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Non-statistical nature of fragments' spin distributions in binary nuclear fission

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Since for spontaneous and low-energy induced fission, compound fissile nuclei and primary fission fragments in the vicinity of the scission point are in cold nonequilibrium states [1], when constructing the spin distributions of these fragments, it is necessary to take into account [2,3] only zero transverse bending- and wriggling-vibrations of the indicated fissile nuclei. Expressing the normalized distribution function of $W\left(\mathbf{J_1},\mathbf{J_2}\right)$ fission fragments over spins $\mathbf{J_1}$ and $\mathbf{J_2}$ in terms of the product of the squared moduli of the wave functions of zero bending- and wriggling-vibrations, one can obtain [4]:

$W\left(\mathbf{J_1},\mathbf{J_2}\right)=\frac{4J_1J_2}{\pi C_b C_w}\exp\left[-\frac{1}{2}\left(\frac{1}{C_b}+\frac{1}{C_w}\right)\left(J_1^2+J_2^2\right)+\left(\frac{1}{C_b}-\frac{1}{C_w}\right)J_1J_2\cos\phi\right]$, (1)

where $\phi\,(0\le\phi\le2\pi)$ is the angle between the two-dimensional spin vectors of fragments $\mathbf{J_1}$ and $\mathbf{J_2}$ lying in plane XY. By integrating in (1) over variables J_2 and ϕ, one can obtain [4] the normalized distribution of spin J_1 of the first fission fragment and estimate the average value $\bar{J}_1$ of spin J_1:

$W(J_1)=\frac{4J_1}{C_b+C_w}\exp\left[-\frac{2J_1^2}{C_b+C_w}\right], \bar{J}_1=\int\limits_0^\infty J_1W(J_1)dJ_1=\frac{1}{2}\sqrt{\frac{\pi}{2}}(C_b+C_w)^{1/2}$.(2)

For a fissile nucleus ^{236}U at values [4] of parameters $M_w=1.6\cdot10^6\mathrm{MeV}\cdot\mathrm{Fm}^2\cdot\mathrm{s}^2$; $M_b=2.0\cdot10^6\mathrm{MeV}\cdot\mathrm{Fm}^2\cdot\mathrm{s}^2$; $K_w=295\mathrm{MeV}\cdot\mathrm{rad}^{-2}$; $K_b=52\mathrm{MeV}\cdot\mathrm{rad}^{-2}$; $\hbar\omega_w=2.3\mathrm{MeV}$; $\hbar\omega_b=0.9\mathrm{MeV}$; $C_w=132\hbar^2$ and $C_b=57\hbar^2$, it follows that the energies of vibrational quanta $\hbar\omega_w$ and coefficients C_w for wriggling-vibrations turn out to be noticeably larger than those for bending-vibrations. This means that the main contribution to $\bar{J}_1$ (2) comes from wriggling vibrations. Then the calculated value $\bar{J}_1=8.6$ correlates well with the experimental [5] average values of the spins of fission fragments $\bar{J}_1=7$–9.

This means that the spin distribution of fission fragments is determined with a good degree of accuracy by taking into account zero wriggling and bending vibrations of a composite fissile system. This confirms the assumption [6] about the inequality of the statistical Gibbs distribution with temperature T for the spin distribution of fragments, which is used in [1].

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