論文の内容の要旨
Dissertation Abstract

Examination of the $^{30}S(\alpha,p)$ thermonuclear reaction rate by $^{30}S+\alpha$ resonant elastic scattering
($^{30}S+\alpha$ 共鳴散乱による$^{30}S(\alpha,p)$熱核反応率の考察)

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We performed the first measurement of $^{30}S+\alpha$ resonant elastic scattering to experimentally examine the $^{30}S(\alpha,p)$ stellar thermonuclear reaction rate in Type I X-ray bursts. We observed new alpha-resonances within the astrophysical energy region of interest.

Type I X-ray bursts are a class of astronomical objects modeled very successfully as thermonuclear runaway in the envelope of an accreting neutron star in a binary system. These are the most frequent thermonuclear explosions in the universe, where the nucleosynthesis of hydrogen and helium powers a sudden increase in x-ray flux within seconds and the release of some 10^{40} egs. The nuclear trajectory runs along the neutron-deficient side of the chart of nuclides, involving hundreds of isotopes and around a thousand nuclear processes. However, burst models indicate that only a much smaller number of nuclear processes play a predominant role in the burst physics and resulting light curve.

The $^{30}S(\alpha,p)$ reaction has been consistently identified as one such crucial reaction in X-ray bursts, alone contributing more than 5% to the total energy generation rate, altering the subsequent neutron star crustal composition to influence the inertia of future bursts, and perhaps even being responsible for rare, bolometerically double-peaked X-ray bursts. Yet, extremely little information is known about the $^{30}S(\alpha,p)$ reaction rate experimentally, nor about the compound nucleus ^{34}Ar above the alpha-threshold at excitation energies of 8-9 MeV corresponding to X-ray burst peak temperatures of 1.3 GK. As such, the $^{30}S(\alpha,p)$ reaction rate is presently estimated theoretically by the Hauser-Feshbach statistical model; similar α-induced reactions near this mass region on even-

even nuclei are known to be dominated by narrow, isolated, natural-parity, α-cluster resonances, calling into the question the validity and reliability of such an approach. In light of this, an experimental investigation of the ^{30}S(α,p) stellar reaction rate, and hence the α resonances in ^{34}Ar, is extremely well-motivated. In this thesis, we populate ^{34}Ar by the entrance channel ^{30}S+α in search of alpha-cluster resonances – a tried and true method for such inquiry.

The present lack of experimental information on the ^{30}S(α,p) reaction is not so surprising. As ^{30}S has a half-life of 1.2 seconds, a ^{30}S radioactive ion beam (RIB) and a thick-target inverse-kinematics technique are necessary for the present work. Utilizing the Center for Nuclear Study low-energy radioactive ion beam separator (CRIB) of the University of Tokyo, a ^{30}S RIB was produced and delivered to the experimental target at 2 MeV/u, 40% purity, and 10^4 particles per second. This is a unique RIB in all the world, and no other facility has reported the capability to produce a ^{30}S beam remotely close to these figures. The method to produce and characterize such a ^{30}S RIB is presented and summarized based on four years of dedicated research into the topic.

We impinge the ^{30}S radioactive ion beam on a state-of-the art active target containing 90% helium gas by volume. In a conventional nuclear physics reaction or scattering experiment, the beam hits a target surrounded by detectors, and the data acquired are extrapolated and/or interpolated to infer the results. However, in the case of an active target, which we call the GEM-MSTPC, the helium gas is simultaneously part of the target and detector system. The GEM-MSTPC system provides a plethora of data, over-constraining the kinematics of the nuclear interaction. Furthermore, the beam, target, and detector system are intricately related: the target gas is part of the detector; the detector has a high-voltage and the injected beam is highly charged, distorting the electric field; and our goal is to measure the beam's nuclear interaction with the target material. As such, we finely tune the GEM-MSTPC during the accelerator machine time, because it is impossible to reproduce the experimental conditions otherwise. The setup, design, and operation of the GEM-MSTPC active target system is described to elucidate these inter-related points.

Given a radioactive ion beam and an active target – along with conventional detectors – the amount of data are relatively large, and the most important point is that the full system is calibrated in a self-consistent manner. Because the data are over-constrained, internal calibration is not only possible but essential. The fact of generally lacking free parameters implies finally that one must ultimately set aside the portions of the data with the largest error. However, by approaching the science in this manner, the adopted results have a strong reliability against systematic error – which is notoriously challenging to quantify and identify. For instance, we found that the charge collected by the backgammon-type readout pattern had an unexpectedly strong dependence on ionizing radiation position and inclination angle. Conversely, we successfully measured the ^{30}S Bragg curve, and determined that the stopping power of ^{30}S in the He+CO_2 gas mixture was 50% larger than theoretical estimates.

By combining the best data from the different components of our full detector system, we solved the kinematic equation for ^{30}S+α resonant elastic scattering and extracted an excitation function. Several resonance-like structures were clearly observed, including within the astrophysical Gamow window at $E_{cm} = 2.2 \pm 1.2$ MeV. The excitation function can be fit with an R-Matrix analysis to extract important level parameters, such as the excitation energy, spin-parity, and alpha-width. These crucial quantum properties can then be utilized in the very near future to calculate the first-ever experimentally-derived $^{30}S(\alpha,p)$ resonant stellar reaction rate at the energy region of interest for Type I X-ray bursts.