Spin cut-off factor of nuclear level densities in heavy nuclei

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Introduction

The density of nuclear levels provides information about the structure of highly excited nuclei and is also a basic quantity in nuclear reaction theory. Gilbert and Cameron [1] proposed a formula, composed of four-parameters, which combines the shifted Fermi gas formula at high excitation energies with a constant temperature formula [2] for lower energies. By fitting the four constants in both regions, experimental data may be well reproduced. The BSFG model was later proposed [3-6] in order to account for shell effects. In this model, both the energy shift and the level density parameter(LDP) a are considered as adjustable parameters, which allows to obtain a reasonable fit to the experimental level densities over a wider range of excitation energies. Afterwards, some phenomenological methods have been proposed to correctly describe the thermal damping of shell effects with increasing excitation energy [7-9]. In these methods, the idea was to reproduce as well as possible the energy dependence of the LDP taken from microscopic calculations, in order to give better absolute values of the nuclear level density(NLD).

In all level density expressions, the LDP and the spin cut-off parameter σ^2 are crucial. More recently Gholami et al. [10] calculated the spin cut of parameters using the Fermi gas model since their calculations for NLD and LDP agrees well with the experimental data [11-14]. They have compared their result for even-even, odd-odd and odd-A nuclei with Gilbert and Cameron expression [1] and the rigid body expression.

Methodology

In this present paper we present the calculated spin cut-off parameter for the nuclei in the heavy mass region using the statistical theory. The grand canonical partition function Q $(\alpha_Z, \alpha_N, \beta, \gamma)$ for a hot rotating nucleus is given by Q $(\alpha_Z, \alpha_N, \beta, \gamma) = \sum \exp(-\beta E_i + \alpha_Z Z_i + \alpha_N N_i + \gamma M_i)$. The total energy E is the sum of the single particle energies occupied by fermions. The Lagrangian multiplier α_Z, α_N and γ conserve the proton number, neutron number and total angular momentum of the system for the given temperature $T = 1/\beta$. The rotational energy E_{rot} is given as $E_{rot}(M,T) = E(M,T) - E(0,T)$ and hence the effective excitation energy $U_{eff}(T) = U(T) - \delta B$ where $\delta B = -\delta E_{shell}$ is the ground state shell correction. This is due to the fact that a part of the excitation energy is used up to overcome the shell forces which are deformation dependent. The total excitation energy is obtained using $E_{ex} = U(M,T) = U_{eff}(T) + E_{rot}(M)$. The single particle level density parameter a(M,T) as a function of angular momentum M and temperature T is extracted using the equation $a(M,T) = S^2(M,T)/4\,U(M,T)$.

Results and Discussion

In Fermi-gas model the spin cut-off parameter is determined according to the formula $\sigma^2 = m^2 gt = It/\hbar^2$, where m^2 is the average of the square of the single particle spin projections, $t = \{(E-\delta)/a\}^{1/2}$ is the temperature, $g = 6a/\pi^2$ is the single particle level density, I is the rigid body moment of inertia expressed as $I = (2/5)\mu AR^2$, where μ is the nucleon mass, A is the mass number and $R = 1.25A^{1/3}$ is the nuclear radius. The spin cut-off parameter in rigid body model is $\sigma^2 = 0.0146A^{5/3}t = 0.0146A^{5/3}\{(E-\delta)/a\}^{1/2}$. On the other hand the Gilbert and Cameron [1] used $m^2 = 0.146A^{2/3}$. and the corresponding formula is $\sigma^2 = 0.089A^{2/3}a\{(E-\delta)/a\}^{1/2}$. The said two equations for σ^2 have the same energy and A dependence $\{\sigma^2 \sim A^{7/6}(E-\delta)^{1/2}\}$ but differ by a factor of ≈ 2 [15]. These calculations show the suppression of the moment of inertia at low temperatures compared to its rigid body value. Thus uncertainties in spin cut off parameter transform to corresponding uncertainties of total level densities derived from neutron resonance spacing.

To obtain a close value of the spin cut-off parameter we have used the formula $\sigma^2 = 0.0445A^{2/3}a\{(E\text{-}\delta)/a\}^{1/2}$ where the temperature, t = $\{(E\text{-}\delta)/a\}^{1/2}$, is taken from the statistical temperature derived from the theory. We have compared the results with the Gilbert and Cameron expression, rigid body approximation and the calculation by Gholami et al.[8] using microscopic theory. The comparative results of spin cut-off parameter against mass number for the odd-odd, even-even and odd-A nuclei in the heavy mass region are calculated. The figs.1 & 2 show the close agreement of our results (marked as '*stat*' with downward triangle shape) with the other calculated values presented in literatures [1,10]. Generally the calculated values of the spin cut off parameter agrees well in the mass region >220 and lies slightly lower than the values of ref.[10] and higher than ref.[1] and rigid body calculation.

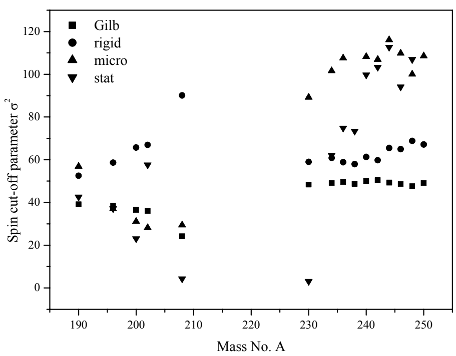

Fig. 1 Spin cut off parameter σ^2 for even-even heavy nuclei calculated using the modified formula plotted with *Gilb*: Gilbert and Cameron expression *rigid*: rigid body approximation and *micro*: microscopic theory

Summary

The spin cut-off parameter, which is an important parameter for all statistical model codes, has been calculated with a modified formula to suit to the other calculated values and obtained a comparable result. This calculation is performed by considering the calculated statistical temperature, and hence the methodology may be more suitable to till higher mass region.

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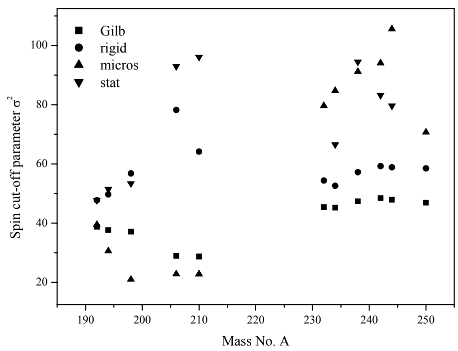

Fig. 1 Same of fig. 1 for odd-odd heavy nuclei.

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