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Neutron–Neutron Quasifree Scattering at 14.1 MeV

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Abstract. We present results obtained from the D$(n, 2n)p$ reaction at $E_{inc} = 14.1$ MeV. They indicate that the differential cross-section at $\theta_{N1} = \theta_{N2} = 40°$, $\phi_{12} = 180°$ (exact pole location $E_p = 0$) is substantially smaller than the corresponding value at $\theta_{N1} = \theta_{N2} = 30°$ ($E_p = 180$ keV). The experimentally found ratio of about 3 represents an angular variation which is similar to, but more marked, than that observed for the D$(p, 2p)n$ reaction and that predicted by an 'exact' three-body calculation.

Many complete experiments on 3-nucleon reactions [1, 2] have shown that the differential cross-section goes through a pronounced maximum in the neighbourhood of a kinematic configuration favouring quasifree scattering (QFS). This behaviour has been observed down to very low bombarding energies of the order of ~5 MeV [3]. Whereas for energies $\gtrsim 150$ MeV the impulse approximation (IA) accounts well for the experimental data [4], anomalies and deviations have appeared at low energy. In particular the behaviour of the differential cross-section in *p–p* and *n–p* quasifree scattering, as well as the ratio of the D$(p,pp)n$ and D$(p,np)p$ cross-sections, seems not to be fully understood [5, 12]. In particular, and in opposition to generally adopted ideas, the behaviour of the break-up cross-section as a function of the spectator energy is already predicted by the IA model [6], while the absolute value is much too high. Only the now available 'exact' three-body calculations can pretend to give acceptable predictions for the shape, behaviour and absolute value of the break-up cross-section. The only experimental value concerning the *n–n* QFS published to date, is the result of Slaus et al. [7]. Though a complete measurement of the D$(n, 2n)p$ reaction is particularly time-consuming, it seems important to study the *n–n* QFS, for the absence of Coulomb interaction in this reaction could provide interesting comparison with the data existing for charges particules and with predictions from 'exact' calculations.

In our experiment, 14.1 MeV neutrons from the T(d,n) ^{4}He reaction are incident on a spherical C_6D_6 target [8]. The neutron beam is collimated both by a pipe through a Fe–Paraffin shielding and electronically by the associated α-particle method [9].

The break-up neutrons are detected in two NE 213 liquid scintillators ($15 \times 15 \times 4$ cm^3), placed 120 cm from the target and at symmetric angles, $\theta_{N1} = \theta_{N2}$, $\phi_{12} = 180°$, about the beam axis. For each break-up, a reference point in time was obtained by detecting the α-particle associated with the neutron emission at the source. The time differences, $\mathrm{ToF}_{\alpha-N1}$ and $\mathrm{ToF}_{\alpha-N2}$, between this event and the detection of the break-up neutrons were measured simultaneously.

Although redundant for the definition of the final state configuration of the break-up products, the detection of the break-up proton in a scintillator target can usually be used to effectively reduce background [7, 9]. However, since in our case the energy of the proton passes through zero, this was not possible. Therefore particular attention was paid to other means of background reduction. In particular, n–γ discrimination [10] was applied to the output of both neutron detectors and events due to moderated background neutrons were suppressed by electronic biases.

Contamination of the kinematical region of interest is possible from the $^{12}C(n,n')^{12}C^*$ ($Q = -7.66$ MeV) reaction. However, the advantage of using ^{12}C-based deuterated compounds as target material is that at angles $30° \lesssim \theta \lesssim 50°$ the differential cross-section for this reaction is extremely low [11]. The magnitude of this contamination can be assessed by comparison with the yield of the $^{12}C(n,n')^{12}C^*$ ($Q = -9.63$ MeV)

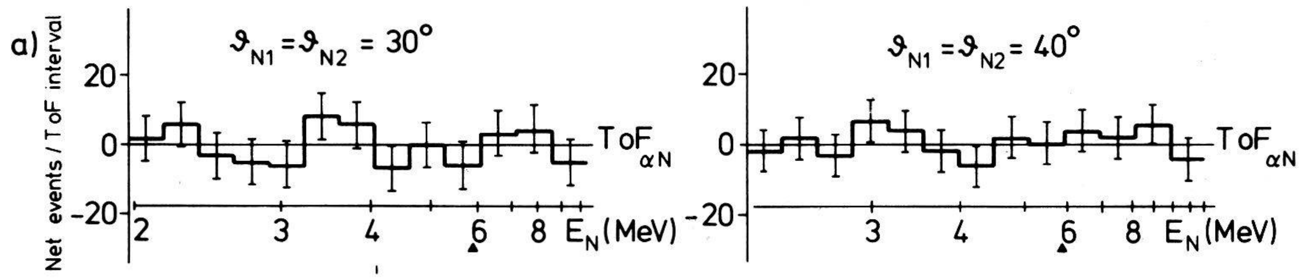

Figure 1a
Projections on the $ToF_{\alpha-N}$ axis of the difference between the background obtained both with the C_6D_6 target (interpolated under the QFS kinematical region) and with the graphite target (normalized to 100 h). The difference is seen to be zero to within experimental uncertainty. The triangles indicate the points corresponding to $E_p \simeq 180$ keV (30°), resp. $E_p \simeq 0$ (40°).

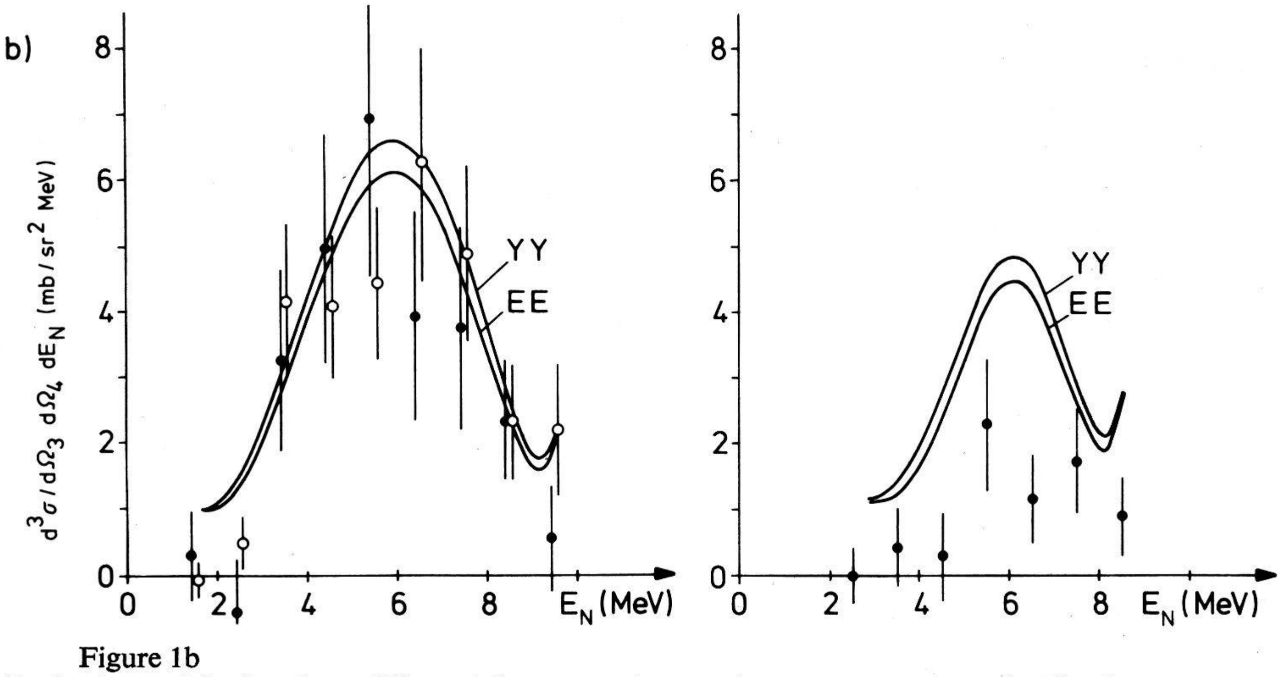

Figure 1b
Projections of the break-up differential cross-section on the neutron energy axis. The dots represent our measurements. Besides statistical uncertainties, the error bars comprise uncertainties in the angular resolution and the detector efficiency. The open circles are the results of Slaus et al. [7]. The two solid curves are Ebenhöh's calculations. Y and E stand respectively for the Yamaguchi and exponential form factors [13].

reaction. This can easily be evaluated because it is 3 to 5 times larger and because its contribution lies outside the kinematical curve for neutrons from the $D(n,2n)p$ reaction. As a supplementary test, separate measurements were also performed with a graphite sphere in place of the C_6D_6 target.

With the rate of detected break-up events of about 1 count per hour, we have performed two measurements of 100 h each for $\theta_{N1} = \theta_{N2} = 30°$ and $\theta_{N1} = \theta_{N2} = 40°$ in order to test the feasibility of such an experiment. Two further measurements of 50 h each with the graphite target have permitted us to confirm that no unwanted correlation from competing reactions contaminate the kinematical region of interest. Moreover they have shown that the background outside this region is the same as with the deuterated target (see Fig. 1a).

Our results show that (see Fig. 1b): 1) the differential cross-section at $\theta_{N1} = \theta_{N2} = 30°$ is compatible with that obtained by Slaus et al. [7], within the limits of experimental uncertainty, which is still rather large in both experiments; 2) the differential cross-section at $\theta_{N1} = \theta_{N2} = 40°$ is approximately 3 times smaller than that at 30°. This result is similar to, though more marked, than results obtained with the $D(p,2p)n$ reaction [12]; 3) the results obtained at 30° agree with the 'exact' calculations of Ebenhöh [13], but a discrepancy in the absolute value appears at 40°.

We have demonstrated that kinematically complete experiments of the $D(n,2n)p$ reaction, even without information about the break-up proton, are possible and give useful results. The advantage in performing them lies in the fact that it permits us to study the interesting final state configuration for which $E_p = 0$. It is thought that the results obtained thus far justify further effort, because the study of this specific reaction represents a test for the now available 'exact' calculations (no Coulomb interaction). More precise measurements have been undertaken with a C_6D_{12} target.

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