Comitato Nazionale per L'Energia Nucleare
ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Trieste
63/1

INFN/BE-63/2
27 Maggio 1963

R. Malaroda, G. Poiani and G. Pisent : ON THE D-WAVE CONTRIBUTION IN THE n-He^4 ELASTIC SCATTERING AT 15 MeV.

Reparto Tipografico
dei Laboratori Nazionali di Frascati
Cas. Postale 70 - Frascati (Roma)

Istituto Nazionale di Fisica Nucleare
Sezione di Trieste

INFN/BE-63/2
27 Maggio 1963.

R. Malaroda, G. Poiani and G. Pisent[(x)]: ON THE D-WAVE CONTRIBUTION IN THE n-He^4 ELASTIC SCATTERING AT 15 MeV[(o)].

It is well known that in the energy range 0-10 MeV the n-He^4 scattering is satisfactorily accounted for by an S and P wave analysis. Above the energy of about 10 MeV the expected contribution of D waves makes the phase shift analysis particularly complicated, so that the existing analyses of data are unsatisfactory.

In order to attempt to clarify this situation, a measurement was made of the angular distribution of neutrons scattered elastically by α-particles at an energy of 14.9 MeV, using the well known method of recoils developed by Baldinger et al. and Barschall et al. [(1)]. Neutrons were obtained from the reaction D + T by bombarding a tritium in zirconium target with deuterons of 150 KeV. The detector was a cylindrical ionization chamber of high volume (80 l), whose external electrode had a diameter of 28 cm, and which was filled with a mixture of argon and helium in the ratio 1:4 at a pressure of 4.5 atm. The chamber was placed about 100 cm from the target, and separated from it by a wall of concrete. A beam of neutrons, of the mean diameter of 7 cm, was allowed to enter the chamber, along its longitudinal axis. The measured spectrum interested neutrons scattered at angles not lower than 48^o in the CM system. It is believed that the corrections to the data for the background and the argon contributions, can be reliably evaluated in this angular region.

As is well known, the pulse distribution in the ionization chamber must be corrected for some geometrical and physical effects. In our case, owing to the large dimensions of the chamber, the so called "wall effect" connected with the geometrical shape of the counter can be neglected, while careful corrections are necessary for the radial dependence of the pulse height. This effect which tends to deform the angular distribution, is particularly critical when one tries to extract from the angular distribution information about the very small contributions of the D doublet. The main difficulty of the procedure lies in the fact that the correction to be applied to the experimental distribution $\sigma_{exp}(\theta)$, in order to find the true cross section $\sigma(\theta)$, is a function of $\sigma(\theta)$ itself, which is unknown. The problem can be solved exactly in the following way.

(x) - INFN, Sezione di Padova.

(o) - This work has been carried out under Contract EURATOM-CNEN

Let L_{max} be the maximum orbital angular momentum involved at the energy considered. The cross section is

$$k^2 \sigma(\theta) = \sum_{N=0}^{2L_{max}} A_N \cos^N \theta \tag{1}$$

and the uncorrected distribution has the form

$$k^2 \sigma_{exp}(\theta) = \sum_{N=0}^{2L_{max}} A_N f_N (\cos \theta) . \tag{2}$$

The functions $f_N(\cos \theta)$ can be easily calculated from the law of distribution of the pulse heights[2]. The f_N depend only on the geometrical characteristics of the chamber. Since Eq. (2) is linear in the A_N, a least squares fit to $\sigma_{exp}(\theta)$ yields to a straightforward determination of the coefficients A_N, and consequently, of the cross section $\sigma(\theta)$.

It should be noted that this procedure depends on L_{max}, and is exact if no angular momenta higher than L_{max} are present.

The normalization of the coefficients A_N was determined from previous measurements of the total cross section[3]. From these coefficients the S, P and D phase shifts have been calculated using the methods described in reference (4)[x].

The solution of the phase shift equations in the approximation $L_{max} = 1$ gives in general 8 solutions[4]. Among these, only 4 are, in our case, consistent with values extrapolated from lower energies. These solutions are shown in Table I.

Table I

solution	δ_1^0	δ_3^1	δ_1^1
P_a	-82^o	108^o	70^o
P_b	-98^o	95^o	57^o
P_c	-89^o	111^o	74^o
P_d	-91^o	92^o	55^o

In the approximation $L_{max} = 2$, the situation is only apparently more complicated. In fact, among the large number of solutions (32 in general), only few are real in practical cases. In our case 18 sets of solutions are allowed and, among these, only 2 are consistent with the S and P phase shifts extrapolated from lower energies. They are shown in Table II.

(x) - Numerical calculations have been set up with an IBM 704 (Centro Calcolo CNEN, Bologna) and an IBM 1620 (Centro Calcolo dell'Università, Trieste)

(o) - The phase shifts are denoted by δ_{2J}^L .

Table II

solution	δ_1^0	δ_3^1	δ_1^1	δ_5^2	δ_3^2
D_a	-76^o	119^o	74^o	-14^o	-12^o
D_b	-103^o	87^o	42^o	13^o	13^o

Fig. 1 shows the cross sections calculated by P phase shifts (solid line) and D phase shifts (dashed line). The experimental points reported in the figure have been corrected in the $L_{max} = 2$ approximation. The root mean square errors are 5.0 mb and 3.1 mb, in the $L_{max} = 1$ and $L_{max} = 2$ approximation respectively.

In order to discriminate among the mathematical solutions, the polarization calculated from the phase shifts has been compared with the asymmetries measured by the Wisconsin group(5) at the energy of 16.4 MeV (Fig. 2). The smooth behaviour of the phase shifts in this energy region makes the comparision meaningful in spite of the difference between the two energies. The calculated polarization has been normalized in order to reach the best agreement with the measured asymmetries. The required values of P_1 (polarization of the incident neutrons) are indicated in the Figure.

The best agreement with the shape of the asymmetry is given by solution D_a, while the expected value of P_1 (= - 0.51)(5) is reproduced better by solution D_b. Furthermore, it must be noted that calculations performed by using a simple potential to describe the n-α interaction, predict positive D phase shifts, and therefore support the choice of the D_b solution. These calculations have been set up with two different potentials (square well and Saxon and Wood's potential), using extrapolated values of the parameters which reproduce the experimental data at lower energies. With both potential shapes and with slight variation of the parameters, a strong indication for D phase shifts ≥ 0 has been found(x).

In the $L_{max} = 1$ approximation, the 4 mathematical solutions give rise to a similar polarization behaviour, and therefore do not appear to be distinguishable either from cross section or from polarization experiments. Nevertheless, the choice of the D_a or D_b solution for $L_{max} = 2$ implies automatically the choice of the P_a or P_b respectively, which is the corresponding solution for $L_{max} = 1$(o).

According to values quoted in the literature, other authors' measurements(5, 6) are in fairly good agreement with our S and P phase shifts, and give contradictory indications about the sign of the D doublet.

The slightly conflicting situation concerning the D-phase shifts can be understood by inspecting the curves of Figs. 1 and 2. In fact, one can easily see that a pure S and P wave approximation is able to reproduce satisfactorily

---

(x) - These calculation are in progress in collaboration with Dr. A. M. Saruis.

(o) - For details about the classification of the mathematical ambiguities in the solution of the phase shift equation, see ref. (4).

both differential cross section and polarization experiments. The intrinsic difficulty of extracting clear cut D wave components from the data at this energy is easily recognized. Therefore, the unambigous sign assignment to the D doublet will probably be given by experiments performed at higher energies.

The authors are pleased to thank Professor C. Villi for helpful discussions. Thank are also due to Professor H. H. Barschall for having sent to us his results prior to publication.

References:

(1) - E. Baldinger, P. Huber, and S. Staub, Helv. Phys. Acta 11, 245 (1939); H. H. Barschall and M. H. Kanner, Phys. Rev. 58, 590 (1940).

(2) - D. H. Wilkinson, "Ionization chambers and counters" (Cambridge 1956).

(3) - Los Alamos Physics and Cryogenics Group, Nucl. Phys. 12, 291 (1959).

(4) - G. Pisent, Helv. Phys. Acta 36, 248 (1963).

(5) - T. H. May, R. L. Walter and H. H. Barschall, "Scattering of polarized neutrons by α-particles", to be published.

(6) - J. D. Seagrave, Phys. Rev. 92, 1222 (1953); K. W. Brockman, Phys. Rev. 110, 163 (1958); S. M. Austin, H. H. Barschall and R. E. Shamu, Phys. Rev. 126, 1532 (1962); see also: U. Fasoli and G. Zago, paper to be published on Nuovo Cimento.

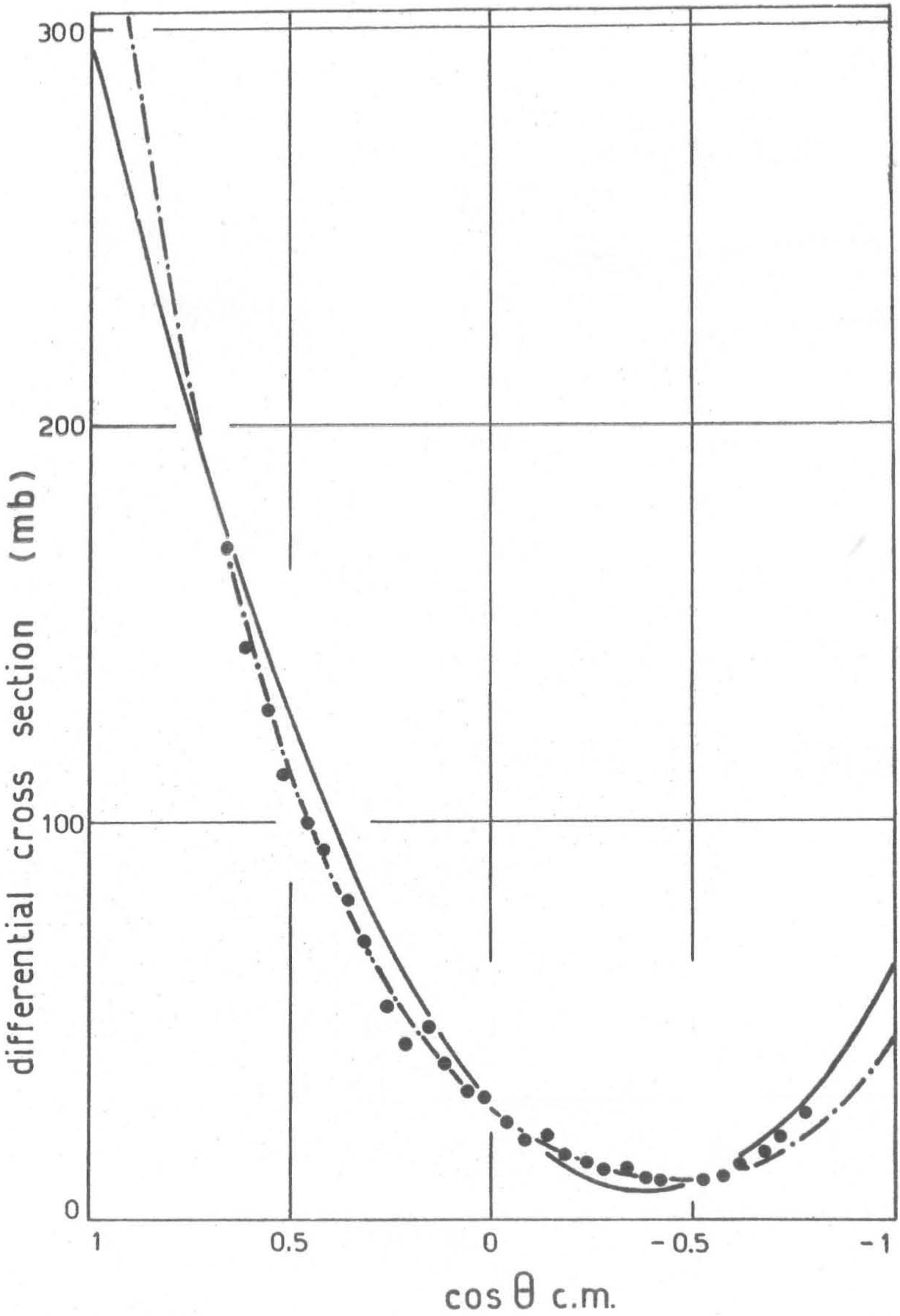

FIG. 1

14.9 MeV differential cross section. Experimental points (●) are compared with curves calculated by D_a, D_b (—— · —— · ——), and by P_a, P_b, P_c, P_d (————————) phase shifts.

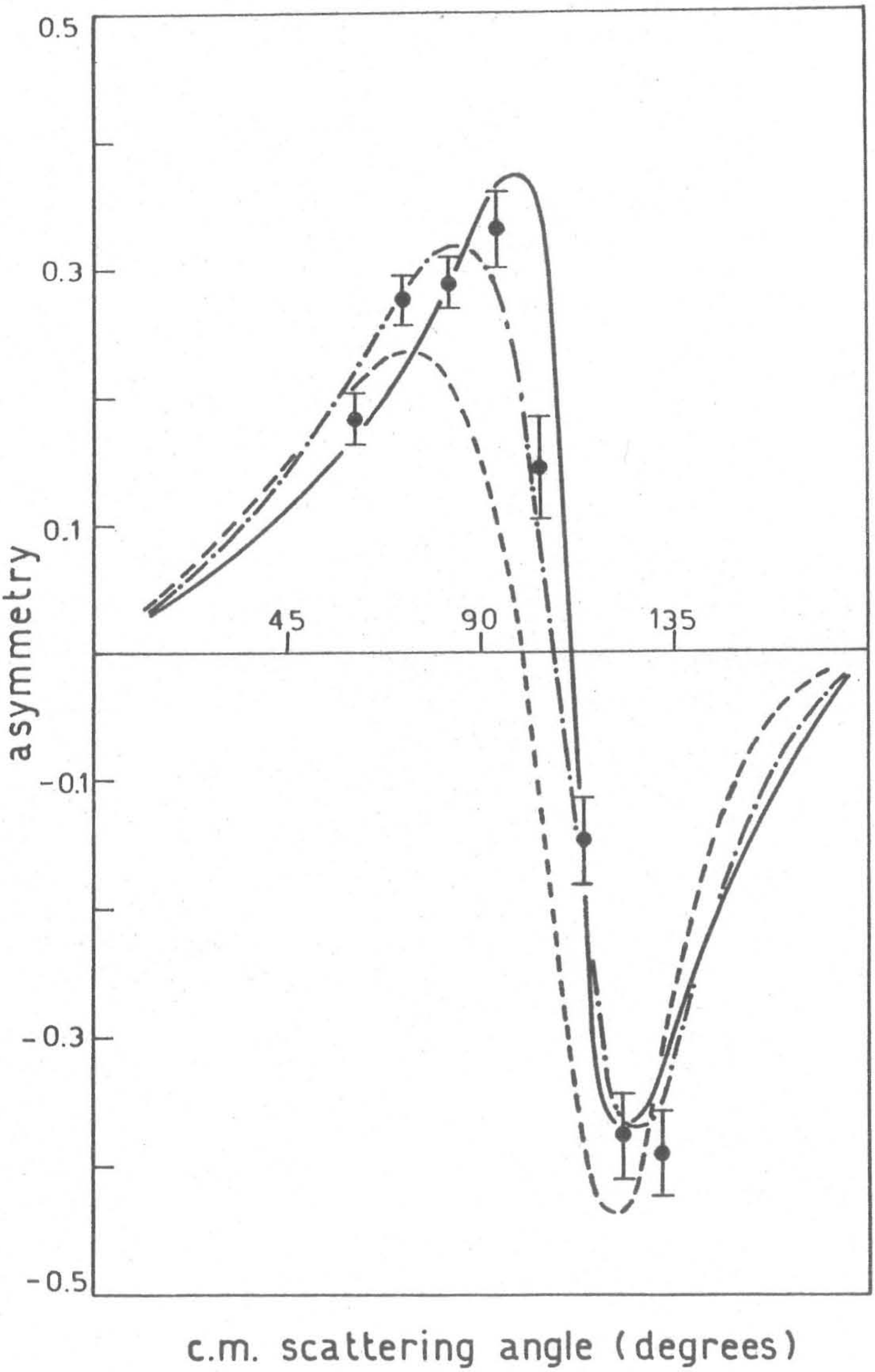

FIG. 2

Asymmetry of polarized neutrons versus C. M. scattering angle. Points refer to experimental measurements at the energy of 16.4 MeV[5]. Curves indicate asymmetries (14.9 MeV) calculated by phase shifts, using the polarization of the incident neutrons P_1 as an adjustable parameter. —·—·—·— D_a phase shifts, P_1 = -0.38; ------ D_b phase shifts, P_1 = -0.51; ——— P_a solution, P_1 = -0.38, or P_b solution, P_1 = -0.40 (these two curves are indistinguishable in the figure).