Self-consistent mean-field approach to the statistical level density in spherical nuclei

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We have applied the thermodynamical approach to a study of the statistical level density, $\rho(E_{\mathrm{ex}})$, of a nucleus. The approach is based on the extended Thomas-Fermi approximation (ETF) with Skyrme forces. The adopted approach describes successfully the basic nuclear liquid-drop properties as well as the single particle characteristics related to the nuclear mean field. The ETF approximation employed with Skyrme forces can be considered as a unification of both fundamental nuclear models: the liquid drop model and the shell model. In a practical sense, this approach allows us to evaluate the quantum single-particle corrections to the bulk liquid drop characteristics, in particular, the shell corrections to the mass formula and the deformation energy. An advantage of this approach is that the nuclear mean field is consistent with the nuclear liquid drop because both of them are generated by the common Skyrme forces.

To evaluate the statistical level density $\rho(E_{\mathrm{ex}})$ we need to know the excitation energy E_{ex} which is a complicate problem for a system of strongly interacting particles like a nucleus. We pointed out that a significant progress is achieved by use of the Landau's conception of quasiparticles where the excitation energy E_{ex} is derived within a Fermi-gas system of noninteracting quasiparticles and thereby depends on the mean field $V(\boldsymbol{r})$ and the effective mass m^* of the quasiparticle. In our consideration, the nuclear mean field $V(\boldsymbol{r})$ and the single-particle level density $g(\epsilon)$ are derived within the ETF using the effective SkM* and KDE0v1 Skyrme interactions. Using the Wigner distribution function in phase space $f(\boldsymbol{r},\boldsymbol{p})$, we have presented a semiclassical derivation of the single-particle level density $g(\epsilon)$ and the number of states $N(\epsilon)$ embedded in potential well $V(\boldsymbol{r})$ with energy below ϵ. Analyzing the value of $N(\epsilon)$, we have shown that the $\hbar^2$-corrections to $N(\epsilon)$ play only a minor role.

Applying the Landau's conception of quasiparticles, we have evaluated the excitation energy E_{ex} and the statistical inverse level density parameter K of the nucleus. The evaluation of the excitation energy E_{ex} needs the single particle states near Fermi energy only. This fact confirms the Landau's conception of quasiparticles and allows one to use the Fermi-gas approach to evaluate the nuclear excitation energy. Involving the effective mass $m^*(r)$ of quasiparticles, we took into consideration both contributions to $m^*(r)$ caused by the non-locality of the nucleon-nucleus interaction (k-mass $m_k^*(r)$) which is generated by the Skyrme interaction and the correlation correction (frequency dependent ω-mass $m_\omega^*(r)$) which arises from the scattering of nucleons from low-lying surface vibrations of the nucleus. We have shown that the presence of the frequency dependent ω-mass $m_\omega^*(r)$ distorts significantly the selfconsistent mean field and leads to an enhancement of the single particle level density near the Fermi surface. We have shown (see Fig. 1) that the ETF approximation with Skyrme interaction provides a quite satisfactory description of average A-dependence of the statistical inverse level density parameter K.

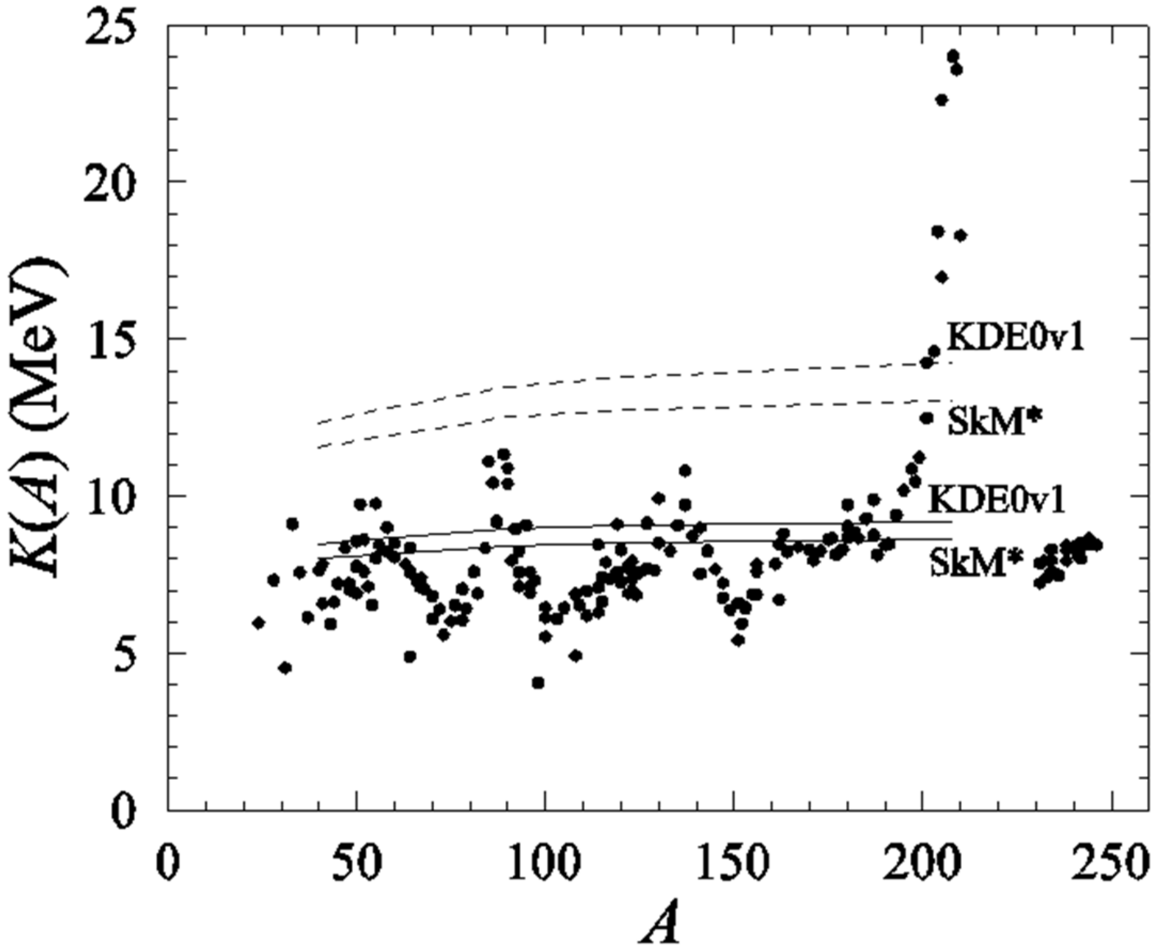

FIG. 1. Experimental values of $\boldsymbol{K}$ for even-even nuclei (solid points). The solid lines represent the ETF calculations with Skyrme interactions SkM* and KDE0v1 with effective mass $\boldsymbol{m}^*_{q,\omega}(\boldsymbol{r})$. The dashed lines are for he case $\boldsymbol{m}^*_{q,\omega}(\boldsymbol{r}) = \boldsymbol{m}$. See Ref. [1] for details of the calculations

Using the ETF finite-depth potential $V(\boldsymbol{r})$, we have paid a special attention to the accuracy of the derivation of the level density $g(\epsilon)$ in continuum at $\epsilon > 0$. The subtraction of the free space contribution from $g(\epsilon)$ allows one to prevent a spurious contribution to the excitation energy E_{ex}. A spurious contribution to E_{ex} occur due to the free space states which are not associated with the potential well $V(\boldsymbol{r})$. Our numerical calculations for the Skyrme ETF potential show that the correct subtraction of the free-state contribution from the continuum states reduces strongly the result for the excitation energy E_{ex} and thereby increases the result for K in the case of high enough temperatures, see Fig. 2.

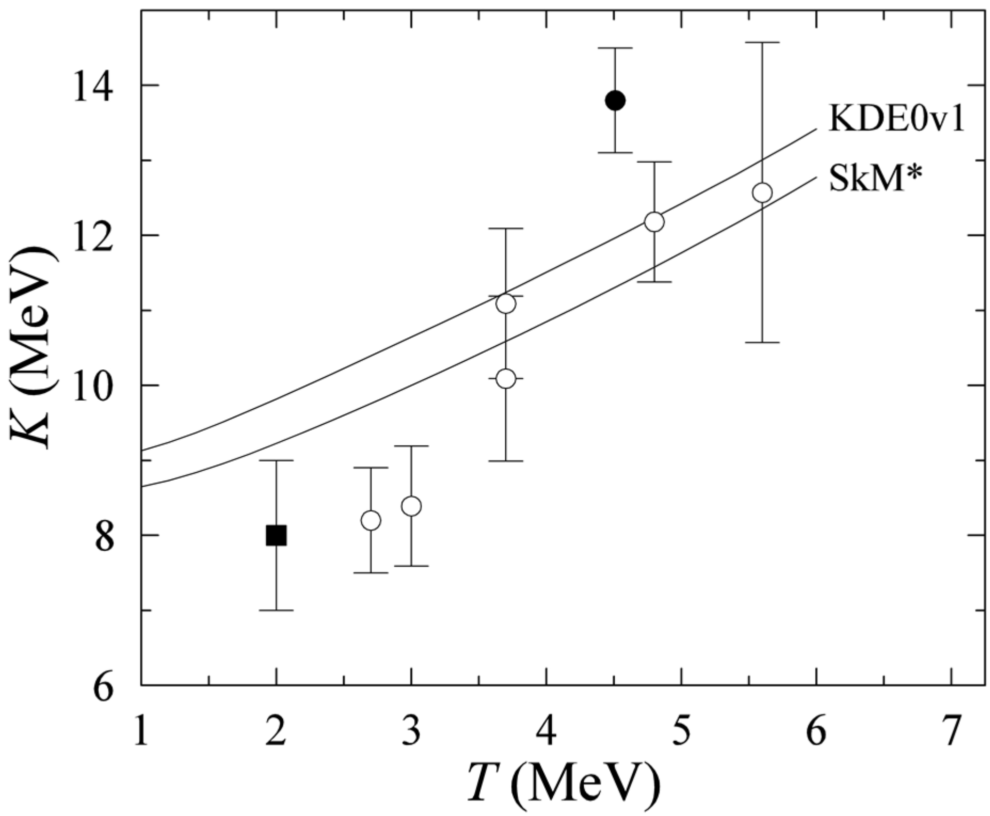

FIG. 2. The calculated temperature dependence of the inverse statistical level-density parameter $\boldsymbol{K(T)}$ for the nucleus with $\boldsymbol{Z = 60}$ and $\boldsymbol{A = 160}$ for Skyrme interactions SkM* and KDE0v1 (solid lines), is compared with the experimental data. See Ref. [1] for details

[1] V.M. Kolomietz, A.I. Sanzhur, and S. Shlomo, Phys. Rev. C **97**, 064302 (2018).