ESTIMATING UNKNOWN SPINS FROM RANDOM MATRIX THEORY

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The neutron resonances, especially in heavy fissioning nuclei, were extensively studied during last 60 years. The renewed interest to their properties is related to the problem of quantum chaos. In the region of low neutron energies, the resonances are very narrow and well separated. The large lifetime and the small energy spread allow one to interpret a resonance as a fully equilibrated compound state. Intrinsic wave functions of such states are very complex superpositions of a great number (typically $10^5 - 10^6$) of simple shell model configurations, with presumably random phases. Since the individual properties of resonances are apparently unpredictable, the statistical approach is the only possible.

The sequences of neutron resonances served as the first testing ground for the application of ideas of quantum chaos [1]. The s-wave resonances with the same quantum numbers J^π reveal a good agreement with the Wigner nearest level spacing distribution

$$P_W(s) = \frac{\pi s}{2} e^{-\pi s^2/4} \tag{1}$$

which shows a generic level repulsion at short distances. Here the energy levels are to be unfolded (the spacings s measured in the units of the mean local spacing D). The reduced (normalized by $E^{-1/2}$ in order to eliminate the phase space factors) neutron widths γ are known to have the Porter-Thomas (PT) distribution

$$P_{PT}(\gamma;\langle\gamma\rangle) = (2\pi\langle\gamma\rangle\gamma)^{-1/2} e^{-\gamma/2\langle\gamma\rangle}. \tag{2}$$

Both distributions (1) and (2) characterize a chaotic quantum system. They were already used by the experimentalists [2] in order to extract the properties of invisible fine-structure states in an experiment with a relatively poor resolution, $\Delta E \gg D$.

In the case of the nonzero target spin I_0, the compound nucleus after the s-wave neutron capture can have two spin values $I = I_0 \pm 1/2$. Spin values of individual resonances are mostly unknown, and the experimental data consist of lists of energies and widths of resonances belonging in fact to different classes. Existing statistical theory gives only a rough prediction of the total level density $\rho(E)$ for various values of I. However, in a chaotic system local correlations and fluctuations of spectra can distinguish the cases of a single sequence (all constants of motion are destroyed) and of several superimposed sequences which differ by conserved quantum numbers. This was clearly shown in the shell model consideration for the sd-nuclei [3]. The calculations in the proton-neutron formalism with the isospin-invariant interaction give the levels of all isospins simultaneously. The study of their spectra, including short range level interaction, $P(s)$, and long-range fluctuations, Δ_3-statistics, easily recognize pure and mixed sequences.

Using these ideas we analyze the empirical sets of resonances for ^{233,235}U and ^{239,241}Pu. Assuming two involved pure subsets with the weights α and $1-\alpha$, we apply the results of random matrix theory [4] for a two-component sequence. The comparison of empirical nearest level spacing distributions $P(s)$, spectral rigidities $\Delta_3(L)$ and reduced width distributions should result in the consistent determination of the fraction α. Of course, the applicability of random matrix theory will be checked at the same time.

This study is in progress. The next steps should include the comparison with statistical models of level densities and some corrections for possible presence of the third sequence (if K-quantum number is not completely destroyed [5]) and for experimental errors. In this way quantum chaos can help in recovering dynamical information which was apparently lost in the experiment.

References

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