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Comparison of quasifree $(p,2p)$ with (p,pn) scattering as a check of the impulse approximation

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It is shown that the ratio of the cross sections of quasifree $(p,2p)$ and (p,pn) reactions in complex nuclei for identical and suitable geometries can be reliably calculated in the distorted wave impulse approximation. A comparison with preliminary experimental results supports the validity of the impulse approximation for the medium energy scattering of nucleons.

[NUCLEAR REACTIONS $^{12}C(p,2p)$, (p,pn), $E=400$ MeV, checked DWIA.]

I. INTRODUCTION

The theory of quasifree knockout reactions represents probably the most direct application of the impulse approximation in medium energy scattering.[1-3] In fact, one of the first applications of this approximation was the description of knockout reactions,[4-6] and the expression "quasifree" characterizes[7] the basic meaning of the approximation.

As the impulse approximation is an essential ingredient of most theories of medium energy reactions, it is natural to attempt to check it experimentally in the special case of quasifree scattering by the comparison of calculated and measured cross sections. Many experimental investigations of $(p, 2p)$ and $(e, e'p)$ scattering (for reviews see for example Refs. 8 and 9) have confirmed the semiquantitative validity of the distorted wave impulse approximation (DWIA) for complex nuclei. It is, however, difficult to give from these results a convincing estimate of the error of the approximation, even in cases in which the uncertainty caused by the off-shell effects is expected to be negligible. The reason is that the magnitude of the cross sections in the mentioned reactions is sensitively dependent on the distortion of the wave functions of the proton(s) which traverse the nucleus. In particular, the imaginary part of the optical potentials, representing the multiple scattering, may reduce the quasifree cross section by an order of magnitude. It is evident that a relatively small change in the somewhat uncertain imaginary optical potentials may easily change the normalization of the cross section by any factor of the order 1. A good fit to an experimental result may therefore partly be due to a fortunate adjustment of the distorting potentials.

Recently, a meaningful and interesting check of the DWIA was published,[10] which consisted of measuring and calculating the quasifree cross section for the $2s$ state of ^{40}Ca in different geometries, but always keeping the momentum transfer equal to zero. In this way the variation of the distorted momentum distribution is minimized. The comparison of the observed and computed cross section ratios was quite favorable, but the variation of the calculated distorted momentum distribution, which suffers from the uncertainties mentioned above and enters directly in the ratios, was still by a factor of 2.

It is, therefore, of interest that there exist different quasifree processes which have, to a good approximation, equal distortions and which consequently differ almost only by the knockout process itself. Comparing such cases, one may to a large extent eliminate the uncertainty of the distortion and check whether and to which accuracy the differences in the matrix elements of the free collisions are reflected in the observed quasifree cross sections, as is predicted by the impulse approximation.

One such case is given by coplanar quasifree scattering with polarized protons.[11,12] If one neglects the spin-orbit distortion, which has been estimated to be small,[13] the distortion becomes independent of the polarization of the incoming proton. On the other hand, in suitably selected cases the nuclear proton, which is knocked out, can be strongly polarized. In such a case the matrix element of the corresponding free collision is, in general, heavily dependent on the polarization of the incoming proton. The measurement of this polarization dependence has been initiated recently[14-17] and may in the foreseeable future lead to a better knowledge of the quantitative validity of the impulse approximation.

The main point of the mentioned comparison is that different measurements are made (by changing the polarization) in a single kinematical situation.

It is the purpose of the present paper to investigate another case in which a similar situation occurs, namely the one in which not the spin, but the isotopic spin is varied. In particular, we shall compare quasifree $(p, 2p)$ and (p, pn) processes in nuclei with $T=0$, for example, the reactions $^{12}C(p, 2p)^{11}B$ and $^{12}C(p, pn)^{11}C$. These processes have recently been measured and analyzed by a TRIUMF group.[16] Their preliminary analysis seems to indicate deviations by nearly a factor of 2 from the impulse approximation. Such deviations would cast serious doubt on the basis of calculations and conclusions made in the past for quasifree scattering and other medium energy processes. It is, therefore, desirable to study the mentioned knockout processes, and this is the purpose of the present paper.

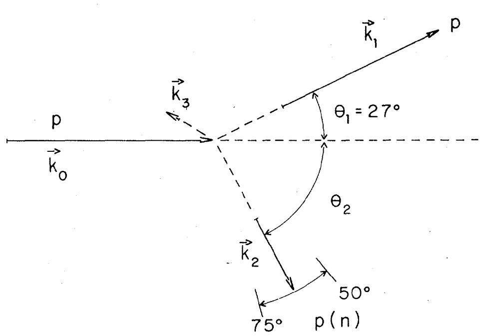
Section II describes the way in which the $(p, 2p)$ and (p, pn) processes may be compared. The sizes of the main corrections are calculated in Sec. III and the TRIUMF results are analyzed in Sec. IV. Finally, some concluding remarks are made.

II. COMPARISON OF $(p,2p)$ WITH (p,pn) CROSS SECTIONS

The cross section for quasifree scattering in the DWIA is given by[7-9]

$$\frac{d^3\sigma}{d\Omega_1 d\Omega_2 dE} = \left(\frac{4}{\hbar^2 c^2}\right)\left(\frac{k_1 k_2 \overline{E}_0^2}{k_0 E_3}\right) \times |g'|^2 \frac{d\sigma_{\text{free}}}{d\overline{\Omega}}(\overline{E}_0, \overline{\theta}, P_{\text{eff}}), \tag{1}$$

where $|g'|^2$ is the distorted momentum distribution; the indices 0, 1, and 2 refer to the incoming and the two emerging nucleons, respectively, and 3 refers to the nuclear nucleon (as in Fig. 1). The free cross section $(d\sigma_{\text{free}}/d\overline{\Omega})$ is taken at energy $\overline{E}_0$, angle $\overline{\theta}$, all quantities being defined in the center of mass system corresponding to the



RATIOS OF CROSS SECTIONS

FIG. 1. The geometry of the quasifree scattering process considered in Sec. III.

quasifree collision. In the derivation of this formula, besides the impulse approximation for the scattering matrix element of the knockout process, the factorization assumption has also been used. This means essentially that a fixed (average) value of the nucleon-nucleon matrix element is taken, in spite of the fact that, because of the distortion, the momentum and energy values of the nucleon-nucleon collision in the nucleus have a certain spread around the asymptotic ones. For nucleon-nucleon quasifree reactions at a few hundreds of MeV the factorization is expected to be a good approximation, as long as one avoids momentum regions of the cross section distributions which are mainly made up of multiple scattered nucleons. These are the regions where the undistorted momentum distributions vanish or are small as, for example, for zero momenta in $l \neq 0$ knockouts or on the high momentum tails. This is an important restriction which will come up again when we analyze the available experimental data.

As the nuclear proton is, in general, effectively polarized[7] by the nuclear spin-orbit coupling before it is knocked out, the free cross section in formula (1) is to be taken according to the expression[18]

$$\frac{d\sigma_{\text{free}}}{d\overline{\Omega}}(\overline{E}_0, \overline{\theta}, P_{\text{eff}}) = \frac{d\sigma_{\text{free}}}{d\overline{\Omega}}(\overline{E}_0, \overline{\theta}, 0) \times [1 + P_{\text{eff}} P(\theta)], \tag{2}$$

where we have assumed that the incoming beam is unpolarized.

It is well known that the value to be taken for this cross section is somewhat uncertain, as the binding of the nuclear proton causes the knockout process to have a kinematics which cannot exactly occur in any free process. This "off-shellness" will be discussed in Sec. III.

As was remarked in the Introduction, the main uncertainty in the calculation of formula (1) is contained in the factor $|g'|^2$, the distorted momentum distribution. We shall consider $(p, 2p)$ and (p, pn) knockout processes on a $T=0$ nucleus leading to final states which are each other's mirror image in isospace. In this case one expects the two $|g'|^2$'s to be about equal and one might therefore think of canceling the uncertainty of this factor by taking the ratio of the two cross sections for identical geometries to obtain

$$\frac{\dfrac{d^3\sigma}{d\Omega_1 d\Omega_2 dE}(p, 2p)}{\dfrac{d^3\sigma}{d\Omega_1 d\Omega_2 dE}(p, pn)} = \frac{\dfrac{d\sigma_{\text{free}}}{d\overline{\Omega}}(p, 2p)}{\dfrac{d\sigma_{\text{free}}}{d\overline{\Omega}}(p, pn)} C(E, \theta), \tag{3}$$

where

$$C(E,\theta)=\frac{|g_p'|^2}{|g_n'|^2}\frac{(k_1\bar{E}_0^2/E_3)_{(p,2p)}}{(k_1\bar{E}_0^2/E_3)_{(p,pn)}} .$$

Equation (3), therefore, expresses that the quasifree cross sections should have the ratio of the corresponding free ones up to the correction factor $C(E,\theta)$, which is nearly 1. In this comparison, the earlier mentioned regions where the undistorted momentum distributions are very small should be avoided. If a sufficiently accurate estimate of the factor $C(E,\theta)$ could be made, expression (3) would allow a direct check on the impulse approximation. One of the difficulties of Eq. (3) is caused by off-shell effects, which introduce an uncertainty in the matrix elements to be taken for the free cross sections.

The main reasons why $C(E,\theta)$ in Eq. (3) is not exactly equal to one are the following:

(a) The difference in kinematical factors, because of the difference in proton and neutron separation energies and the freedom of choosing the "corresponding" free cross sections.

(b) The influence of the differences in the optical potentials for the $(p,2p)$ and (p,pn) processes, because of the different residual nuclei. Here enters also the slight variation of the asymptotic momenta caused by the different separation energies.

(c) The difference in the nuclear wave functions, entering through $|g'|^2$, because of the Coulomb force, which is responsible for the difference in binding energy. In Sec. III we shall investigate the size of these corrections in a specific example.

In the spirit of the DWIA, we have neglected higher order processes which through excited intermediate nuclear states lead to the considered one hole final state. One might, in particular, worry over the effect of the charge exchange of an emerging particle, which may transform a $(p,2p)$ process into a (p,pn) one and vice versa. Such processes have been discussed as the explanation for an unexpected yield distribution in pion carbon reactions at resonance energy. In our case, to result in the selected final hole state the charge exchange after a knockout process could, in lowest order and in the single particle model, only take place with one of the nucleons in the considered final hole state. This should occur in such a way that this nucleon after the charge exchange just fills up the hole of the original knockout process. These would seem to be very unlikely events. Furthermore, these processes would tend to equalize the $(p,2p)$ and (p,pn) yields, and their total effect is therefore proportional to the relative difference of the two quasifree cross sections, which turn out to be nearly equal under the conditions we consider. We therefore believe that we can safely neglect the charge exchange, although we have not made a numerical estimate of it.

III. ESTIMATES OF THE CORRECTIONS

To calculate the various corrections which cause $C(E,\theta)$ in Eq. (3) to deviate from unity, we take the concrete example of the measured reactions $^{12}C(p,2p)^{11}B$ and $^{12}C(p,pn)^{11}C$ leading to the $\frac{3}{2}^-$ grounds states of ^{11}B and ^{11}C. The incoming proton energy is 400 MeV and the geometry is sketched in Fig. 1. The kinetic energy of the outgoing nucleon 2 is varied in the range between 78 and 108 MeV.

The calculations, including the one of the effective polarization of the nuclear proton, have been performed in the WKB approximation. As the corrections turn out to be small, this approximation should be sufficiently accurate, although some values of the energy T_2 are on the low side. For the distortions we have used square well central potentials. Again, because the corrections will be small, their model dependence should be unimportant. The values of the potentials were calculated from the forward nucleon-nucleon scattering amplitudes[19] and are given in Fig. 2.

(a) Off-shell and kinematical factor effects. We have estimated the off-shell effects by taking the on-shell matrix elements for the free collision, calculated for two extreme cases. In one case we took the free process as being the Lorentz transform of a process which has the actual angles occurring in the quasifree reaction, and in which the final kinetic energies are given by T_1 and T_2. In

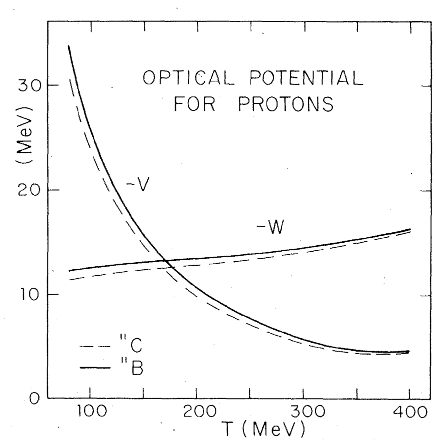


FIG. 2. Values for the (central square well) optical proton potentials $V + iW$ used, calculated following Ref. 19.

the other case the same angles were taken, but the event was defined by the kinetic energies T_0 and the one of the nuclear nucleon:

$$T_3 = [\hbar^2 c^2 (k_1 + k_2 - k_0)^2 + M^2 c^4]^{1/2} - Mc^2 .$$

In nearly all published calculations known to us (see for instance Ref. 20) in which off-shell matrix elements have been extrapolated with the help of various models, cross section values have been found which differ from the "initial prescription" less than the values following from the "final prescription." We therefore believe that the difference of these cross sections multiplied with the corresponding kinematical factors is a reasonable upper limit for the off-shell effects.

In the curves showing our final results (Fig. 6 and Fig. 7) we have indicated this maximum uncertainty by the width of the curves. To achieve this maximum in the ratio of the cross sections (Fig. 7) it was often necessary to take for one of the processes the initial prescription and for the other one the final prescription. Essentially, because the incoming momentum is so much larger than the considered nuclear momenta, the off-shell effects are small.

(b) The effect of the difference in the distortion. If the initial nucleus with $T=0$ would really generate the optical potentials, the proton and neutron distortions would be equal, up to a very small Coulomb effect. However, the optical potentials felt by the incoming and the two emerging particles are for the (p,pn) and $(p,2p)$ case generated by different residual nuclei ^{11}C and ^{11}B. In the present approximation this is also true for the incoming particles, because the scattering on the nucleon to be knocked out in ^{12}C is already taken into account by the explicitly calculated knockout process. On the other hand, the emerging neutron in the (p,pn) reaction feels, because of isospin invariance, the same potential as the corresponding proton in the $(p,2p)$ reaction. Therefore, only the incoming and one outgoing proton suffer the effects of different potentials.

We first give a semiquantitative estimate of the size of this effect. Because the effect of the strongly absorbing imaginary optical potentials dominates over the effect of the real ones, it is clear that we only need to consider the differences in the imaginary potentials.

For our square well potentials, the absorptions may be defined by the mean free paths, given by

$$\lambda = 1/\bar{\sigma}\gamma\rho , \qquad (4)$$

in which λ is the mean free path, $\bar{\sigma}$ is the average total proton-nucleon cross section, $\gamma = 1 - \frac{7}{5}\epsilon_F/T$ is the correction factor for the Pauli principle, and ρ is the average nuclear density. For the two residual nuclei ^{11}C and ^{11}B the average proton cross sections are

$$\bar{\sigma}(^{11}C) = \frac{6\sigma_{pp} + 5\sigma_{pn}}{11}$$

and (5)

$$\bar{\sigma}(^{11}B) = \frac{5\sigma_{pp} + 6\sigma_{pn}}{11} ,$$

where the σ's are the free total cross sections. The ratios of the proton absorbing potentials are therefore

$$\frac{W(^{11}C)}{W(^{11}B)} \approx \frac{\bar{\sigma}(^{11}C)}{\bar{\sigma}(^{11}B)} \approx 1 + \frac{\sigma_{pp} - \sigma_{pn}}{11\bar{\sigma}(^{11}B)} \approx 1 - 0.04. \qquad (6)$$

As an upper limit one may take the total proton path equal to the nuclear diameter, which is equal to about two mean free paths. The resulting change in the cross section ratio is for this case

$$e^{-2(1-0.04)}/e^{-2} = e^{0.08} \approx 1.08.$$

Explicit calculations of the distorted momentum distributions using optical potentials relevant for the incoming and emerging particles have confirmed this (over) estimate. An example is shown in Fig. 3, where we have used the optical potentials of Fig. 2. We conclude that also the effect of the different residual nuclei is quite small and can therefore to a good approximation be corrected for.

(c) The difference of the proton and neutron single particle wave functions caused by the Coulomb interaction. This effect might on first sight appear to be the most important one to cause $C(E,\theta)$ in Eq. (3) to differ from unity. The point is that, because of the strong absorption, the quasifree processes mainly take place at the nuclear surface, which means that the magnitudes

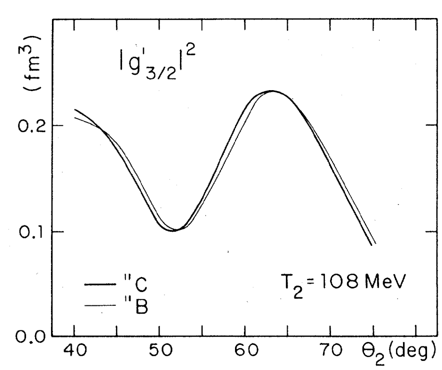


FIG. 3. An example of distorted momentum distributions for the reactions $^{12}C(p,pn)^{11}C$ and $^{12}C(p,2p)^{11}B$. To show the effect of the different residual nuclei, only the optical potentials have been taken different, not the asymptotic momenta.

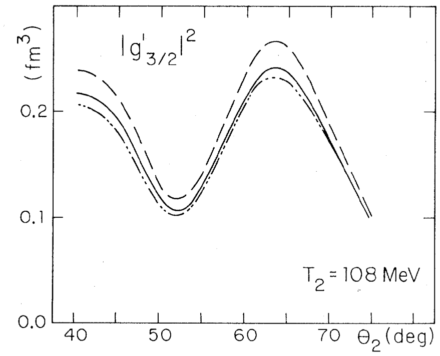


FIG. 4. Distorted proton momentum distributions for single particle wave functions generated by a square well giving the experimental proton binding energy (dashed curve), by a square well giving the neutron binding energy (dashed-dotted curve), and by the same well plus Coulomb potential, giving again the proton binding energy (full curve).

of the exponential tails of the nuclear single particle wave functions are essential. In addition, in practice only the distribution of rather low momentum components is observed, which is influenced in the same sense by the effect on the wave function of the binding energy. The dashed lines of Fig. 4 show the distorted momentum distributions [always for the actual $(p, 2p)$ kinematics] of $P_{3/2}$ wave functions, generated by square well potentials of the same radius $R = 3.12$ fm and values -43.4 and -47.1 MeV, adjusted to give the observed proton and neutron binding energies of 16 and 19 MeV, respectively. Clearly, the resulting difference is not insignificant.

The situation is greatly improved by the fact, already known for isospin analog states of heavy nuclei, that the soft Coulomb force does not easily change a wave function generated by strong interactions. It is namely more realistic to obtain the observed difference of the proton and neutron separation energy, not by changing the depth of the shell model potential, but by adding the average nuclear Coulomb potential. As a result, the tail of the Coulomb potential outside the strong potential will depress the tail of the wave function, counteracting the effect of the decrease in binding energy. The full curve of Fig. 4 is the distorted proton momentum distribution corresponding to the neutron shell model potential with the average nuclear Coulomb potential added. We remark that the computer solution of the corresponding eigenvalue problem which generated our wave function gave also a quite good value for the difference of the separation energies for the proton and the neutron.

It is clear that the total effect of the Coulomb potential on the wave function is small and, in fact, one does very well by simply taking the neutron shell model potential also for the calculation of the proton wave function. It appears that factor $C(E, \theta)$ in Eq. (3) is quite near to one and that it consequently can be calculated up to a small relative error. In Sec. IV we compare Eq. (3) with measurements recently made by the TRIUMF group.

IV. COMPARISON WITH EXPERIMENT

In this section we shall compare expression (3) with the experimental results for the quasifree $^{12}C(p, 2p)^{11}B$ and $^{12}C(p, pn)^{11}C$ reactions, obtained by the TRIUMF group[16,17] with 400 MeV incoming protons. We shall use the WKB approximation for the distorted waves, which is expected to be reasonably good for the energies involve. Anyhow, in the comparison the errors in the distortion will to a high degree cancel.

First we compute the separate cross sections according to expression (1). For this the free cross sections of Eq. (2) for unpolarized incoming protons but polarized target nucleons are needed.

The quantities $(d\sigma_{\mathrm{free}}/d\bar{\Omega})$ and $P(\theta)$ have been computed using and slightly extrapolating the phase shifts of Ref. 21. The results were checked by comparing them with a good part of the large body of existing experimental data for (p, p) and (p, n) scattering at laboratory values between 150 and 450 MeV. In all cases we obtained a good fit.

The effective polarization of the target nucleon, which is of course dependent on the kinematics of the quasifree process, was computed as in Ref. 11. Some typical results for neutron $P_{3/2}$ wave functions are shown in Fig. 5. As we found in Sec. III, these values should, to a good approximation, also be valid for the $P_{3/2}$ protons. Because the $\frac{3}{2}$ states are involved, the theoretical maximum value[22] of the effective polarization is $\frac{1}{2}$ and the calculated curves are not very much lower than this

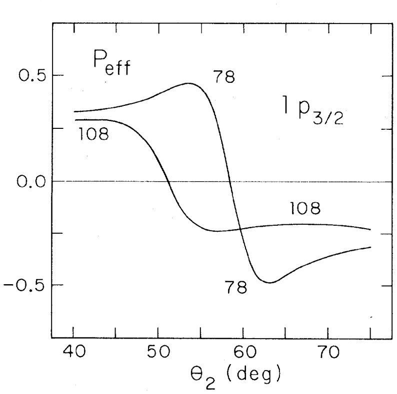


FIG. 5. The effective polarizations for the geometry of Fig. 1 with $T_2 = 78$ and 108 MeV.

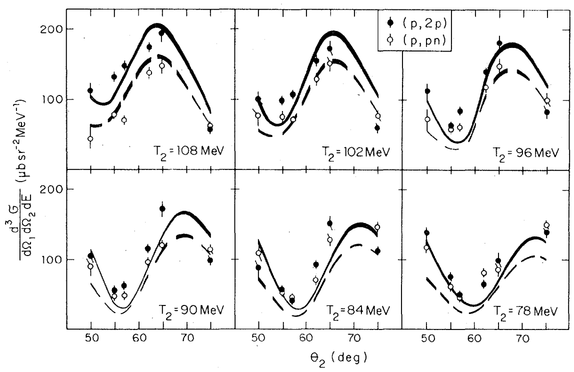


FIG. 6. The preliminary results of the TRIUMF experiment, together with our calculated curves. The widths of these curves are a measure of the off-shell uncertainty.

value. As typical values for $P(\overline{\theta})$ and also for the effective polarization are $\frac{1}{3}$, one sees from expression (2) that the cross sections are affected by about 10%. In the ratio of the cross sections the effect is mostly smaller, because the functions $P(\overline{\theta})$ for (p,p) and (p,n) scattering tend to have in our case the same sign and comparable magnitudes.

The data points for various geometries of the TRIUMF experiment are shown in Fig. 6. This figure also shows the results of our calculations. The experimental results are given in an arbitrary unit and, therefore, the absolute fit with our curves is accidental. It is clear that our distortions do not always fill up sufficiently the minima of the undistorted p-wave distributions. As was mentioned earlier, the widths of the curves in this figure and in Fig. 7 correspond to the uncertainty caused by off-shell effects.

More meaningful than Fig. 6 is the comparison according to expression (3) of the ratios of experimental quasifree and free cross sections times $C(E,\theta)$, which should be equal. This comparison is made in Fig. 7. In particular, at 62° and 65°, which is near to the maximum of the momentum distribution, the ratios of quasifree and free cross sections are equal to a quite satisfactory degree. At the angles where the undistorted momentum distributions are small there are differences, but, as we remarked earlier, it is to be expected that in such regions the impulse approximation and factorization are not good approximations. At present we have no definite explanation for the differences at the three lowest energies points at 75°.

In Fig. 7 we have also indicated that ratios of the free cross sections, without the correction factor $C(E,\theta)$. Clearly, the correction is not large and therefore its model dependence should be unimportant. One might wonder why the off-shell widths of the corrected ratios are larger than those of the uncorrected free cross section ratios. The reason is that to each (initial or final state) prescription, one has to take the corresponding kinematical factor in the quasifree cross section formula. It turns out that these factors enlarge the difference. In other words, the squares of the matrix elements (which are the quantities really entering in the quasifree cross sections) have a larger variation than their pro-

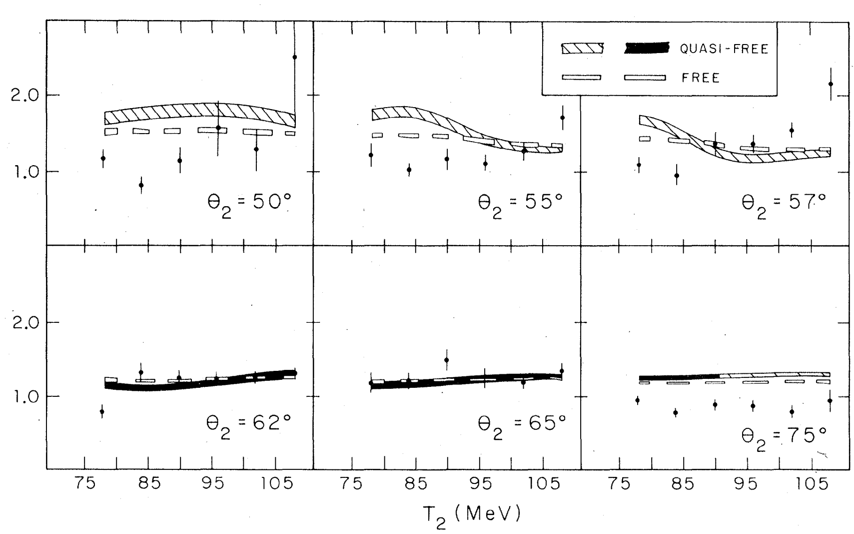


FIG. 7. Preliminary experimental and theoretical ratios of $(p,2p)$ to (p,pn) cross sections; the curves give our calculated values and are full where the geometry is such that they are meaningful. The free cross section ratios are shown by open rectangles. The widths of the curves and rectangles reflect their off-shell uncertainty.

duct with the kinematical factors which equals the free cross section.

V. CONCLUDING REMARKS

The results indicate that the impulse approximations is quite good for our case. Deviations of calculated and preliminary measured cross section ratios occur mainly in regions where Eq. (3) is not applicable. Butfor a more certain and quantitative estimate it would be desirable to have definitive measurements on ^{12}C and on other nuclei as ^{16}O and ^{40}Ca, in particular, for the regions near the maxima of the momentum distributions. The use of a polarized beam would add a dimension to the analysis.

As was remarked in the Introduction the preliminary analysis[16] of the TRIUMF group gave a considerable deviation of the free and quasifree cross sections. We do not yet quite understand this difference with our results.

Finally, it has to be said that the impression one obtains only on the basis of the present comparison may be too optimistic. The impulse approximation may contain errors which (also) cancel in the cross section ratios. An example is the effect of short range correlations. These will cause knockout processes to lead with a certain probability to two or more particle excitations, at the cost of the quasifree cross section. The resulting reduction factor represents an error in the impulse approximation but cancels in the comparison which we have made. These questions merit a separate investigation; anyhow, the comparison discussed in the present paper is able to considerably narrow down the uncertainties of the approximation.

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[1]G. F. Chew, Phys. Rev. 80, 196 (1950).
[2]G. F. Chew and M. L. Goldberger, Phys. Rev. 87, 778 (1952).
[3]K. M. Watson, Phys. Rev. 89, 575 (1953).
[4]O. Chamberlain and E. Segrè, Phys. Rev. 87, 81 (1952).
[5]J. B. Cladis, W. N. Hess, and B. J. Moyer, Phys. Rev. 87, 425 (1962).
[6]H. Tyrén, P. Hillman, and Th. A. J. Maris, Nucl. Phys. 7, 10 (1958).
[7]Th. A. J. Maris, Nucl. Phys. 9, 577 (1958/59).
[8]T. Berggren and H. Tyrén, Annu. Rev. Nucl. Sci. 16, 153 (1966).
[9]G. Jacob and Th. A. J. Maris, Rev. Mod. Phys. 38, 121 (1966); 45, 6 (1973).
[10]P. G. Roos, N. S. Chant, D. W. Devins, D. L. Friesel, W. P. Jones, A. C. Attard, R. S. Henderson, I. D. Svalbe, B. M. Spicer, V. C. Officer, and G. G. Shute, Phys. Rev. Lett. 40, 1439 (1978).
[11]G. Jacob, Th. A. J. Maris, C. Schneider, and M. R. Teodoro, Phys. Lett. B45, 171 (1973); Nucl. Phys. A257, 517 (1976).
[12]M. R. Teodoro, Ph.D. thesis, Universidade Federal do Rio Grande do Sul, 1976 (unpublished).
[13]C. Schneider, Nucl. Phys. A300, 313 (1978).
[14]V. S. Nadejdin, N. I, Petrov, V. I. Satarov; JINR Report No. E1-7559, Dubna, 1973 (unpublished); Yad. Fiz. 26, 230 (1977) [Sov. J. Nucl. Phys. 26 (2), 119 (1977)].
[15]P. Kitching, C. A. Miller, D. A. Hutcheon, A. N. James, W. J. McDonald, J. M. Cameron, W. C. Olsen, and G. Roy, Phys. Rev. Lett. 37, 1600 (1976).
[16]W. J. McDonald, D. M. Sheppard, J. M. Cameron, W. K. Dawson, P. Kitching, C. A. Miller, G. C. Neilson, W. C. Olsen, G. M. Stinson, D. A. Hutcheon, and J. G. Rogers, TRIUMF Progress Report No. 51, 1977 (unpublished).
[17]P. Kitching, private communication.
[18]L. Wolfenstein and I. Ashkin, Phys. Rev. 85, 947 (1952).
[19]A. K. Kerman, H. McManus and R. M. Thaler, Ann. Phys. (N. Y.) 8, 551 (1959).
[20]E. F. Redish, G. F. Stephenson, Jr., and G. M. Lerner, Phys. Rev. C 2, 1665 (1970).
[21]M. H. McGregor, R. A. Arndt, and R. M. Wright, Phys. Rev. 182, 1714 (1969).
[22]Th. A. J. Maris, M. R. Teodoro, and C. A. Z. Vasconcellos (unpublished).