PHYSICAL REVIEW C VOLUME 35, NUMBER 3 MARCH 1987

Double charge exchange on ^{56}Fe

H. T. Fortune* and S. Mordechai†
University of Pennsylvania, Philadelphia, Pennsylvania 19104
and University of Texas at Austin, Austin, Texas 78712

R. Gilman,‡ K. Dhuga,§ and J. D. Zumbro
University of Pennsylvania, Philadelphia, Pennsylvania 19104

G. R. Burleson and J. A. Faucett
New Mexico State University, Las Cruces, New Mexico 88003

C. L. Morris
Los Alamos National Laboratory, Los Alamos, New Mexico 87545

P. A. Seidl** and C. Fred Moore
University of Texas at Austin, Austin, Texas 78712

(Received 20 October 1986)

Previous data for (π^+,π^-) double charge exchange on ^{56}Fe have been extended by measuring forward-angle cross sections at six additional energies.

An earlier paper[1] reported cross sections for the double charge exchange (DCX) reaction ^{56}Fe$(\pi^+,\pi^-)^{56}$Ni at five pion energies and a laboratory angle of 5° for two 0^+ final states—the ground state (g.s.) ($T=0$) and the analog state ($T=2$) at 9.6 MeV. Both excitation functions were essentially monotonic—that for the g.s. falling as T_π increased from 164 to 292 MeV and that for the analog state rising. Both features were similar[2–5] to those observed for other light nuclei. But in virtually all other cases, the nonanalog excitation functions peaked near 164 MeV, and the analog [double isobaric analog state (DIAS)] excitation functions had a minimum or plateau near that energy. We have therefore extended the previous data by measuring cross sections at five additional energies, viz., 80, 100, 120, 180, and 230 MeV plus an overlap point at 292 MeV.

Experimental details were as reported previously, except that for the present work a full $^{\rm nat}$Fe target was used. Its areal density was 2.44 g/cm^2. Results (circles) are plotted in Fig. 1, which also contains the previous data (crosses). We note that, with the new data, the nonanalog (g.s.) excitation function does exhibit a peak—but near 140 MeV, lower than previously observed for any nonanalog transition. And the analog excitation function now appears to have a minimum near 140–160 MeV and an increase below that energy.

In fact, above 100 MeV, the DIAS data for ^{56}Fe are qualitatively similar to those for ^{18}O (Ref. 2), except that the ^{56}Fe cross section rises faster with increasing pion energy. This difference can be seen in Fig. 2, in which we plot the ^{56}Fe DIAS data from Fig. 1, and compare it to the earlier ^{18}O data[2,6] with two different normalizations.

Standard theories[7] of analog DCX predict that forward-angle cross sections should scale as $(N-Z)(N-Z-1)/2A^{10/3}$. For ^{56}Fe and ^{18}O, the ratio would be 0.136, and this is the factor multiplying the ^{18}O cross sections before plotting the solid curve. We thus note that, at high pion energies, the ^{56}Fe and ^{18}O cross sections are in about the expected ratio.

However, near 140 MeV, the ^{56}Fe DIAS cross section is smaller than that for ^{18}O by about a factor of 30, as indi-

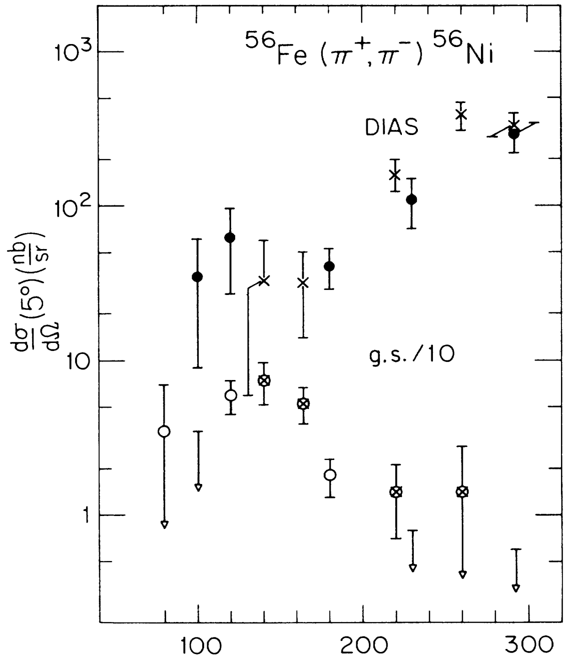

FIG. 1. Plot of 5° ^{56}Fe$(\pi^+,\pi^-)^{56}$Ni cross sections for g.s. and 0^+, $T=2$ state at 9.6 MeV excitation. Previous data are plotted as crosses, new data as circles. The g.s. data have been divided by a factor of 10 for this plot.

©1987 The American Physical Society

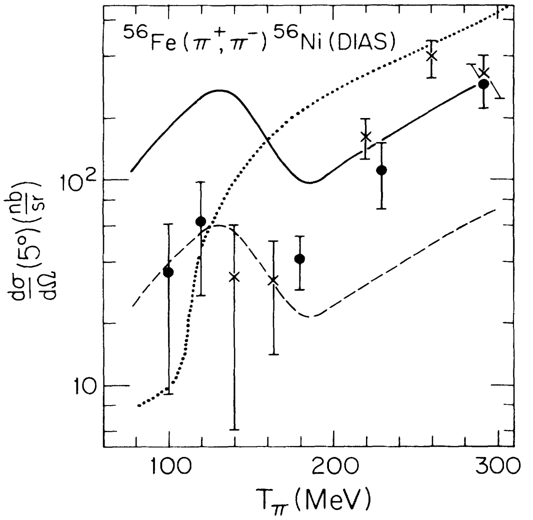

FIG. 2. The ^{56}Fe DIAS data compared with smooth curves drawn through the ^{18}O data, normalized downward by a factor 0.136 (solid line) and 0.030 (dashed line). The dotted curve results from first-order calculation.

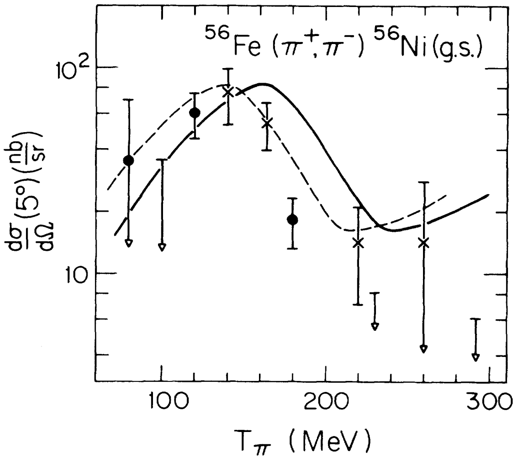

FIG. 3. The ^{56}Fe(g.s.) data compared with smooth curves drawn through the ^{16}O data, unshifted (solid line) and shifted (dashed line). The curves have been multiplied by a factor of 0.188 before plotting.

cated by the dashed line. Furthermore, it is the ^{56}Fe cross section that more closely resembles the expected DIAS behavior. The dotted curve is a lowest-order calculation with the code PIESDEX.[8] It is thus likely that the ^{18}O cross section is enhanced at energies near 140 MeV, rather than the ^{56}Fe cross section being too small.

The ^{56}Fe nonanalog (g.s.) data are plotted in Fig. 3, and compared with a smooth curve drawn through earlier ^{16}O nonanalog data.[4,9] For both curves, the ^{16}O data have been multiplied by a factor of 0.188. The solid curve has no energy shift; the dashed curve has been shifted downward by 24 MeV. This factor of 0.188 is the ratio expected for the $A^{-4/3}$ mass dependence previously observed[10] for nonanalog g.s.→g.s. transitions.

The shifted curve gives a better representation of the ^{56}Fe(g.s.) data, but it appears that the peak in the ^{56}Fe data is also somewhat narrower than in ^{16}O. The energy shift is roughly that needed to equate the π^- energies in the two cases, as $Q=-5.7$ MeV for ^{56}Fe and -28.4 MeV for ^{16}O.

For the analog case, our results contradict the implication in Ref. 11 that DIAS cross sections all have the same energy dependence. It is obvious from Fig. 2 that the ^{18}O and ^{56}Fe energy dependences are different. In Ref. 11, it is noted that the average ratio of cross sections at 292 and 180 MeV for about eight nuclei is $\sigma(292)/\sigma(180)=2.9\pm0.2$. For ^{56}Fe, the ratio is 7.5 ± 2.5. At slightly lower energies, the effect is even greater, as mentioned above. At 292 MeV the ^{56}Fe/^{18}O ratio is 0.135 ± 0.024, to be compared with an expected ratio of 0.136. However, for five energies between 100 and 180 MeV, the ^{56}Fe/^{18}O ratio is 0.034 ± 0.009. Hence, the energy dependence of the DIAS cross section in ^{56}Fe is considerably different from that in ^{18}O.

We acknowledge support from the National Science Foundation, the U.S. Department of Energy, and the Robert A. Welch Foundation.

---

*Permanent address: Physics Department, University of Pennsylvania, Philadelphia, PA 19104.

†Permanent address: Physics Department, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel.

‡Present address: Argonne National Laboratory, Argonne, IL 60439.

§Present address: New Mexico State University, Las Cruces, NM 88003.

**Present address: Lawrence Berkeley Laboratory, Berkeley, CA 94720.

[1] P. A. Seidl *et al.*, Phys. Rev. Lett. **50**, 1106 (1983).

[2] S. J. Greene *et al.*, Phys. Rev. C **25**, 927 (1982).

[3] P. A. Seidl *et al.*, Phys. Rev. C **30**, 973 (1984).

[4] S. J. Greene *et al.*, Phys. Lett. **88B**, 62 (1979).

[5] L. C. Bland *et al.*, Phys. Lett. **128B**, 157 (1983).

[6] P. A. Seidl *et al.*, Phys. Lett. **154B**, 255 (1985).

[7] M. B. Johnson, Phys. Rev. C **22**, 192 (1980).

[8] M. B. Johnson and E. R. Siciliano, Phys. Rev. C **27**, 730 (1983).

[9] L. C. Bland *et al.*, J. Phys. G **8**, L173 (1982).

[10] C. L. Morris *et al.*, Phys. Rev. C **25**, 3218 (1982).

[11] K. K. Seth *et al.*, Phys. Lett. **155B**, 339 (1985).