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$^{16}O(t, ^3He)^{16}N$ reaction and the low-lying $T = 1$ levels of mass 16†

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The $^{16}O(t, ^3He)$ reaction at an incident energy of 23.5 MeV has been used to study the low-lying levels of ^{16}N. A comparison of these results with a previous study of the $^{16}O(^3He, t)^{16}F$ reaction permits assignment of $J^\pi = 0^-(1^-)$, $1^-(0^-)$, $2^-(3^-)$, and $3^-(2^-)$ for the ground, 0.197-, 0.424-, and 0.720-MeV states of ^{16}F, respectively.

[NUCLEAR REACTIONS $^{16}O(t, ^3He)$, $E = 23.5$ MeV. ^{16}N levels, analog identification in ^{16}O, ^{16}F, deduced J^π in ^{16}F.]

The lowest $T = 1$ levels of mass 16 are explained as single-particle, single-hole excitations relative to the ^{16}O ground state. Four low-lying states are observed: $J^\pi = 0^-$ and 1^- and $J^\pi = 2^-$ and 3^- corresponding to $p_{1/2}{}^{-1}s_{1/2}$ and $p_{1/2}{}^{-1}d_{5/2}$ configurations, respectively. The wave functions of these states are expected to be quite pure as there are no other known[1] $T = 1$ levels below an excitation of 3 MeV. These levels are known[1] in all three nuclei of the $T = 1$ triad $^{16}N(T_z = 1)$, $^{16}O(T_z = 0)$, and $^{16}F(T_z = -1)$; however, in ^{16}F, spins and parities have not been established for these levels.

^{16}F can only be studied using three light-ion induced transfer reactions: $^{14}N(^3He, n)$ (Refs. 2, 3), $^{16}O(p, n)$ (Ref. 4), and $^{16}O(^3He, t)$ (Ref. 5). A study of the systematics of the analogs of levels in ^{16}N and ^{16}O utilizing the expected energy shifts between ^{16}O and ^{16}F suggests[3-6] a spin sequence of 0^-, 1^-, 2^-, 3^- for the four low-lying levels in ^{16}F. However, a sequence of 0^-, 2^-, 1^-, 3^- has been indicated based on the widths of the levels of ^{16}F measured in a study of the $^{14}N(^3He, n)$ reaction.[2] Several other experiments with information regarding the spins of these states also have been reported: (1) Tentative L values have been suggested from studies[3] of the $^{14}N(^3He, n)$ reaction at incident energies of 10, 12.5, and 13 MeV; however, angular distributions are not shown and the $J^\pi = 1^+$ ground state spin of ^{14}N does not permit a unique spin determination except for $L = 0$ transitions. Furthermore, it has been shown[7] that non-direct stripping processes may dominate the $^{14}N(^3He, p)$ two nucleon transitions to the ^{16}O ground state at incident energies up to >13 MeV. Similar effects might be expected in the $^{14}N(^3He, n)$ reaction. (2) The relative cross sections of this same $^{14}N(^3He, n)$ study have been compared[3] to $^{14}N(t, p)$ transitions[8] to the analogs of the four low-lying states in ^{16}N; however, the selectivity among these levels is not large in the two nucleon transfer reactions. (3) The second and third excited states in ^{16}F are populated with much larger cross sections than the ground and first excited state in the $^{16}O(p, n)$ reaction[4] and especially in the $^{16}O(^3He, t)$ reaction.[5,9]

The present communication presents data for the $^{16}O(t, ^3He)$ reaction populating the low-lying levels of ^{16}N. Assuming isobaric invariance, the $^{16}O(t, ^3He)$ and $^{16}O(^3He, t)$ reactions should populate analogs in ^{16}N and ^{16}F with similar strength. Since the second and third excited states in ^{16}F were populated with $^{16}O(^3He, t)$ cross sections over an order of magnitude larger than the ground and first excited states[5,9] it should be possible to study the analog identification between ^{16}N and ^{16}F by comparing results of the $^{16}O(^3He, t)$ and $^{16}O(t, ^3He)$ reactions.

The $^{16}O(t, ^3He)^{16}N$ reaction was studied using the 23.5-MeV triton beam of the Los Alamos Van de Graaff facility. The reaction products were measured at laboratory angles of 20, 25, and 30° using an E-ΔE silicon surface-barrier detector telescope. The experimental procedures were identical to those in Ref. 10. A ^3He energy spectrum measured at a lab angle of 30° is shown in Fig. 1. Similar transitions are observed from reactions on ^{16}O target impurities in the spectra of previously published $(t, ^3He)$ studies.[10,11]

The ground state, $J^\pi = 2^-$, and the 0.297-MeV level, $J^\pi = 3^-$, of ^{16}N are consistently observed (see Fig. 1 and Refs. 10, 11) to be selectively populated by the $^{16}O(t, ^3He)$ reaction when compared with transitions to the 0^- and 1^- states at 0.121 and 0.397 MeV in ^{16}N. The shape of the $(t, ^3He)$ angular distributions for such bombarding energies does not vary rapidly with angle.[12] Therefore, it

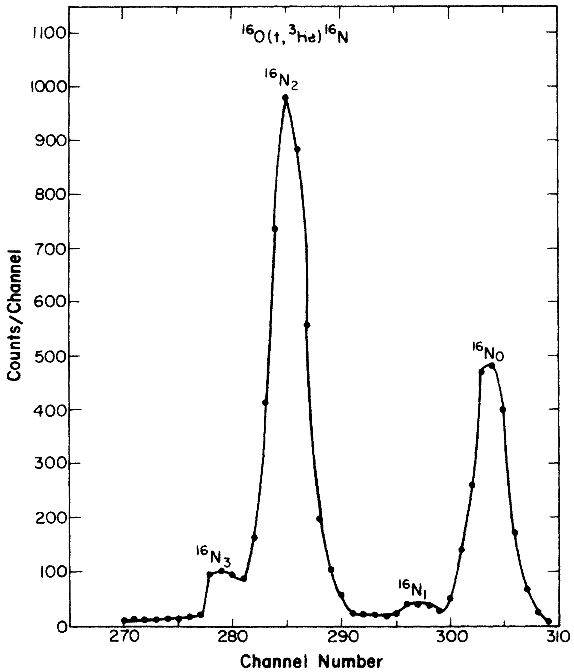

FIG. 1. ^{3}He energy spectrum for the reaction ^{16}O-(t, ^{3}He)^{16}N measured at a laboratory angle of 30° and at an incident energy of 23.5 MeV. The subscripts 0, 1, 2, and 3 identify the ground, 0.121-, 0.297-, and 0.397-MeV states in ^{16}N.

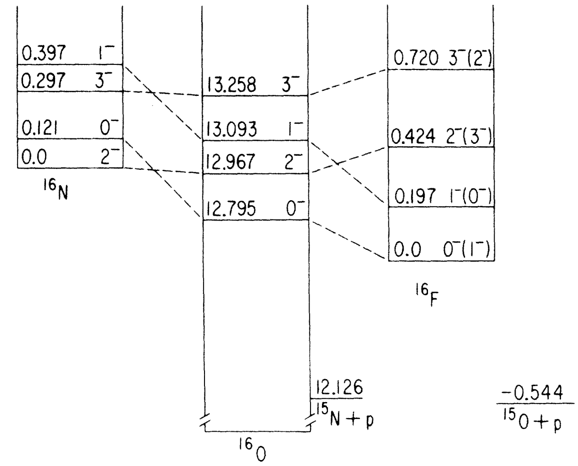

FIG. 2. Summary of the low-lying $T=1$ levels of mass 16. The diagrams corresponding to individual isobars have been shifted to account for the Coulomb energy and neutron-proton mass difference.

is possible to identify the ground, $J^\pi = 2^-$ and 0.297-MeV, $J^\pi = 3^-$, states in ^{16}N that are selectively populated in ^{16}O(t, ^{3}He) with the 0.424- and 0.720-MeV levels in ^{16}F which were populated with large ^{16}O(^{3}He, t) cross sections.[5,9] Similarly the 0.121-MeV, $J^\pi = 0^-$ and 0.397-MeV, $J^\pi = 1^-$ levels in ^{16}N can be associated with the ground and 0.197-MeV states of ^{16}F. This identification assigns either 0^- or 1^- to the ground and 0.197-MeV states of ^{16}F and 2^- or 3^- to the 0.424- and 0.720-MeV states of ^{16}F. Since the splitting of states in a particle-hole configuration is 200–300 keV in ^{16}N and ^{16}O and should be independent of T_z, it is assumed that the spin sequence within the $p_{1/2}{}^{-1}s_{1/2}$ and $p_{1/2}{}^{-1}d_{5/2}$ configurations do not reverse between ^{16}O and ^{16}F. Therefore J^π of 0^-, 1^-, 2^-, and 3^- are preferred for the ground 0.197-, 0.424-, and 0.720-MeV states, respectively, in ^{16}F. This is the spin sequence consistent with the predicted energy shifts of the $T=1$ nuclei of mass 16. The scheme of levels for ^{16}N, ^{16}O, and ^{16}F are summarized in Fig. 2. The diagrams for the individual isobars have been shifted to account for the Coulomb energy[13] and the proton-neutron mass difference. The downward shift of the 0^- and 1^- states with increasing Z has been explained[5,6,14] in terms of the Thomas-Ehrman shift.[15]

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the more weakly populated ground and 0.197-MeV states of ^{16}F were not observed because of poor statistics. It is apparent, however, that the cross sections corresponding to the 0.424- and 0.720-MeV levels are considerably larger than those for the ground and 0.197-MeV states at incident ^3He energies below that of Ref. 5 and comparable to the incident triton energy of the present $^{16}O(t, ^3He)$ study.

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