Sequential decay of ^{16}Ne($2^+{}_1$)

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I have computed the width for sequential $2p$ decay of the first 2^+ state of ^{16}Ne, using a potential model and convolution over the first two resonances in ^{15}F. The result is 83 keV, somewhat larger than a recent computed value of 56 keV and smaller than the experimental value of 150(50) keV.

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I. INTRODUCTION

The mechanism of two-proton decay in light nuclei is still a matter of some debate. For a nucleus $A + 2p$, several processes could contribute, including sequential p decay through intermediate states in nucleus $A + p$ [1]; simultaneous emission of two protons as ^{2}He, which then breaks up into $2p$ [1]; and something called "democratic" decay [2] in which two protons are emitted simultaneously, but not as ^{2}He. As the energy available for decay increases, the sequential mode is expected to eventually dominate.

In this context, the 2^+ first-excited state of ^{16}Ne poses a special problem. Experimental values of its width (Table I) have been reported as 200(200) [3], <50 [4], and 150(50) [5] keV. The best available theoretical estimate of the width for sequential decay is only about 56 keV [6]. That paper stated "This conflict suggests either some deficiency in the calculations or the possibility that the observed peak has other contributions, for example, from the second 0^+ state." The latter is not a likely explanation, because the predicted energy of the second 0^+ state in ^{16}Ne is 2.735 MeV [7], while the 2^+ state is at 1.69(3) MeV [5,6]. For this reason, I have repeated the calculation of the width of this 2^+ state for the sequential mechanism, using a potential model and a convolution procedure to account for the widths of the first two states in ^{15}F. The relevant energies and decay paths are depicted in Fig. 1.

II. CALCULATIONS AND RESULTS

A calculation of the widths for sequential decays through these resonances involves an integral over the energy profile of the intermediate-state resonances. The relevant equation is

$$\Gamma_{\rm seq}(E_T) = \frac{\int \mathrm{Prof}(E_{14p})\Gamma(E_T - E_{14p})dE_{14p}}{\int \mathrm{Prof}(E_{14p})dE_{14p}},$$

where E_{14p} is the energy of the second proton in the sequential decay, $E_T - E_{14p}$ is the energy of the first one, and Prof is a profile function of Breit-Wigner shape. In the present case, E_T is 3.16 MeV [5,6]. For evaluation of this expression, the $^{15}\mathrm{F} + p$ single-particle (sp) widths were calculated in a potential well with geometric parameters r_0, $a = 1.26$, 0.60 fm, and $r_{0c} = 1.40$ fm. For the $^{14}\mathrm{O} + p$ profile functions of the two relevant ^{15}F resonances, I used sp widths computed in the same potential, together with spectroscopic factors for the mirror states in the reaction $^{14}C(d,p)$ [8]. The two are related by the expression $\Gamma = S\Gamma_{\rm sp}$.

As would be expected, the results of such a procedure depend somewhat on the energies and widths of the intermediate ^{15}F resonances. The energy of the lowest resonance in ^{15}F has been variously reported as $1.45^{+0.16}_{-0.10}$ or $1.29^{+0.08}_{-0.06}$ [9] and 1.29–1.51 [10] MeV. Some time ago, I investigated the interdependence of energies of the lowest 0^+, $T = 2$ states in $A = 16$ nuclei and the lowest $1/2^+$ and $5/2^+$ $T = 3/2$ states in $A = 15$ nuclei. I concluded [11] that the best agreement with all known data required an energy of 1.336(45) MeV for the ground state (g.s.) resonance in ^{15}F, with an s^2 fraction of 0.43(4) for the $0^+, T = 2$ states. More recently, with a different approach, Grigorenko *et al.* [12] performed a similar analysis, with similar results—but with a slightly different g.s. resonance energy of 1.405(15) MeV.

In the reaction ^{14}C(d,p), the spectroscopic factor for the g.s. of ^{15}C is reported as $S = 0.88$. With mirror symmetry, this S should be the same in ^{15}F. I have performed the present calculations for that S in ^{15}F. For the $5/2^+$ resonance, I earlier [11] pointed out a problem with its experimental width. The computed sp width for a d resonance at 2.785 MeV is 277 keV. In ^{14}C(d,p), S is 0.69. I have used a width of 190 keV computed with this S. Energies and widths of the intermediate ^{15}F resonances used in the present analysis are listed in Table II.

Of course, the results depend on the assumed configuration amplitudes of the 2^+ wave function. For this purpose, I have used the wave function from an earlier shell-model calculation for ^{16}C [13]. The intensities are listed in the last column of Table III. Contributions from the various sequential decay paths are listed in Table IV.

The procedure is to compute, as a function of energy, s and d sp widths for $^{15}\mathrm{F} + p$. Then, for each decay path, the

TABLE I. Widths (keV) reported for ^{16}Ne($2^+{}_1$).

Source	Width	Reference
Measured	200(200)	[3]
	<50	[4]
	150(50)	[5]
Computed	56	[6]

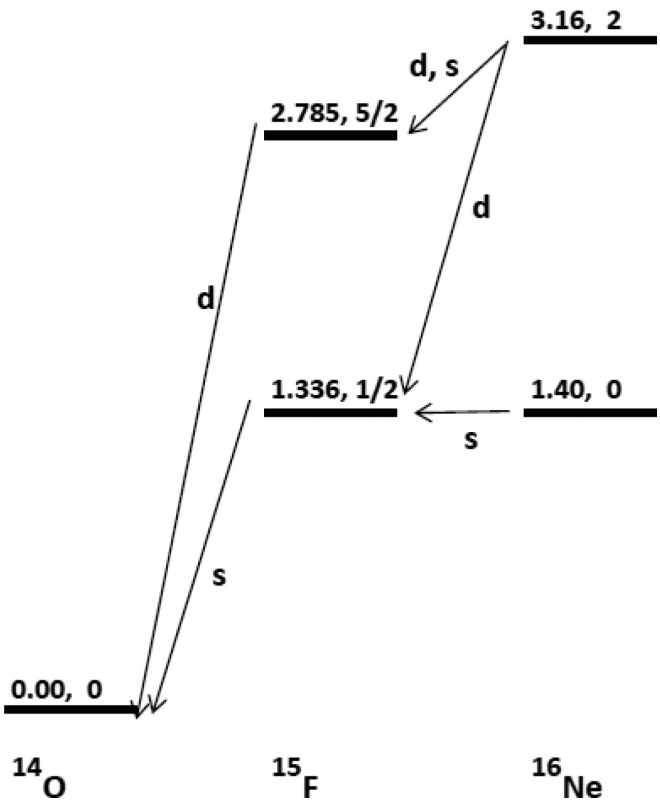

FIG. 1. Relevant energies and decay paths for the sequential decay $^{16}\mathrm{Ne} \to {}^{15}\mathrm{F} + \mathrm{p} \to {}^{14}\mathrm{O} + 2p$. All the indicated states have positive parity.

convolution integral above provides a sp width (column 4 of Table IV) for each branch $^{16}\mathrm{Ne} \to {}^{15}\mathrm{F} + p \to {}^{14}\mathrm{O} + 2p$. These must then be multiplied by the $^{16}\mathrm{Ne} \to {}^{15}\mathrm{F} + p$ spectroscopic factors listed in Table IV to obtain the calculated widths in the last column. These spectroscopic factors were computed from the 2^+ wave function [13]. Note that decays through the $1/2^+$ g.s. resonance provide a calculated width of $49(= 44 + 5)$ keV, while decay through the $5/2^+$ first-excited resonance gives a width of 34 keV. Thus, I find that decays through the $5/2^+$ resonance are only slightly smaller than those through the $1/2^+$ resonance. This contradicts an earlier suggestion that the first 2^+ state of ^{16}Ne decays "predominantly via the g.s. resonance" [14]. Reference [6] considered several refinements to the 2^+ decay process. None of them gave agreement with the measured width. They suggested that the decay might contain interference between sequential decay

TABLE II. Energies and widths (both in MeV) of two lowest resonances in $^{15}\mathrm{F} = {}^{14}\mathrm{O} + p$ used in the present analysis.

J^π	E	Γ
$1/2^+$	1.336	0.79
$5/2^+$	2.785	0.19

TABLE III. Wave-function intensities for $^{16}\mathrm{Ne}(2^+{}_1)$.

Config.	Ref. [6]	Ref. [13][a]
p shell	0.041	Not included
$(1d_{5/2})^2$	0.054	0.368
$(1d_{5/2})(2s_{1/2})$	0.159	0.570
$(1d_{5/2})(1d_{3/2})$	Not listed	0.003
$(1d_{3/2})(2s_{1/2})$	0.713	0.060
$(1d_{3/2})^2$	0.012	Not included

[a]Used in the present analysis.

and another mechanism, which they called a "tethered decay mechanism" [6].

The total computed width for sequential decay is 83 keV, considerably larger than the earlier value of 56 keV [6]. The wave-function intensities from that paper are listed in the middle column of Table III. I considered the possibility that the $(1d_{5/2})(2s_{1/2})$ and $(1d_{3/2})(2s_{1/2})$ intensities have been interchanged in that calculation, because it is unlikely that the lowest 2^+ state could contain such a large $1d_{3/2}$ contribution as is listed in the table of [6]. Interchanging those two intensities would have produced a total width of 74 keV, not very different from my result of 83 keV. However, Grigorenko [15] has stated that their table [6] does not contain a misprint, and that any problem with the wave function is not merely an interchange of two components.

If I had used widths for $^{15}\mathrm{F} \to {}^{14}\mathrm{O} + p$ that correspond to unit spectroscopic factors rather than those from $^{14}\mathrm{C}(d,p)$, the computed width would have been about 105 keV. If, for some reason, the widths should be added coherently, the results of Table IV would correspond to a total computed width of 160 keV.

III. SUMMARY

In summary, a calculation of the width for sequential proton decay of the first 2^+ state of ^{16}Ne provides a value of 83 keV, which is 1.4σ smaller than the most recent experimental width of 150(50) keV. A smaller uncertainty in this width would aid in assessing the possibility of other mechanisms for this decay.

TABLE IV. Decay paths and computed widths (keV) for sequential decay of $^{16}\mathrm{Ne}(2^+{}_1)$.

Intermediate state	$(nlj)_1$	$(nlj)_2$	Γ_{sp}	S_1[a]	Γ_{calc}[b]
$1/2^+$	$1d_{5/2}$	$2s_{1/2}$	77	0.570	44
$1/2^+$	$1d_{3/2}$	$2s_{1/2}$	77	0.060	5
$5/2^+$	$2s_{1/2}$	$1d_{5/2}$	57	0.570	32
$5/2^+$	$1d_{5/2}$	$1d_{5/2}$	2.8	0.735	2.1
$5/2^+$	$1d_{3/2}$	$1d_{5/2}$	2.8	0.003	0.008
Sum					83

[a]Spectroscopic factor for first-emitted proton.
[b]$\Gamma_{\mathrm{calc}} = S_1\Gamma_{\mathrm{sp}}$, where S_1 is the spectroscopic factor for $^{16}\mathrm{Ne}(2^+{}_1) \to {}^{15}\mathrm{F}(1/2^+ \text{ or } 5/2^+) + p$.

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