Enhancement of Casimir Friction due to the Finite Lifetime of Atomic Levels

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In a largely forgotten work of Einstein and Hopf it has been shown [1] that a polarizable particle (eg. atom) moving relative to a thermal photon bath encounters a friction force. The same effect has recently been been rediscovered on the basis of the fluctuation-dissipation theorem [2]. The resulting thermal friction force is proportional to an integral over the imaginary part of the dynamic polarizability of the atom [2, 4]. We present a simple explanation for blackbody friction in terms of a Doppler shift of the thermal radiation in the inertial frame of the moving atom: the blue-shifted photons from the front are absorbed with higher probability then the red-shifted photons from the back, leading to a net friction force [4]. A similar, but signifficantly larger effect is present for atom moving relative to solid medium [3]. The friction force for both blackbody friction (BBF) and atom-surface non-contact friction (ASF) cases is proportional to the velocity of the atom, and can be expressed as:

$$F_{\rm BBF} = v\,\frac{\hbar}{6\pi^2 c^4 \epsilon_0}\int_0^\infty {\rm d}\omega\,\omega^5\left(-\frac{\partial\eta(\omega;T)}{\partial\omega}\right){\rm Im}\,\alpha(\omega)\,, \tag{1}$$

$$F_{\rm ASF} = v\,\frac{\hbar}{4\pi^2 \epsilon_0}\int_0^\infty {\rm d}\omega\left(-\frac{\partial\eta(\omega;T)}{\partial\omega}\right){\rm Im}\,\alpha(\omega)\int_0^\infty {\rm d}q\,q^4\,e^{-2qz}\left[2\,{\rm Im}R^{\rm TM}(q,\omega)+\left(\frac{\omega}{cq}\right)^2{\rm Im}R^{\rm TE}(q,\omega)\right]\,, \tag{2}$$

where the polarizability tensor of the particle is assumed to be isotropic, $R^{\rm TM}$ and $R^{\rm TE}$ are the reflectivities of the solid surface and $\eta(\omega;T)$ is the Bose-Einstein factor $1/(\exp(\hbar\omega/kT)-1)$.

Using a numerical approach, we find that both the blackbody friction and atom-surface Casimir friction is larger than previously thought by orders of magnitude [5]. This enhancement is due to far off-resonant driving of transitions by low-frequency thermal radiation. At typical temperatures, the blackbody radiation maximum lies far below the atomic transition wavelengths. Surprisingly, due to the finite lifetime of excited atomic levels, which gives rise to Lorentzian line shape of the imaginary part of the dynamic polarizability, far off-resonant excitation leads to the dominant contribution to blackbody and atom-surface friction.

The main off resonant contribution to the non-contac friction comes from frequencies much lower then the resonant frequency of the atom. We have derived this low frequency contribution in a gauge invariant and have shown that it can be computed from the resonant part of the polarizability and has to be subsequently added to this resonant part:

$$\begin{aligned}{\rm Im}\,\alpha(\omega) &= \frac{\omega^3}{6\pi\epsilon_0 c^3}\,|\alpha(\omega)|^2 + {\rm Im}\,\alpha_{\rm res}(\omega)\,,\\ {\rm Im}\,\alpha_{\rm res}(\omega) &= \frac{\pi}{2}\sum_i \frac{f_{i0}}{E_i-E}\,\delta(E_i-E+\hbar\omega)\,.\end{aligned}$$

Numerical evaluation of the friction coefficients demonstrate that off-resonant part of the polarizability leads to huge enhancement of non-contact friction between atoms and solid surfaces. Our work also clears the confusion present in the existing literature (see [3, 7]) where the nonresonant contribution has been either ignored, or added on top of the contribution resulting from the total imaginary part of the polarizability, potentially leading to double counting of the same physical effect.

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