EXCITATION OF HIGH-SPIN STATES IN ^{49}Ti BY THE (p, π^-) AND (d, α) REACTIONS

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States in ^{49}Ti have been studied by the ^{51}V(d, α)^{49}Ti reaction with 28 MeV deuterons. Angular distributions are used to pick out those states that are populated by ΔL = 6 angular momentum transfer. Comparison with microscopic distorted wave calculations using $f_{7/2}$ shell-model spectroscopic amplitudes suggest that the strong states observed at 3968 and 4388 KeV in the (d, α) reaction have spins 15/2$^-$ and 19/2$^-$ respectively, and are the same states that have been strongly in recent (p, π^-) experiments.

Recently [1], a series of (p, π^-) measurements at the Indiana University Cyclotron Facility (I.U.C.F.) on targets with A = 13–92 at energies of about 200 MeV have revealed a striking selectivity in the population of discrete final states. The ground and low-lying states are only weakly excited, while states near 5–7 MeV in light nuclei and 3–5 MeV in heavier nuclei are strongly populated. Vigdor et al. [1] propose that these states are highly-aligned, two-particle, one-hole (2p–1h) configuration high-spin states, which are favored by the large momentum transfer in the (p, π^-) reaction. Brown et al. [2] have proposed a simple microscopic model for this reaction which successfully accounts for the observed features of the relative cross sections for the $f_{7/2}$ shell targets. In this model, other factors also turn out to be important, such as statistical spin factors and nuclear structure factors (the jj–LS transformation coefficients) which favor high spin.

Vigdor et al. [1] suggest for example, that in the reaction ^{48}Ca(p, π^-)^{49}Ti the strongly excited levels at 4.4(0.1) MeV and 4.0(0.1) MeV (see fig. 1a) are due to

the configuration $[\pi(f_{7/2})^2]^{6+} \otimes [\nu(f_{7/2})^{-1}]^{7/2^-}$ with $J \leqslant 19/2^-$. The energy resolution of these measurements was of the order of 250 keV. A spin of 19/2$^-$ has been assigned to a level at 4383 keV by Behar et al. [3] on the basis of γ-ray measurements in the reaction ^{48}Ca(α, 3nγ)^{49}Ti. However, the density of levels is high, with 18 reported levels between 3.8 MeV and 4.5 MeV [4,5]. Of these, only six have been assigned J^π values. Thus, the two (p, π^-) peaks could each be due to several unresolved levels). In order to test the hypothesis of ref. [1], it is essential to locate the 2p–1h high-spin states by a selective reaction carried out with good resolution, for it could be that the 19/2$^-$ level reported by Behar [3] is not the simple 2p–1h state.

A reaction fulfilling these requirements was investigated [6] with the Princeton University AVF Cyclotron and QDDD spectrometer, namely ^{51}V(d, α)^{49}Ti at 28 MeV. The (d, α) reaction is known to favor the pickup of the proton–neutron pair in the completely aligned $(1f_{7/2})^2 J$ = 7 configuration due to the geometrical co-
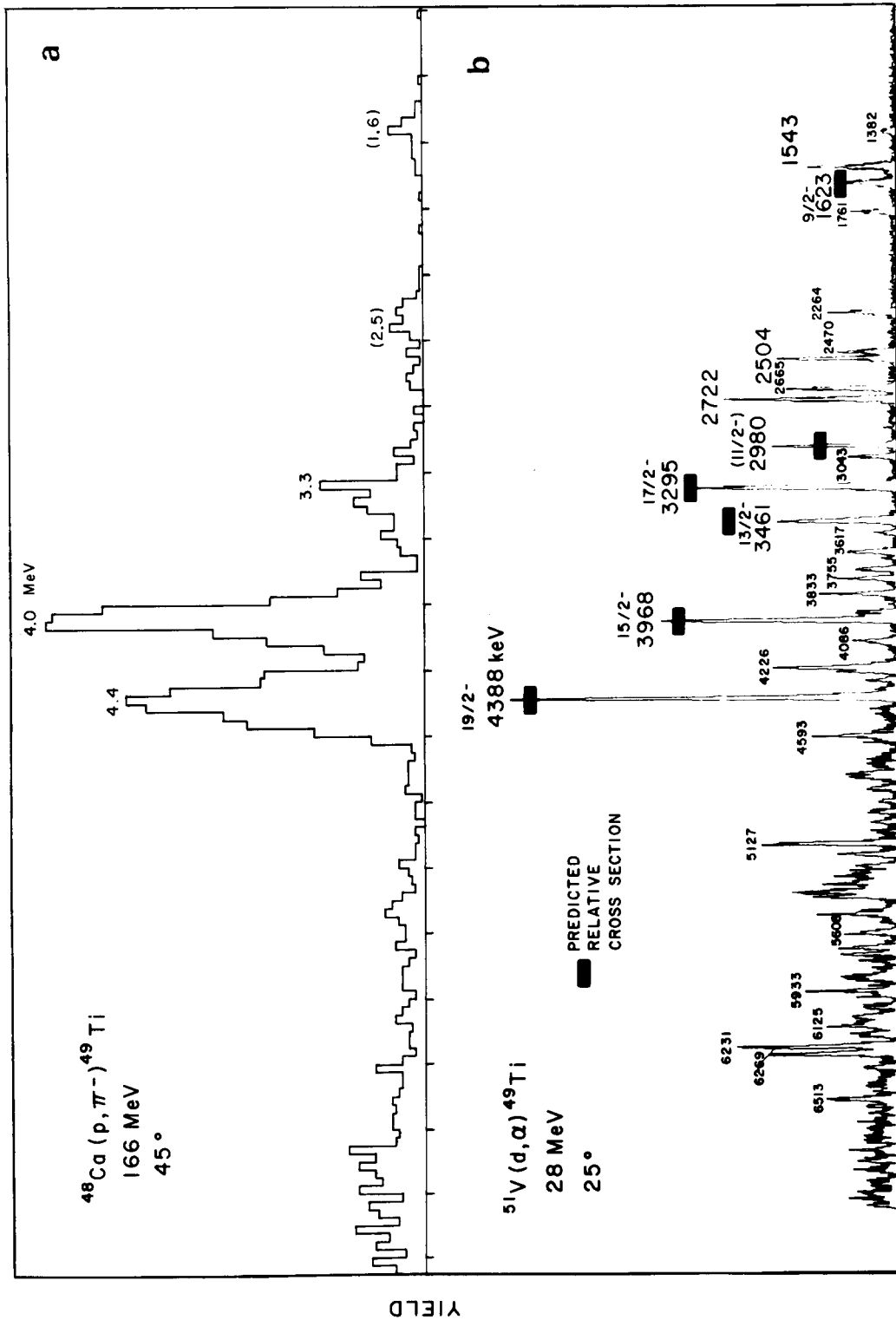
Fig. 1. (a) The ^{48}Ca(p, π^-)^{49}Ti spectrum [1] at 45°, E_X in MeV. (b) The ^{51}V(d, α)^{49}Ti spectrum at 25° and 28 MeV. The scales of excitation energies are about the same for (a) and (b). Peaks are labelled with excitation energy in keV. Suggested spins and parities are shown for states which have $\Delta L = 6$. Predicted cross sections are shown (in arbitrary units) by the heavy bars.

efficients in the structure factors [7]. In addition, the Q_0 value of 7.07 MeV gives rise to a large momentum mismatch between the entrance and exit channels. Earlier (d, α) measuremtns [4] did not identify the stretched states, although the poor resolution experiment of Grossiord [8] at 28 MeV yielded data consistent with ours.

Our goal was to locate possible candidates for high-spin 2p–1h states, namely, those with strong yields in the (d, α) reaction. The actual J-values cannot be determined from angular distributions alone. A much more definitive analysis would be obtained using polarized deuterons [9], and determining the vector analyzing powers as well as differential cross sections. Such experiments are currently underway at the IUCF [10].

In the present measurements, we obtained data at laboratory angles of 15°, 25° and 30°. A 25° spectrum with 18 keV resolution is shown in fig. 1b. The energy calibration was determined using the accurate energies (better than 3 keV) of ref. [5] between 1 and 3 MeV. Our excitation energies agree within 5 keV with those of ref. [5] up to 4.4 MeV. Beyond 4.4 MeV, the level density is too high to permit identification with levels listed in ref. [4], but we expect our values for sharp peaks to be good to 10 keV.

The peaks with bars on them designate the levels which show $\Delta L = 6$ transfer. The height of each bar corresponds to the relative computed cross section. Note the close qualitative correspondence of the (p, π^-) spectrum to these peaks. We can obtain information on the transferred orbital angular momentum (ΔL) from the angular distributions. The ratio of cross section at 25° to that at 15° was found to be 0.95 ± 0.05 for six of the levels, and 0.20 to 0.65 for about 22 other levels. Microscopic distorted wave calculations carried out with the optical-model parameters of ref. [11] and with spectroscopic factors obtained from $f_{7/2}$ shell-model wave functions (those calculated with the "^{42}Sc" interaction of ref. [12]) showed the former ratio was expected for predominantly $\Delta L = 6$ transfers, while for $\Delta L < 6$, the smaller ratios were expected.

The $\Delta L = 6$ levels are at 1623 (9/2$^-$), 2980 (11/2$^+$, 13/2$^-$), 3295 (17/2$^-$), 3461 (5/2$^-$–13/2$^-$), 3968 (unassigned and 4388 (19/2$^-$) keV where the spin assignments for the 1st, 3rd and 6th of these levels. An assignement of 13/2$^-$ for the 3461 keV level is consis-

tent with the possible J^π values previously given, and with the calculated position and strength of the second 13/2$^-$ state. However, one cannot definitely exclude the possibility that it is the third 11/2$^-$ state (see fig. 2). The angular dependence and large cross section of the 3968 keV level suggest that it is the expected, but hitherto unidentified 15/2$^-$ state. The angular dependence for the 2980 keV state is inconsistent with that predicted for the first 13/2$^-$, but agrees with calculations for the second 11/2$^-$ state (in disagreement with published assignments). In addition to these, the data for the 1543 keV level suggest it is the lowest 11/2$^-$ state, while that for the 2722 keV level are consistent
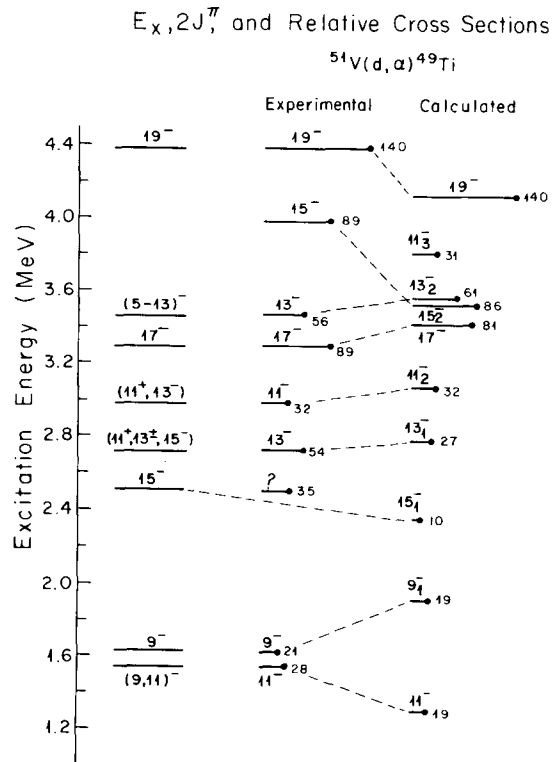

Fig. 2. Comparison of E_x, $(2J)^\pi$, and relative (d, α) strengths for states with $J^\pi \geqslant 9/2^-$. The 25° data of the present experiment are in the center, showing the relative cross sections and our suggested spins. To the right, are the shell-model predictions for E_x and the relative calculated cross section at 25°. To the left, are levels reported in refs. [3–5] (only eight out of 40 levels between 1.3 and 4.4 MeV had been assigned J^π $\geqslant 9/2^-$). Not shown are the predicted weak peaks corresponding to $(9/2^-)_2$ and $(9/2^-)_3$ at 3414 and 4933, which have not yet been identified experimentally.

with predictions for the lowest $13/2^-$ state. The reported [3] $15/2^-$ level at 2506 keV was expected to have a cross section about one third of that of our observed peak at 2504 keV. While our peak may be due mostly to the known $1/2^+$ state at 2504 keV [5], it seems unlikely that such a low-spin state should be so strong; it is more likely that the calculated strength for the $15/2^-$ state is in error.

The above information for states with $J^\pi \geqslant 9/2^-$ is summarized in fig. 2 in wich E_x, $2J^\pi$ and relative strengths are shown. For the middle set of levels, we list our energies, the spins which are consistent with our angular data, and relative cross sections. On the right are the predicted energies and the relative DWBA (FRNL) cross sections. Previous data from refs. [3–5] are shown on the left-hand side.

In summary, if we restrict our attention to the (d, α) peaks designated as having highly-aligned configuration with $J^\pi \geqslant 9/2$, see that the (p, π^-) spectrum is very similar, supporting the view that both reactions selectively populate 2p–1h stretched states. The comparative weakness of the $13/2^-$ and $17/2^-$ levels in the (p, π^-) reaction is expected on the basis of the jj to LS transformation coefficients [2]. This weakness, relative to the $19/2^-$ and $15/2^-$ levels is also a feature of three-particle transfer reactions [13,14] such as (α, p), (p, α), etc. These reactions also have large momentum mismatch, and thus the $^{46}Ca(\alpha, n)^{49}Ti$ reaction should yield spectra even more similar to the (p, π^-) spectrum than does the (d, α) reaction. It is interesting to note the $^{42}Ca(p, \pi^-)^{43}Ti$ spectrum [1] suggests strong excitation of the $15/2^-$ and $19/2^-$ states, as do those of the $^{40}Ca(\alpha, p)^{43}Sc$ [13] and $^{46}Ti(p, \alpha)^{43}Sc$ [14] reactions for the corresponding mirror states of ^{43}Ti. (In all three reactions, the $13/2^-$ and $17/2^-$ states are suppressed.) Finally, a more complicated reaction [15] also having large momentum transfer is $^{48}Ca(^{16}O, ^{15}C)^{49}Ti$. This must go by two steps, e.g. pickup of a neutron followed by two-proton stripping. Kovar et al. [15] present a spectrum showing large peaks in the vicinity of 4 MeV which could be the stretched states seen in fig. 1. Their spectrum is complicated by the strong population of $^{15}C^*$ (747 keV). The reaction $^{48}Ca(^9Be, ^8He)^{49}Ti$ should yield a similar, but simpler spectrum, since for ^8He only the ground state is particle stable.

In conclusion, we see that there are a number of reactions which selectively populate high-spin states of ^{49}Ti. Levels of other nuclei excited by (p, π^-) reactions are identifiable through use of two- or three-particle transfer (or by appropriate two-step) reactions. As a final point, we note that our $^{51}V(d, \alpha)^{49}Ti$ spectrum at 25° at 28 MeV (fig. 1) and Nann's 14° spectrum at 78 MeV [10] are virtually identical in the relative magnitudes of the various peaks. This remarkable feature confirms the basic assumption in the DWBA that the kinematic and nuclear-structure factors are separable. Thus, in both of these spectra $\Delta L = 6$ transfer dominates, and the relative strengths of the various states are then determined by nuclear structure factors, i.e. the two-particle fractional parentage coefficients combined with the $jj–LS$ transformation factors.

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