POLARIZATION OF NEUTRONS FROM THE T(p, n) He^3 REACTION AND OF PROTONS FROM THE He^3(n, p) T REACTION

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Submitted to JETP editor May 26, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **37**, 1183-1186 (November, 1959)

Polarization of neutrons produced in the T (p, n) He^3 reaction by 8 — 10 Mev protons was determined by measuring the right-left asymmetry of protons produced in the inverse reaction He^3 (n, p) T. The dependence of the asymmetry on the angle of proton emission from the He^3 (n, p) T reaction has also been measured. Polarization of the T (p, n) He^3 neutrons and He^3 (n, p) T protons attains 30% for an angle of incidence of about 40° and primary proton energy of about 10 Mev. The polarization decreases as the proton energy is diminished but the angle of emission corresponding to peak polarization does not change appreciably.

THE energy dependence of the T (p, n) He^3 cross section[1,2] as well as that of the total neutron cross section[3] of He^3 exhibits resonance, from which it is inferred that alpha particles have a 22-Mev excited state with spin and parity 2^-.[2,4] This is confirmed by the shape of the neutron spectrum from the T (d, n) reaction[5] and by the spectrum of inelastically scattered electrons.[6] However the spectrum of protons scattered inelastically by He^4 contains broad groups[7,8] which are evidently associated with a large contribution by other states of the final He^4 nucleus. The great weight of the 1^- state at about 25 Mev is indicated by the energy dependence of the T (p, γ) He^4 and He^4 (γ, p) T reactions, which are electric dipole transitions.[9,10] Various experimental data and their interpretation are thus far not in agreement concerning the states of He^4, so that further investigation is of interest.

For this purpose it is important to study the polarization of neutrons from T (p, n) He^3 and of protons from He^3 (n, p) T, which is the subject of the present paper. In reference 11 it is shown that the polarization of T (p, n) He^3 neutrons for proton energy E_p = 1.46 Mev, which is somewhat above the reaction threshold (1.019 Mev) is close to zero at 50°. This does not exclude the possibility of appreciable polarization at proton energies greatly exceeding the threshold and the resonance value (~ 3 Mev).

The study of neutron polarization from T (p, n) He^3 is also of great methodological importance since this reaction is widely used as a convenient source of fast monoenergetic neutrons.

Barschall[12] has suggested the use of inverse reactions for the study of polarization. We have used this method to determine simultaneously the polarization of T (p, n) He^3 neutrons and of protons from the inverse reaction He^3 (n, p) T. When the products of both reactions are observed at certain definite (Barschall) angles the right-left asymmetry gives the square of the polarization directly. In our case the Barschall angles and the corresponding polarizations are quite small; our measurements were made principally at large angles. When polarization depends smoothly on the angle and on energy, Barshall's method can be extended to a broader angular range. We observed appreciable polarization at approximately twice the Barschall angle and determined the angular dependence and energy dependence of the polarization. Therefore the determination of the absolute value of the polarization is not confined to Barschall angles.

The reaction T (p, n) He^3 was excited in a tritium-zirconium target about 0.2 Mev thick by an external cyclotron beam of protons with initial energy 10 Mev. The protons were slowed down in platinum foils placed directly ahead of the target. A chamber 5 cm in diameter and 5 cm deep filled with He^3 at 10 atmos served as the radiator of the proportional telescope[13] and was positioned 50 cm from the target at the angle θ_1 to the beam. The grid of openings in the helium cell wall, facing the telescope counters, was covered with 10μ iron foil. The telescope rotated about an axis passing through the center of the radiator, so that protons from the reaction He^3 (n, p) T occurring in the radiator were registered at angles θ_2 to the right and to the left of the neutron beam emitted at angle θ_1. The symmetry of θ_2 was checked by replacing helium with hydrogen in the radiator and recording the intensity of recoil protons as a function of θ_2

to the right and left. The telescope was set for the steeply dropping final portion of the recoil-proton spectrum in order to accentuate the angular dependence. The position of the telescope corresponding to $\theta_2 = 0$ was determined within 0.1° from the steep slopes of the curve registered with the hydrogen radiator.

The proton intensity from the $He^3(n, p)T$ reaction at different angles θ_2 to the right and left was measured for different values of E_p and θ_1. The most pronounced effect was observed at $E_p = 9.9$ Mev and $\theta_1 = 40°$. Figure 1 shows the asymmetry coefficient $R = N_r/N_l$ as a function of θ_2.

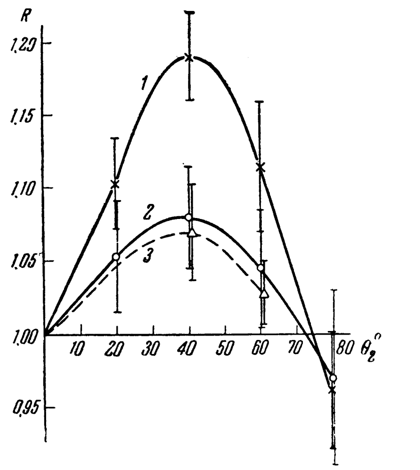

FIG. 1. Right-left asymmetry of protons from He^3 (n, p) T as a function of the angle of emmission. Curve 1 – $\theta_1 = 40°$, $E_p = 9.9$ Mev, $E_n = 7.7$ Mev; curve 2 – $\theta_1 = 16.5°$, $E_p = 9.9$ Mev, $E_n = 8.8$ Mev; curve 3 – $\theta_1 = 40°$, $E_p = 8.0$ Mev, $E_n = 6.1$ Mev.

Here N_r and N_l are the numbers of counts to the right and left relative to the same proton flux impinging on the target, as measured by an integrator. The indicated errors are entirely statistical. N_r and N_l are the differences between the counts obtained with the helium radiator and with an empty chamber. The background from the tritium target backing was also taken into account. In the general case we have

$$R = (1 + P_1P_2)/(1 - P_1P_2),$$

where P_1 is the polarization of neutrons from $T(p, n)He^3$ and P_2 is the polarization of protons from $He^3(n, p)T$. As θ_2 is varied only P_2 changes, while P_1 remains constant but of unknown magnitude. For $\theta_2 = \theta_1 = 40°$ $P_2 \neq P_1$ since θ_1 and θ_2 are greater than the Barschall angles and the second reaction takes place at a somewhat lower energy than the first reaction. At the Barschall angle $\theta_1 = 16.5°$ the energy of neutrons from the first reaction is $E_n(16.5°) = 8.85$ Mev, while at $\theta_1 = 40°$ we have $E_n(40°) = 7.72$ Mev. If only a slight change of polarization accompanies an energy difference of 1.1 Mev we may assume $P_1(40°) = P_2(40°)$ and use the $R(\theta_2)$ curve to calculate $P_{1,2}(\theta_{1,2})$. Figure 1 also gives the plot of $R(\theta_2)$ for the same energy $E_p = 9.9$ Mev at the Barschall angle $\theta_1 = 16.5°$ (curve 2). Because of the small polarization at $\theta_1 = 16.5°$ this curve is relatively less accurate but the angular distribution $R(\theta_2)$ is of the same character. Curve 3 was plotted for $E_p = 8.0$ Mev and $\theta_1 = 40°$. With decreasing proton energy the magnitude of the polarization is diminished but the angular distribution is of the same type. Therefore the polarization P calculated from $R(40°, 40°)$ assuming $P_1 = P_2$ actually pertains to the intermediate energy $E_n \approx 8.3$ Mev and in the given experiment $P_1(40°) > P > P_2(40°)$. Having determined $P_1(40°)$ in this manner we may obtain $P_{1,2}(\theta)$ for all values of θ_2 for which $R(\theta_1 = 40°, \theta_2)$ was measured.

Figure 2 shows the polarization of neutrons from the reaction $T(p, n)He^3$ and of protons from $He^3(n, p)T$ as a function of the angle θ.

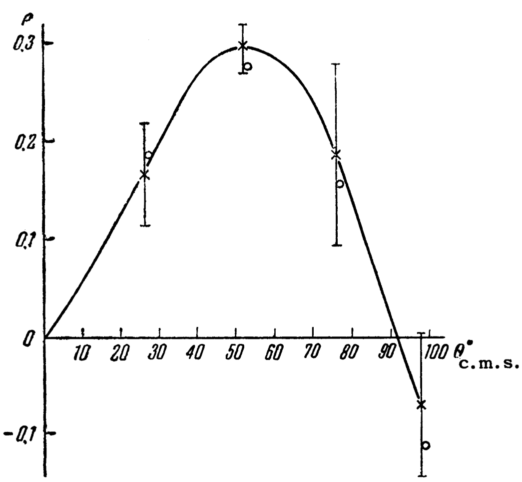

FIG. 2. Angular dependence of neutron polarization from $T(p, n)He^3$ at $E_p = 9.9$ Mev. × – $\theta_1 = 40°$, $E_n = 7.7$ Mev; ○ – $\theta_1 = 16.5°$, $E_n = 8.8$ Mev.

The plotted points were obtained by means of the curve $R(\theta_1 = 16.5°, \theta_2)$, which gives the polarization directly under the Barschall conditions. This result is relatively less accurate, although both results are in good agreement. Figure 3 shows the dependence of maximum polarization on primary particle energy for both reactions $T(p, n)He^3$ and $He^3(n, p)T$. It is evident from Figs. 2 and 3 that neutron polarization from $T(p, n)He^3$ at about 40° reaches 30% for $E_p = 9.9$ Mev and probably increases further with E_p. Thus the $T(p, n)He^3$ reaction is a good source of neutrons with a fairly high degree of polarization at $E_n = 8$ Mev and probably also at higher energies.

A different method would be required to deter-

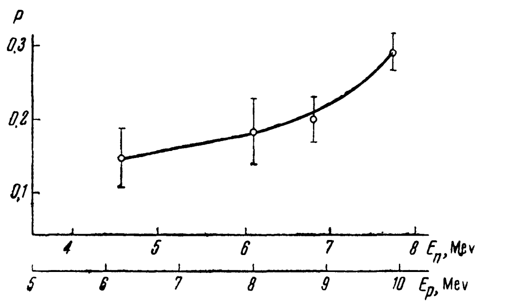

FIG. 3. Polarization of neutrons from $T(p, n)He^3$ and of protons from He^3 (n, p)T as a function of primary particle energy at 40° in the laboratory system.

mine also the direction of the polarization. The angular dependence of the polarization is apparently associated mainly with interference of the $P_{3/2}$ and $P_{1/2}$ states of emitted nucleons. The first of these states corresponds to resonance in $T(p, n)He^3$ at $E_p = 3$ Mev. The observed polarization and the energy dependence do not contradict the hypothesis of Baz' and Smorodinskiĭ[4] that a second state exists at an energy E_p greater than 3 Mev. Enhanced polarization is not surprising if the phases of the $P_{3/2}$ and $P_{1/2}$ states vary differently with energy. However, it follows from an analysis of neutron angular distributions that d phases become appreciable at $E_p = 10$ Mev and thus complicate the interpretation of the polarization.

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Translated by I. Emin
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