Mechanism for double-charge exchange in heavy ion reactions

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(Received 2 October 1985)

The double-charge exchange reaction $^{40}Ca(^{14}C,^{14}O)^{40}Ar$ is studied in terms of a two-step mechanism associated with the independent excitation of target proton and neutron pairing modes. Macroscopic pair-transfer form factors are employed in the coupled-channel analysis.

An important aspect of the description of the nuclear many body problem in terms of elementary modes of excitation is explored by the study of the multiple excitation of these degrees of freedom in collision experiments. In the case of pair transfer modes, for example, considerable theoretical and experimental work has been devoted to investigating the transfer of more than one pair of nucleons in reactions induced by heavy ions.[1] To the same class of experiments belong double-charge exchange processes like the $(^{14}C,^{14}O)$ reaction on ^{40}Ca measured by Drake *et al.*,[2] which exhibits surprisingly large cross sections leading to the 0^+ and 2^+ final states in ^{40}Ar. A first attempt to account for these data in terms of pairing modes was reported in Ref. 3, where it was suggested as a mechanism for the reaction the simultaneous one-step excitation of the neutron and proton modes. In this case the transition was ascribed to the interaction between the two different nucleon pairs. The results of these calculations, which underestimated the observed cross sections,[8] seem to rule out the one-step process as the leading reaction mechanism.

Our approach to the problem is still based on the idea of treating the residual ^{40}Ar target as a double-phonon state mounted over a ^{40}Ca core. However, we consider the observed cross sections to be mostly built up from the excitation of these modes as independent degrees of freedom. An indication favoring such a two-step description was provided by the appreciably large cross sections measured in the same experiment for the intermediate two-proton pickup reaction $^{40}Ca(^{14}C,^{16}O)^{38}Ar$.

Since the quadrupole state at 2.17 MeV in ^{38}Ar was populated with a probability comparable to that of the ground state, the low-lying 2^+ states were included in the analysis as intermediate channels in both ^{38}Ar and ^{42}Ca. A sketch of the different routes considered in the calculation is given in Fig. 1. As indicated in the figure, the assumption of independent proton and neutron modes leads to the use of the same coupling matrix elements for each basic transition, independent of the fact that the other reaction may or may not have taken place.

The first step of the analysis is the description of the two-particle transfer processes to be subsequently used as intermediate steps in the full calculation. For this purpose we make use of the model description introduced in Ref. 4. Here the relevant couplings are attributed to the nuclear mean fields inducing generalized transitions between the single-particle components in the correlated pair states. This point of view effectively uncouples the excitation of projectile and target modes and allows for the introduction of product wave functions. As a practical aspect, the identification of a local pair transition density also leads to a simple operational framework which parallels the one conventionally used for inelastic excitations. In what follows we shall assume that the observed cross sections are mostly determined by the excitation of the target modes.

The values of the pairing deformation parameter β_p can be extracted from the magnitudes of the measured cross sections. Results obtained from calculations for the proton pair $\lambda=0$ and $\lambda=2$ pickup reactions are shown, together with the data, in Fig. 2. To generate the optical distorted wave functions we have used the standard real potential from Ref. 5. The same geometry but a strength about ten times lower (cf. the figure caption) was used for the imaginary part, consistent with the surface transparency characteristic of light-ion induced reactions.[6] The results of the calculations have been averaged over

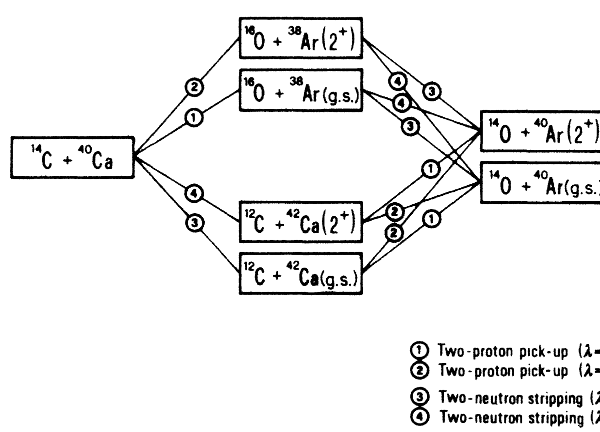

FIG. 1. Sketch of the different channels and couplings used in the description of the $^{40}Ca(^{14}C,^{14}O)^{40}Ar$ reaction.

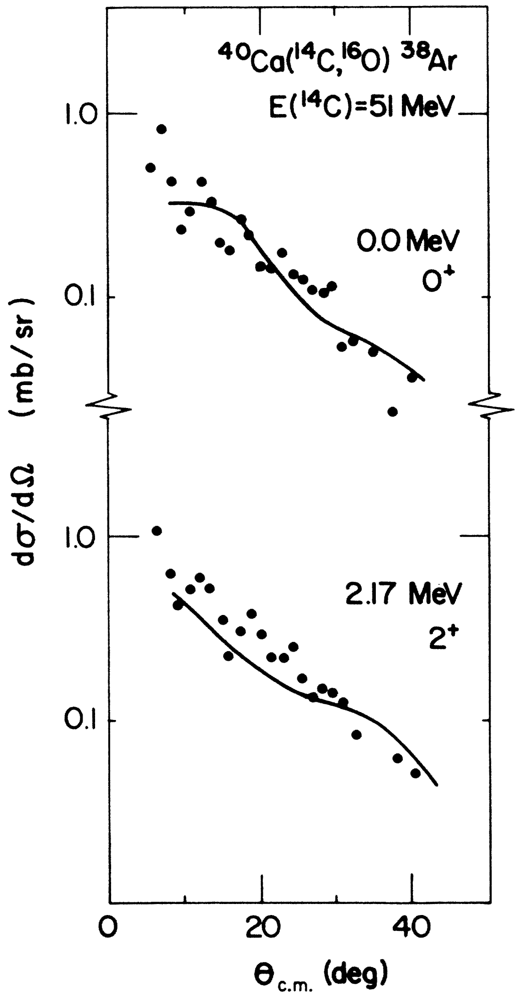

FIG. 2. Angular distributions obtained for the excitation of the 0^+ and 2^+ states in the ^{40}Ca(^{14}C,^{16}O)^{38}Ar reaction. Experimental data are from Ref. 2. The calculated cross sections are averaged over $\Delta\theta = \pm 5°$. A Woods-Saxon optical potential has been used with parameters $V = -49.2$ MeV, $r_v = r_w = 1.164$ fm. $a_v = a_w = 0.63$ fm, and $W = -3.5$ MeV. See the text for the coupling potentials.

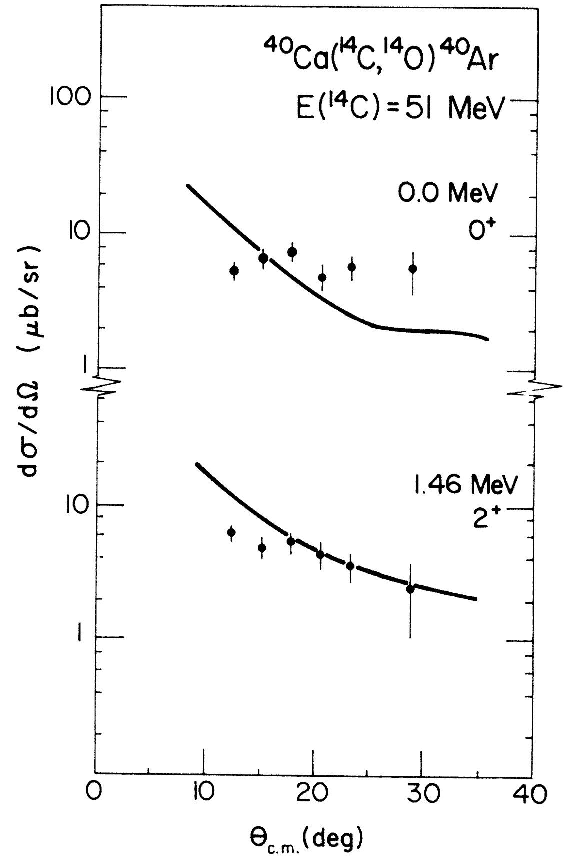

FIG. 3. Angular distributions obtained for the excitation of the 0^+ and 2^+ states in the ^{40}Ca(^{14}C,^{14}O)^{40}Ar reaction. Experimental data are from Ref. 2. The calculated cross sections are averaged over $\Delta\theta = \pm 5°$. For the optical potential see the caption to Fig. 2.

$\Delta\theta = \pm 5°$, partly to account for the experimental resolution and partly to stress the fact that we only aim at a description of the absolute magnitude of the cross sections and are not interested in details of the angular distributions. The values $\beta_p = 3$ and $\beta_p = 3.6$ were used for the $\lambda = 0$ and $\lambda = 2$ transitions, respectively. These quantities, which give a measure of the collectivity induced by the pairing correlations, are comparable to values found in other nuclei.[4] Note, however, that the procedure used to obtain these values may include also the same possible admixture of excitation of projectile pair modes. For the neutron pair transfer, independent experimental evidence is not available to determine the value of β_p, which in this analysis therefore remains as a scaling parameter. We have used $\beta_p = 3.6$.

Having fixed in this way the coupling interactions for each single step, the full calculation for the double-exchange process has been performed making use of a standard coupled channel code[7] within the coupling scheme displayed in Fig. 1. The resulting cross sections for the population of the 0^+ and 2^+ final states are shown together with the data in Fig. 3, again averaged over $\Delta\theta = \pm 5°$. The calculations account for the correct order of magnitude. A major effect in the resulting cross sections is due to the coherent contribution of the different routes leading to the final states. For example, leaving aside the intermediate 2^+ states in the coupled-channel calculation reduces the angular distributions by a factor of ~ 3. We have also noticed that the absolute magnitude of the cross sections is rather sensitive to the choice of optical parameters.

To summarize the present paper, a satisfactory understanding of the absolute magnitude of the double-charge exchange process in the heavy ion reaction ^{40}Ca(^{14}C,^{14}O)^{40}Ar can be obtained by a reaction mechanism based on the independent excitation of proton and neutron pair modes. The couplings to these modes have been expressed in terms of macroscopic pair-transfer form factors, with strength parameters comparable to values found in other nuclei.

[1]W. Von Oertzen, in *Frontiers in Nuclear Dynamics,* edited by R. A. Broglia and C. H. Dasso (Plenum, New York, 1985), p. 241.

[2]D. M. Drake, J. D. Moses, J. C. Peng, Nelson Stein, and J. W. Sunier, Phys. Rev. Lett. **45**, 1725 (1980).

[3]D. R. Bes, O. Dragun, E. E. Maqueda, and R. J. Liotta, Phys. Lett. **106B**, 1 (1981); in *Nuclear Physics,* edited by C. H. Dasso, R. A. Broglia, and A. Winther (North-Holland, Amsterdam, 1982), p. 243; D. R. Bes, O. Dragun, and E. D. Maqueda, Nucl. Phys. **A405**, 313 (1983).

[4]C. H. Dasso and G. Pollarolo, Phys. Lett. **155B**, 223 (1985).

[5]P. R. Christensen and A. Winther, Phys. Lett. **65B**, 19 (1976).

[6]M. C. Lemaire, Phys. Rep. **7C**, 280 (1973).

[7]P. D. Kunz, coupled channel code CHUCK (unpublished).

[8]D. R. Bes, private communication.