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Bonn potential and electron-deuteron scattering at high momentum transfer

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Deuteron electrodisintegration $d(e,e')$ near threshold is calculated using the various energy-independent Bonn potential versions. At high momentum transfer they lead to rather different results compared to other realistic *NN* potentials. This can only be partly explained by a different *D*-state admixture strength. The potential effect is particularly strong for the transverse form factor, but is also present for the longitudinal one. The latter is influenced in a similar way as the longitudinal part of the elastic deuteron form factor $A(q^2)$ which we have considered in addition.

In the past a great deal of work was devoted to testing various models of the *NN* interaction by studying the electromagnetic deuteron structure in photo- and electro-induced reactions. Without a doubt a lot of progress has been made over the years. However, problems still remain, in particular, for two processes at high momentum transfer, namely elastic *e-d* scattering and electrodisintegration near threshold. Besides the question of the importance of relativistic corrections, a controversial discussion has developed concerning the question of the proper electromagnetic form factor for the exchange current,[1] which has an important impact on the results,[2] in fact, much more important than the dependence on the hitherto known *NN* potential models. Only when the new Bonn potential was published[3] did a strong potential model dependence become evident.[4] Similarly, strong potential effects were found for elastic *e-d* scattering.[5-7] But in both cases no consistent calculation with the full Bonn model was performed, since one has to consider additional complicated currents due to the complexity of the potential. In fact, for the deuteron breakup only the energy-independent *r*-space version of the Bonn potential was used. However, the energy-independent Bonn potentials (*r* and *q* space) were criticized by Desplanques[8] because of their low *D*-state probability P_D and their poor description of the ϵ_1 mixing parameter in *NN* scattering. In particular, he showed in a model study that P_D should be increased by about 1.5%–2% when deriving an energy-independent version from an energy-dependent potential model. Such an increase was not taken into account for the original *q*- and *r*-space one-boson exchange versions of the Bonn potential leading to a rather weak tensor force. The latter might also be the origin of the poor description of the ϵ_1 mixing parameter.

The aim of the present work is to study whether the above-mentioned different results with the energy-independent *r*-space Bonn potential are a specific feature of the low P_D and the poor ϵ_1 and thus due to a poor approximation of the full model. For this purpose we consider the various new *r*- and *q*-space approximations to the full model of the Bonn potential,[9] which show a considerable variation in the *D*-state admixture probability as listed in Table I. The nomenclature for the different approximations of the Bonn potential follows that of Tables A1 and A3 of Ref. 9 for Q and R, respectively. Furthermore, as shown in Fig. 1, models Qb and Qc lead to a similarly good description of the experimental ϵ_1 like the Bonn full model and the Paris potential,[10] while for the various *r*-space versions ϵ_1 is somewhat too low at higher energies. We would like to mention that the previous models Q and R of Ref. 3 are very close to the new models Qa and Ra of Ref. 9, respectively.

Considering first the deuteron electrodisintegration near threshold, we show in Fig. 2 results for the impulse approximation (IA). It is evident that for a higher P_D the minimum is increased and shifted towards lower momentum transfer due to the destructive interference between the *S*- and *D*-state contributions. But this model dependence is not simply a question of *D*-state admixture strength, since even with the models Qc and Rb one still gets quite different results compared to the ones with the Paris potential, which has almost the same P_D (5.77%). Therefore the differences between the Bonn and Paris potentials are only partly due to the difference in P_D but also partly due to the different radial behavior of the *S* and *D* waves. We show, in addition, results for the Argonne potentials v_{14} and v_{28} (Ref. 11) which are similar to the ones with the Paris potential.

Also, in Fig. 3 the contributions of meson-exchange (MEC) and isobar currents (IC) are included. For the

TABLE I. *D*-wave probability P_D for the various Bonn potentials.

Model	P_D (%)
Full	4.25
Qa	4.38
Qb	4.99
Qc	5.61
Ra	4.75
Rb	5.53

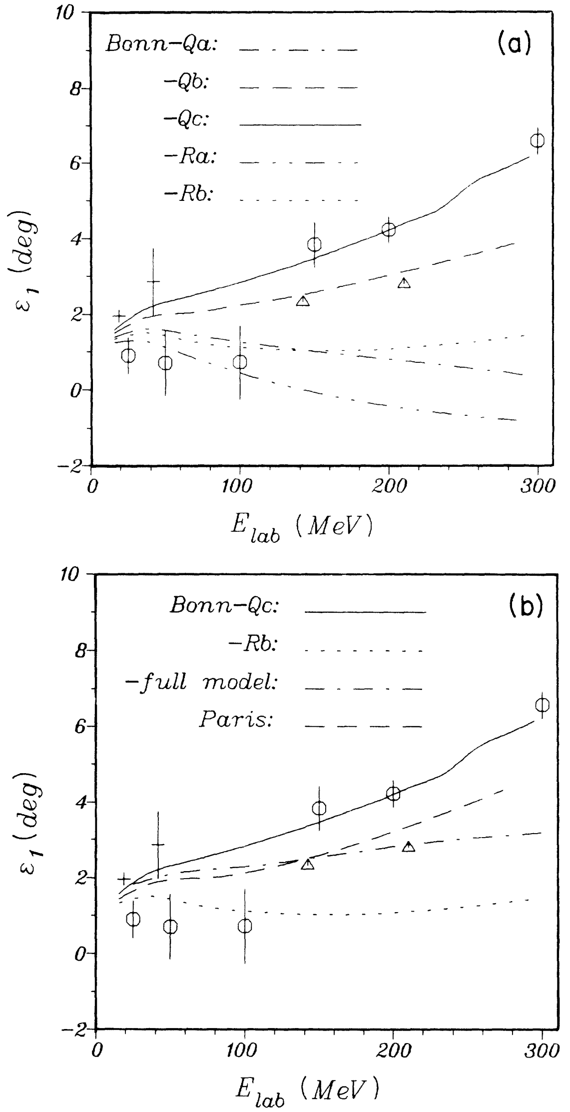

FIG. 1. NN-scattering parameter ϵ_1: (a) for the energy-independent Bonn potential versions; (b) for Bonn Qc, Rb, and full model as well as for the Paris potential. Experimental data taken from Ref. 9.

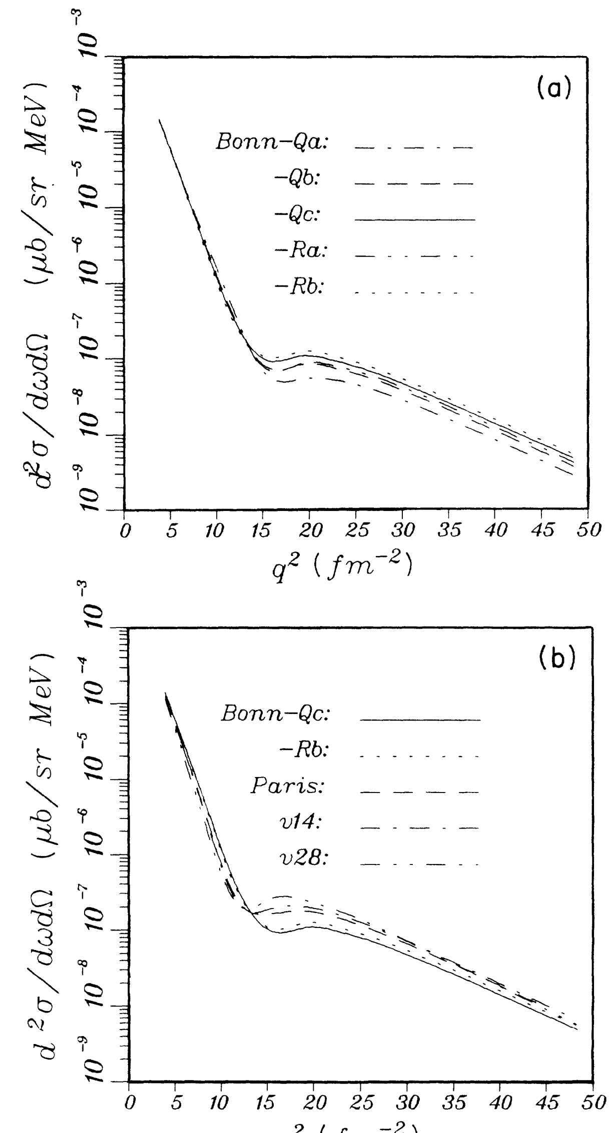

FIG. 2. Cross section for $d(e,e')np$ at $E_{np}=1.5$ MeV and $\theta_e=155°$ as a function of the four-momentum transfer q^2 in IA with $G_{En}=0$: (a) for the various Bonn potentials; (b) for Paris, Argonne v_{14} and v_{28}, and Bonn Qc and Rb potentials.

Bonn and Paris potentials consistent π and ρ exchange are taken into account, while for the phenomenological Argonne potentials π- and ρ-exchange currents are used with $\Lambda_\pi=5$ fm^{-1} (monopole), $g^2_{NN\rho}/4\pi=0.95$, $f_{NN\rho}/g_{NN\rho}=6.1$, and $\Lambda_\rho=1.3$ GeV (dipole) for simplicity even though one loses consistency in this case. However, from our experience with the Paris potential we do not consider this inconsistency as serious, at least at moderate momentum transfer. Other exchange currents are negligible for deuteron electrodisintegration near threshold.[12] Contrary to the IA results, the model dependence remains comparably small between the various Bonn potentials. Only beyond 20 fm^{-2} (for the r-space versions) and 25 fm^{-2} (for the q-space versions) do the differences become significant.

Figure 3(b) shows that Paris and Argonne potentials lead to a shallow minimum for the cross section at about 20–25 fm^{-2}. For the Bonn potentials this minimum is much less pronounced—in the case of the q-space versions only a shoulder remains—and shifted by about 10 fm^{-2} to higher momentum transfer. Figure 3(c) gives the dependence of the Bonn Qc result on electromagnetic form factors. Already the consideration of the neutron electric form factor G_{En} (Ref. 13) matters quite a lot, while the use of F_1^V instead of G_E^V as an exchange current form factor leads to the well-known drastic increase of the cross section in the region of momentum transfer, where one has a destructive interference between IA and MEC.[1] The comparison with experimental data from Saclay (Refs. 14 and 15) and SLAC (Ref. 16) shows that, using the Bonn potential, one gets a better agreement if one takes G_E^V as the MEC form factor, assuming a nonvanishing electric form factor G_{En} of the neutron. The use of F_1^V does not lead to a better agreement for the Bonn potential

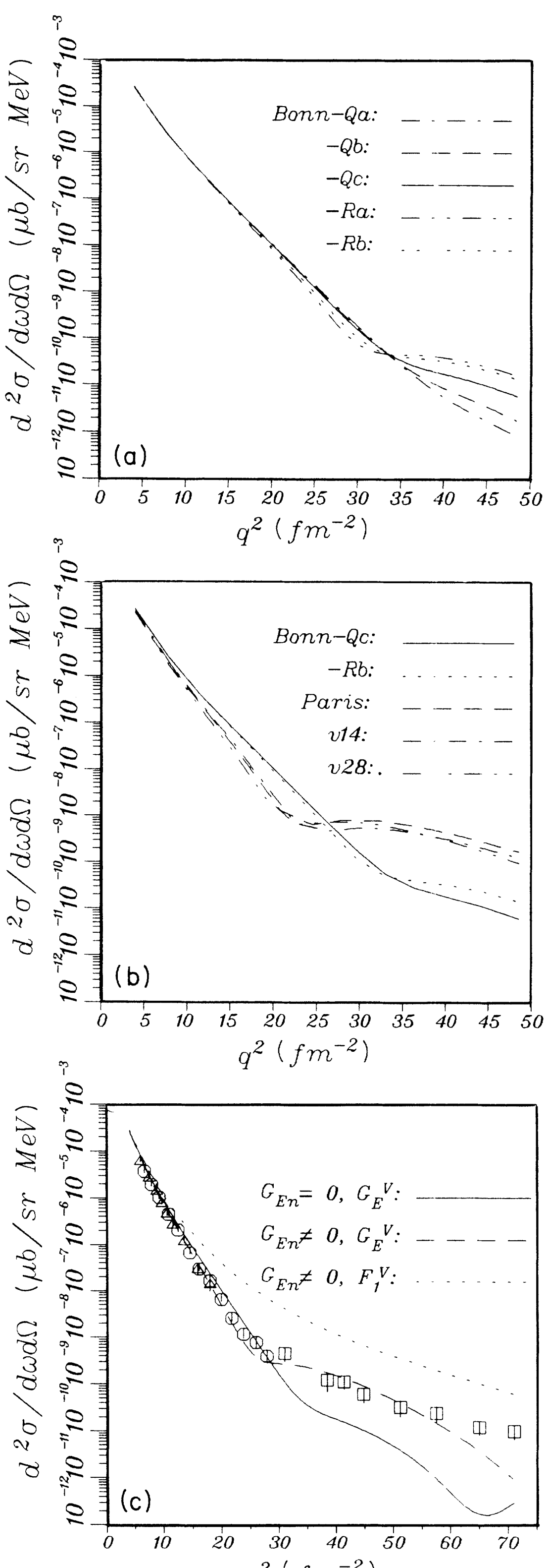

FIG. 3. (a),(b) As in Fig. 2, but with inclusion of MEC (form factor G_E^V) and IC. (c) Effect of electromagnetic form factors for Bonn Qc: $G_{En}=0$ [solid curve, same as solid curve in (b)], G_{En} from Ref. 13 (with $p=5.6$) with G_E^V for MEC (dashed curve) and with F_1^V for MEC (dotted curve). Experimental data for $\theta_e=155°$ from Ref. 14 (triangles), Ref. 15 (circles), and for $\theta_e=180°$ from Ref. 16 (squares).

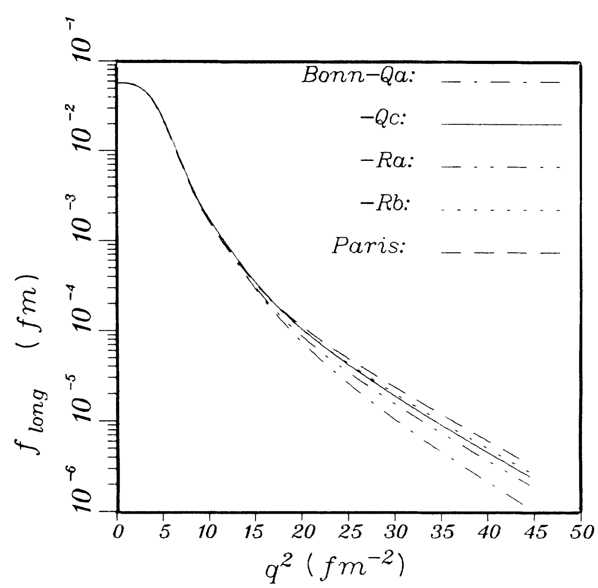

FIG. 4. $f_{\rm long}$ for $d(e,e')np$ at $E_{np}=1.5$ MeV with various potential models as function of four-momentum transfer q^2.

as Fig. 3(c) shows. This is also the case with other neutron form-factor fits. However, the calculations are nonrelativistic, and thus these results should be interpreted with care.[1] A final judgement as to the quality of agreement has to await inclusion of relativistic effects and a better knowledge of the nucleon form factors in that region of momentum transfer.

Because of the strong backward electron scattering angle the cross sections of Figs. 2 and 3 are governed by the transverse form factor. Since it is interesting to see whether one also finds a strong model dependence for the longitudinal form factor, we show in Fig. 4 $f_{\rm long}$ at $E_{np}=1.5$ MeV. In fact, one notes rather strong differences among the various Bonn potentials and with

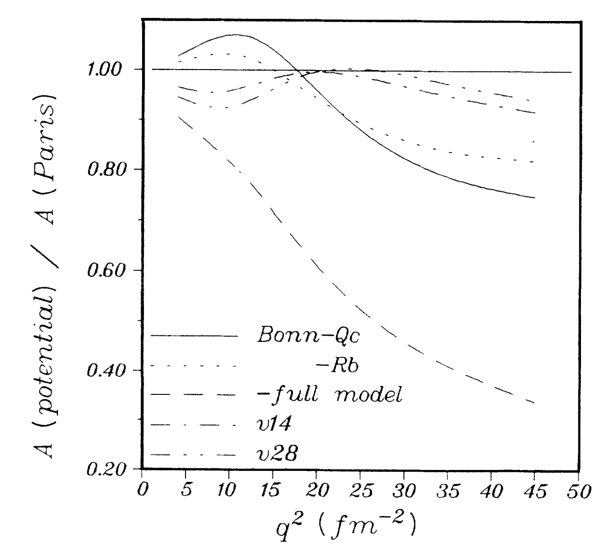

FIG. 5. Longitudinal part of the elastic deuteron form factor $A(q^2)$ for various potentials relative to the one for the Paris potential as a function of the four-momentum transfer q^2.

growing P_D they approach the $f_{\rm long}$ of the Paris potential. However, differences remain, though they are less important than in Figs. 2 and 3. Furthermore, we would like to mention that the Argonne potentials lead to results similar to the Paris potential.

The differences of $f_{\rm long}$ between Bonn Ra and Qa and the Paris potential are rather similar to those found for the elastic deuteron form factor $A(q^2)$.[6,7] In order to see the effect of the new Bonn versions we have also studied the elastic form factor. However, we consider here only the dominant longitudinal part ($C0$ and $C2$ multipoles). As the general behavior is rather similar to that of Fig. 4, and in order to account better for the differences, we show the results in Fig. 5 relative to the result with the Paris potential. Here we also consider the full Bonn model. As already known,[5–7] it leads to a completely different elastic form factor than the Paris potential, while the Bonn Qc and Rb results are already much closer to the Paris result, but still quite different. Again we show results for the Argonne potentials. Since v_{28} explicitly includes Δ degrees of freedom, we have taken into account the isobar contributions to the form factor in this case. Both Argonne potentials lead to somewhat different results than the Paris potential, even though differences are smaller than for the Bonn potentials.

The potential model dependence of the elastic form factor is particularly important with regard to a determination of G_{En} from elastic e-d scattering. In view of the above situation inelastic $\vec{e}$-d scattering in the quasielastic region seems to be much more advantageous, since for certain polarization observables one has a linear dependence on G_{En} and only a negligible potential model dependence.[17]

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