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Helium is often used as an analyzer of polarized neutrons. The analyzing power of helium is usually calculated from phase shifts for the scattering of neutrons by alpha-particles. A dearth of experimental information has made it difficult to determine phase shifts for neutron-alpha scattering above a neutron energy of about 25 MeV. Complex proton-alpha phase shifts do not adequately reproduce total [1] and differential [2] cross section measurements above this energy.

Measurements of the angular variation of the asymmetry in the scattering of partially polarized neutrons by alpha-particles have recently been made by ARIFKHANOV et al. [3] at neutron energies of 25 and 28 MeV. The source of polarized neutrons was the $T(d, n)^4He$ reaction, for which the neutron polarization is not accurately known.

A search for phase shifts which best fit the n-alpha data at each of these energies was carried out with the help of a computer program [4] which systematically varied an initial set of phase shifts until ε^2, the overall squared error of fit was minimized. In the present search, ε^2 was taken to have the form:

$$\varepsilon^2 = \frac{1}{3\,N} \left\{ \sum_{i=1}^{N} \left[\frac{\sigma(\theta_i) - \sigma^c(\theta_i)}{\Delta\sigma(\theta_i)} \right]^2 + \frac{N}{Q} \sum_{i=1}^{Q} \left[\frac{[A(\theta_i)/P_1] - P^c(\theta_i)}{[\Delta A(\theta_i)/P_1]} \right]^2 + N \left[\frac{\sigma_T - \sigma_T^c}{\Delta\sigma_T} \right]^2 \right\},$$

where $\sigma(\theta_i) \pm \Delta\sigma(\theta_i)$, $A(\theta_i) \pm \Delta A(\theta_i)$, and $\sigma_T \pm \Delta\sigma_T$ are the experimental differential cross sections, asymmetries and total cross section and their uncertainties; $\sigma^c(\theta_i)$, $P^c(\theta_i)$, and σ_T^c are the differential cross sections, polarizations and total cross section calculated from the phase shifts; N and Q are, respectively, the number of angles at which differential cross sections and asymmetries were measured. P_1 is the neutron source polarization used in the asymmetry measurements. The factors N/Q and N were introduced to weight equally the three independent sets of measurements (differential cross sections, asymmetries, and total cross section). The factor $1/(3\,N)$ normalizes ε^2 such that $\varepsilon = 1$ if the deviation between measured and calculated quantities is equal to the experimental uncertainty.

Several sets of proton-alpha phase shifts [4, 5] which include partial waves of $l \leqslant 3$ in the energy region of interest were used as initial sets. The real parts of all

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phase shifts and the imaginary parts of the F-wave phase shifts were first held fixed at their initial values, and the imaginary parts of the S-, P-, and D-wave phase shifts were adjusted until ε^2 was minimized. This procedure was repeated for fourteen different values of P_1, the neutron source polarization, between 0.35 and 0.60. For all initial sets of phase shifts used, a plot of ε^2 against P_1 exhibited a minimum. At each neutron energy, the minimum obtained from each initial set occured at very nearly the same value of P_1. Over a range of values of P_1 near this minimum, absorption in only the $P_{3/2}$ and $D_{3/2}$ waves was required to fit the data at 25 MeV. At 28 MeV, absorption in the $D_{5/2}$ wave was required in addition. The imaginary parts of the phase shifts and P_1 were then fixed at the values which resulted in the smallest ε^2, and the real parts of the phase shifts were adjusted until ε^2 was further minimized. The real parts of the phase shifts required changes of less than 3° from the initial values in order to improve the fit.

Phase shifts resulting in the best fit to the data are given in Table 1. The values of ε given in column 9 indicate the quality of the fit at both energies.

Table 1

Real part of phase shifts for neutron-alpha scattering in degrees. The quantities in parentheses are inelastic parameters. The inelastic parameter is defined as exp $(-2\ \mathrm{Im}\delta)$ where $\mathrm{Im}\delta$ is the imaginary part of the phase shift. The inelastic parameters are given when they are less than unity.

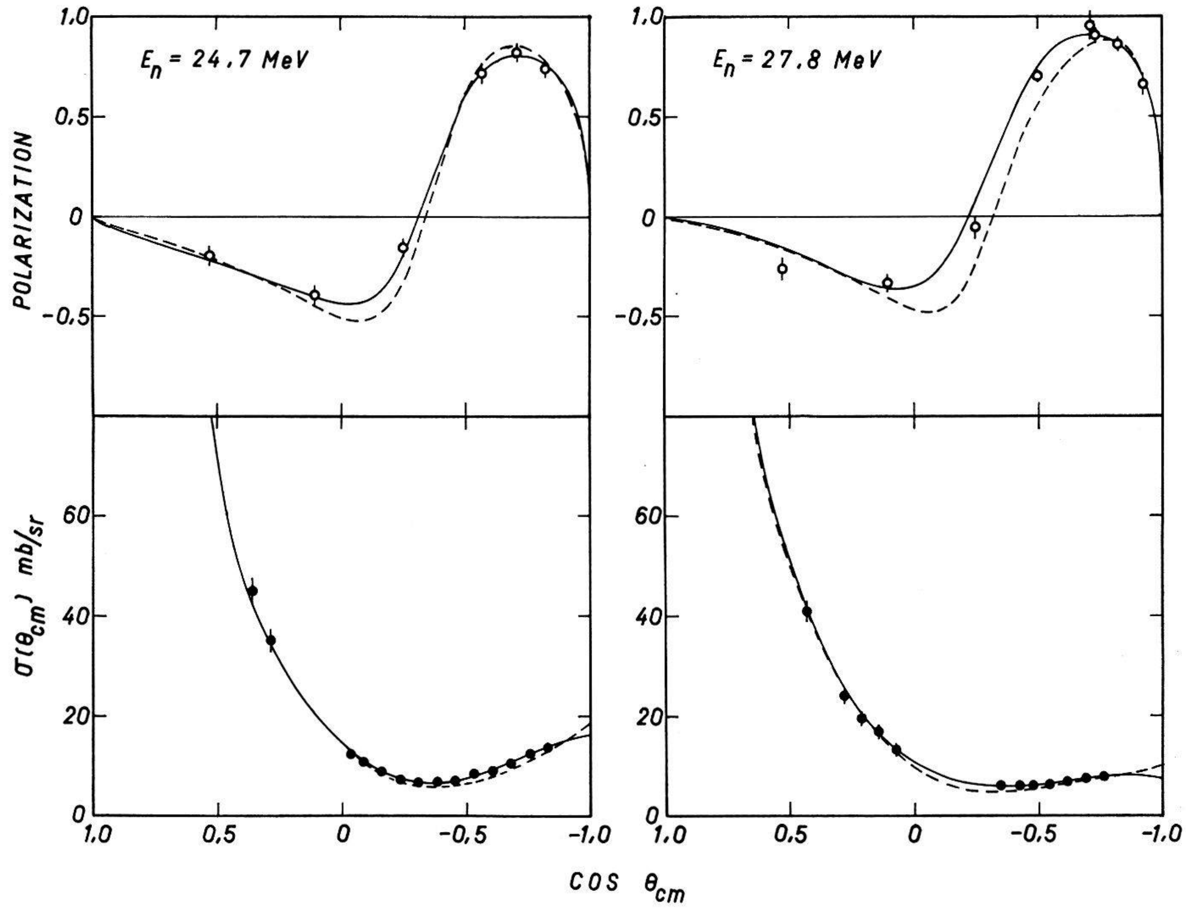
Neutron energy (MeV)	$S_{1/2}$	$P_{1/2}$	$P_{3/2}$	$D_{3/2}$	$D_{5/2}$	$F_{5/2}$	$F_{7/2}$	ε
24.7	83	50	91 (0.86)	8 (0.87)	16	5	4	0.4
27.8	83	49	87 (0.79)	8 (0.80)	19 (0.93)	3	3	0.9

Polarizations and differential cross sections calculated from these phase shifts are compared with experimental data in the Figure. The differential cross section points at 27.8 MeV were interpolated between measurements made at 26.6 and 28.6 MeV. Uncertainties were taken to be those of the higher energy measurements. Published uncertainties, with the exception of scale factor uncertainties, are shown by error bars when they are larger than the size of the symbols. The polarization points are the asymmetry measurements of ref. [3] which have been divided by the values of P_1 determined in the analysis and tabulated in column 5 of Table 2. The sign of P_1 is in accordance with the Basel convention. Values of P_1 which increase ε^2 by a factor of 2 are listed as uncertainties in P_1.

Table 2

Source of polarized neutrons used in the neutron-alpha asymmetry measurements of ref. [3]. The deuteron bombarding energy E_b and the laboratory angle θ of emission of the partially polarized neutrons of energy E_n are also listed.

Reaction	E_b (MeV)	θ (lab)	E_n(lab) (MeV)	P_1
$T(d, n)^4He$	9.1	30°	25	$+0.43 \pm 0.03$
$T(d, n)^4He$	12.0	30°	27.8	$+0.46 \pm 0.03$



Polarizations and differential cross sections as a function of the cosine of the center-of-mass scattering angle for the scattering of 24.7 and 27.8 MeV neutrons by alpha-particles. Polarizations deduced from asymmetry measurements of ref. [3] (open circles) and differential cross section data of ref. [2] (solid circles) are compared with curves calculated from phase shifts given in Table 1 (solid curves) and from phase shifts of ref. [2] (dashed curves).

The present phase shifts fit all available data better than previously proposed phase shifts for the neutron-alpha system at these energies [2], although there is little difference between them. Further measurements, particularly of the cross sections for non-elastic processes will be necessary in order to establish the complex phase shifts with greater certainty.

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