POPULATION OF LEVELS IN ^{15}O UP TO 15 MeV IN EXCITATION BY THE ^{14}N(^{3}He,d) REACTION* **

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The ^{14}N(^{3}He,d) reaction was studied at a beam energy of 20 MeV to search for major single-particle strength above 9 MeV in ^{15}O. No such strength was found up to 15 MeV in excitation. Comparison with the ^{12}C(^{6}Li,t) reaction allows the firm assignment of $9/2^+$ to the strongly populated state in ^{15}O at 10.46 MeV. With this result, the mirror ^{15}N–^{15}O spin-parity values can be made up to 11 MeV in both nuclei, which are given in this work.

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1. Introduction

The early observation of selective, strong population of well-isolated levels in light nuclei through the comparison of single- and multi-particle transfer reactions at excitation energies as high as 20 MeV demonstrated that understanding of the structure of these levels would lead to advances in the development of nuclear structure theory. A recent study of the ^{14}N(d,p) reaction [1] with a focus on exploring possible single-particle strength up to 13 MeV in excitation in ^{15}N demonstrated that the first few levels of a given spin and parity exhaust most of this strength. This means that the observed levels above about 10 MeV in excitation have other configurations, confirming early structure calculations that suggested the existence of structures such as $3p$–$4h$ in ^{15}N [2]. The high lying level structure of ^{15}O is less

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well-known because its low binding energy to proton decay (7.3 MeV) makes characterization of its levels above this energy through gamma-ray measurements not possible. The low-lying levels around 8 MeV or so have been extensively characterized because of their importance to our understanding of the hydrogen burning in the CNO cycle. These studies have been carried out by mapping the resonance structures around the proton threshold through the $^{14}\mathrm{N}(p,\gamma)$ [3] and $^{14}\mathrm{N}(p,p)$ [4] reactions. Also, asymptotic normalization coefficients (ANC) have been extracted from $^{14}\mathrm{N}(^{3}\mathrm{He},d)$ reaction studies [5, 6] around this threshold to compare with the spectroscopic factor results from the resonance studies.

It is somewhat surprising that the latest compilation [7] of spins and parities in ^{15}O still has brackets around the values for numerous levels, showing that there is still uncertainty in their determination below 11 MeV in excitation. As a part of the study of the levels in ^{15}N [1], it was possible to identify an experimental level with each calculated level done with a modern shell model that combined cross shell and *sd* shell interactions up to 12 MeV in ^{15}N excitation. The key to being able to establish the one-to-one correspondence between known and calculated levels were those populated by the (d,p) reaction in the 10–12 MeV excitation region. Based on the previous work, the present study of the $^{14}\mathrm{N}(^{3}\mathrm{He},d)$ reaction was undertaken with the experimental capability to observe the population of levels up to 15 MeV in ^{15}O excitation and to use these results to make mirror assignments between ^{15}N–^{15}O.

2. Experiment

The $(^{3}\mathrm{He},d)$ measurements were carried out with the Florida State University tandem-linac accelerator complex. A melamine ($C_3H_6N_6$) target was bombarded by a 20 MeV ^{3}He beam. This beam energy was chosen because of previously published work by Bertone *et al.* [5] that had excellent resolution of the final deuteron products for states in ^{15}O below 9 MeV. A silicon surface barrier ΔE–E telescope was used to collect data for laboratory angles from 10°–45°. Typical beam currents were 30 enA and a monitor detector showed that there was no degradation of the target during the run. A typical spectrum with the focus on displaying populated levels between 5 and 16 MeV in excitation is shown in Fig. 1. A three-particle transfer reaction spectrum is also displayed in Fig. 1 to show the difference in selectivity between single-particle and three-particle transfer reactions [8]. The error in the excitation energies of the peaks identified in the single-particle transfer reaction is ±10 keV and that for the three-particle transfer reaction is ±15 keV.

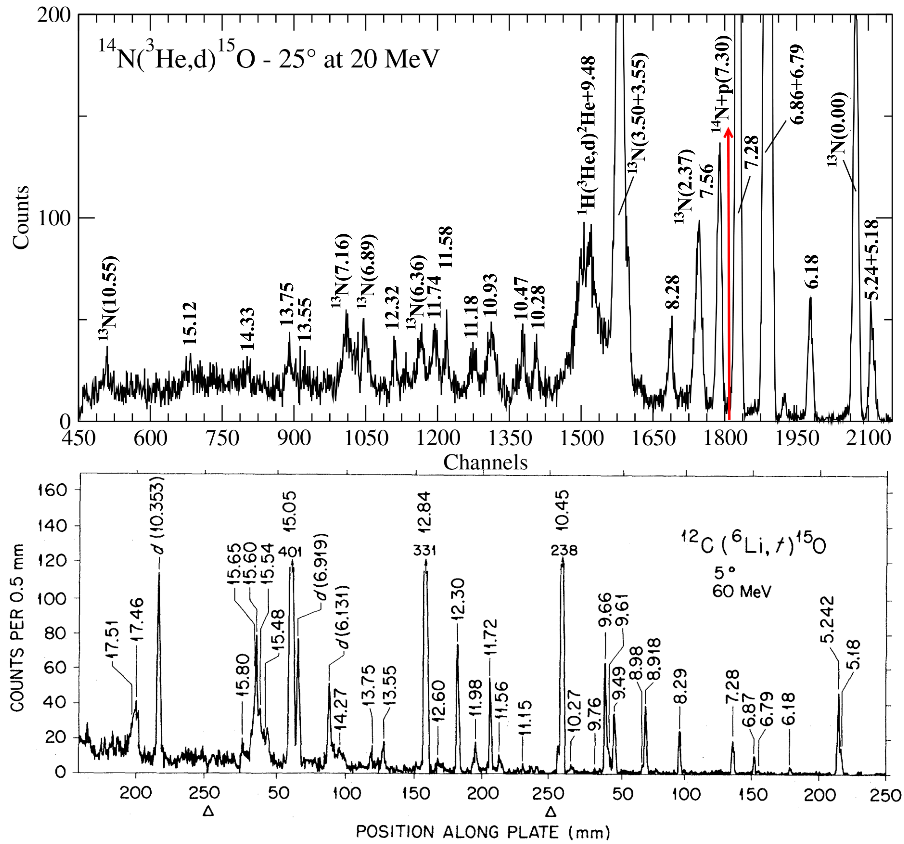

Fig. 1. Plots of typical spectra with the focus on displaying populated levels between 5 and 16 MeV in excitation, for both single-particle and three-particle transfer reactions. This figure allows direct comparison between the two transfers.

3. Results

The first thing to notice in comparing the two spectra of Fig. 1 is that the strongest peaks in the single-particle spectrum occur below 8.5 MeV whereas for the three-particle transfer, they are above this energy. This difference demonstrates the evolution of the structure of ^{15}O from that of a single proton added to ^{14}N to that where one has a core of ^{12}C, and primarily $3p$–$4h$ states [2]. The strong peak observed in the three-particle transfer data at 10.45 MeV provides the anchor for the unambiguous identification of mirror states between ^{15}N and ^{15}O. The most recent compilation for ^{15}O has the $9/2^+$ assignment for this peak in brackets implying this value is uncertain. The strong peak at 10.693 MeV in ^{15}N observed in three-particle transfer reactions was definitively shown to have a spin parity of $9/2^+$ through study of the gamma decays from this peak [9]. The question of the spin-parity of the peak at this excitation energy arose because of the previously known $3/2^-$ level at 10.702 MeV [7] and the fact that the angular momentum mismatched three-particle transfer reaction should strongly populate high spin states, thus not favoring the $3/2^-$ level. As one might expect, the same exact situation occurs in ^{15}O with a $3/2^-$ state occurring at 10.48 MeV. In

TABLE I

Assigned Mirror States in ^{15}N and ^{15}O with energy differences.

^{15}N		^{15}O			ΔE [MeV]
E [MeV]	J^π	E [MeV]	J^π	J^π	^{15}N–^{15}O
5.270	$5/2^+$	5.227	$5/2^+$	$5/2^+$	0.029
5.299	$1/2^+$	5.183	$1/2^+$	$1/2^+$	0.166
6.323	$3/2^-$	6.176	$3/2^-$	$3/2^-$	0.148
7.155	$5/2^+$	6.859	$5/2^+$	$5/2^+$	0.296
7.300	$3/2^+$	6.793	$3/2^+$	$3/2^+$	0.508
7.567	$7/2^+$	7.276	$7/2^+$	$7/2^+$	0.291
8.312	$1/2^+$	7.557	$1/2^+$	$1/2^+$	0.756
8.571	$3/2^+$	8.284	$3/2^+$	$3/2^+$	0.287
9.050	$1/2^+$	8.743	$1/2^+$	$1/2^+$	0.307
9.152	$3/2^-$	8.922	$(3/2^-)$	$1/2^{+a}$	0.230
9.155	$5/2^+$	8.922	$5/2^+$	$5/2^+$	0.233
9.222	$1/2^-$	8.982	$(1/2^-)$	$1/2^{-a}$	0.242
9.760	$5/2^-$	9.488	$5/2^-$	$5/2^-$	0.272
9.829	$7/2^-$	9.660	$(7/2^-)$	$7/2^{-a}$	0.169
9.925	$3/2^-$	9.609	$3/2^-$	$3/2^-$	0.316
10.066	$3/2^+$	9.484	$(3/2^+)$	$3/2^{+a}$	0.58
10.450	$5/2^-$	10.290	$(5/2^-)$	$5/2^{-a}$	0.160
10.533	$5/2^+$	10.300	$5/2^+$	$5/2^+$	0.233
10.693	$9/2^+$	10.461	$(9/2^+)$	$9/2^{+a}$	0.229
10.702	$3/2^-$	10.480	$(3/2^-)$	$3/2^{-a}$	0.222
10.804	$3/2^+$	10.506[b]	$(3/2^+)$	$3/2^{+a}$	0.298
11.236	$7/2^+$	10.917	$7/2^+$	$7/2^+$	0.318
11.293	$1/2^-$	11.025	$1/2^-$	$1/2^-$	0.267
11.438	$1/2^+$	10.938	$1/2^+$	$1/2^+$	0.500
Avg. Dif.					0.294

[a]Denotes J^π assignment suggested from the present work. The bracketed spin parities are shown to be consistent with the current compilations.

[b]Recent compilation has a bracket, which denotes uncertainty in its existence. Mirror assignment confirms its existence. Unless otherwise noted, J^π for ^{15}N and ^{15}O, and energy for ^{15}O were taken from [7].

the present work, one sees that there is no strong peak at around 10.46 MeV in the single-particle spectrum but there is one in the (^{6}Li,t) so that no confusion can be made between the location of the two $9/2^+$ mirror levels in these nuclei [8].

Table I contains all levels known in ^{15}N up to 11.5 MeV in excitation with their spin-parity values. This information is then used to make a one-to-one correspondence with reported levels in ^{15}O, many of which have spin-parities in brackets. The reason for some of the uncertainty in spin-parity values is the low decay threshold energy for $^{15}\mathrm{O} \rightarrow {}^{15}\mathrm{N} + p$ (7.30 MeV) which makes their determination difficult since it is not possible to use normal gamma decay techniques to make firm assignments. In almost all cases, the bracketed spin-parity value is found to be the correct one. The only major change is for one of the 8.922 MeV levels which in the compilation is listed as $(3/2^-)$ but the only possible mirror state has a firm $1/2^+$ assignment so we have assigned this level as $1/2^+$. As a result of the current work, all spin-parity values should now be considered to be determined in ^{15}O up to 11 MeV in excitation.

In summary, comparison between spectra of the ^{14}N(^{3}He,d) and ^{12}C(^{6}Li,t) reactions shows a marked contrast in the strongly populated peaks, with the single-particle strength occurring primarily below 9 MeV in excitation and the three-particle strength lying above 10 MeV. This comparison along with the known spin-parity assignments made to the levels in ^{15}N yields firm mirror pair identification between the two nuclei up to 11 MeV in both nuclei.

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