PHOTODISINTEGRATION OF THE DEUTERON AT MEDIUM ENERGIES

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An analysis is made of earlier experimental data on photodisintegration of the deuteron. Results are obtained for four angular distribution parameters at six values of the γ-quantum mean energy between 50 and 150 Mev. The results are compared with the most recent theoretical calculations. In the greater part of the investigated energy region the agreement is found to be good, the experimental values slightly exceeding the theoretical ones at the highest energies. Some conclusions concerning the theory of photodisintegration of the deuteron are drawn, and some possible reasons why the theoretical values are smaller are discussed. In conclusion it is explained why new and more precise experiments on the photodisintegration of the deuteron at energies below the meson production threshold should be carried out.

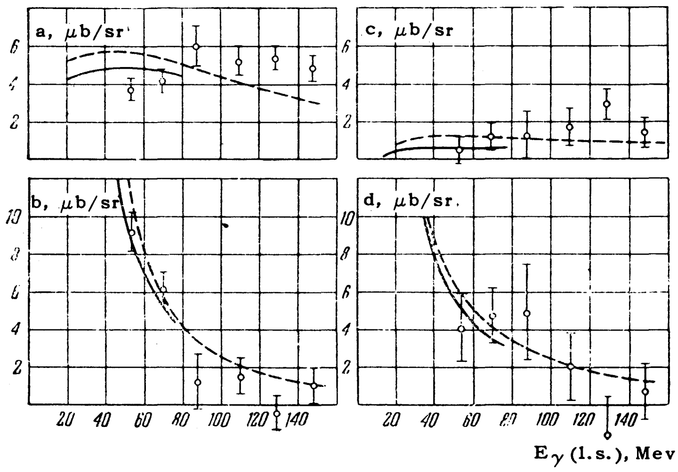
MANY recent theoretical papers [1-9] are devoted to photodisintegration of the deuteron at energies below the threshold of pion photoproduction. It is interesting in this connection to analyze the agreement between the results of these papers and the experimental data.

We know that multipole expansion is valid for photodisintegration of deuterons in this energy region. Under these conditions, taking into account only the fundamental dipole transitions and their interference with the quadrupole transitions, one possible angular dependence of the differential cross section is

$$d\sigma/d\Omega = a + b\sin^2\theta + c\cos\theta + d\sin^2\theta\cos\theta. \quad (1)$$

The theoretical papers [1-9] contain numerical values of the parameters of this distribution, calculated for different γ-quantum energies.

To compare the theoretical and experimental results it is necessary to approximate sufficiently detailed experimental data on the angular distribution of the process by means of a relationship such as (1). Until recently, in spite of the large number of cited experimental data, no such approximation was made and there were no experimental data whatever on the parameters of the distribution (1). In this connection, attempts undertaken in several theoretical papers to compare theory with experiment were unwittingly incorrect and incomplete. For example, Zernik et al [4-9] compared a summary theoretical angular-distribution curve, plotted from (1) with experiment. It is obvious that such a comparison is limited, for it extracts but a fraction of the obtainable information from the available experimental material. Authors of several other papers used for the comparison experimental results obtained by approximating the angular distributions with a formula such as



Results of approximation of experimental angular distribution[10] by means of an equation similar to (1) and a comparison with the results of the theoretical calculations of[2] (solid curve) and of[4] (dashed curve).

$$d\sigma/d\Omega = (a^* + b^*\sin^2\theta)(1 + 2\beta\cos\theta), \quad (2)$$

tacitly assuming thereby that the values of a^* and b^* should coincide with the values of a and b when the data are approximated by expression (1). Naturally, no comparison is possible in this case for the parameters c and d.

We have approximated, with the aid of expression (1), previously published experimental data on the angular distribution.[10] The results obtained for parameters a and b differ considerably, although without apparent regularity, from the values of a* and b* obtained earlier in an approximation by means of (2). The experimental results for all four parameters of the distribution (1), obtained for six values of the mean γ-quantum energy in the approximate range from 50 to 150 Mev (see the figure), have made it possible to make in this interesting region a correct and complete comparison of the results of the most recent theoretical calculations with experiment. The direct results of the comparison and the conclusions that can be drawn for the theory of deuteron photodisintegration can be briefly formulated as follows.

1. In the major part of the investigated medium-energy range, at least up to 100 or 120 Mev, the experimental results for all four parameters of the distribution (1) agree, within the limits of experimental accuracy, with the results of the most complete theoretical calculations.[2,4,6,9] This leads to the following conclusions:

a) In the stated energy region, the interaction between the electromagnetic field and a two-nucleon system can be correctly described as an interaction with the current and magnetic moments of the nucleon, without resorting to an explicit account of meson effects.

b) A quantitative agreement with experiment is obtained within the energy region only for those theoretical calculations [2,4,6,9] in which a consistent account is taken of a whole series of circumstances, the role of which was previously neglected, namely: transitions to the $^3F_2$ state, tensor interaction of the nucleons in the final states, and contribution from certain "non-fundamental" multipole terms to the cross section.

c) A quantitative agreement with experiment is obtained only for calculations in which use is made of those sets of phase shifts of nucleon-nucleon interaction in ^3P_J states, which correspond to a positive sign of the tensor potential (see, in particular,[7,8]).

d) The limited accuracy of both the experimental and the theoretical results does not permit at present an unambiguous choice between the two values of the probability D-wave in the deuteron, used in different variants of the calculation.

2. In the region of the highest energies investigated in [10], starting approximately with 100—120 Mev, the experimental results for the isotropic component of the angular distribution and for the component proportional to cos θ exceed noticeably the results of the theoretical calculations (see the figure). This calls for an explanation, which we find by referring, as is usually done, to the virtual meson effects that are possible in this energy region. It seems to us, however, that it is necessary above all to exercise greater care in the usual calculations, in which meson effects are not taken into account, namely:

a) Kramer and Werntz [6] have shown that the interference cross section terms such as $^3E1 \cdot {}^3M2$ and $^1M1 \cdot {}^1E1$ (the superscript denotes the multiplicity of the final state), which are not accounted for in the calculations by other workers, change noticeably the form of the angular distribution even at 50—70 Mev. In the energy region we are considering, they can manifest themselves even stronger, changing the entire pattern of the comparison between theory and experiment.

b) We have made a consistent classification of the multipole cross section terms that can arise in photodisintegration of the deuteron, with an estimate of the relative order of magnitude of the terms. We have established thereby that two other terms of the cross section, namely $^3E1 \cdot {}^3E3$ and $^3E1 \cdot {}^3E1_{s.o.}$, can make a contribution of the same order of magnitude as $^3E1 \cdot {}^3M2$ (the subscript s.o. denotes second order in the expansion of the corresponding amplitude in powers of kr). The former of the foregoing cross-section terms has never appeared in any of the published papers. The contribution of the latter term to the total cross section was essentially calculated by Hsieh [3] but was disregarded in the other papers. According to the foregoing estimates, this term becomes noticeable at energies on the order of 80 Mev and increases rapidly with increasing energy. The classification has disclosed, furthermore, seven other hitherto uncalculated cross-section terms; these may turn out to be of the same order of magnitude as the term $^1M1 \cdot {}^1E1$ which, according to Kramer and Werntz [6] yields an unexpectedly large contribution.

c) Our analysis has shown that the isotropic component of the angular distribution and the component proportional to cos θ are more sensitive to the splitting of the phases of the final states ^3P_J than the other components, while the component proportional to cos θ is furthermore sensitive to the splitting of the ^3D_J phases. A numerical analysis of the isotropic component at energies below 100 Mev was made by Kramer.[7] It is possible that more accurate numerical values of the phase shifts, obtained in the future by further research on the nucleon-nucleon interaction, will change appreciably the foregoing components of the angular distribution.

Summarizing, it appears quite likely that improvements in the theoretical results with account of the foregoing remarks will yield better agreement between theory and experiment over the entire range of energies below the threshold of pion photoproduction, without resorting (in explicit form) to an account of meson effects. The use of two versions of calculations, similar in all respects except for the D-wave probability for the ground state of the deuteron, will probably permit a final choice between the two values, 4 and 7%, which are under discussion at the present time.

In conclusion we note that the accuracy of the experimental results obtained for the parameters c and d is low, although the initial data used for the angular distribution [10] are the most detailed of those published. (The results that can be obtained from the measurements of a recently published paper by Galey [11] are subject to much greater errors, precisely because of the poor investigation of the angular distribution.) In this connection, it seems advisable to set up new, more detailed measurements of the angular distribution of the photodisintegration of the deuteron in the range of energies near the pion photoproduction threshold (for example, 50—200 Mev). In these measurements it is essential to increase the number of investigated angles (at least to 10 or 12) and the range (10 — 170°, and if possible 0 — 180°). When an accuracy on the order of 5% is attained for the parameters c and d, the comparison with the theoretical calculations can be used to verify the results of the phase-shift analysis of nucleon-nucleon interaction not only in the ^3P_J states, but also in the ^3D_J states.

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