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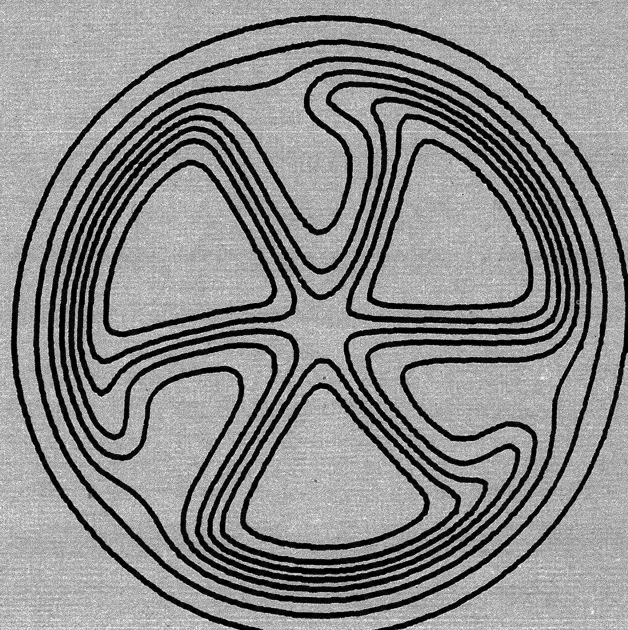

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A Microscopic Description of IAS Transitions Induced by 25-, 35-, and 45-MeV Protons*

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ABSTRACT

Differential cross sections have been measured for (p,n) reactions to the isobaric analogs of the targets ^{48}Ca, ^{90}Zr, ^{120}Sn, and ^{208}Pb at proton bombarding energies of 25, 35, and 45 MeV. The isospin-flip strength of a phenomenological nucleon-nucleon force has been determined with microscopic DWBA calculations including the "knockon" exchange amplitude. At the higher proton energies a realistic G-matrix effective interaction also provides a reasonable account of the observed angular distributions.

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Many nuclear reaction cross sections have been adequately reproduced with simple one-body-potential models. However, the goal of calculating nuclear scattering in terms of realistic forces between the individual nucleons persists. The central-force part of the effective nucleon-nucleon interaction may be expressed in the form:

$$V_{ij}=V_0 g_0(r_{ij})+V_\sigma g_\sigma(r_{ij})\sigma_i\cdot\sigma_j+V_\tau g_\tau(r_{ij})\tau_i\cdot\tau_j+V_{\sigma\tau}g_{\sigma\tau}(r_{ij})\sigma_i\cdot\sigma_j\tau_i\cdot\tau_j.$$

Attempts to extract empirical strengths from scattering data have been reviewed by Austin.[1] Assuming a Yukawa radial dependence with a 1.0-F range, he concludes that $V_0=27\pm5$ MeV, $V_{\sigma\tau}=12\pm2\frac{1}{2}$ MeV, and that V_σ and V_τ are poorly determined. In particular, his compilation includes values of V_τ from below 10 to nearly 30 MeV.

Since the isospin-flip term of the effective interaction is the only central-force component which contributes to the direct amplitude for charge-exchange scattering to $J^\pi=0^+$ isobaric analog states (IAS), these reactions are quite sensitive to V_τ. Except for the smallness of cross sections typically observed, (^3He,t) is the most experimentally convenient charge-exchange reaction with which to study such transitions. Unfortunately, conventional DWBA calculations have often been in relatively poor agreement with the data.[2] Besides the usual optical-model ambiguities for complex projectiles, complications of the reaction mechanism have been proposed. In particular, a (^3He,α)(α,t) amplitude larger than the direct amplitude has been calculated[3] for $^{48}Ca(^3He,t)^{48}Sc$ (IAS) at 23 MeV. Generally accepted optical-model parameters are available for the (p,n) charge-exchange reaction, but it has been suggested that neutron pickup followed by proton stripping may also interfere with the direct amplitude in this case.[4] The significance of (p,d)(d,n) contributions is currently under investigation by several groups including our own. We do not address this problem directly in the present paper. However, we demonstrate that straightforward DWBA calculations employing reasonable forces are capable of accounting for (p,n)-IAS angular distributions to a degree comparable with analogous (p,p') studies.

The Michigan State University Cyclotron provided beams of 25-, 35- and 45-MeV protons for inducing the reactions $^{48}Ca(p,n)^{48}Sc$, $^{90}Zr(p,n)^{90}Nb$, $^{120}Sn(p,n)^{120}Sb$, and $^{208}Pb(p,n)^{208}Bi$. The targets were self-supporting rolled foils with thicknesses of 1-30 mg/cm^2 and isotopic enrichments in excess of 96%. Differential cross sections for transitions to the isobaric analogs of the target ground states have been extracted from neutron time-of-flight spectra such as the example in fig. 1.

The basic experimental technique has been previously discussed by Jolly et al.[5] However, for this second generation of (p,n) measurements at M.S.U., we have introduced significant improvements into the system. The foremost ameliorations include a more efficient detector and a redesigned beam transport system. The latter affords reduced background, extended angular distributions, and essentially complete beam current collection. Thus, it is no longer necessary to rely on a proton monitor for normalization.

Improvements have also been made in the method of reducing time-of-flight spectra to cross sections. The computer code ANNIE[6] is used to obtain least-squares fits to neutron peaks with a fold of resolution functions representing beam energy spread, target thickness, straggling, kinematic broadening, scintillator thickness, electronic plus beam-burst time spread, and intrinsic state width. The error bars displayed on the data in fig. 2 have been obtained from curvature matrices determined by the peak-fitting algorithm, with additional contributions from the uncertainties in IAS intrinsic widths. The principal error in the absolute magnitude of the data is the estimated $\pm 10\%$ reliability of our version of Kurz's code[7] for the neutron detection efficiency calculations. There are also small uncertainties in target thickness, beam current integration, and neutron attenuation along the flight path, which may introduce additional systematic errors estimated to be less than 5%.

The theoretical angular distributions in fig. 2 have been calculated with the code DWBA70,[8] which includes the "knockon" exchange amplitude without approximations. The proton and neutron distorted waves have been generated with the Becchetti-Greenlees "Coulomb-corrected" optical-model parameters.[9] For ^{120}Sn the bound states have been represented by BCS wave functions.[10] Elementary shell-model configurations have been assumed for the other targets: $(f_{7/2})^8$, $0.8(g_{9/2})^{10} + 0.6(g_{9/2})^8(p_{1/2})^2$, and $(h_{9/2})^{10}(f_{7/2})^8(i_{13/2})^{14}(p_{3/2})^4(f_{5/2})^6(p_{1/2})^2$ for the excess neutrons in ^{48}Ca, ^{90}Zr, and ^{208}Pb, respectively.

Woods-Saxon potentials have been adjusted to bind the valence nucleons at the appropriate energies (except for the unbound IAS protons in ^{90}Nb, ^{120}Sb, and ^{208}Bi, which DWBA70 treats as bound by 0.01 MeV). The dashed curves result from phenomenological nucleon-nucleon forces taken from Austin's analysis,[1] with $V_\sigma = V_{\sigma\tau}$ and $V_\tau = 12$ and 18 MeV. The solid curves have been calculated with a realistic force derived by Bertsch[11] from the Reid soft-core potential.[12] For compatability with DWBA70, a superposition of four Yukawa potentials (with ranges of 0.2, 0.4, 0.5, and 0.7 F) has been determined[13] by fitting harmonic-oscillator matrix elements to the original G-matrix. Only the central, even terms have been retained for the present calculations.

Both the phenomenological and realistic forces yield angular distributions which follow the data but are generally smoother. The similarity in shape of the dashed and solid curves results from the $0^+ \rightarrow 0^+$ IAS transitions being dominated by the monopole component of $V_\tau g_\tau(r_{ij})$. With the 1.0-F range Yukawa form for g_τ, the best overall fits to our data at proton energies of 25, 35, and 45 MeV are obtained with $V_\tau = 19\frac{1}{2}$, $15\frac{1}{2}$, and $13\frac{1}{2}$ MeV, respectively. The spread for individual targets combined with the aforementioned experimental errors indicates that these phenomenological values are reliable within about ± 2 MeV. The G-matrix interaction produces nearly the same cross sections for these reaction as a 1.0-F Yukawa with $V_\tau = 13\frac{1}{2}$ MeV. Thus, it accounts for the data quite well at 45 MeV and fairly well at 35 MeV. However, the experimental cross sections at 25 MeV

are consistently larger than predicted. Love and Satchler have noted[14] the same difficulty for $^{90}Zr(p,n)^{90}Nb$ (IAS) at 18.5 MeV in a study employing another realistic effective interaction, the long-range part of the Hamada-Johnston potential.[15] The volume integrals of the isospin-flip components of this potential and the long-range part of the Kallio-Kolltveit potential[16] are the same as for 1.0-F Yukawas with $V_\tau \approx 12$ and 14 MeV, respectively,[1] in close agreement with the monopole charge-exchange strength of the G-matrix for the Reid soft-core potential.

Additional estimates of V_τ may be obtained from optical-model analyses of elastic and "quasi-elastic" (charge-exchange) scattering. To first order in the effective nucleon-nucleon interaction, V_τ is proportional to the magnitude of the real isovector term in the optical-model potential.[17] A macroscopic DWBA analysis of 94-MeV (p,n)-IAS data by Thurlow[18] yields only about 1/3 the isospin-flip strength found at 40 MeV in a similar study by Jolly et al.[5] Satchler has suggested[19] that the large energy dependence may only reflect uncertainties in the optical-model parameters available for DWBA calculations at 94 MeV. Nevertheless, using the parameters quoted by Thurlow, we have been able to fit the 94-MeV data for ^{27}Al, ^{51}V, and ^{208}Pb with V_τ averaging $8\frac{1}{2}$ MeV, a decrease of only 37% from our value at 45 MeV. The apparent discrepancy between the macroscopic and microscopic analyses results from the very limited angular range of the 94-MeV data coupled with the sensitivity of the forward-angle peak to the form-factor. Thus, more extensive angular distributions are necessary for a reliable determination of V_τ at 94 MeV.

Our phenomenological values for $V_\tau(E_p)$ give slopes of -0.4, -0.2, and -0.1 for the ranges 25-35, 35-45, and 45-94 MeV, respectively. Thus, although the isospin-flip component of the effective nucleon-nucleon interaction appears to be stronger at low energies than the theoretical predictions, our results indicate that V_τ is leveling off as the bombarding energy increases. Furthermore, for $E_p \gtrsim 35$ MeV we conclude that the isospin-flip strengths of realistic forces are consistent with the (p,n)-IAS data.

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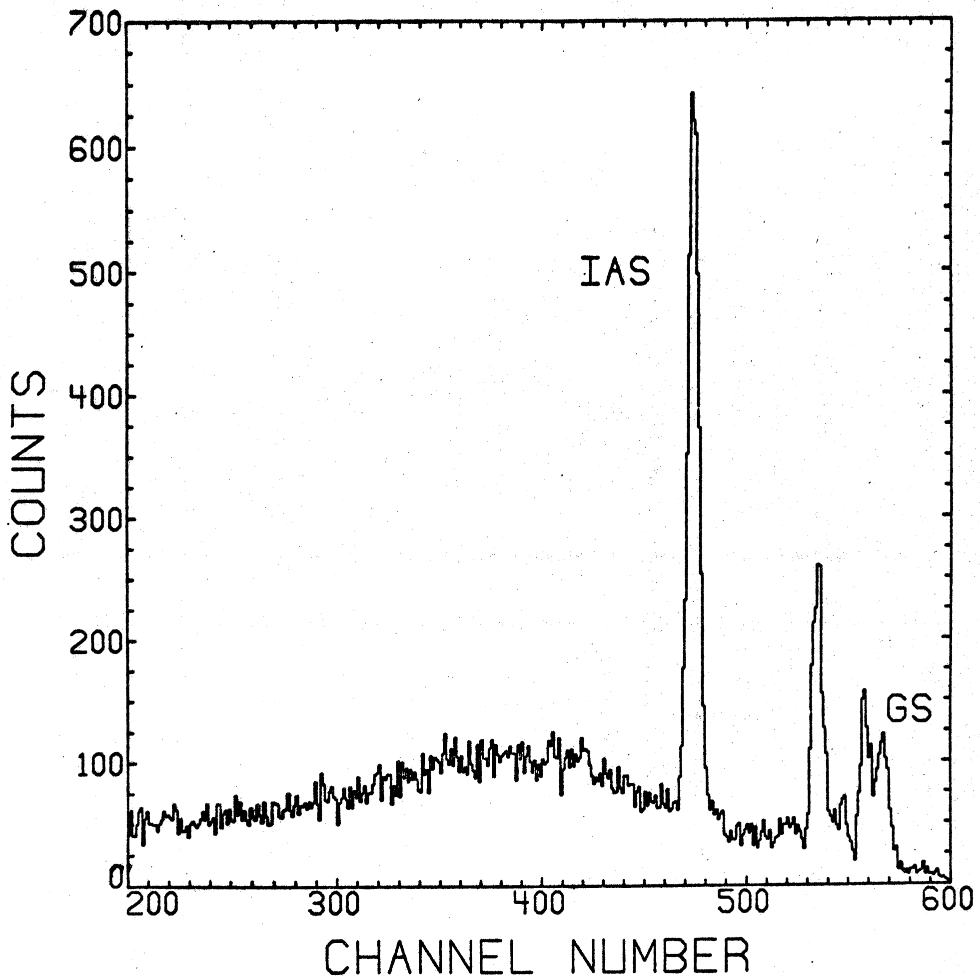
FIGURE CAPTIONS

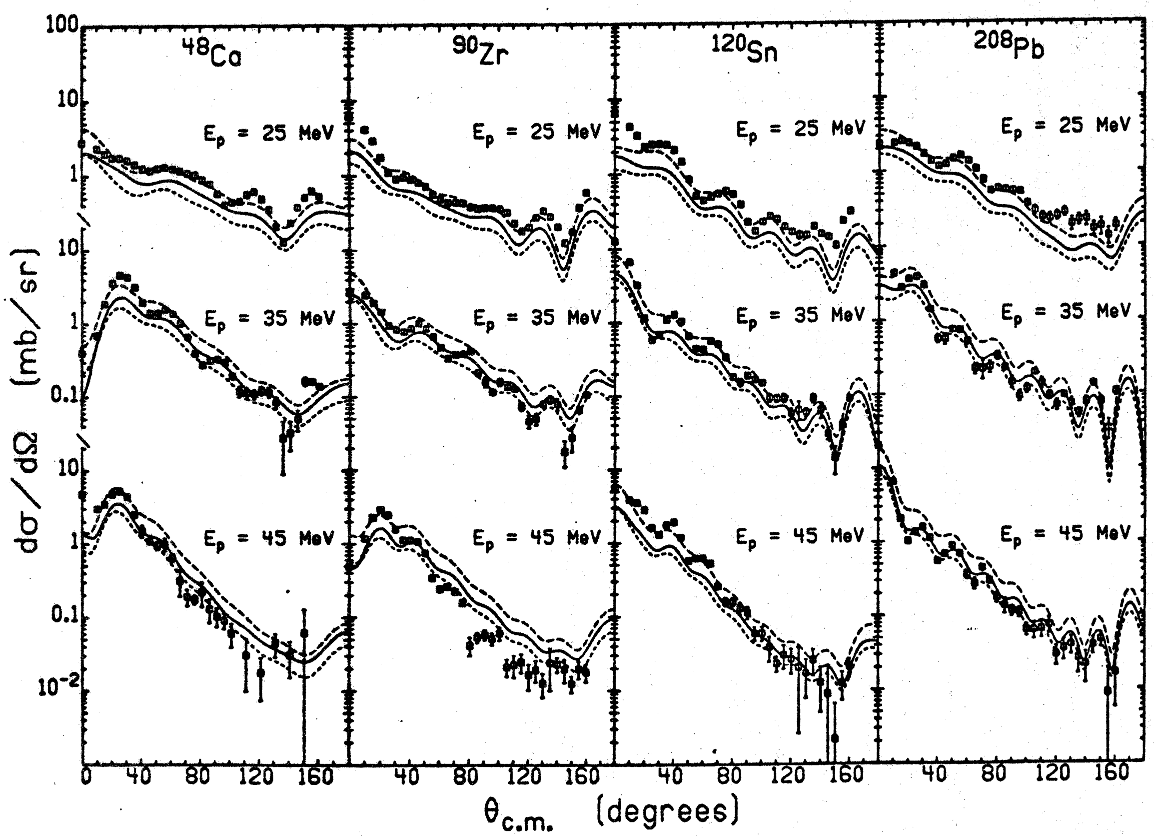
Fig. 1: Neutron time-of-flight spectrum for $^{90}Zr(p,n)^{90}Nb$ at E_p=35 MeV. The scattering angle is 0° and the flight path is 7.22 m.

Fig. 2: Comparison of experimental (p,n)-IAS angular distributions with microscopic DWBA calculations based on phenomenological (dashed) and G-matrix (solid) effective nucleon-nucleon interactions. The short and long dashes correspond to V_τ=12 and 18 MeV, respectively.



COUNTS
CHANNEL NUMBER
IAS
GS

Fig. 1



48Ca
90Zr
120Sn
208Pb
Ep = 25 MeV
Ep = 35 MeV
Ep = 45 MeV
dσ/dΩ (mb/sr)
θc.m. (degrees)

Fig. 2