The Ontological Cost of Vacuum Energy Regularization

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Abstract: Vacuum regularization in quantum field theory (QFT) commonly relies on high-frequency cut-offs to yield finite energy values. While this is a standard computational necessity, it leads to a fundamental contradiction: the set of excluded frequency modes is frame-dependent due to Doppler shifts. Consequently, what one observer cuts off, another may retain. This discrepancy undermines the Lorentz invariance of the vacuum and introduces a deeper ontological inconsistency: entire field modes, and with them physical objects, can be removed from existence by switching frames. This paper isolates and foregrounds this overlooked problem, showing that no cut-off scheme can preserve observer-independent physical content.

The Necessity of Cut-Offs In standard QFT, vacuum energy integrals diverge unless a high-frequency cut-off is imposed. This cut-off removes ultraviolet modes beyond a chosen scale (e.g., Planck frequency). The motivation is clear: without discarding these modes, energy densities reach unphysical infinities and lead to absurd predictions such as spontaneous black hole formation. Therefore, some form of regularization is not optional but structurally necessary.

Frame Dependence of Mode Removal Once a cut-off is imposed in a given frame, its effect is not Lorentz invariant. Due to relativistic Doppler shifts, the same field mode may lie below the cut-off in one frame but exceed it in another. Thus, a particular frequency mode might be included in one observer's vacuum and excluded in another's. This means that the physical content of the vacuum becomes frame-dependent, violating the core requirement of Lorentz invariance.

A Concrete Implication: Mode Elimination of Real Objects Suppose a mode corresponding to the electromagnetic binding of an electron in a hydrogen atom is present in one frame. In another frame moving rapidly relative to the first, the Doppler-shifted version of that same mode may lie above the cut-off and thus be removed from the theory. In effect, an entire bound state—or any physical configuration tied to a precise spectrum—can be erased merely by changing reference frames. This is not just a change in energy evaluation; it is a logical contradiction in what is considered to exist.

Philosophical Consequence This contradiction exposes an ontological vulnerability in the vacuum's role within QFT. If a consistent cut-off is necessary, but no cut-off can preserve the same mode content across frames, then the vacuum cannot maintain an objective physical structure. The issue is not about calculating the right energy; it's about defining what exists. A theory that allows an electron to exist in one frame and not in another undermines its own physical realism.

Postscript and Further Implications If vacuum regularization leads to unavoidable frame-dependent mode removal, then the concept of a spontaneously active vacuum field must be reconsidered. It suggests that vacuum activity is not fundamental, but arises only in response to external quantum states. Similarly, elementary particles should not be expected to fluctuate or transform without external interaction. These conclusions emerge naturally from the internal inconsistency exposed above.

Final remark: None of the above denies the predictive successes of QFT in local, laboratory-scale phenomena. However, when extrapolated to global or cosmological contexts, the same framework has led to increasingly exotic and arguably unrealistic constructs. These include, for example, the derivation of the Casimir effect formula (not the effect itself, which is real), the idea of black hole evaporation, and a multitude of paradox-driven or speculative theoretical extensions. The present critique is directed not at the empirical power of QFT, but at the interpretational consequences of its foundational assumptions.