Pion double charge exchange on Ca isotopes

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A simple two-amplitude model introduced to relate pion double charge exchange on ^{16}O and ^{18}O is used to predict cross sections for $^{42-48}$Ca, based solely on experimental data for ^{40}Ca and simple predictions for double isobaric analog transitions. The presence of the "forbidden" core component increases the expected ^{42}Ca cross sections by a factor of 6 above the double isobaric analog transition prediction and changes the expected ^{48}Ca/^{42}Ca ratio by a factor of 4.5.

[NUCLEAR REACTIONS $^{40-48}$Ca$(\pi^+,\pi^-)^{40-48}$Ti; $\theta=5°$, $E_\pi=164$, 292 MeV, two-amplitude model of cross sections.]

The most striking feature of pion-induced double charge exchange (DCX) reactions on nuclei is the observation[1,2] that cross sections for "forbidden" DCX (on targets with isospin $T=0$ or $\frac{1}{2}$) are comparable to "allowed" DCX (on targets having $T \geq 1$). We shall use "forbidden" and "allowed" in this context throughout. The former must proceed via an isotensor operator in the nuclear space, whereas the latter may contain isoscalar, vector, and tensor components. But whatever the mechanism for DCX on $T=0$ targets, it can surely contribute for $T \geq 1$ targets as well.

Neither mechanism of DCX is very well understood, but a simple two-amplitude model[3] has succeeded in describing data[4] for DCX on ^{18}O as arising from a combination of "forbidden" and "allowed" transitions. In Ref. 3, these are referred to as non-DIAT (nondouble isobaric analog transition) and DIAT, respectively. In that reference, the allowed amplitude was taken from a calculation of Miller and Spencer,[5] and the forbidden amplitude was taken from experimental data[3] for DCX on ^{16}O. The two amplitudes were added, *each with unit multiplication factor,* the only parameter being an energy-dependent phase, which, however, turned out to have a rather simple behavior, beginning near zero at low π energies and becoming near 90° at energies near 170 MeV. It is significant that no enhancement or quenching factors were needed in order to correctly account for the ^{18}O data.

One feature of the data and the model is that the forbidden process is most important near 160 MeV, becoming virtually ignorable at energies near 300 MeV. If the model is correct, we would expect to see its consequences in DCX on other isotopic sequences. In the present paper, we use simple theoretical features of allowed DCX and a measured value[6] of the DCX cross section on ^{40}Ca to predict DCX cross sections on other isotopes of Ca. Throughout, we consider forward-angle cross sections only.

In the model of Johnson,[7] allowed DCX (DIAT) cross sections vary with N, Z, A according to the expression

$$\sigma \alpha (N-Z)(N-Z-1)A^{-10/3} .$$

Thus, in any model of DIAT, the cross section for ^{42}Ca would be $(\frac{42}{18})^{-10/3}=5.93\times10^{-2}$ of that for ^{18}O. At 164 MeV, Miller and Spencer[5] predict $\sigma(^{18}\mathrm{O}) =0.55\,\mu$b/sr, a value which gave reasonable agreement in the model of Ref. 3. Thus, we would expect $\sigma(^{42}\mathrm{Ca})=3.3\times10^{-2}\,\mu$b/sr at 164 MeV for the allowed DIAT route. To this, however, we must add the contribution from the ^{40}Ca core—the "forbidden" non-DIAT component. A measurement[6] for ^{40}Ca$(\pi^+,\pi^-)^{40}$Ti at 164 MeV and 5° gives $\sigma(^{40}\mathrm{Ca})=0.155\pm0.025\,\mu$b/sr.

Now, in the ^{16}O-^{18}O pair, the relative phase near

TABLE I. Calculated forward-angle cross sections (in μb/sr) for DCX on $^{42-48}$Ca.

Nucleus	164 MeV Core (non-DIAT)[a]	DIAT[b]	Total[c]	292 MeV Total = DIAT[d]
^{42}Ca	0.155 ± 0.025	3.3×10^{-2}	0.19 ± 0.03	0.14
^{44}Ca	0.155 ± 0.025	0.168	0.32 ± 0.03	0.73
^{48}Ca	0.155 ± 0.025	0.585	0.74 ± 0.03	2.56

[a]As measured in ^{40}Ca$(\pi^+, \pi^-)^{40}$Ti (Ref. 6).
[b]Using predicted DIAT cross section of 0.55 μb/sr for ^{18}O (Ref. 5) and $(N-Z)(N-Z-1)A^{-10/3}$ dependence of Ref. 7.
[c]For a relative phase of 90° between the two routes.
[d]Ignores non-DIAT route at this energy.

164 MeV was approximately 90°, so that if we assume similar behavior of phase with energy for Ca, we may merely add cross sections—there is no interference term. The phase is not accurately determined in Ref. 3 for ^{18}O$(\Delta\phi = 93 \pm 9°$ at 164 MeV) and, up to now, has not been reliably calculated in any model, so our estimate may be somewhat in error. But in any case, it must be *near* 90°. In what follows, we use a phase of 90° throughout. *Except for this phase, there are no adjustable parameters in our calculation.*

Thus, for ^{42}Ca at 164 MeV, we predict a cross section of 0.19 ± 0.03 μb/sr, where the uncertainty arises from that of the ^{40}Ca measurement. Note that, unlike ^{18}O, the bulk of this ^{42}Ca cross section comes from the "forbidden" route. Our predicted value is about six times that expected solely from DIAT!

For ^{44}Ca and ^{48}Ca, if the cores remain unchanged, the "forbidden" cross section will be the same as for ^{40}Ca and ^{42}Ca, whereas the "allowed" cross section will increase as $(N-Z)(N-Z-1)A^{-10/3}$. Resulting cross section predictions are listed in Table I. We note that our two-amplitude model predicts a ratio $\sigma(^{48}\mathrm{Ca})/\sigma(^{42}\mathrm{Ca}) = 3.9 \pm 0.5$, rather than the value of 18 expected[7] for DIAT alone. Thus, at 164 MeV, the presence of the non-DIAT route is predicted to increase the ^{42}Ca DCX cross section by a factor of 6 and to decrease the ^{48}Ca/^{42}Ca ratio by a factor of about 4.5 from predictions that ignore this component.

At 292 MeV, the situation is quite different. There the non-DIAT amplitude is negligible, as evidenced by very small DCX cross sections measured[8] at that energy for $T = 0$ targets. Indeed, the measured[8] ^{18}O cross section at 292 MeV is 2.40 ± 0.19 μb/sr, and the calculated DIAT value[5] is 2.4 μb/sr, giving further evidence that the non-DIAT process can be ignored at this energy.

Knowledge of the ^{18}O cross sections and nonimportance of the non-DIAT route at 292 MeV allow simple predictions for ^{42,44,48}Ca at this higher energy. They are obtained from ^{18}O simply by scaling as $(N-Z)(N-Z-1)A^{-10/3}$. These values are also listed in Table I.

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