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Excitation energy of the second excited state of ^{12}C†

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The excitation energy of the second excited state of ^{12}C is measured to be 7655.2 ± 1.1 keV. The current best value, including the present work, for the 3α-^{12}C(7.65 MeV) Q value is 380.1 ± 1.0 keV.

[NUCLEAR REACTIONS $^{12}C(p, p)^{12}C$ measured E_x of ^{12}C(7.65 MeV).]

The rate for the two important steps in stellar helium burning, $\alpha + \alpha \rightleftharpoons {}^8Be + \alpha \rightleftharpoons {}^{12}C(7.65\text{ MeV}) \rightarrow {}^{12}C + \gamma$, depends linearly on the radiation width of the 7.65-MeV state of ^{12}C and exponentially upon the Q value, $Q = M_{3\alpha} - M_{7.65}$.

There have been three recent accurate measurements[1-3] giving this Q value and Barnes and Nichols[4] point out that the uncertainty in the overall reaction rate is now limited by the somewhat contradictory measurements of Γ_γ. Nevertheless, we have remeasured the ^{12}C(7.65 MeV) excitation energy for two reasons. First, one of the three recent accurate measurements[1] was made at this laboratory using the 50-cm spectrograph and at the same time the excitation energy of the first excited state of ^{12}C was measured. That result for the first state is about 2 standard deviations above the current best average of 4439.43 ± 0.25 keV given in Ref. 5. Using our 100-cm spectrograph we measure[6] 4439.5 ± 1.0 keV. If the high value for the first excited state in Ref. 1 were caused by a systematic error then the second excited state energy might also be in error, even though it agrees well with other measurements. Second, with the 100-cm spectrograph we can reduce our uncertainty to that found by averaging the current best three numbers[1-3] ($\simeq 1$ keV).

In the present experiment we used the $^{12}C(p,p)^{12}C$ reaction and the techniques and error analysis follow those described in Ref. 6 except instead of determining the bombarding energy and angle from elastically scattered groups only, the ^{12}C(4.44 MeV) state and well-known ($\Delta E_x < 0.2$ keV) states in ^{56}Fe and ^{60}Ni were also used. This reduces certain errors, especially systematic errors. Our result is 7655.2 ± 1.1 keV, and the average of all work is 7655.2 ± 0.8, Table I.

The measurement of the second excited state in Ref. 1 is seen to be consistent with all other results. We suggest that the deviation of 2σ from the current best average value for the first excited state energy is merely a statistical fluctuation. Other excitation energies measured at about the same time agree well with independent measurements. For example, the excitation energy[7] of the ^{11}B state at 4.44 MeV agrees with a recent measurement by Kashy, Benenson, and Nolen[8] supporting the assumption of small systematic error in the 50-cm values.

With the addition of our measurement the uncertainty in the Q value for $3\alpha \rightarrow {}^{12}C$(7.65 MeV) has equal contributions from the uncertainty in the 3α mass (0.75 keV) and the excitation energy (0.79 keV). The resultant uncertainty in the reaction rate is $\simeq 10\%$ and is well below that due to the radiation width.

TABLE I. Summary of excitation energy measurements of the second excited state of ^{12}C and Q values for $^{12}C^* \rightarrow 3\alpha$.

Authors	E_x (keV)	Q (keV)
Austin, Trentleman, and Kashy (Ref. 2)	7656.2 ± 2.1	
Stocker, Rollefson, and Browne (Ref. 1)	7655.9 ± 2.5	
McCaslin, Mann, and Kavanagh (Ref. 3)	7654.2 ± 1.6	
Present work	7655.2 ± 1.1	
Average of excitation measurements	7655.2 ± 0.8	380.3 ± 1.1
Barnes and Nichols (Ref. 4)		379.6 ± 2.0
Average		380.1 ± 1.0

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