THE CONTRIBUTION OF PICKUP CHANNELS TO THE HELION OPTICAL POTENTIAL

By A. M. Kobos*,** and R. S. Mackintosh

University of Oxford, Nuclear Physics Laboratory, Oxford

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The coupled reaction channel formalism has been employed to determine the contribution to the helion optical potential of strongly coupled alpha particle channels. The effect is large from 18 MeV to 51 MeV and probably to much higher energies. This result is important for *ab initio* calculations of helion (or alpha particle) optical potentials, or for the use of these projectiles in nuclear shape or size measurements, since the strong transfer contributions are peaked in the nuclear surface.

1. *Introduction*

In this paper we attempt to evaluate the contribution which strongly coupled alpha particle channels (i.e. ^{3}He, α processes) make to the helion optical potential. In order to do this we employ the coupled reaction channel, CRC, formalism [1–5] and a refitting procedure described [1] previously. The principle is similar to that used to determine the contribution of collective states to the optical potentials of various projectiles [6–8]. In Ref. [1] the CRC method was used to explore in some detail the nature of the "pickup contribution" (that is, the effect of strongly coupled deuteron channels) to proton scattering. More recently [5] we have shown that pickup channel coupling calculated with the CRC method readily gives a good fit to certain proton scattering data that could not be fitted with the normal optical potential. It is found that the pickup channels make a strong contribution to the absorptive part and also considerably modify the real part of the optical potential, especially in the surface, so that any deductions about nuclear sizes from folding models would be invalid[1] where the pickup channels are not included explicitly. In the present paper, we shall show that exactly the same is true for helion scattering, the effects being parallel in nearly all respects.

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* On leave from Institute of Nuclear Physics, Cracow, Poland.

** Present address: Instytut Fizyki Jądrowej, Radzikowskiego 152, 31-342 Kraków, Poland.

[1] The same is true where a calculation of the absorptive term is attempted.

In Section 2 we shall discuss the formal limitations of our form of the CRC formalism, but we wish to state our belief that what follows is sufficient evidence that coupling terms involving pickup channels make a very significant contribution to the helion optical potential to motivate the application of the more complete (and computationally difficult) theory to the problem. By the latter we mean a CRC theory including all non-orthogonality terms, and the finite range kernel *and* sufficient pickup states to get a reasonable representation of the effect. Should the present method prove to give sufficiently accurate cross sections, it will have the great advantage that it is fast enough to allow the fitting of cross sections with the inclusion of CRC effects simultaneously involving many transfer states. This is an essential part of the procedure [1] for calculating the pickup contribution to the helion OMP, but also is necessary if any attempt is made to use CRC effects to explain particular features of the data, as proved possible with protons [5].

We wish to emphasize the following points:

1. The truncation employed herein implies that we have a lower limit to the effect. The inclusion of larger numbers of states at high excitations does not cause cancellations (see Section 3).

2. The effect of pickup channels upon elastic scattering is the case where non-orthogonality effects are probably not too important (see Section 2). The effect might be large for (^{3}He, α) cross sections.

3. The use of the zero range approximation does not invalidate the result, as explained in Section 2.

4. Notwithstanding notes (2) and (3) above, we find a remarkable and consistent improvement to (^{3}He, α) cross sections. The improvement is *much* greater than that obtained by using the finite range DWBA code LOLA to improve the DWBA results (Section 3).

5. With regard to note (2) above, we have not attempted to evaluate the effects o deuteron channels which could give an additional contribution of comparable magnitude.

6. By studying cases with various nuclei and various energies, we have shown that the effects found cannot be due to fortuitous circumstances but are a consistent and general effect that appears to be large even for 80 MeV helions.

2. The CRC procedure

We have previously [1] described a procedure by which the "pickup contributions" to elastic scattering may be evaluated using the CRC formalism. For the present case, where helions are incident on a target $A(N, Z)$, among the outgoing channels are those corresponding to an alpha particle and states of an $(A-1)\,(N-1, Z)$ nucleus. It is the effect of these latter channels that we here consider explicitly. The effect of all other channels, collective states etc., are considered to be responsible for the remaining "background" absorption. The reasons, mentioned in general terms in the introduction, for giving this particular attention to the pickup contributions will become clear from the results of the calculations.

For any particular total angular momentum and parity (I, Π) there is a single incoming helion partial wave. For given (I, Π) the wavefunction then is assumed to have the form

$$\Psi^{(I,\pi)}(A+3) = \frac{1}{r_h} U_0^{(h)}(r_h)\varphi_0(A, \hat{r}_h) + \frac{1}{r_\alpha} \sum_i U_i^{(\alpha)}(r_\alpha)\varphi_i(A-1, \hat{r}_\alpha), \tag{1}$$

where the $U_i^{(\alpha)}(r_\alpha)$ correspond to outgoing α-particles only. The coupled equations by which $U_0^{(h)}$ and $U_i^{(\alpha)}$ are determined are those employed by Coker, Udagawa and Wolter [2], Mackintosh [1, 3] and many others in which the "non-orthogonality" terms are omitted, and based on a zero-range interaction. We shall address these points below. The essence of the method is as follows:

The CRC equations are solved with potentials which fit elastic scattering when $U^{(h)}$ and $U^{(\alpha)}$ are uncoupled. The resulting $U^{(h)}$ and $U^{(\alpha)}$ will be such that the helion elastic scattering fit is completely spoiled. The helion and (since it proves necessary) alpha particle optical potentials are then readjusted until the elastic scattering is fitted once more. The differences between the old and new optical potentials then constitute the transfer contribution to the optical potential. The chance of getting a unique potential depends upon the quality and character of the data, but judgement concerning this must depend upon the consistency of many such calculations. In our model, there is no coupling between the states of the $(A+1)$ nucleon α-channel nucleus.

Neglect of the non-orthogonality terms

In general, when a light ion, a, scatters from a nucleus A it will be coupled to pickup channels $(a+1)(A-1)$. Then exact calculations of non-orthogonality effects by Imanishi et al. [9] and by Cotanch [10] as well as arguments by Imanishi et al. [9] and Udagawa et al. [11] based on considerations of what terms can act in low order show that of the three coupled reactions involved, the $A(a, a)A$ scattering cross section, although strongly influenced by cross-channel coupling, is little affected by the non-orthogonality terms. The inclusion of these would give a slight increase in the effect. For our present purposes where there are many uncertainties in the pickup channel optical potential and in the coupling term this is quite acceptable. For the case of the $A(a, a+1)(A-1)$ and $(A-1)(a+1, a+1)(A-1)$ reactions, the angular distributions are in the published examples greatly modified by non-orthogonality terms. The result of all this is that it is permissable to calculate the effect of the coupling to pickup channels on elastic (including quasi-elastic [12] and inelastic [3]) scattering using the present simplified procedure.

Zero range approximation

In nearly all the numerical cases studied by Ohmura et al. [4] there is very litle difference between their finite range CRC and zero range CRC results. The results of Ref. [5] also point to the general suitability of the zero range approximation for the p-d case. For the (^{3}He, α) case, especially when not "well matched" [13] the situation is less clear. We have performed exact finite range calculations with the DWBA code LOLA and these give little improvement to the (^{3}He, α) fits although there are changes in the angular distributions. Using standard approximate procedures, the finite range effects were *larger* in magnitude than with exact calculations and did not give fits which were better than those calculated using zero range. We did not use these methods. In this regard, it may be observed that since these approximate methods involve the optical potentials, and since these are different for the coupled and uncoupled cases, the *changes* in finite range correction could have a larger effect on the transfer process than the coupling itself (although the effect on the elastic scattering is of lower order). This is not a problem, since insofar as we have succeeded in refitting the data, the effective potentials required for any coupled and uncoupled cases are the same: in one case it is the optical potential and in the coupled case it is the new optical potential plus the effective interaction induced by the coupled reaction channels. Since the *total* potentials are the "same" for CRC and DWBA calculations, the finite range correction that would be calculated using standard approximate methods is the same for each case.

3. *Calculated cases*

We discuss here the two cases which were studied in most detail. Some calculations at lower (18 MeV) and higher (82 MeV) energies support the general conclusions derived from these cases.

3.1. 37.7 MeV helions on ^{58}Ni

There are five strong and rather low-lying states in ^{57}Ni: 0.0 MeV ($3/2^-$), 0.77 MeV ($5/2^-$), 2.58 MeV ($7/2^-$), 5.23 MeV ($7/2^-$) and 5.58 MeV ($1/2^+$). We confined ourselves to these states; some justification of this will be found in section 3.3 where we discuss the l and Q-dependence of the channel coupling effects. Because of the restrictions of our CRC code we performed two CRC analyses each with 4 states in ^{57}Ni coupled to the helion channel:

(*i*) 0.0+0.77+2.58+5.58 MeV states (referred to as CRC4A hereafter),

(*ii*) 0.0+0.77+2.58+5.23 MeV states (referred to as CRC4B hereafter).

The CRC calculation with the original optical model potential of Urone et al. [14] gave a very poor fit to the helion elastic scattering data. The original alpha particle optical potential was that of Edwards, Kraushaar and Ridley [15] who performed a DWBA analysis of the ^{58}Ni(^{3}He, α) reaction at this energy. By modifying these potentials we were able to get a fit to the elastic helion scattering data which was nearly indistinguishable on a graph from the excellent original optical model fit of Urone et al. [14] as well as restoring the optical model total reaction cross-section. The optical model and refitted CRC potentials are compared in Table I.

For the CRC4A cases the helion potential is deeper and of greater radial extension than the OM potential and the absorption is reduced. The additional attractive component in the real potential balances the surface repulsive effect of the transfer states. There is also a repulsive effect in the spin-orbit potential. Moreover, the coupling appears to make necessary a deeper alpha particle potential. This is an effect which appears to increase with increasing energy. Although the helion potential volume integral J_h is increased

TABLE I

The reaction $^{58}Ni(^{3}He, \alpha)$ ^{57}Ni at 37.7 MeV. DWBA and CRC optical potential parameters

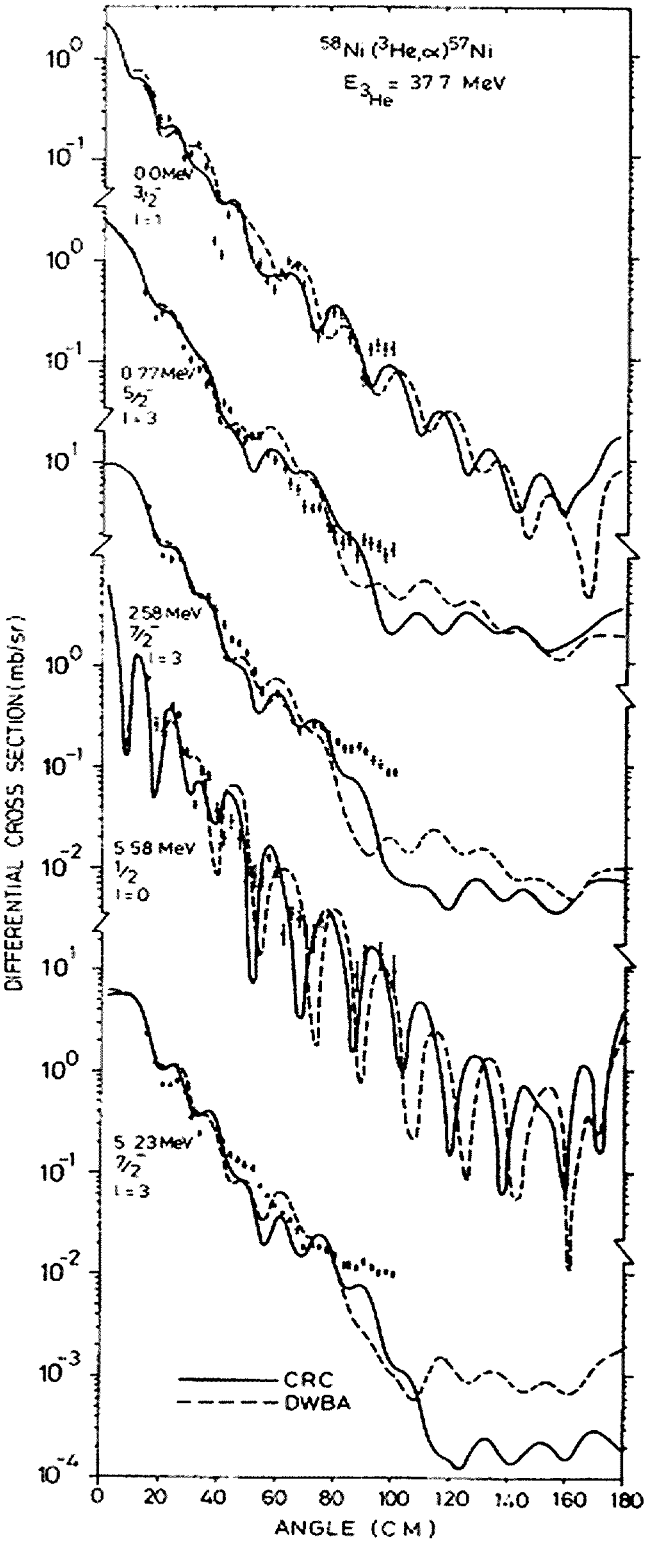
	U (MeV)	r_{ou} (fm)	a_u (fm)	W (MeV)	r_{ow} (fm)	a_w (fm)	U_{so} (MeV)	r_{so} (fm)	a_{so} (fm)	$\langle r^2\rangle^{1/2}$ (fm)	J_U MeV fm³
				Surface		^{3}He					
ωWBA	134.17	1.10	0.835	22.30	1.276	0.797	2.0	1.14	0.690	4.53	344
CRC4A	141.0	1.13	0.834	20.90	1.277	0.797	2.3	1.14	0.690	4.59	368
CRC4B	142.0	1.15	0.834	19.00	1.285	0.798	2.1	1.14	0.690	4.64	406
				Volume		α					
DWBA	165.1	1.29	0.674	14.89	1.67	0.463	—	—	—	4.590	584.9
CRC4A	172.0	1.29	0.676	15.00	1.67	0.463	—	—	—	4.594	609.9
CRC4B	171.0	1.29	0.676	16.50	1.67	0.463	—	—	—	4.594	606.3

by 12% (18% for CRC4B) the alpha potential volume integral J_α is increased only by 4%. This is because only one helion channel is coupled to each alpha particle channel. Although the changes in optical model parameters are substantial they do not correspond to different discrete families. In the limit of weak coupling the CRC potential would be the same as the OM one. Hence we can say that in the refitting process we have identified the pickup contribution to the helion optical potential. The 5.23 MeV ($l = 3, j = 7/2^-$) state (CRC4B) case had a greater effect on the elastic scattering than the $l = 0$ state at 5.58 MeV, and a different set of optical model parameters was required. This is reflected in the resulting CRC4B parameters (Table I) which imply that the surface repulsion and absorption generated by the $l = 3$ state are greater than that generated by the $l = 0$ state. We also present in Table II the effect of reaction channel coupling on the quality of pick-up reaction fits to the data of Ref. [15]. The uncoupled cases marked DWBA in Table II use the potential OM of Table I. In Table II we present the χ^2 values for pickup fits both before refitting, i.e. with the OM potential and after refitting, i.e. with the CRC potentials. The CRC4A total pickup cross-sections are lower than the DWBA ones and the percentage of the reduction differs for various states.

TABLE II

The reaction $^{58}Ni(^{3}He, \alpha)^{57}Ni$ at 37.7 MeV. Total reaction and total pickup crosss sections for DWBA and CRC calculations abd χ^2-values for pickup reactions

	σ_R mb	Elastic Scattering fitted or not	σ_{pu} 0.0 MeV mb	σ_{pu} 0.77 MeV mb	σ_{pu} 2.58 MeV mb	σ_{pu} 5.58 MeV mb	σ_{pu} 5.23 MeV mb	χ^2 0.0 MeV	χ^2 0.77 MeV	χ^2 2.58 MeV	χ^2 5.58 MeV	χ^2 5.23 MeV
DWBA	1718.98	yes	0.526	0.645	3.042	0.479	2.443	2033	1077	3394	1758	5693
CRC4A	1715.48	no	0.466	0.617	2.948	0.438	—	881	504	3114	1272	—
CRC4B	1715.91	no	0.480	0.618	2.932	—	2.353	1313	568	3148	—	5304
CRC4A	1719.0	yes	0.483	0.633	2.997	0.450	—	938	897	1984	753	—
CRC4B	1718.93	yes	0.540	0.655	3.063	—	2.40	1200	1143	1920	—	4084



$^{58}Ni(^3He,\alpha)^{57}Ni$
$E_{^3He}$ = 37.7 MeV
0.0 MeV 3/2⁻ l=1
0.77 MeV 5/2⁻ l=3
2.58 MeV 7/2⁻ l=3
5.58 MeV 1/2 l=0
5.23 MeV 7/2⁻ l=3
CRC
DWBA
DIFFERENTIAL CROSS SECTION (mb/sr)
ANGLE (C M)

Fig. 1 shows the original DWBA and CRC4A fits to the transfer states under consideration. The bottom section of Fig. 1 shows the fit for the 5.23 MeV state that was obtained with the CRC4B parameters. The CRC4B fits to the first three states although somewhat worse than the CRC4A fits would not differ very much on the graph from those shown. It can be seen from Fig. 1 that the CRC4A fits are much closer to the experimental data than the DWBA fits. This is clear also from the χ^2 values given in Table II. This is the effect referred to in comment number 4 of Section 1.

3.3. 51.3 MeV helions on ^{58}Ni

Elastic scattering angular distributions of helions on ^{58}Ni were measured by Bingham and Halbert [16] together with (^{3}He, α) cross sections which were analysed according to a standard DWBA procedure. We have used their pickup data to permit a realistic (within the limitations of the model) estimation of pickup contributions to helion scattering at 51.3 MeV. It is necessary to use experimental pickup data in order to ensure that the pickup strength is realistic. This proved to be essential since the pickup cross sections are sensitive to changes in the OM potentials as well as CRC effects. One constraint on our new potentials is that the pickup cross sections have, overall, the correct magnitude, irrespective of possible effects of the neglect of non-orthogonality on the details of the angular distribution. This condition was adhered to in all cases studied.

Ref. [16] contains 8 families of helion optical potential parameters and 2 families of alpha particle potential parameters. As our starting OM potential we chose that labelled *F* of their Table I for helion, and labelled *J* of their Table IV for alpha particles. These were chosen since it seemed that a depth of the helion real potential about 130—140 MeV was physically most reasonable and the potential *F* contained a spin-orbit term. The

TABLE III

The reaction ^{58}Ni(^{3}He, α)^{57}Ni at 51.3 MeV. DWBA and CRC optical potential parameters

	U (MeV)	r_{ou} (fm)	a_u (fm)	W_{vol} (MeV)	r_{ow} (fm)	a_w (fm)	U_{so} (MeV)	r_{so} (fm)	a_{so} (fm)	$\langle r^2\rangle^{1/2}$ (fm)	J_U MeV fm^3
					^{3}He						
DWBA	136.1	1.06	0.847	13.80	1.71	0.701	2.26	1.06	0.847	4.47	321.5
CRC3	137.1	1.103	0.842	12.40	1.72	0.703	3.70	1.103	0.842	4.55	355.5
CRC4	138.0	1.118	0.842	10.90	1.74	0.704	3.90	1.118	0.842	4.59	369.9
					α						
DWBA	105.15	1.404	0.621	37.56	1.404	0.621	—	—	—	new	344.5
CRC3	185.00	1.294	0.631	39.56	1.294	0.631	—	—	—	potential	486.3
CRC4	195.00	1.284	0.631	39.56	1.284	0.631	—	—	—	family	501.8

Fig. 1. CRC and DWBA fits to experimental differential cross sections of the ^{58}Ni(^{3}He, α)^{57}Ni reaction at 37.7 MeV

potential J for alpha particles was found in Ref. [16] to be the best one. These potentials are labelled OM in Table III. In Section 3.1 we found that the $7/2^-$ ($l=3$) pickup state in ^{57}Ni at 5.23 MeV had a strong effect on the helion elastic scattering. To study this problem we again performed our CRC analysis in two steps as follows:
(*i*) 0.0+0.77+2.58 MeV states coupled to elastic scattering (labelled CRC3),
(*ii*) 0.0+0.77+2.58+5.23 MeV states coupled (labelled CRC4).

As at 37.7 MeV, CRC calculations with the OM parameters gave no fit at all to the elastic scattering. By refitting the elastic scattering angular distribution and total cross

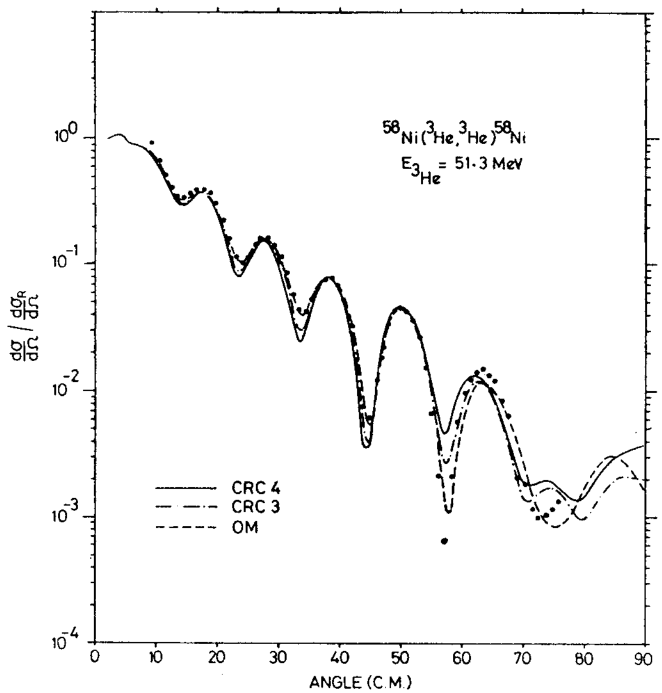


Fig. 2. CRC and optical model fits to experimental differential cross section of elastic helion scattering from ^{58}Ne at 51.3 MeV

section we obtained the potentials labelled CRC3 and CRC4 in Table III. In Fig. 2 the refitted elastic scattering is shown. We were not able in this case to fit helion elastic scattering as well as we could at 37.7 MeV, in particular the diffraction minima are not correct. Within the framework of our model this implies that the true "bare" (i.e. without pickup contributions) optical potential cannot be represented by a local OMP with the usual parametrizations. Alternatively, it may be the result of our truncation, it being likely that at the higher helion energies, a larger number of pickup states are required, see Section 3.3. From Table III we see that after refitting, the real helion potential is somewhat deeper and considerably extended in radius, the spin-orbit potential is deeper and the absorption is reduced. Thus the pickup channels have a repulsive effect which extends to the spin-orbit component (there is no polarization data) and, of course, an absorptive action. The large change in the spin orbit potential was required in order to get a reasonable fit to the diffraction minima in the helion elastic scattering. The 5.23 MeV state has a very strong individual effect as is seen in the different between the CRC3 and CRC4 potentials. Comparison of the increase in the volume integrals of the helion potentials for 37.7 and 51.3 MeV suggests that the surface repulsion effect decreases somewhat with energy over this energy range (see Section 4). The modification of the helion potentials does not correspond to any change in potential family. However, as can be seen from Table III, it was necessary to change the family to which the alpha particle potential belonged suggesting the possible

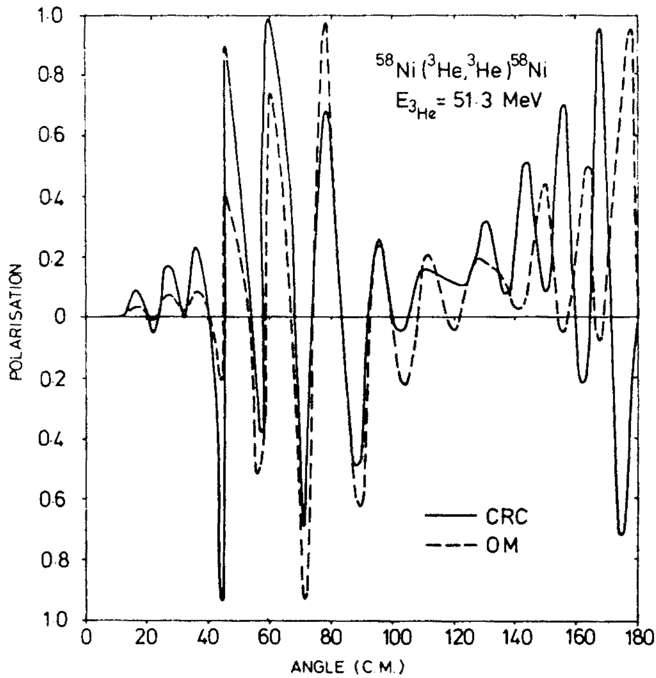
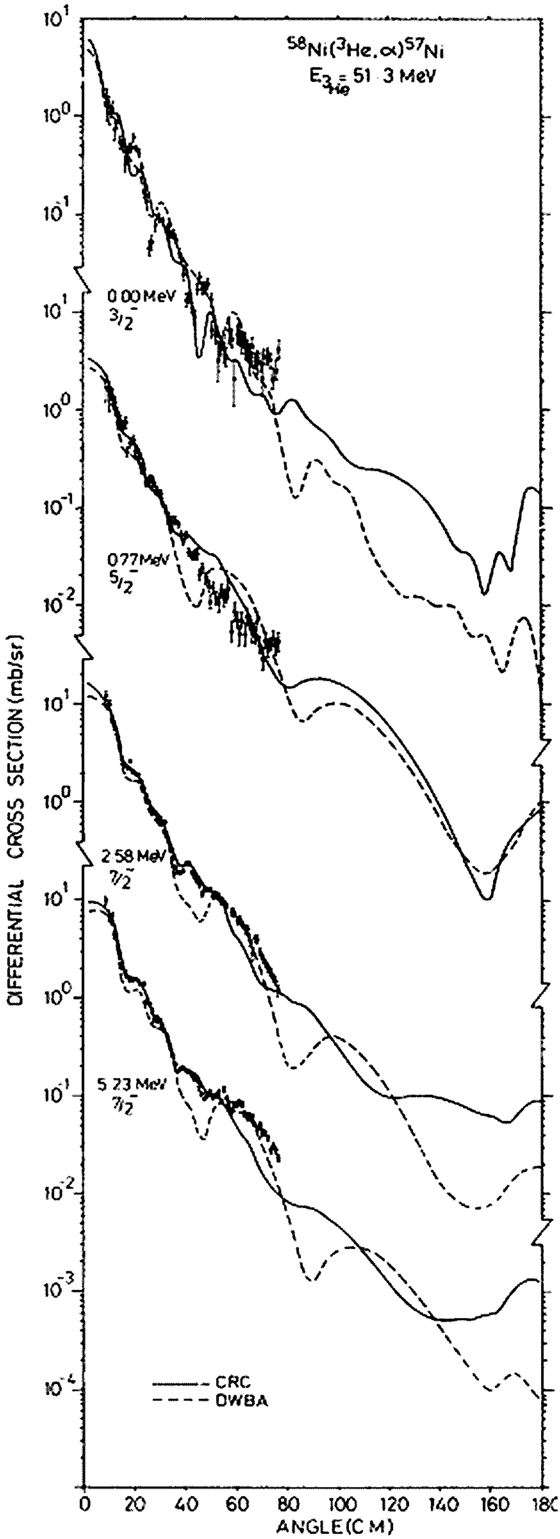


Fig. 3. CRC and optical model polarisations for elastic helion scattering from ^{58}Ni at 51.3 MeV

use of the CRC procedure as a means of finding the correct potential family. It was the need to fit the *helion elastic scattering* which made the change in alpha potential family necessary. In view of the recent interest in helion polarization phenomena we illustrate in Fig. 3 the large difference between the OM and CRC calculated polarisation.

One result of these calculations which cannot be ignored is the striking qualitative improvement to the (^{3}He, α) angular distributions which is illustrated in Fig. 4 and Table IV. This is especially the case for the 7/2$^-$ states. It is essentially a CRC effect since the qualitative improvement described below (the disappearance of certain minima) occurs before refitting. Refitting the elastic scattering then corrects the normalization of the pickup angular distributions. In general, changes in the potentials which improve the fit to the helion scattering also improve the fit to the pickup cross sections and vice versa. The particular qualitative improvement in the pickup angular distributions is the disappearance



$^{58}Ni(^{3}He,\alpha)^{57}Ni$
$E_{^3He}$ = 51.3 MeV
0.00 MeV 3/2⁻
0.77 MeV 5/2⁻
2.58 MeV 7/2⁻
5.23 MeV 7/2⁻
CRC
DWBA
DIFFERENTIAL CROSS SECTION (mb/sr)
ANGLE (C M)

of the deep minima near 50°. In extensive exact finite range DWBA calculations with the code "LOLA", it was found [17] that these minima could not be removed with any discoverable optical potentials. These exact finite range calculations also showed that at this energy the zero range approximation does not seriously alter the angular distribution. The asymmetry of the transfer reaction is greatly modified by CRC effects.

TABLE IV

The reaction $^{58}Ni(^{3}He,\alpha)^{57}Ni$ at 51.3 MeV. Total reaction and total pickup cross sections for DWBA and CRC calculations and χ^2-values for pickup reactions

	σ_R mb	Elastic Scattering fitted or not	σ_{pu} 0.0 MeV mb	σ_{pu} 0.77 MeV mb	σ_{pu} 2.58 MeV mb	σ_{pu} 5.23 MeV mb	χ^2 0.0 MeV	χ^2 0.77 MeV	χ^2 2.58 MeV	χ^2 5.23 MeV
DWBA	1723.54	yes	0.585	0.559	2.736	2.141	889	1738	3028	3283
CRC3	1720.42	no	0.506	0.519	2.582	—	696	1053	4746	—
CRC4	1720.35	no	0.499	0.515	2.554	1.991	714	1061	5196	9235
CRC3	1723.11	yes	0.576	0.648	3.172	—	831	552	1118	—
CRC4	1723.81	yes	0.618	0.695	3.347	2.610	784	1011	822	1616

In order to determine whether our results were affected by the equality of real and imaginary geometrical parameters in the alpha particle potential we briefly explored the use of the potentials of Weisser et al. [18]. Detailed fitting was not attempted but the fits were comparable to those found previously without alpha potential adjustment. There was a clear preference for the potential 158.9 MeV deep over that 111.4 MeV deep. This suggests once more how simultaneous CRC fits to elastic scattering and pickup differential cross sections can be used to settle questions of the optical potential ambiguities.

3.3. Dependence on l and Q

A series of calculations were carried out at 18 MeV for ^{64}Zn target nuclei. Since numerical data for the elastic scattering was not available only qualitative conclusions were possible. The general results were very similar to those at 37.7 and 51.3 MeV. However, model calculations carried out at this energy revealed interesting behaviour of the l- and Q-dependence of the transfer processes. In summary:

1. There is a strong Q-dependence of the effect on elastic scattering. Thus at these energies one should not use sum rules to estimate the total effect, this latter being concentrated in states of low excitation.

2. For a given spectroscopic factor the cross section is largest where there is good angular momentum matching, but this corresponds to a relatively small CRC effect on elastic scattering. This is largest for low excitation energy states with *poor matching.*

Fig. 4. CRC and DWBA fits to experimental differential cross sections of the $^{58}Ni(^{3}He,\alpha)^{57}Ni$ reaction at 51.3 MeV

This occurs since for these states, the alpha particle is redirected by momentum conservation *into* the nucleus where it is absorbed. This absorption is reflected in added absorption of the helions. The angular momentum matching condition results in an l-dependence which at 18 MeV manifests itself in the fact that states of low l have the largest effect. At higher energies this trend was not obviously present.

3. Therefore, at least at 18 MeV, a few strong low-lying states give a reasonable measure of the effect.

4. In extensive calculations with from one to four states there is no indication that omitted high lying could in any way cancel the effects of the low-lying states. In fully consistent calculations there is a tendency to converge (i.e. the total effect is less than the sum of the effects of individual states) as the wavefunctions become depleted in the surface. This is a higher order effect and reflects the fact that the total transfer contribution has some limit.

4. Conclusions

The major result of this work is the finding that a large contribution to the helion optical potential arises from the coupling to alpha particle channels, an effect that must be reckoned with in any attempt to calculate the helion optical model potential. The fact that these coupling effects are strong is of wide significance for any helion induced reaction. For example it raises the question of the relationship of real to imaginary deformation parameters in helion scattering from deformed nuclei. The surface peaked nature of the transfer induced potential carries the particular implication that any attempt to use strongly interacting particles for shape or neutron density measurements would be invalid without proper consideration of transfer effects. The large change in the rms radius of helion potential induced by coupling to the alpha particle channels has a significant implication for such measurements applying elastic scattering analyzed by folding model. Although the non-orthogonality problem makes it questionable whether direct information concerning stripping contributions to alpha particle scattering could be extracted using a similar procedure, our refitting of the helion scattering has given indirect evidence that there are indeed similar large contributions to the alpha particle OMP. It may even be possible to use CRC calculations for the resolution of OMP ambiguities. The notable improvement to the pickup angular distributions, albeit often over a limited angular range, may suggest that at 50 MeV or higher with strongly absorbed projectiles, the neglect of the non-orthogonality terms does not entirely invalidate our calculation of the (^{3}He, α) angular distributions. The total pickup cross sections do not show the same relative proportionality for CRC calculations as for DWBA calculations. However, this does not seem to imply changed spectroscopic factors since changes are in the more backward angles.

One feature of these calculations which we must remark upon is the manner in which parameter changes which improve angular distributions in one partition always also improve them in the other.

Concerning the uniqueness of the determination of the transfer components in the helion OMP, extensive calculations suggest the following. The general surface peaked nature of these components together with the volume integrals appear to be quite firmly established. In Fig. 5 we show the repulsive pickup contributions calculated by subtracting the OM and CRC potentials of Tables I and III. They are compared in this figure with a similar curve illustrating the increment in the proton potential due [5] to the coupling to deuteron channels. For helions, the effect is nearly as large at 51.3 MeV as at 37.7 MeV.

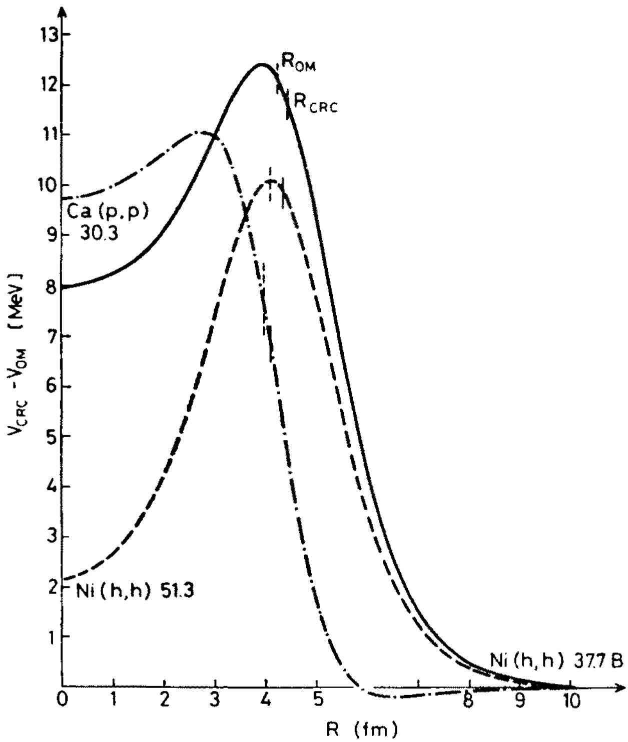


Fig. 5. Increment in real optical model potential arising from the coupling to pickup channels — the three cases plotted correspond to the 37.5 MeV case labelled CRC4 and the proton case of Ref. [5]. Positive values corresponds to repulsive effects of pickup channels

This behaviour is universally characteristic of transfer contributions in all cases studied including the model calculations of Ref. [1]. Even with the simplified theory used here it is difficult to do the searching required to unambiguously determine the transfer-generated component of the optical potential. With a full finite range calculation with orthogonality terms included it would be virtually impossible. For this reason, the large effects found herein demonstrate, if nothing else, the urgency of complete calculations, necessarily model calculations, which can evaluate the goodness of the approximations which we have made in this energy and target mass region.

Since the preparation of the first version of this paper, an article by Shepard, Kunz and Kraushaar [19] has appeared. The same CRC formalism was used but with a somewhat different purpose in mind. Their general result that the channel coupling effect is large is in agreement with our's.

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