$L=1\,\alpha$ widths near 5 MeV in ^{19}F

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(Received 7 July 2003; published 18 September 2003)

Using the strong 1^- state in ^{20}Ne as a standard, we have analyzed data for α transfer on ^{15}N and have extracted α widths for six states between 5.3 and 6.6 MeV in ^{19}F. Additionally, results for the 3.91-MeV state allow an estimate of the α width for the mirror ^{19}Ne(4.03).

DOI: 10.1103/PhysRevC.68.034317 PACS number(s): 21.10.Jx, 25.40.Hs, 27.20.+n

For an unbound state, its particle decay width can be determined in two independent ways—by forming the state as a resonance or by populating it as a (temporary) final state in a reaction. The total width manifests itself as the width of a bump in a cross section plotted vs the appropriate energy—the center-of-mass (c.m.) bombarding energy in the resonance case, and the c.m. outgoing particle energy in the second situation. Partial widths are determined from cross-section strengths. When the particle emitted in a resonance decay is the same as the particle transferred in a direct stripping reaction, the spectroscopic factor S provides a convenient meeting ground between the two. If $\Gamma_{\rm expt}$ is the particle decay width of the state, and $\Gamma_{\rm sp}$ is the calculated single-particle width for that particle from a state at that energy and decaying with the appropriate angular momentum, then the spectroscopic factor is $S=\Gamma_{\rm expt}/\Gamma_{\rm sp}$. (If isospin Clebsch-Gordan coefficients are involved, then $C^2S=\Gamma_{\rm expt}/\Gamma_{\rm sp}$). For the stripping reaction, the experimental cross section is proportional to S (actually C^2S) times a theoretical cross section calculated for $S=1$, again for the appropriate kinematics and angular momentum.

A state whose width is known, and is a significant fraction of the single-particle value, can be used as a standard to "self-normalize" the direct transfer process [1]. In such cases, the width of another state can be determined without going through the intermediate step of evaluating a spectroscopic factor, which is notorious for being very sensitive to, e.g., details of the potential geometry. The width thus extracted is much less sensitive. Let the standard reaction proceed from J_{1i} to J_{1f} via transfer of a particle with orbital angular momentum L_1 and total angular momentum J_{1x}. Then

$$\sigma_1(\theta)=NC_1^2S_1\frac{(2J_{1f}+1)\sigma_{L1\rm th}(\theta)}{(2J_{1i}+1)(2J_{1x}+1)}.$$

The quantity N may be poorly determined, and, as mentioned, $\sigma_{\rm th}(\theta)$ may depend sensitively on geometric parameters of the various potentials. For the same reaction going from J_{2i} to J_{2f} via transfer of L_2,J_{2x}, we have

$$\sigma_2(\theta)=NC_2^2S_2\frac{(2J_{2f}+1)\sigma_{L2\rm th}(\theta)}{(2J_{2i}+1)(2J_{2x}+1)}.$$

Replacing S_k by $\Gamma_{k\rm expt}/\Gamma_{k\rm sp}$, we get

$$\Gamma_{2\rm expt}=\Gamma_{1\rm expt}\frac{(2J_{1f}+1)(2J_{2i}+1)(2J_{2x}+1)}{(2J_{2f}+1)(2J_{1i}+1)(2J_{1x}+1)}\left[\frac{\sigma_{2\rm expt}(\theta)}{\sigma_{1\rm expt}(\theta)}\right]\times\left[\frac{\Gamma_{2sp}}{\Gamma_{1sp}}\right]\left[\frac{\sigma_{L1\rm th}(\theta)}{\sigma_{L2\rm th}(\theta)}\right].$$

If the two states have comparable Q values and are in the same or a nearby nucleus, and if they are formed with the same L transfer, then the dimensionless quantities in square brackets are very stable and easy to determine.

We have used this technique [1] to compare the ^{15}N(^{6}Li,d)^{19}F and ^{16}O(^{6}Li,d)^{20}Ne reactions, using a strong 1^- state in ^{20}Ne as our standard, and extracting (in that case) a width for an unbound state in ^{19}Ne that is the mirror of the ^{19}F state reached via α transfer. In the present work, we have applied the method to extract spectroscopic factors and widths for other ^{19}F states reached via $L=1$. We have examined both the 22-MeV (^{6}Li,d) data of Refs. [1,2] and (^{7}Li,t) data at 15 and 20 MeV [3]. Relative to the strongest states, the weak states are observed to be weaker in (^{7}Li,t) than in (^{6}Li,d)–perhaps implying that other, nondirect mechanisms (e.g., compound nucleus) are less important for (^{7}Li,t). In order not to deal with Hauser-Feshbach calculation, we have chosen to work with the (^{7}Li,t) data—which has the extra advantage that both experimental and theoretical angular distributions are reasonably structureless, making it much easier to normalize one to the other.

The 1^- level at 5.788 MeV in ^{20}Ne [4] has $\Gamma_\alpha=28\pm3$ eV and is thought to be dominated by configurations $(sd)^3(fp)$—in SU(3) language [5] $(\lambda\mu)=(90)$. It thus has $q=9$, where $q=2N+L$, N being the number of nodes in the radial wave function, not counting the ones at $r=0$ and infinity. With a real Woods-Saxon potential having $r_0=1.40$ fm, $a=0.60$ fm $[R=r_0(16)^{1/3}]$, plus the Coulomb potential of a uniformly charged sphere, the single-particle α width for $q=9$ at this energy is $\Gamma_{\rm sp}=31.3$ eV, giving $S_\alpha=0.895\pm0.090$. Now, if a very different geometry had been chosen, $\Gamma_{\rm sp}$ (and hence S_α) would have been drastically different. This S_α "goes with" this geometry. We will see later that most of this sensitivity disappears if we look only at widths.

The states of interest in ^{19}F [6] are those reached via $L=1$ and with Q values lying in the vicinity of that for the ^{20}Ne(1^-) state. They are three $1/2^+$ and three $3/2^+$ states,

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TABLE I. Levels of ^{19}F, with previous information and present results (E_x in MeV±keV, Γ's in keV).

E_x [a]	J^π [a]	Γ_{expt} [a]	S [b] $(=\Gamma_{expt}/\Gamma_{sp})$	S [c] (^{7}Li,t)	Γ_a [c] (^{7}Li,t)
5.337±2	$1/2^{(+)}$	1.30±0.5 [d]		0.64±0.07	1.9±0.2
5.5007±1.7	$3/2^+$	4±1 [e]	0.47±0.12	0.48±0.06	4.10±0.48
5.938±1	$1/2^+$			0.090±0.013	5.6±0.08
6.255±1	$1/2^+$	8	0.046	<0.10	<17.5
6.4967±1.4	$3/2^+$			0.07±0.01	23±4
6.5275±1.4	$3/2^+$	4	0.011	<0.03	<11
3.91	$3/2^+$		0.076 [f]	0.052	7.5×10^{-9} [g]

[a]Reference [6], unless noted otherwise.
[b]Reference [7].
[c]Present.
[d]Reference [10].
[e]Reference [10] has Γ=4.7±1.6 keV.
[f]References [1,2].
[g]For mirror level in ^{19}Ne.

whose properties are listed in Table I. Note three of the six have known widths, three do not. An earlier work [7] had searched for $(\lambda\mu)=(90)$ α strength in ^{19}F, using α widths to calculate S. Rogers, Beukens, and Diamond [8] suggested long ago that the first two of these states might be the $1/2^+$ and $3/2^+$ states of this configuration. We will assume $q=9$ for the states analyzed herein, but converting to results for $q=7$ is straighforward.

Having (^{7}Li,t) data at both 15 and 20 MeV allows an estimation of any nondirect component to the cross section. Consistency of the results at the two energies demonstrates that such components are unimportant for all but the weakest states. We will return to this point later. Results for S_α and Γ_α are listed in Table I. Two states have only upper limits, because only upper limits exist for the cross sections. Two of the other states are weak, and widths might be (slightly) smaller than the ones we quote here if a small CN cross section is present. For the two weak states, whose α widths were previously known, our upper limits agree with previous information, but are less restrictive. A recent value of $\Gamma_\alpha=1.3\pm0.5$ keV [10] for the 5.337-MeV level agrees with our value, but has a larger uncertainty. The 5.50-MeV $3/2^+$ state previously had $\Gamma_\alpha=4\pm1$ keV. Our result $\Gamma_\alpha=4.10\pm0.48$ agrees and has a smaller uncertainty. A new measurement [10] of 4.7±1.6 keV agrees with the previous value and with our result. Our widths for the other two states are new.

With the new values of S_α the summed $L=1\,\alpha$ strength (combining the present results with the $L=1\,S_\alpha$ of Ref. [7] is 0.80 for $1/2^+$, and 0.56 for $3/2^+$, compared to 0.90 in ^{20}Ne. It thus appears that we have observed most of the $1/2^+$ $L=1$ strength, but that appreciable $3/2^+$ $L=1$ strength remains to be identified. Of course, some of these states could involve $q=7$ rather than $q=9$, but it is likely that most of the $q=7$ strength (for all odd L) resides in the ground-state band.

Concerning the question of sensitivity of S_α and Γ_α to changes in geometry, if we use $r_0=1.94$ fm, rather than 1.40 fm, for the 5.50-MeV state, the resulting S_α is 0.121 ±0.015, drastically different from the value 0.48±0.06 obtained from $r_0=1.40$. But the new α width becomes $\Gamma_\alpha=3.50\pm0.44$, reasonably close to the old value $\Gamma_\alpha=4.10\pm0.48$. This strong insensitivity of Γ_α to geometrical parameters arises because σ_{DW} and Γ_{sp} both behave similarly with changes in r_0. As it is Γ_α that is a physical quantity, and not S_α, it is convenient to think of S_α as merely a step along the way to obtaining Γ_α, rather than as a property of the state. One should never expect agreement for S_α's computed with different potential geometries. But, with care, Γ_α values agree reasonably well.

We turn briefly now to the 3.91-MeV $3/2^+$ state, whose mirror in ^{19}Ne is of astrophysical interest [1,9,11,12]. It is somewhat far away from the present region of analysis, involving a slightly larger kinematic correction, but still well within the appropriate interval. The present results for that state provide $S_\alpha=0.034$ for $q=9$. Converting to $q=7$ gives $S_\alpha=0.052$. Analysis of the (^{6}Li,d) data [2] resulted in $S_\alpha=0.076$ for this state—even after removing a CN contribution. The value $S_\alpha=0.076$ corresponds to $\Gamma_\alpha(^{19}\mathrm{Ne})=11$ μeV [2]. Thus our present S_α would give 7.5 μeV. The ^{15}O (α,γ) rate calculated in Ref. [1] used $\Gamma_\alpha=9.9\pm1.5$ μeV and hence may be too high by a factor 1.3.

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