Laboratory tests of astrophysical equations of state at low densities

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Reliable understanding of the nuclear equation of state, EOS, over a wide range of densities and temperatures is crucial in both nuclear science and to our understanding of stellar matter and stellar evolution. In the latter context it is well-known that a valid treatment of the correlations and clusterization in low density matter is a vital ingredient of stellar models. To meet the need for the nuclear input, some well -known extensive calculations and existing tabulations, based on varying effective interactions, were developed and have served as standard input for a wide variety of astrophysical simulations[[1,2]. More recently some new approaches have produced new predictions [3-9 HORO] While all of the models in use predict strong alpha clustering of the matter at low densities, ρ, and temperatures, T, they differ significantly in their quantitative predictions, usually tabulated as alpha mass fractions, at specified T and ρ.

Clearly the absolute alpha yields and mass fractions depend upon the model specific nucleon-nucleon interaction assumed and mathematical approximations of a given model. In addition, as all of the treatments assume chemical equilibrium, they also depend upon the number and type of competitive species included in the calculation. In an equilibrium situation, all relevant equilibria must be simultaneously satisfied. Thus, if relevant species are not included the calculated mass fractions of the alpha particles and other nuclei will be in error.

For this reason we do not believe that a direct comparison with calculated alpha mass fractions is the appropriate way to test the models. We choose rather to compare the experimentally derived equilibrium constants for alpha production with those of the models. The model derived equilibrium constants should be independent of the choice of competing species in a particular model.

Specifically we define the equilibrium constant, $K_C(\alpha)$, as

$$K_C(\alpha) = \rho_\alpha / [(\rho_p^2)(\rho_n^2)]$$

Where ρ_α , ρ_p and ρ_n are respectively the densities of alpha particles, protons and neutrons.

Clustering in low density nuclear matter has been investigated using the NIMROD multi-detector. Thermal coalescence models were employed to extract densities, ρ, and temperatures, T, for evolving systems formed in collisions of 47A MeV $^{40}Ar + ^{112}Sn$, ^{124}Sn and $^{64}Zn + ^{112}Sn$, ^{124}Sn. The yields of d, t, ^{3}He and ^{4}He have been determined at ρ = .002 to .032 nucleons/fm^3 and T= 5 to 10 MeV. The experimentally derived equilibrium constants for d, t, ^{3}He and ^{4}He production are presented in Figure 1. The model comparisons are in progress.

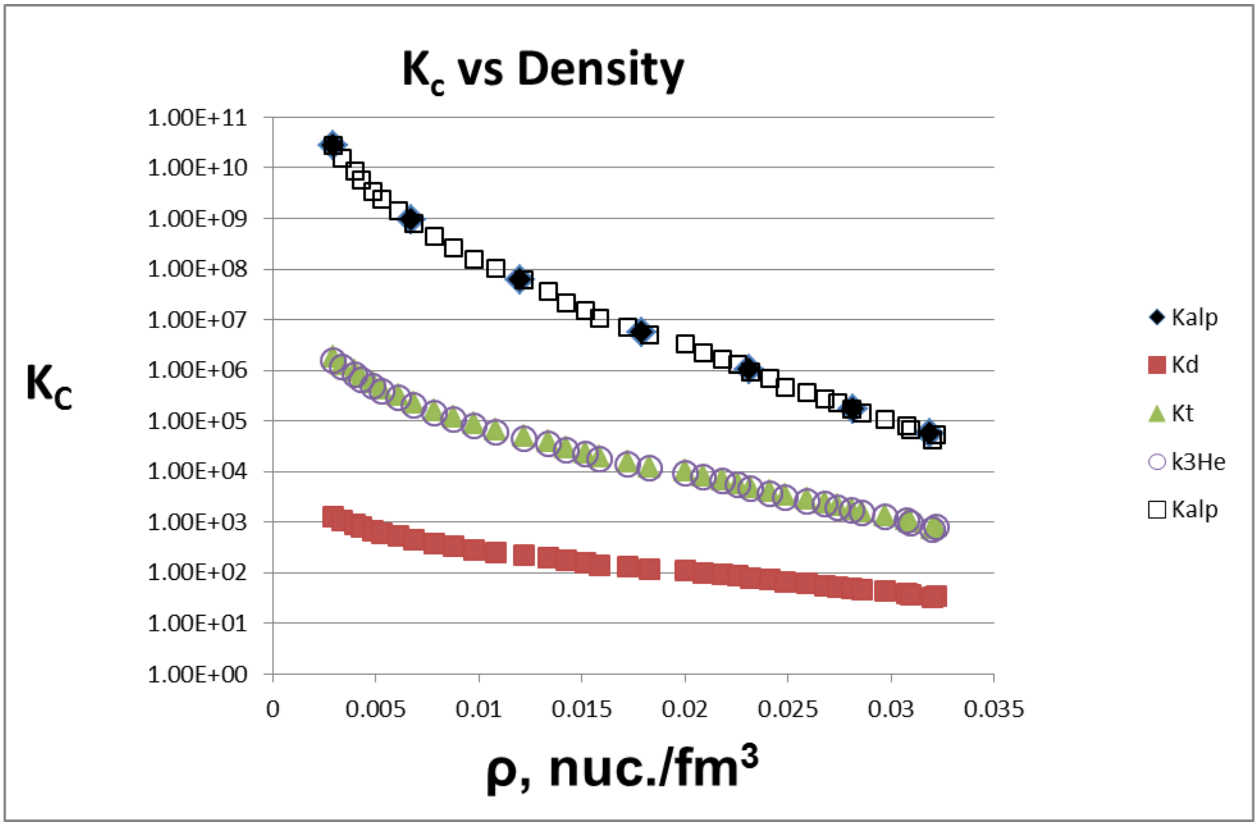

FIG. 1. Experimentally derived equilibrium constants for cluster formation at low density and moderate temperature. For the purpose of future comparisons with model calculations we have also interpolated the experimental results to determine the equilibrium constants for alpha particle formation at integral temperatures from 4 to 12 MeV. The values of K_C for these integral temperatures are indicated by solid diamonds.

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