Forces of the quantum vacuum: from recoil forces to quantum friction

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The quantum vacuum is one of the most counter-intuitive concepts of quantum electrodynamics. Whereas the classical vacuum refers to a region of space that is devoid of any particles or fields, its quantum counterpart contains fluctuating electromagnetic fields even in the most idealised case. Their structure depends sensitively on the environment, as can be described by macroscopic quantum electrodynamics in the presence of linear absorbing and dispersing media. When interacting with polarisable atoms, these fluctuating fields or virtual photons can lead to very real forces. I will present the basic formalism of macroscopic quantum electrodynamics and apply it to dispersion forces and quantum friction.

I will start by addressing a very old puzzle regarding the van der Waals force between and excited and a ground-state atom. Surprisingly, it is found that the force on the excited atom exhibits oscillations in its dependence on the interatomic distance while that on the ground state atom is strictly monotonous. The apparent violation of the action-reaction principle is resolved when taking into account the recoil of the photon emitted by the excited atom. Anisotropic spontaneous emission is shown to also occur for a single excited atom with circular dipole moment which is placed above a plane surface or a nanofiber. In both cases, a lateral Casimir–Polder force arises due to photon recoil.

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{fig1.png}
\caption{Van der Waals force between an excited Rb atom and a ground-state Cs atom.}
\end{figure}

For an atom that moves with respect to a plane metal surface, a dissipative quantum friction force has been predicted which is due to the excitation of image currents inside the metal. We study the phenomenon in the time domain to find three asymptotic regimes which are governed by short-time dynamics, Markovian decay and long-time algebraic decay of atomic dipole-dipole correlations. We propose to observe quantum friction indirectly by measuring motion-induced shifts and broadenings of atomic emission lines. The effect is strongest for short distances and vertical motion of the atom.