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BRIEF REPORTS

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Double analog state in odd-A nuclei

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Measurements were performed using pion double charge exchange to observe the double isobaric-analog state (DIAS) in the odd-A nuclei ^{51}V, ^{59}Co, ^{115}In, and ^{197}Au. These results are combined with data for other odd-A targets and used to investigate the N, Z, and A dependence of DIAS cross sections.

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The (π^+,π^-) pion double-charge-exchange (DCX) reaction has been used extensively to observe the double isobaric analog state (DIAS), which by the selective nature of this reaction is strongly populated. The energy, angle, and mass dependences of DIAS cross sections have been investigated for DCX on many different nuclei (Refs. [1–4], and references therein). But almost all of these nuclei have been of even mass—few measurements have been made using odd-A nuclei. The mechanism for populating the DIAS is potentially much simpler for even-A targets than for odd A. Even in single charge exchange to the isobaric-analog state, three separate amplitudes can contribute for odd-A targets [5], but only one for even A.

Prior to the present work, odd-A DIAS data existed at 295 MeV and 5° for ^{51}V [2] and ^{209}Bi [6], both with large uncertainties. The only other odd-A measurement at energies near the Δ resonance were for ^{93}Nb and included an angular distribution at 295 MeV [7], and 5° cross sections at $T_\pi = 164, 230, 295$ MeV [8]. The previous 295 MeV, 5° DIAS cross sections for odd-A nuclei are listed in Table I.

Recently there have been investigations into the systematics of resonances built on the giant dipole which are observed in pion DCX [9, 10]. In the (π^+,π^-) reaction these resonances are the dipole analog (DA) and the double dipole (DD). The spectrometer settings used in some of these experiments were such that the DIAS could be observed in the same measurements as the DA and the DD. The DA and DD cross sections and systematics have already been published [9, 10]. We now present the DIAS cross sections and systematics.

The measurements were performed at the Clinton P. Anderson Meson Physics Facility (LAMPF) in Los Alamos, using the energetic pion channel and spectrometer (EPICS). The channel and spectrometer were configured in the standard small-angle DCX setup [11]. The measurements were performed at a pion energy of 295 MeV, this being the highest beam energy the chan-

TABLE I. DIAS cross sections for odd-A nuclei prior to the present work (T_π = 295 MeV, and $\theta = 5°$).

Nucleus	$d\sigma/d\Omega$ (μb/sr)	Ref.
^{51}V	0.766 ± 0.155	[2]
^{93}Nb	0.630 ± 0.030	[7][a]
	0.512 ± 0.022	[8][b]
^{209}Bi	0.46 ± 0.15	[6]

[a] This reference also contains an angular distribution.
[b] This reference also contains 5° cross sections at T_π = 164 and 230 MeV.

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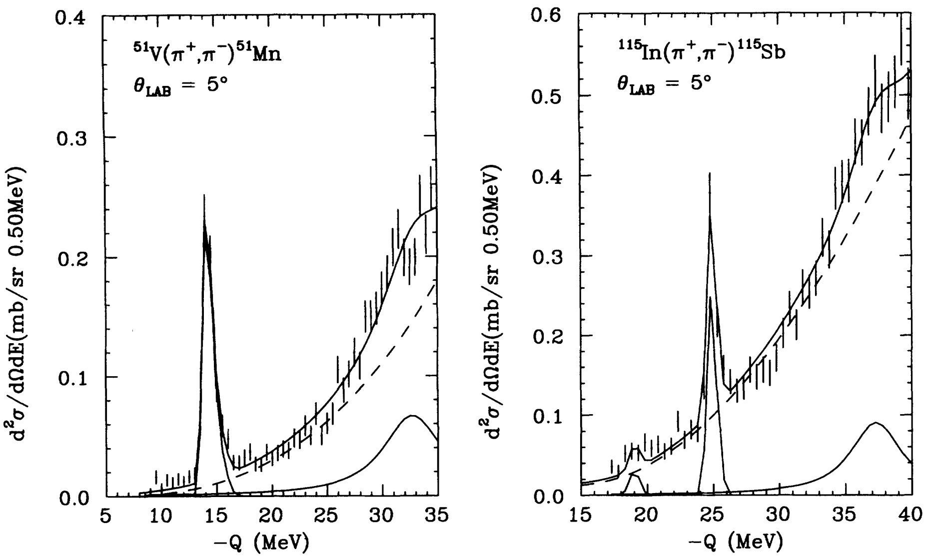

FIG. 1. Energy spectra for ^{51}V and $^{115}In(\pi^+,\pi^-)$ at T_π = 295 MeV and 5°. The large central peak is the DIAS signal. In ^{115}In a weaker state was observed at $Q = -19.0$ MeV.

nel can reliably reach. Elastic scattering on the DCX targets was used to calibrate the energy of the channel and to find the experimental resolution shape of the system. Absolute normalizations were obtained by measuring elastic scattering on targets of CH_2, and comparing the experimental yields with cross sections calculated from π-nucleon phase shifts [12]. The EPICS spectrometer will detect pions in a range of ±8% of the central pion momentum. By changing the spectrometer magnetic fields and focusing the 4.44-MeV state in ^{12}C at several places on the focal plane, the acceptance function of the spectrometer was determined. Other experimental details can be found in Refs. [9] and [13].

The targets used in the present experiment were full sheets of mono-isotopic (natural) ^{51}V, ^{59}Co, ^{115}In, and ^{197}Au [9]. Elastic measurements on these targets determined the offsets in beam energy and energy losses in the target. Typical elastic peak widths were of the order of 0.5 MeV and were dominated by straggling in the target. The DCX data were fitted with the elastic line shape on top of a third-order polynomial background. For states with natural width, a Lorentzian peak shape folded with the elastic line shape was used in the fits. Sample DCX spectra from two of the targets, ^{51}V and ^{115}In, are displayed in Fig. 1. The DIAS is observed as a clean peak above the pion DCX background at $Q = -24.9$ MeV for ^{115}In, and at $Q = -14.08$ MeV for ^{51}V. The broad DA peaks are also apparent, and have been fitted using the same folded peak shape as in Ref. [9], mentioned above. Below the DIAS at $Q = -19.0$ MeV in ^{115}In is a weakly excited state. These states below the DIAS are not fully understood at this time, but have also been observed in other nuclei—both in even and odd A [7, 8, 14]. In the present work, ^{115}In was the only nucleus to clearly exhibit this type of state.

The other pion DCX data were analyzed in this manner, and from the fits Q values and cross sections of the DIAS were obtained. Measurements were made for $^{197}Au(\pi^+,\pi^-)$, both at 5° and 9°, and these data were analyzed, but the statistics were such that we have only an upper limit for the DIAS peak at 9°. Cross sections and Q values of all DIAS peaks observed in the present work are listed in Table II. These values have been com-

TABLE II. DIAS cross sections measured in this work, at 295 MeV.

Target	$-Q$ (MeV)	θ_{lab}	$d\sigma/d\Omega$ (μb/sr)
^{51}V	14.08 ± 0.02	5°	0.626 ± 0.033
		11°	0.239 ± 0.017
		22.5°	0.117 ± 0.020
^{59}Co	16.10 ± 0.06	5°	0.319 ± 0.054
		11°	0.092 ± 0.011
^{115}In	24.90 ± 0.03	5°	0.452 ± 0.036
		9°	0.074 ± 0.029
^{197}Au	34.68 ± 0.13	5°	0.35 ± 0.10
		9°	< 0.13

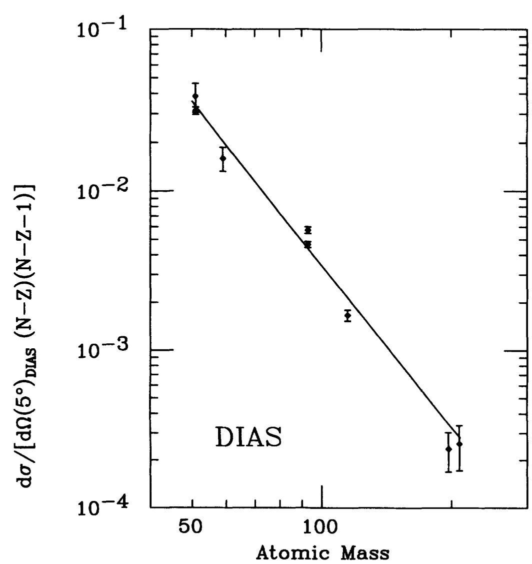

FIG. 2. Mass dependence of odd-A DIAS cross sections at T_π = 295 MeV and 5°. The straight line is the fit to the data using the formula in the text.

bined with other DIAS cross sections on odd-A nuclei, ^{93}Nb and ^{209}Bi [6–8]. The combined data set has been fitted with the M. Johnson form of the mass dependence [15]

$$\frac{d\sigma}{d\Omega}(5^\circ) = f(N-Z)(N-Z-1)\left(\frac{42}{A}\right)^\alpha . \quad (1)$$

The best fit is displayed with the data in Fig. 2. The results of this fit are $f = 64.4 \pm 4.9$ nb/sr, and an exponent $\alpha = 3.38 \pm 0.21$. These values are consistent with the fits of DIAS cross sections for even-mass nuclei [1], which have $f = 68 \pm 3$ nb/sr, and exponent $\alpha = 3.24 \pm 0.05$. The DIAS results for odd-A nuclei (though not as well determined) thus appear to be consistent with those for even-A nuclei, despite the more complicated reaction mechanism.

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