Observation of a Double Isobaric Analog State in the Reaction ^{209}Bi(π^+, π^-)^{209}At

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Pion double charge exchange has been used to populate the double isobaric analog state in ^{209}At with use of the neutron-rich target ^{209}Bi. The data were obtained at an energy of 292 MeV and at an angle of 5°, as the double-charge-exchange reaction mechanism has been shown to be dominated by analog transitions under these conditions in previous work on light nuclei. The measured cross section is found to be in good agreement with semiclassical predictions by Johnson.

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Double isobaric analog states (DIAS), i.e., states with $T = T_Z + 2$, are known to exist in light nuclei. Because of their high excitation energies, observing such states requires either a probe which will selectively excite them or some unique signature of the DIAS so that they can be separated from the background of lower-T states. The first observation of DIAS was made by Garvey, Cerny, and Pehl[1] using the reaction (p,τ) on targets of ^{26}Mg, ^{54}Fe, and ^{49}Ti. Such a reaction is unsuitable for observing DIAS in the large-A region of the periodic table because the ratio of cross sections for populating $T = T_Z + 2$ states to $T = T_Z$, in a given nucleus, is approximately $1/T^2$.[2]

The only reported observation of a DIAS in heavy nuclei by Hoffmann *et al.*[3] used the isospin forbidden reaction

$$p + {}^{209}\text{Bi} \rightarrow {}^{210}\text{Po(DIAS)} \rightarrow {}^{209}\text{Bi(IAS)} + p \rightarrow {}^{208}\text{Pb(g.s.)} + 2p,$$

where the two deexcitation protons where detected in coincidence to provide a unique signature of the reaction. More recent attempts to reproduce the results of this experiment have failed.[4]

Although the possibility of exciting DIAS with use of pion double charge exchange (DCX) at energies near the (3,3) resonance has been recognized for some time,[5] beams with sufficient pion flux and spectrometer systems with adequate energy resolution to study this reaction have not been available until recently.[6] Initial studies of DCX were quite disappointing with regard to observing DIAS in high-A nuclei since, in the low-A region at energies below the (3,3) resonance, both analog and nonanalog transitions were observed to be equally likely. Also DCX cross sections appeared to drop sharply as a function of A.[6]

More recent results,[7,8] which have extended forward-angle DCX measurements to energies well above the (3,3) resonance on isotopic pairs of targets: ^{16,18}O and ^{24,26}Mg, have led to several important observations: (1) The analog to nonanalog cross-section ratios at 5° increase from a minimum of 3:1 and 1.2:1 at energies near the (3,3) resonance to 20:1 and 70:1 at 292 MeV for the oxygen and magnesium isotopes, respectively; (2) although cross-section angular distributions have nonsimple diffraction shapes at 164 MeV,[9] angular distributions at 292 MeV on both ^{18}O and ^{26}Mg are consistent with simple diffraction shapes with use of appropriate strong-absorption radii; and (3) analog DCX cross sections on both ^{18}O and ^{26}Mg peak at 292 MeV and are about a factor of 3 larger than at energies near the (3,3) resonance. Thus it appears that DCX at energies above the resonance may show the needed analog dominance to study DIAS in heavy nuclei.

Consequently, we have undertaken a study of the reaction ^{209}Bi(π^+,π^-)^{209}At(DIAS). The data were obtained at an incident pion energy of 292 MeV (lab) and at 5° (lab), using the EPICS facility at the Clinton P. Anderson Meson Physics Facility.[10] The addition of a dipole magnet at the front

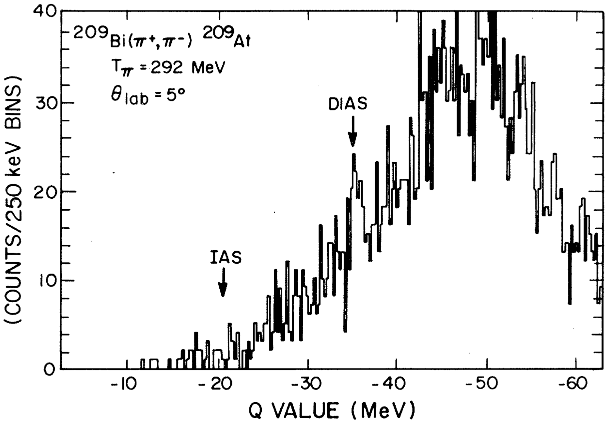

FIG. 1. Double-charge-exchange spectrum on ^{209}Bi. The arrows indicate the expected locations of the isobaric analog state (IAS) and of the double isobaric analog state (DIAS).

of the spectrometer to permit small-angle DCX measurements has been described previously.[7]

The result consists of one DCX Q-value spectrum (Fig. 1). The energy where the DIAS is expected to occur can be calculated by

$$Q = -2E_C + 2(M_n - M_p) = -35.2 \text{ MeV}, \qquad (1)$$

where E_C is the Coulomb displacement energy[11] and $M_n - M_p$ is the neutron-proton mass difference. A peak can be seen to occur near this energy, which is marked by a vertical arrow in the figure. An analysis of this peak, located at 35 ± 1 MeV (most of the error in the location comes from systematic errors), indicates it is about standard deviations above the background. The width of the state is about 1 MeV and the cross section to this state is 0.46 ± 0.15 μb/sr.

Assuming analog dominance and using a semiclassical theory, Johnson[12] has derived a simple expression for the A dependence of pion DCX cross sections to DIAS given by

$$d\sigma(\theta = 0°)/d\Omega \simeq \sigma_0 A^{-10/3}(N-Z)(N-Z-1). \qquad (2)$$

In Fig. 2 we show the present datum along with the two previously reported[7,8] cross sections for DCX to DIAS at 292 MeV and 5°. Fitting the data with the above form gives $\sigma_0 = 20$ mb/sr and accounts for the A dependence of these cross sections remarkably well.

In conclusion, we have observed the DIAS of the ground state of ^{209}Bi in ^{209}At using the pion DCX reactions. The Q value for this reaction agrees with predictions based on Coulomb displacement energies measured in earlier studies of IAS. The cross sections for exciting the DIAS in pion DCX are remarkably well described by a

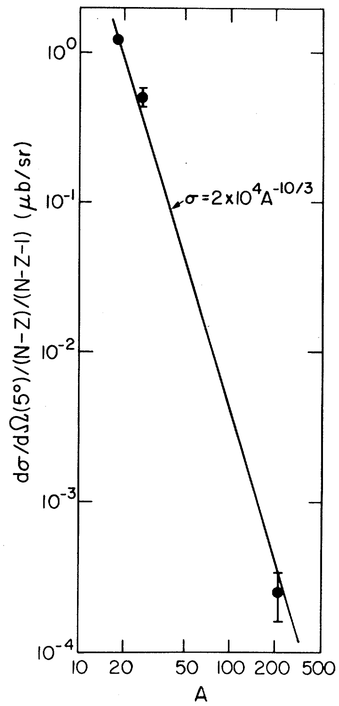

FIG. 2. A dependence of all of the measured 5° cross sections for DCX transitions to DIAS at 292 MeV. The solid curve is a prediction based on the semiclassical approximation of Johnson (Ref. 12) as given in Eq. (2).

single semiclassical theory of such transitions.

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[1]G. T. Garvey, J. Cerny, and R. H. Pehl, Phys. Rev. Lett. 12, 726 (1964).
[2]J. P. Schiffer, in *Isospin in Nuclear Physics*, edited by D. H. Wilkinson (North-Holland, Amsterdam, 1969), p. 667.
[3]G. W. Hoffmann *et al.*, Phys. Rev. Lett. 28, 41 (1972).
[4]W. E. Benenson, private communication.
[5]P. E. Boynton, Phys. Rev. 174, 1083 (1968).
[6]M. D. Cooper, in Proceedings of the LAMPF Workshop on Pion Single Charge Exchange, 1979, edited by H. Baer, D. Bowman, and M. Johnson, LASL Report No. LA-7892, 1979 (unpublished), p. 194; K. K. Seth, *ibid*, p. 201.
[7]S. J. Greene *et al.*, Phys. Lett. 88B, 62 (1979).
[8]G. R. Burleson, in Proceedings of the Workshop on Nuclear Structure with Intermediate Energy Probes, 1980, edited by H. A. Thiessen, LASL Report No. LA-8303-C, 1980 (unpublished); S. J. Greene, *ibid.*
[9]K. K. Seth *et al.*, Phys. Rev. Lett. 43, 1574 (1979).
[10]"A Proposal for EPICS," LASL Report No. LA-4534-MS, 1970, edited by H. A. Thiessen (unpublished).
[11]G. M. Crawley *et al.*, Phys. Rev. C 2, 1071 (1970).
[12]M. B. Johnson, Phys. Rev. C 22, 192 (1980).