Width of ^{12}O(g.s.)

H. T. Fortune
Department of Physics & Astronomy, University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA

R. Sherr
Department of Physics, Princeton University, Princeton, New Jersey 08544, USA
(Received 25 June 2003; published 9 September 2003)

We have calculated the expected width for ^{12}O sequential decay through a broad ^{11}N(g.s.) to ^{10}C(g.s.) and for simultaneous (^{2}He) decay by convoluting $2p$ decay widths with the pp relative energy. Both widths are found to be about 60 keV.

DOI: 10.1103/PhysRevC.68.034309 PACS number(s): 23.50.+z, 27.20.+n, 21.10.Tg

The value of the width of the ground state (g.s.) of ^{12}O is still uncertain. Several experiments [1,2] suggest values near 400–600 keV, but in all cases their resolution was of the same order, making decomposition of the peak difficult. An unpublished pion experiment [3] provides an upper limit of 100 keV for this width.

Also largely unknown is the competition between simultaneous (^{2}He) and sequential ($^{12}\mathrm{O}\rightarrow{}^{11}N+p\rightarrow{}^{10}C+p+p$) decays. One experiment [2] suggests an upper limit of 7% for ratio of simultaneous to sequential decays. Most calculations [4] of the total width expected for sequential decay through a $1/2^{+}$ ^{11}N(g.s.) give values in the range 10–100 keV. Calculations of the width for ^{2}He decay depend sensitively on the relative energy between the two protons. For example, if this relative energy is zero, the width is 340 keV [5], while a relative energy of 700 keV gives a width of 22 keV.

In a recent paper, Grigorenko *et al.* [6] have calculated widths of the ground states of ^{12}O and ^{16}Ne, using two different hyperspherical harmonic models. In the first of these, they construct a three-body source function, produce a three-body wave function in a box, and attach it to a decaying asymptotic form. They use repulsive cores to approximate the Pauli principle. The second is a potential model, with three-body bound and continuum states from which they project out the Pauli-forbidden states. They add a collective potential in order to get the correct energy for the g.s. For ^{12}O, the two models produce similar results. Their two main conclusions are (1) a significant breaking of isospin symmetry—"at the level of tens of percents" (for example, their s^2 component in ^{12}O is 1.5–2.0 times what it is in ^{12}Be); (2) the three-body decay mechanism is neither diproton or sequential. The two models give comparable widths—66^{+17}_{-11} keV in the first and $\approx$60 keV in the second.

In an earlier paper, we estimated the s^2 content of ^{12}Be and ^{12}O (which we took to be equal—hence no isospin symmetry breaking). Of course, the radial wave functions of the protons in ^{12}O are different from those for neutrons in ^{12}Be—it is merely the orbital occupancies that we take to be equal.

In the present paper, we have computed the width for sequential decay in the manner of Barker [4], but using widths for each step of the decay calculated in a Woods-Saxon well, rather than in *R*-matrix formulation. We have also computed the ^{2}He width by convoluting the calculated widths with a variety of $p+p$ profile functions, in order to weight with the appropriate relative energies.

For sequential decay through a ^{11}N(g.s.) at $E_p=1.4$ MeV, our convolution gives $\Gamma=74$ keV if both single-particle spectroscopic factors are 1.0. Our wave function [5] gives $S_1=1.04$ (out of a maximum of 2.0) and the mirror S_2 is known [7] to be 0.75, for a product $S_1S_2=0.80$. Hence, our value for Γ_{seq} is 58 keV (see Table I).

For the simultaneous decay, we have tried several different profile functions. Some of these peak near 700 keV, others in the range 500–600 keV. It turns our that the final result is reasonably insensitive to the details. For the numerical work presented here, we used the $0°\epsilon$ dependence of Ref. [8]. As ϵ (the relative proton energy) goes from 0 to 1 MeV, the energy in the ^{2}He center-of-mass motion goes from 1.78 to 0.78 MeV. We have calculated the widths for $n=1$ and $n=2$ appropriate to p-shell and sd-shell ^{2}He, respectively. The former is found to be about 70% of the latter, relatively independent of the energy. For $n=2$, the width is 227 keV for $\epsilon=0$ and 15.3 keV for $\epsilon=700$ keV. The convoluted $n=2$ ($n=1$) ^{2}He width is 43.6 keV (30.5 keV) if the ^{2}He cluster spectroscopic factor is 1.0. As both p and sd shell excitations are present, we must add the amplitudes, not the widths. For the p shell part, we note that Cohen and Kurath [9] give $S=0.786$ for $^{12}\mathrm{Be}\rightarrow{}^{10}\mathrm{Be}$. Our adopted wave function [5] has 33% p shell, 52% s^2, and 15% d^2. With this s^2/d^2 ratio, the cluster value of S_{sd} is 0.81. Our total Γ_{sim} is thus $(0.51\sqrt{\Gamma_1}+0.74\sqrt{\Gamma_2})^2$, i.e., $\Gamma_{sim}=59$ keV. This value is surprisingly (or perhaps, not so surprisingly) close to the value of $\Gamma_{seq}=58$ keV.

Why, then, does the ^{12}O decay experiment [2] find so little simultaneous decay? We suggest that the answer may be found in interference between simultaneous and sequential decays. We note that in Ref. [2], at the three smallest

TABLE I. Widths for $^{12}\mathrm{O}\rightarrow{}^{10}\mathrm{C}+2p$.

Decay mode	Γ_{sp} (keV)[a]	Γ_{calc} (keV)
Sequential[b]	74	58
Simultaneous $n=1$, $n=2$	30.5, 43.6	59

[a]Γ_{sp} is the width if relevant spectroscopic factors are unity.
[b]Through ^{11}N($1/2^{+}$) at $E_p=1.4$ MeV.

angles the ratio $\sigma_{exp}/\sigma_{seq}$ is 0.50 ± 0.16, i.e., more than three standard deviations from unity, whereas at the same four angles $\sigma_{exp}/\sigma_{sim}$ is 0.067 ± 0.021.

This result could be explained if the interference at these angles is destructive. A complete explanation would require the sign of this interference to change near the angle at which the simultaneous process peaks, i.e., destructive at small angles and constructive at large angles.

Within the experimental uncertainties, the simultaneous decay would be in the range 27–46 % of the total, with sequential decay in the range 73–54 %. As both calculated widths are near 60 keV, it is very likely that an accurate measurement of the ^{12}O(g.s.) width will provide a value less than 100 keV, rather than the currently accepted 500–600 keV.

We acknowledge interesting correspondence with F. C. Barker.

[1] G.J. Kekelis *et al.*, Phys. Rev. C **17**, 1929 (1978).
[2] R.A. Kryger *et al.*, Phys. Rev. Lett. **74**, 860 (1995), and references therein; Phys. Rev. C **58**, 2568 (1998).
[3] R. Ivie, Master's thesis, University of Pennsylvania, 1992.
[4] F.C. Barker, Phys. Rev. C **59**, 535 (1999); **63**, 047303 (2001).
[5] R. Sherr and H.T. Fortune, Phys. Rev. C **60**, 064323 (1999).
[6] L.V. Grigorenko, I.G. Mukha, I.J. Thompson, and M.V. Zhukov, Phys. Rev. Lett. **88**, 042502 (2002).
[7] D.L. Auton, Nucl. Phys. **A157**, 305 (1970); B. Zwieglinski, W. Benenson, R.G.H. Robertson, and W.R. Coker, *ibid.* **A315**, 124 (1979).
[8] H. Okamura, Phys. Rev. C **60**, 064602 (1999).
[9] S. Cohen and D. Kurath, Nucl. Phys. **A141**, 145 (1970).