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A SURVEY OF THE ANGULAR DISTRIBUTION DATA ON n-p SCATTERING BELOW 10 MeV

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In view of the n-p scattering investigations now in progress in this laboratory the bulk of the published experimental data concerning the range below 10 MeV have been analysed. Contrary to the generally assumed isotropy of the angular distributions in this energy range, analysis of the available sparse data suggests the presence of a more complex structure in the differential cross-section.

Introduction

The angular dependence of the differential cross-section of the n-p scattering at low energies is as a rule determined from angular distribution of the recoil protons, since the recording of the scattered neutrons involves more difficulty. For detecting the protons their ionizing power is utilized, either by visualization of the ionization tracks or by converting the ionization energy into electronic pulses. To reach a good resolution is problematic with both method around the C.M. angles $\vartheta = 0^{o}$ and $\vartheta = 180^{o}$.

Working with the track visualization method /cloud chamber, nuclear emulsion/ whether thin proton radiator or, preferably, protons dispersed in the sensitive volume of the detector are used as target, all protons scattered after collision into the total solid angle are detected. Therefore, the angular distribution of the protons gives the differential cross-section multiplied by the factor $\sin\vartheta_{p,C.M.}$. To have a good resolution even for angles about the C.M. angles $\vartheta_{p} = 0^{o}$, 180^{o}, a certain number of events is necessary, implying a relatively too great deal of evaluation effort. In the bulk of measurements the statistics is not good enough to resolve the first and the final angular range of the width $\Delta\vartheta = 20^{o}$ or rather 40^{o}.

With the scintillation and ionization /proportional/ counters the small energy part of protons, i.e. the angular range about $\vartheta_{p,C.M.} = 180^{o}$, is not detectable because of the electronic noise. Also around $\vartheta_{p,C.M.} = 0^{o}$ the angular resolution is strongly restricted. Namely, the angular distribution is determined from the energy distribution by the equation $E_p = E_o \cos^2\Theta_p$ /all quantities in laboratory system, E_o is the neutron energy before the scattering/. The same equation gives the relationship between the angular and the energy resolution as $\Delta\vartheta_{p,C.M.} \approx \frac{2}{E_o} \cdot \frac{\Delta E_p}{\sin\vartheta_{p,C.M.}}$. Thus the angular resolution grows rapidly worse when ϑ goes to 0^o, which can be illustrated with the following remark. For $\Delta E/E=10\%$ the angular resolution at $\vartheta_{p,C.M.} = 0^o$ is $\Delta\vartheta_{C.M.}=37^o$ and even for $\Delta E/E=1\%$ the angular resolution is not better then $\Delta\vartheta_{C.M.} = 12^o$.

Survey of the Data

Within the range concerned, measurements with relatively good energy resolution are published only for the neutron energies 2.5, 3.27 and 8.8 MeV, respectively. Available data are discussed for each group separately.

2.5 MeV

At this energy, measurements were carried out with neutrons obtained from the reaction D/d,n/ for deuteron energy E_d = 100 - 200 keV and neutron direction $\Theta_n = 90^o$. The earliest experiments were performed with track visualization of the recoil protons. Mention must be made of the works of Bonner [1], Dee and Gilbert [2] and Lampson [3]. Angular distribution of the n - p scattering was found in each of these investigations anisotropic for E_n = 2.5 MeV due to the excess of the small angle protons over those of medium angles. In ref. [2] this departure is given as /10±10/%. In refs. [2] and [3] the departure was interpreted as a consequence of the long range component of the nuclear forces, while in ref. [1] merely as an error in the background correction. According to the frequently quoted work of Barschall and Kanner [4], one of the first measurements with ionization counting, the differential cross-section is isotropic. However, this very measurement yielded also for the n-d scattering an isotropic differencial cross-section and we learnt from a number of later experiments /e.g. refs. [5], [6]/ as well as from well established theoretical considerations /see ref. [7]/ that the distribution is, actually, by far not isotropic. It is this why present author questions the reliability of ref. [4]. A later repetition of the experiment by Coon and Barschall [5] exhibited a definite excess of the forward scattered protons with a relatively good statistics. Also, the deviation from isotropy seems to involve a fine structure, too /Fig.1/. Finally, we refer to the measurement of Caplehorn and Rundle [6] with a cloud chamber. Their data, grupped int 10 ranges of angle, show an isotropic angular distribution with an error of ± 10% /see Fig.2/.

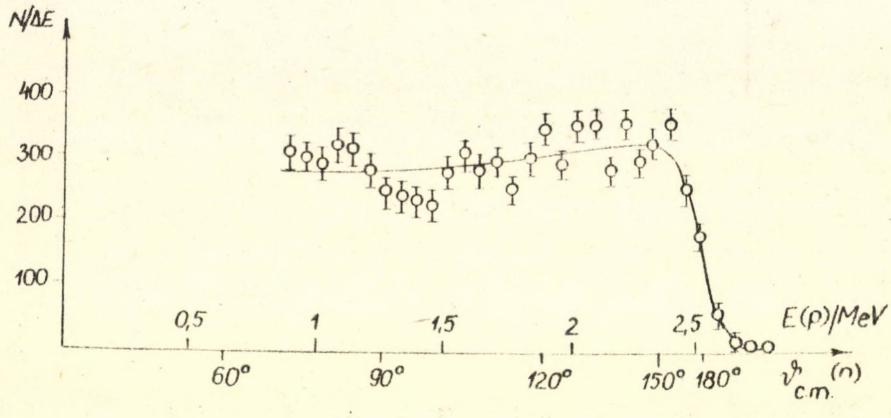

Fig. 1

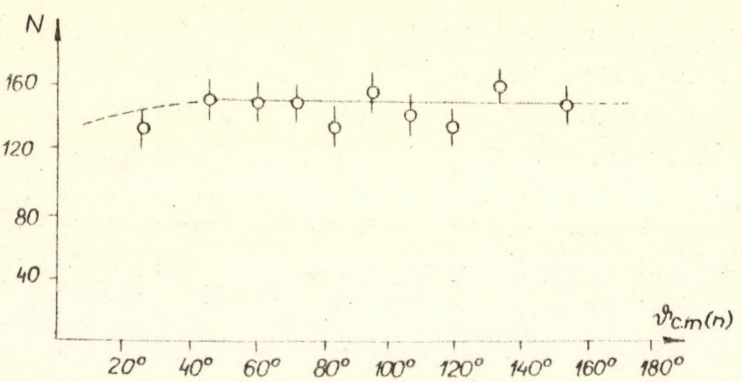

Fig. 2

3.27 MeV

At this energy only a single experiment is known [8], [9]. Hamouda and Montmollin carried out their measurement in two runs. At the perpendicular position of a flat Wilson-chamber they measured the protons scattered backward in C.M. system, while the forward scattered protons were measured at a lengthways position. The whole measurement gave an isotropic angular distribution with good enough statistics over the whole angular range though the first and final part being unresolved /Fig. 3/.

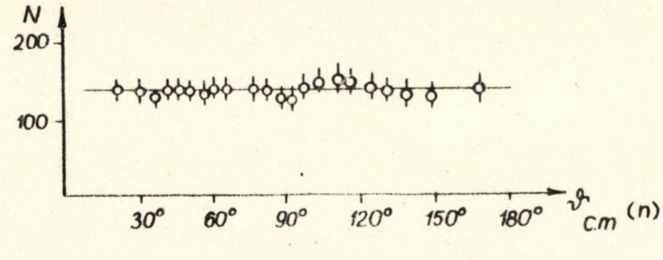

Fig. 3

8.8 MeV

In the work Champion and Powell, neutrons were obtained from B^{11}/d,n/ reaction and the recoil protons were recorded by emulsion techniques [10]. Protons from the scattering of the 8.8 MeV neutron group were selected and analysed. Averaged over larger angular ranges, an excess of about 20 p.c. was found in the differential cross-section at small proton angles as compared to the medium angular range. What was, however, completely new, an oscillation of the period of 24^{0} in C.M. angles was to be extracted for the angular dependence of differential cross-section. The statistical error permits a smooth fit, but there is a good indication for periodicity.

The result is shown in Fig. 4 as normalized to an isotropic angular distribution of same integrated cross-section. In this connection one may refer to the measurement of Coon and Barschall at 2.5 MeV [5], within which a similar pattern to that of Fig. 4 was found without being, however, such a pronounced one as that.

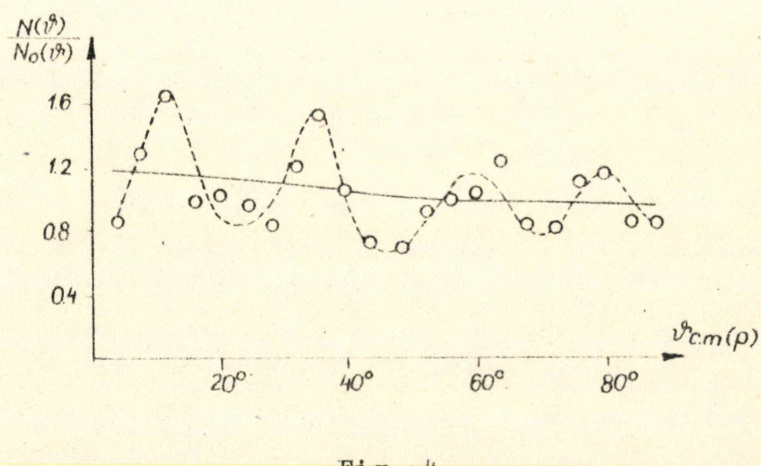

Fig. 4

Prior to 1968 no other measurements were available on the subject.

Discussion

Theoretical prediction for the upper limit of a possible contribution from partial waves with $\ell > 0$ to the integrated cross-section of the n-p scattering below 10 MeV is about 1 ‰ [11]. Such an estimation suggest that when discussing the n-p scattering within this energy range considerations can be confined to s -waves. In other words, the differential cross-section at a given energy should be independent of the scattering angle. Measurements in the neutron energy range 10-90 MeV confirm this prediction since angular distributions become more and more isotropic when neutron energy is decreased [12]. Nevertheless, based on the low energy data, we insist on stating that angular distributions below 10 MeV do not exhibit the predicted simple picture. Actually, anisotropy was found even below 10 MeV to be important. Only a single measurement at 3.27 MeV [8], [9] resulted, within experimental error, in an isotropic angular distribution. At 2.5 and 8.8 MeV almost each of the measurements showed anisotropy. What is more, at 8.8 MeV an even more complex structure seems to be present in the distribution.

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