MEASUREMENT OF THE POLARIZATION OF PROTONS ELASTICALLY SCATTERED ON D^2, T^3, *AND* He^3 *NUCLEI*

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The polarization of protons scattered by He^3 is measured for energies between 2.7 and 4 MeV and at a c.m.s. scattering angle of 40°. When the energy increases above 2.5 MeV, an appreciable polarization appears and reaches a maximum ($P = (30 \pm 5)\%$ at $E = 3.37$ MeV); at higher energies the polarization begins to drop off. Protons scattered by tritium at 40° (c.m.s.) and 3.0 MeV are almost unpolarized. At 3.48 MeV the polarization is $(-22 \pm 11)\%$. The polarization of 3.1 and 3.3 MeV protons scattered by deuterium is insignificant. He^4 was used for the polarization analysis. The doubly scattered protons were recorded with photographic plates.

In spite of the large number of investigations devoted to few-nucleon systems, there are still not enough experimental data, so that the calculations are based on the crudest of assumptions. There are particularly few data with which to explain the spin dependence of the nuclear forces. In this respect, polarization measurements are of great importance.

We measured the polarization of protons elastically scattered by D^2, T^3, and He^3 in the energy interval from 2.5 to 4 MeV.

A proton beam of set energy from the electrostatic accelerator entered a gas chamber filled with D^2, T^3, or He^3, through a nickel foil 1.75 mg/cm^2 thick. The gas chamber was made in the form of a cylinder. On the side surface of the cylinder was a window covered with mica foil 1.4 mg/cm^2 thick. The scattered protons entered the analyzer through this window and through collimating diaphragms.

The degree of polarization was measured with He^4. The protons scattered by the He^4 were recorded on photographic plates. The He^4 pressure in the analyzer was 780 mm Hg.

The He^3 which we used had practically no impurities. The tritium contained 0.8% hydrogen and 0.3% deuterium. The hydrogen and deuterium admixture amounted to 1.8%. Technical 99.7% pure helium was used for the analysis.

Only elastic scattering takes place in interactions between protons and He^3, and practically no neutron background is produced by the accompanying reactions. The scattering of protons by deuterons was not accompanied by a noticeable background.

The polarization of the protons scattered by the tritium is difficult to measure because of the large neutron background from the $T(p,n)He^3$ reaction. To reduce the background, a paraffin shield was placed between the first and second scatterers. However, even in this case the background was 20—30% of the effect. Consequently the background was included in the calculations of the polarization for (p, T^3) scattering. In all other cases the measurement errors were due only to the statistical scatter.

As is well known, the degree of polarization of particles with spin ½ is determined by measuring the azimuthal asymmetry of the protons (R), elastically scattered by nuclei with zero spin, using the well known formula

$$R = (1 + P_1 P_{an}) / (1 - P_1 P_{an}),$$

where P_{an} can be calculated from the geometry of the polarimeter and from the (p, He^4) elastic scattering phase shifts. The measured polarization (P_1) is assumed positive in the direction of the normal $\mathbf{k}_p \times \mathbf{k}_{p'}$ to the scattering plane, where the vectors $\mathbf{k}_p$ and $\mathbf{k}_{p'}$ are the directions of the incident and scattered protons.

The most consistent measurements of the polarization for the (p, He^3) scattering were made at $\theta_1 = 39°40'$ c.m.s. and are listed in Table I. The polarization first increases from 6% at $E_p = 2.70$ MeV, reaches a maximum near 3.5 MeV, and then decreases. Inasmuch as the contribution from the interaction with the orbital momentum $l > 0$ decreases with decreasing energy, we must assume that the polarization will also decrease. Such a resonant behavior can apparently be interpreted

Table I

E_p at the instant of first scattering	E_p for scattering by He^4, MeV	P_{an}, %	P_1, %	ΔP_1%
2.71	2.16	+80	+6	±6
2.88	2.34	+73	+11	±5
3.11	2.53	+67	+16	±5
3.37	2.40	+70	+30	±5
3.93	2.51	+68	+24	±6

as the manifestation of a virtual Li^4 state.

Table II lists the results of the measurement of polarization by He^3 at other angles. The fact that the polarization is smaller at 58°40′ and 76°50′ than at 39°40′ at the corresponding energies is evidence of the resonant character of the P wave.

Frank and Gammel[1] made a phase-shift analysis of the elastic scattering of protons by He^3, assuming that only S and P waves participate. In such a case it is necessary to determine six phase shifts δ (for the waves $^1S_0$, $^3S_1$, $^1P_1$, $^3P_0$, $^3P_1$, and $^3P_2$) and, naturally, the problem becomes indeterminate, for obviously no analysis can be made on the basis of data on the angular distributions only. Using some simplifying assumptions, particularly that there is no splitting of the P wave, the authors confined themselves to four phase shifts ($^1S_0$, $^3S_1$, $^1P_1$, and $^3P_1$) and obtained their energy dependences in the interval 1—3.5 MeV. The calculations were made in the Born approximation, which in this case results in large errors.

Recently a different type of phase-shift analysis was made[2] for the (p, He^3) scattering in the 0—8 MeV interval. S, P, and D waves were included, and the spin-orbit splitting was not taken into account. The analysis has shown that the contribution of the D waves is very small. The experimental and calculated angular distributions and excitation functions were in good agreement at low energies. However, a deviation is observed with increasing energy, and apparently reflects the splitting of the triplet phases. Our measurements have shown that at energy from 0 to 2.5 MeV, the scattering apparently does not depend indeed on the spins of the interacting particles, and the premises on which the phase shift analysis was based in [1,2] can be regarded as justified. However, at energies above 2.5 MeV spin-orbit splitting of the P wave takes place, as is manifest in the polarization. Thus, in spite of the good agreement with experiment, the phase-shift analysis of [1,2] does not reflect the true picture of the interaction. An exact phase-shift analysis should take into account the splitting of the P-wave triplet phases.

Table III shows the results of the polarization of protons elastically scattered by tritium.

Only at E_p = 3.48 MeV (θ = 39°40′) is a noticeable polarization observed. Unfortunately, there are no measurements at energies above 3.5 MeV, so that no conclusion can be drawn.

A phase-shift analysis of proton-tritium scattering was also made by Frank and Gammel. As in the case of (p, He^3) scattering, four phase shifts were taken into account—two singlet ($^1S_0$, $^1P_1$) and two triplet ($^3S_1$, $^3P_1$). The low value of the polarization shows that the interaction in the energy interval up to 3.5 MeV actually is independent of the spins of the colliding particles. Therefore the simplifying assumptions made by these authors are justified.

A study of the elastic scattering of protons by tritium nuclei is also of interest from the point of view of a search for excited states of the α particle. A hypothesis was advanced in many papers

Table II

θ	E_p at the instant of first scattering	E_p for scattering by He^4, MeV	P_{an}, %	P_1, %	ΔP_1, %
58°40′	2.89	2.04	+92	+10	±6
58°40′	3.33	2.44	+68	+23	±6
76°50′	3.93	2.43	+68	+13	±4

Table III

θ	E_p at the instant of first scattering	E_p for scattering by He^4, MeV	P_{an}, %	P_1, %	ΔP_1, %
39°40′	2.89	2.31	+74	− 1	±10
39°40′	3.06	2.48	+70	− 3	±12
39°40′	3.21	2.64	+64	0	±10
39°40′	3.48	2.81	+60	−22	±11
58°40′	3.58	2.31	+74	− 3	±12

Table IV

θ	E_p at the instant of first scattering	E_p for scattering by He^4, MeV	P_{an}, %	P_1, %	ΔP_1, %
44°40′	3.11	2.26	+78	+2	±2
64°40′	3.34	2.17	+80	+3	±3
45°[6]	3.34			+6	±6
45°[6]	3.74			+4	±5
90°[6]	3.45			−2	±5

[3-5] that there are three such states at excitation energy 20 MeV (0^+), 22 MeV (2^-), and 23 MeV (1^-). The last two states are regarded as a result of spin-orbit splitting of the P wave. In spite of the large number of investigations devoted to this problem, there is no convincing proof of the existence of these levels to date.

Our measurements were carried out in the region of indicated excitation energy. The polarization, as can be seen from Table III, was small. Therefore the second and third levels do not come into play to any significant degree.

The polarization of the protons scattered by deuterium (Table IV) is zero within the limits of measurement error.

In this case our results do not contradict the earlier measurements of Shafroth et al[6], whose results are also listed in Table IV. The absence of polarization is observed also for neutrons scattered by deuterium at the indicated energies. Therefore an analysis of a three-nucleon system without account of spin-orbit interaction is apparently justified.

1 R. M. Frank and J. L. Gammel, Phys. Rev. **99**, 1406 (1955).

2 Tombrello, Miller, Jones, Phillips, and Weil, Nucl. Physics **39**, 541 (1962).

3 Bergman, Isakov, Popov, and Shapiro, JETP **33**, 9 (1957), Soviet Phys. JETP **6**, 6 (1958).

4 Vlasov, Kalinin, Ogloblin, Samoilov, Sidorov, and Chuev, JETP **28**, 639 (1955), Soviet Phys. JETP **1**, 500 (1955).

5 A. I. Baz' and Ya. A. Smorodinskii, JETP **27**, 382 (1954).

6 Shafroth, Chalmers, and Strait, Phys. Rev. **118**, 1054 (1960).

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