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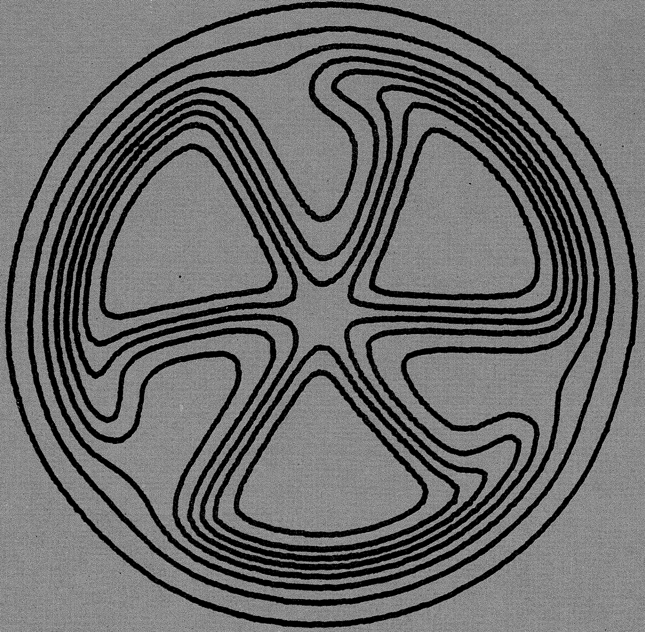

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^{40}Ar(p,n) Reaction to the Anti-Analogue State in ^{40}K*

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ABSTRACT

We have measured ^{40}Ar(p,n)^{40}K(AAS) differential cross sections at 24 MeV and made microscopic DWBA calculations for these cross sections. Unlike the (^{3}He,t) reaction to the same state, where it was necessary to invoke a two-step mechanism, the (p,n) data are fitted by the one-step calculation. A one-step calculation also fits 22.8-MeV (p,n) ^{40}K(IAS) data with the same nucleon-nucleon interaction used in the AAS calculation.

Just as a transition to the isobaric analog state (IAS) of a target is strong and insensitive to details because of the near-perfect overlap of target and IAS wave functions, a transition to the anti-analog state (AAS) may be expected to be small and insensitive to details because of the almost complete

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orthogonality of target and AAS wave functions. This sensitivity has been seen in (^{3}He,t) reactions to AAS in several nuclei where it was found that the L=0 angular distributions expected of $0^+ \to 0^+$ transitions were not observed.[1] Cross sections for the ^{40}Ar(^{3}He,t)^{40}K(AAS) computed by Schaeffer and Bertsch[2] with the direct microscopic model were one to two orders of magnitude below the observed values, but a reasonable fit was obtained when the two-step pickup-stripping process (^{3}He,α)-(α,t) was included.[2] Similar results were obtained by Coker, Udegawa, and Wolter[3] who fitted both 35-MeV[1] and 18-MeV[4] data. Experimental discrepancies with expected shapes of angular distributions have also been noted when the transferred L>0.[5] For the ^{48}Ca(^{3}He,t)^{48}Sc reaction two-step calculations using (^{3}He,α)-(α,t)[2,6] or, in addition, (^{3}He,d)-(d,t)[7] have produced fits to data where one-step calculations clearly disagreed with experiment. It seems well documented that a reaction mechanism including two-step amplitudes is needed to describe (^{3}He,t) reactions.

In order to test for the presence of a two-step amplitude in (p,n) reactions we have investigated the ^{40}Ar(p,n)^{40}K(AAS) reaction with 24-MeV protons. Neutrons were detected with a liquid scintillator, time-of-flight spectrometer[8] having an instrumental resolution of ∿0.5 nsec. In order to achieve an energy resolution sufficient to resolve the AAS neutron group (ex. ^{40}K=1.64 MeV) from the stronger group at 1.96 MeV, the flight path was increased from the normal value of ∿4.5 meters to 11.5 meters. At this flight path the maximum reaction angle at which neutrons could be observed, and therefore the maximum angle for this experiment, was 35°. The target was a one-inch long gas cell, with entrance and exit windows of 2-mil aluminum foil, operated at a pressure of 1.8 atmospheres. The neutron energy resolution computed and observed in the spectra was ∿0.18 MeV. One spectrum is shown in Fig. 1. According to the known energies of ^{40}K states[9] the nearest neighbor to the AAS is the 1.96-MeV state, from which the AAS is adequately resolved. Other peaks in the spectrum may arise from excitation of doublets or clusters of states. The twin peaks marked "Al windows" in Fig. 1 arise from the ground state transition in the aluminum entrace (right-hand peak) and exit (left-hand peak) windows. The centroids of these peaks are separated by an amount corresponding to the sum of the proton energy losses in one half the entrance window, the argon gas target, and one half the exit window.

Because we used a makeshift geometry in order to achieve a long flight path for this experiment, it was not convenient to measure the proton beam charge. Instead, we observed the IAS group in each spectrum and used the published IAS cross sections,[10] which were measured at the University of Colorado, to obtain, by simple ratio, the AAS cross sections. A -6% correction was applied because the computed detection efficiencies[11] for the IAS and AAS neutron groups were 0.032 and 0.034, respectively. It is assumed that the IAS cross sections are almost the same at 22.8 MeV, where the Colorado measurements were made, and at 24.0 MeV, where our measurements were made. In fact, DWBA calculations of cross sections at these two energies give differences of only a few percent. Both the Colorado IAS cross sections and our AAS cross sections are plotted in Fig. 2. Errors shown are relative only and include the uncertainties of background subtraction. In absolute value the IAS data have an 11% error; the AAS data have the same 11% error plus a presumably smaller error for the difference between IAS cross sections at 22.8 and 24.0 MeV. The AAS point at 15° is a composite of four runs; Fig. 1 is the spectrum of one of these runs.

The curves in Fig. 2 are the results of microscopic computations with the one-step distorted-wave code DWBA-70[12] of J. Raynal and R. Schaeffer. In this code both the direct and exchange amplitudes are included in the computation. The dashed curves in the figure are for direct only; the solid curves include exchange, which is obviously not negligible. The ^{40}Ar wave function was taken as a pure $d_{3/2}^{-2}\ f_{7/2}^{2}$ configuration. All bound-state wave functions were derived from a Woods-Saxon potential with radius parameter 1.25F, diffuseness 0.65F, and spin-orbit strength 6 MeV. Proton and Neutron optical-model parameters had the "best-fit" values of Becchetti and greenlees.[13] The nucleon-nucleon effective interaction had the shape of a single Yukawa with range 1.0F. and strengths with the phenomenological values: V_0=-27 MeV, $V_{\sigma\tau}$=12 MeV; neither V_σ nor V_τ was fixed by Austin's phenomenological survey.[14] For V_σ we used the Kallio-Kolltveit value,[15] 6.5 MeV, and for V_τ we used 20 MeV.[16]

The good fit to the AAS (p,n) data in comparison with very large discrepancies between theory and experiment found in (^{3}He,t) reactions indicates that multi-step processes are much less important in (p,n) reactions. Perhaps it is to be expected that multi-step processes should readily occur when the initial and final particles are composites of nucleons. Although we have demonstrated with only one case the adequacy of a one-step treatment for the (p,n) reaction, this conclusion may be true in general because the case chosen has an intrinsically small one-step cross section and is therefore sensitive to the display of other processes.

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Figure Captions

Fig. 1 Neutron time-of-flight spectrum at 15° for 24-MeV protons on ^{40}Ar.

Fig. 2 ^{40}Ar(p,n)^{40}K cross sections to the IAS (at 22.8 MeV) and AAS (at 24.0 MeV) of the target. The IAS data are taken from ref. 10. The curves are from DWBA one-step microscopic calculations made under conditions described in the text. The dashed curves are for the direct transition only; the solid curves have both direct and exchange.

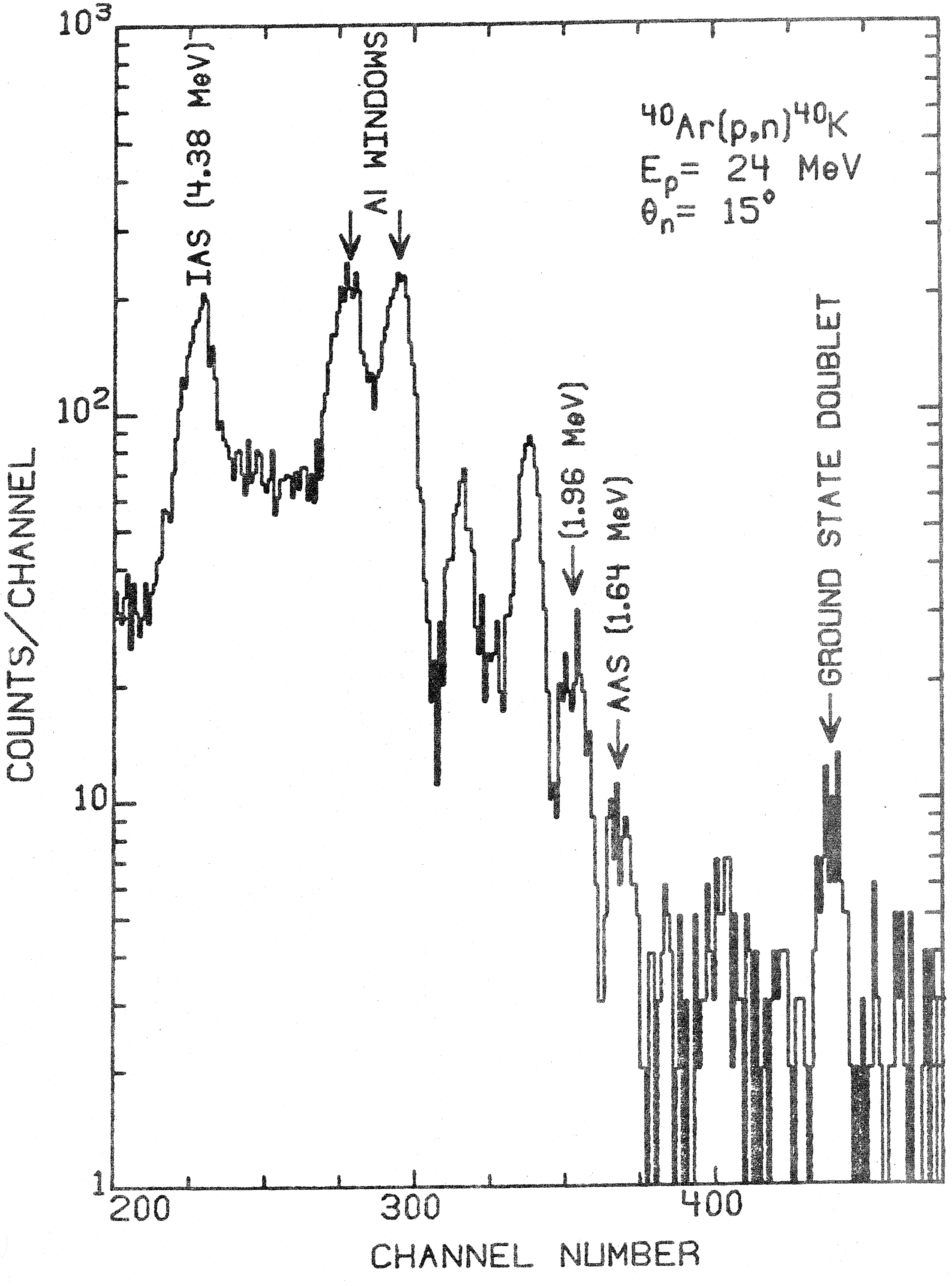
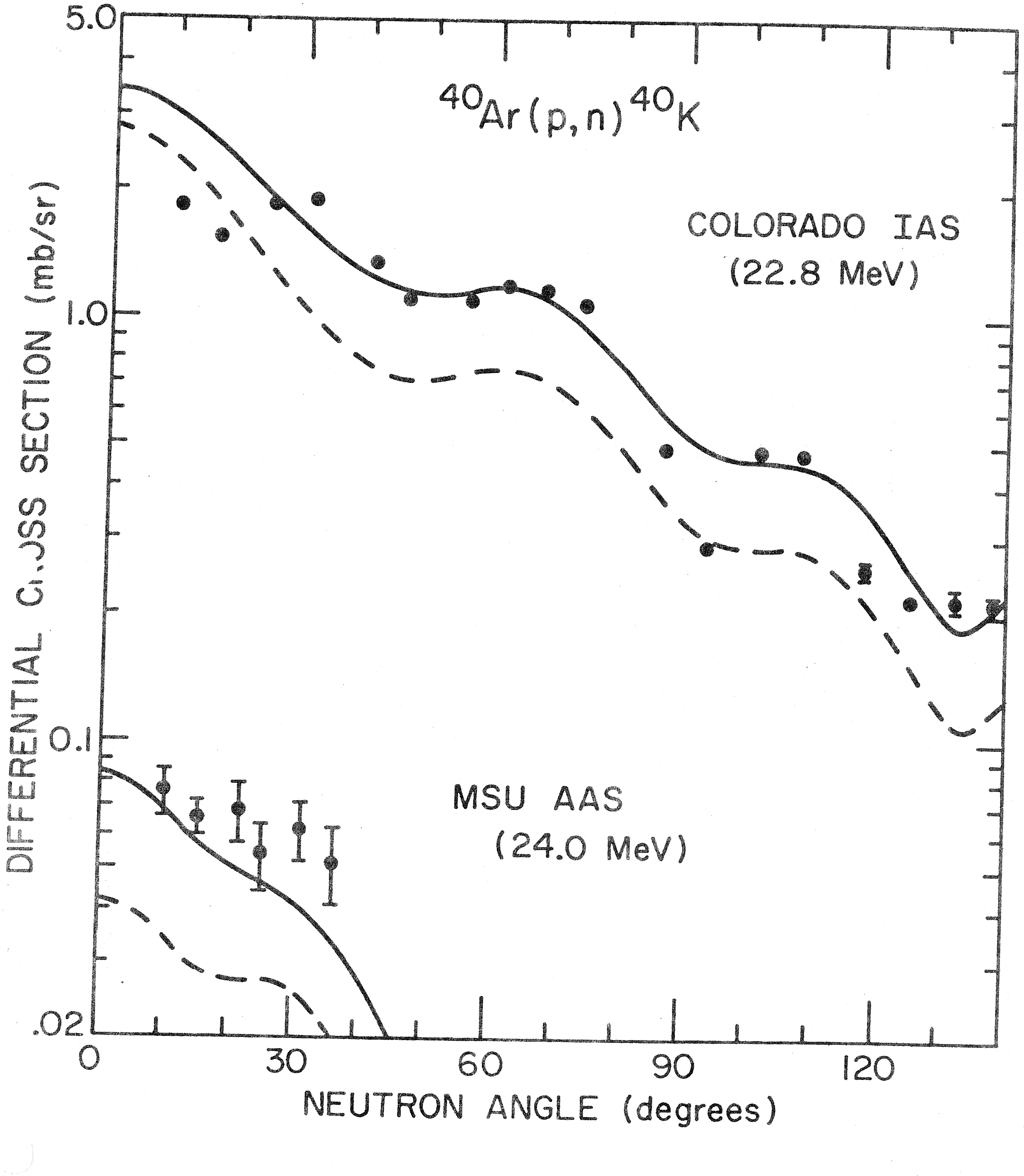

$^{40}Ar(p,n)^{40}K$
E_p= 24 MeV
θ_n= 15°
IAS (4.38 MeV)
Al WINDOWS
(1.96 MeV)
AAS (1.64 MeV)
GROUND STATE DOUBLET
COUNTS/CHANNEL
CHANNEL NUMBER
10^3
10^2
10
1
200
300
400

Figure 1



$^{40}Ar(p,n)^{40}K$
COLORADO IAS
(22.8 MeV)
MSU AAS
(24.0 MeV)
DIFFERENTIAL C.,JSS SECTION (mb/sr)
5.0
1.0
0.1
.02
0
30
60
90
120
NEUTRON ANGLE (degrees)

Figure 2