TESTS OF EFFECTIVE INTERACTIONS FOR NUCLEON SCATTERING
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ABSTRACT

Significant progress has been made over the past several years in developing energy- and density-dependent effective interactions and optical potentials based on free nucleon-nucleon potentials. This leads to the hope that the nucleon-scattering reaction mechanism may be well enough known to probe details of nuclear spectroscopy (i.e., transition densities) more accurately than with purely phenomenological approaches. Of particular interest to this conference is the possibility of separating neutron and proton transition densities by comparing proton and neutron scattering, which can be done reliably only if the isovector parts of the effective interaction are well known. This paper attempts to assess the accuracy of presently available interactions through comparisons with elastic and inelastic scattering over a wide mass range, and also with the (p,n) isobaric-analog reaction. Particular emphasis has been placed on the isovector parts of the interaction and on Coulomb corrections by comparing proton and neutron scattering on the same targets. In a number of cases, precise neutron data have been measured to facilitate these comparisons.

I. INTRODUCTION

An important goal of the study of nuclear reaction mechanisms is to understand scattering cross sections in terms of the interaction between the nucleons of the projectile and those of the target. The work described in this paper employs a one-step folding model to describe the potentials for nucleon scattering (optical potential for elastic scattering, or form factor for inelastic and charge-exchange reactions). Because the free nucleon-nucleon interaction has a short-distance behavior that is too strong to be used in a perturbative framework, this approach requires an effective nucleon-nucleon interaction. Until a few years ago, the properties of the effective interaction were determined primarily from phenomenological parameterizations of simple interaction forms (e.g., a real interaction with a single Yukawa form factor, and with several strength parameters representing the various components of the interaction).

A typical study of such an interaction has been given by Austin.¹ Although the phenomenological interactions yielded useful comparisons with data in a limited range of energies and angular-momentum transfer, particularly when the calculated form

factors were supplemented with phenomenological imaginary parts, the wide range of data presently available from low through intermediate energies has demanded an effective interaction that is so complicated that it requires further theoretical guidance for its parameterization. The most important characteristics of the effective interaction that must be described are its exchange mixture, range structure, and dependence on energy and density. A major step during the past decade has been the development of effective interactions²⁻⁵ and nuclear-matter optical potentials⁶ based on free nucleon-nucleon interactions and the use of the techniques of nuclear many-body theory. These calculations address the characteristics of an effective interaction listed above. Additionally, most of them³⁻⁶ yield estimates of the imaginary components of the interaction (or potential). The strong calculated density dependence requires the use of a local density approximation (LDA) in applying the results to finite nuclei.

This work presents results from a systematic comparison of several theoretical interactions, together with the necessary local-density and exchange approximations, with experimental results for elastic, inelastic, and isobaric-analog charge-exchange reactions. It is expected that the merits and deficiencies of the theoretical interactions will give guidance for the development of a more general phenomenological interaction.

In principle, when a DWBA description of an inelastic or charge-exchange reaction is appropriate, the same effective interaction should be used to describe the distorting optical potentials and the transition form factors. We present several examples of these types of reactions, to assess whether such a consistent treatment is within reach of the currently available interactions and the approximations used to implement them. A further goal is to understand whether the interactions are sufficiently reliable to yield accurate spectroscopic information, such as the reduced transition strengths $B(EL)$ and ratios M_{11}/M_p of neutron to proton multipole matrix elements for a given transition. Extracting such information depends on the accuracy of the isospin terms in the interaction, and accordingly neutron and proton scattering on the same target nucleus has been analyzed in nearly all cases.

Since the purpose of the present work is to test the reaction mechanism, we have concentrated on cases for which there is already experimental knowledge of the relevant ground-state or transition densities. The proton densities are accurately known from electron scattering, and the neutron densities have either been inferred from the results of 800-MeV proton scattering experiments, or assumed (in the case of self-conjugate nuclei) to be equal to the proton densities. For a particular nucleus and effective interaction, the procedure that has been followed is to first calculate the real and imaginary central potentials and the spin-orbit potential in a folding model. Details of the calculations may be found in Refs. 7,8. Elastic scattering is calculated by inserting these potentials into a spherical

optical-model code, and comparison with experimental data is made by least-squares adjustment of two normalizing parameters λ_V and λ_W for the real and imaginary central parts of the optical potential U:

$$U = \lambda_V V + i \lambda_W W + V_{S.O.} \quad (1)$$

In the energy range considered here, it has not been found necessary to alter the spin-orbit potential.

Comparison of the normalizing parameters for neutron and proton scattering constitutes a first test of the accuracy of the isospin content of the microscopic reaction mechanism. Once the energy dependence of the normalizing parameters has been established by the analysis of elastic scattering, normal-parity inelastic scattering and charge exchange are then calculated in DWBA with no further parameter variation. The same normalizing factors are applied to the real and imaginary central parts of the form factors that are used for the elastic distorting potentials.

Achieving consistency between proton and neutron scattering requires not only an adequate description of the isovector parts of the effective interaction, but also a correct treatment of Coulomb effects on proton scattering. To understand whether the common practice of replacing the incident energy E by $E - V_{Coul}$ everywhere in a local optical potential is reasonable, it is necessary to clarify the sources of energy dependence in the optical potential. In the microscopic folding model we identify two separate energy dependences. One of these is the intrinsic E -dependence of the effective interaction, which is weak for the real part, but strong for the imaginary part. The other is an energy dependence associated with the local-momentum approximation for exchange, in which conservation of energy is employed to eliminate the momentum dependence arising from the exchange approximation:

$$p^2/2m = E - V_{nuc} - V_{Coul}. \quad (2)$$

The combination $E - V_{Coul}$ explicitly appears in the exchange approximation; this is well understood to be responsible for the major part of the energy dependence of the real optical potential. We have argued⁷ that the energy dependence of the effective interaction should be measured from the Fermi energy, and that the near equality of neutron and proton Fermi energies in a heavy nucleus implies that effective interactions for neutron and proton scattering at the same incident energy should be evaluated at the same energy, rather than at energies shifted by the Coulomb potential. As will be illustrated below, this choice is necessary to achieve neutron-proton consistency for the imaginary potential.

II. INTERACTIONS AND CALCULATIONAL DETAILS

We have tested the central effective interactions of Brieva and Rook³ and Yamaguchi et al.⁵, both based on the Hamada-Johnston⁹ potential, but calculated with different

numerical techniques; Yamaguchi et al. also required self-consistency in the energies appearing in the Bethe-Goldstone equation. We have also tested the potential of Jeukenne, Lejeune, and Mahaux⁶ (JLM), based on the Reid hard-core potential¹⁰. The JLM nuclear-matter optical potential has been treated as an effective interaction by dividing it by the density, and accounting for the range of the interaction a posteriori by a multiplicative Gaussian form factor with an empirically determined range parameter. This procedure, originally discussed by JLM for elastic scattering, has also been applied previously to inelastic scattering and charge exchange¹¹. Since exchange has already been included in the JLM nuclear-matter optical potential, which is local, the distinction between intrinsic and exchange energy dependences may not be utilized in comparing neutron and proton scattering. However, JLM have concluded that proton scattering should be calculated with the substitution $E \rightarrow E - V_{\text{Coul}}$ in both the real and imaginary parts of the potential. Calculations of an effective interaction based on the Paris potential¹² in the range 25-100 MeV have been reported by von Geramb at this conference. Since this interaction has shown promise in the range 100-400 MeV⁴, it will be interesting to compare its predictions with those of the above interactions.

In the present energy range, we have found that the real, density- and energy-independent spin-orbit interaction of Bertsch et al.² (Elliott matrix elements) provides a remarkably successful description of elastic-scattering analyzing-power angular distributions, without requiring renormalization. This interaction is very similar to that of Brieva and Rook³. The spin-orbit interaction of Yamaguchi et al. is also very similar in shape (or in its q -dependence), but its strength is lower than that of Bertsch et al. The spin-orbit interaction of Bertsch et al. has been used for all the calculations herein, except those involving the Yamaguchi et al. potential, in which case the spin-orbit interaction of Yamaguchi et al. has been used, with its strength normalized upward by 30%.

The shape and strength of the calculated form factors and potentials depend on the prescription used to evaluate the density dependence of the effective interaction. We have consistently employed a "midpoint LDA," in which the density is calculated at the arithmetic mean of the projectile and target coordinates. Comparisons of potentials calculated with various prescriptions may be found in Ref. 8. The choice of prescription mainly affects the normalization of the imaginary central potential, at the level of $\approx 15\%$; the shape differences, when the potentials are viewed in q -space, appear at values of momentum transfer too large to have very important effects on the scattering angular distributions.

A further technical point concerns the use of effective-mass factors to modify parts of the calculated potentials. It has been pointed out by Negele and Yazaki¹⁴ that the imaginary part of the JLM potential should be multiplied by a factor m_k/m , which is the part of the effective mass associated with nonlocality (or, alternatively, momentum dependence); a similar discussion has been

given by Fantoni et al.¹⁵. To understand whether a similar factor should be applied to optical potentials based on effective interactions requiring an explicit approximation for exchange, we have examined the reduction of the folding potential from a nonlocal to a local form by extending the technique of Fiedeldey¹⁶, who studied the Perey-Buck transformation. We conclude¹⁷ that if the real potential is used in eq. (2) to eliminate the momentum dependence, then an effective mass factor should multiply the imaginary potential; the correct factor depends on the radial and exchange structure of the interaction, and is calculated along with the optical potential. On the other hand, if the potential V_{nuc} in eq. (2) is the full, complex optical potential, which yields a complex wave number, no effective-mass correction is required. The near equivalence of these two procedures has been verified by calculation. The consequence of either approach is a reduction of the imaginary-potential volume integral by 20-30%, and a slight shift in the shape of the imaginary potential toward a more surface-peaked form, which is in the direction of improved agreement with phenomenological potentials. Extending the same derivation to reactions (i.e., inelastic scattering and charge exchange) shows that no effective-mass corrections should be made to the DWBA form factor, but that the initial- and final-state wave functions should each be multiplied by a Perey factor, which is just the square root of the momentum-dependent effective-mass

Figure 1

Figure 2

factor $\sqrt{m_k/m}$. The Perey factors, which are typically in the range 0.8-0.85, reduce the reaction cross section by 20-30%, and thus should be included when consistency between elastic scattering and reactions is sought.

III. ELASTIC SCATTERING

Fig. 1 shows calculations with the Brieva-Rook interaction of proton and neutron elastic scattering from ^{208}Pb , and Fig. 2 shows the corresponding normalizing coefficients. The sources of the data are listed in Ref. 7. The dashed curves were calculated with a neutron density proportional to the proton density¹⁸. The solid curves, calculated with a neutron density inferred from 800-MeV neutron scattering¹⁹, show that low-energy nucleon scattering is sensitive to small differences in the shape of the densities (in this case, to the slope of the density in the surface region). The normalizing parameters show that consistency between neutron and proton scattering is achieved only if Method I is used for evaluating the energy dependence of the interaction; in Method II this energy dependence is measured from the Fermi surface, whereas in Method I the substitution $E + E - V_{\text{Coul}}$ is used. Angular distributions calculated with the JLM and Yamaguchi et al. potentials are very similar, and are not shown; however, the normalizing coefficients are shown in Figs. 3 and 4. Consistency between neutron and proton scattering is achieved in the JLM calculations if the Coulomb correction (CC) suggested by JLM is applied only to the real part of the proton potentials. Calculations with the Yamaguchi et al. interaction

Figure 3

Figure 4

were made only with Method I. We note that the real normalizing factors for all three interactions are within $\approx 10\%$ of unity. On the other hand, the imaginary factors show a systematic decrease with decreasing energy below 30 MeV, which may reflect the inability of nuclear-matter based potentials to account for the lowered density of states at low energies near a doubly-magic nucleus. Neutron analyzing-power data²⁰ are compared with calculations using the BBML² spin-orbit interaction and the JLM and Brieva-Rook central potentials in Fig. 5; the agreement is excellent in both cases.

Results of a similar study⁸ of the Brieva-Rook and JLM potentials for a medium-weight nucleus (^{54}Fe) are shown in Figs. 6-10. Only the neutron data^{8,21-23} are shown; the 24-MeV analyzing-power data are for natural Fe, and were analyzed as ^{56}Fe . The JLM potentials yield a better reproduction of the angular distributions and less energy dependence in the normalizing parameters than the Brieva-Rook. By examination of the q -space behavior of the potentials, we have concluded⁸ that the systematic overshoot of the low-angle cross sections and the total cross sections with the Brieva-Rook potentials is correlated with an anomalous "bump" at the nuclear surface in the real potential; as will be shown below, this feature is absent in optical potentials generated from the interaction of Yamaguchi et al., which is also based on the Hamada-Johnston potential.

As a further systematic test of the mass dependence of the potentials, angular distributions of 14.6-MeV elastically scattered neutrons have been measured on a series of targets from $A = 9$ to 209, and compared with the scattering calculated from the

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Brieva-Rook and JLM potentials²⁴. The results from $A = 9$ to 59, shown in Fig. 11, illustrate the worsening of the agreement with decreasing target mass at both forward and backward angles for the Brieva-Rook potentials, whereas the JLM potentials yield reasonable agreement for nuclei as light as ^{12}C . The poorer agreement for ^9Be is probably due largely to the spin (3/2) of this nucleus, which allows the probe to sense the nuclear deformation directly in a one-step process.

The JLM potentials have proven to yield quite stable results for the light nuclei. Proton and neutron scattering from ^{12}C , ^{13}C , ^{14}C , and ^{16}O in the range 20-50 MeV appears to be consistent with constant real and imaginary normalizing parameters of 1.0 and 0.8, respectively. Figs. 12 and 13 show comparisons with angular distributions for neutron²⁵ and proton²⁶ scattering on ^{12}C . We note the well-known difficulty of reproducing the back-angle behavior of proton-scattering data on $A=4N$ nuclei. Nevertheless, the JLM potentials yield agreement with the data that is at least as good as obtained²⁸ with the phenomenological proton potential of Fabrici et al.²⁷, who have made a systematic study of proton scattering on light nuclei. Calculations with the Brieva-Rook interaction are compared with neutron scattering, while results with the Yamaguchi et al. interaction are shown for the proton data. The interaction of Yamaguchi et al. yields results that are qualitatively very similar to those for JLM; however, the imaginary normalization is rather small (≈ 0.5).

As a final example, Fig. 14 shows neutron total cross sections for ^{140}Ce in the range 4-60 MeV, compared with

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

calculations using the Brieva-Rook and JLM potentials. The total cross sections with the Brieva-Rook interaction are systematically high over the entire energy range, whereas reasonable agreement with the JLM potentials is obtainable with only slight, energy-independent normalizations.

To illuminate partially the different results obtained with the various interactions, the real and imaginary central potentials calculated with each of the interactions are shown in Fig. 15 for 30 MeV neutron scattering on ^{208}Pb . The differences between the potentials are quite pronounced, with the JLM resembling most closely the phenomenological forms. The absence of the surface anomaly in the Yamaguchi et al. potential suggests that this feature of the Brieva-Rook potential is associated with the treatment of the many-body problem, rather than an intrinsic feature of the underlying Hamada-Johnston interaction. We also note that the Yamaguchi et al. imaginary potential appears to be insufficiently damped in the nuclear interior.

IV. CHARGE EXCHANGE

Two apparent problems arise in applying the folding model to the (p,n) reaction to isobaric-analog states. The first is that the Q-value, which is large in heavy nuclei, seems to render ambiguous the choice of energy at which the quantities in the form factor are evaluated. The second concerns the use of the Fermi energy as the basis for evaluating the energy dependence of the effective interaction. In the present case, there are two Fermi energies, corresponding closely to the lowest $T-1/2$ and $T+1/2$ levels in the compound system; these are separated by a symmetry energy Δ_{ef} , which is similar in magnitude to the Coulomb displacement energy (or $-Q$).

We have investigated¹⁷ these problems by writing the (p,n) reaction in nonlocal, coupled isospin channels, requiring isospin conservation for the nuclear interaction, identifying the potential functions that appear with quantities calculated in a folding model, and then making the usual local-momentum approximation for exchange. This procedure fully prescribes the energy dependence. In a heavy nucleus, we find that the form factor is proportional to the difference of proton-target and neutron-target optical potentials $U_p(E_p, k_p) - U_n(E_n, k_n)$. In this expression, the E 's represent the energy at which the interaction is to be evaluated; E_p is the incident proton energy, and $E_n = E_p - \Delta_{\text{ef}}$. The local momenta k_p and k_n correspond to proton and neutron elastic scattering with incident energies E_p and $E_p + Q$, respectively. If the effective interaction were independent of energy, this procedure would correspond closely to that of Brieva and Lovas³⁰; however, the energy dependence induces an extra contribution to the form factor, whose form is that of an isoscalar density folded with the difference of isoscalar effective interactions evaluated at E_p and E_n .

We have calculated the (p,n) charge-exchange reaction to the isobaric-analog state in the reaction $^{208}\text{Pb}(p,n)^{208}\text{Bi}$ using

the DWBA. Results with the Brieva-Rook and JLM interactions are compared with data³¹ at 25, 35, and 45 MeV incident energy in Figs. 16 and 17. The experimentally-determined proton and neutron densities underlying these calculations are the same as those used earlier for elastic scattering.

The solid curves in Fig. 16 represent a fully self-consistent treatment using the Brieva-Rook interaction, whereas the dashed curve was calculated with the microscopic form factor, but with phenomenological distorting potentials³². It is clear that the goal of a satisfactory self-consistent calculation has not been attained. However, the reasonable agreement when the phenomenological distortion is used suggests that the main problems may lie with the details of the effective interaction (e.g., distorting effects of the potential-surface anomaly), rather than with the approach.

Self-consistent calculations with the JLM interaction are shown in Fig. 17. The form factors were obtained by subtracting proton and neutron potentials at incident energies separated by $\Delta\epsilon_F$. For consistency with the results of Fig. 3, a Coulomb correction was applied only to the real part of the proton potential. Although the angular-distribution structure is reproduced, the calculations are deficient in magnitude by a factor typically in the range 4-6. The origin of a discrepancy in magnitude with a similar calculation in Ref. 11 is not understood.

The problems in reproducing the magnitude of the (p,n) reaction focus attention on the fact that the ratio of real isovector to isoscalar terms in the nuclear-matter based microscopic optical potentials is significantly smaller than that

Figure 16

Figure 17

found in phenomenological potentials and effective interactions. The ratio is density dependent, and decreases with increasing density for all interactions tested. To illustrate this, we have calculated the real potentials for 30-MeV neutron scattering on ^{208}Pb , parametrized them as $V = -V_0 + V_1(N-Z)/A$, and find the following results for the ratio V_1/V_0 near the origin and at 7 fm, which is approximately half maximum density:

	R = 0 fm	R = 7 fm
Brieva-Rook	0.21	0.33
Yamaguchi et al.	0.28	0.37
JLM	0.19	0.24

As examples of phenomenological results, $V_1/V_0 = 0.5$ for the Becchetti-Greenlees potential³³, and for the empirical interaction of Austin¹, $v_\tau/v_0 = 0.54$. The discrepancy in the magnitude of the cross sections calculated with the JLM potentials is very likely to be correlated with the very low isovector strength shown above, and the systematically small values of the ratio raise the question as to whether the nuclear-matter approach can yield an accurate description of the isovector interaction.

V. INELASTIC SCATTERING

We show examples of self-consistent inelastic scattering calculations for the first 2^+ level in ^{54}Fe ($E_x = 1.41$ MeV), and the first 3^- levels in ^{208}Pb (2.62 MeV) and 160 (6.13 MeV). Further details of the calculational techniques that are specific to inelastic scattering may be found in Refs. 34,35.

Calculations³⁶ with the Brieva-Rook interaction for neutron and proton scattering are compared with data^{36,37} in Figs. 18 and 19. The proton transition density was a Tassie-model form, normalized to the $B(E2)$ determined from Coulomb excitation³⁸. The solid curves show the excellent agreement obtained with a neutron transition density 0.8 times that for protons, which is in accord with the core-polarization model of Brown and Madsen³⁹. The dashed curve in Fig. 19, calculated with the hydrodynamic assumption (N/Z) for the ratio of neutron to proton transition densities, is clearly inconsistent with the combined study of neutron and proton scattering.

Fig. 20 shows calculations using the Brieva-Rook and JLM interactions in comparison with data for neutron⁴⁰ and proton^{41,42} scattering to the first 3^- state of ^{208}Pb . The proton and neutron transition densities were taken from analyses of electron⁴³ and 800-MeV proton⁴⁴ scattering measurements, respectively. The 61.4-MeV proton data are acceptably reproduced with both interactions. It should be noted that the neutron/proton transition-density ratio is 1.73, which is slightly larger than the hydrodynamic value 1.54. The JLM results are in qualitative accord with a calculation¹¹ using theoretical (RPA) transition densities. On the other hand, the results at lower energies, where both proton and neutron data are available,

Figure 18

Figure 19

Figure 20

Figure 21

are much less satisfactory. Both interactions, particularly the Brieva-Rook, underpredict the forward cross sections. This characteristic of the Brieva-Rook calculations is reminiscent of that for the (p,n) reaction. Although the behavior of the calculations is similar for both protons and neutrons in the 20-25 MeV range, it is evident that in this nucleus no reliable conclusion may be drawn about the ratio of neutron to proton transition densities by comparison of neutron and proton probes with the interactions presently available in this energy range.

As a final example, Fig. 21 shows calculations with the JLM interaction for proton scattering^{4,5} near 25 and 40 MeV to the first 3⁻ level of ¹⁶⁰, using a transition density⁶ derived from electron scattering. Even though these parameter-free calculations are deficient at back angles, they are comparable in quality to phenomenological treatments.

VI. SUMMARY AND ACKNOWLEDGMENTS

The degree of success obtained in the systematic analyses of the previous sections shows that the folding-model approach with nuclear-matter based effective interactions is very useful, even though the results are not universally perfect. The model is quite successful in reproducing elastic-scattering differential cross sections and analyzing powers, particularly when the JLM interaction is used for the central potential. The model works well over a wide mass range, without requiring (or, in fact, allowing) arbitrary changes in geometrical parameters. The model provides a suitable framework for addressing the problems of Coulomb effects and the consistent treatment of elastic scattering and reactions, since the sources of energy dependence and of nonlocality in the reaction model are explicit. In some cases, such as the ⁵⁴Fe inelastic-scattering example, the model appears adequate for the extraction of spectroscopic information on neutron-proton transition density differences by comparison of neutron and proton scattering. On the negative side, there is significant variation of the predictions of the various effective interactions, even of those based on the same underlying nucleon-nucleon potential. The isovector spin-independent parts of the interactions appear to be too small, particularly for the JLM calculations, which otherwise are very successful.

Our conclusion from the present work is that the folding-model approach shows the promise of providing a self-consistent treatment of elastic scattering and reactions, and that efforts should be made to further refine the effective interactions. These efforts should include not only further development of theoretically-based interactions, such as those investigated here, but also the development and testing of phenomenological interactions guided by the features of the theoretical interactions that appear to be successful. Neutron-scattering data, in comparison with proton data, will continue to be of great importance in evaluating the isospin-dependent parts of these interactions.

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REFERENCES

1. S. M. Austin, in The (p,n) Reaction and the Nucleon-Nucleon Force, C. D. Goodman et al., eds., Plenum, N. Y., 1980, p. 203.
2. G. Bertsch, J. Borysowicz, H. McManus, and W. G. Love, Nucl. Phys. A284, 399 (1977).
3. F. A. Brieva and J. R. Rook, Nucl. Phys. A291, 299, 317 (1977); Yukawa parameterization of interaction by H. V. von Geramb.
4. L. Rikus, K. Nakano, and H. V. von Geramb, Nucl. Phys. A414, 413 (1984), and references therein.
5. N. Yamaguchi, S. Nagata, and T. Matsuda, Prog. Theor. Phys. (Japan) 70, 459 (1983).
6. J. P. Jeukenne, A. Lejeune, and C. Mahaux, Phys. Rev. C16, 80 (1977); A. Lejeune, Phys. Rev. C21, 1107 (1980).
7. F. S. Dietrich et al., Phys. Rev. Lett. 51, 1629 (1983).
8. S. H. Mellema, R. W. Finlay, F. S. Dietrich, and F. Petrovich, Phys. Rev. C28, 2267 (1983).
9. T. Hamada and I. D. Johnston, Nucl. Phys. 34, 382 (1962).
10. R. V. Reid, Ann. Phys. (N.Y.) 50, 411 (1968).
11. Ch. Lagrange and J. C. Brient, J. Phys. (Paris) 44, 27 (1983).
12. M. Lacombe et al., Phys. Rev. C21, 861 (1980).
13. F. A. Brieva and J. R. Rook, Nucl. Phys. A297, 206 (1978).
14. J. W. Negele and K. Yazaki, Phys. Rev. Lett. 47, 71 (1981).
15. S. Fantoni, B. L. Friman, and V. R. Pandharipande, Phys. Lett. 104B, 89 (1981).
16. H. Fiedeldey, Nucl. Phys. 77, 149 (1966).
17. F. S. Dietrich and F. Petrovich, to be published.
18. B. Frois et al., Phys. Rev. Lett. 38, 152 (1977).
19. G. W. Hoffmann et al., Phys. Rev. C21, 1488 (1980).
20. G. Bulski et al., Proc. Int. Conf. Nucl. Data, Antwerp, 1982; J. P. Delaroche et al., Phys. Rev. C28, 1410 (1983).
21. S. M. El-Kadi et al., Nucl. Phys. A390, 509 (1982).
22. C. E. Floyd in Polarization Phenomena in Nuclear Physics -- 1980, AIP Conf. Proc. No. 69, G. G. Ohlson et al., eds. (AIP, New York, 1981).
23. C. Wong, J. D. Anderson, J. W. McClure, and B. D. Walker, Phys. Rev. 128, 2339 (1962).
24. L. F. Hansen et al., to be published in Phys. Rev. C, Jan., 1985.

25. A. S. Meigooni, J. S. Petler, and R. W. Finlay, Phys. Med. Biol. 29, 643 (1984).
26. N. L. Back, F. S. Dietrich, I. Proctor, and J. Woodworth, to be published.
27. E. Fabrici et al., Phys. Rev. C21, 830 (1980).
28. N. L. Back, private communication.
29. H. C. Camarda, T. W. Phillips, and R. M. White, Phys. Rev. C29, 2106 (1984).
30. F. A. Brieva and R. G. Lovas, Nucl. Phys. A341, 377 (1980).
31. R. R. Doering, D. M. Patterson, and A. Galonsky, Phys. Rev. C12, 378 (1975).
32. D. M. Patterson, R. R. Doering, and A. Galonsky, Nucl. Phys. A263, 261 (1976).
33. F. D. Becchetti and G. W. Greenlees, Phys. Rev. 182, 1190 (1969).
34. F. Petrovich and W. G. Love, Nucl. Phys. A354, 499 (1981).
35. J. J. Kelly et al., Phys. Rev. Lett. 45, 2012 (1980).
36. S. H. Mellema, R. W. Finlay, F. S. Dietrich, and F. Petrovich, Phys. Rev. C29, 2385 (1984).
37. P. J. Van Hall et al., Nucl. Phys. A291, 63 (1977).
38. M. J. LeVine, E. K. Warburton, and D. Schwalm, Phys. Rev. C23, 244 (1981).
39. V. R. Brown and V. A. Madsen, Phys. Rev. C11, 1298 (1975), and V. A. Madsen, private communication.
40. R. W. Finlay et al., Phys. Rev. C30, 796 (1984).
41. J. Saudinos et al., Phys. Lett. 22, 492 (1966).
42. A. Scott, N. P. Mathur, and F. Petrovich, Nucl. Phys. A285, 222 (1977).
43. D. Goutte et al., Phys. Rev. Lett. 45, 1618 (1980).
44. L. Ray and G. W. Hoffmann, Phys. Rev. C27, 2133 (1983).
45. D. Bayer, thesis, Michigan State University (1971), unpublished.
46. J. J. Kelly, thesis, Massachusetts Institute of Technology (1981), unpublished.