Towards an Improved Level Density Description for Unstable Nuclei

T. Rauscher[1,2], F.-K. Thielemann[2], K.-L. Kratz[1]
[1]Institut für Kernchemie, Universität Mainz, Mainz, Germany
[2]Harvard-Smithsonian Center for Astrophysics, Cambridge MA, USA

Astrophysical investigations of the nucleosynthesis in stars (r-process, rp-process) and in the early Universe require the knowledge of thermonuclear rates involving exotic nuclei which currently are not accessible experimentally. In most cases the statistical model approach (Hauser-Feshbach, HF) is used for cross section and reaction rate calculations. (Only when the level density of a nucleus becomes too low (<10 MeV^{-1}), the direct reaction mechanism may dominate [1,2]. This is the case for nuclei close to magic numbers). Essential for the quality of the HF-calculations is the employed level density description [2]. It is also important to have a reliable criterion enabling one to decide which reaction model to apply. The level density predictions are the weakest point in the present procedures for HF cross section calculations [2].

The nuclear level density $\rho(U)$ usually is described with the backshifted Fermi gas expression [2,3]. Then $\rho(U)$ is dependent only on two quantities: the level density parameter a and the backshift δ, which determines the energy of the first excited state. In order to get a reasonably good fit to experimental level densities it was necessary to divide the nuclei into three classes [2] (nuclei close to magic numbers, other spherical nuclei, and deformed nuclei), thus increasing the number of parameters by a factor of three. The deviations were still up to a factor of 4–5.

Employing a different treatment of the density parameter a which includes thermal damping of shell effects [4], it was possible to improve the fit to the experimental values. All nuclei can now be described with a single parameter set consisting of just three parameters. In our attempts to further improve the results, we combined this approach with a more consistent evaluation of the pairing gap $\Delta_{\mathrm{n,p}}$ which is directly related to the backshift δ [2,3]. We calculated the neutron pairing gap Δ_{n} via the even-odd mass difference $\frac{1}{4}[E^G(Z,N-2)-3E^G(Z,N-1)+3E^G(Z,N)-E^G(Z,N+1)]$, where $E^G(Z,N)$ is the mass for the nucleus (Z,N) [5]. The same procedure can be applied for the proton energy gap Δ_{p}. Thus, better structural effects can be incorporated in a consistent way, regardless of the mass formula used.

We fitted experimentally known values of 278 nuclei using different mass formulae [6,7] and the standard, smooth treatment of the pairing gap ($\delta \propto 12/\sqrt{A}$) [2,4] as well as the method described above. As a preliminary result we found the best fit using the Möller mass formula [7] with the pairing gaps determined by the mass differences, and with shell corrections from Gilbert and Cameron [3] (Fig.1). The mean deviation of the calculated level spacing to the experimental one is 1.7, which is an improvement to earlier fits (see above). As can be seen in Fig.1, the values are concentrated in a quite narrow band. Since the shape of the band is not very sensitive to the mass formula used, it seems to indicate that the method by Gilbert and Cameron of determining shell corrections (i.e. the parametrization into a (N,Z)-dependence) might not work well for deformed nuclei. However, in order to calculate level densities for nuclei far from stability, one still has to rely on these shell correction predictions. An inclusion of deformation effects might bring further improvement.

Acknowledgement: TR is supported by the Alexander von Humboldt foundation.

Figure 1: Ratio of predicted to experimental level spacings at the neutron separation energy with the improved description utilizing shell corrections from Gilbert and Cameron [3].

References

[1] H. Oberhummer, G. Staudt; in Graduate Texts in Contemporary Physics, Springer Verlag, p. 29 (1991).

[2] J.J. Cowan et al.; Phys. Rep. 208, 267 (1991).

[3] A. Gilbert, A.G.W. Cameron, Can. J. Phys. 43, 43 (1965).

[4] A.S. Iljinov et al.; Nucl. Phys. A543, 517 (1992).

[5] R.-P. Wang et al.; Phys. Lett. B 284, 196 (1992).

[6] E.R. Hilf et al.; CERN 76-13, 142 (1976).

[7] P. Möller et al.; At. Dat. Nucl. Data Tabl. (1994), in print.