Existence of Temperature on the Nanoscale

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We consider a regular chain of quantum particles with nearest neighbor interactions in a canonical state with temperature T. We analyze the conditions under which the state factors into a product of canonical density matrices with respect to groups of n particles each and under which these groups have the same temperature T. In quantum mechanics the minimum group size n_{min} depends on the temperature T, contrary to the classical case. We apply our analysis to a harmonic chain and find that $n_{\mathrm{min}} = \mathrm{const}$ for temperatures above the Debye temperature and $n_{\mathrm{min}} \propto T^{-3}$ below.

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Recent progress in the synthesis and processing of materials with structures on nanometer length scales calls for better understanding of thermal properties of nanoscale devices, individual nanostructures, and nanostructured materials. Experimental techniques have improved to such an extent that the measurement of thermodynamic quantities like temperature with a spatial resolution on the nanometer scale seems within reach [1–4]. These techniques have already been applied for a new type of scanning microscopy, using a temperature sensor [5] that shows resolutions below 100 nm.

divide this system into subgroups, and analyze for what subgroup size the concept of temperature is applicable.

We adopt here the convention that a local temperature exists if the considered part of the system is in a canonical state; i.e., the distribution is an exponentially decaying function of energy characterized by one single parameter. This implies that there is a one-to-one mapping between temperature and the expectation values of those observables, by which temperature is usually measured. After proper calibration, such measurements thus all yield the same temperature, contrary to distributions