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The following is a short survey of the work of DUBBELDAM *a.o.* [1, 2, 3][1]) on the measurement of the polarization of D–D neutrons. The accuracy up till now obtained with the familiar method of turning the detectors 180° around the primary neutron beam is not very great. This is caused mainly by the possibility of introducing false asymmetries and insufficient shielding. This can be avoided by using a method due to HILLMAN [4] *a.o.* Hillman determined the polarization of 100 MeV neutrons with fixed detectors by turning the polarization vector with a solenoid.

In applying this method to the case of 3 MeV D–D neutrons, some difficulties arise, concerning the collimation and the intensity of the neutrons. It is obvious that the intensity is very important. Therefore it is necessary that the solenoid is as short as possible and has a rather large inner diameter determined by the need of having not too small scatterers. Therefore a very compact solenoid with forced air cooling was designed with a great current density: 4.6 A/mm^2 while the normal value for technical coils is 2 A/mm^2. The length of the solenoid is 780 mm, the inner diameter is 46 mm. The required current of 57 A was stabilized to better than 1%. The maximum dissipated power was about 8 kW. There is an influence of the magnetic field of the solenoid on the pulse height of the photomultipliers. The resulting correction can be determined experimentally and amounts to about 3%. The experimental set-up is given in figure 1.

The neutrons were produced in a gold drive-in target, a carbon scatterer was used as analyzer and stilbene crystals mounted on E.M.I. photomultipliers as detectors. The polarization vector was turned 90° to the left, and then 90° to the right, by reversing the current through the solenoid.

With this set-up first of all the left-right asymmetry for $E = 450$ keV and $\vartheta_{1\,\mathrm{lab}} = 50°$ was measured as a function of the current through

[1]) Numbers in brackets refer to References, page 165.

the solenoid and an accuracy of 5% in the asymmetry was easily obtained.

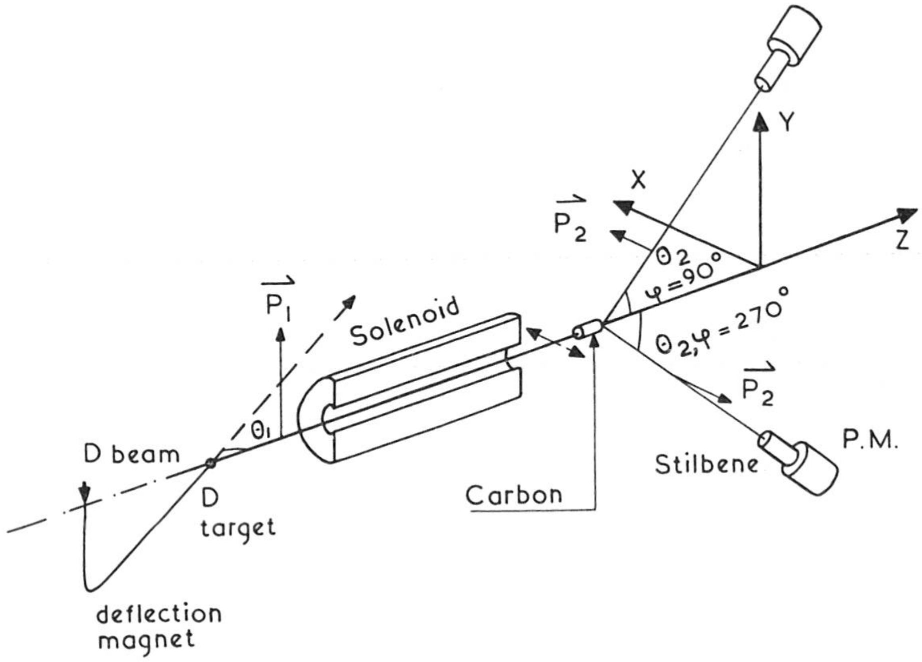

Figure 1
Schematic view of the experimental set-up

Next the polarization of D–D neutrons as a function of the deuteron energy for two different values of ϑ_1 was measured. The values for ϑ_1 were chosen for the following reason: the polarization of D–D neutrons can be described by the formula due to FIERZ [5]

$$\Pi(E_D, \vartheta_1) = \sigma_1\, a \sin 2\,\vartheta_1 + \sqrt{\sigma_0\, \sigma_2}\, \alpha \sin 2\,\vartheta_1 + \sigma_2\, \beta \sin 2\,\vartheta_1\, (3 \cos^2 \vartheta_1 - 1)$$

where Π is the differential polarization defined as the product of the polarization and the differential cross-section; σ_0, σ_1 and σ_2 are the 'approach cross sections' for the $l = 0{,}1$ and 2 waves defined and computed by BEIDUK, PRUETT and KONOPINSKI [6]; E_D is the deuteron energy and α, β and a are constants. The second and third term disappear if in the nucleon-nucleon interaction only central and tensor forces are present. Without these terms there is a sin $2\vartheta_1$ dependence. If a deviation of this sin $2\vartheta_1$ dependence is found one can say something about a possible spin-orbit coupling in the nucleon-nucleon interaction. For that purpose ϑ_1 was chosen: 50° and 22° 30′, the angles where the third term is zero and extreme.

The polarization P_1 of the neutrons can be obtained from the measured asymmetry R by $R = P_1 P_2$ with P_2 defined as the polarization of the neutrons resulting from the scattering of an unpolarized neutron beam by carbon. The value found for P_1 depends on the known values for P_2. There are two computations of P_2 from different phase analyses, one by MEIER [7] *a.o.* and an other by WILLS [8] *a.o.* In figure 2 the two sets of values for P_2 are given, they show appreciable differences – in the place of the positive peak and in the large negative values on each side of the peak.

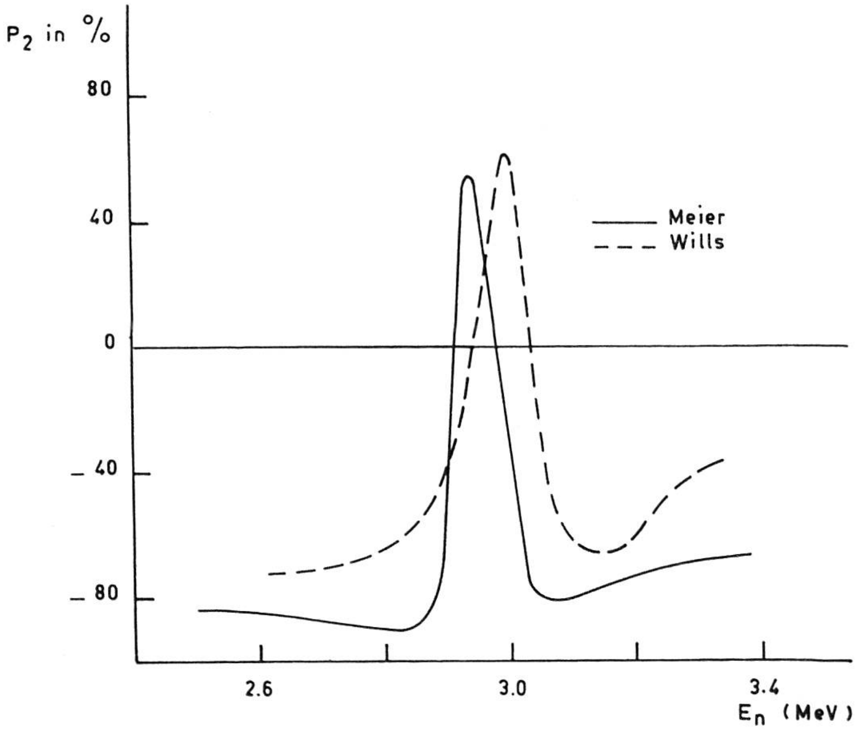

Figure 2

$P_2(\vartheta_2 = 45^\circ)$ as a function of the neutron energy from phase analyses of MEIER and WILLS

As a thick drive-in target was used average values for the asymmetry were obtained. It is rather difficult to interpret these values. Therefore we computed with the thin target data from the literature and P_2 of MEIER and of WILLS the asymmetry that can be expected for a thick target and compared this with our measurements. The computation is as follows:

The differential cross section for the carbon scatterer is in the case of a solenoid,

$$\sigma_c(\vartheta_2, \varphi) = \sigma_c(\vartheta_2) \left(1 \pm P_1(E_D, \vartheta_1)\, P_2(E_n, \vartheta_2) \sin \frac{a\, I}{\sqrt{E_n}} \right)$$

as is evident from the formula of WOLFENSTEIN, $\sigma_c(\vartheta_2)$ is the unpolarized differential cross section, $a\, I/\sqrt{E_n}$ is the angle over which the polarization vector is turned by the solenoid with a a constant, I the current through the solenoid and $\sqrt{E_n}$ the square root of the neutron energy which is proportional to the velocity for the neutrons, The (+) sign is for the rotation of 90° to the right, the (—) sign for 90° to the left.

The numbers of neutrons are in the two cases:

$$N_{\pm} = \varepsilon K \int_0^{E_{D\,max}} \sigma_c(E_n, \vartheta_2) \left(1 \pm P_1(E_D, \vartheta_1)\, P_1(E_n, \vartheta_2) \sin \frac{a\, I}{\sqrt{E_n}}\right) N(E_D)\, dE_D$$

with $N(E_D)$ the neutron spectrum, ε the efficiency and K a constant. One finds from the definition of R:

$$R_{av} = \frac{N_+ - N_-}{N_+ + N_-} = \frac{\int_0^{E_{D\,max}} \sigma_c(E_n, \vartheta_2)\, P_1(E_D, \vartheta_1)\, P_2(E_n, \vartheta_2) \sin \frac{a\, I}{\sqrt{E_n}}\, N(E_D)\, dE_D}{\int_0^{E_{D\,max}} \sigma_c(E_n, \vartheta_2)\, N(E_D)\, dE_D}.$$

For $\sigma_c(E_n, \vartheta_2)$ are taken the values of MEIER [7]. In this formula the neutron spectrum is not yet known; it can be found approximately in the following manner

$$\begin{aligned} N(E_D)\, dE_D &= \text{const}\ \varrho_D(z)\, \sigma(E_D, \vartheta_1)\, dz \\ &= \text{const}\ \varrho_D(z)\, \sigma(E_D, \vartheta_1) \left(\frac{dE_D}{dz}\right)^{-1} dE_D\ ; \end{aligned}$$

ϱ_D is the deuteron density in the target at the depth z.

For the stationary case holds $\varrho_D = Q_z/\alpha$ where α is the diffusion constant for deuterons in gold and Q the deuteron source strength. The range-energy relation gives that dE_D/dz is nearly a constant. $\sigma(E_D, \vartheta_1)$ can be taken linear with energy for E_D is less than 500 keV. So the spectrum is the product of two linear terms, i.e. a parabola.

From the thin target measurements of MEIER, PASMA and LEVINTOV we determined that to a good approximation:

$$P_1\,(E_D, \vartheta_{1\,\text{lab}} = 50°) = \sqrt{0.18\, E_D}\ \%, \qquad E_D \text{ in keV},$$

the result of this computation is given in figure 3.

The points are our measurements. The curve computed with MEIER's data agrees much better with this measurement than that with the values of WILLS. For $\vartheta_1 = 22°\ 30'$ the same computation is made (see figure 4). P_1 is computed with the sin $2\,\vartheta_1$ dependence of the differential polarization, that is the first term of the formula of FIERZ.

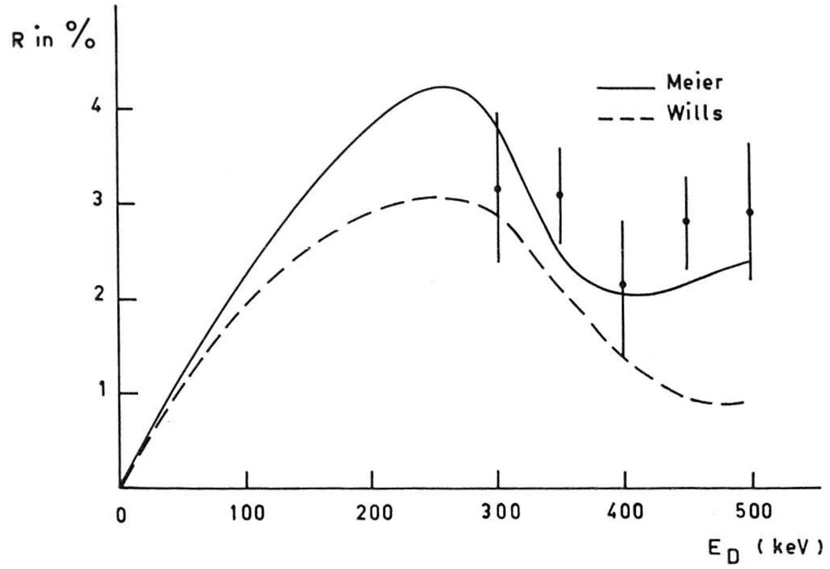

Figure 3

R_{av} as a function of E_D at $\vartheta_{1\,lab} = 50°$. The curves are computed as explained in the text

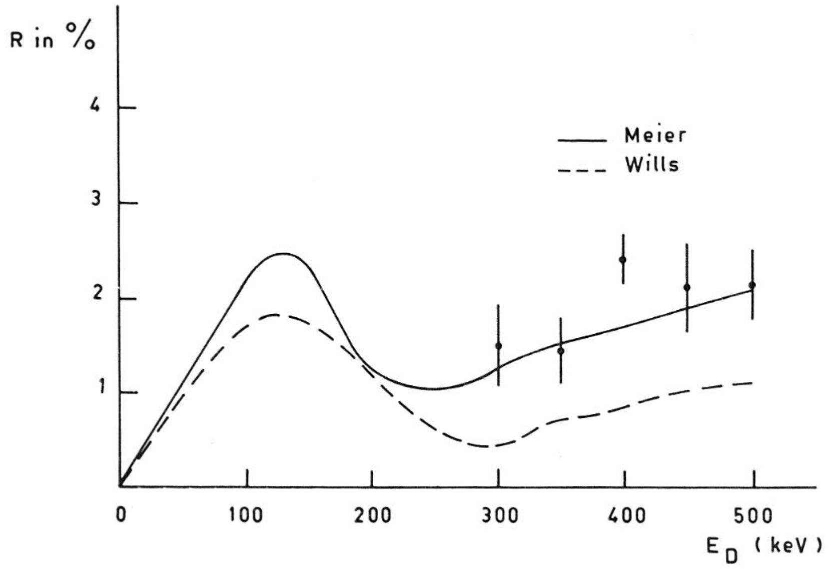

Figure 4

R_{av} as a function of E at $\vartheta_{1\,lab} = 22°\ 30$. The curves are computed as explained in the text

Again MEIER agrees better with the experimental points than WILLS. Further it is evident from the figures 3 and 4 that the sin $2\,\vartheta_1$ dependence is not contradictory to the thick target measurements. Therefore it is impossible to decide for the existence of the spin-orbit coupling in the nucleon-nucleon interaction. It is, however, also impossible to conclude to the non-existence. Therefore, the measurements are continued with a thin target and for several values of ϑ_1.

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