# Energy dependence of cross sections for pion double charge exchange on $^{60,62,64}$Ni

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Double charge exchange cross sections have been measured at $\theta_L = 5°$ and $T_\pi =$ 230, 180, and 140 MeV for targets of $^{60,62,64}$Ni. Results are compared with previous data at 292 MeV and with a generalized seniority model. [S0556-2813(97)02005-0]

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Pion-induced double charge exchange (DCX) has been investigated at several incident energies for $^{58}$Ni, for which the double isobaric analog state (DIAS) is the ground state (g.s.). References [1,2] present 5° cross sections at a single incident energy of 292 MeV, while Ref. [3] measured an excitation function from 120 to 292 MeV, again at 5°.

A separate experiment [4] presented 292-MeV results for $^{60,62,64}$Ni. Combined with $^{58}$Ni data, the DIAS and g.s. cross sections were compared to predictions of a generalized seniority model [5,6], which gives

$$\sigma_{\rm DIAS} = \frac{n(n-1)}{2}\left|\alpha + \frac{\beta}{n-1}\right|^2,$$

$$\sigma_{\rm g.s.} = \frac{n(n-2)(2\Omega+2-n)}{2(2\Omega+1)(n-1)}|\beta|^2.$$

Apart from a factor $(A_0/A)^C$, the amplitudes $\alpha,\beta$ are independent of $N,Z,A$ of the target, but they do depend on incident energy and scattering angle. The quantity $\Omega$ is six for Ni ($2\Omega$ represents a full shell), and $n$ is the neutron excess, $n=N-Z$. In the amplitude, the exponent $C$ is about 1.5. As we are dealing with a very narrow range of $A$, we ignore this factor. At 292 MeV, the results were consistent with the generalized seniority model. The present experiment deals with results for $^{60,62,64}$Ni at other energies.

The experimental setup was as in Ref. [4], except that the strip target contained two pieces of $^{60}$Ni, and no $^{\rm nat}$Ni. Rather, $^{\rm nat}$Ni data points were obtained with a separate full target. Peak areas were extracted in the usual manner. Normalization runs using a $CH_2$ target were performed at each bombarding energy. Resulting DIAS cross sections are listed in Table I and plotted in Fig. 1 for each isotope.

Because DIAS cross sections and pion beam fluxes are larger at 292 MeV, statistics are limited at these lower energies. Nevertheless, we can compare results with seniority-model predictions. Within the limited statistical accuracy, the $^{60,62,64}$Ni DIAS data allow extraction of $\alpha,\beta$, and their relative phase $\varphi$. The quantities of $\alpha,\beta$ are related to the earlier [4,5] $A,B$ by $A=\alpha+\beta/\Omega$, $B=[(\Omega-1)/\Omega]\beta$. At 292 MeV, fitting only DIAS cross sections resulted in $\alpha\approx\beta$

TABLE I. Cross sections (in nb/sr) for the DIAS as a function of energy at 5° (laboratory) for natural and isotopic Ni targets.

| $T_\pi$ (MeV) | $^{60}$Ni | $^{62}$Ni | $^{64}$Ni | $^{\rm nat}$Ni |
|---|---|---|---|---|
| 292[a] | 295±55 | 471±72 | 974±172 | 198±26 |
| 260 | | | | 196±46 |
| 230 | 172±29 | 360±71 | 584±114 | 168±37 |
| 180 | 89±38 | 325±89 | 463±142 | |
| 164 | | | | 100±33 |
| 140 | 52±45 | 93±82 | 212±159 | 136±117 |

[a]Ref. [4].

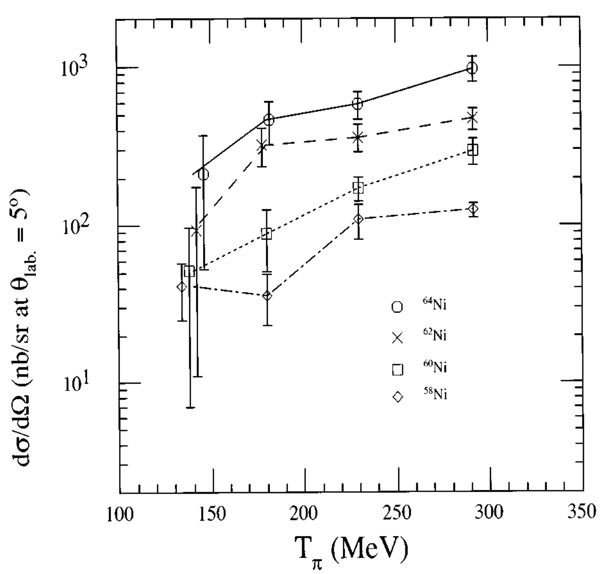


FIG. 1. Cross sections at 5° vs $T_\pi$ for the DIAS in $^{58,60,62,64}$Ni$(\pi^+,\pi^-)$. Data for $^{58}$Ni are from Ref. [3], and other 292-MeV data are from Ref. [4].

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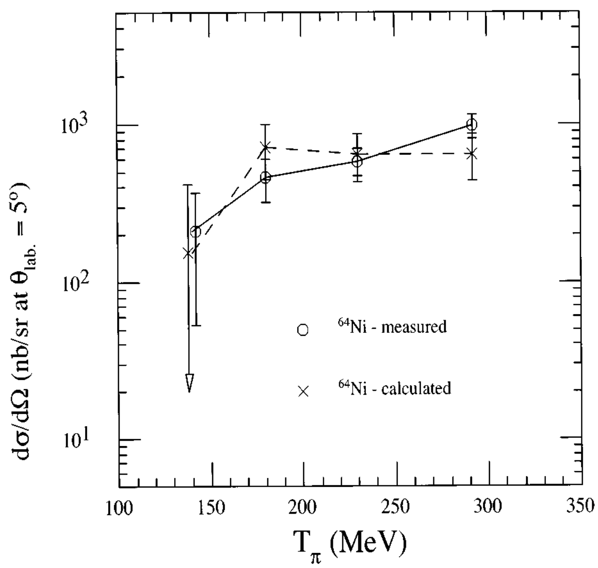


FIG. 2. Measured cross sections for $^{64}$Ni (circles) and those calculated (crosses) from $^{58,60,62}$Ni using generalized seniority: $\sigma_{64}=(4\sigma_{58}-18\sigma_{60}+20\sigma_{62})/7$.

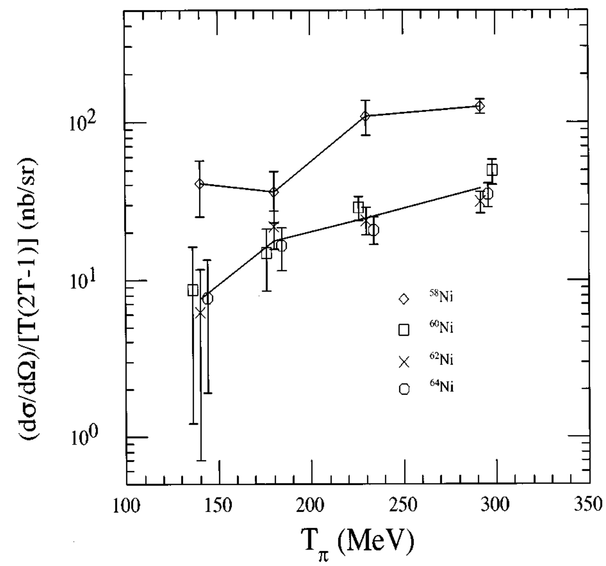


FIG. 3. Plot of $\sigma/[T(2T-1)]$ for $^{58,60,62,64}$Ni.

and $\varphi\sim 90°$, whereas a simultaneous fit to g.s. and DIAS gave $\varphi\sim 0°$ and a smaller $\beta$. Or we can combine with $^{58}$Ni (Table II) and arrive at a test of the model — which allows one of the four DIAS cross sections to be written in terms of the other three. Figure 2 plots the values of $\sigma_{64}$ thus obtained, along with its measured values. The agreement is fair.

Seniority (or generalized-seniority) models provide a convenient prescription for seeing how $T=1$ nuclei differ from all others — it is only for $T=1$ that the $\beta$ term contributes fully; for $T>1$, it is attenuated by a factor $1/(n-1)$. Seldom are statistics good enough to separately distinguish the $\beta$ coefficient in these higher $T$ nuclei, but it is frequently the case that $T=1$ differs appreciably from the others. In the present example, we can note that difference by plotting $\sigma/[T(2T-1)]$ as is done in Fig. 3. There we see that the reduced cross section for $T=1$ is significantly greater than for the other three nuclei — all of which are essentially identical.

TABLE II. Measured 5° cross sections (nb/sr) for $^{58,64}$Ni and calculated $^{64}$Ni cross section.

| | | $^{64}$Ni | |
|---|---|---|---|
| $T_\pi$ (MeV) | $^{58}$Ni[a] | measured | calculated[b] |
| 292 | $125\pm13$ | $974\pm172$ | $648\pm211$ |
| 230 | $109\pm27$ | $584\pm114$ | $649\pm217$ |
| 180 | $36\pm13$ | $463\pm142$ | $720\pm272$ |
| 140 | $41\pm16$ | $212\pm159$ | $155\pm261$ |

[a]Ref. [3].

[b]Calculated from other three isotopes using generalized seniority (Refs. [4,5]).

One motivation of the present study was to try to determine if the energy dependence of the DIAS cross sections were different for different isospin. A hint of a difference is apparent in Fig. 1 where the gap between data for $^{58,60}$Ni and $^{62,64}$Ni appears larger at 180 MeV than at other energies. This difference is scarcely statistically significant, but we can average cross sections at the two lowest and two highest energies separately (Table III) to decrease the uncertainties. When we do that, we find

$$\frac{\langle\sigma(140{,}180\ \ \mathrm{MeV})\rangle}{\langle\sigma(230{,}292\ \ \mathrm{MeV})\rangle}$$

for $^{58,60}$Ni is $0.33\pm0.08$, while for $^{62,64}$Ni it is $0.50\pm0.11$. The ratio of the two ratios is $0.65\pm0.21$—not quite twostandard deviations from unity. Thus, despite the appearance in Fig. 1, we observe no statistically significant differences in the excitation functions of the four nuclei.

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TABLE III. Cross sections averaged for two low and two high energies.

| $T_\pi$(MeV) | $^{58}$Ni | $^{60}$Ni | $^{62}$Ni | $^{64}$Ni | $^{nat}$Ni |
|---|---|---|---|---|---|
| 230,292 | $122\pm12$ | $199\pm26$ | $415\pm51$ | $703\pm95$ | $188\pm21$ |
| 140,180 | $38\pm10$ | $74\pm29$ | $209\pm60$ | $352\pm106$ | $103\pm32$ |
| Ratio | $0.31\pm0.09$ | $0.37\pm0.15$ | $0.50\pm0.16$ | $0.50\pm0.16$ | $0.55\pm0.18$ |
| Ave. all $T_\pi$ | $80\pm8$ | $137\pm19$ | $312\pm39$ | $528\pm71$ | $162\pm18$ |
| $\sigma_{\mathrm{ave}}/[T(2T-1)]$ | $80\pm8$ | $22.8\pm3.2$ | $20.8\pm2.6$ | $18.9\pm2.5$ | |

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