THE PICKUP-STRIPPING MECHANISM FOR INELASTIC AND QUASI-INELASTIC SCATTERING

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The (h, t) reaction can be dominated by the formation of an intermediate alpha-particle cluster. This process accounts for the relatively large cross sections for high spin transfer and the $L = 1$ shape of some $0^+ \rightarrow 0^+$ transitions.

The general assumption for the (h, t) reaction mechanism is that the reaction proceeds through the charge-exchange part of the two-body nucleon-nucleon interaction [1]. However, serious discrepancies [2,3] have been seen when comparing the predictions of this model with experiment. The calculated [2] cross sections are too weak by factors from 2 to 500, the difference increasing almost exponentially with increasing spin transfer. The most striking discrepancy is the breakdown of commonly accepted selection rules for inelastic or quasi-inelastic scattering: Hinrichs et al. [3] observed an $L = 1$ shape instead of $L = 0$ for some $0^+ \rightarrow 0^+$ transitions to antianalogue states.

As proposed earlier [4] these reactions should be described by an additional mechanism which is the pickup of a particle, forming an intermediate alpha cluster, followed by stripping. In second order perturbation theory, the corresponding transition matrix is:

$$T^{(2)} = \frac{1}{(2\pi)^3} \int \mathrm{d}\boldsymbol{k} \sum_n \langle \mathrm{t}^{(-)} A^* | V | \alpha (A-1)_\mathrm{n} \rangle \times \frac{1}{E - E_\mathrm{n}^{A-1} - E_\alpha + \mathrm{i}\epsilon} \langle \alpha (A-1)_\mathrm{n} | V | \mathrm{h}^{(+)} A \rangle \qquad (1)$$

where A and $(A-1)_\mathrm{n}$ denote the nuclear states with A and $A-1$ particles, and t, h, and α denote the internal and optical wavefunctions of the projectile. If in addition we assume that all the states $(A-1)_\mathrm{n}$ containing large components of a hole in the j-shell coupled to A have about the same energy E_n^{A-1}, $T^{(2)}$ becomes:

$$T^{(2)} = D_0^2 \sum_{jj'} \langle A^* | a_{j'}^+ a_j | A \rangle \langle \mathrm{t}^{(-)} \varphi_{j'} | G | \mathrm{h}^{(+)} \varphi_j \rangle \qquad (2)$$

where G is the α-particle Green function, and D_0 is the one-particle transfer strength [5].

It may be seen from eq. (2) that the second order (hα), (αt) process is sensitive to exactly the same correlations between the ground and excited states as the direct (h, t) process, and may therefore be expected each time a direct (h, t) transition occurs. However, the effective interaction, $D_0^2 G$, has a nonlocality characteristic of the alpha propagation, which is much longer than the nonlocality inherent in the two-body interaction. Similar arguments could be used in favor of the formation of an intermediate deuteron. However, the coupling constant D_0 is substantially smaller in this case. We neglected the (hd), (dt) process in the computation below, although further investigations in this direction are planned.

To understand the origin of the $L = 1$ angular distribution to antianalogue states, consider the transition density for exciting the analogue state (IAS) and the antianalogue state (AAS) from the parent ground state. In ^{40}Ar, these two states are described as $[\mathrm{d}_{3/2}^{-2}\, \mathrm{f}_{7/2}^{2}]_{T=2}$ and $[\mathrm{d}_{3/2}^{-2}\, \mathrm{f}_{7/2}^{2}]_{T=1}$, respectively. Two single-particle transition den-

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sities contribute to the transition, $f_{7/2} \to f_{7/2}$ and $d_{3/2} \to d_{3/2}$. These are expressed in LS coupling as follows,

$$\phi^*_{lj}(\boldsymbol{r}_1)\phi_{lj}(\boldsymbol{r}_2) = \{\langle (l\tfrac{1}{2})^j (l\tfrac{1}{2})^j|00\rangle F(R)f(r) + \\ + \langle (l\tfrac{1}{2})^j (l\tfrac{1}{2})^j|(11)^0\rangle(\boldsymbol{r}\times\boldsymbol{R})\cdot \boldsymbol{S}G(R)g(r)\} \quad (3)$$

where $r = r_1 - r_2$ and $R = \frac{1}{2}(r_1 + r_2)$, and the operator S_m transfers spin $(1, m)$ from particle 2 to particle 1. At small r, the two single-particle transition densities have a coherence in the first term for the IAS. This is obvious, since the transition density of the T-operator is concentrated at $r = 0$ Thus the IAS transition density closely corresponds to $L = 0$, $S = 0$, $J = 0$ transfer. The second term corresponds to an $L = 1$, $S = 1$, $J = 0$ excitation and is the only one left in the AAS transition density, due to the interference of the $f_{7/2}$ and $d_{3/2}$. However, this term requires nonzero r and therefore a nonlocal operator to induce the transition.

The order of magnitude of the two step process can be estimated from the size of the (h, α) cross section [7]. From the optical theorem, this cross section is related to the two-step scattering amplitude at 0^o. This estimate leads to a cross section of several μb/sr. Other processes involving a nonlocal effective interaction can also lead to an $L = 1$ shape for the AAS. Exchange effects have been considered [8], but give small contributions.

In fig. 1 we show the result of some calculations of ^{40}Ar(h, t)^{40}K in the plane wave approximation with a cutoff of $R = 1.4\,A^{1/3}$, and zero range interactions. The simple one-step calculation with distorted waves and a finite range interaction leads to $L = 0$ angular distributions for both states with a ratio $\sigma_{AAS}/\sigma_{IAS} \approx 1/100$. The dashed line in the figure shows the cutoff plane wave calculation of the one step process with the $d_{3/2} \to d_{3/2}$ transition operator adjusted to give the same ratio of cross sections. In the curves shown by the solid line, we have added the contribution of $T^{(2)}$, using $D_0 = 43$ MeV$\cdot$fm$^{3/2}$. This value was chosen to reproduce the experimental ratio of $\sigma_{AAS}/\sigma_{IAS} \approx 1/10$, and is considerably smaller than the value required in distorted wave calculations. This is to be expected, since our calculation has a no optical absorption. The calculation shows that the IAS is hardly affected at all by the two-step mechanism, and that the AAS has the empirical $L = 1$ shape.

Another discrepancy explained by the (hα), (αt) process are th abnormally strong cross-

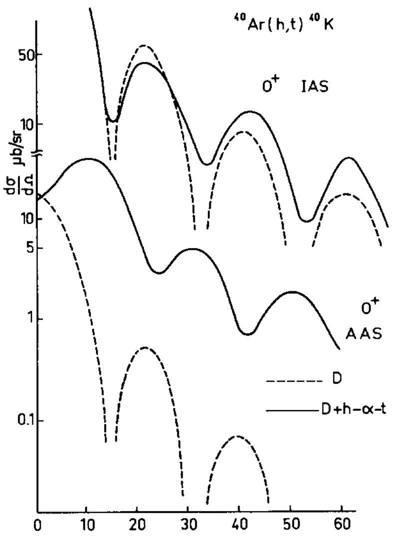

Fig. 1. Comparison of the usual [1] one-step calculation (dashed line) for the (h, t) reaction with the full calculation including the (hα), (αt) contribution (full line).

sections for high spin transfer J. The ratio σ_J/σ_0 for the $f_{7/2} \to f_{7/2}$ transition of ^{48}Ca(h, t)^{48}Sc, taken at the first maximum is seen experimentally [6] to decrease (table 1) by a factor of 4, whereas the one step (h, t) calculation predicts a decrease by two orders of magnitude. The (hα), (αt) process entirely dominates for these high spin transfers (the 0^+ cross-section is almost not changed, as for the IAS on fig. 1) and leads to the needed increase for the 4^+ and 6^+ excitations (table 1). The strength D_0 used in this calculation is the same as used previously. For the $f_{7/2} \to f_{7/2}$ transitions to unnatural parity states in ^{48}Sc, the (hα), (αt) contribution is still too strong and further investigations have to be done.

We have shown that the (h, t) reactions proceeds in most cases via an intermediate α-particle. This process can be expected to be as important for (h, h') and(t, t') scattering, and is presumably the explanation of the $L = 1$ shape seen in the excitation of the second 0^+ state in ^{90}Zr by (tt') scattering (the cancellation of the $g_{9/2}$ and $p_{1/2}$ proton transitions suppress the $L = 0$ excitation). An interesting experiment would be the (h, h') scattering to the same state. According to our model, it should lead to an $L = 0$ shape since the $L = 1$ transition can only be due to an intermediate deuteron (helions exciting protons cannot cluster into α-particles).

Table 1
Ratio of the cross-sections for the $f_{7/2} \rightarrow f_{7/2}$ transition $^{48}Ca(h,t)\,^{48}Sc$ at the first maximum.

σ_J/σ_0	0^+	4^+	6^+
(h,t)	1	0.05	0.01
(h,t) + (h,α)(α,t)	1	0.7	0.5
Exp.	1	0.5	0.25

i) for the direct (h,t) process with a 1.4 fm Yukawa interaction
ii) for the full calculation including the (hα), (αt) contribution
iii) for the experimental cross sections of Bruge et al. [6].

The importance of such stripping and pick-up processes should also be studied for (p, p'), (p, n) as well as for two particle transfer reactions where for instance (αh), (hd) can compete with the direct (α, d) process

References

[1] V. A. Madsen, Nucl. Phys. 80 (1966) 177; N. K. Glendenning and M. Veneroni, Phys. Rev. 144 (1966) 839.
[2] P. Kossanyi, P. Roussel, H. Faraggi and R. Schaeffer, Nucl. Phys. A148 (1970) 181; R. Schaeffer, Nucl. Phys. A164 (1971) 145.
[3] R. Hinrichs, R. Sherr, G. Crawley and I. Proctor, Phys. Rev. Letters 25 (1970) 829.
[4] G. Bertsch and R. Schaeffer, Proc. of the Gull Lake Symposium, Michigan, September 1971.
[5] R. Stock et al., Nucl. Phys. A104 (1967) 136.
[6] G. Bruge et al., Nucl. Phys. A129 (1969) 417.
[7] D. M. Youngblood et al., Nucl. Phys. A143 (1970) 512.
[8] R. Schaeffer, Nucl. Phys. A158 (1970) 321.
[9] J. Raynal, Proc. Madison Conference (1970).

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