used to justify their procedure for calculating capture ratios.

[10]In writing Eq. (1a), we have made use of the usual convention that all $R_{ns}(0)$ and $R_{ns}'(0)$ are real. The exact expression (reference 9) is, of course, independent of all phase conventions.

[11]H. Brysk and M. E. Rose, Oak Ridge National Laboratory Report ORNL-1830, 1955 (unpublished); Revs. Modern Phys. 30, 1169 (1958). Small corrections for L_{II} capture and electron binding energy are included in the predictions of the usual theory.

[12]D. R. Hartree and W. Hartree, Proc. Roy. Soc. (London) A164, 167 (1937); 166, 450 (1938); S. J. Czyzak, Astrophys. J. Suppl. Ser. No. 65, 7, 53 (1962). The orthogonality relation $\langle 1s|2s\rangle = 0$ is not well satisfied for many of the wave functions in the literature, and hence these wave functions cannot be used in our calculations.

[13]All quantities that appear in Eq. (1a), except $\langle 1s'|2s\rangle$ and $\langle 2s'|1s\rangle$, are known to an accuracy of the order of one percent. Since the L_I to K ratio depends only slightly (~1 percent) on $\langle 2s'|1s\rangle$ one can use precision measurements of L to K ratios to determine experimentally the electron overlap integral $\langle 1s'|2s\rangle$. It will be interesting to see if the method of self-consistent fields can predict these integrals accurately.

[14]I am grateful to Professor R. W. Fink for bringing this interesting example to my attention.

DEMONSTRATION OF A POLARIZED He^3 TARGET FOR NUCLEAR REACTIONS*

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and

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This Letter reports the results of nuclear scattering from a polarized target of He^3 gas. The results to be described show that it is possible to prepare a polarized He^3 target, which is suitable for use in nuclear experiments with beams of fast charged particles, by using the optical pumping techniques of Walters, Colegrove, and Schearer.[1]

It is known that strong nuclear spin-orbit forces act when He^4 is scattered by He^3 near to the $\frac{7}{2}^-$ resonant state, at 4.53-MeV excitation, in Be^7. The scattering has been observed and the data have been phase-shift analyzed[2]; the polarization of the He^3 particles, after scattering, has been deduced from the scattering phase shifts.[3] The calculated polarization was found to be quite large at certain scattering angles and bombarding energies so that large azimuthal scattering asymmetries are to be expected for a polarized He^3 target. These facts provide a natural means for testing the He^3 gas target for polarization.

Figure 1 shows a schematic diagram of the apparatus. The basic principles of the production of He^3 polarization have been given in reference 1. Briefly, the method is as follows: Metastable $2\,^3S_1$ He^3 atoms are formed in the He^3 cell by a weak electric discharge. When circularly polarized $2\,^3S_1 - 2\,^3P_0$ resonance radiation, directed along a small applied magnetic field, is absorbed by the metastable $2\,^3S_1$ atoms, they become polarized. This polarization is transferred, by collisions involving exchange of metastability, to the more numerous ground-state atoms. In equilibrium the ground-state atoms attain the same polarization as the met-

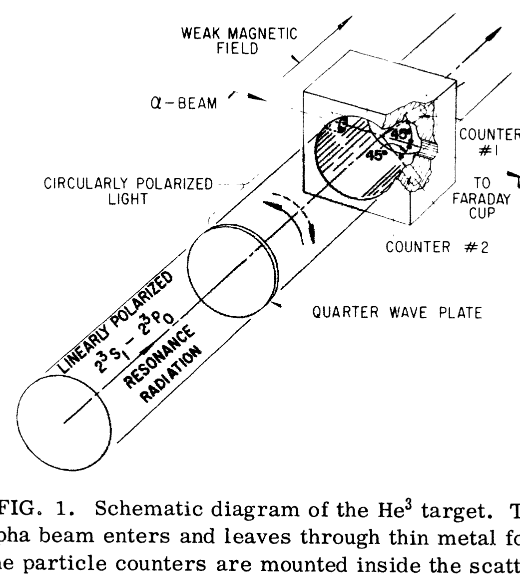

FIG. 1. Schematic diagram of the He^3 target. The alpha beam enters and leaves through thin metal foils. The particle counters are mounted inside the scattering chamber, which is constructed of brass with Pyrex light windows.

astable atoms. The direction of the induced He^3 polarization vector is either parallel or antiparallel to the direction of the pumping light, depending on whether the light is right- or left-hand circularly polarized. The percentage polarization in the target gas cell was measured by the optical means described in reference 1.[4] In this experiment the optically measured polarization was $8.5\% \times (1 \pm 0.2)$.

A beam of He^{++} ions from the Rice University tandem Van de Graaff accelerator was passed through the He^3 gas cell by traversing two thin foils. The beam was directed as shown in Fig. 1. Two ORTEC surface-barrier detectors labeled 1 and 2, each placed behind identical particle telescopes, allowed the detection of scattered alpha particles and recoiling He^3 particles. These counters were placed at identical angles of 45 degrees either side of the beam direction as shown in Fig. 1. At this angle the He^3 recoils correspond to He^3 scattering at 90 degrees in the center-of-mass system. If there is no target polarization, the scattering intensity into the two counters should, of course, be equal although the recoiling He^3 particles would have a net polarization. However, if the target is polarized, the two scattering intensities will not be equal.

The experiment consisted of measuring the number of counts of He^3 recoils, N_1 and N_2, in the counters 1 and 2, respectively, for a given sense of circular polarization of the resonance radiation. If P_t is the polarization of the target, and P_n is the polarization of He^3 which would result from scattering from an unpolarized target, then $P = P_t P_n = (N_1 - N_2)/(N_1 + N_2)$. The sense of circular polarization of the resonant radiation producing the He^3-target polarization could be made either right- or left-handed by a 90-degree change of the orientation of the linear polarization of the light beam incident on the quarter-wave plate (see Fig. 1). This change of the sense of light polarization results in a reversal of P_t, the He^3-target spin polarization. Thus a 90-degree rotation of a linear polarizer will reverse the sign of the observable quantity P.

The details of the behavior of P_n also allowed a reversal of P to be detected: There were expected to be two regions of large P_n, of opposite signs, for the He^3 recoils at alpha-particle laboratory energies of 6.53 and 7.33 MeV (see reference 3). The expected values of P_n were about -80% and +80%, respectively, with the sign of reference 3 reversed to conform to the Basel convention.

In a preliminary experiment the energy position of the $\frac{7}{2}^-$ alpha-He^3 scattering resonance was observed. This observation permitted proper allowance to be made for the energy loss of the alpha particles in the beam entrance foil so that the two bombarding energies listed above could be established accurately.

The value of P was measured at 6.53 and 7.33 MeV for alpha-particle bombardment of the polarized target. It was expected that P should be of opposite signs (for a fixed P_t) for these two energies. The results are summarized in Table I, and are compared to the expected values computed from the optically measured value of P_t and the values of P_n calculated from phase shifts. It is seen that the agreement of the calculated and measured values of P are satisfactory both in magnitude and in the expected reversal of sign at the two bombarding energies.

The data used in preparing Table I for 7.33-MeV bombarding energy are analyzed further in Table II. Table II shows that the expected reversal of target polarization, as measured by nuclear scattering, occurred when the direction of circular polarization was reversed: A reversal of the sign of P_t was observed to produce the expected reversal of sign of P.

The data of Tables I and II were obtained in a period of a few hours with the cell pressure at about 1 mm STP and with the rather weak He^{4++} beam of 10 to 20 nanoamperes.

It should be pointed out that this target has several advantages, such as high nuclear purity and the comparative simplicity of room temperature operation, over condensed targets prepared

Table I. The calculated and measured values of the polarization P for He^3, He^4 scattering at 90 degrees in the center-of-mass system and at the indicated alpha-particle bombarding energies. The value of P_n is taken from reference 3; the value of P_t is measured optically (see reference 1). The data for both types of circular polarization ($M = \pm I$) have been used with $M = -I$ defined as producing positive P_t. Tabulated is $P_{\text{calculated}} = |P_t| P_n$ and $P_{\text{measured}} = [(N_1 - N_2)/(N_1 + N_2)][-M/I]$.

E_α (MeV)	P_n	P_t (optical)	P (calculated)	P (measured)
6.53	-80% ×(1 ± 0.1)	8.5% ×(1 ± 0.2)	-6.8% ×(1 ± 0.3)	-5.2% ×(1 ± 0.3)
7.33	+80% ×(1 ± 0.1)	8.5% ×(1 ± 0.2)	+6.8% ×(1 ± 0.3)	+5.7% ×(1 ± 0.3)

Table II. The calculated value of P is compared to the value of P measured by nuclear scattering of alpha particles from the gas target for the two directions of circular polarization of the resonant radiation. $M = \pm I$ corresponds to right- or left-handed polarization, respectively. The alpha-particle energy was 7.33 MeV, and He^3 recoils at 45 degrees (lab) were observed. P (measured) is given by $P = (N_1 - N_2)/(N_1 + N_2)$. $P = P_t P_n$ was calculated from the optically measured value of $P_t = (-M/I)(\Delta I/2I)$, and $P_n = +80\% \times (1 \pm 0.1)$ (see reference 3).

M	P_t (optical)	P (calculated)	P (measured)
$-I$	+8.5% ×(1 ± 0.2)	+6.8% ×(1 ± 0.3)	+6.8% ×(1 ± 0.3)
$+I$	−8.5% ×(1 ± 0.2)	−6.8% ×(1 ± 0.3)	−4.5% ×(1 ± 0.5)

at liquid helium temperatures by "solid" or Overhauser effects. In any case, such low-temperature methods have not as yet been applied successfully to He^3. Although the low atomic density may preclude certain measurements, targets of the type described here should be adequate for a wide variety of nuclear scattering experiments. Furthermore, it is believed that improvements in the optical design may allow a substantial increase in the value of P_t (see reference 1).

These results demonstrate the feasibility of using such polarized He^3 targets for nuclear experiments. It is planned to continue to study the above process and, in addition, to investigate the nuclear reactions produced by the bombardment of such targets by protons, deuterons, He^3, and heavy ions.

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†On leave from North Texas State University, Denton, Texas.

[1]G. K. Walters, F. D. Colegrove, and L. D. Schearer, Phys. Rev. Letters 8, 439 (1962).

[2]P. D. Miller and G. C. Phillips, Phys. Rev. 112, 2048 (1958).

[3]G. C. Phillips and P. D. Miller, Phys. Rev. 115, 1268 (1959).

[4]The formula for the polarization P, appearing in reference 1, should read $P = \frac{1}{2}(\Delta I/I)$. This formula applies for polarizations below about 25%, according to calculation, and has been verified experimentally by comparison with nuclear magnetic resonance measurements of the polarization (see reference 1).

K^+-p SCATTERING; THE PHENOMENOLOGY OF A REPULSIVE INTERACTION*

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This Letter is concerned with some recent K^+-proton elastic scattering data[1] in the laboratory energy range 20 MeV to 450 MeV, and their proper interpretation. On the basis of potential scattering, it is demonstrated that these data now yield, besides the range of this dominantly repulsive interaction, a clear indication that the potential is attractive at its outer fringe. It may therefore be possible, by more sophisticated theoretical methods, to learn easily about the elementary K-pion interaction, for example, from this very simple scattering situation.

The experimental data were analyzed[1] to give, in more detail than was previously possible, the energy dependence of the s-wave phase shift δ, the only contributor to scattering at these energies. This energy dependence was then fitted to the effective-range formula $k \cot\delta = a^{-1} + \frac{1}{2} r_0 k^2$, producing the values $a \simeq 0.29$ F, $r_0 \simeq 0.50$ F. We wish to point out that the $k \cot\delta$ expansion is not appropriate to dominantly repulsive interactions, and that when it is used, the parameters a and, especially, r_0 do not have their usual connotation.[2] A more appropriate expansion is obtained, and an inequality established which enables us to draw our conclusion about the sign of the outer fringe of the interaction.

The $k \cot\delta$ expansion has proved very useful in treating attractive interactions, both as a shape-independent representation of potential scattering, and as a phenomenological presumption about interactions of unknown structure. The first term of the expansion, representing scattering by an equivalent zero-range potential, is already a useful approximation. The wave function extends throughout the region of the interaction so that the

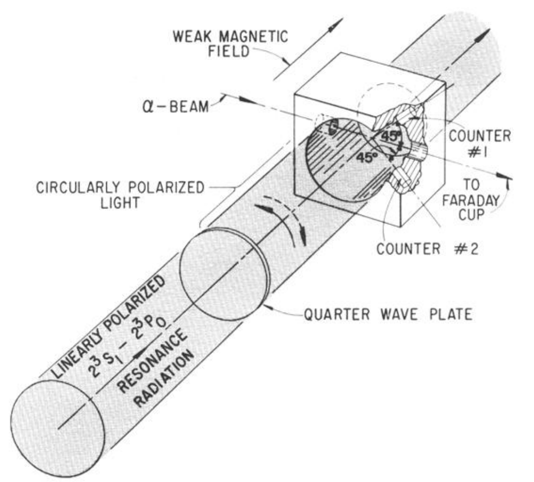

FIG. 1. Schematic diagram of the He^3 target. The alpha beam enters and leaves through thin metal foils. The particle counters are mounted inside the scattering chamber, which is constructed of brass with Pyrex light windows.