ergy. Magnon sidebands having energy separations higher than 53.6 cm^{-1} are also present in Saito's spectrum and these energies can be made to correspond closely to combinations of the calculated energies. Even though the interpretation here appears to be quite satisfactory, it may not be unique. For example, if next-nearest-neighbor interactions, exciton-magnon interactions,[14] and/or the effects[15] of the excited ions on the spin-wave spectrum are appreciable, different assignments might be possible in view of the large number of magnon sidebands in the spectrum.

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[1] A. Platzker and F. R. Morgenthaler, Phys. Rev. Letters 22, 1051 (1969), have raised a mild note of protest concerning the use of the term parallel pumping in describing these experiments. We feel the term is appropriate simply because the *net* static moment (nuclear or electronic), the rf magnetic field, and the dc magnetic field are all parallel. Moreover, just as in the case of a ferromagnet, a single photon is converted directly into a magnon pair, and the conversion takes place by *nonresonantly* pumping on the precessional mode involved, i.e., by "parallel" pumping the mode.

[2] L. W. Hinderks and P. M. Richards, J. Appl. Phys. 39, 824 (1968).

[3] M. H. Seavey, J. Appl. Phys. 40, 1597 (1969).

[4] K. Lee, A. M. Portis, and G. L. Witt, Phys. Rev. 132, 144 (1963).

[5] L. W. Hinderks and P. M. Richards, Phys. Rev. (to be published).

[6] See, e.g., V. G. Bar'yakhtar, V. V. Gann, and V. P. Krasnov, Fiz. Tverd. Tela 10, 2335 (1968) [translation: Soviet Phys.–Solid State 10, 1837 (1969)]; V. V. Gann, Fiz. Tverd. Tela 9, 3469 (1967) [translation: Soviet Phys.–Solid State 9, 2734 (1968)]; M. A. Savchenko, Fiz. Tverd. Tela 6, 864 (1964) [translation: Soviet Phys.–Solid State 6, 666 (1964)].

[7] A. Zalkin, K. Lee, and D. H. Templeton, J. Chem. Phys. 37, 697 (1962).

[8] R. D. Burbank and H. T. Evans, Acta Cryst. 1, 330 (1948).

[9] V. Minkiewicz and A. Nakamura, Phys. Rev. 143, 361 (1966).

[10] L. B. Welsh, Phys. Rev. 156, 370 (1967).

[11] E. H. Turner, Phys. Rev. Letters 5, 100 (1960); R. C. LeCraw and L. R. Walker, J. Appl. Phys. 32, 167S (1961); F. R. Morgenthaler, J. Appl. Phys. 34, 1289 (1963); F. A. Olson, J. Appl. Phys. 34, 1281 (1963); R. L. Comstock and W. G. Nilsen, Phys. Rev. 136, A442 (1964); W. G. Nilsen, R. L. Comstock, and L. R. Walker, Phys. Rev. 139, A472 (1965).

[12] The sound velocities in the basal plane of CsMnF$_3$ have been measured by R. Weber and are as follows: $v_l = (4.16 \pm 0.02) \times 10^5$ cm/sec, $v_{s1} = (2.24 \pm 0.03) \times 10^5$ cm/sec, $v_{s2} = (2.31 \pm 0.03) \times 10^5$ cm/sec, where v_l is the longitudinal velocity and v_{s1} and v_{s2} are the shear-wave velocities.

[13] F. Saito, "Exciton, Magnon, and Phonon Structures and Their Temperature Dependences of the Absorption Spectra of CsMnF$_3$ in the 3900-Å Region" (to be published).

[14] R. J. Elliott, M. F. Thorpe, G. F. Imbusch, R. Loudon, and J. B. Parkinson, Phys. Rev. Letters 21, 147 (1968).

[15] T. Tonegawa, Progr. Theoret. Phys. 41, 1 (1969).

POLARIZATION OF ^{3}He ELASTICALLY SCATTERED FROM ^{4}He†

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The polarization of ^{3}He nuclei elastically scattered from ^{4}He has been measured. Absolute polarization values are determined from three asymmetries measured at appropriate energies and angles using double-scattering techniques. A polarization angular distribution at 13-MeV ^{3}He energy indicates general agreement with previously reported phase shifts.

In recent years there have been several ^{3}He nuclear polarization measurements by means of scattering techniques.[1-4] However, each reports only a single point and none was fortunate enough to combine large asymmetries with reasonably large counting rates. The measurements reported here are much more suitable for use as an analyzer or polarizer in a ^{3}He double-scattering experiment. In addition, the present results can be used in the absolute calibration of polarized ^{3}He targets.

Some details of the double-scattering technique which are employed in the present experiment have been reported in earlier triton-polarization work.[6] Typical primary and secondary beam currents of double-charged helium ions are 1 μA and 0.5 pA, respectively. Collimators between the primary and secondary chambers limit the angular spread to ±1.5° and limit the effective target thickness to 9.6 atm cm (approximately 600 keV). The particles are detected in the secondary scattering chamber with an array of eight ΔE-E telescopes.[7] Backgrounds are less than 15%.

Three dependent asymmetry measurements were made to determine absolute polarization values. Those polarizations are labeled P_1, P_2, and P_3 in Table I. The errors in Table I are the statistical uncertainties. Any contribution to the asymmetries from systematic errors are less than 0.02. All subsequent polarization values in Table I were obtained with P_1 or P_2 as the known polarizer.

The signs of the polarizations were determined from the phase shifts of Spiger and Tombrello[8] (positive is taken as $\vec{k}_{\text{in}} \times \vec{k}_{\text{out}}$). The phase shifts of Ref. 8 were obtained from extensive ^{4}He(^{3}He, ^{3}He)^{4}He differential cross-section measurements at ^{3}He energies between 5 and 18 MeV. Spiger and Tombrello determined the imaginary part of the phase shifts from reaction cross-section data and varied the real parts of the phase shifts to obtain a least-squares fit to the data for the elastic cross section.

The present data at 13.0 MeV are shown in Fig. 1. The curve was calculated from the 12.968-MeV phase shifts of Ref. 8. A least-squares fit[9] to cross section and polarization data, in which only real phase shifts were allowed to vary, agreed only slightly better with the present data. This indicates that at least one of the imaginary phase shifts in Ref. 8 at 12.968 MeV is not correct. Allowing the imaginary parts of the phase shifts to change results in considerable improvement in the polarization fits without impairing the fits to the cross-section data. To be meaningful, however, any new set of phase shifts must be determined at several energies and vary smoothly with energy as do those of Ref. 8.

Table I. Summary of ^{3}He polarization results.

$\theta_{\text{c.m.}}$ (deg)	^{3}He energy (MeV)	Absolute measurements	Polarization
28.9	13.0		+0.440 ± 0.061
40.1	13.0	P_2	+0.639 ± 0.035
52.1	13.0		+0.726 ± 0.084
60.6	13.0		+0.337 ± 0.092
77.2	13.0		−0.436 ± 0.122
85.3	13.0		−0.917 ± 0.128
142.0	13.0	P_1	−0.606 ± 0.033
40.1	8.8		−0.351 ± 0.046
40.1	8.3	P_3	−0.604 ± 0.033
40.1	7.8		−0.610 ± 0.075

The polarizations in the region of 7.8 to 8.8 MeV represent averages over rather large energy and angular intervals. Since phase-shift analyses assume no energy or angular spread, these points must be used with caution in a phase-shift search.

The results reported here will be used as a tool to study several other few-nucleon problems in the near future. An accurate determination of the optical-model spin-orbit potential for the elastic scattering of ^{3}He ions from intermediate weight nuclei will probably require polarized beams of higher energy.

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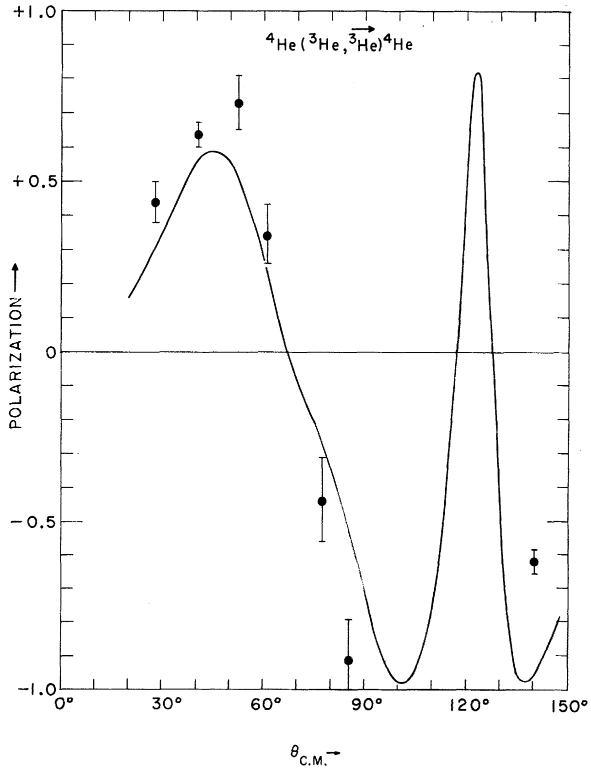

FIG. 1. ^{3}He polarization data at 13.0 MeV. The curve was calculated from the 12.968-MeV phase shifts of Spiger and Tombrello (Ref. 8).

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[1] E. T. Boschitz and J. S. Vincent, in International Nuclear Physics Conference, Gatlinburg, Tennessee, 12-17 September 1966, edited by R. L. Becker and A. Zucker (Academic Press, Inc., New York, 1967), p. 1023.

[2] G. C. Phillips, in International Symposium on Polarization Phenomena of Nucleons. 2nd, Karlsruhe, September, 1965. Proceedings, edited by P. Huber and H. Schopper (Birkhauser Verlag, Stuttgart, Germany, 1966), p. 113.

[3] R. L. Hutson, S. Hayakawa, M. Chabre, J. J. Kraushaar, B. W. Ridley, and E. T. Boschitz, Phys. Letters 27B, 153 (1968).

[4] One other measurement [W. E. Burcham, J. B. A. England, J. E. Evans, A. Garcia, R. G. Harris, and C. Wilne, in International Congress on Nuclear Physics, Paris, 1964, Proceedings, edited by P. Gugenberger (Centre National de la Recherche Scientifique, Paris, 1964), Vol. 2, p. 77] is not consistent with the later results of Hutson et al. (Ref. 3) and P. E. Hodgson, Advan. Phys. 17, 563 (1968).

[5] Hodgson Ref. 4, p. 578.

[6] P. W. Keaton, Jr., D. D. Armstrong, and L. R. Veeser, Phys. Rev. Letters 20, 1392 (1968).

[7] D. D. Armstrong, J. G. Beery, E. R. Flynn, W. S. Hall, P. W. Keaton, Jr., and M. P. Kellogg, Nucl. Instr. Methods 70, 69 (1969).

[8] R. J. Spiger and T. A. Tombrello, Phys. Rev. 163, 964 (1967); R. J. Spiger, thesis, California Institute of Technology, 1967 (unpublished).

[9] The computer program SCRAM5 [S. J. Moss and W. Haeberli, Nucl. Phys. 72, 429 (1965)] was used to perform the phase-shift search.

SPIN DETERMINATION FOR RESONANCES DECAYING TO EXCITED $J=0$ STATES*

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The angular distribution of a (p,p') resonance reaction leading to an excited $J_f=0$ target state allows an unambiguous determination of the spin of the resonance. As an example we investigate isobaric analog resonances in ^{95}Nb decaying to the 1.30-MeV 0^+ state in ^{94}Zr and discuss the weak-coupling nature of their parent states in ^{95}Zr, based upon the spin assignments made.

A method commonly used to determine spins of low-lying states in the neutron-rich neighbor (nC) of an even-even nucleus (C) is to measure the polarization in the isobaric analog system (A) of nC. Both double-scattering[1] and polarized-beam[2] techniques were applied to elastic proton scattering through analog resonances on closed neutron-shell targets. Depending on the ratio of the partial width $\Gamma_p{}^A$ to the total width Γ, this method works successfully for resonances with $\Gamma_p{}^A/\Gamma > 0.1$, but fails for analogs whose parent states have very small (d,p) spectroscopic factors and which decay predominantly to excited target states (C^*). Since a study of these states reveals correlations existing between the core states C^* and the nC system,[3] spin and parity assignments for their analog resonances would be desirable.

In this Letter we describe a technique which can be applied whenever there exists an excited $J_f=0$ target state fed in a (p,p') reaction through isolated resonances having unique spins J and parities π.

Because of angular-momentum conservation, the spins j_i and j_f of the protons in the entrance and exit channels, respectively, are equal to J, and the expansion of the on-resonance angular distribution in terms of even Legendre polynomials takes the simple form[4]

$$W(\theta)=1+\sum_{L=2}^{L_{\max}} B_L P_L(\cos\theta), \qquad (1)$$

where

$$L_{\max}=2J-1,$$

and

$$B_L=(2J+1)(2L+1)\begin{pmatrix} J & J & L \\ \frac{1}{2} & -\frac{1}{2} & 0 \end{pmatrix}^2.$$

Evaluating the B_L coefficients one finds that all, including $B_{L_{\max}}$, are positive and of the order of unity; thus the highest order polynomial $P_{L_{\max}}$ dominates the shape of the angular distribution and allows an unambiguous determination of the