Does localization occur in collective nuclear motion?

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Large-amplitude collective nuclear motion is frequently described by a collective Hamiltonian [1], where the mass parameter is determined within the cranking approximation while the potential energy is defined by the ground-state expectation value of the many-body Hamiltonian as function of the collective variable q. However, due to quasi-crossings of levels the mass parameter exhibits large fluctuations as function of q. These fluctuations become dramatic if the collective motion in excited adiabatic states is considered. The reason is that the number of quasi-crossings of many-body levels becomes extremely large.

We have studied this complexity of collective motion within the diabatic description [1, 2], where the single-particle wavefunctions are smoothly varying as function of q. Every diabatic many-body configuration, defined by a Slater determinant (Fock state) of diabatic single-particle states, exhibits a minimum in the energy as function of q, which determines the ground state of this diabatic configuration. These diabatic many-body states $\Phi_j(q_j)$ are localized in q and serve as a basis for the description of collective motion. The non-orthogonality of the basis states is not large and would lead to some tails in q-space after orthogonalization.

The local diabatic states are coupled by residual two-body interactions. The eigenstates are determined by diagonalization of the total Hamiltonian. These eigenstates may turn out to be localized around certain q-values or extended over the whole q-space according to the density of states. The occurrence of localization would have significant qualitative and quantitative consequences for observables in large-amplitude collective nuclear motion, e.g. in fusion and fission processes.

We have investigated [3] the occurrence of localization for a schematic diabatic single-particle model with random two-body interactions [4] between the Fock states. The diabatic single-particle levels are equidistant (distance Δ) with constant slopes $+a$ and $-a$. The magnitude of the non-vanishing two-body interactions are chosen from a Gaussian distribution multiplied with a strength factor λ. Within this model the Fock states are localized at a discrete set of equidistant points q_m (distance $\delta = \Delta/a$) and are coupled by two-body interactions within a class m and to the neighbouring classes $m \pm 1$ and $m \pm 2$. We treat about 4000 Fock states which cover all states up to about 5Δ excitation energy.

The degree of localization is described by the correlation function

$$\mathcal{R}(\Delta q, E) =$$
$$\langle |\langle \Phi_j(q_j = q_m)| \tfrac{1}{\mathcal{H} - E + i\eta} |\Phi_{j'}(q_{j'} = q_m + \Delta q)\rangle|^2 \rangle_{j,j',m}$$

which measures the mixing of two local Fock states at a distance Δq in the same eigenstates with energies around E averaged over all Fock states. Since localized eigenstates spread over only a few neighbouring Fock states, a correlation function indicates the occurrence of localization when it is sharply peaked at $\Delta q = 0$.

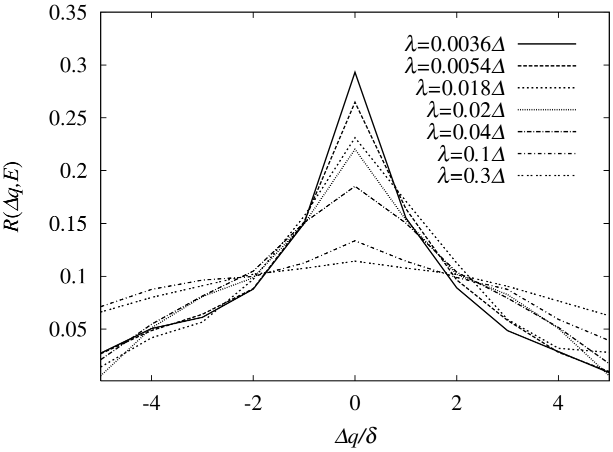

Figure 1: Correlation function $\mathcal{R}(\Delta q, E)$ as function of Δq at the excitation energy $E = 4\Delta$ for different values of the coupling strength λ.

Some numerical results are shown in Fig.1 for the correlation function $\mathcal{R}(\Delta q, E)$. We observe localization for small interaction strengths λ. However, with increasing λ the correlation function broadens continuously, indicating that there is a smooth transition to extended eigenstates. From the present study we are not able to perform the thermodynamic limit to macroscopic systems. From a simple scaling estimate we expect that no localization survives in that limit, and hence there is no indication for Anderson localization [5]. On the other hand, Rupp et al. [6] predict localization for our hierachies m of states which have couplings not depending on the hierarchy. This discrepancy may be due to the differences in the coupling schemes and statistical assumptions (cf. [4, 6, 7]).

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