Classical Theory of Mirror-Mediated Cooling

J. Bateman, A. Xuereb, H. Ohadi, N. Cooper, and T. Freegarde

School of Physics and Astronomy, University of Southampton, United Kingdom

We have calculated, using a classical approach, the frictional force on a polarisable particle which is illuminated with far-detuned light and coupled, via the dipole force, to its reflection.

Established methods for cooling atoms with light require a closed optical transition; they rely on the atom to provide the necessary dissipation. A new breed of techniques is emerging in which particles and light are coupled using the dipole rather than the scattering force; for these, it is the light, not the particle, which provides dissipation. Examples include cavity-mediated cooling[1,2] and the proposed mirror-mediated cooling[3]. For these techniques, the only property required of the particle is that it be polarisable; specifically, there is no need for a closed optical transition. Potentially, we can achieve direct, optical cooling of molecules and even much larger structures, such as micro-cantilevers[4].

In cavity-mediated cooling, a particle is placed at the focus of an optical cavity which is pumped with light sufficiently detuned from any absorption feature that dissipation can be neglected. The standing wave in the cavity acts as an optical lattice and exerts a force on the particle; simultaneously, the position of the particle relative to this standing wave influences the phase-delay of light crossing the cavity. Hence, the particle affects the field and the field affects the particle. Similarly, in mirror-mediated cooling, a particle is placed in front of a mirror and is illuminated by far off-resonant laser light. Light passing the particle is perturbed by it, and this perturbed field is reflected back onto the particle; hence, the particle is coupled to a time-delayed image of itself. This retarded interaction is common to both mirror- and cavity-mediated cooling, and is the essential ingredient for cooling via the dipole force.

These techniques are often described using the same tools, such as fully-quantum treatments or the semi-classical approximation, as are used for the more traditional schemes, such as Doppler cooling. However, the dipole interaction is, for our purposes, adequately described by a classical field interacting with a classically polarisable particle. Hence, a fully classical approach is appropriate, and is complimentary to quantum mechanical models. For example, using a fully classical model we can readily treat three dimensions and tensor propagators; by contrast, mirror-mediated cooling has thus far been described using a generalisation of transfer matrices[5], and it is unclear whether this approach can be extended beyond one dimension.

We begin with a moving polarisable particle in front of a mirror and we ask how long it takes a perturbation in the field, caused by this particle, to return to this particle; we find that even this seemingly simple question must be treated with care. Armed with our solution, we ask what field we should expect at the particle when we include the propagated perturbation to the field. Our approach is general: we apply it to one-dimension for comparison with the result obtained via the transfer matrices, and then, using the tensor propagator, we find a full-three dimensional expression for an infinite plane mirror. Finally, we discuss the application of this result to large polarisable particles, such as micron-scale glass beads, and to arbitrarily curved mirror surfaces and cavities.

---

[1] P. Horak, G. Hechenblaikner, K. Gheri, H. Stecher, and H. Ritsch, Phys. Rev. Lett. **79**, 4974 (1997)
[2] D. Leibrandt, J. Labaziewicz, V. Vuletić, I. Chuang, Phys. Rev. Lett. **103**, 103001 (2009)
[3] A. Xuereb, P. Horak, T. Freegarde, Phys. Rev. A **80**, 013836 (2009)
[4] S. Gröblacher, K. Hammerer, M.R. Vanner, M. Aspelmeyer, Nature **460**, 724–727 (2009)
[5] A, Xuereb, P. Domokos, J. Asbóth, P. Horak, and T. Freegarde, Phys. Rev. A **79**, 053810 (2009)