ditions required for optimum output on the $7\,^3D$-$4\,^3P$ transition are compatible with an indirect process of this type. As with the other noble gases, the metastable densities may interfere with the inversion through resonance trapping of the $4\,^3P$-$2\,^3S$ transition and electron excitation of the $4\,^3P$ term. Indirect support of this conclusion has been obtained by observing that a slight trace of nearly any impurity will enhance the oscillation, presumably through ionizing collisions with the $2\,^3S$.

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POLARIZATION IN PROTON-He^4 SCATTERING AT 38 MeV*

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With the polarized proton source[1] which was developed for the Minnesota linear accelerator, the polarization of the protons scattered by He^4 at 38.4 MeV was measured.

The incident 39.9-MeV polarized proton beam was focussed to a spot $\frac{3}{32}$ in. wide and $\frac{1}{4}$ in. high by a pair of quadrupole magnets on the liquid helium target. The experimental setup and procedures used here and other experiments which have been done with solid targets will be reported in more detail in the near future. The liquid helium target was contained in a 1.7-cm diameter by 4-cm high cyclinder made of 1-mil Mylar, which was attached to a 2.3-liter reservoir. The whole assembly was surrounded by a liquid nitrogen heat shield, which made possible 14 hours of experimental observation for each liquid helium filling. The energy loss in the liquid helium target was 3.2 MeV so that the mean energy was 38.3 ± 0.5 MeV. Two identical NaI crystal counters, each subtending a fixed solid angle to the target, were used as detectors. The angular resolution was $\pm 1.5°$ to $\pm 2.3°$, the variation depending on the finite thickness of the target and the angle of scattering. The beam intensity was about 1.5×10^6 protons per second with a maximum polarization of 38%.

The orientation of the beam polarization can be readily changed to up or down by reversing the direction of the spin-orienting magnetic field in the ionizer of the polarized source. This means that the asymmetry measurements can consist of a pair of runs with the beam polarization up and down instead of a left-right asymmetry measurement with fixed polarization direction. This makes it possible either to set both counters at different angles on the same side of the incident beam or to set them at the same angle on the opposite side of the beam. Measurements made with the two configurations for the same scattering angle agree with each other within statistical errors. Beam polarization was measured during the run by observing the change in beam intensity with the sextupole magnet on and off. This method was checked at 10 MeV with p-He^4 polarization data of Rosen et al.[2] and found to be reliable.[3]

For each angle, background counts due to the Mylar target container were measured and corrections were made in the results which are summarized in Table I. The errors given in Table I arise solely from counting statistics which are much larger than all other sources of errors. By monitoring and controlling the beam position at the quadrupole magnets, it was possible to minimize the fluctuations in the beam direction and/or position at the target. This makes the errors due to the spurious asymmetry negligible when compared to the statistical errors. There exists a relative error of about 10% due to the uncertainty of the beam polarization. This is due mainly to the uncertainty in the 10-MeV p-He^4 polarization of Rosen et al.,[2] which was used for the calibration of our method of measuring beam polarization.

Table I. p-He^4 polarization.

	E_p = 38 MeV	
θ_L	$\theta_{c.m.}$	Polarization P %
20	25.05	0.3 ± 1.5
25	31.25	+2.0 ± 0.8
30	37.4	+0.7 ± 1.7
35	43.5	-0.9 ± 2.1
40	49.5	-0.3 ± 2.3
45	55.5	-9.1 ± 2.6
50	61.4	-10.2 ± 2.0
55	67.2	-10.8 ± 4.8
60	72.9	-10.2 ± 3.5
65	78.5	-17.6 ± 4.4
70	84.0	-16.3 ± 3.4
75	89.4	-26.8 ± 4.4
80	94.7	-32.9 ± 5.7
85	99.9	-43.7 ± 4.9
90	104.95	-36.7 ± 6.0
95	109.9	-26.5 ± 5.1
100	114.7	-6.3 ± 5.7
105	119.4	10.2 ± 6.8
110	124.0	27.0 ± 5.1
115	128.5	55.7 ± 5.2
120	132.9	73.0 ± 5.2
125	137.2	73.8 ± 4.3
130	141.8	82.4 ± 5.7
135	145.5	81.0 ± 6.1
140	149.5	79.2 ± 4.6
145	153.5	59.4 ± 5.8
150	157.4	50.7 ± 6.7

Because of the large energy loss inherent in p-He^4 scattering at large angles, proton energy spectra of those measurements made at angles greater than 130° lab showed no appreciable decrease in counts in those channels of the pulse-height analyzer which corresponded to protons of lesser energy than that of elastically scattered protons. This absence of a clean peak could possibly cause an error in the asymmetries due to gain shifts in the electronics. However, the upper limit of this error was found from measurements to be smaller than the statistical error.

In Fig. 1 our experimental results are plotted together with the p-He^4 polarization at 40 MeV, as predicted by Gammel and Thaler,[4] who calculated the polarization from the p-He^4 elastic scattering cross-section data observed by Brussel and Williams.[5] There is an appreciable disagreement between the experimental data and the theoretical curves in the angular region larger than 80° c.m. This suggests that further theoretical analysis would be desirable. This work is now underway at Livermore and Oak Ridge.[6]

The p-He^4 polarization at backward angles is of practical interest for the production of high-energy polarized protons by Rosen's α-p recoil

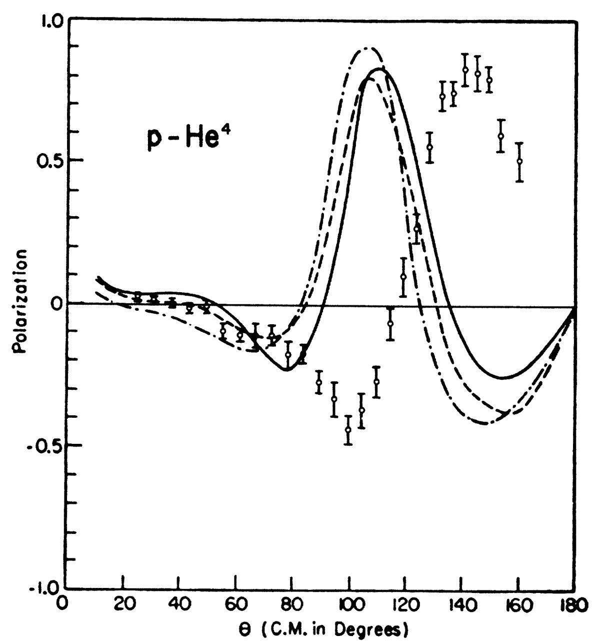

FIG. 1. Polarization in p-He^4 scattering at 40 MeV. The sign of P follows that of the Basel convention. The three curves are the predictions of Gammel and Thaler,[4] based on the phase shifts they calculated to give reasonable fits to the measured elastic differential cross sections[5] and which suggest an "optical model" potential.

method. Our results, together with the existing lower energy data,[7] show that a high-intensity α beam of any energy up to 160 MeV from an AVF cyclotron can be conveniently used to produce highly polarized protons of energy up to 80 MeV.

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POLARIZED TARGETS AS DIRECT REACTION MECHANISM PROBES*

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Recent advances both in low-temperature and high-magnetic-field technology indicate that it is quite feasible to consider the future availability of polarized targets.[1] Theoretical studies have already indicated the extent to which polarized beams provide detailed information concerning reaction mechanisms.[2] It is the purpose of this Letter to indicate the added information to be gained through the use of polarized targets. First, there is the extra complexity of nuclear polarization, characterized by additional parameters, the exact number being dependent on the spin of the nucleus; but of much greater significance is the fact that nuclear polarization effects highlight the reaction mechanism[3] in a much more direct way than is the case for polarized projectiles if we employ current reaction formulations. This holds even in the case where the projectile and target are of common spin, for example, in a deuteron stripping process on a spin-1 target.

We consider a nucleus of spin a with component α. Its polarization is conveniently designated by the tensor[4]

$$\rho_{k\kappa}(a) = \sum_{\alpha\alpha'} \langle a\alpha|\rho|a\alpha'\rangle \cdot (-1)^{a-\alpha'}(a\alpha, a-\alpha'|k\kappa),$$

with $k \leq 2a$. This tensor is defined in terms of an arbitrary density matrix, ρ. In most situations the density matrix, ρ, will be diagonal if referred to a polarization axis which defines the axis of symmetry. We label the tensors in this diagonal representation by the real parameters, $\bar{\rho}_{k0}(a)$.

It is desirable to express the polarization tensors in a coordinate system appropriate to the reaction, say where the z axis is in the direction of the incident beam and the y axis is normal to the reaction plane. Then, the polarization is characterized by the tensors,

$$\rho_{k\kappa}(a) = [(4\pi)^{1/2}/\hat{k}]\bar{\rho}_{k0}(a)Y_k^{\kappa^*}(\theta, \phi),$$

where θ and ϕ are the polar and azimuthal angles of the quantization axis and quantities such as $(2x+1)^{1/2}$ are denoted by $\hat{x}$. Parity considerations show that, provided there is no measurement of the polarization in the exit channel, these tensors give rise to asymmetries in the azimuthal angular distribution, which vary as $\cos\kappa\phi$ or $\sin\kappa\phi$ according as k is even or odd.

We shall use a distorted-wave formalism, making the sole restriction that the distortion in each channel be independent of nuclear spin. Otherwise, we make no assumptions concerning the spin-dependence of the interaction and, in particular, of the distortion in each channel. If we