that the underlying RMF model for the quasiparticle description with $n_0 = 0.149$ fm^{-3}, $E_{\rm sym}(n_0) = 32.73$ MeV gives a reasonable behavior at high density similar to the MDI, x=0 parametrization. We thus see that our approach successfully interpolates between the clustering phenomena at low density and a realistic description around normal density.

In the right panel of Fig. 2 we compare to the experimental results, full (red) circles (Tab. I, col. 6) in an expanded low-density region. Besides the MDI parametrization we show the QS results [8] for T=1, 4, and 8 MeV, which are in the range of the temperatures in the experiment. The QS results including cluster formation agree well with the experimental data points, as seen in detail in Fig. 1. We conclude that medium-dependent cluster formation has to be considered in theoretical models to obtain the low-density dependence of the symmetry energy that is observed in experiments.

The temperatures and densities of columns 2 and 3 in Tab. I will be modified if medium effects on the light clusters are taken into account [24]. We have carried out a self-consistent determination of the temperatures $T^{\rm sc}$ and densities $n^{\rm sc}$ taking into account the medium-dependent quasiparticle energies as specified in Ref. [12] (columns 9 and 10 of Tab. I). Compared to the Albergo method results [20], the temperatures $T^{\rm sc}$ are about 10 % lower. Significantly higher values are obtained for the inferred densities $n^{\rm sc}$ which are more sensitive to the inclusion of medium effects. We have also calculated the free and internal symmetry energies corresponding to these self-consistent values of $T^{\rm sc}$ and $n^{\rm sc}$ according to Ref. [8] (columns 11 and 12 of Tab. I). These results are also shown in the right panel of Fig. 2 as open (purple) circles. The resultant internal symmetry energies are 15 to 20 % higher than the QS model values for T and n given in columns 2 and 3 in Tab. I.

We have restricted our present work to that region of the phase diagram where heavier clusters with $A > 4$ are not relevant. The generalization of the given approach to account for clusters of arbitrary size would lead to an improvement in the low-density, low-temperature region when nuclear statistical equilibrium is assumed. Alternatively, one can introduce the formation of heavier nuclei in the presence of a nucleon and cluster gas, cf. Refs. [25, 26].

The simplest approach to model the formation of heavy clusters is to perform inhomogeneous mean-field calculations in the Thomas-Fermi approximation assuming spherical Wigner-Seitz cells. In Fig. 2 (left panel) preliminary results for the zero-temperature symmetry energy of such a calculation is shown by the long-dashed line using the same RMF parametrization as for the QS approach introduced above; for details see Ref. [27]. The symmetry energy in this model approaches a finite value at zero density in contrast to the behavior of the MDI parametrizations and conventional single-nucleon quasiparticle descriptions.

In conclusion, we have shown that a quantum-statistical model of nuclear matter, that includes the formation of clusters at densities below nuclear saturation, describes quite well the low-density symmetry energy which was extracted from the analysis of heavy-ion collisions. Within such a theoretical approach the composition and the thermodynamic quantities of nuclear matter can be modeled in a large region of densities, temperatures and asymmetries that are required, e.g., in supernova simulations.

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