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Authors
Ascuitto, R.J.
Glendenning, Norman K.

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R. J. Ascuitto and Norman K. Glendenning

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DISCLAIMER

ON THE SYSTEMATICS OF THE INTERFERENCE BETWEEN DIRECT AND INDIRECT MODES IN TWO-NUCLEON PICKUP AND STRIPPING REACTIONS BETWEEN HEAVY-IONS*

R. J. Ascuitto
Wright Nuclear Structure Laboratory
Yale University
New Haven, Connecticut 06520

and

Norman K. Glendenning
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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The interference between direct and indirect modes of excitation of vibrational states in two-nucleon transfer reactions are of opposite sign for stripping as compared to pickup reactions. If the indirect modes are sufficiently strong, destructive interference gives rise to a dip in the angular distribution at the grazing angle, compared to the normal shape when the interference is constructive. The absolute sign of the interference may change through a string of isotopes thus revealing details of the structure of vibrational states not accessible through other experiments.

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The effect of indirect transitions on two-nucleon transfer reactions involving light projectiles was calculated to be strong for spherical vibrational nuclei [1], and in the case of deformed nuclei, the experimental confirmation of the effect was very striking [2,3]. Such effects must therefore be anticipated in heavy ion reactions. Unfortunately, our knowledge of the strength of inelastic cross sections is not so complete as yet for heavy ions as to make

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the magnitude of the effect so certain. Nonetheless, there is an indication that the deformation constant, β, deduced from proton and heavy ion scattering are nearly the same [4]. We use this literally in fixing the strength of the inelastic branch in our calculations, but there is an uncertainty at this point.

In this note, we point out the possible existence of systematics in the interference between direct and indirect modes that would reflect on intimate details of the structure of vibrational states.

We reported earlier on the $^{120}Sn(^{18}O,^{16}O)$ reaction which exhibited a strong destructive interference between the direct and indirect modes of exciting the 2^+ state in ^{122}Sn [5]. Here we point out that the interference is of opposite sign in the stripping and pickup reactions to vibrational states. This is illustrated in figs. 1 and 2 for both heavy and light tin isotopes. Since both direct and indirect modes have cross sections which are peaked near the grazing angle [5], the interference can actually produce a dip at the grazing angle if the indirect amplitudes are sufficiently close in magnitude to the direct. This is calculated to be the case for the 2^+ state of the heavy tin isotopes, fig. 1, where the dip is readily apparent for the stripping reaction. This is in contrast to the pickup reaction where the interference is constructive and the resultant cross section therefore has the "normal" shape. The indirect modes are calculated to be unimportant for the ground state transition. They are not as strong in the light isotopes even for the 2^+ and consequently no interference dip occurs there, fig. 2.

At this point we note that the details of our results depend upon the structure of the nuclei. These calculations employed a two-quasiparticle description of the vibrational state [6]. An R.P.A. calculation could have produced quantitatively different results. However, both descriptions would have led to an opposite sign of the interference for stripping and pickup though they would not necessarily agree on the absolute sign. The parentage amplitudes connecting the four states shown in fig. 3 are given by [7,8]

$$\beta_{ab0}(0_A \longleftrightarrow 0_{A+2}) \simeq \left(\frac{2j_a+1}{2}\right)^{\frac{1}{2}} V_a U_b \delta_{ab} \tag{1}$$

$$\beta_{abJ}(0_{A+2} \longleftrightarrow J_A) = \left(\frac{2J+1}{1+\delta_{ab}}\right)^{\frac{1}{2}} [V_a V_b \psi_{ab} - U_a U_b \phi_{ab}] \tag{2}$$

$$\beta_{abJ}(0_A \longleftrightarrow J_{A+2}) = -\left(\frac{1}{1+\delta_{ab}}\right)^{\frac{1}{2}} [U_a U_b \psi_{ab} - V_a V_b \phi_{ab}] \tag{3}$$

$$\beta_{ab0}(J_A \longleftrightarrow J_{A+2}) \simeq \beta_{ab0}(0_A \longleftrightarrow 0_{A+2}) \tag{4}$$

where β is defined in general as

$$\beta_{abJ} = [(2J_p+1)(1+\delta_{ab})]^{\frac{1}{2}} \langle \Phi_{J_p}(A+2) \| [d_a^+ d_b^+]_J \| \Phi_{J_t}(A) \rangle \tag{5}$$

where d_a^+ creates a particle in the state $n_a \ell_a j_a$. In the production of the ground state in both stripping and pickup reactions, transitions 1 and 4 are indirect, while 2 is the direct amplitude for pickup and 3 is the direct amplitude for stripping. The opposite sign of these amplitudes, 2 and 3, is what determines their opposite interference characteristics with the direct modes.

The situation is different for production of the ground states. Both 2 and 3 are the lowest order indirect modes and since they are of opposite sign they tend to cancel each other accounting for the weak indirect contribution to the ground state transitions.

We have so far remarked on the opposite signs of the two parentage amplitudes. For two quasiparticle states (TDA) the ϕ are zero and the ψ_{ab} are to be identified with the quasiparticle amplitudes η_{ab} of our earlier paper [8]. In this case the absolute sign of the interference is that illustrated by our figures, and is destructive for stripping. However, the form of the parentage amplitudes admits a more complex behaviour. For example, through a series of isotopes the relative importance of ψ and ϕ could change. At the same time the U and V factors are changing. It could then happen that the absolute sign of the β's would be opposite for light and heavy members of an isotopic series, and that in the neighborhood of the change, the two amplitudes would not necessarily have opposite signs. A systematic study of pickup and stripping reactions throughout a series of isotopes (or isotones for proton transfer) is therefore likely to yield structural details that have not been accessible in other experiments.

APPENDIX

The parameters and nature of the calculation reported here were described in ref. 5 except that here we generated single-particle states in a Woods-Saxon potential, all having a binding of one-half of the two neutron separation energy. These are used as the basic states from which the nuclear states are built. Earlier we had used an average potential. The difference in the final results is slight.

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Figure Captions

Fig. 1. The stripping and pickup cross sections for the ground state and 2^+ state, computed with direct and indirect transitions (CCBA). The indirect transitions almost cancel each other for the ground state. However, for the 2^+, they interfere destructively with the direct, for the stripping reaction, producing the dip at the grazing angle. For the pickup reaction, they interfere constructively and preserve the characteristic peak at the grazing angle. The two ground state cross sections would be time reversed reactions except for the finite Q-value and the use of the 100 MeV incident energy for each.

Fig. 2. This figure contains material analogous to fig. 1 for the light end of the tin isotopes. Here the indirect transitions are weaker compared to the direct than was the case for the heavy isotopes of fig. 1. Consequently the difference in the 2^+ states is smaller. Cross sections are in mb./sr. The top scale refers to the 0^+ and the bottom to the 2^+ state.

Fig. 3. The parentage amplitudes, Eqs. 1, ... 4, correspond to the four connections shown here. The transitions 2 and 3 have opposite sign. Since they are each a segment of the two second order transitions to the ground in both pickup and stripping, they tend to cancel each other, yielding a small second order contribution to the ground state. For the 2^+ state however, 2 is direct for a pickup reaction and 3 is direct for stripping, while 1 and 4 are segments of the second order routes. The opposite sign of 2 and 3 implies opposite interference of direct and indirect transitions in stripping compared to pickup.

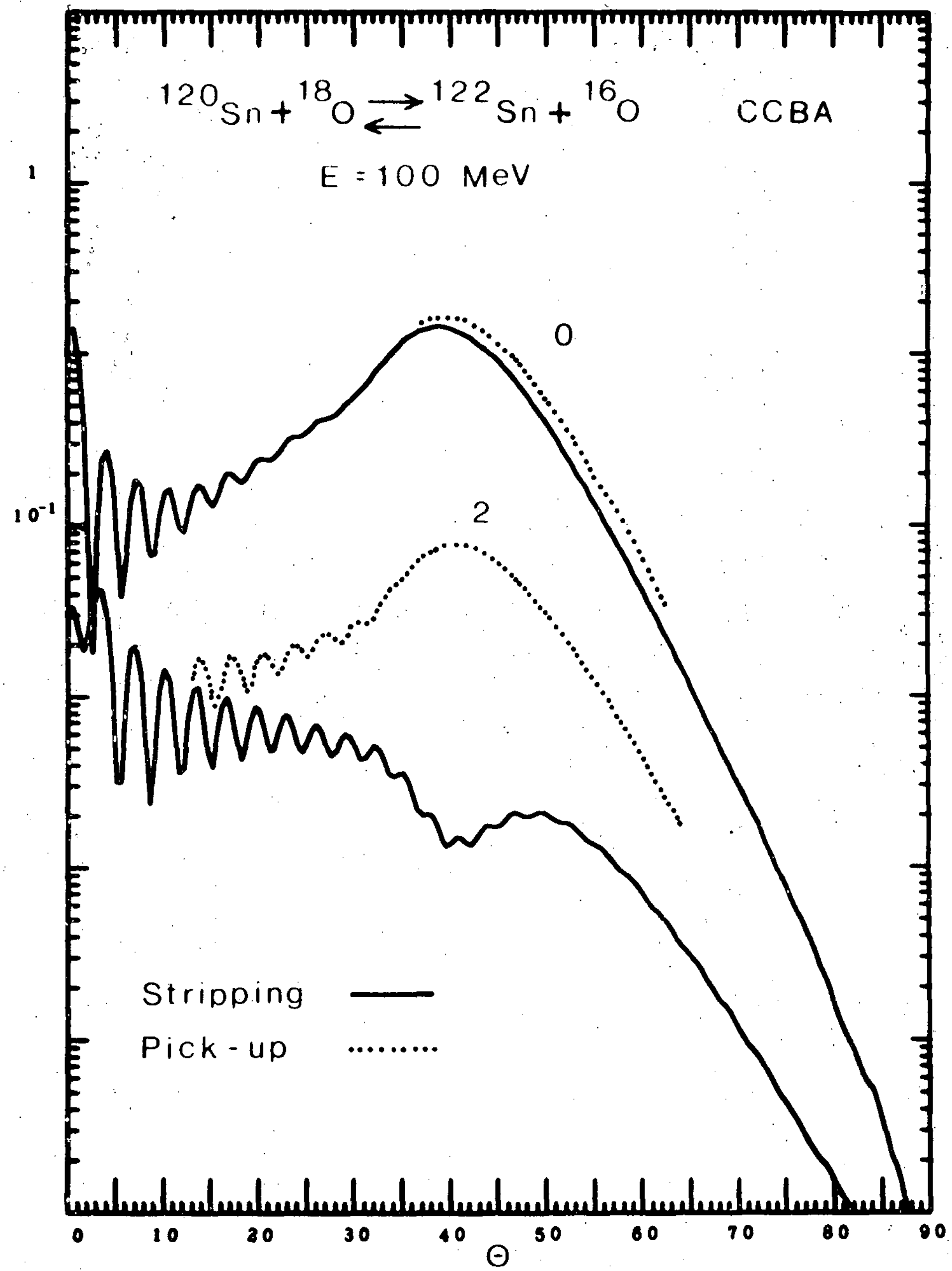

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Fig. 1

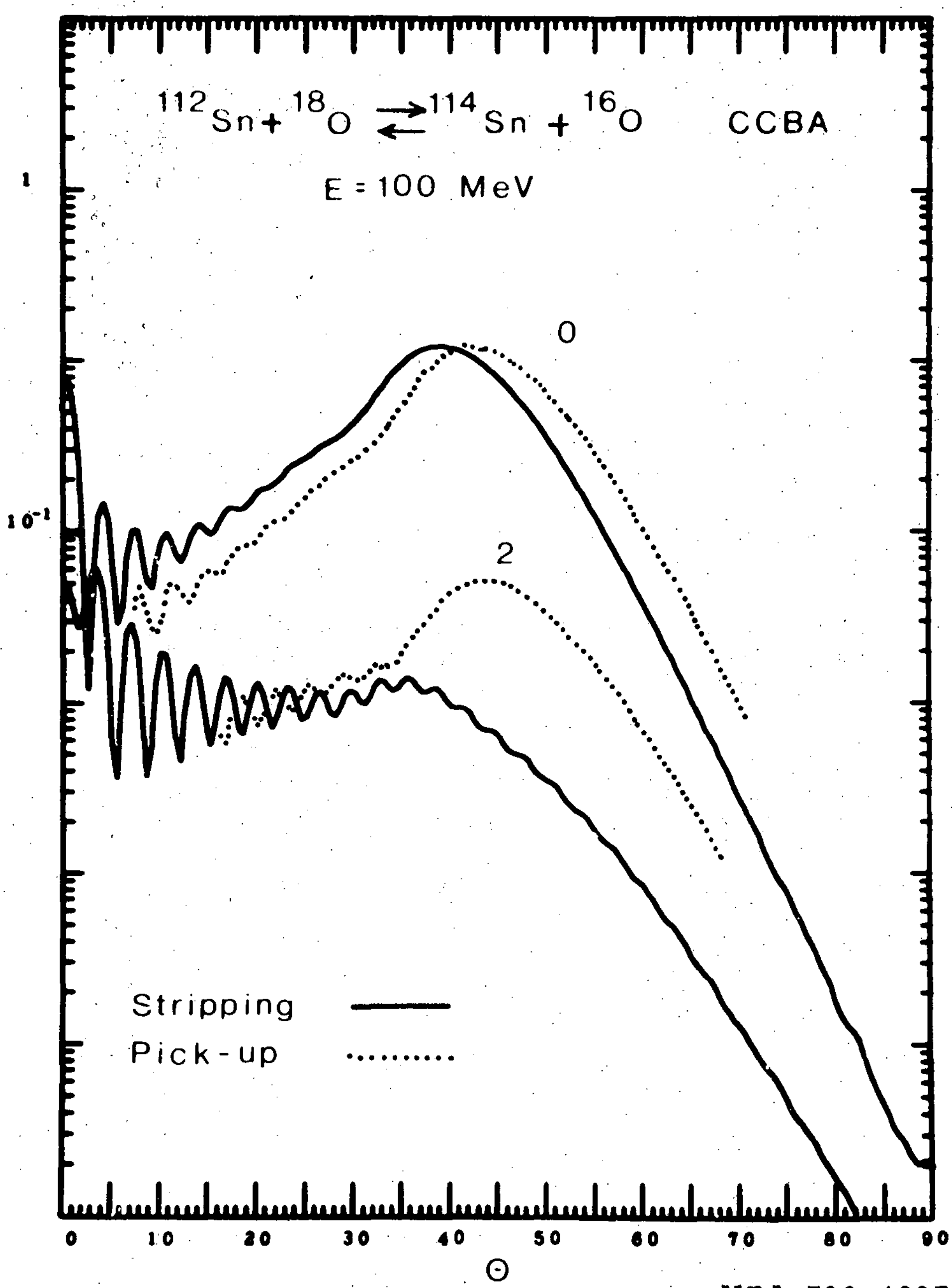

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Fig. 2

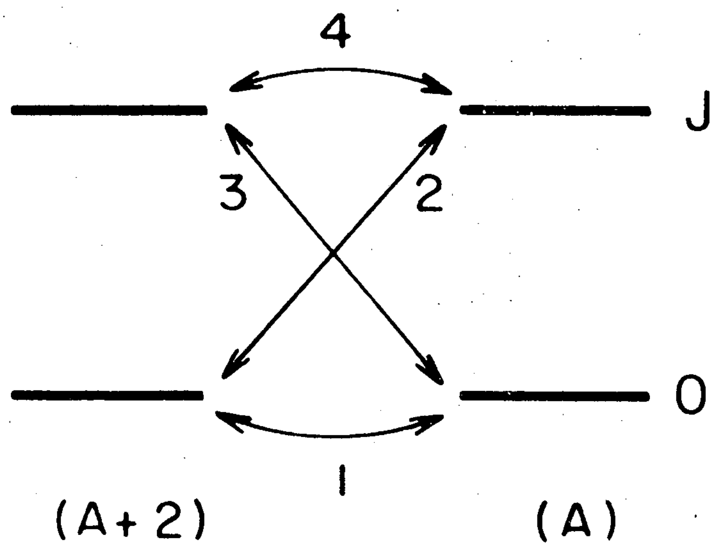

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Fig. 3

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LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720