Testing constant-temperature approach for nuclear level density[†]

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According to thermodynamics, the nuclear temperature is a parameter, which is defined from the nuclear level density (NLD) $\rho(E)$ as

$$T = \left[\frac{\partial \ln \rho(E)}{\partial E}\right]^{-1}. \tag{1}$$

In the first model for NLD proposed by Bethe, the NLD is approximately described as $\exp(2\sqrt{aE^*})$ with the level-density parameter a. The nuclear temperature T, defined from Eq. (1), is then proportional to the square root of the excitation energy E^*, viz $T \simeq \sqrt{E^*/a}$, *i.e.* it increases with E^*. However this model fails to describe the NLD at low excitation energies below the particle separation threshold. The constant-temperature (CT) model, suggested by Gilbert and Cameron,[1)] assumes that the NLD at low excitation energies ($E^* \leq 10$ MeV) can be described by a constant temperature T, namely

$$\rho(E^*) = \frac{1}{T} e^{(E^*-E_0)/T} \equiv B(T) e^{E^*/T} , \tag{2}$$

with $B(T) = [Te^{E_0/T}]^{-1}$, where T and E_0 are obtained by fitting to the experimental NLD. This model has become increasingly popular in the study of NLD in recent years, where it has been suggested that its validity can be extended to much higher excitation energies up to E^* around 20 MeV for ^{60}Ni and ^{60}Co isotopes.[2)] Therefore, it is highly desirable to analyze the validity of this phenomenological model by using a microscopic model, which is able to describe the NLD in both low as well as resonance energies. Recently a unified approach has been proposed to simultaneously describe both the NLD and radiative strength function (RSF) based on the solution of exact pairing (EP) problem in combination with the independent-particle model (IPM), which is referred to as EP+IPM hereafter.[4)]

In the present work, by using the NLD predicted within the EP+IPM method, which agrees well with the experimental data, the nuclear temperature T is calculated from the derivative of logarithm of NLD (1). This temperature T increases almost linearly with the excitation energy E^*. However this increase is relatively slow so that T can be considered as a constant of around 0.5 MeV at $0 < E^* \leq 10$ MeV. Meanwhile, in ^{60}Ni, the CT model can describe rather well the experimentally extracted NLD with a constant temperature between $1.3 \leq T \leq 1.5$ MeV up to $E^* = 20$ MeV, *i.e.* much higher than the particle separation threshold, in excellent agreement with the experimental finding of Ref. 2) (Fig. 1). It is also shown that pairing plays an important role in maintaining this nearly-constant value of temperature at low excitation energy. In this way, the EP+IPM offers a consistent description of the NLD, which goes smoothly from the low-energy region $E^* \leq 5$ MeV to the higher one (up to 20 MeV for Ni isotopes and 10 MeV for Yb isotopes) without the need of matching the CT model at low energy and the Fermi-gas one at high energy, as often done by using the composite level-density formula.[1)] Last but not least, the fact that the NLD at low excitation energy, even at $E^* = 0$, can be well described by the CT model at a constant nonzero temperature also supports the suggestion of introducing a ground-state's effective temperature.[5)]

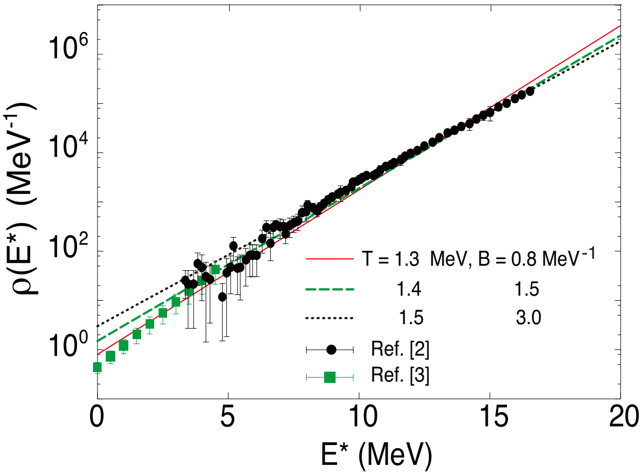

Fig. 1. Comparison of NLDs obtained from the CT model (2) and experimental NLDs for ^{60}Ni.

References
1) A. Gilbert, A. G. W. Cameron, Can. J. Phys. **43**, 1446 (1965).
2) A. V. Voinov *et al.*, Phys. Rev. C **79**, 031301(R) (2009); EPJ Web of Conferences **21**, 05001 (2012).
3) `https://www-nds.iaea.org/RIPL-3/`.
4) N. Quang Hung, N. Dinh Dang, L. T. Quynh Huong, Phys. Rev. Lett. **118**, 022502 (2017).
5) V. Zelevisnky, Proc. of 12th Int'l Spring Seminar on Nuclear Physics, Sant'Angelo d'Ischia, May 15-19, 2017 (*to be published*).

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