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NEUTRON POLARIZATION IN THE REACTION T (d, n) He^4

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The azimuthal asymmetry in the scattering on He nuclei of neutrons from the reaction T (d, n) He^4 ($E_d = 9.9 \pm 0.7$ Mev) is measured for various angles of neutron emission θ_n. A marked asymmetry is found at $\theta_n = 70°$ (laboratory system). The azimuthal asymmetry is measured at this emission angle as a function of the angle of scattering on He^4. The results are compared with n-He^4 (Seagrave) and p-He^4 (Gammel-Thaler) scattering phase shifts. The polarization of the investigated neutrons estimated on the basis of the Gammel-Thaler phase shifts is $P_T(70°) = (+32.1 \pm 3.0)\,\%$ (the direction along the normal $\mathbf{k}_n \times \mathbf{k}_d$ is considered positive).

THE weak polarization of neutrons from the T (d, n) He^4 reaction (deuteron energy $E_d = 1.8$ Mev) has been previously[1] ascertained. The present paper investigates the possibility of using the same reaction as a source of polarized neutrons for $E_d \approx 10$ Mev.

A beam of 12.3-Mev deuterons from the Institute of Theoretical and Experimental Physics cyclotron was focused on a zirconium target 0.6 Mev thick which was saturated with tritium. The average current was 1.5 μamp with a 5×3 mm spot of the beam on the target. A 103-mg/cm^2 platinum foil was laid directly against the target to separate it from the working volume of the cyclotron.

The azimuthal asymmetry of the neutron scattering was measured in a helium analyzer described earlier.[2,3] The helium pressure in the proportional counters was varied from 7 to 20 atm, depending on the neutron emission angle, and was held constant within ±0.5%. The length of the effective volume of the counters was ~ 20 mm, and the working voltage was 600 — 1200 v. To maintain the gas amplification factor constant, a continuous convective flow of helium was maintained in a metallic-calcium column, connected to the counters and heated to 300°.

Departing from previous practice,[1-3] the proportional counters were calibrated with Po^{210} α particles. The polonium was deposited on a platinum foil, which was fitted tightly to the inner walls of the counter. The presence of a constant background of Po^{210} α particles had no effect on the asymmetry measurements, since their energy was less than the energy of the recoil He^4 nuclei over the whole of the angular interval used. A fission chamber was used as a monitor, and a current integrator applied to measure current passing through the target.

We did not know in advance either the angles at which the neutrons were polarized in the T(d, n)He^4 reaction or the n-He^4 scattering phase shifts at neutron energies $E_n \gtrsim 20$ Mev. Preliminary measurements of the azimuthal scattering asymmetry were therefore made as a function of the neutron emission angle (θ_n) with the counters set at $\varphi_\alpha = \pm 35°$ [$\varphi_\alpha = (\pi - \varphi_n)/2$, where φ_n is the scattering angle of the neutrons on He^4 nuclei in the center-of-mass system (cf. Fig. 1 in [2])]. This angle was chosen from polarization curves for p-He^4 scattering at $E_p \gtrsim 18$ Mev.[4] As a result, the following values for the azimuthal asymmetry $R = I_1/I_2$ are obtained (I_1 and I_2 are the counting rates in the directions $+\varphi_\alpha$ and $-\varphi_\alpha$, the + sign referring to the case when φ_α is taken in the same direction as θ_n):

θ_n (l.s.), deg:	30	50	60	70	90
E_n, Mev:	25.8	23.6	22,2	20.7	17.9
R:	1.03±0.03	1.12±0.03	1.06±0.04	1.34±0,09	1,06±0.08

Since the measurements were made in a "good geometry",[3] anisotropy of the angular distribution in the T (d, n) He^4 reaction was not taken into account (the correction was ~ 1%). The target construction permitted measurement of the background associated with neutrons coming from the diaphragms, the target backing, etc. The background was negligibly small at small θ_n; at $\theta_n = 90°$ (lab. system) it was ~ 15% of the counts in the utilized analyzer channel.

The second stage of the work consisted of measuring the dependence of the azimuthal asymmetry on the angle φ_n of neutron scattering on He^4 nuclei at the angle $\theta_n = 70°$ (lab. system) of neutron emission from the target. R and the product of the polarizations for the given reaction and analyzer are connected by the well-known relation:

$$P_T(\theta_n)\,P_{He}(\varphi_n) = (1 - R)/(1 + R),$$

where $P_T(\theta_n)$ is the neutron polarization in the reaction T (d, n) He^4 (neutrons emitted at an angle of θ_n to the target); $P_{He}(\varphi_n)$ is the polarization of neutrons scattered on He^4 at an angle of φ_n; and R is the azimuthal asymmetry in the scattering. The polarization is considered positive in the direction $\mathbf{n} = \mathbf{k}_n \times \mathbf{k}_d$.

The following results were obtained:

φ_n (l.s.), deg	90	110	124	136	150
R	0.71±0.05	1.34±0.09	1.53±0,15	1,50±0.10	1,26±0.15
$-P_T(70°)\,P_{He}(\varphi_n)$, %	−17.0±3.4	14.5±3.3	20,9±4.5	20.0±3,2	11.5±5.9

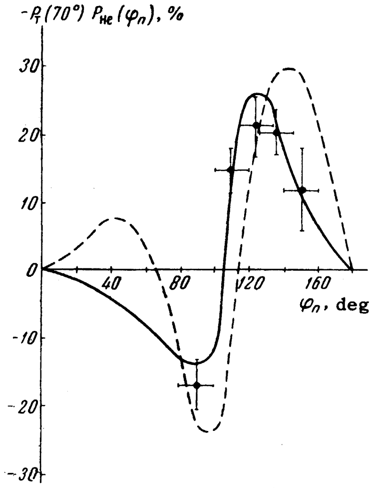
Only statistical errors are indicated here.

The figure shows values obtained for $P_T(70°) \times P_{He}(\varphi_n)$ as well as the results of calculating the same quantity from phase shifts for n-He^4 scattering (according to Seagrave[5]) and p-He^4 scattering (according to Gammel-Thaler[6]). The spread of angles of the recoil He^4 nuclei inside the counters was taken into account in the calculation of the curves.

The best agreement between calculated curves and experimental results is attained when the polarization $P_{He}(\varphi_n)$ is computed from Gammel-Thaler phase shifts[6] and the neutron polarization in the reaction T (d, n) He^4 has the value

$$P_T(70°) = (32.1 \pm 3.0)\ \%.$$

The figure indicates a definite disagreement between our results and the Seagrave phases at $E_n \approx 20$ Mev. It must, however, be observed that the Seagrave analysis does not claim to give a quantitative agreement at such energies. On the other hand, the agreement of our n-He^4 scattering data with calculations from p-He^4 scattering phase shifts (which are based on more significant experimental material) is not strange, since in large momentum transfers the angular dependences of polarization in p-He^4 and n-He^4 scattering should not be very different.



$-P_T(70°)\,P_{He}(\varphi_n)$ as a function of the angle of neutron scattering on He^4 ($E_n = 20.7 \pm 0.4$ Mev). The solid curve is calculated from Gammel-Thaler phase shifts,[6] the dashed from Seagrave phase shifts.[5] The curves are normalized to the polarization $P_T(70°) = 32.1\%$.

Thus our results may be considered as an experimental confirmation of Gammel-Thaler phase shifts at $E_n \sim 20$ Mev. If this is so, the small azimuthal asymmetry in n-He^4 scattering observed at $\varphi_\alpha = 35°$ for neutrons coming at angles $\theta_n < 70°$ from the T (d, n) He^4 reaction is actually evidence of small polarization at these angles.

There is the hypothesis[7] that the reaction T (d, n) He^4 proceeds by the stripping mechanism at small angles θ_n. In this case the polarization in the region of angles around the Butler peak must be small for this reaction, since the angular momentum of the captured proton $l_p = 0$. Neutron polarization at large emission angles can arise as a result of a spin-orbit interaction between departing neutron and α particle.[8,9]

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