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Adiabatic and sudden regimes in the Unruh effect

Content

The Unruh effect predicts that a uniformly accelerated observer perceives a change in their vacuum state [1]. This phenomenon is a direct result of quantum field theory and relativity. Although direct experimental confirmation is still pending, interesting proposals already exist [2]. Currently, there is debate about the physical origin of the effect [3], particularly regarding whether it should be interpreted as a consequence of acceleration present since arbitrarily remote times, or of sudden acceleration. The first case could occur in cosmological contexts, and the second in possible artificial realizations.

In this work, we claim that particle production requires sudden acceleration. In this scenario, starting from rest with a preselected initial state, we conclude that acceleration induces a non-trivial change in the observables. This is reflected in the expectation value of the particle number. There are, therefore, two equivalent descriptions: transforming the observables or transforming the states, both leading to the same physical results. Furthermore, in a cosmological context, the system would have always evolved within a closed dynamics and would effectively remain in thermal equilibrium. Consequently, particle production would no longer manifest at late times after equilibrium is reached.

To test our hypothesis, we introduce a metric defined by an adiabaticity parameter λ, that continuously connects the flat Minkowski spacetime metric with the Rindler observer metric (constant acceleration). This new metric corresponds to a curvilinear coordinate system associated with new adiabatically accelerated observers.

Under these conditions, we analyze the first-order corrections in λ to the solutions of the resulting Klein–Gordon equations and study how these corrections modify the Bogoliubov coefficients that relate the creation and annihilation operators between the accelerated and inertial frames.

By calculating the transition coefficients between modes using the Klein–Gordon inner product, we find that in the adiabatic limit $\lambda \to 0$, these coefficients tend to zero, as expected in flat spacetime, indicating the absence of particle production. In contrast, in the sudden acceleration limit $\lambda \to \infty$, we recover the result associated with the Rindler metric. Our results show that particle production in the Unruh effect depends essentially on the non-adiabatic nature of the acceleration and not on acceleration alone. These results continue our previous line of research on the Unruh effect [4,5].

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[4] M. A. Estévez and E. Sadurni. Particle radiation produced by accelerated systems and their analogy with damped oscillators. Rev. Mex. Fis. S, 4(2):1–4, 2022.

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Summary

We study the difference between adiabatic and sudden acceleration in the Unruh effect (the phenomenon of particle production for uniformly accelerated observers). Using a metric that interpolates between Minkowski and Rindler spacetime, parameterized by an adiabaticity parameter, we analyzed the coefficients of the Bogoliubov transformation. In the adiabatic limit, the Minkowski vacuum is recovered and particle production is suppressed, while in the sudden (non-adiabatic) regime, mode mixing, i.e., particle production, is induced. These results suggest that the detection of the Unruh effect depends essentially on how the acceleration is physically introduced, in addition to the preselection of the initial vacuum state.

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