# *ASYMMETRY OF DOUBLE SCATTERING OF NEUTRONS ON HELIUM*

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Right-left asymmetry of doubly scattered initially unpolarized 15 MeV neutrons is measured by double scattering of the neutrons by gaseous helium. Satisfactory agreement is obtained with calculations based on Seagrave phase shifts.

THE scattering of nucleons by $He^4$ as a 'fundamental' particle is of great interest in nuclear physics. Having many advantages over other nuclei, $He^4$ is also one of the principal analyzers for the study of nucleon polarization effects.

A phase shift analysis of n-$He^4$ scattering, based on experimental angular-distribution data, was made by Huber and Baldinger [1] for neutron energies up to $E_n \sim 5$ MeV and by Seagrave [2] up to $E_n \sim 15$ MeV. There are major differences between the two sets of phase shifts for n-$He^4$ scattering, particularly in $P_{1/2}$. The data on p-$He^4$ scattering give independent information on the n-$He^4$ scattering phase shifts. An approximate recalculation of the p-$He^4$ scattering phase shifts was made by Adair [3] and by Doddler and Gammel [4]. Their results agree well with the data of Seagrave, with the exception of $P_{1/2}$, in the neutron energy region up to $E_n = 4$ MeV. The dependence of the phase shifts of n-$He^4$ scattering on the neutron energy is given in Fig. 5 of [5].

Polarization is more sensitive to inaccuracies in the determination of phase shifts than are angular distributions, so that experiments with polarized neutrons can yield valuable information on the phase-shift analysis. A refinement of the phase-shift analysis of n-$He^4$ scattering was made in [5] using partially polarized neutrons with initial energies of 2.45 and 3.4 MeV. This research confirmed the Seagrave phase shifts. The calculation data are presented in Fig. 9 of [5]. We have continued the research of [5] in a higher region of neutron energies and used for this purpose double scattering of unpolarized neutrons by $He^4$.

## EXPERIMENTAL PROCEDURE

Experiments on double scattering of neutrons were not carried out, because of the difficulties connected with the high neutron background and the limited intensity of the neutron sources. In all the experiments on scattering of fast polarized neutrons, partially polarized neutrons from nuclear reactions have been used. The neutrons thus obtained were scattered, and the right-left asymmetry in scattering was observed. We succeeded in avoiding difficulties connected with the neutron background by using a gaseous helium scintillator, which served as a first scatterer, and by using the neutron registration method proposed in [5]. The idea of the method is to register not the neutrons directly scattered by the helium, but the recoil nuclei which correspond to these neutrons.

In experiments on double scattering, the nucleons which are partially polarized in the first scattering are scattered again. Following the second scattering, the differential cross section is given by the expression

$$\sigma = \sigma_0 (1 + \mathbf{P}_1 \mathbf{P}_2),$$

where $\sigma_0$—differential scattering cross section for the unpolarized beam, $\mathbf{P}_1$ and $\mathbf{P}_2$—vectors of the polarization arising when the unpolarized nucleons are scattered by the first and second target respectively. The vectors $\mathbf{P}_1$ and $\mathbf{P}_2$ are perpendicular to the scattering plane.

In the investigation of the neutron polarization produced in scattering by $He^4$, we have used unpolarized neutrons with initial average energy of 14.9 MeV. Figure 1 shows the experimental setup.

The deuterons $D^+$, accelerated to 250 keV, bombarded a tritium target T. The ion current to the target was $\sim 100\ \mu A$. The center of the helium

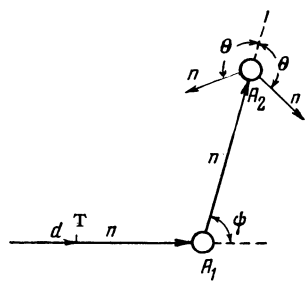


FIG. 1. Diagram of the experiment.

scatterer $A_1$ was placed 12 cm away from the target at zero angle to the deuterons incident on the target; the center of the second helium scatterer $A_2$ was 85 cm from the first scatterer at an angle $\psi = 90°$ (c.m.s.) relative to the deuteron beam. Following the second scattering by $A_2$, neutrons scattered at $\theta = \pm 135°$ (c.m.s.) were registered. In measuring the ratios of the counting rates, which are proportional to the differential cross sections, at angles $\theta = 135°$ and $\theta = -135°$, we obtained the right-left asymmetry due to the polarization of the neutrons in the first and second scatterings:

$$R = \sigma(-135°)/\sigma(+135°) = (1 - P_1P_2)/(1 + P_1P_2).$$

The experimentally obtained asymmetry can be compared with that calculated from Seagrave's phase shifts [2]. The agreement between experiment and calculation is necessary if the phase shift analysis of n-$He^4$ scattering in the energy region 10—15 MeV is correct.

The first scatterer was a gas-filled scintillation counter. The second was a proportional counter filled with $He^4$. Instead of registering the neutrons scattered at ±135° (c.m.s.) we registered the particles which had recoiled at the corresponding angles. The pulses from counters $A_1$ and $A_2$ were fed to a coincidence circuit with resolution time 2 μsec. Figure 2 shows the block diagram of the entire apparatus.

The gaseous-helium scintillation counter used in the experiment is described in detail in [6]. The stainless steel housing of the counter was in the form of a cylinder 6 cm in diameter and 12 cm long. One end of the housing terminated in a hemisphere of 3 cm radius, and the other in a smooth transition from the inner walls to the photo cathode of the photomultiplier. The wall thickness was 1.5 mm. The inside surface was covered with aluminum which in turn was coated with a thin layer of quaterphenyl, which served as the radiation spectrum converter. The open end of the counter was covered with plexiglas. On the inside surface of the plexiglas there was also a layer of quaterphenyl. The counter was filled with helium to 93 atmospheres without additional gas additives. The flashes due to the helium recoil nuclei were registered through the plexiglas window by an FEU-29 photomultiplier. Figure 3 shows the integral spectrum, plotted during the experiment, of the pulses due to 14.5 MeV neutrons. Figure 4 shows the differential spectrum of the pulses from the 3 MeV neutrons, plotted at the end of the experiment (45 days after filling the counter with helium). As can be seen from the figure, the minimum energy with which neutron registration is possible is near 800 keV. The discrimination threshold of the pulses from the scintillation counter to the coincidence circuit was approximately 1 MeV.

The proportional counter combines the scatterer and the scattered-neutron detector. The detector analyzer (see Fig. 5) comprises five parallel-connected counters 1. Each counter consists of steel tubes 19 mm in diameter (wall thickness 0.1 mm) and 280 mm long, polished tungsten filaments and telephone insulators. The counters are arranged in one plane with a spacing of 40 mm. This spacing is due to the choice of

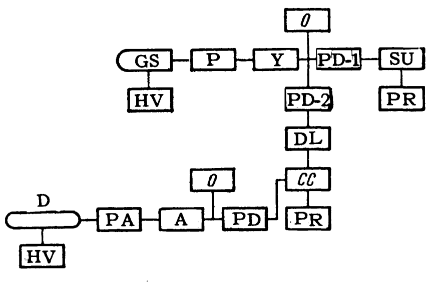


FIG. 2. Block diagram of electronic equipment: D—helium detector, HV—high voltage, PA—pre-amplifier, A—amplifier, O—oscilloscope, PD—pulse discriminator, CC—coincidence circuit, DL—decay line, GS—gas-filled scintillator with photomultiplier, P—PU-349 attachment, SU-scaler, PR—pulse recorder.

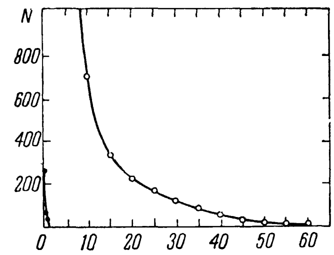


FIG. 3. Integral spectrum of pulses from 14.5 MeV neutrons, o—photomultiplier and amplifier noise. The abscissas represent the registration threshold.

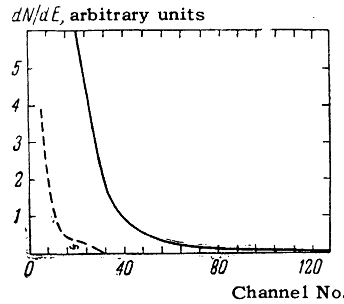


FIG. 4. Differential spectrum of pulses from 3-MeV neutrons: solid curve—neutrons plus photomultiplier noise, dashed curve—photomultiplier and amplifier noise.

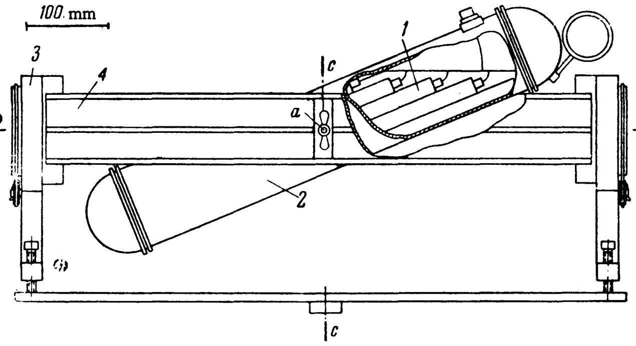


FIG. 5. Overall view of analyzer-detector.

the optimum value of the ratio of the effective detector volume to its working volume. The counters are in a common cylinder 2 and operate under identical conditions. The cylinder is connected to posts 3 through frame 4 and can be rotated about 3 axes: aa, bb and cc. The axis aa is perpendicular to the plane of the diagram. The gas pressure in the cylinder is 2.8 atmospheres. The scattering angle of the recoil $\alpha$ particles is $\alpha = 22.5°$ (l.s.) which corresponds to a neutron secondary scattering angle $\theta = 135°$ (c.m.s.). The $\alpha$ particles scattered at 22.5° (l.s.) had an energy $E_\alpha = 5.51$ MeV. The pulses formed from counters $A_1$ and $A_2$ were fed to the coincidence circuit. A 40 $\mu$sec delay line was used to exclude random coincidences.

The asymmetry of the secondary scattered neutrons was measured for two displacements of the discriminator, corresponding to 42 and 24 per cent of the maximum amplitude of the pulses from the recoil $\alpha$ particles at 22.5°. The ratio of the effect to the background was in the mean 1.5 and the effect itself produced about 0.5 pulses per minute.

## RESULTS

The experimental values obtained for the asymmetry of secondary scattering of neutrons by $He^4$ were $R_{exp} = 1.44 \pm 0.31$ and $R'_{exp} = 1.26 \pm 0.29$, corresponding to two values of the discrimination threshold, 42 and 24 per cent respectively of the maximum amplitude of the recoil $\alpha$ particles. A large solid angle, corresponding to some region of the neutron scattering angles, was used in the experiment in the second scattering by $He^4$. The scattering angles, which corresponded to the tracks of the recoil $\alpha$ particles used in the measurement of the asymmetry, were determined from the orientation of the tracks. The polarizations $P_1$ and $P_2$ corresponding to neutron energies 14.9 and 10.1 MeV were taken from the calculations based on Fig. 9 of [4]. The polarizations corresponding to the average effective angular resolutions are $P_1 = 0.805$ and $P_2 = 0.309$ (42 per cent discrimination threshold) and $P_1 = 0.805$, $P_2 = -0.123$ (24 per cent discrimination threshold). The values of $P_2$ were calculated taking into account the anisotropy of the scattering of the 10-MeV neutrons by $He^4$ [7] and the dependence of the polarization on the azimuth angle. In determining the scattering asymmetry, $R_{calc}$, account was taken of the influence of the anisotropy of scattering of 15 MeV neutrons on the value of the asymmetry. The correction for the anisotropy of the scattering of the 15 MeV neutrons averaged over all the counters [7] amounts to approximately 5 per cent. Taking the corrections into account, we have $R_{calc} = 1.75$ and $R'_{calc} = 0.862$. The calculated and experimental values of the asymmetry are listed in the table, where statistical errors are also shown.

| | Discrimination threshold | |
|---|---|---|
| | 42 % | 24 % |
| $P_1$ | −0.805 | −0.805 |
| $P_2$ | 0.309 | −0.123 |
| $R_{exp}$ | 1.44±0.31 | 1.26±0.29 |
| $R_{calc}$ | 1.75 | 0.862 |

When a phase shift set with $\delta_2^+ = \delta_2^-$ is used, a somewhat better agreement with experiment is observed: $R_{calc} = 1.77$ and $R'_{calc} = 1.03$.

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