Inclusion of Quantum Fluctuations in Wave Packet Dynamics [*]

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We have addressed the treatment of quantum fluctuations in microscopic descriptions based on wave packets, a problem encountered in a broad range of fields involving quantum physics. Since the wave packets are not energy eigenstates, the statistical operator $\exp(-\beta\ \hat{H})$ cannot be treated as a c-number. In order to take account of the associated spectral distribution and ensure that the statistical properties are quantal, it is necessary to introduce suitable modifications relative to the ordinary equations of motion for the wave packet parameters which are basically classical in character, having been derived from the time-dependent variational principle.

We have formulated a simple but apparently successful treatment by including the first correction term in the cumulant expansion of the statistical weight. The associated small parameter is $\sigma_E^2/T\mathcal{H}$, where $\mathcal{H} \equiv \langle \boldsymbol{Z}|\ \hat{H}|\boldsymbol{Z}\rangle$ is the mean energy of a wave packet and σ_E^2 is the corresponding energy variance. This approach is exact when the spectral distribution is of Poisson form, and the corresponding effective level spacing is $D \equiv -\partial \log \mathcal{H}_\beta / \partial\beta = \sigma_E^2/\mathcal{H}$. It is then straightforward to write down the improved expression for the statistical weight. Moreover, the associated thermal distortion of the internal structure of the wave packet can be determined.

Since our initial suggestion [1] that this treatment might be useful has led to some debate [2,3], we have discussed and illustrated the various possible approaches to determining the statistical behavior of one-body observables, such as the occupation number. The key to resolving the issue lies in the inevitable distortion of the many-body wave packet caused by the canonical operator $\exp(-\beta\ \hat{H})$.

The practical utility was exemplified by ^{12}C and ^{40}Ca which exhibit the desired evolution from a quantum fluid to a fragment gas, as the temperature is raised.

The quantum fluctuations can be incorporated into the dynamics by allowing stochastic transitions between the wave packets [4]. This can conveniently be done by introducing a quantum Langevin force in the equations of motion for the wave packet parameters. We derived the general form of the associated transport coefficients and verified that the proper microcanonical equilibrium distribution is indeed achieved. Simple approximate expressions for the specific values of the transport coefficients were then obtained, leading to a practically useful treatment.

The proposed extension of the standard treatment represents a formally well based approach. Moreover, it leads to the desired statistical properties in static scenarios and can be included in the dynamics in a conceptually simple and tractable manner. The method may, therefore, find useful application in the context of microscopic simulations of actual many-body processes, such as the production of nuclear fragments [5] and atomic clusters [6].

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