulomb excitation of light nuclei by heavy ions is sufficiently different from Coulomb excitation of heavier nuclei that variations of previously used methods[1] are necessary. The technique described in this Letter is based on a comparison of the inelastic scattering cross section at two well separated c.m. angles and gives a 10-20% effect for a difference in Q of 0.25 b. The inelastically scattered projectiles and recoil target nuclei, corresponding to two widely separated c.m. scattering angles of the projectile, are observed in a single solid-state detector placed at an appropriate forward laboratory angle. To separate the unresolved inelastic peaks from the elastic peaks in the particle spectrum of the solid-state detector, coincident gamma rays are detected in NaI(Tl) counters. An array of six 5-in. diam by 6-in. long NaI(Tl) detectors is used to give high efficiency for detecting the deexcitation gamma rays and to obtain the angular correlations necessary to correct for the "deorientation" effect (see below).

A schematic view of the experimental arrangement is given in Fig. 1(a). A 62-MeV ^{35}Cl^{6+} beam from the Chalk River MP tandem accelerator was used to bombard 250-μg/cm^2 thick self-supporting foils of ^{24}Mg. The angular position (θ_L, φ_L) of the symmetry axes of the six gamma counters is listed on the right-hand side of Fig. 2. A particle spectrum observed at 28° in a surface barrier detector is shown in Fig. 1(b). The inelastic groups from Coulomb excitation of the 1369-keV, $J^\pi = 2^+$ state in ^{24}Mg are not resolved. The c.m. scattering angles for the peaks labeled ^{35}Cl and ^{24}Mg are 72.8° and 123.1° (inelastic groups), or 71.2° and 124.0° (elastic groups), respectively.

The inelastic particle spectrum observed in fast coincidence ($\tau \sim 14$ nsec) with the six NaI(Tl) detectors mounted on the Chalk River LOTUS goniometer is shown in Fig. 1(c). A random contribution, amounting to 3% of the events between channel numbers 100 and 400, has been subtracted. The inelastic particle groups are well resolved and the error in the ratio of the peak intensities due to "tailing" was estimated to be small (<0.7%). A gamma-ray spectrum in coincidence with inelastically scattered ^{35}Cl [Fig. 1(d)] shows the Doppler-shifted peak from deex-

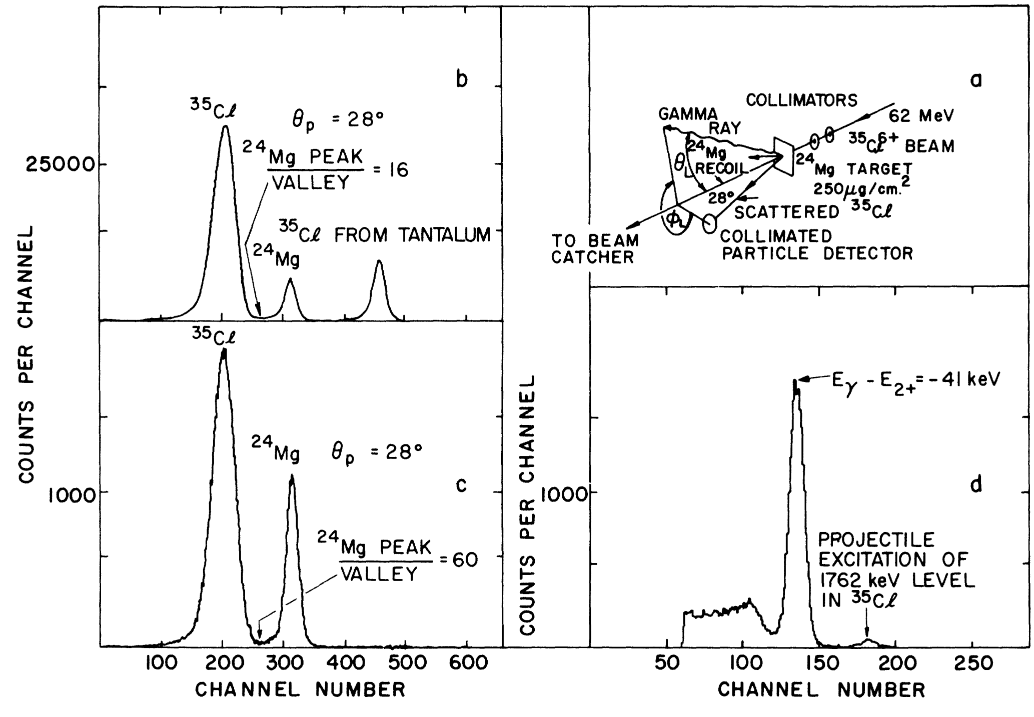

FIG. 1. The experimental spectra obtained for the Coulomb excitation of ^{24}Mg by 62-MeV ^{35}Cl. (a) A schematic diagram of the experimental arrangement. (b) The direct-particle spectrum observed with a surface barrier detector. The peak at channel 480 results from a tantalum contamination in the target. (c) The particle spectrum, corrected for 3% randoms, in coincidence with 1369-keV gamma rays. (d) A gamma-ray spectrum in coincidence with ^{35}Cl recoils. The spectra coincident with ^{24}Mg recoils are essentially similar.

citation of the $J^\pi = 2^+$ state in ^{24}Mg and a small peak from projectile excitation of the second excited state in ^{35}Cl. A correction of 1 to 2% was made for the contribution of this line to the photopeak of the ^{24}Mg line. The error in the photopeak area introduced through projectile excitation of the first excited state in ^{35}Cl at 1.220 MeV is negligible because of its small $B(E2)$ value.[2]

The intensity under the photopeak is

$$Y(\theta_{\rm c.m.},\theta_L,\varphi_L)=\epsilon(E_\gamma)(Y_0+G_2Y_2+G_4Y_4),$$

where

$$Y_k\equiv Y_k(\theta_{\rm c.m.},\theta_L,\varphi_L)=\frac{d\sigma_{\rm Ruth}(\theta_{\rm c.m.})}{d\Omega_p}\sum_{\kappa=-k}^{k}\int_{\Omega_\gamma}F(\Omega_\gamma)\frac{dW_{k\kappa}(\theta_{\rm c.m.},\Omega_\gamma)}{d\Omega_\gamma}d\Omega_\gamma,$$

and $\epsilon(E_\gamma)$ is the gamma-ray detection efficiency. The counter angles θ_L, φ_L are defined in Fig. 1(a), and $F(\Omega_\gamma)$ is the measured response function of the NaI(Tl) crystal. The angular distribution tensors $dW_{k\kappa}(\theta_{\rm c.m.},\Omega_\gamma)/d\Omega_\gamma$ were obtained from the computer code of Winther and de Boer.[3] Because of the high velocity of the excited ^{24}Mg nuclei ($\beta = v/c = 0.061$ and 0.039), kinematic transformation factors are important and were taken into account exactly.

The coefficients G_2 and G_4 describe the attenuation of the angular distribution caused by deorientation of the nuclear spin.[4] The ^{24}Mg recoil nuclei leaving the target foil are highly ionized and the magnetic hyperfine interaction causes a precession of the nuclear spin about the total spin of the ion. G_2 was obtained by fitting the two gamma-ray angular distributions coincident with ^{24}Mg and ^{35}Cl recoils, while G_4 was fixed relative to G_2 by assuming a random static perturbation.[5] This choice is reasonable and of little consequence since the gamma counter angles were chosen in such a way that $|Y_4|/Y_0$ was on the average only 0.05. The result is $G_2(\theta_{\rm c.m.} = 72.8°, \beta = 0.061) = 0.915^{+0.050}_{-0.035}$ and $G_2(\theta_{\rm c.m.} = 123.1°, \beta = 0.039) = 0.940 \pm 0.025$ for an assumed quadrupole moment of $Q = -0.24$ b and does not depend strongly on Q.

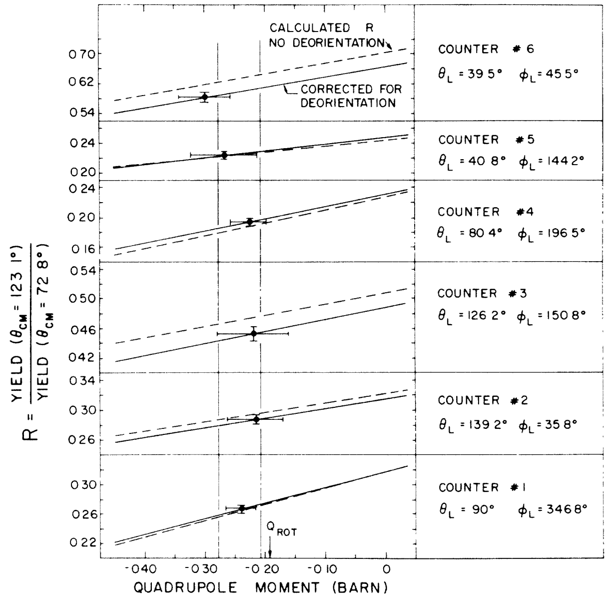

FIG. 2. The calculated ratio of the yield at $\theta_{\rm c.m.} = 123.1°$ to the yield at $\theta_{\rm c.m.} = 72.8°$ as a function of the static quadrupole moment and the experimentally measured ratio for each gamma-ray detector. The average value $Q = -0.243 \pm 0.035$ b is indicated by vertical lines.

The ratio of the photopeak intensities $R \equiv Y(\theta_{\rm c.m.} = 123.1°)/Y(\theta_{\rm c.m.} = 72.8°)$ calculated for $Q = 0$ and $Q = -0.24$ b shows a 10-20% difference depending on the NaI(Tl) counter position. The calculated R is found to be insensitive to the average bombarding energy, to the energy loss of the ingoing and outgoing particles, and to the assumed $B(E2)$ value for the $2^+ \rightarrow 0^+$ transition. R is shown in Fig. 2 as a function of Q for the six NaI(Tl) detectors together with the measured values. The weighted average of the data yields $Q = -0.243 \pm 0.035$ b for the quadrupole moment of the first excited state in ^{24}Mg. This value agrees with recent measurements[6,7] using different methods, but is more accurate. The accuracy of the present experiment allows a sensitive test of the rotational model predictions of the $E2$ matrix elements in ^{24}Mg.

The $E2$ matrix element of the $2^+ \rightarrow 0^+$ transition was obtained from a comparison of the elastic and inelastic cross sections for $\theta_{\rm c.m.} = 72.8°$, using the measured photopeak efficiency of the NaI(Tl) detectors. We obtain a $B(E2, 0^+ \rightarrow 2^+)$ value of $(0.0425 \pm 0.0029)e^2$ b^2 corresponding to $\Gamma = 20.3 \pm 1.4$ Weisskopf units (W.u.)[8] which can be compared with previous measurements using resonance fluorescence scattering[9] ($\Gamma = 21.2 \pm 2.4$ W.u.), inelastic electron scattering[10] ($\Gamma = 21.7$

± 2.2 W.u.) and Doppler-shift attenuation[7] ($\Gamma = 24.5 \pm 2.2$ W.u.). In the rotational model, the present value of 20.3 ± 1.4 W.u. corresponds to a static quadrupole moment of $|Q_{\rm rot}| = 0.185 \pm 0.013$ b.

The measured value of Q is larger by about 30%. It would not be reasonable to ascribe this difference, which may not be significant in view of the errors, to a breakdown of the semiclassical approximation made in the calculation of the Coulomb excitation process, because the distance of closest approach is about 50 times the deBroglie wavelength of the projectile for the present experimental conditions. It is interesting to note that the static quadrupole moments derived from the $4^+ \to 2^+$, $6^+ \to 4^+$, and $8^+ \to 6^+$ transitions seem to decrease as one goes up the $K = 0$ band.[11] This in turn would increase the discrepancy with the measured Q of the 2^+ state and thus indicate a significant deviation from the predictions of the rotational model.

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[1] J. de Boer and J. Eichler, in Advances in Nuclear Physics, edited by M. Baranger and E. Vogt (Plenum Press, Inc., New York, 1968), Vol. 1.

[2] O. Häusser, D. Pelte, T. K. Alexander, and H. C. Evans, to be published.

[3] A. Winther and J. de Boer, in Coulomb Excitation, edited by K. Alder and A. Winther (Academic Press, Inc., New York, 1966), p. 303.

[4] I. Ben Zvi, P. Gilad, M. Goldberg, G. Goldring, A. Schwarzchild, A. Sprinzak, and Z. Vager, to be published.

[5] E. Matthias, S. S. Rosenblum, and D. A. Shirley, Phys. Rev. Letters 14, 46 (1965).

[6] A. Bamberger, P. G. Bizzeti, and B. Povh, Phys. Rev. Letters 21, 1599 (1968).

[7] D. Pelte, O. Häusser, T. K. Alexander, and H. C. Evans, to be published.

[8] D. H. Wilkinson, in Nuclear Spectroscopy, edited by F. Ajzenberg-Selove (Academic Press, Inc., New York, 1960), Part B.

[9] S. J. Skorka, D. Evers, J. Hertel, J. Morgenstern, T. W. Retz-Schmidt, and H. Schmidt, Nucl. Phys. 81, 370 (1966).

[10] O. Titze, private communication.

[11] I. Wright, private communication, cited by H. E. Gove, University of Rochester Report No. UR-NSRL-7 (unpublished).

EXCHANGE DEGENERACY AND REGGE DIPS*

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It is shown that exchange degeneracy leads to dips in differential cross sections when trajectories pass through nonsense, wrong-signature values. The proof does not assume the absence of Gribov-Pomeranchuk fixed poles.

One of the more important successes of Regge-pole theory has been the prediction of dips in differential cross sections at values of momentum transfer at which trajectories pass through nonsense, wrong-signature values.[1] This mechanism has been used to explain the dips in the πN charge-exchange differential cross section at the value of t (≈ -0.5 GeV^2) at which $\alpha_\rho = 0$, and in the $\pi^+ p$ elastic differential cross section at the value of u (≈ -0.2 GeV^2) at which $\alpha_N = -\frac{1}{2}$. However, considerable doubt has been cast on these explanations by the realization[2] that the existence of Gribov-Pomeranchuk fixed poles[3] invalidates the theoretical proof of the necessity of dips. As has been recently emphasized by Oehme,[4] dips might exist in spite of fixed poles; whether they do or not is a question of dynamics. It is the purpose of this note to suggest that the dynamics associated with exchange degeneracy in certain cases leads to dips in differential cross sections, independently of any question involving Gribov-Pomeranchuk poles.

As was reviewed in a recent paper by Chiu and Finkelstein,[5] work on finite-energy sum rules[6] and on the structure of the overlap function[7] indicates that, in reactions with quantum numbers such as to forbid coupling to any known resonance, the imaginary parts of the exchanged Regge trajectories (excluding the Pomeranchukon) must cancel.[8] To see how this requirement can