Towards quantum theory of entropic gravity: Can dissipative interactions resemble potential forces?

Denys I. Bondar

Department of Physics, Tulane University, New Orleans, LA 70118, USA

Within classical statistical mechanics, a dissipative environment exerts a statistical force (also known as a fluctuation induced force or entropic force) on a probe immersed in that environment. Statistical forces are phenomenological forces that can be used to describe the statistical tendency of a macroscopic system to evolve towards states with greater entropy. For example, consider a polymer that has many possible configurations of equal energy. If such a polymer is immersed in a heat bath, then it will tend to arrange itself into configurations that maximize its entropy. Since shorter configurations have greater entropy, the statistical tendency for the polymer to increase its entropy results in a propensity for it to arrange itself in a shorter configuration. This behaviour looks as though it were induced by an elastic force. Verlinde [J. High Energy Phys. 04 (2011) 029] proposed the concept of entropic gravity to interpret gravity as an emergent statistical force.

We will discuss the extension of the notion of statistical forces into the domain of quantum physics. We will show in general that it is hard to distinguish between the influence of dissipative and potential interactions, especially when the evolution of the expectation values of coordinates and momentum of a quantum particle is concerned. A quantum statistical force will be implemented to enhance a desired quantum dynamical property by mimicking a potential force. We illustrate our approach on quantum tunneling. According to widespread belief, interaction with a dissipative bath destroys the coherence of the quantum particle thereby suppressing tunneling rates. However, we show that there exists a class of environments which significantly enhance tunneling rates. This effect is not simply due to thermal excitation; these environments exert a quantum statistical force on the particle, which opposes the force exerted by the potential barrier (see Figure). Generalizations to other effects (e.g., trapping, effective mass assignment, and pseudorelativistic dynamics) will also be discussed [Shanon L. Vuglar et al., Phys. Rev. Lett. 120, 230404 (2018)].

FIG. 1: Wigner function plots for the coherent tunneling and dissipation assisted tunneling. Plots (a)-(c) depict the closed system tunnelling: (a) as the wavepacket approaches the potential barrier, (b) as the wavepacket interacts with the potential barrier, and (c) after the wavepacket is predominantly reflected from the potential barrier. Plots (d)-(f) depict the open system coupled to an environment tailored to enhance tunneling (d) as the wavepacket approaches the potential barrier, (e) as the wavepacket interacts with the potential barrier, and (f) after the wavepacket goes through the potential barrier. The black lines depict level sets of the Hamiltonian. Plots (g)-(i) depict a coherent free particle (i.e., no barrier and no environment).