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Lorentz-invariant description of the Feigel process for the extraction of momentum from the vacuum

(2-month study, prepared by A. Rathke)

Several futuristic concepts of space propulsion rely on the properties of the quantum vacuum. In particular the generation of Alcubierre bubbles [1] relies on the violation of energy conditions, which seems to be achievable by quantum vacuum effects only - if at all. Also the idea of using vacuum forces directly for propulsion has reached some circulation [2]. Although both of these concepts are far from realisation it seems nevertheless desirable to follow scientific developments which could finally lead to enabling technologies or rule out these ideas in principle.

In the last few years the understanding of the quantum vacuum in the presence of external fields has made considerable progress in areas, which seem relevant for the above ideas. In particular it has been demonstrated that the well-known Casimir formula for the force between two perfectly conducting plates in vacuum will experience considerable modification in more realistic settings. Both calculations of the interaction of the vacuum polarisation with classical boundaries [3,4] as well as mode counting arguments [5] have demonstrated that generically an ultraviolet (UV) cut-off on vacuum forces will arise which severely limits the magnitude of vacuum forces in realistic situations. Whereas the proof of existence of the UV cut-off is a recent achievement the existence of such a cut-off had been anticipated for quite some time [6].

The existence of the UV cut-off to vacuum forces and energy densities which is generic to quantum field theories and does not rely on any specific theory of quantum physics (e.g. is valid also in stochastic models of quantum physics [7]) wipes out the vision of mining unlimited energies from the vacuum and the generation of macroscopically relevant negative energy densities and vacuum forces has to be reformulated in terms of a stacking problem of hypothetical nano-devices. Whereas the existence of UV cut-off thus also serves as a cut-off the high-flying ideas of vacuum engineering an other totally unexpected result on the physics of the quantum vacuum stirs ones imagination:

Recently A. Feigel has demonstrated that in the presence of media with certain electromagnetic properties momentum can be extracted from the vacuum of quantum electrodynamics [8]. The result fits well into the recent findings on the existence of a UV cut-off in vacuum forces since also the extraction of momentum is limited by UV effects. However one would not have expected that the extraction of momentum from the QED vacuum is possible *at all* because the conservative nature of the electromagnetic field should prohibit such processes. Some doubt however remains about the reliability of Feigel's result due to the fact that the calculations were conducted in non-covariant fashion. Thus, in particular in view of the highly surprising result, a suspicion remains that the extraction of momentum is just an artifact of the 3-dimensional formulation of the problem.

The aim of this study is to reconsider the situation discussed by Feigel using the Lorentz-invariant representation of electrodynamics. In this way the result of Feigel should be either recovered or, if discrepancies arise, their origin shall be discussed and a reliable result shall be derived. The treatment of the problem should be at a level suitable for publication in a peer-reviewed physical journal. A publication of the results is encouraged.

Task summary

- Derive a Lorentz invariant description of the Feigel process.
- Discuss the result in comparission with [8].

References

[1] M. Alcubierre, "The warp drive: Hyper-fast travel within general relativity," Class. Quant. Grav. **11**, L73 (1994) [arXiv:gr-qc/0009013].

[2] M. Tajmar, *Advanced space propulsion systems*, (Springer, Wien, Austria, 2002).

[3] R. L. Jaffe, "Unnatural acts: unphysical consequences of imposing boundary conditions on quantum fields," AIP Conf. Proc. **687**, 3 (2003) [arXiv:hep-th/0307014].

[4] N. Graham, R. L. Jaffe, V. Khemani, M. Quandt, O. Schroeder and H. Weigel, "The Dirichlet Casimir problem," Nucl. Phys. B **677**, 379 (2004) [arXiv:hep-th/0309130].

[5] M. Scandurra, "QFT limit of the Casimir force," arXiv:hep-th/0306076.

[6] S. A. Fulling, *Aspects of quantum-field theory in curved space-time*, (Cambridge University Press, Cambridge, UK, 1990), p. 114.

[7] L. De La Pena, "Stochastic electrodynamics: its development, present situation and perspectives," in: Cali 1982, proceedings, Stochastic processes applied to physics and other related fields, 625-633.

[8] A. Feigel, "Quantum vacuum contribution to the momentum of dielectric media," Phys. Rev. Lett. 92, 020404 (2004) [arXiv:physics/0304100].