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Width of the 6^-, $T=1$, $E_x=14.36$ MeV state in ^{28}Si and its relationship to intermediate energy inelastic scattering

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The width of the 6^-, $T=1$, $E_x=14.36$ MeV state in ^{28}Si has been measured via the ^{27}Al$(p,p)^{27}$Al reaction. The value of $\Gamma=3.7\pm0.4$ keV yields a single particle fraction $\beta_1{}^2=0.68\pm0.07$ which is shown to be consistent with the combined results for the inelastic excitation of this state by $\pi^{\pm}$, p, and e^- and the ^{27}Al$(^3$He$,d)^{28}$Si (g.s.) reaction.

[NUCLEAR REACTIONS ^{27}Al$(p,p_{0,1,2})^{27}$Al; $E_p=2.70-3.06$ MeV; determined width and deduced single particle fraction for ^{28}Si state at $E_x=14.36$ MeV.]

The last three years have provided nuclear physics with a variety of new intermediate energy inelastic scattering data.[1] Proton inelastic scattering in the 100–140 MeV range, pion scattering near the (3,3) resonance, and high resolution electron scattering appear to be powerful tools for investigating nuclear structure.[2] However, conclusions concerning nuclear structure will depend upon (1) understanding the reaction mechanism and (2) selecting reasonable models for comparison with data. It is necessary to perform numerous tests of these two points before the intermediate energy results can add to the knowledge of nuclear structure in a manner consistent with low energy measurements. The present paper provides one such test.

There are many nuclear levels for which excitation by p, $\pi^{\pm}$, and e^- yield consistent results under the assumption that the levels and corresponding ground states possess a certain structure. Perhaps the most useful of these levels have been the stretched state configurations in which a particle is promoted from the active hole orbit with largest j_h to the active particle orbit with largest j_p to form a state with maximum total J. Because of their high spins, these states are preferentially excited in high momentum transfer reactions and also remain relatively pure due to the low density of states with large J. Owing to their stretched character, the direct inelastic excitation of these states is completely described by a single spin transition density which allows for a direct comparison of (e,e'), (p,p'), and (π,π') scattering.[2–5] Obtaining consistent results for the different probes for these stretched states provides evidence that the reaction mechanisms are understood and that a reasonable approximation for their structure has been assumed.

It is now desirable to select from those observed states which have yielded consistent inelastic results that subgroup of states which can be compared with low energy results. One such state is the 6^-, $T=1$, $E_x=14.36$ MeV level in ^{28}Si. The purpose of this paper is to present a measurement of the width of this state via the resonance reaction, ^{27}Al(p,p), and to demonstrate that the measured value of 3.7 ± 0.4 keV corroborates the structure assumed in the inelastic scattering results. In addition this measurement provides information complementary to inelastic scattering and should aid in understanding future excitations of this level.

The experiment was performed with the high resolution system on the 3 MV Van de Graaff accelerator of Triangle Universities Nuclear Laboratory. The ^{27}Al(p,p_0), (p,p_1), and (p,p_2) reactions were measured from $E_p = 2.70$ to 3.06 MeV. The targets were 1–2 μg/cm^2 of aluminum evaporated onto thin carbon backings; the overall resolution was 350 eV full width at half maximum (FWHM).

The elastic scattering cross section for a portion of these data is shown in Fig. 1. The solid line in Fig. 1 is a preliminary fit to these data utilizing a multilevel, multichannel R-matrix code.[6] The elastic cross section is dominated by a series of broad $l=0$ resonances and one very strong resonance near $E_p = 2.87$ MeV. The strong resonance at $E_p = 2.873$ MeV definitely has $l=3$ with a strongly preferred $J=6$ assignment, and is thus the $T=1$ state observed in the inelastic scattering reactions on ^{28}Si.

Twenty-two resonances were observed in the preliminary analysis; some of these resonances have appreciable strength in our inelastic channels. The 6^- state has no observed strength in either of our inelastic channels, although inelastic decay from low spin states makes a precise determination of the lower limit difficult. α channels are open, but decay to the 0^+ ground state is not allowed, and decay to the 2^+ first excited state of ^{24}Mg was not observed by Neal and Chagnon.[7] The capture reaction was studied by Miehe *et al.*[8] and by Neal and Lam.[9] We obtain an excellent fit to the 6^- state assuming $\Gamma_p = \Gamma_{\text{total}}$. Our value for the width is $\Gamma_p = 3.7 \pm 0.4$ keV.

If one proceeds as in Refs. 2–5, the ^{28}Si ground

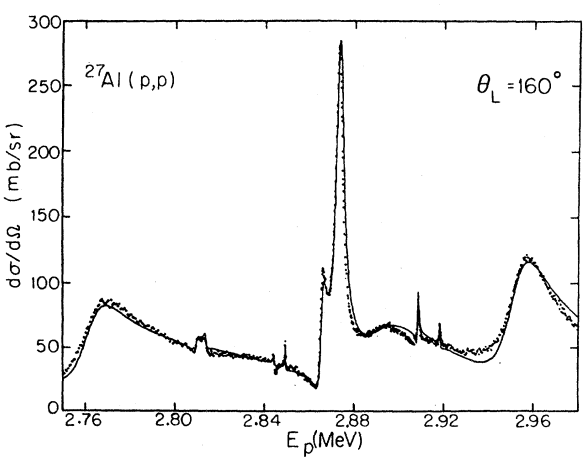

FIG. 1. The ^{27}Al(p,p) differential cross section at $\theta_L = 160°$ in the vacinity of the $J^\pi = 6^-$, $T=1$ state at $E_p = 2.873$ MeV. The solid curve is the result of a multilevel, multichannel R-matrix calculation.

state, $|i\rangle$, is assumed to be a closed $0d_{5/2}$ shell plus a more complicated component,

$$|i\rangle = \alpha_1|0\rangle + \alpha_2|c_i\rangle \ , \quad \alpha_1^2 + \alpha_2^2 = 1 \ . \tag{1}$$

The 6^-, $T=1$ state is similarly taken to be a pure particle hole excitation plus a more complicated component,

$$|f\rangle = \beta_1[a^\dagger_{f_{7/2}} a_{d_{5/2}}]^{6,1}|0\rangle + \beta_2|c_f\rangle \ , \quad \beta_1^2 + \beta_2^2 = 1 \ . \tag{2}$$

Since the direct inelastic excitation operator is a single particle operator, the transition, $|0\rangle \rightarrow |np\text{-}nh\rangle$, $n > 1$, will not proceed. Therefore it is not unreasonable to expect that the dominant contribution to the inelastic cross section comes from $|0\rangle \rightarrow [a^\dagger a]^{6,1}|0\rangle$. If the transition between pure states $|0\rangle \rightarrow [a^\dagger a]^{6,1}|0\rangle$ is declared a sum rule, then the fraction of the sum rule exhausted by the transition provides a measure of $\alpha_1^2\beta_1^2 \equiv S_{\text{ph}}^2$. For the 6^-, $T=1$ state, the (π,π'),[10] (p,p'),[11] and (e,e')[12] data agree remarkably well with the average value of $S_{\text{ph}}^2 \sim 0.31$.[2–5] The results of these experiments are summarized in Ref. 4.

This consistency among experiments provides confidence in one's understanding of the reaction mechanisms. One may then proceed to make the conclusion that the ^{28}Si ground state and 6^-, $T=1$ state deviate substantially from the single particle shell model, such that $S_{\text{ph}}^2 \sim 0.31$. A comparison with ^{27}Al$(p,p)^{27}$Al results can now be demonstrated consistent with this conclusion.

Experimental evidence is available for the structure of the ^{28}Si ground state. If one assumes that ^{27}Al (ground state) $\equiv d_{5/2}^{-1}(p)|0\rangle$ and that ^{28}Si (ground state) $\equiv |0\rangle$, then $(^3\text{He},d)$ data account for only 44% of calculated strength.[13] This is a considerable departure from the single particle model and the 6^-, $T=1$ state would necessarily be a fairly pure single particle state if S_{ph}^2 does equal 0.31. Specifically, it would have to look like an $f_{7/2}$ particle coupled to the $A=27$ core $0.31/0.44 \times 100 = 70\%$ of the time.

The present experiment provides this information on the 6^-, $T=1$ state. The measured width of 3.7 keV can be used to extract the single particle fraction as follows. The width of an $f_{7/2}$ proton resonance at $E_p^{\text{c.m.}} = 2.77$ MeV in a Woods-Saxon well with geometry, $V = 58.62$ MeV, $r_0 = r_{\text{so}} = r_c = 1.2$ fm, $a_0 = a_{\text{so}} = 0.569$ fm, and λ of the Thomas spin-orbit term =25, is 10.8 keV. For a pure $T=1$ state, which spends one-half of its time as a proton coupled to ^{27}Al, this gives $\Gamma_p = 5.4$ keV. The well geometry was determined by requiring that the resonance appear at 2.77 MeV and that the well best fitted in the important surface region that potential obtained by single folding the V_0 component of the g matrix of Bertsch *et al.*[14] The single particle fraction is then Γ/Γ_p

$=3.7/5.4=0.68\pm0.07$, which is in near agreement with the value of 0.70 from combining the inelastic scattering and (^{3}He,d) results. The inelastic scattering conclusion concerning the single particle fraction of the $0^+\rightarrow6^-$, $T=1$ transition is therefore consistent with resonance measurements.

This paper has described a measurement of the width of the 6^-, $T=1$, $E_x=14.36$ MeV state in ^{28}Si. It was demonstrated that the measured value of $\Gamma=3.7\pm0.4$ keV yields a single particle fraction of 0.68 ± 0.07 which is consistent with intermediate energy inelastic scattering values. This measurement has not only provided a test of the understanding of the intermediate energy inelastic scattering mechanism, but also can provide the experimentalist with valuable information on high energy resolution at this excitation energy. In addition, the present measurement shows that the 6^-, $T=1$ state is a good single particle state and other reactions which proceed via a single particle mechanism should show large yields. Finally, this measurement represents only one demonstration of the consistency between low energy and intermediate energy results. Centainly an effort should be made to increase the amount of data where low and intermediate energy experiments overlap so that additional comparisons can be made.

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