3 - 21 A New Technique to Measure the ^{12}C(^{12}C, α_0)^{20}Ne Cross Section at Stellar Energies*

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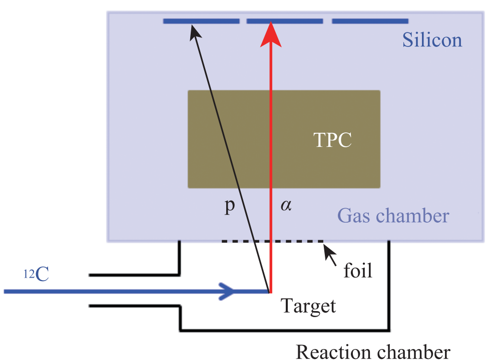
Stars with initial mass $\gtrsim$8M$_{\text{sun}}$ burn the carbon element after consuming most of its helium materials. The ^{12}C+^{12}C fusion reaction is the primary reaction of the carbon burning process, producing magnesium and other elements including neon, sodium and oxygen[1]. Since the astrophysical energy ($E_{\text{c.m.}}=1\sim3$ MeV) is much lower than the height of the repulsive Coulomb barrier ($E_{\text{c.m.}}$=5.8±0.3 MeV), ^{12}C+^{12}C fusion cross sections are extremely small and hence very challenging to measure in the laboratory[2, 3]. To continue the ^{12}C+^{12}C measurements at lower energies, both high intense beams and new detection technologies are required to increase the reaction yields and effectively suppress the huge background, respectively.

We started an experimental project to study the astrophysically important fusion reactions at deep sub-barrier energies based on the Low Energy high-intensity high-charge-state ion Accelerator Facility (LEAF), Lanzhou[4]. The ^{12}C beam with an intensity up to 45 pμA has been successfully applied on our high power carbon target without damage. Meanwhile, the beam energy was calibrated using ^{12}C(p, γ), ^{27}Al(p, γ) and ^{15}N(p, $\alpha\gamma$) reactions. The measured energy resolution for ^{12}C beam at $\sim$ 0.5 MeV/u is less than 0.2% (1σ).

The ^{12}C(^{12}C, α_0)^{20}Ne cross section was measured from 0.65 to 0.37 MeV/u. The alpha particles were measured using a novel tracking technique based on Time Projection Chamber (TPC)[5]. TPC was filled with a gas mixture of He and 5% CO_2 mixture at a pressure of 135 mbar. A schematic drawing of the experiment setup is shown in the left panel of Fig. 1. Reaction products pass through the TPC active region and are stopped by silicon detectors. Due to the accurate tracking and particle identification capabilities, interested products from ^{12}C+^{12}C can be discriminated against contaminations from beam induced reactions and natural radioactivities. At the energy of $E_{\text{c.m.}}$=2.22 MeV, one α_0 event is found with a total charge of 0.9 mC accumulated in the target, as shown in the righ panel of Fig. 1. Deduced thick-target yield for α_0 channel is $1.38^{+2.41}_{-0.87}\times10^{-17}$/^{12}C, representing the state-of-the art best sensitivity in direct measurements. Our preliminary result demonstrates that TPC detection technique holds considerable promise in the ^{12}C+^{12}C fusion studies. A campaign is being planned to measure the ^{12}C(^{12}C, α)^{20}Ne cross section down to $E_{\text{c.m.}}\approx$2 MeV. Our measurement will be able to check the existence of the strong resonance around $E_{\text{c.m.}}$=2.1 MeV reported by an earlier experiment[6].



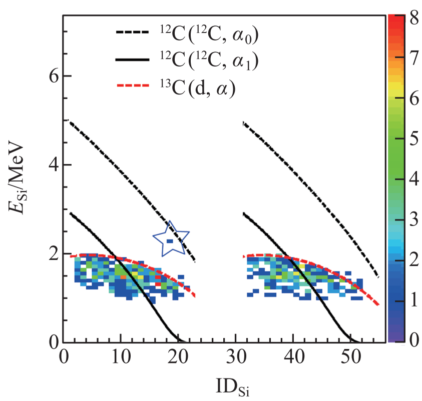


Fig. 1 (color online) Left: schematic drawing of detection array. Right: energy measured in silicon versus the silicon strip channel. The marked data point is identified as α_0 particle, which is obtained at the $^{12}C^{4+}$ beam of 370 keV/u. Lots of α particles from ^{13}C(d,α) reaction are also observed because a small amount of DH^+ are transported with the $^{12}C^{4+}$ beam.

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3 - 22 Study of the Urca Cooling Ability of ^{63}Fe-^{63}Mn

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The temperature in the crust of an accreting neutron star is believed to have a significant impact on observable phenomena at the outer layer of a neutron star. This temperature is regulated by various factors, such as heating from nuclear reactions, neutrino cooling processes and heat transport from the interior[1]. Among these, Urca process is considered to be the primary mechanism for neutrino cooling.

Urca process is a cycle consisting of electron capture and β^- decay. Nuclei participate in the Urca process are Urca pairs. The concept of Urca process was first introduced in 1941 by Gamow. In 2014, Schatz considered the Urca process in neutron stars for the first time. They calculated the cooling ability of 85 odd-A nuclei and identified ^{63}Fe-^{63}Mn as a non-significant Urca pair. This result is supported by a recent experiment, which suggests that the ground state J^π of ^{63}Fe could be $1/2^-$[2]. Such a value of J^π leads to a second-order forbidden transition between the ground states of ^{63}Fe and ^{63}Mn. However, the systematics of nuclear structure suggests that the ground state J^π of ^{63}Fe may have a possible value of $5/2^-$. The value given by β^- decay of ^{63}Mn is also $5/2^-$[3]. Therefore, the transition between the ground states of ^{63}Fe and ^{63}Mn could be an allowed transition, and the cooling ability of ^{63}Fe-^{63}Mn needs to be recalculated.

The cooling ability of an Urca pair is quantified by the neutrino luminosity, which refers to the energy loss caused by neutrinos. In the previous work, ^{33}Al-^{33}Mg is identified to be the strongest Urca pair with neutrino luminosity $L_\nu = 0.042 \times 10^{36} \mathrm{erg \cdot s^{-1}}$[4,5]. Here we find that the neutrino luminosity of ^{63}Fe-^{63}Mn is $L_\nu = 0.039\ 7 \times 10^{36} \mathrm{erg \cdot s^{-1}}$, with the ground state J^π of ^{63}Fe as $5/2^-$. Our calculation indicates that the neutrino luminosity of ^{63}Fe-^{63}Mn is comparable to that of ^{33}Al-^{33}Mg.

Overall, we recalculate the cooling ability of ^{63}Fe-^{63}Mn, using a suggested ground state $J^\pi = 5/2^-$ of ^{63}Fe from the systematics of nuclear structure. Our result suggests that ^{63}Fe-^{63}Mn is a significant Urca pair. The discrepancy between our result and previous one is primarily attributed to the uncertainty surrounding the ground state J^π of ^{63}Fe. Therefore, it is essential to determine the J^π of the ground state of ^{63}Fe or the transition strength between the ground states of ^{63}Fe and ^{63}Mn in future experiments.

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