ence neutrons in the state j. If the ^{206}Pb wave functions are written as

$$0_1{}^+ = a[p_{1/2}{}^{-2}]^{J=0} + b[f_{5/2}{}^{-2}]^{J=0},$$

$$0_2{}^+ = -b[p_{1/2}{}^{-2}]^{J=0} + a[f_{5/2}{}^{-2}]^{J=0},$$

then

$$\langle 0_1{}^+|\sum e_n r^2|0_2{}^+\rangle = 2ab[\langle p_{1/2}|e_n r^2|p_{1/2}\rangle - \langle f_{5/2}|e_n r^2|f_{5/2}\rangle].$$

The matrix element for the $p_{1/2}$ neutrons can be obtained from the ^{207}Pb-^{208}Pb isotope shift while, in a simple model, $\frac{1}{2}$ of that for ^{204}Pb-^{206}Pb yields the value of $z^{-1}\langle f_{5/2}|e_n r^2|f_{5/2}\rangle$. Using values quoted by Krainov and Mikulinskii[12] for the isotope-shift data and $a = 0.87$, $b = 0.25$ (obtained by truncating the wave functions of Ref. 7), one finds $\rho = \langle f|\sum e_n r^2|i\rangle/(1.2A^{1/3})^2 = (1.64 \pm 1.01)\times 10^{-2}$. This result is consistent with the experimental value $\rho = (2.6 \pm 0.3)\times 10^{-2}$. It would be most interesting to reduce the large uncertainty in the isotope-shift data so as to test more crisply the ideas presented here. Hopefully, this can be done with the intense muon beams available at the new meson physics facilities.

*Work supported in part by the U. S. Atomic Energy Commission.

†Work supported in part by the National Science Foundation.

[1]H. C. Griffin and A. M. Donne, Phys. Rev. Lett. 38, 107 (1972).

[2]P. Richard, N. Stein, C. D. Kavaloski, and J. S. Lilley, Phys. Rev. 171, 1308 (1968).

[3]R. S. Hager and E. C. Seltzer, Nucl. Data, Sect. A 6, 1 (1969).

[4]J. L. Quebert, K. Nakai, R. M. Diamond, and F. S. Stephens, Nucl. Phys. A150, 68 (1970).

[5]E. L. Church and J. Weneser, Phys. Rev. 100, 943 (1955), and 103, 1035 (1956).

[6]M. E. Rose, *Internal Conversion Coefficients* (North-Holland, Amsterdam, 1958).

[7]W. W. True, Phys. Rev. 168, 1388 (1968).

[8]S. Siegal and L. Zamick, Nucl. Phys. A145, 89 (1970).

[9]I. Sick, H. Flocard, and M. Veneroni, Phys. Lett. 39B, 443 (1972).

[10]In the calculations of True, Ref. 7, components outside the f-p-h shell ($i_{13/2}$) are too small to account for the experimental strength.

[11]A. S. Litvinenko, N. G. Shevchenko, A. Yu. Buki, G. A. Savitskii, V. M. Khvastunov, A. A. Khomich, V. N. Polishcuk, and I. I. Chkalov, Yad. Fiz. 14, 479 (1971) [Sov. J. Nucl. Phys. 14, 269 (1972)]; V. M. Khvastunov, N. G. Afanasyev, V. D. Afanasyev, I. S. Gulkarov, A. S. Omelaenko, G. A. Savitsky, A. A. Khomich, N. G. Shevchenko, V. S. Romanov, and N. V. Rusanova, Nucl. Phys. A146, 15 (1970).

[12]V. P. Krainov and M. A. Mikulinskii, Yad. Fiz. 4, 928 (1966) [Sov. J. Nucl. Phys. 4, 665 (1967)].

New Method for Determining Polarization Standards in Nuclear Reactions

P. W. Keaton, Jr., D. D. Armstrong, R. A. Hardekopf, P. M. Kurjan,† and Y. K. Lee‡
Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico 87544
(Received 7 July 1972)

We discuss and apply a general method for measuring the difference of polarization observables from their maximum allowed value. Relatively crude double-scattering experiments determine the proton polarization for 12-MeV p-^{4}He scattering with an absolute uncertainty of 1 part in 1000. It is anticipated that these concepts can be applied to higher-energy reactions where experiments do not lend themselves easily to precision measurements and where basic symmetries appear more likely to break down.

A null technique is suggested that may be used to determine spin-polarization values very precisely. The technique is applied to determine a proton polarization standard 4 times more accurately than previously obtained. The goal is to eventually establish standards precise enough to test fundamental symmetries.

Linear and quadratic relations that are model independent exist between the polarization observables of two interacting particles.[1] When one of the observables is found to approach very nearly its maximum allowable value, the others in a quadratic relation must be close to zero. For example, in the reaction ^{4}He$(p,p)^4$He the Wolfenstein polarization observables P, R, and A obey the well-known relation $P^2+R^2+A^2=1$. [As the relation $P^2+R^2+A^2=1$ actually holds for any combination of particles which have the spin configuration $0+\frac{1}{2}\to 0+\frac{1}{2}$, the concept also applies to ^{12}C$(t,p)^{14}$C, $\pi+p\to\pi+p$, etc.] At appropriate energies and angles where it is known that the proton polarization P approaches its maximum value of unity, relatively crude measurements (± 0.03) of $R \approx 0$ and $A \approx 0$ (which are double-scattering experiments using a polarized proton beam) determine the *difference* of P^2 from unity, with a typical accuracy of $\pm(0.03)^2 \simeq \pm 0.001$. Three such places are known to exist for p-^{4}He scattering below 13 MeV.[2] For spin-1 particles, one can use the spin configuration $1^+ + 0^+ \to 0^+ + 0^-$ (intrinsic parity is denoted by a superscript), which may be obtained, for example, by the reaction ^{18}O(d, α)^{16}N$_{0^-}$* to determine spin-1 polarization precisely. The relevant quadratic relation is $A_y^2 + (\frac{2}{3}A_{xz})^2 + [\frac{1}{3}(A_{zz} - A_{xx})]^2 = 1$, where the A's are the appropriate polarization tensors for a Cartesian description of a spin-1 beam. They may be measured in a single scattering experiment with a polarized deuteron beam. An experiment to find energies and angles where $A_y \approx 1$ is in progress.

The validity of the above quadratic relation between P, R, and A depends on the reversibility of the scattering process. In fact, Simonius[3] has shown that the complete quantum mechanical description of particles with spin can be deduced from transformation properties if, in addition, one assumes reversibility of scattering processes. Since it can be argued that reversibility must hold whenever the classical concept of a potential is applicable, we may safely assume the quadratic relation in low-energy experiments such as the present one.

In the present experiment, 12-MeV protons polarized in the scattering plane bombarded a ^{4}He gas target. The component of polarization $p_{x'}$ of the scattered proton in the reaction plane and perpendicular to the scattering direction $\vec{k}_{out}$ was detected with a polarimeter. When the incident-beam polarization is oriented parallel with the incident-beam direction $\vec{k}_{in}$, the beam polarization is denoted by p_z, and is related to $p_{x'}$ by $p_{x'} = p_z A$. When the incident beam polarization is oriented perpendicular to $\vec{k}_{in}$, the beam polarization is denoted by p_x, and is related to the new value of $p_{x'}$ by $p_{x'} = p_x R$. When the incident beam is unpolarized, the polarization of the outgoing proton perpendicular to the reaction plane (parallel with the y axis along $\vec{k}_{in} \times \vec{k}_{out}$) is denoted by $\vec{P}$. These then are the definitions of the three Wolfenstein polarization observables[4] P, R, and A. The differential cross section for an incident beam of arbitrary polarization $\vec{p}$ is given by $I(\theta) = I_0(\theta)(1 + \vec{p} \cdot \vec{P})$, where θ is the angle between $\vec{k}_{in}$ and $\vec{k}_{out}$, and $I_0(\theta)$ is the differential cross section for an unpolarized beam.

The results of these measurements are summarized in Table I, where R and A are reported for several values of scattering angle. The last column indicates that $(P^2 + R^2 + A^2)^{1/2}$ does equal unity within statistics, which can be used as a consistency check on the measurements. The data are summarized in Fig. 1 and compared with predictions of an optical-model potential for p-^{4}He scattering.[5] Of particular interest is the consideration of the measurements of R and A listed in Table I at 112°. Using $P^2 = 1 - R^2 - A^2$, we deduce the value of $P = 0.9998^{+0.0002}_{-0.0010}$. The statistical uncertainties are obtained by setting $P = (1 - \rho^2)^{1/2}$ and $P_\pm = [1 - (\rho \mp \Delta\rho)^2]^{1/2}$, where $\rho^2 = R^2 + A^2$, bearing in mind that P cannot exceed 1.0. This value of P may be compared with the 112° point of Ohlsen *et al.*[6] listed in Table I under the column P. In Ref. 6, the beam polarization was determined by an atomic-beam method.

TABLE I. ^{4}He(p,p)^{4}He at 12.00 ±0.01 MeV.

θ_{lab} (deg)	$\theta_{c.m.}$ (deg)	P[a]	R	A	$(P^2+R^2+A^2)^{1/2}$
30.0	37.3	...	0.784 ±0.016	−0.558 ±0.026	...
45.8	56.3	−0.402 ±0.004	0.491 ±0.021	−0.765 ±0.022	0.994 ±0.020
60.8	73.6	−0.600 ±0.004	0.068 ±0.033	−0.789 ±0.027	0.994 ±0.022
75.6	89.8	−0.776 ±0.005	−0.447 ±0.048	−0.476 ±0.047	1.014 ±0.031
109.0	122.9	0.976 ±0.006	0.011 ±0.046[b]	0.229 ±0.048[b]	1.003 ±0.012
112.00	125.60	0.9980 ±0.0043	0.0180 ±0.030[b,c]	−0.0044 ±0.032[b,c]	0.9982 ±0.0043
115.0	128.3	0.9837 ±0.006	−0.063 ±0.047[b]	−0.055 ±0.040[b]	0.987 ±0.007

[a]Taken from Ref. 6.

[b]Finite-geometry corrections for angular resolution were made using the shape distributions calculated from Ref. 5. All corrections were less than 0.008.

[c]Absolute uncertainties include ±0.01 for instrumental asymmetries.

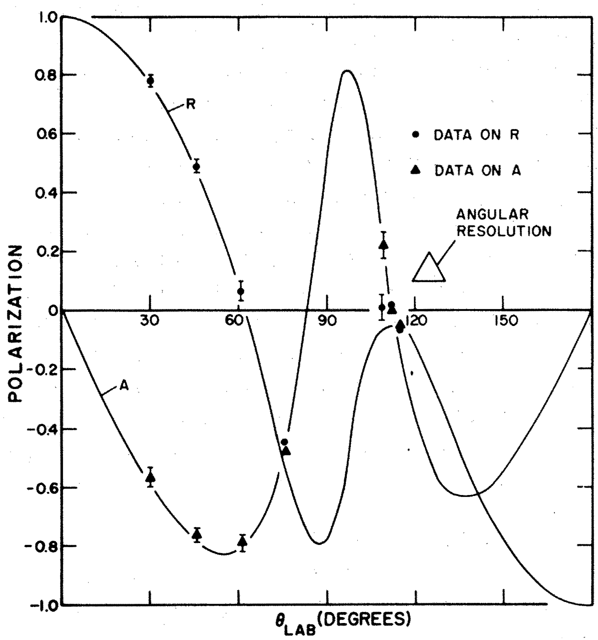

FIG. 1. Measured values of the Wolfenstein polarization observables (Ref. 4) R and A as defined in the text and reported in Table I. They are determined as a function of proton scattering angle θ_{1ab} by a double-scattering experiment with 12-MeV polarized protons incident on a ^{4}He target. The fact that R and A are both 0 at $\theta_{1ab} = 112°$ is most relevant to this paper. The lines show predictions of an optical potential (Ref. 5) for comparison.

The experiment utilized the Los Alamos Scientific Laboratory Lamb-shift polarized ion source[7] and tandem Van de Graaff facility to produce a polarized beam which bombarded a 1.3-cm-diam cylinder containing 5.5 atm pressure of ^{4}He cooled to liquid-nitrogen temperature. The beam was limited by 3.2-mm square slits 25 cm in front of the ^{4}He target, and the beam direction was maintained by two other pairs of slits—one pair $2\frac{1}{2}$ m in front of the target and the other pair $\frac{1}{2}$ m behind the target. Beam intensity on target was typically maintained at 80 nA with a polarization of 0.85. The scattered protons were collimated into a polarimeter with a double-slit system subtending 4.8° full width at half-maximum (FWHM). The polarimeter contained an 18.3-mg/cm^2 natural-carbon target as an analyzer and detected protons scattered at ± 45° with two ΔE-E silicon surface-barrier detector telescopes demanding 32 nsec coincidence time resolution between detector pairs. The polarimeter, which was calibrated with a polarized beam in a separate experiment, had a typical analyzing power of $\alpha \approx -0.7$. Reversing the spin direction at the source gave no perceptible change in slit current readings, and consequently instrumental asymmetries were kept below ± 0.01. In addition, at the three angles greater than 90° (back angles), data were taken for the polarimeter first to the left and then to the right of the beam. This determines the mean scattering angles to ± 0.04°. [Uncertainties in the four angles forward of 90° (forward angles) are estimated to be ± 0.2°.] The forward-angle data were repeated with a ^{4}He polarimeter which was subsequently developed, and excellent agreement was obtained. Those forward-angle data reported in Table I are a statistical average of the measurements with the two polarimeters. The back-angle data rate was ≈ 0.1 count/sec, and a 20% background originated from the neutrons produced in the 2.5×10^{-4}-cm-thick Havar windows on the ^{4}He target. The mean energy of the incident beam on ^{4}He was 12.00 ± 0.01 MeV and the energy spread was 45 keV FWHM. Physically, the spin direction of the incident beam was parallel to Earth's surface in the reaction plane and the polarimeter detected protons scattered up (U) and down (D). The asymmetry detected was $A_{UD} = (U-D)/(U+D) = \pm p_x \alpha$, from which R or A could be calculated. A was measured by making the angle between $\vec{k}_{in}$ and the spin direction of the incident beam 0°, and R was measured by making that angle 90° in the reaction plane. The angle of the incident spin direction was determined to within ± 1°.

There are several advantages to using a null method to determine polarization standards precisely. First, since a zero value of asymmetry is to be measured rather than a large value, the possibility of depolarization at the > 0.1% level does not affect the absolute uncertainty. Likewise, fluctuations and uncertainties of the absolute polarization of the incident beam at that same level need not be considered. Also, one does not face here such very practical problems as absolute dead-time corrections to electronic counting systems with two branches—the one branch counting 10 times faster than the other. Furthermore, it is worth noting that the present experiment can, in principle, be considered as independent of all previous measurements of polarization. For example, if the incident beam from a "black box" bombards a ^{4}He target at 12 MeV and if U-D detectors at ± 112° in the laboratory give an asymmetry of $A_{UD} = 0.9$, one can conclude from the cross-section formula that $|\vec{p}\cdot\vec{P}| = 0.9$ and that the beam polarization is $p = 0.95 \pm 0.05$ (up to a sign). Using this value of p to determine the analyzing power α of the polarimeter, one can then measure R and A. In particular, say,

$$R_{\text{expt}} = \frac{A_{UD}}{p_x \alpha} \pm R_{\text{expt}} \left[\left(\frac{\Delta A_{UD}}{A_{UD}} \right)^2 + \left(\frac{\Delta p_x}{p_x} \right)^2 + \left(\frac{\Delta \alpha}{\alpha} \right)^2 \right]^{1/2},$$

and since $A_{UD} \to 0$ with $\Delta A_{UD}/A_{UD} \approx 1$, the 5% uncertainty in $\Delta p_x / p_x$ and $\Delta\alpha/\alpha$ contributes only a small amount to the first determination of R_{expt} and A_{expt}. Using $P^2 = 1 - R^2 - A^2$ determines P with only a small uncertainty which, in turn, can be used to determine the original value of $p = 0.9$ with a smaller uncertainty than before. A second iteration of the calculation then arrives at a precise determination of P.

It is a pleasure to acknowledge helpful discussions with John L. Gammel about quadratic relations.

*Work performed under the auspices of the U. S. Atomic Energy Commisssion.

†Summer research assistant from Stanford University, Stanford, Calif. 94305.

‡Visiting staff member from The Johns Hopkins University, Baltimore, Md. 21218.

[1]P. L. Csonka and M. J. Moravcsik, Phys. Rev. 152, 1310 (1966); M. Simonius, "Theory of Polarization Measurements I and II" (unpublished); G. G. Ohlsen, P. W. Keaton, Jr., and J. L. Gammel, in *Proceedings of the Third Symposium on Polarization Phenomena in Nuclear Reactions, Madison, Wisconsin, 1970,* edited by H. H. Barschall and W. Haeberli (Univ. of Wisconsin Press, Madison, Wis., 1971), p. 512; G. G. Ohlsen, J. L. Gammel, and P. W. Keaton, Jr., Phys. Rev. C 5, 1205 (1972).

[2]G. R. Plattner and A. D. Bacher, Phys. Lett. 36B, 211 (1971).

[3]M. Simonius, "General Scattering Theory: Rotation Properties and Test of Quantum Mechanics by Polarization Measurements" (unpublished).

[4]L. Wolfenstein, Annu. Rev. Nucl. Sci. 6, 43 (1956).

[5]G. R. Satchler, L. W. Owen, A. J. Elwyn, G. L. Morgan, and R. L. Walter, Nucl. Phys. A112, 1 (1968).

[6]G. G. Ohlsen, J. L. McKibben, G. P. Lawrence, P. W. Keaton, Jr., and D. D. Armstrong, Phys. Rev. Lett. 27, 599 (1971).

[7]J. L. McKibben, in Proceedings of the Symposium of Northeastern Accelerator Personnel, Tallahassee, Florida, 23–24 March 1972 (to be published); J. L. McKibben, in Proceedings of the Second International Conference on Polarized Targets, Berkeley, California, 1971, Lawrence Berkeley Laboratory Report No. LBL-500 (to be published); J. P. McKibben, G. P. Lawrence, and G. G. Ohlsen, in *Proceedings of the Third Symposium on Polarization Phenomena in Nuclear Reactions, Madison, Wisconsin, 1970,* edited by H. H. Barschall and W. Haeberli (Univ. of Wisconsin Press, Madison, Wis., 1971), p. 828; G. P. Lawrence, G. G. Ohlsen, and J. L. McKibben, Phys. Lett. 28B, 594 (1969).

Failure of the Coexistence Model to Account for Observed Two-Neutron Pickup Cross Sections*

E. G. Adelberger,† P. T. Debevec,‡ G. T. Garvey, and R. Ohanian
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540
(Received 14 August 1972)

We have studied the (p,t) reaction on ^{18}O and ^{42}Ca at $E_p = 41.7$ MeV. The observed yields to the 0^+, $T=0$ states in ^{16}O and ^{40}Ca are at variance with distorted-wave Born-approximation predictions using the coexistence model to describe the initial and final states of the targets. By use of wave functions which employ a more extensive set of configurations, satisfactory agreement with the observed yields is achieved for the reaction $^{18}\text{O}(p,t)^{16}\text{O}$.

The inclusion[1-4] of deformed multiparticle-multihole configurations into the set used to generate the low-lying states near doubly magic nuclei has led to spectacularly successful results. This *Ansatz,* often termed the coexistence model, produces acceptable energy spectra and gives good agreement with observed electric quadrupole transition rates. For example, in ^{40}Ca the calculation of Gerace and Green[3,4] reproduces the twenty or so levels below 7 MeV and properly accounts for more than twenty $B(E2)$ values.[5] In ^{16}O there is not such a large body of data but the model again seems quite successful.

In this Letter we wish to point out that this coexistence model fails to describe the results of two-neutron pickup experiments on the "doubly magic"-plus-two-neutron targets ^{18}O and ^{42}Ca. In the coexistence model these targets are described as superpositions of spherical two-particle and deformed four-particle, two-hole (4p-2h) states.