Communications

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α-transfer spectroscopic factors in ^{23}Na

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α-transfer spectroscopic factors computed from shell-model wave functions for ^{19}F and ^{23}Na generated in the full sd-shell model space with the Chung-Wildenthal interaction are in good agreement with experimental ^{19}F(^{6}Li, d)^{23}Na results, contrary to previous SU(3)-type calculations.

[NUCLEAR STRUCTURE ^{23}Na; Calculation of α spectroscopic factors in full sd basis; comparison with experiment and SU(3).]

In a recent study[1] of the reaction ^{19}F(^{6}Li, d)^{23}Na, relative α-transfer spectroscopic factors S_α were found to be in serious disagreement with both pure SU(3) predictions[2] and with results of a shell-model calculation[1] that included only leading SU(3) representations in the model space. Among the major difficulties were the following:

(1) For the ground-state $K=\frac{3}{2}$ band, the predicted relative α-transfer spectroscopic strengths for the two J values of each L transfer disagreed with the experimental results, i.e., the predictions as to which member of each pair was more strongly populated disagreed in each case with experiment.

(2) The first $\frac{1}{2}^+$ state, at 2.39 MeV, observed experimentally to be strong, was predicted to have zero strength, whereas the second $\frac{1}{2}^+$ state, at 4.43 MeV, was observed to be weak but predicted to be strong.

(3) Relative to the average of all the other states, the observed ground state α-transfer spectroscopic strength was much stronger than predicted.

Recently, theoretical α-transfer spectroscopic factors for sd-shell nuclei calculated from wave functions generated in the full sd-shell model space have been reported[3] for transitions between all pairs of experimentally accessible ground states. Using the same method and set of consistent wave functions[4] as in Ref. 3, we have calculated α-transfer spectroscopic factors for the reaction ^{19}F(^{6}Li, d)^{23}Na. The results are found to be

TABLE I. Excitation energies and S_α's for ^{23}Na.

E_x (MeV) Exp.	E_x (MeV) Calc.	J^π	S_α (^{6}Li, d)	S_α Full-sd	S_α SU(3) [a]
0.0	0.0	$\frac{3}{2}^+$	1.0	1.0	1.0
0.44	0.39	$\frac{5}{2}^+$	0.40	0.78	3.38
2.08	2.15	$\frac{7}{2}^+$	1.98	2.81	2.29
2.39	2.14	$\frac{1}{2}^+$	4.0	5.02	0.0
2.70	2.76	$\frac{9}{2}^+$	0.66	1.39	5.83
2.98	2.83	$\frac{3}{2}^+$	0.85	0.64	3.75
3.92	3.70	$\frac{5}{2}^+$	(1.12)	6.68	1.37
4.43	4.37	$\frac{1}{2}^+$	0.54	2.05	6.67
4.78	4.69	$\frac{7}{2}^+$	1.44	3.17	6.53
5.38	5.41	$(\frac{5}{2}^+)$	0.34	0.01	3.52
5.54	5.64	$\frac{11}{2}^+$	(1.84)	0.75	0.89
6.23	6.21	$\frac{13}{2}^+$	...	0.49	2.67

[a] Reference 2.

TABLE II. Summed spectroscopic factors for $^{19}F \rightarrow {}^{23}Na$.

J^π	Summed strength Exp.	Full-*sd*	SU(3)	L	Summed strength Exp.	Full-*sd*	SU(3)
$\frac{1}{2}^+$	(4.5)	7.07	6.67	0	(4.5)	7.07	6.67
$\frac{3}{2}^+$	1.85	1.64	4.75	2	3.71	9.11	13.62
$\frac{5}{2}^+$	2.86	7.47	8.27				
$\frac{7}{2}^+$	3.42	5.98	8.82	4	4.08	7.37	14.65
$\frac{9}{2}^+$	0.66	1.39	5.83				
$\frac{11}{2}^+$	(1.84)	0.75	0.89	6	(1.84)	1.24[a]	3.56[a]
$\frac{13}{2}^+$	...	0.49	2.67				
	$K=\frac{3}{2}$ ground-state band				5.88	7.22[a]	16.06[a]
	All others				8.29	17.57	21.84

[a] Include predicted S_α for $\frac{13}{2}^+$ state.

in good agreement with the experimental observations, contrary to the previous SU(3) predictions.

In Table I are listed the excitation energies and values of S_α for all states[5] below 6 MeV excitation in ^{23}Na whose structures are reasonably well understood (Refs. 5 and 6 and references therein) and the $\frac{13}{2}^+$ state of the ground-state $K=\frac{3}{2}$ band. It can be seen that the calculated excitation energies are in very good agreement with experiment. In addition to the values of S_α from the present full-*sd* wave functions, the pure SU(3) predictions[2] are also listed for comparison. It is immediately apparent from Table I that most of the deficiencies of the SU(3) predictions do not appear in the new shell-model results.

For states of the $K=\frac{3}{2}$ ground-state band, the present calculations, carried out in the full *sd*-shell space with the Chung-Wildenthal interaction, correctly predict the observed "strong-weak" feature of the $\frac{3}{2}^+$-$\frac{5}{2}^+$ ($L=2$), $\frac{7}{2}^+$-$\frac{9}{2}^+$ ($L=4$), and $\frac{11}{2}^+$-$\frac{13}{2}^+$ ($L=6$) pairs of states. The experimental value of $S_\alpha(\frac{3}{2})/S_\alpha(\frac{5}{2})=2.5$ is to be compared to the new theoretical value of 1.3 rather than the pure SU(3) value of 0.3. Similarly, the experimental value of $S_\alpha(\frac{7}{2})/S_\alpha(\frac{9}{2})=3.0$ is to be compared to the new theoretical value of 2.0 rather than the pure SU(3) value of 0.4. The new theoretical value of $S_\alpha(\frac{11}{2})/S_\alpha(\frac{13}{2})=1.5$ rather than the pure SU(3) value of 0.3. While the cross section of the $\frac{11}{2}^+$ state at 5.54 MeV was measured in the experiment of Ref. 1, the $\frac{13}{2}^+$ state at 6.23 MeV was not directly observed. The experimental upper limit thereby set on the cross section of the $\frac{13}{2}^+$ state relative to the $\frac{11}{2}^+$ state is thus consistent with the predictions of the present calculation but, again, inconsistent with the pure SU(3) prediction.

The present calculations also remedy the glaring discrepancies which existed between experimental and pure SU(3) theory for the $\frac{1}{2}^+$ states. The new predicted $S_\alpha(\frac{1}{2})$ are 5 and 2 for the first and second $\frac{1}{2}^+$ states, in much better agreement with the values 4 and 0.5 experimentally measured than were the pure SU(3) values of 0 and 7. Additionally, the new predicted S_α for the second $\frac{7}{2}^+$ state is in better agreement with experiment than is the much-too-large SU(3) value.

The present calculations fail to improve the agreement between theory and experiment for the second and third $\frac{5}{2}^+$ states in that they predict a larger value than is measured (albeit with a large uncertainty resulting from the incompletely resolved 3.85 MeV $\frac{5}{2}^-$ state) for the 3.92 MeV, second $\frac{5}{2}^+$ state and a vanishing, rather than only smaller, value for the third $\frac{5}{2}^+$ state.

The summed α-transfer spectroscopic strengths (relative to the $\frac{3}{2}^+$ ground-state strength) for various J and L values for all the states listed in Table I are listed in Table II. It can be seen that the summed spectroscopic strengths for the full shell-model calculation are also in better agreement with experiment than are the SU(3) values. The principal remaining discrepancy is for $L=2$ or $J=\frac{5}{2}$, where the large difference in spectroscopic strengths comes mainly from the previously mentioned 3.92 MeV $\frac{5}{2}^+$ state, which was not resolved from a nearby $\frac{5}{2}^-$ state in the experiment. Otherwise, all the summed spectroscopic strengths are within a factor of 2 of the experimental results which is quite acceptable at our present state of competence in extracting experimental values of S_α. In Table II are also listed the summed α-transfer spectroscopic strengths (again relative to the $\frac{3}{2}^+$ ground-state strength) of members of the ground-state $K=\frac{3}{2}$ band, and of

all other states listed in Table I. The full-sd calculation correctly accounts for the ground-state band strength, while overpredicting the summed strength of the remaining other states by a factor of approximately 2. The SU(3) predictions,[2] on the other hand, give summed strengths which are in both cases larger by almost a factor of 3 than experiment.

The conclusion of the present investigation is that α-transfer spectroscopic factors calculated from wave functions characterized by full configuration mixing in the $d_{5/2}$-$s_{1/2}$-$d_{3/2}$ model space give a rather successful accounting of the experimental results of the ^{19}F(^{6}Li, d)^{23}Na reaction, in contrast to the inadequacies of simple SU(3) predictions. It remains to study the puzzle of why the introduction of a limited amount of configuration mixing to the pure SU(3) structure as was done in the shell-model calculations whose results are quoted in Ref. 1 should yield even poorer correspondence with experiment than those of the pure SU(3) model.

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