Quantum friction — Dispersion forces on moving atoms and molecules

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**Background:** A striking feature of the quantum mechanical interaction between atoms or molecules and the electromagnetic field is the existence of dispersion forces such as Casimir–Polder and van der Waals forces [1]. These ‘forces out of nothing’ are a result of the quantum fluctuations of the electromagnetic field that are strongly modified if the atom or molecule comes close to a macroscopic dielectric object. Casimir–Polder forces currently present the limit as to how close neutral atoms can be held near microstructured surfaces known as atom chips (see left figure). At present, dispersion forces are therefore seen as nuisance effects. However, as we gain a deeper understanding of their origin and their functional dependencies on geometric and electromagnetic properties of the macroscopic materials, we get into a position in which we can use dispersion forces as engineering tools to coherently manipulate atoms or molecules very close to surfaces.

![Image of atom chip and microstructured surface](image)

**FIG. 1:** Left figure: Atom chip used to trap ultracold Rb atoms near a gold surface. Right figure: Microstructured surface consisting of spherical cavities with diameters of less than one micrometer.

**Project:** In this project the focus will be on one particular aspect of manipulating atoms or molecules with macroscopic bodies, namely the effect on atomic motion. In this context, the investigation will concentrate on quantum friction (Casimir–Polder) forces that act on atoms or molecules moving close to a macroscopic body, and which could potentially be used to decelerate particles. The aim of this project is to find a consistent quantum theory of these friction forces which, on the one hand, can be used as a testbed of a general theory of field quantization in moving dielectrics, and on the other hand serves as the starting point for a variety of experimental applications.

The project contains a mix of analytical and numerical problems. Whereas the foundational part of the project involves mostly analytical investigations, the applications to real-world scenarios often requires numerical studies, too.

**First year project:** In the first year project you will familiarise yourself with the quantum theory of light in dielectrics [1]. As a first application, you will be looking at the simple example of quantum friction forces on an atom moving near a flat surface at zero temperature. The aim is to investigate the effects of surface plasmons on the friction force, and in particular to understand the role of the electromagnetic properties of the surface.

**PhD project:** Of particular interest will be the functional dependencies of the quantum friction forces on material parameters such as geometry, dielectric and magnetic response properties, and temperature. Dielectric properties of a material can be tailored very effectively by structuring surfaces on the nanometer or micrometer scale. For example, you will study the enhancement of friction forces by designing interfaces that are able to excite surface plasmon resonances (for example, see right figure).

Parallel to these investigations you will use the knowledge of Casimir–Polder forces on moving atoms to construct and test a quantum theory of light in moving media, which will be a major step towards a relativistic quantum theory of light with macroscopic bodies. This in turn leads to a variety of other applications such as quantum friction between macroscopic bodies, the dynamical Casimir effect and photon production between moving magnetoelectric bodies, and possibly even sonoluminescence.