structure into its quasi-molecular or cluster components.

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Neutron Blocking in α-Particle–Transfer Reactions*

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The $(d,{}^6\mathrm{Li})$ α-transfer reaction on several even-A and odd-A tin isotopes has been investigated at $E_d = 35$ MeV. A significant reduction (~ factor 2) in transition strength is observed for the odd-A target nuclei. This reduction is attributed to the "blocking" effect of unpaired nucleons and is comparable to that observed in (p,t) reactions.

The effects of the Pauli exclusion principle manifest themselves in a dramatic fashion in two-nucleon–transfer reactions such as (p,t) and (t,p). A recent study of the (p,t) reaction[1] on even-A and odd-A tin isotopes has demonstrated the "blocking" effect of unpaired target nucleons. Typically, the ground-state → ground-state (g.s.) transition strengths are reduced by a factor of about 2 for $J^\pi=\frac{1}{2}^+$ odd-A targets compared with adjacent $J^\pi=0^+$ targets.[1] Recent theoretical models[2] and experiments[3] indicate a close connection between two-nucleon- and α-transfer reactions. As a further test of such a correlation, we have investigated the $(d,{}^6\mathrm{Li})$ reaction on targets of $^{116-120}\mathrm{Sn}$. A preliminary report has been presented elsewhere.[4]

The experiments were performed with a 35-MeV deuteron beam from the University of Mich-

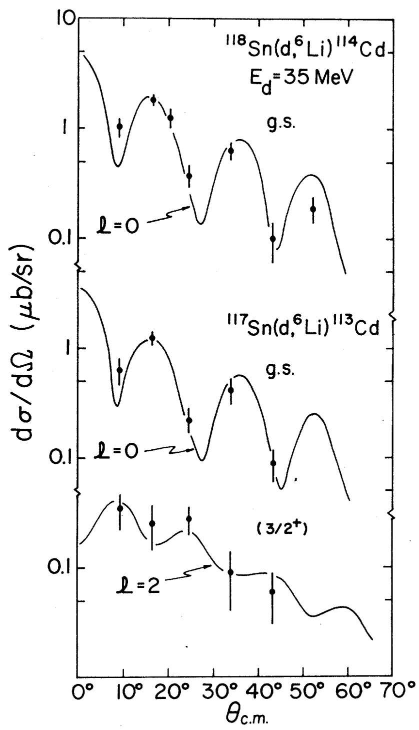

FIG. 1. Differential Sn(d, ^{6}Li) cross section for transitions to states in ^{114}Cd and ^{113}Cd (the data for the $J^\pi = \frac{3}{2}^+$ state in ^{113}Cd may include a small contribution from an unresolved $J^\pi = \frac{11}{2}^-$ level; see text). The curves are zero-range distorted-wave Born-approximation (DWBA) calculations (see Ref. 3) and have been averaged over the experimental angular acceptance ($\Delta\theta \approx 5°$).

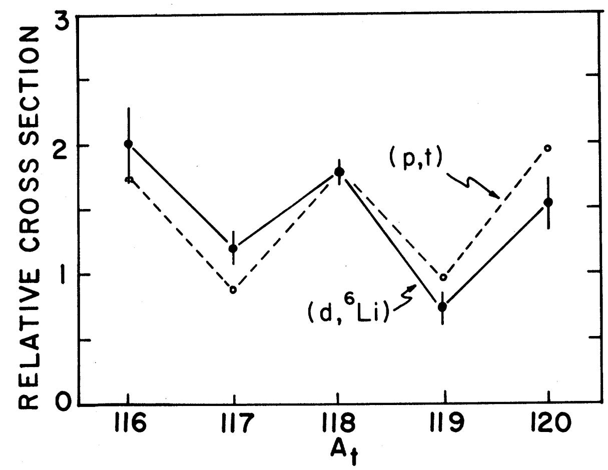

FIG. 2. A comparison of Sn(d, ^{6}Li) and Sn(p,t) g.s. → g.s. cross sections for targets with mass numbers A_t. The (d, ^{6}Li) data are differential cross sections in microbarns per steradian at the first l = 0 maximum beyond 0° ($\theta \approx 16°$) for E_d = 35 MeV. The (p,t) data are integrated cross sections (arbitrary units) for E_p = 20 MeV (Ref. 1). The latter have been normalized to the (d, ^{6}Li) for A_t = 118.

igan 2-m cyclotron. The targets consisted of isotopically enriched material evaporated as 200–600-μg/cm^2 layers onto 40-μg/cm^2 carbon backings. Reaction products were detected and identified in the focal plane of a magnetic spectrometer ($\Delta\theta \sim 5°$) by use of solid-state position-sensitive detectors. The ^{6}Li momentum resolution corresponded to 25 to 40 keV (full width at half-maximum) in energy. The target thicknesses were determined in three different ways: (i) by elastic ^{3}He scattering (E = 45 MeV); (ii) by elastic deuteron scattering (E = 35 MeV); and (iii) by α-particle energy-loss measurements (E = 5.5 MeV). We estimate the uncertainties in cross sections due to possible systematic errors to be less than ± 15%.

Angular distributions were measured for ^{117,118}Sn and data at selected angles (l = 0 maxima) were obtained for the other targets. The ^{118}Sn(d, ^{6}Li)^{114}Cd(g.s.) and ^{117}Sn(d, ^{6}Li)^{113}Cd(g.s.) angular distributions are shown in Fig. 1. Both transitions are expected to proceed by the same orbital angular momentum transfer of l = 0 ($0^+ \to 0^+$ and $\frac{1}{2}^+ \to \frac{1}{2}^+$, respectively). The two angular distributions are in fact similar to each other and resemble other known l = 0 angular distributions in this mass region.[5,6] The curves included in Fig. 1 are zero-range DWBA calculations assuming a direct α-cluster transfer[3] and are in substantial agreement with the data. At the bottom of Fig. 1 we also present data and calculations for ^{117}Sn(d, ^{6}Li)^{113}Cd to the incompletely resolved low-lying excited states in ^{113}Cd. Other data in this mass region[5,6] indicate that the low-spin $J^\pi = \frac{3}{2}^+$ state (l = 2) would dominate. The DWBA calculations are consistent with this assignment although the large experimental uncertainties preclude a more definitive statement. In any case, it appears that the g.s. → g.s. transitions proceed by a direct and characteristic l = 0 transfer.

The (d, ^{6}Li) g.s. → g.s. cross sections obtained at the first l = 0 maximum beyond 0° ($\theta_t \sim 16°$) are shown in Fig. 2 for $^{116-120}$Sn. The cross sections for the odd-A nuclei are about half that of the adjacent even-A nuclei although all transitions must proceed by l = 0. This feature was observed consistently at all observation angles. Such an odd-even effect cannot be due to the dependence on Q values or binding energies as these vary smoothly, changing by less than 250 keV between isotopes. The variation in the (d, ^{6}Li) cross sec-

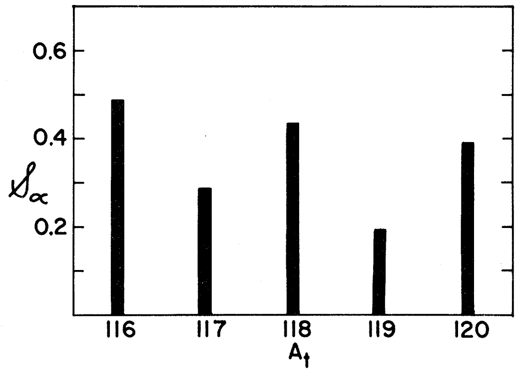

FIG. 3. α-particle spectroscopic factors for Sn(d, ^{6}Li)Cd (g.s.) normalized such that $S_\alpha = 1.0$ for ^{20}Ne(d, ^{6}Li)^{16}O (g.s.) at $E_d = 35$ MeV (Ref. 8).

tions is quite similar to that observed[1] in the (p, t) reaction. This fact is illustrated in Fig. 2 where the integrated (p,t) g.s. → g.s. cross sections are displayed together with the (d, ^{6}Li) data. The close similarity between the α-transfer and two-neutron–transfer data suggests that the two protons transferred in (d, ^{6}Li) act primarily as "spectators." It also suggests that $s_{1/2}$ orbitals, as expected,[1,7] are very important in multinucleon-transfer reactions since this is the orbital "blocked" in the odd-A Sn isotopes.[1]

α-particle "spectroscopic factors," S_α, deduced from our data by use of zero-range DWBA are given in Fig. 3. The calculations are normalized such that $S_\alpha = 1.0$ for ^{20}Ne(d, ^{6}Li)^{16}O at $E_d = 35$ MeV.[8,9] As anticipated, the S_α values show the same odd-even variation as observed in the cross-section data. While finite-range and other effects may slightly alter the results obtained with the above DWBA calculations and hence the absolute S_α values,[8] they are not expected to change the systematic features shown in Fig. 3.

It is hoped that the study of neutron blocking and related phenomena in (d, ^{6}Li) and other α-transfer reactions will provide further insight into the nature of multinucleon-transfer reactions and of clustering in heavy nuclei, and serve as a quantitative test for microscopic theories.

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Evidence for Residual K-Shell Excitation in Chlorine Ions Penetrating Carbon*

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Chlorine ions at 70 and 140 MeV energy impinge upon ~1-μg/cm^2 Cu targets, in one case after emerging from a carbon prefoil and in the second striking Cu on the back side of a carbon foil. The latter approach leads to an appreciable increase in the Cu K x-ray yield, an effect which is explained in terms of residual Cl K-shell excitation and which is in accord with a simple model of competing rearrangement processes.

One of the interesting aspects of the passage of ions through solids is the possibility of residual excitation in the electronic orbitals of the projectile due to collision times which are shorter than de-excitation lifetimes. Such an ion emerges from the solid and de-excites via photon or Au-