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SYMMETRY AND COULOMB CORRECTIONS IN LIGHT NUCLEAR SYSTEMS

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ABSTRACT

An approximation which describes the Coulomb-nuclear interference in a two-body manner is used to calculate i) vector analyzing powers in elastic p-d scattering and ii) phase shifts for p-α scattering. Comparison with experiments indicate that a good deal of the observed differences in charge symmetric three- and five-nucleon reactions can be covered by Coulomb interference effects. Calculations for the four-nucleon system confirm this observation. It appears to be questionable that nuclear charge asymmetry has to be invoked to explain current experiments.

INTRODUCTION

Polarization experiments have become increasingly important in the study of symmetries. Parity and time reversal invariance are the primary subjects of current investigation, but isospin conservation, or more precisely, charge symmetry of the nuclear interaction is also being questioned. In what follows we concentrate on charge symmetry and consider the three, four, and five-nucleon systems as test cases. In each of these three light nuclear systems there are polarization experiments for charge symmetric reactions[1-3] available which have been subject for speculation about a possible breaking of charge symmetry. The differences in most of the nucleon analyzing powers measured in charge symmetric reactions are sizable and cannot be explained by pure Coulomb corrections with no account of interference. Consequently, one might be tempted to assign these differences to a real deviation from nuclear charge symmetry. At the moment, however, such a conclusion seems to be premature, since no attempt has been made to calculate the Coulomb nuclear interference effect (CI) on polarization observables exactly.

To circumvent the troubles with the CI, experiments have been performed at energies where the CI effect is expected to be negligible, but again this is an assumption which has to be justified by an exact calculation. These experiments[4] do not indicate a substantial deviation from charge symmetry. Nevertheless, we cannot conclude that no charge asymmetry is present at these energies where significant differences in charge symmetric reactions have been found. It might still take a while before exact calculations of the CI will be at hand. Therefore, an approximate treatment of the CI is desirable to obtain at least an estimate on the order of the magnitude of the effect.

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Approximate Coulomb corrections have been applied in the four and five-nucleon system, but none in the three-nucleon system. Both the resonating group approach of Hofmann and Zahn [5] and the R-matrix method of Dodder et al. [6,7] suggest that most of the difference in charge symmetric reactions can be covered by CI effects. We should, however, keep in mind that i) not all available experimental data have been analyzed and ii) the Coulomb problem has not been treated exactly. The subsequent discussion on charge symmetry and Coulomb effects should be understood within these constraints.

As mentioned before no calculation has been performed wich takes into account the CI on three-nucleon polarization observables. We now fill this gap and present results for p-d vector analyzing powers which include the CI effect in an approximate way [8]. See section II. The method essentially treats the Coulomb force as a two-body problem, but takes into account the finite charge distribution of the composite particle. To test our approximation in higher nuclear systems, which in fact is more favourable for our two-body treatment than the three-nucleon scattering system with its loosly bound deuteron, we have also calculated CI effects in the five-body system and compare it to the R-matrix results. See section III. In section IV we briefly discuss the status in the four-nucleon system and summarize the results.

THREE-NUCLEON SYSTEM

Unfortunately the elastic scattering data for mirror reactions at the same energy are very sparse. Nucleon analyzing powers have been measured at 12 [9] and lately at 14 MeV [1]. The first mentioned experiments show only minor differences for the mirrior reactions $^2H(\vec{p},p)^2H$ and $^2H(\vec{n},n)^2H$, whereas the 14 MeV data show measurable differences. More measurements with comparable precision at various energies are necessary to read off a clear trend. On the theoretical side, not being able to include the Coulomb force exactly, we should try to obtain at least an estimate on the magnitude of the CI effect. For this purpose we make use of a quasi two-body method [10] which has been derived from the three-body momentum Faddeev equation. The differential cross sections obtained with this approximation are in some qualitative agreement with those obtained from a Faddeev calculation which takes into account the Coulomb force exactly in first order. Extending this approximation scheme to coupled states by utilizing methods developed for the two-body system [11,12] we are able to apply two-body Coulomb corrections to the amplitudes, which involve on-shell quantities only. [8]

If we restrict our investigation to vector analyzing powers we can find an even simpler way to calculate the influence of the CI. Since the nucleon analyzing power at lower energies($<$15 MeV) is mainly sensitive to the spin transition in the three-nucleon P-waves [13] we can -as a first step- drop coupling into states other than P-waves. In a second step we include other couplings but in general we persue the philosophy to allow one coupling in each J^{π} state only. This enables us to express the scattering matrix in the

Stapp parameterization (no generalization of the Stapp parameterization for 3 x 3 matrices is known to date). Now we can carry over the two-body methods and calculate Coulomb corrections to the nuclear bar phase parameters.

The simple recipe to obtain the two-body CI corrections to the phase parameters is given by

$$\overline{\delta}^{r}_{1(2)}(p) = \tilde{\alpha}_{1(2)}(p)\{\overline{\delta}^{s\,\prime}_{1(2)}(p) + \frac{\sin 2\overline{\delta}^{s}_{1(2)}(p)}{2p\cos 2\overline{\varepsilon}^{\,s}(p)} - \pi p V'_{1(2)}(p)$$

and

$$\overline{\varepsilon}^{r}(p) = \frac{\tilde{\alpha}_1(p)+\tilde{\alpha}_2(p)}{2}\{\overline{\varepsilon}^{s\,\prime}(p) + \frac{1}{2p\cos 2\overline{\varepsilon}^{s}(p)}[\sin 2\overline{\varepsilon}^{s}(p)+\sin(\overline{\delta}^{s}_1(p)+\overline{\delta}^{s}_2(p))]\} \tag{1}$$

and in a similar way for the other mixing parameters $\overline{\zeta}$ and $\overline{\eta}$. 1 and 2 designate the states which are mixed. $\overline{\delta}^{r}$ and $\overline{\varepsilon}^{r}(\overline{\zeta}^{r},\overline{\eta}^{r})$ are the CI corrections to the strong phase parameters $\overline{\delta}^{s}$ and $\overline{\varepsilon}^{s}(\overline{\zeta}^{s},\overline{\eta}^{s})$. $\tilde{\alpha}(p)$ and V' reflect the influence of the finite charge distribution of the deuteron. V' is the difference of the full electromagnetic potential of the deuteron and the point-like Coulomb potential. The angular momentum dependent $\tilde{\alpha}(p)$ is given by

$$\tilde{\alpha}_{\ell}(p) = \frac{2\gamma}{\pi}\int_0^{\infty}\frac{x^2dx}{1-x^2}\int_{-1}^{1}\frac{dyP_{\ell}(y)f\{p^2(1+x-2xy)\}}{1+x^2-2xy} \tag{2}$$

where γ is the Coulomb parameter and $f(q^2)$ is the form factor for the (spherical) charge distribution. For reasons of simplicity we employ here the same S-wave Yamaguchi form factor as being used in Ref. 10.

If we now take phase parameters of a model n-d calculation which uses a realistic nucleon nucleon interaction (we would certianly prefer to take the phase parameters of a n-d phase shift analysis, but to our knowledge no reliable analysis has been performed yet) like, e.g., the parameters given by Stolk and Tjon[14] we can calculate the Coulomb corrections of Eq. (1). Expressing the polarization observables in terms of scattering matrix elements once with and once without CI corrections we obtain the results for the vector analyzing powers as displayed in Figs. 1 and 2. At lower energy (5.5 MeV) the CI effect almost halves A_y, but enhances iT_{11} by approximately one third. The influence of the pure Coulomb contribution can be neglected everywhere except in the forward direction. At 14.1 MeV the CI is already much smaller, but still of measurable amount in A_y. The opposite trend in the CI for A_y and iT_{11} still persists. We should mention that the n-d curves do not exactly coincide with the curves given by Stolk and Tjon. This can be understood since it has been shown before[13] that neglecting certain coupling produces

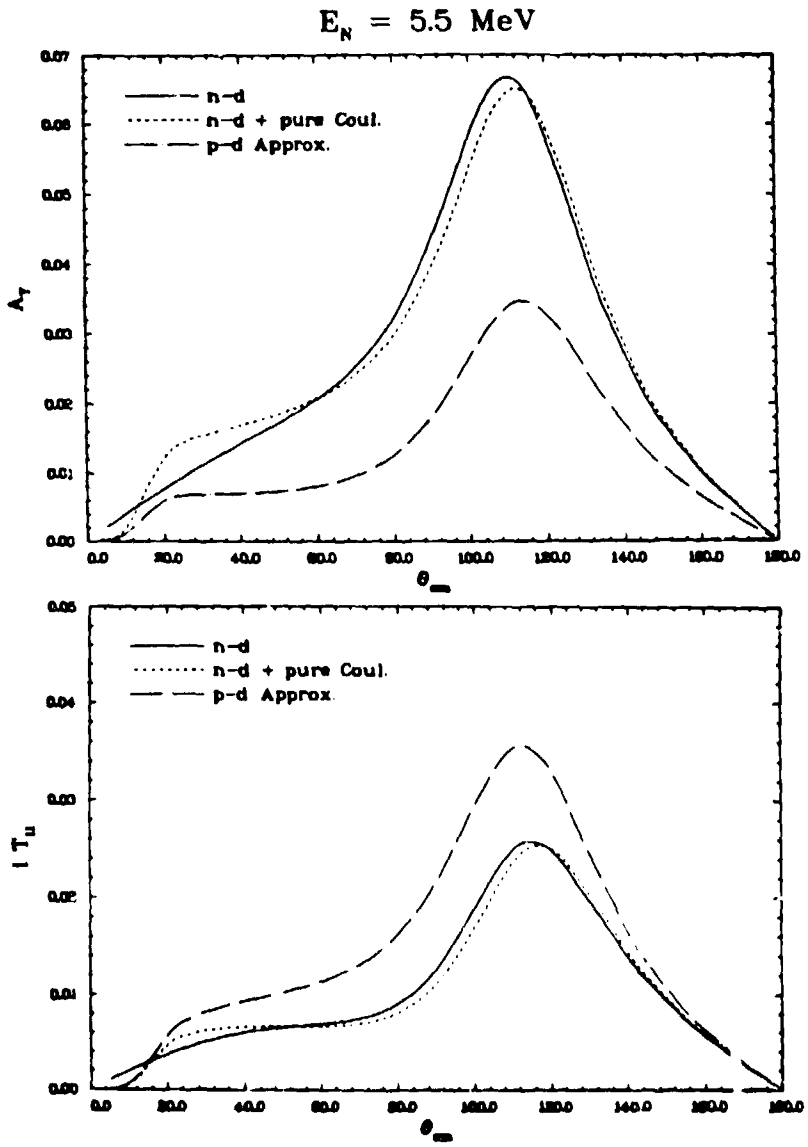

Fig. 1. Vector analyzing powers A_y and iT_{11} for elastic n-d and p-d scattering at E_{Lab} = 5.5 MeV for the incident nucleon.

a small deviation from the final result.

It is interesting to note that the 14 MeV experiments(Fig.3) display the same trend in A_y. Even the magnitude happens to be close to our prediction. We might therefore conclude that the two-body CI effect reaches an order of magnitude which would suffice to explain the current differences in A_y. However, we should remember that i) the experiments at 12 MeV [9] do not show measurable differences in A_y which seems to be in disagreement with the 14 MeV data and ii) our treatment of the CI is an approximation to be tested by future exact calculations. It might occur that the three-body feature of the CI would put back our two-body CI to acchieve agreement with the 12 MeV experiment. In the event, which cannot be excluded from the very be-

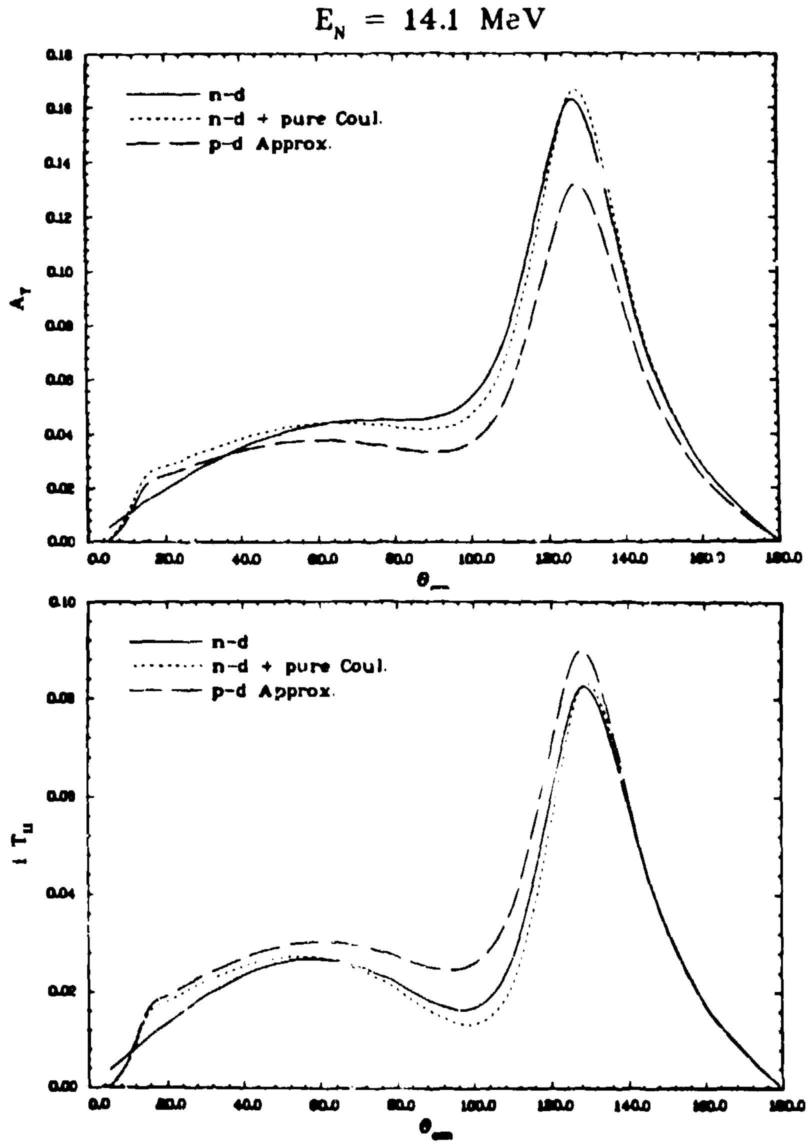

Fig. 2. Same as Fig. 1, but E_{Lab} = 14.1 MeV.

ginning, that the exact CI predicts A_y to be bigger for p-d than for n-d we would then be back to invoking nuclear charge asymmetry to explain differences with experiment. On the other hand, taking the small charge asymmetry(≈80 keV) [15] found in the three-nucleon bound states as a scale for the scattering problem one might have doubts about the observability of this effect.

Finally we should be aware that, as our CI correction tends to suppress the nucleon analyzing power, it does not help to resolve the puzzling problem of model n-d calculations, namely why calculations using "realistic" nucleon-nucleon potentials consistently predict significantly lower A_y when compared with p-d data.[14,16,17]

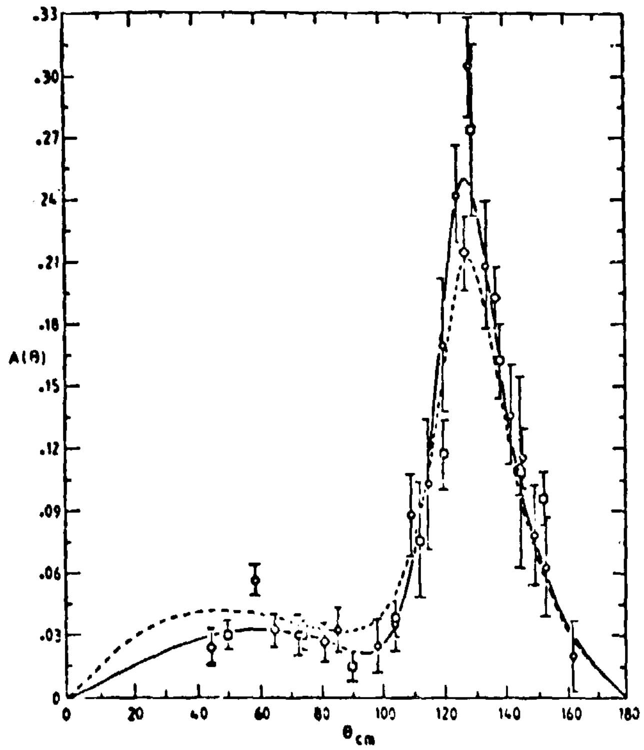

Fig. 3. Solid line is a fit to the n-d data and dashed line to the p-d data.

FIVE NUCLEON SYSTEM

Numerous experimental data are available for both elastic p-α and n-α scattering. The phase shifts[6,18] seem to be rather well established up to 20 MeV displaying partly large differences for the mirror reactions. Dodder et al. have demonstrated with their R-matrix calculation that these differences can be produced to a large extent by CI effects. Extending our quasi two-body method to the five-nucleon system provides us with a further test of its applicability. In addition, comparing it with the CI approximation as applied in the R-matrix calculation (essentially the CI is incorporated through i) matching of the internal wave function to the Coulomb wave at a certain radius and ii) an "internal" correction which represents a crude approximation of the few-body aspects of the CI) should tell us how close the CI comes to being a two-body effect.

We adapt Eqs. (1) and (2) for the five-nucleon system by using an appropriate e.m. form factor for the charge distribution of the α particle[19] which again affects $\delta_\ell(p)$ and $V'_\ell(p)$ only. Then we take the n-α phases from the R-matrix method (the "R-matrix phases" are in reasonable agreement with those of Ref. 18), calculate p-α phases, and compare them with the R-matrix results (Figs. 4 & 5). The overall agreement of the two approximations is striking. This merely confirms that the CI in the p-α elastic scattering is almost a two-body effect. We have left out the resonant $P_{3/2}$ wave where the agreement is poor. But this was to be expected from the very beginning since

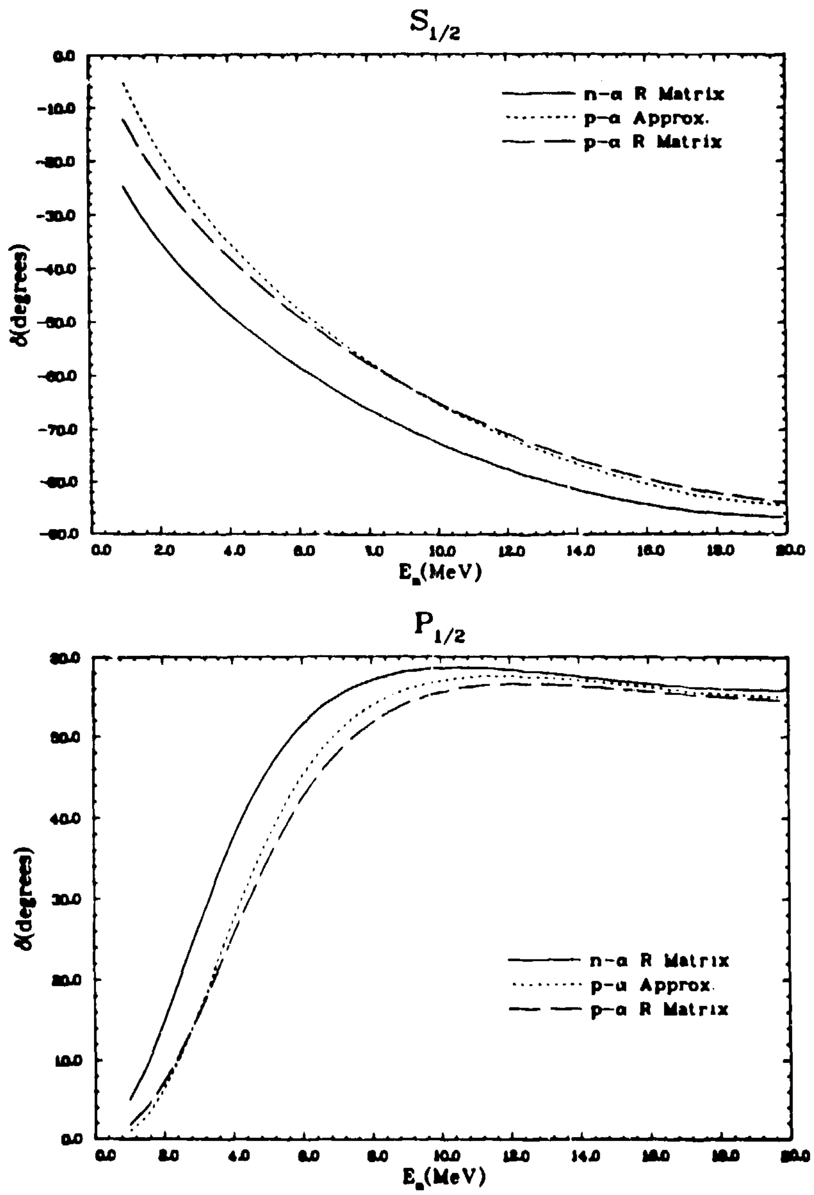

Fig. 4. Phase shifts for n-α and p-α scattering.

our approximation does not handle (strong) resonances properly.[20]

SUMMARY

Looking at the elastic scattering of neutron and protons on deuterons respectively α particles we have found that the two-body type CI effect is of an order of magnitude big enough to explain roughly the observed differences in mirror reactions. Nucleon analyzing powers calculated by Hofmann and Zahn for the four-nucleon charge symmetric reaction $^2H(d,\vec{n})^3He$ and $^2H(d,\vec{p})^3He$ show the same trend. We should, however, note that a new measurement of the latter reaction[21] seems to indicate that the experimental situation is not yet fully settled. Recoil corrected continuum shell model calculations by Philpott and Halderson[22] and R-matrix calculations[7] applied to

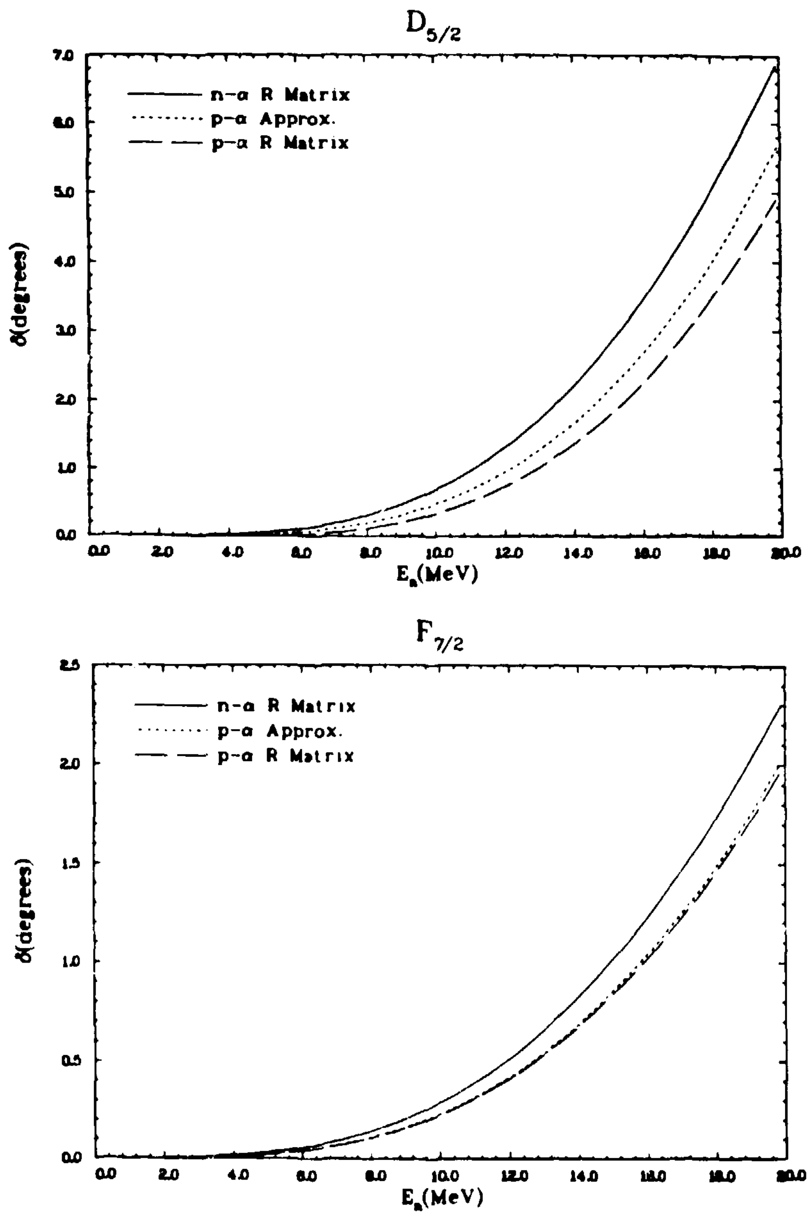

Fig. 5. Same as Fig. 4.

different four-nucleon reactions seem to underline the relative importance of CI effects.

Although there is some strong evidence that CI effects must not be neglected, particularly at lower energies, one should be careful in drawing conclusions about the actual need of nuclear charge asymmetry. Still too many unknowns are involved which, on the other hand, could be reduced drastically if more accurate data of mirror reactions at the same energy and an exact treatment of the CI were available.

REFERENCES

1. J. E. Brock, A. Chisholm, J. C. Duder, and R. Garret, Few Body Systems and Nuclear Forces, ed. H. Zingl, M. Haftel, and H. Zankel (Springer, Berlin,1978), vol.I; J. C. Duder, M. Sosnowski, and D. Melnik, ibi. A. Chisholm, J. C. Duder, and R. Garret, contribution to this conference.
2. V. König, W. Grüebler, R. A. Hardenkopf, B. Jenny, R. Risler, H. R. Bürgi, P. A. Schmelzbach, and R. E. White, preprint(Zürich,1979).
3. L. J. Dries, H. W. Clark, R. Detomo,Jr., J. L. Regner, and T. R. Donoghue, Phys. Rev. C21, 475 (1980).
4. K. Nisimura, K. Imai, T. Matsusue, H. Shimizu, R. Takashima, K. Hatanaka, T. Saito, A. Okihana, contribution to this conference.
5. H. M. Hofmann and W. Zahn, contribution to this conference.
6. D. C. Dodder, G. M. Hale, N. Jarmie, J. H. Jett, P. W. Keaton,Jr., R. A. Nisley, and K. Witte, Phys. Rev. C15, 518 (1977).
7. G. M. Hale and D. C. Dodder, Few Body Systems and Nuclear Forces, ed. H. Zingl, M. Haftel, and H. Zankel (Springer,Berlin,1978), vol. II.
8. G. M. Hale and H. Zankel, to be submitted for publication.
9. W. Tornow, P. W. Lisowski, R. C. Byrd, and R. L. Walter, Nucl. Phys. A296, 23 (1978).
10. M. I. Haftel and H. Zankel, Los Alamos preprint (1980).
11. J. Fröhlich, L. Streit, H. Zankel, and H. Zingl, J. Phys. G6, 841 (1980).
12. J. Fröhlich, L. Streit, and H. Zankel, Phys. Lett. 92B, 8 (1980).
13. C. Fayard, G. H. Lamot, and E. Elbaz, Proc. Troisieme Session d' Etudes de Physique Nucleaire, La Toussuire (1975).
14. C. Stolk and J. A. Tjon, Nucl. Phys. A295, 384 (1978).
15. R. A. Brandenburg, S. A. Coon, and P. U. Sauer, Nucl. Phys. A294, 305 (1978).
16. J. J. Benajoun, J. Chauvin, C. Gignoux, and A. Laverne, Phys. Rev. Lett. 36, 1438 (1976).
17. P. Dolleschal, private communication (1980).
18. R. A. Arndt and L. D. Roper, Phys. Rev. C3, 903 (1970); R. A. Arndt, L. D. Roper, and R. L. Shotwell, Phys. Rev. C3, 2100 (1971).
19. R. F. Frosch, J. S. McCarthy, R. E. Rand, and M. R. Yearian, Phys. Rev. 160, 874 (1967).
20. H. Kriesche and H. Zankel, J. Phys. G6, 853 (1980).
21. P. P. Guss, K. Murphy, R. C. Byrd, C. E. Floyd, S. A. Wender, R. L. Walter, T. B. Clegg, and W. R. Wylie, contribution to this conference.
22. R. J. Philpott and D. Halderson, Nucl. Phys. A321, 295 (1979).