# Peaks in the low energy d + p breakup cross section and the repulsive Coulomb force

H. Kröger, A. M. Nachabe, and R. J. Slobodrian
*Université Laval, Département de Physique, Laboratoire de Physique Nucléaire, Québec G1K 7P4, Canada*
(Received 14 January 1985)

New experimental data of the kinematically complete differential cross section for the d + p → p + p + n reaction are presented. Evidence is given to explain the major peak occurring in all measurements in terms of a Coulomb effect.

In the analysis of few-nucleon breakup reactions, one is used to interpret enhancements or peaks in the cross section in terms of final state peaks or quasifree scattering peaks. The final state peaks occur where the relative energy of two outgoing nucleons is very small and they are ascribed to a NN anti-bound-state pole in the second sheet of the singlet $T$ matrix. The quasifree scattering peak occurs if one of the outgoing nucleons has a vanishing laboratory energy and the peak reflects the momentum distribution in the deuteron. Both are due to a mostly attractive NN force. On the other hand it is well known that the repulsive Coulomb force is responsible for a strong peak in the cross section (actually, the cross section tends to infinity), namely, the Rutherford peak in the elastic forward scattering reaction of charged particles.

Here we report some recent kinematically complete measurements of the differential cross section for the reaction d + p → p + p + n very near the breakup threshold. The data displayed in Figs. 1–4 correspond to two bombarding energies and several proton-proton detection angles (because of kinematical reasons, the range of the latter is restricted at low energies). One observes a common structure in all cases, namely, the cross section displays a major bump with a relatively sharp peak.

In this Brief Report we want to give some evidence which supports that this structure is due to the repulsive Coulomb force.

In our case the peak is certainly not a Rutherford peak because the reaction is not the elastic scattering process. Quasifree scattering has a threshold $E_d^{lab} = 4|B^d|$, where $B^d$ in the deuteron binding energy. Our experimental bombarding energy of 7.4 and 7.5 MeV lies below this threshold. Final state interaction can occur. The positions where the relative energy of two nucleons has a minimum, which corresponds to a final state peak, are indicated in Figs. 1–4 by "fin. st.". In all cases there is a position of a final state configuration near the main peak but not at it. Finally one has to consider the phase space factor. Actually for the

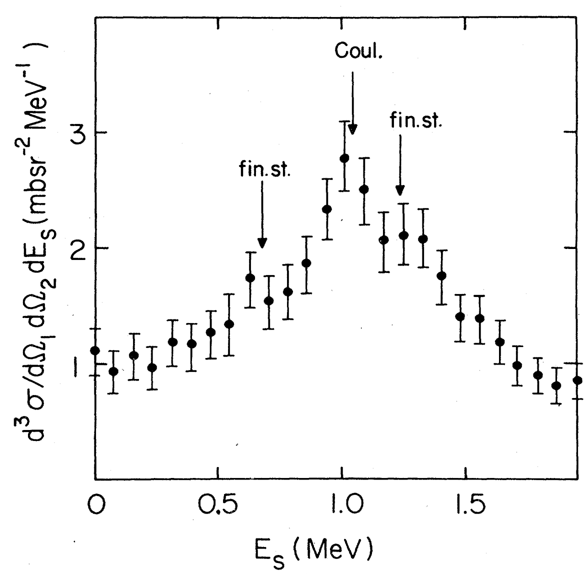


FIG. 1. pp correlation spectrum for d + p breakup at $E_d^{lab} = 7.4$ MeV and 12°-12° pp detection angles. $E_s$ is the energy along the kinematical arcus. The position of a minimum in the relative energy of a NN pair is indicated by "fin. st.," and the position of the maximum in the relative energy of the pp pair is indicated by "Coul."

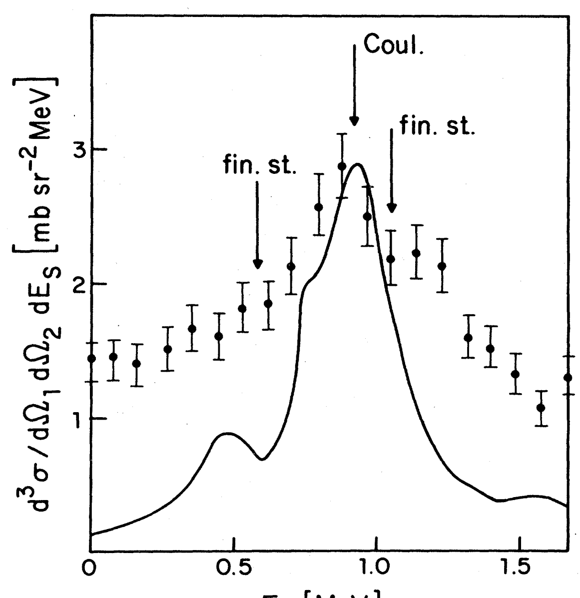


FIG. 2. Same as Fig. 1, but at 13°-13°. The solid curve shows the results of a full three-body calculation including the Coulomb force, the absolute magnitude of the curve being adjusted to the experimental data.

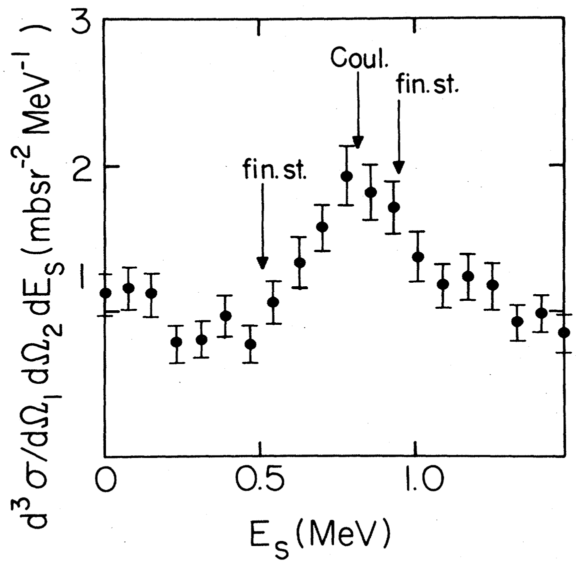


FIG. 3. Same as Fig. 1, but at 13.5°-13.5°.

reactions discussed here the phase space factor shows some enhancement in the region of the main peak but it is by far not as pronounced as the experimental main peak which can be seen from Ref. 1.

In our opinion the following points support a Coulomb effect as an explanation of the main peak.

(a) In all data, we find the position of the main peak in the very neighborhood of the point, where the relative energy of the two outgoing protons has a maximum, indicated in Figs. 1–4 by "Coul."

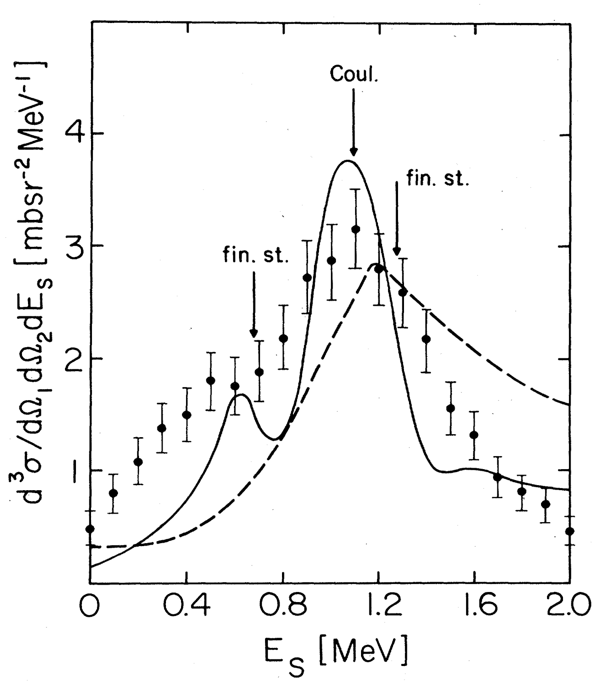


FIG. 4. Same as Fig. 1, but at $E_d^{lab} = 7.5$ MeV and 13°-13°. The solid curve shows the results of a full three-body calculation. The dashed curve shows the results of an approximate calculation, using a projection on the deuteron state in the subsystem of the incoming scattering state and neglecting the strong NN force in the outgoing scattering state. The absolute magnitudes of both calculated curves are adjusted to the experimental data.

(b) The bombarding energies $E_d^{lab} = 7.4$ and 7.5 MeV correspond to relative kinetic energies of the outgoing three nucleons after cm subtraction of 0.241 and 0.275 MeV, respectively, which are small compared to the deuteron binding energy. It is well known that in the low energy limit the pp Coulomb potential tends to dominate over the NN strong potential (some explicit comparison of matrix elements is given in Ref. 2). Thus in the outgoing channel the growing influence of the repulsive pp Coulomb potential tends to separate the protons, which is most likely to occur if the pp relative energy is large. This is expressed by an enhancement in the cross section, in agreement with (a).

(c) Also p + d breakup calculations based on Faddeev-equations[3] show a major jump agreeing in shape and position with the data.

(d) We have performed a d + p breakup calculation using the strong approximation of Møller wave operator (SAM) approach. The SAM method, described in Refs. 4 and 5, is a time dependent method for the calculation of $S$ matrix elements, which allows us to treat also the long range Coulomb force. In the calculation, the Coulomb force has been treated properly and the strong NN force was described by a separable potential, taken from Ref. 5. However, only the relative shape of the cross section has been calculated, while the absolute magnitude has been adjusted to the experimental data. The results of the calculation are shown in Fig. 2 for $E_d^{lab} = 7.4$ MeV and 13°-13° pp detection angles and in Fig. 4 for $E_d^{lab} = 7.5$ MeV and 13°-13° pp detection angles. Both curves display a major bump and the position of the main peak agrees very well with (i) the maximum of the relative energy between the outgoing protons (denoted by "Coul") and (ii) the position of the main peak of the experimental data.

(e) We have performed another d + p breakup calculation using again the SAM approach and the same potentials as in (d) but making the following approximations: In the calculation of the d + p scattering state from the incoming channel we have projected the two-body subsystem motion on the deuteron wave function, thus obtaining an effective two-body problem. In the outgoing channel we have neglected the strong NN potential and considered only the pp Coulomb potential [for justification see (b)] and obtained also an effective two-body problem. Again we have adjusted the absolute magnitude of the cross section to the experimental data. The calculated magnitude is by a factor of 5 too small. However, one should note that the Coulomb interaction can produce significant effects at a low energy. For example, a factor of 30 was found in absolute magnitude between experimental d + p and calculated d + n breakup cross sections at 7.4 MeV[2] and the factor of 5 should be seen in relation to this. The result for $E_d^{lab} = 7.5$ MeV and 13°-13° pp detection angles is shown in Fig. 4. The calculation exhibits a peak in close neighborhood of the experimental peak. One should note that due to the omission of strong NN forces in the outgoing channel no final state interaction can occur in this case.

In conclusion, we have given some evidence for the interpretation as Coulomb effect for common peaks in the data of low energy d + p breakup cross sections. However, a definite answer would require a comparison with d + n data. In the neutral d + n calculation given in Ref. 2, there was not such a broad bump like in the d + p data.

The authors gratefully acknowledge support from the Natural Sciences and Engineering Research Council of Canada and la Fondation de Chercheurs et d'Action Concertée du Québec.

[1]R. J. Slobodrian, S. S. Dasgupta, C. Rioux, F. Lahlou, and R. Roy, J. Phys. (Paris) **42**, 13 (1981).
[2]H. Kröger and R. J. Slobodrian, Phys. Lett. **144B**, 19 (1984).
[3]R. J. Slobodrian and P. Doleschall, Phys. Lett. **101B**, 1 (1981).
[4]H. Kröger, Phys. Lett. **135B**, 1 (1984).
[5]H. Kröger and R. J. Slobodrian, Phys. Rev. C **30**, 1390 (1984).