PHYSICAL REVIEW C **88**, 034328 (2013)

Structure of ^{10}He and the reaction ^{8}He(t, p)

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

(Received 18 August 2013; revised manuscript received 18 September 2013; published 30 September 2013)

I review the situation regarding the ground and low-lying states of ^{10}He, with special emphasis on the reaction ^{8}He(t,p). I present calculations of relative cross sections for 0^+ and 1^- states. I conclude that the strong state reported near 5.5 MeV is probably not 1^-.

DOI: 10.1103/PhysRevC.88.034328 PACS number(s): 21.60.Cs, 25.55.Hp, 25.60.−t, 27.20.+n

I. INTRODUCTION

The structure of ^{10}He is very poorly known [1]. Several different experiments [2–9] have provided quite different energies and widths for even the ground state (g.s.), as listed in Table I. Using proton knockout from ^{11}Li, Johansson *et al.* [8] provided two analyses. One had a narrow g.s. at 1.42(11) MeV plus a correlated background. The other involved two overlapping resonances: 0^+ at 1.54(11) MeV and 2^+ at 3.99(26) MeV. In a later paper [9], they concluded that the E_{2n} region from 3 to 5 MeV was dominated by the 2^+ (whose configuration contained only 24% p shell), with the 0^+ g.s. lower. The theoretical situation is also confusing. Earlier, Aoyama *et al.* [10], in an ^{8}He-n-n model, had found the ^{10}He g.s. to be near 1.8 MeV. Later, Aoyama suggested the g.s. was near threshold and was mostly of s^2 configuration [11]. Korsheninnikov *et al.* [12] used 1.15 MeV for the energy of the $1/2^-$ resonance in ^{9}He and deduced the ^{10}He g.s. was near 1 MeV and was mostly p shell. Grigorenko and Zhukov [13] (called GZ hereinafter) have discussed the problems with the ^{10}He(g.s.). They suggested a p-shell 0^+ state in the range 2.0–2.3 MeV, and an s^2 "alternative" g.s. at $E < 0.25$ MeV. For the p-shell estimate, they used the ^{9}He $1/2^-$ energy of 2.0(2) MeV from the ^{8}He(d,p) reaction [14] (in reverse kinematics). To explain the correlation pattern, Golovkov *et al.* [14] found it necessary to include $1/2^+$-$1/2^-$ interference as well as interference with a $5/2^+$ state above 4.2 MeV. GZ theorized that the p-shell 0^+ state might appear as a peak in the cross section near 1.2 MeV (rather than 2.0–2.3 MeV) in reactions involving ^{11}Li.

Various investigations [4,6,8,9] differ as to the identity of the first two excited states of ^{10}He (see Table II). The 2^+ energy is given (in MeV) as 3.24(20) [4], > 6 [6], 3.99(26) [8], or 3–5 [9]. Because ^{12}Be and ^{10}He have the same number of neutrons, it might be reasonable that the lowest few states in the two nuclei should be similar. In ^{12}Be, the three lowest excited states are 2^+, 1^-, and 0^+ at excitation energies of 2.10 [15], 2.70 [16], and 2.24 [17] MeV, respectively. Thus, we expect the first three excited states of ^{10}He to have these J^π, though not necessarily in the same order.

Much of the information concerning ^{12}Be came from the ^{10}Be(t,p) reaction [15,18]. This was the first experiment to demonstrate a large $(sd)^2$ component in ^{12}Be(g.s.), predicted earlier by Barker [19]. A ^{12}Be(g.s.) wave function consisting of 68% $(sd)^2$ and 32% p-shell components [20] is in good agreement with many observables [21]. The excited 0^+ state is well described as the orthonormal linear combination of these two components—as evidenced by its very small cross section in (t,p), its $B(E2)$ to the first 2^+ state [22,23], and especially by its B(GT) from ^{12}B(g.s.) [24].

II. CALCULATIONS

One possible explanation for the fact that the "g.s." of ^{10}He appears at different energies in different reactions could be that two 0^+ states are present at low energies and their relative population is different in different reactions. Recall from the Introduction above that GZ produced a p-shell 0^+ at 2.0–2.3 MeV and an s^2 one below 0.25 MeV.

It might be expected that the ^{8}He(t,p) and ^{10}Be(t,p) reactions should be similar. The amount of the $(sd)^2$ configuration in ^{10}He(g.s.) is unknown, as is the definite location of a possible s-wave structure in ^{9}He. For the ^{8}He(t,p) reaction, I find that

TABLE I. Energy and width (both in MeV) of ^{10}He(g.s.) from various reactions.

Reaction	E_{2n}	Γ	Ref.
H(^{11}Li,2p)	1.7(3)(3)		2
^{2}H(^{11}Li,^{3}He)	1.2(3)	<1.2	3
^{10}Be(^{14}C,^{14}O)	1.07(7)	0.3(2)	4
^{14}Be–2p2n	1.60(25)	1.8(4)	5
^{3}H(^{8}He,p)	2.1(2)	~2	6
^{3}H(^{8}He,p)	~ 3		7
p knockout from ^{11}Li	1.42(10), or 1.54(11)	1.11(76), or 1.91(41)	8

TABLE II. Energies and widths (both in MeV) of states in ^{10}He from reactions listed.

Reaction	J^π	E_{2n}	Γ	Ref.
^{10}Be(^{14}C,^{14}O)	0^+	1.07(7)	0.3(2)	4
	(2^+)	3.24(20)	1.0(3)	
	(3^-)	6.80(7)	0.6(3)	
^{8}He(t,p)	0^+	2.1(2)	~2	6
	1^-	~5.5	~2.5	
	2^+	>6		
p KO from ^{11}Li	0+	1.54(11)	1.91(41)	8
	2+	3.99(26)	1.64(89)	

0556-2813/2013/88(3)/034328(3)

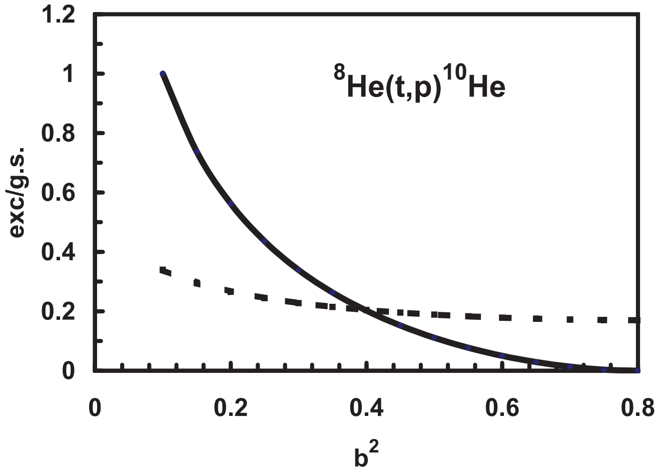

FIG. 1. As a function of the assumed fraction of $(sd)^2$ component in ^{10}He(g.s.), the ratio of cross sections expected for an excited 0^+ (solid) and 1^- (dashed) state relative to the g.s. in the reaction ^{8}He(t,p).

the calculated cross section for the s^2 state is about four times that for the p-shell 0^+ state. There is no evidence yet of an excited 0^+ state in ^{10}He. For definiteness, following GZ, if I take the s^2 energy to be 0.20 MeV and the p-shell 0^+ to be 2.15 MeV, a 4:1 ratio of strengths would produce a peak near 0.6 MeV. If these two states mix, as they must, the ratio will decrease below 4:1, and the peak will move upward in energy. Of course, mixing moves the two states apart. With the energies of GZ for the un-mixed states, any appreciable mixing would put the lower state below threshold—where presumably no state exists. Thus, if the two 0^+ states mix considerably, the s^2 energy would, of necessity, be higher than that suggested by GZ.

These two 0^+ states may be close enough and wide enough that their contributions cannot be separated experimentally. But, it is still possible to compute, as a function of the mixing, the expected cross-section ratio of the two states in the ^{8}He(t,p) reaction. Results are displayed as the solid curve in Fig. 1 for the exc/g.s. ratio as a function of b^2—the intensity of $(sd)^2$ in the g.s. It can be seen that the excited state would be stronger than the g.s. if b^2 is less than about 12%. The excitation energy difference of the two states could be in the 2–3 MeV range, and it is a minimum (in a two-state model) for 50% configuration mixing. If the g.s. is mostly s^2, as implied by the calculations of GZ, the excited 0^+state will be extremely weak. This was indeed observed to be the case in ^{12}Be.

The ^{8}He(t,p) experiment of Ref. [6] (in reverse kinematics) reported a 1^- state at ~5.5 MeV as the first excited state of ^{10}He, with a yield larger than that for the g.s. It would not be surprising if the first excited state turned out to be 1^-, with the 2^+ somewhat higher. But, it would be very surprising to find this 1^- state strongly populated in the (t,p) reaction. In ^{10}Be(t,p) the 1^- cross section is only about 17% of that for the g.s. I have estimated the cross section for the 1^-, assuming only that its neutron structure is the same as that of the first 1^- in ^{12}Be. Of course, the 1^- cross section does not depend on the amount of 0^+ mixing in ^{10}He. But, I prefer to deal in dimensionless ratios, and the 1^-/g.s. ratio does depend on such mixing because the g.s. cross section does. Figure 1 shows, as a dashed curve, a plot of the expected 1^- to g.s. ratio as a function of the g.s. mixing. The ratio is seen to be quite small for any 0^+ mixing. It is thus unlikely that a 1^- state in ^{10}He contributes to the extent reported in Ref. [6].

Because all the states of ^{10}He are unbound, any reaction will be plagued by a real three-body continuum background, extending to well below the g.s. At fixed angle, this background can (will) interfere with any actual resonances, which will also interfere with each other if they overlap. This interference can produce unusual energy and angular distributions. In Ref. [25] it is suggested that such interference effects (including interference between overlapping 0^+ and 2^+ states) could explain the results of Ref. [6] without the need for a 1^- state. I agree.

III. SUMMARY

I have reviewed the conflicting information concerning the g.s. and first few excited states of ^{10}He. One possible explanation for the g.s. confusion could be the presence of overlapping 0^+ resonances, whose relative strengths differ in various reactions. For the ^{8}He(t,p) reaction, I have estimated the cross-section ratio of these two 0^+ states, as a function of the mixing between the s^2 and p-shell basis states. I have also estimated the expected relative cross section for the first 1^- resonance. I conclude that the strong structure reported near 5.5 MeV [6] is probably not 1^-.

---

[1] D. R. Tilley *et al.*, Nucl. Phys. A **745**, 155 (2004).
[2] T. Kobayashi, K. Yoshida, A. Ozawa, I. Tanihata, A. Korsheninnikov, E. Nikolsky, and T. Nakamura, Nucl. Phys. A **616**, 223c (1997).
[3] A. A. Korsheninnikov *et al.*, Phys. Lett. B **326**, 31 (1994).
[4] A. N. Ostrowski *et al.*, Phys. Lett. B **338**, 13 (1994).
[5] Z. Kohley *et al.*, Phys. Rev. Lett. **109**, 232501 (2012).
[6] S. I. Sidorchuk *et al.*, Phys. Rev. Lett. **108**, 202502 (2012).
[7] M. S. Golovkov, Phys. Lett. B **672**, 22 (2009).
[8] H. T. Johansson *et al.*, Nucl. Phys. A **842**, 15 (2010).
[9] H. T. Johansson *et al.*, Nucl. Phys. A **847**, 66 (2010).
[10] S. Aoyama, K. Katō, and K. Ikeda, Phys. Rev. C **55**, 2379 (1997).
[11] S. Aoyama, Nucl. Phys. A **722**, C474 (2003).
[12] A. A. Korsheninnikov, B. V. Danilin, and M. V. Zhukov, Nucl. Phys. A **559**, 208 (1993).
[13] L. V. Grigorenko and M. V. Zhukov, Phys. Rev. C **77**, 034611 (2008).
[14] M. S. Golovkov *et al.*, Phys. Rev. C **76**, 021605(R) (2007).
[15] D. E. Alburger, D. P. Balamuth, J. M. Lind, L. Mulligan, K. C. Young, Jr., R. W. Zurmühle, and R. Middleton, Phys. Rev. C **17**, 1525 (1978).
[16] H. Iwasaki *et al.*, Phys. Lett. B **491**, 8 (2000).
[17] S. Shimoura *et al.*, Phys. Lett. B **560**, 31 (2003).
[18] H. T. Fortune, G.-B. Liu, and D. E. Alburger, Phys. Rev. C **50**, 1355 (1994).

[19] F. C. Barker, J. Phys. G **2**, L45 (1976).
[20] H. T. Fortune and R. Sherr, Phys. Rev. C **74**, 024301 (2006).
[21] H. T. Fortune and R. Sherr, Phys. Rev. C **85**, 051303 (2012).
[22] S. Shimoura *et al.*, Phys. Lett. B **654**, 87 (2007).
[23] H. T. Fortune, Phys. Rev. C **85**, 044309 (2012).
[24] R. Meharchand *et al.*, Phys. Rev. Lett. **108**, 122501 (2012).
[25] L. V. Chulkov, T. Aumann, B. Jonson, T. Nilsson, and H. Simon, Phys. Lett. B **720**, 344 (2013).