False vacuum decay in non-equilibrium situations

Background

In quantum field theory, the study of a metastable state decaying into the true vacuum is central tool for many physical phenomena. Examples are possible phase transitions in the early universe, origin of the cosmic inflation and metastability of the Higgs vacuum. Such events are preceded by quantum mechanical nucleation of bubbles which expand and fill the whole universe. In condensed matter physics, false vacuum decay corresponds to first-order phase transitions.

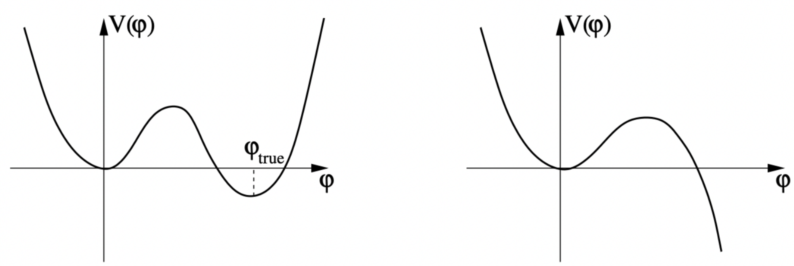

Figure 1: Scalar potential with false vacuum at $\varphi = 0$. (a) The true vacuum exists at a finite value of the field. (b) The potential is unbounded from below and the false vacuum decay leads to the run-away as $\varphi \longrightarrow \infty$.

False vacuum decay occurs when the potential of the field has the form shown in figure 1(a). A quantitative description of false vacuum decay can be explored in the semiclassical approximation, that involves the tunnelling of such a metastable state constrained by certain boundary conditions. I first studied how this description is considered in quantum mechanics of many variables. Taking the continuous limit, there is a direct resemblance between the case of false vacuum decaying in scalar field theory and the decay of a metastable state in the quantum mechanics of many variables.

Strategy

The existing semiclassical methods are suitable for systems in thermal equilibrium. The central idea behind my project is to extend the methods to the decay of a false vacuum under non-equilibrium situations, corresponding to time-dependent boundary conditions. In particular, the motion of a single reflecting boundary (a moving mirror, see figure 2) induces disturbance in the quantum state and an irreversible production of entropy would occur that leads to new field quanta. This is expected to enhance the probability of the false vacuum decay.

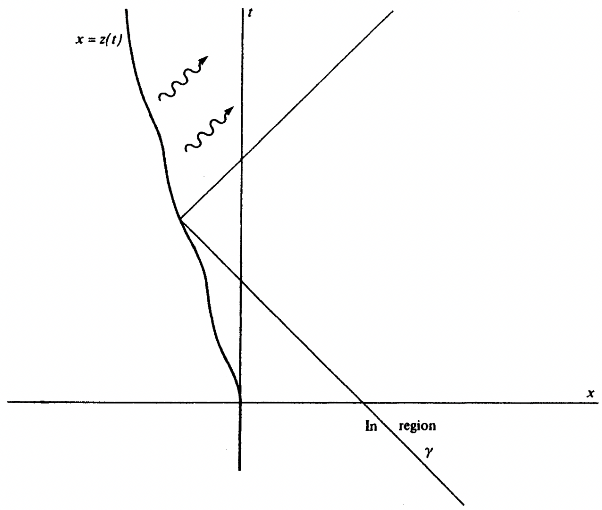

Figure 2: Radiation by moving mirror where the incoming null rays reflect. The scalar field vanishes on the boundary.

Exploring a specific example of a field theory with potential of the type shown in figure 1(b) will allow me to identify the key features of the false vacuum decay phenomena in non-equilibrium cases. Boundary conditions for false vacuum decay are set by time-ordered Green's function. We will find this Green's function and match it with non-linear solution to get the nucleated bubble.

Progress made to date

Referring mainly to two directed readings (Birrell et al., 1984) & (Rubakov, 2009) and the paper (Shkerin & Sibiryakov, 2021).

A thorough background of the following topics were required to build an understanding of the approach outlined in my research project:

Special Relativity, Quantum field theory in Minkowski spacetime and therein, scalar field quantization, Stress-energy-momentum Tensor, Time-ordered Green's functions, thermal Green's functions, Path integral quantization, geometry of flat spacetime, Tunneling probabilities in terms of Euclidean action (bounce solution), Decay of a false vacuum in scalar field theory.

References

Birrell, N. D., Birrell, N. D., & Davies, P. (1984). Quantum fields in curved space.

Rubakov, V. (2009). Classical theory of gauge fields. In *Classical theory of gauge fields*. Princeton University Press.

Shkerin, A., & Sibiryakov, S. (2021). Black hole induced false vacuum decay from first principles. *Journal of High Energy Physics*, *2021*(11), 1–71.