Microscopic studies on level density and spin cut off factor

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Introduction:

The atomic nucleus comprises a unique system in that it exhibits both microscopic features and statistical aspects generally explained in terms of level density. The spin and excitation energy dependence of the level density provides a strongest test for nuclear models. Since the phase-space governs the properties of a large class of nuclear reactions, a precise knowledge of level density is essential to understand the nuclear reactions. The level densities are usually discussed in terms of a Fermi gas model which includes shell effects representing the impact of microscopic nucleonic motion on the average properties of nuclei [1, 2].

In this present study, we have calculated level density parameter, back shift energy and spin cut-off factor using statistical theory to study the dependence of shell effects, angular momentum and excitation energy.

The single particle energies ε_i and spin projections m_i as a function of deformation parameter are obtained by diagonalizing the Nilsson Hamiltonian in the cylindrical basis. The single particle energies are generated up to N=11 levels which are found to be sufficient for the range of temperatures used in the present study.

We start with the partition function $Q(\alpha,\beta,\lambda)$ of the deformed nuclear system of N neutrons and Z Protons. The Lagrangian multipliers α, β and λ conserves the particle number, total energy and angular momentum of the system. The grand canonical partition function of the system is written in terms of the projection $\pm m_k$ of the deformed oscillator potential of the Nilsson – type Hamiltonian diagonalized with cylindrical basis.

Formalism:

On the basis of statistical theory, the grand canonical partition function for a hot rotating nucleus is given by [1],

$$Q = \sum_i \exp(-\beta E_i + \alpha_N Z_i + \alpha_N N_i + \lambda M_i) \quad (1)$$

where the Lagrangian multipliers α_Z, α_N, λ, β conserve the proton number, neutron number, angular momentum M along the space fixed Z-axis and total energy for a given temperature T=1/ β.

The level density parameter can be written as,

$$a(M,T) = \frac{S^2(M,T)}{4E^*(M,T)} \quad (2)$$

The level density is obtained by using Bethe formula,

$$\rho = \frac{\sqrt{\pi}\,\exp(2\sqrt{aE^*})}{\{12a^{1/4}(E^*)^{5/4}\}} \quad (3)$$

Then, Snover's level density can be written as [1],

$$\rho = \frac{(2I+1)\sqrt{a}\,\exp(2\sqrt{aE^*})}{\{24\sqrt{2}(E^*+T)^2\Im^{3/2}\}} \quad (4)$$

where I be the angular momentum and T be the temperature, $\Im = 0.0138A^{5/3}\,\mathrm{MeV}^{-1}$ be the rigid body moment of inertia [2].

The back shift energy δ_E can be written as,

$$\delta_E = E^* - T\log_e\rho \quad (5)$$

The spin cut-off parameter is obtained by using Gilbert-Cameron expression [3],

$$\sigma^2 = 0.0888\,A^{\frac{2}{3}}\sqrt{a(E^* - \delta_E)} \quad (6)$$

$$\sigma^2 = \frac{0.0146}{2a}A^{\frac{5}{3}}\left(1 + \sqrt{4a(E^* - \delta_E)}\right) \quad (7)$$

Results and discussion:

The single particle level density parameter 'a' has been calculated as a function of temperature, angular momentum and deformation degrees of freedom including pairing correlation for about 3159 nuclei. For illustrative purpose, the level density parameter as a function of mass number A for spin less systems is plotted in Fig.1. The level density parameter values have been compared with the level density parameter values obtained from a microscopic theory [3]. It is found that the value of one eighth or one seventh of the mass number is well reproduced in our calculations.

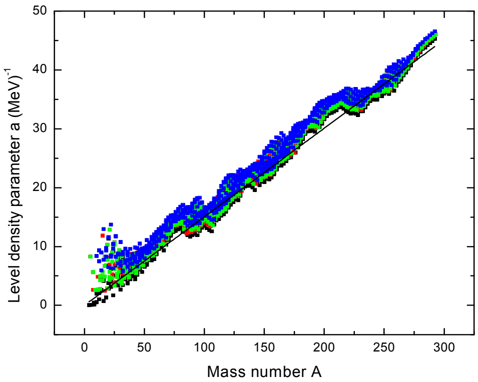

Fig.1: The level density parameter as a function of mass number. The straight line which approximates the average trend corresponds to a=A/7.

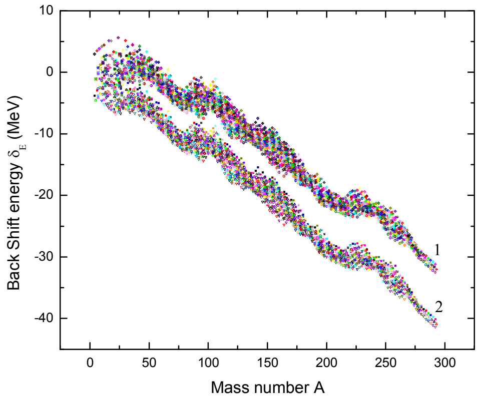

Fig. 2: The back shift energy as a function of mass number.

The back shift energy extracted for various types of nuclei (odd A, even-even, and odd-odd) are shown in Fig.2 and the numbers on the curve represents (1) the back shift energy extracted from Bethe's level density formula and (2) the back shift energy extracted from Snover's level density formula.

The odd-even effect could probably be explained by the pairing energies. It is obvious from the figure that the back shift energies are related to neutron and proton pairing energies. This results in rather large negative δ_E values for odd-odd nuclei and slightly negative δ_E values for even-even nuclei. The values of back shift energy extracted from Bethe's level density formula is found to be slightly higher than the value of back shift energy extracted from Snover's level density formula.

The calculated spin cut-off parameter values are plotted in Fig. 3. It agrees very well with results obtained from the microscopic theory [3]. Further investigations are in progress.

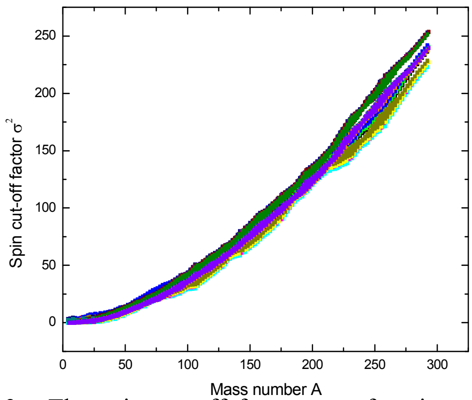

Fig. 3: The spin cut-off factor as a function of mass number

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