Symmetry energy of dilute nuclear matter: an S-matrix approach

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The symmetry energy of an asymmetric nuclear system is defined as the energy change in making the system isospin symmetric. The symmetry energy coefficient C_E has been defined in several ways in literature:

$$I.\ \ C_E(\rho, T) = \frac{[E(\rho, X, T) - E(\rho, X = 0, T)]}{X^2}, \quad (1)$$

$$II.\ \ C_E(\rho, T) = [E(\rho, X = 1, T) + E(\rho, X = -1, T)]/2 - E(\rho, X = 0, T), \quad (2)$$

and

$$III.\ \ C_E(\rho, T) = \frac{1}{2}\left(\frac{\partial^2 E(\rho, X, T)}{\partial X^2}\right)_{X=0}. \quad (3)$$

where X is the neutron-proton asymmetry parameter. Similar definitions follow for the free symmetry energy coefficient C_F. For uniform nuclear matter, all the above definitions lead to practically the same values, however, since dilute nuclear matter becomes clusterized, the above definitions may lead to different results making an unambiguous definition of C_E or C_F difficult.

Experimentally, C_F can be measured from isoscaling [1, 2] as

$$C_F = \frac{\alpha T}{4\left[(Z/A)_1^2 - (Z/A)_2^2\right]}, \quad (4)$$

where $(Z/A)_i$ are the proton fractions in the two similar fragmenting systems at same temperature; α is the slope of the logarithm of the multiplicity ratios of isotopes produced from the two systems plotted against the neutron number. From C_F, C_E can also be calculated

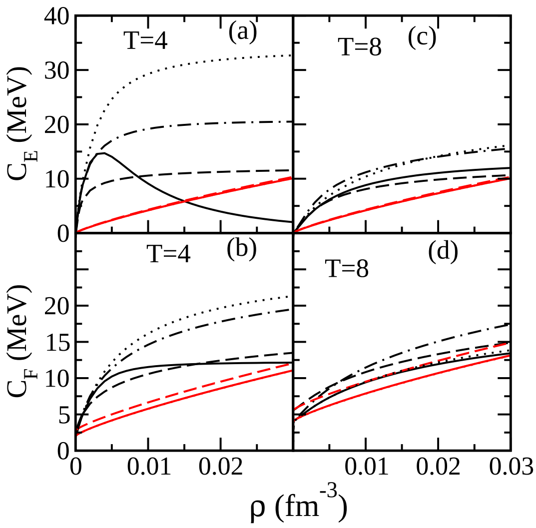

FIG. 1: Symmetry coefficients obtained in different definitions (see text).

as $C_E = C_F + TC_S$, C_S being the symmetry entropy coefficient calculated in a theoretical model. This is referred to as definition IV for the symmetry coefficients.

The cluster composition of dilute matter is calculated in the S-matrix approach [3]. This is in essence a virial expansion, it contains all the dynamical information on the microscopic interaction in the partition functions corresponding to contributions from stable single-particle states of clusters of different sizes formed in the system and their scattering states.

The nonuniqueness in the evaluated symmetry coefficients becomes evident from Fig. 1 where they are compared at different densities and temperatures. The full, dashed, dotted and dot-dashed lines correspond to calculations in defs. I, II, III and IV, respectively. The lines in the lighter shade correspond to

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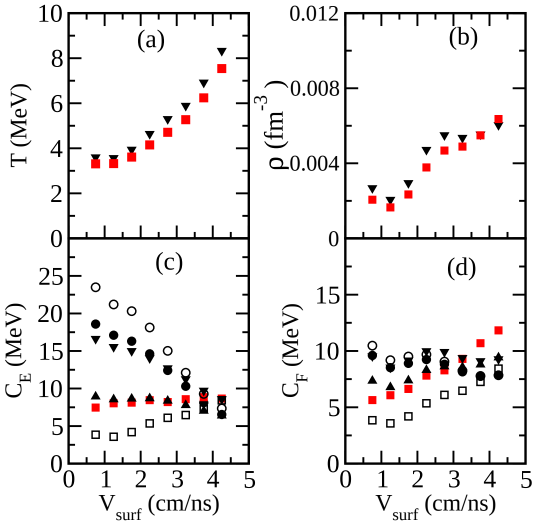

FIG. 2: Comparison of calculated and experimental symmetry coefficients (see text).

those for uniform matter calculated in the Relativistic Mean Field (RMF) theory with defs. I and III.

In Fig. 2, the calculated symmetry coefficients using definitions I, II, IV (filled circles, triangle up, triangle down), III (open circles) and in RMF (open squares) are compared with the recent experimental data (light shaded squares) [1]. The quantity V_{surf} refers to the velocities before the final Coulomb acceleration which are measures of T and ρ of the fragmenting system shown in panels (a) and (b). The light shaded squares there represent experimental data and the inverted triangles are the scattering corrected values.

As can be seen from Fig. 1, in contrast to the results for the symmetry coefficients for uniform matte, those for clusterized matter are not unique, they depend on the choice of the definition used. In a real physical process such as the supernova collapse or its explosive phase, definition I where the coefficients are X-dependent, seem most useful in describing the changing physical entities in an evolving scenario of density, temperature and asymmetry.

Acknowledgments

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