Temperature Measurements in Optical Tweezer Experiments

Mathias Höld, BSc.

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1 Introduction

2 Motivation

3 The experiment

The starting point of this thesis is an experiment conducted by Gieseler et al [3]. It is an optical tweezer experiment, where the motion of a glass nanoparticle in a laser trap was used to investigate the fluctuation theorem[1].

3.1 Experimental setup

In the experiment, a silica nano particle with a radius of about 75 nm and mass of about 3×10^{-18}kg is trapped in a laser beam within a vacuum chamber. The trapping of the silica nano particle (which will be referred to as *glass particle*) is achieved by a gradient force of the laser beam acting on the particle. The experimental setup is depicted in fig. 1.
The particle fluctuates within the trap in all three spatial directions. These fluctuations can be approximated such that they are decoupled, which means that they can be described by a 1-dimensional Langevin equation:

$$\ddot{x} + \Gamma_0 \dot{x} + \Omega_0^2 x = \frac{1}{m} \left(F_{\text{fluct}} + F_{\text{ext}} \right) \tag{1}$$

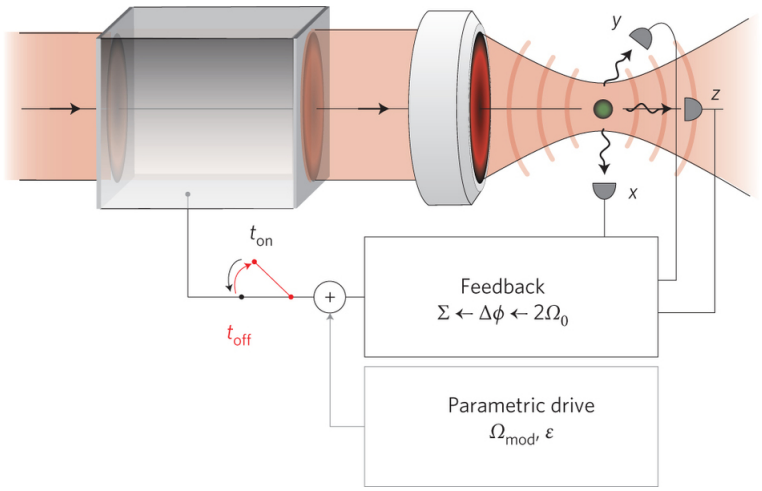

Figure 1: Experimental setup of the optical tweezer experiment. A silica nano particle is trapped in a laser beam via gradient force in a vacuum. The feedback is used to cool down the particle and create a non-equilibrium steady state. In the first part of the experiment, the feedback is turned off and the motion of the particle towards an equilibrated state is observed. In the second part of the experiment, the steady state of the particle is modified by a parametric drive. Both the parametric drive and the feedback are turned off and – as in the first part – the motion of the particle towards an equilibrated state is observerd.

4 Simulation

The problem at hand can be studied on an atomic level with the use of computer simulation. There is a variety of methods for computer simulations that are widely used, one of which being Molecular Dynamics (MD) simulations. The following section will give a brief overview of the concepts of this method, which is followed by the application to the simulation of the experiment.

4.1 Molecular Dynamics

Molecular Dynamics[2] simulations is a technique for simulating, as the name suggests, the dynamics of a classical many-body system. In this case, classical means, that the trajectories of the individual particles are calculated using classical mechanics rather then quantum mechanics. For relatively big atoms/molecules this is a very good approximation, whereas for systems consisting of hydrogen or helium the effects of quantum mechanics cannot be neglected and other methods (such as ab-initio simulation) has to be used.
The dynamics of the system are obtained by solving Newton's equations of motion for every particle.

5 Results

6 Conclusion

References

[1] Gavin E. Crooks. Entropy production fluctuation theorem and the nonequilibrium work relation for free energy differences. *Phys. Rev. E*, 60:2721–2726, Sep 1999.

[2] D. Frenkel and B. Smit. *Understanding Molecular Simulation: From Algorithms to Applications*. Computational science series. Elsevier Science, 2001.

[3] Jan Gieseler, Romain Quidant, Christoph Dellago, and Lukas Novotny. Dynamic relaxation of a levitated nanoparticle from a non-equilibrium steady state. *Nat Nano*, 9(5):358–364, May 2014.