Direct Observation of the Second $J^\pi = 2^+$ State in $^{12}$C and New Triple-$\alpha$ Thermonuclear Reaction Rates\textsuperscript{1}

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During core-collapse supernovae, the triple-$\alpha$ thermonuclear reaction rates at high temperatures can affect the outcome of explosive nucleosynthesis and the production of heavy elements. The question of the existence of a second $J^\pi = 2^+$ state in $^{12}$C has led to a long-standing disagreement in the triple-$\alpha$ thermonuclear reaction rates at high temperatures. This $2^+_2$ state has been directly observed in the $^{12}$C($\gamma$, $\alpha$)$^8$Be reaction using the intense, nearly monoenergetic $\gamma$-ray beams available at the High Intensity $\gamma$ Source (HI\textgamma S) facility. The $\alpha$ particles produced by the photodisintegration of $^{12}$C were detected using an optical time projection chamber (OTPC). This allowed for the measurement of complete angular distributions which were used to determine the $E1$ and $E2$ amplitudes and their relative phases. The $2^+_2$ state was observed in the $E2$ cross section and confirmed in the behavior of the relative phases. This unique combination of a Compton-backscattered $\gamma$-ray beam and an active-target system made possible the first unambiguous identification of this $2^+$ state. New triple-$\alpha$ thermonuclear reaction rates have been calculated based on the results of this experiment, and simulations based on the $\nu\pi$ process \textsuperscript{[1]} have been performed illustrating the effect of the second $2^+$ state in $^{12}$C on the outcome of explosive nucleosynthesis.


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