Neutron-induced triple-alpha enhancement: measuring neutron-induced reactions with TexAT

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The triple-alpha reaction, by which helium is fused to form carbon, is an important reaction mechanism to overcome the A=5, 8 bottleneck which is facilitated by the Hoyle state at 7.65 MeV. The reaction rate is determined by the radiative width, i.e. how often the Hoyle state decays by γ-rays and electron-positron pair to end up with carbon-12 in the ground state. It was suggested that in certain astrophysical environments, an alternative decay path can dominate (by up to a factor of 100): that of neutron up-scattering [1]. In this situation, a low-energy neutron interacts with the excited nucleus and carries away a large amount of energy such that the nucleus can de-excite to the ground state (or the first-excited state). The cross section for this interaction is unknown due to the experimental difficulties in

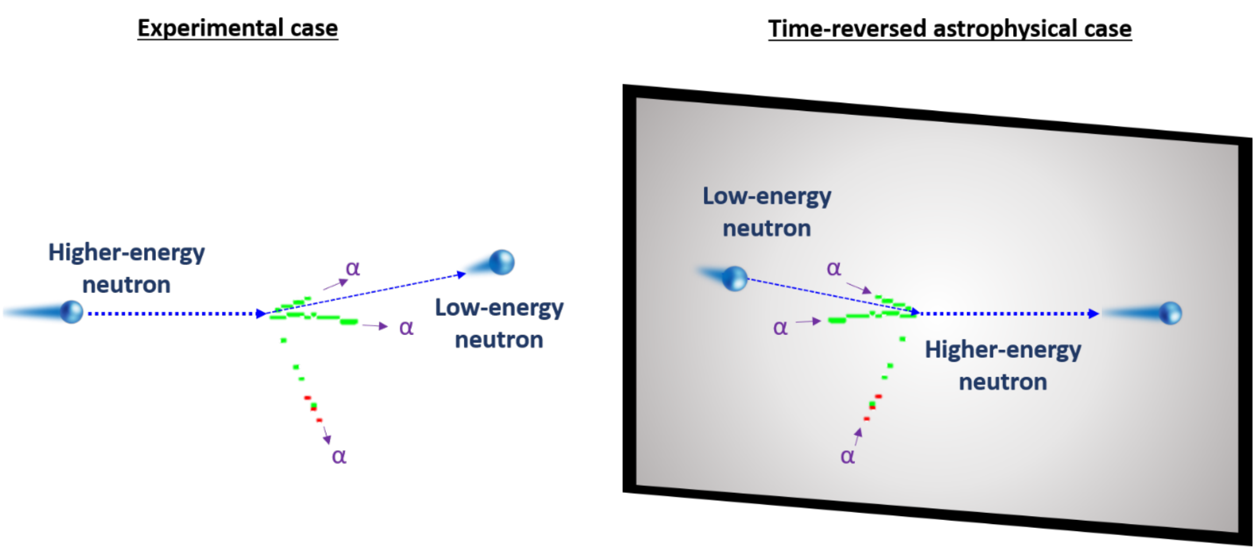

Fig. 1. Relation between the experimentally measured 12C(n,n2)3a reaction studied with TexAT and the astrophysical case whereby a low-energy neutron enhances the triple-alpha reaction.

measuring it. To determine this cross section, the time-reversed reaction has been studied using TexAT [2] which will allow for a measurement of the enhancement of the triple-alpha rate via the effect of the neutrons. The relation between the astrophysical situation and our experiment is shown in Fig. 1.

The time-reversed reaction is that of $^{12}C(n,n_2)3\alpha$ and must be studied in the astrophysically-relevant energy regime of between the threshold at 8.3 MeV, and 10 MeV. This experiment therefore required a high-intensity, monochromatic, collimated neutron source such as that available at Ohio University [3] via the D(d,n) reaction. This well-suited neutron beam is then incident upon TexAT, filled with 50 Torr CO_2 where the charged-particle products can be measured.

Development and modelling (with MCNP and GEANT4) demonstrated the feasibility of this experiment with a neutron beam intensity of ~5000 n/s and a beam resolution of 300 keV (full-width). Additional efforts to provide precise beam normalization were also undertaken and was determined to be possible via:

- Measurement of $^{12}C(n,n_0)$ and $^{16}O(n,n_0)$ elastic scattering inside TexAT.
- Measurement of the $^{1}H(n,p)$ elastic scattering reaction using a CH_2 foil and a silicon detector.
- Activation of metal foils via the $^{27}Al(n,\alpha)$ reaction and measurement with a HPGe detector.
- Normalization using an NE-213 detector placed at 0^{o} after the TexAT detector.

This CENTAUR experiment represented a large collaboration between TAMU, LSU, and WashU as well as collaborators at Ohio University, Sheffield Hallam University (UK), and University of Birmingham (UK). The experiment was started in March 2020 and was 50% complete before being postponed due to COVID19. Preliminary results from a subset of neutron energies indicate the experiment was successful.

The code to reconstruct and analyze the $^{12}C(n,n_2)3\alpha$ events was developed and benchmarked with simulated data. An example of a real event can be seen in Fig. 1 where the 3 α-particles were reconstructed inside TexAT. Current efforts focus on automatic identification and separation of these 3α events from the more numerous (n,n_0) events.

Analysis of the data from the silicon detectors demonstrates the neutron flux rate is in agreement with that expected from the deuteron beam current and gas-cell details. Efforts are currently underway to unfold the neutron energy spectrum from the proton-recoil energy spectrum incorporating multiple effects using GEANT4.

This experiment not only demonstrates the measurement of an important astrophysical reaction but also the first measurement of a neutron-induced reaction with a Time Projection Chamber (TPC) which has garnered an article in Scientific American [4]. The preliminary successes pave the way for a multitude of additional studies using a similar technique.

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