A semi-semiclassical approach to quantum quenches

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Recent years have witnessed an ever increasing interest in the out of equilibrium dynamics of quantum systems. The experimental techniques are developing rapidly and the present experiments call for the development of new analytical and numerical methods that are able to describe non-equilibrium dynamics in closed quantum systems. To give an example, interference experiments with low dimensional cold atomic condensates can be described in principle within a field theoretical framework. However, analytic or numerical methods for studying the dynamics of continuum systems are not in abundance.

We present a hybrid semiclassical method – that we dub semi-semiclassical – which combines a semiclassical description of quasiparticle propagation with a complete quantum-mechanical description of the internal degrees of freedom using a Time Evolving Block Decimation scheme. Our method is capable of describing the non-equilibrium dynamics of one-dimensional lattice and continuum systems up to time scales at which local thermalization occurs. It has all benefits of an intuitive semiclassical picture for the orbital degrees of freedom, while handling internal degrees of freedom completely quantum mechanically allows us to observe phenomena such as entanglement entropy production or phase diffusion.

As a proof of principle, we apply the method to the quench dynamics of a pair of tunnel coupled one dimensional Bose condensates described by the sine—Gordon model and currently studied in matter wave interference experiments. In the so-called universal limit, we are able to determine the complete time dependence of correlation functions analytically. Treating the collisions of quasiparticles quantum-mechanically and going beyond this universal limit by means of our semi-semiclassical method, we demonstrate the emergence of soliton-collision induced phase diffusion, soliton-entropy production and multistep thermalization. Our method can be applied to almost any gapped one-dimensional system, and can also be used to describe the dynamical properties and the formation of non-equilibrium steady states.