Vacuum Viscosity

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Our recent investigation on **moving atom-quantum field interactions** [1] reveals a rather surprising fundamental phenomena: A **nonrelativistic calculation** shows that an object with internal degrees of freedom moving at uniform speed will experience a viscous force from its interaction with a classical field, which we call **vacuum viscosity**, vacuum in the sense of zero temperature, free field with no boundary. However, in a **covariant treatment**, when proper time instead of laboratory time is used, following the dictum of **special relativity** (SR), there is no viscous force other than the well-known radiation reaction. We explain the physical reasons for such a difference: the excitation energy in the atom's internal degrees of freedom can be regarded as a time-dependent renormalized mass. This is a good example of how SR enters in **Newton's first law** and is essential in keeping it intact for moving atoms. The next stage of our work shall consider a quantum field. There, fluctuations of the quantum vacuum may give rise to quantum vacuum viscosity. Quantum vacuum viscosity is similar to the more familiar **quantum friction** but different in major ways: **a)** quantum friction, as has been explored in great details for several decades, shows up only when a neutral atom moves close to the surface of a dielectric medium or a conducting boundary. Here, **there are no boundaries; b)** this vacuum viscosity is **a zero temperature** effect, distinct from the Einstein-Hopf thermal drag; **c) this vacuum viscous force is reactive in nature,** like the reactance of an inductor, **not resistive** (no phase lag), as "friction" may conjure. Whenever backreaction from the field is included in the consideration, the **dissipative dynamics of the system (charge or atom) is intrinsically nonMarkovian**. The conception and investigation of v*acuum viscosity* predated modern quantum friction discovery: It was first proposed in 1970 by Zel'dovich [2] to describe the backreaction effects of vacuum particle production on the dynamics of the early Universe. This idea was quantified and made precise by the rigorous work of many authors in the 70's using quantum field theory in curved spacetime methodologies and **semiclassical gravity theory** for treating **backreaction effects**, captured in terms of **vacuum viscosity** and a **quantum Lenz law [3]**. In our work we adopt a microphysics model in quantum optomechanics with three dynamical variables, called the **mirror/atom-oscillator-field** (**AMOF) model** [4], where the internal (electronic) degrees of freedom (idf) of the atom interact with the field which takes on values at the spacetime point of the atom's external (mechanical) degree of freedom (mdf).

[1] J. T. Hsiang and B. L. Hu, Vacuum viscosity and relativistic inertia of an object with internal degrees of freedom moving in a classical field [in preparation for Phys. Rev. D]

[2] Ya. B. Zel'dovich, Particle production in cosmology, Pis'ma Zh. Eksp. Teor. Fiz. 12, 443 (1970)

[3] B. L. Hu, Vacuum viscosity description of quantum processes in the early universe, Phys. Lett. 90A, 375 (1982); Gravitational entropy of the universe, Phys. Lett. A 97, 368 (1983).

[4] Chad R. Galley, Ryan Behunin and B. L. Hu, Oscillator-Field Models of Moving Mirrors in Quantum Optomechanics Phys. Rev. A 87, 043832 (2013)