Eur. Phys. J. A **16**, 7–9 (2003)
DOI 10.1140/epja/i2002-10101-2

THE EUROPEAN PHYSICAL JOURNAL A

Short Note

$1^+(0^+)$ state at 12.4 MeV in ^{20}Ne

H.T. Fortune[a]

Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, PA, 19104, USA

Received: 19 August 2002 / Revised version: 29 September 2002 /

Communicated by D. Guerreau

Abstract. Careful review of all the evidence makes it clear that at least three states are important at 12.4-MeV excitation in ^{20}Ne (four, if the broad (2^+) at 12.5 MeV is included). The three states are 3^-, 0^+, and $1^+(0^+)$. The latter, which is quite strong in ^{19}F (^{3}He, d) singles, is probably the state observed in coincidence with 6.13-MeV γ-rays in ^{19}F(^{3}He, dγ).

PACS. 21.10.Hw Spin, parity, and isobaric spin – 27.30.+t $20 \leq A \leq 38$

Alpha-particle clustering in light nuclei has long been an interesting topic. Especially intriguing is the occurrence of relatively pure alpha clusters built on excited states. In these cases, states prefer to decay to excited states, even when ground-state decay is highly favored based on penetrability considerations. The nucleus ^{20}Ne provides a rich array of alpha-clustering phenomena, and even 2α (or ^{8}Be) clustering. A 0^+ level at 12.436 MeV [1] has a strong decay branch to the first-excited 0^+ state of ^{16}O, even though gs decay can proceed with the same L value. A 3^- level [1,2] at 12.394 MeV, with a width of 37 keV, decays by emitting an alpha-particle to the 3^- state at 6.13 MeV in ^{16}O. And a 6^+ state at 12.14 MeV [3] decays to this 3^- level. Investigation of the alpha decays of states just above 12 MeV in ^{20}Ne led to the re-discovery of the discrepancy that is the subject of the present note.

The situation concerning levels near 12.4 MeV in ^{20}Ne is somewhat confusing. The reaction ^{18}O(^{3}He, n) [4] populates a state at $E_x = 12.4 \pm 0.03$ MeV. An observation of $L = 0$ provides a $J^\pi = 0^+$ assignment. In ^{19}F(d,n), a state at 12.395 ± 0.010 [5], or 12.397 ± 0.020 [6] is strongly populated with $l = 0$ —providing a firm $J^\pi = 0^+$ or 1^+. The authors prefer isospin $T = 0$ because of the absence of either J^π at the appropriate energy in ^{20}F. Several groups [2,7,8] observed an ^{16}O + α resonance at $E_x = 12.39 \pm 0.01$ MeV, with γ decays primarily to the 1.63-MeV, 2^+, and 4.25-MeV, 4^+, levels of ^{20}Ne —prompting a 3^- assignment. This resonance has $\Gamma = 37 \pm 5$ keV. A state near here has also been observed in ^{19}F (^{3}He, d) [9] and ^{19}F(^{3}He, dγ) [2]. In ref. [9], a known [10] calibration correction, arising from magnet saturation at high field, was not applied. When it is applied, states near 12.3 MeV need to have 31 keV added to their energies of ref. [9]. With this correction, the well-known 2^+, $T = 1$ state at 12.221 ± 0.004 MeV [11] has a corrected energy from ref. [9] of 12.221 ± 0.004 MeV. Internal consistency of energies at different angles provides an uncertainty of 4 keV. The 12.4-MeV state, whose corrected energy is now 12.398 ± 0.004 MeV, has a very clear $l = 0$ pattern, with some $l = 2$. If $l = 2$ is indeed present, and we are seeing a single state, an $l = 0 + 2$ mixture assures $J^\pi = 1^+$. Of course, the possible presence of another state would not remove the rigorous 0^+ or 1^+ assignment arising from $l = 0$. The $l = 2$ cross-section for the 12.398-MeV state is approximately equal to that for the broad 2^+ level nearby, and hence is too strong to arise from incomplete separation of the contributions of these two states. No other known state could provide this $l = 2$ strength. This is not $l = 3$ strength as there is no evidence (see below) for any population of the 3^- level. In ref. [9], the $l = 0$ state sits clearly on the side of a broad state at (corrected) 12.454 MeV ($\Gamma = 160$ keV) —probably the (2^+) state listed in the compilation [11] at 12.472 ± 0.010 MeV, with $\Gamma = 124 \pm 6$ keV. The $l = 0$ state in ref. [9] clearly has no observable natural width. A smooth curve drawn through the peak corresponding to the nearby strong 12.22-MeV state (which has $\Gamma < 1$ keV) fits the 12.398-MeV state peak perfectly. A state with natural width of 37 keV is not possible. Adding such a state to a fit of the spectrum results in zero or (non-physical) negative cross-section for the 37 keV wide state, if the broader 12.5-MeV level is included in the fit (as it surely must be, from inspection of fig. 2 of ref. [9]). At 7.5°, the upper limit for a possible contribution from a state with Γ = 25–50 keV is 2% of the

---

[a] e-mail: `fortune@physics.upenn.edu`

cross-section observed for the 12.398 MeV. At 0° —where the measurements of ref. [2] were carried out— $l = 3$ is even weaker compared to $l = 0$.

The evidence is thus very clear: a state at 12.398 MeV has no observable width, and is populated by $l = 0$ in ^{19}F(^{3}He, d). Nevertheless, evidence is equally clear [1,2,7] for a probable 3^- state as a resonance in ^{16}O + α, with $\Gamma \approx 37$ keV. At least two states must be present. Marrs *et al.* [2] re-measured a portion of the ^{16}O + α resonance region and observed the broad 3^-, but in ^{19}F(^{3}He, dγ) no width (actually $\Gamma < 200$ keV) was obtained. They simply assumed the two reactions were populating the same state. On p. 440 of their paper, they state "this level is seen in both the ^{16}O($\alpha, \alpha'\gamma$) and ^{19}F(^{3}He, dγ) reactions." And later, "Therefore we identify the ^{16}O ($\alpha, \alpha'\gamma$) resonance with the level seen in ^{19}F(^{3}He, d)…" They arrive at this conclusion without any consideration of width, or branching ratio, or even of coincidence to singles ratio in ^{19}F(^{3}He, dγ).

The fact remains that the ^{19}F(^{3}He, dγ) state α decays to the 6.13-MeV 3^- state of ^{16}O. A 3^- ^{20}Ne level can decay by $L = 0$, whereas a (0^+, 1^+) level requires $L = 3$. Could an $L = 3$ alpha decay with such a low energy exist? Well, a case is known, where the decay energy is even lower —the 12.14-MeV, 6^+ state [3] decays to the ^{16}O (3^-) state, requiring $L \geq 3$. Of course, the competing decay there is $L = 6$ to ^{16}O (gs), while a 0^+ ^{20}Ne level could decay to ^{16}O(gs) via $L = 0$. But if $J^\pi = 1^+$, as is likely, that decay is forbidden, and the only competing decays are electromagnetic. The 12.14-MeV 6^+ state has a partial width of 8 ± 4 eV for decay to the 3^-. The single-particle alpha width for $L = 3$, with 2 nodes, is 6.2 eV. For a state at 12.4 MeV, the alpha penetrability is even more favorable, and alpha decay could easily dominate over gamma decay.

To complicate matters even further, as mentioned earlier, there is a report [1] of a 0^+ state at 12.436 ± 0.004 MeV, with a measurable α decay to the excited 0^+ 6.06-MeV level of ^{16}O. This state has $\Gamma = 24.4 \pm 0.5$ keV, and hence could not be the state seen in ^{19}F(^{3}He, d). Its excitation energy also rules it out. If it is present in ^{19}F(^{3}He, d), its cross-section is less than about 5% of that for the stronger 12.4-MeV state.

There is confirmatory evidence that it is the 3^- level that has width. In ^{12}C(^{12}C,α) [12], which would greatly favor 3^- over either 0^+ or 1^+, a state at 12.381 ± 0.006 MeV clearly has appreciable width (Γ = 30–40 keV). A consistent reading of all the data suggests the presence of at least three states here: 3^-, with $\Gamma \approx 37$ keV; 0^+, with $\Gamma \approx 24$ keV; and $1^+(0^+)$, with very small Γ. The 0^+ level has been suggested [1] to be of eight-particle four-hole character —an alpha cluster coupled to the excited 0^+ 6.06-MeV ^{16}O level. The present author supports that view, thinking of it as ^{24}Mg$^* \otimes {}^{12}$C, where ^{24}Mg* is the 0^+ state at 6.44 MeV [13] in ^{24}Mg, strongly populated [14] in α transfer. The 8p-4h 0^+ state at 7.19 MeV in ^{20}Ne, on the other hand, is ^{24}Mg(g.s.) $\otimes {}^{12}$C. Could the 3^- be a similar state, *viz.* an $L = 0$ α cluster coupled to the ^{16}O 3^- state? It could be so. Then what about the $1^+(0^+)$ state? An intriguing possibility is an $L = 3$ alpha cluster built on the ^{16}O 3^- level. This coupling would provide even-parity states with J = 0–6. To estimate the expected position of such a state, we simply add the excitation energy of the strong $3^-\alpha$ state in ^{20}Ne at 7.16 MeV to 6.1 MeV. An energy of 12.4 MeV is close enough that this explanation is a serious possibility. Clearly, it is important to ascertain whether (as we expect) it is the strong $1^+(0^+)$ state in ^{19}F(^{3}He, d) that was observed in ref. [2] in coincidence with 6.13-MeV γ-rays. It may be possible to make this assessment from the coincidence to singles ratio of ref. [2]. They detected the d at zero degrees, where from ref. [9], the 3^- makes at most a few percent contribution to the total yield. Most of the 0° singles cross-section clearly comes from the $1^+(0^+)$ state.

In summary, the ^{19}F(^{3}He, d) reaction [9] populates a strong $l = 0$ state at $E_x = 12.398 \pm 0.0004$ MeV, requiring $J^\pi = 1^+$ or 0^+. This state has no measurable width. Its peak shape is indistinguishable from that of a nearby state whose width is known to be less than one keV. An $l = 2$ component in the 12.398-MeV angular distribution appears too strong to arise from contributions of any known states. Of course, the combination of $l = 0$ and 2 to a single state requires $J^\pi = 1^+$. The absence of measurable width also argues for 1^+, rather than 0^+. In any case, we have made a firm assignment of 1^+ or 0^+, with a strong preference for 1^+.

The known 3^- level at 12.394 MeV is not observed in ^{19}F(^{3}He, d). At an angle of 7.5° the upper limit for a state in this energy region, with width in the range 25–50 keV, is 2% of the cross-section of the 1^+ level. At 0°, where the d was detected in ref. [2], the $l = 3$ is even more suppressed relative to $l = 0$. Also, the 3^-decay to ^{16}O(3^-) has a branching ratio [1] of 1.3%. It is unlikely that the experiment of ref. [2] had the sensitivity to detect alpha decay with such a small branch from such a weak state. Of course, a ratio of coincidence to singles —or a branching ratio— would have settled the question, but none is given in ref. [2]. We thus conclude that it is very likely that the state observed in ^{19}F(^{3}He, dγ) through ^{16}O(3^-) is dominantly the 12.398-MeV 1^+ level. We hope the present note will encourage further experiments and calculations.

References

1. E.F. Garman, L.K. Fifield, W.N. Catford, D.P. Balamuth, J.M. Lind, R.W. Zurmuhle, Nucl. Phys. A **372**, 194 (1981); C.M. Laymon, K.D. Brown, D.P. Balamuth, Phys. Rev. C **45**, R576 (1992).
2. R.E. Marrs, E.G. Adelberger, K.A. Snover, Nucl. Phys. A **277**, 429 (1977).
3. D.P. Balamuth, J.W. Noe, H.T. Fortune, R.W. Zurmuhle, Phys. Rev. C **6**, 1694 (1972).
4. K. Gul, B.H. Armitage, B.W. Hooten, Nucl. Phys. A **153**, 390 (1970).
5. B.T. Lawergren, A.T.G. Ferguson, G.C. Morrison, Nucl. Phys. A **108**, 325 (1968).
6. R.C. Ritter, J.T. Parson, D.L. Bernard, Phys. Lett. B **28**, 588 (1969).

7. J.D. Pearson, R.H. Spear, Nucl. Phys. **54**, 434 (1964).
8. J. John, J.P. Aldridge, R.H. Davis, Phys. Rev. **181**, 1455 (1969).
9. R.R. Betts, H.T. Fortune, R. Middleton, Phys. Rev. C **11**, 19 (1975).
10. J.R. Powers, H.T. Fortune, R. Middleton, O. Hansen, Phys. Rev. C **4**, 2030 (1971).
11. D.R. Tilley, C.M. Cheves, J.H. Kelley, S. Raman, H.R. Weller, Nucl. Phys. A **636**, 249 (1998).
12. L.R. Medsker, H.T. Fortune, R.R. Betts, R. Middleton, Phys. Rev. C **11**, 1880 (1975).
13. R.M. Endt, C. van der Leun, Nucl. Phys. A **214**, 1 (1973).
14. P. Neogy, W. Scholz, J. Garrett, R. Middleton, Phys. Rev. C **2**, 2149 (1970).