Population of $T_<$ states in pion double charge exchange at $T_\pi = 292$ MeV

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Double charge exchange at 292 MeV and 5° populates $T_<$ states with a cross section (summed up to the double analog state) that is simply related to the double analog cross section.

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At a bombarding energy of 292 MeV and a laboratory angle of 5°, double-charge-exchange (DCX) cross sections leading to the double isobaric analog state (DIAS) have been measured for many nuclei—from ^{14}C to ^{208}Pb. In medium to heavy nuclei, the DIAS sits atop a continuum background—which consists of pions from reactions in the target. At large negative Q value, i.e., well above the DIAS in excitation energy, the background is clearly dominated by multibody (mostly four-body) phase space. However, at very low excitation energy some of the background undoubtedly arises from DCX to low-lying states in the residual nucleus. At an arbitrary Q value, the relative contribution of the two processes is unknown. No one has yet calculated the background from anything approaching "first principles." Standard practice is to fit it with a simple algebraic form—either polynomial or exponential in the Q value (or a combination of the two). We would like to understand the background in the two regimes.

For many nuclei, including ^{44}Ca, ^{56}Fe [1], $^{\rm nat}$Se [2], ^{93}Nb [3,4], ^{115}In [5], ^{128}Te [6], and ^{138}Ba [7], one or more discrete states are observed just below the DIAS. The nature of these states and the mechanism for populating them are presently unknown.

In selected experiments [3,4,7–9], the position of the DIAS in the focal plane was such that the resulting histogram contained most of the region below the DIAS (i.e., less negative Q value). In those cases, we have summed the total yield for $Q > Q_{\rm DIAS}$—after correcting for spectrometer acceptance, and with no background subtracted. (In practice, the sum stops just below the DIAS, not at its centroid.) We have then compared this total yield with the extracted DIAS cross section—which has had background subtracted, of course. If the yield below the DIAS comes from populating states in the final nucleus, then all these states must be $T_<$ in character, i.e., they must have isospin lower than that of the DIAS—which, by definition, is the lowest state of that isospin.

For ^{60,62,64}Ni we have removed the electron contribution to the background as described in Ref. [8] and summed the remaining cross section for $Q > Q_{\rm DIAS}$. Results are listed in Table I. For ^{138}Ba, four peaks below the DIAS have a combined cross section (Table II of Ref. [7]) of 1.35 ±0.10 μb/sr, compared with 0.77±0.07 for the DIAS. If all of the cross section up to the DIAS is summed (continuum plus peaks), the sum is 2.22 μb/sr. This value is also listed in Table I, along with results for ^{48}Ca and ^{93}Nb from the references indicated.

The data sample contains only nuclei with $T \geq 2$, as the DIAS is the g.s. for $T = 1$, and no data exist for $T = \frac{3}{2}$. We have selected only those experimental results [3,4,8,9] in which the measured missing-mass histogram covers most or all of the region between the g.s. and the DIAS. Isospins range from $T = 2$ (^{60}Ni) to $T = 13$ (^{138}Ba). Results are listed in Table I, along with other information: T, $Q_{\rm g.s.}$, $Q_{\rm DIAS}$. A regular trend is apparent in the numbers. The ratio $R \equiv \sigma(T_<)/\sigma(\rm DIAS)$ is much smoother than either quantity alone. A systematic fit [10] to DIAS cross sections at 292 MeV and 5° has resulted in σ(DIAS) $= C(N-Z)(N-Z-1)A^{-3.24}$. If the $\sigma(T_<)$ cross sections display the same (or similar) A-dependent distortions as those for the DIAS, taking the ratio would remove most of the distortion factor. If the $T_<$ cross sections depend

TABLE I. DIAS and summed $T_<$ cross sections (DIAS cross sections for Ni nuclei from Ref. [8], for ^{48}Ca from Ref. [9], ^{93}Nb from Ref. [4], and ^{138}Ba from Ref. [7]; summed $T_<$ cross sections for Ni from Ref. [8], others as noted below) for selected nuclei.

		DIAS		$T_<$		
A	T	$-Q$ (MeV)	σ (μb/sr)	$-Q_{\rm g.s.}$ (MeV)	σ (μb/sr)	$R^{\rm a}$
^{60}Ni	2	16.42	0.295±0.55	9.3	0.138±0.036	0.47±0.15
^{62}Ni	3	16.24	0.471±0.72	4.6	0.311±0.053	0.66±0.15
^{64}Ni	4	16.19	0.974±0.172	0.1	0.846±0.133	0.87±0.21
^{48}Ca	4	11.84	1.746±0.290	-5.29	1.36$^{\rm b}$ ± 0.23	0.78±0.23
^{93}Nb	$\frac{11}{2}$	21.92	0.512±0.022	2.58	0.526±0.045	1.03±0.10$^{\rm c}$
^{138}Ba	13	27.0	0.77±0.07	-0.32	2.22±0.14	2.88±0.20$^{\rm d}$

$^{\rm a}R \equiv \sum_{E_x=0}^{E_{\rm DIAS}} \sigma/\sigma(\rm DIAS)$.
$^{\rm b}$Value at 300 MeV: A.L. Williams (private communication).
$^{\rm c}$Reference [4] and M. Kagarlis (private communication).
$^{\rm d}$Reference [7] and J.M. O'Donnell (private communication).

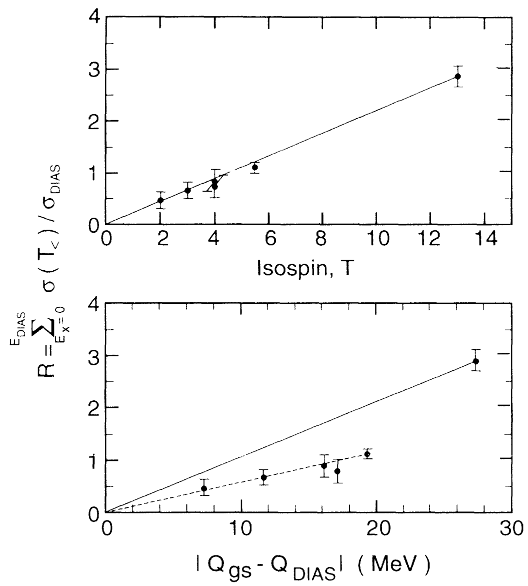

FIG. 1. The quantity $R \equiv \sum_{E_x=0}^{E_{\mathrm{DIAS}}} \sigma/\sigma(DIAS)$ is plotted vs isospin T of the target (top) and $|Q_{\mathrm{g.s.}} - Q_{\mathrm{DIAS}}|$ (bottom), for the (π^+,π^-) reaction at $T_\pi = 292$ MeV and $\theta_{\mathrm{lab}} = 5°$.

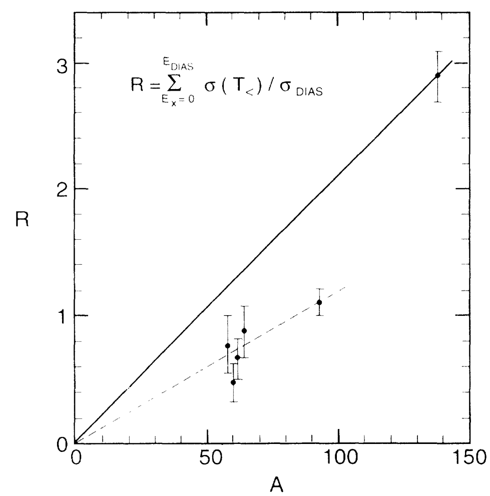

FIG. 2. R values from Table I vs A of the target.

primarily on available phase space, we might expect them to increase with $|Q_{\mathrm{g.s.}} - Q_{\mathrm{DIAS}}|$. In Fig. 1, we plot the quantity $R \equiv \sigma(T_<)/\sigma(\mathrm{DIAS})$ vs T of the target and vs $|Q_{\mathrm{g.s.}}$ - $Q_{\mathrm{DIAS}}|$. Both relationships appear reasonably simple, and are well fitted by a straight line for the lighter nuclei. When plotted vs T, the ^{138}Ba result is consistent with systematics of the other nuclei. When plotted vs $|Q_{\mathrm{g.s.}} - Q_{\mathrm{DIAS}}|$, however, it differs from systematics by about a factor of 2.

If the $T_<$ states and the DIAS have comparable A-dependent distortions, then these results imply $\sigma(T_<) \sim T^3$. Alternately, the summed $T_<$ cross section per MeV of excitation—relative to σ(DIAS)—is roughly a constant. We know of no theoretical ground to expect either result. Investigation of dependence on other variables, e.g., A of the target (Fig. 2) suggests no new information. It would appear that an experiment designed to distinguish between the two possibilities $R \alpha T$ and $R\ \alpha\ |Q_{gs} - Q_{\mathrm{DIAS}}|$ would be worthwhile. We know, from limited data, that the ratio R is a strong function of pion kinetic energy, increasing dramatically as T_π is decreased from 292 to 164 MeV. A more detailed investigation of its energy dependence might also prove enlightening.

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