Quantum-classical correspondence in spin-boson equilibrium states at arbitrary coupling

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It is well known that the equilibrium properties of both quantum and classical nanoscale systems can deviate significantly from standard thermodynamics due to their coupling to an environment. However, insight into the differences between the quantum and classical cases has remained elusive. In this talk, I will present a comprehensive quantitative characterisation of quantum vs classical thermodynamic properties of a spin that is non-negligibly coupled to an environment [1]. First, I will show that for arbitrary coupling strengths, taking the large spin limit of the quantum spin, the quantum mean-force partition function converges to the mean-force partition function of the classical spin. Thus, we demonstrate that the quantum-classical correspondence is maintained at arbitrary coupling strength. This correspondence gives insight into the conditions for a quantum system to be well-approximated by its classical counterpart. Second, I will discuss how, previously identified environment-induced 'coherences' in the equilibrium state of quantum spins, do not disappear in the classical case. Finally, I will show a thorough categorisation of various coupling regimes, from ultra-weak to ultra-strong, for both the quantum and classical spin. We find that the same value of coupling strength can either be 'weak' or 'strong', depending on whether the system is quantum or classical. The presented results shed light on the interplay of quantum and mean force corrections in equilibrium states of the spin-boson model, and will help draw the quantum to classical boundary in a range of fields, such as magnetism and exciton dynamics.

[1] Quantum–classical correspondence in spin–boson equilibrium states at arbitrary coupling. F Cerisola, M Berritta, S Scali, SAR Horsley, JD Cresser, J Anders, arXiv:2204.10874.