Study of the Temperature Effects in Nuclei and the Physics of Stellar Collapse

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Introduction

In a recent work [1] the temperature dependence of the nucleon effective mass has been calculated for the ^{98}mo, ^{64}zn and ^{64}ni nuclei. It was found that in all cases the effective mass decreases appreciably in the 01 MeV temperature interval. This has consequences, among other things, on the level density parameter *a* and on the symmetry energy e_{sym} that can be expressed by the following formula: $e_{sym}(t)=b_{sym}(t)\ (n\text{-}z)^2/a$.

In particular, a ~2.5 MeV increase of the $b_{sym}(T)$ parameter was calculated as T varies from 0 to 1 MeV.

Such a change in the symmetry energy contribution to the binding energy would have strong influence on the dynamics of the supernova collapse and explosion, as predicted in ref. [1]. The properties of various nuclei with $53<A<65$ have been also studied for temperatures $T<1.2$ MeV via Monte Carlo shell model calculations [2].

A temperature dependence of b_{sym} would influence the binding energy and the multiplicity of the particles evaporated from the compound nucleus (CN). In this case, differences between experimental particle multiplicities and those predicted by standard Statistical Model calculations, in which cold nucleus masses are used, should be in evidence. The expected deviation would increase as the temperature of the CN increases.

To study this evolution, excitation functions of the fusion evaporation reactions, starting from the lowest possible excitation energy E_x up to ~100 MeV, i.e., T~3 MeV in this mass region, must be measured.

Also, simultaneous measurements of charged particle multiplicity and energy spectra in the fusion-evaporation channel as a function of the bombarding energy would allow us to disentangle temperature dependent variations of binding energies and level densities. Subtraction technique of the particle spectra or unfolding of the measured temperature and multiplicity parameters as a function of the bombarding energy would allow us to map out the behavior of the different parameters versus T for a given compound nucleus, as already done in the past [3].

Finally, it has to be stressed that, to study in a more quantitative way, the changes on $E_{sym}(T)$, a variation of the N/Z ratio of the compound nucleus, should be desirable. This can be effectively achieved only by using radioactive beams.

The Experiment

As a first step of this project, we have studied the two isobar nuclei ^{98}Mo and ^{98}Tc populated via the fusion reactions of stable ^{11}B and radioactive ^{11}C beams at 110 MeV bombarding energy on a ^{87}Rb target. The target was made by a ClRb evaporation onto a thin C backing. The experiment has been performed at Texas A&M University. The radioactive ^{11}C beam has been produced at the K500 cyclotron using the MARS recoil mass spectrometer to suppress beam contaminations [4]. The obtained beam intensity was 4 x 10^5 particle/s which corresponds, in our case, to a production of about 1 fusion reaction per second, considering a cross section of the order of 1 b and a target thickness of 0.5 mg/cm^2. Particle multiplicity measurement, in coincidence with the Evaporation Residues (ER), has been performed using a closely packed array of silicon detectors (*Si-barrel*) covering about half of the total solid angle. ER have been detected at very forward angles using two silicon detectors of 5 x 5 cm^2 active area, or a large solid angle Parallel Plate Avalanche Counter (PPAC), and identified by measuring their Time Of Flight (TOF) against the cyclotron RF. The experimental set-up used is shown in the picture of Fig. 1.

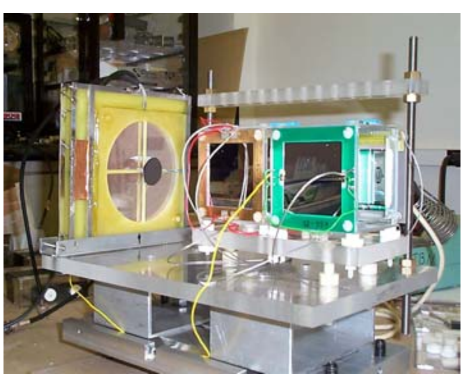

Figure 1: The experimental set up at Texas A&M. The forward trigger detectors (on the left) and the silicon detector array for light particle detection (on the right) are shown.

A test run was performed in July 2001 and the final data taking was successfully done in October 2001. The data analysis of the experiment is now in progress. In the following we report the preliminary results of this analysis. An example of the TOF versus Energy scatter plot for one of the Silicon trigger detectors is reported in Fig. 2 showing the ER identification. The TOF spectrum gated on an

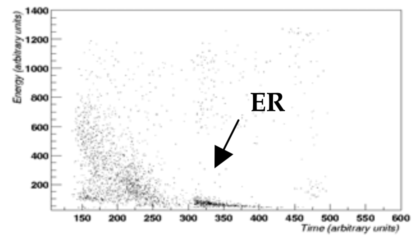

Figure 2: TOF versus Energy from the Silicon trigger detector in coincidence with light charged particle detectors. The arrow marks the Evaporation Residues region.

Energy window corresponding to the ER events is shown in Fig. 3. A good separation between the fusion events on the Cl and the Rb nuclei contained in the target is obtained.

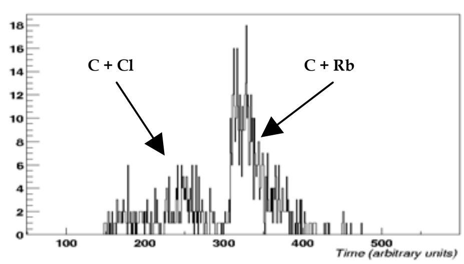

Figure 3: TOF spectrum gated on the energy region of the ER. Events corresponding to the fusion of the ^{11}C beam on the Cl and on the Rb present on the target are marked by arrows.

Finally, in Fig. 4, we report a very preliminary energy spectrum of the light-charged particles (protons and alphas) measured in one of the Si-barrel detectors, and corresponding only to a small fraction of the total available statistics.

From a preliminary estimate of the proton-to-alpha ratio, we observe experimentally a larger proton emission than predicted by Standard Statistical Model calculations. This observation seems to be in agreement with a variation of the symmetry energy term according to the theoretical prediction of the work of P. Donati et al. [1]. The completion of the analysis and comparison with the ^{11}B case is needed to confirm and quantify the effect.

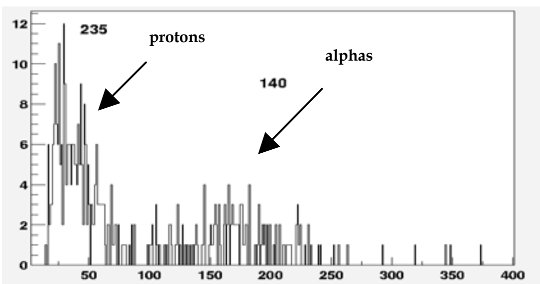

Figure 4: Energy spectrum of one of the barrel silicon detectors in coincidence with the ^{11}C + ^{87}Rb ER. The identification of protons and alphas is evidenced by the arrows.

A further excitation function measurement for the ^{11}B + ^{87}Rb system is planned for May 2002 at the Tandem facility of the Laboratori Nazionali di Legnaro. In this experiment, the 8□LP spectrometer will be used to detect light-charged particles and to study in detail the evolution of the symmetry energy term with the nuclear temperature.

References

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