Shell and collective effects in the nuclear level density

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It is well known that the nuclear level density is an important ingredient in determining nuclear cross sections needed for describing various phenomena in nuclei and Astrophysics objects. Continuing our long term investigation, of taking into accounts effects of the continuum and the temperature dependence of the level density parameter, *a*, [1,2], we have investigated the shell effect on the level density [3]. We derived the statistical level density $\varrho(S)$ as function of the entropy *S* within the micro-macroscopic approximation (MMA) using the mixed micro- and grand-canonical ensembles. This function can be applied for small and, relatively, large entropies *S,* or excitation energies *U* of a nucleus. For a large entropy (excitation energy), one obtains the standard exponential asymptotics, however, with the significant inverse $1/S$ power corrections. For small *S* one finds the usual finite combinatoric expansion in powers of *S*. The transition from small to large *S* is sufficiently rapid in a small region of $S\approx 3-4$. This analytically derived level density is specified for the simplest example of the “classical rotation” as alignment of the single particle (s.p.) angular momenta of nucleons in a spherical infinitely deep potential within the semiclassical periodic orbital theory (POT), and taking into account the shell effects.

The calculations was carried out within the semi-classical extended Thomas Fermi (ETF) approximation, using the POT which unifies the smooth ETF part and oscillating (shell) corrections in terms of short periodic orbits which occupy larger phase-space volume in the potential well. We added the smooth self-consistent ETF values of the level density parameter *a* for the KDE0v1 and SkM* Skyrme forces with accounting for the effective mass m^* from Ref. [2] to the shell corrections in *a* through the level density, and also determined the inverse level density parameter $K(A)=A/a$. As shown in Ref. [2], the effect of the effective mass m^* on the inverse level density $K(A)$ is very strong, by decreasing $K(A)$ by about a factor about 2, that leads approximately to the mean values deduced from the experimental data for neutron resonances [4]. We found qualitatively good agreement between semiclassical POT and quantum-mechanical results with experimental data on $K(A)$ after an overall shift of all $K(A)$ curves by only one parameter betwen particle numbers $A\approx 80=150$. We suggest to use the MMA for small excitation energies to remove descrepancy near the double magic nuclei ^{40}Ca and ^{208}Pb.

We note that the neutron-proton asymmetries and large deformations of the rare earth and actinide nuclei should be also taken into account to improve the theoretical results in comparison with the experimental data on the nuclear level density parameter for neutron resonances.

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