Evanescent light scattering Optical Tweezers

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Abstract auf Englisch (10-15 Zeilen) Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Available at www.github.com/leoole100/fp2.

1 Introduction

1.1 Physical Principles

kompakten Zusammenstellung der physikalischen Grundlagen

Mean square deviation and velocity autocorrelation: https://de.wikipedia.org/wiki/Mittlere_quadratische_Verschiebung#Verbindung_zur_Geschwindigkeitsautokorrelation

$$\langle v(t) \cdot v(t+\tau) \rangle = -\frac{d}{d\tau} \frac{\left\langle r^2(\tau) \right\rangle}{6\tau} \tag{1}$$

$$\Rightarrow \quad \left\langle r^2(\tau) \right\rangle = 6 \int_0^\tau (\tau - s) \langle v(0) \cdot v(s) \rangle \, ds \tag{2}$$

The maxwell boltzmann relations (from script) are given by

$$P(x) \propto \exp\left(-\frac{V(x)}{k_B T}\right) \tag{3}$$

$$V(x) \propto -\frac{\log P(x)}{k_B T} \tag{4}$$

2 Methods

Mit einer Skizze des Versuchsaufbaus

3 Procedure

4 Results

All recorded data and the analysis is available at www.github.com/leoole100/fp2.

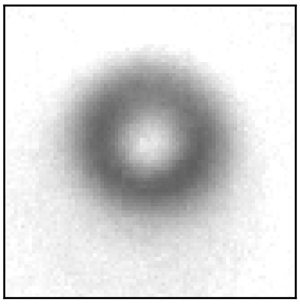

Figure 1 Transmission light microscopy of a observed particle. The radius of the particle is 14(2) px, equivalent to 1.86(27) µm.

4.1 Transmission Light Microscopy

In the first section of the experiment, the particles were observed using a transmission light microscope setup. For this images with a resolution of 600×800px were recorded with a frequency of 10 Hz for 10 min. The images were normalized with a black (illumination off) and white (illumination on, particle not in frame) reference image, to remove the influence of dust in the imaging elements. The particle that was used for this experiment is shown in Figure 1, after the normalization.

CONVERSION PX TO MICROMETER

To determine the trajectory of the particle, a effective center of mass was calculated for each frame:

$$\vec{r}(t) = \iint \vec{r} \cdot \left(1 - I(\vec{r}, t)\right)^2 d\vec{r} \tag{5}$$

The density of the resulting trajectory is shown in Figure 2 for different optical trap stiffnesses. The approximate radius of the optical trap of 2.5 µm is drawn as a red circle. For the trap stiffness of 0, the particle is free to wander around, for the higher stiffnesses like 1.01 the particle is mostly confined to the trap.
For a weak trap like 0.75 the particle is still mostly confined to the trap, but can escape the linear trap region and randomly wander around. This happened multiple times during the shown measurement.

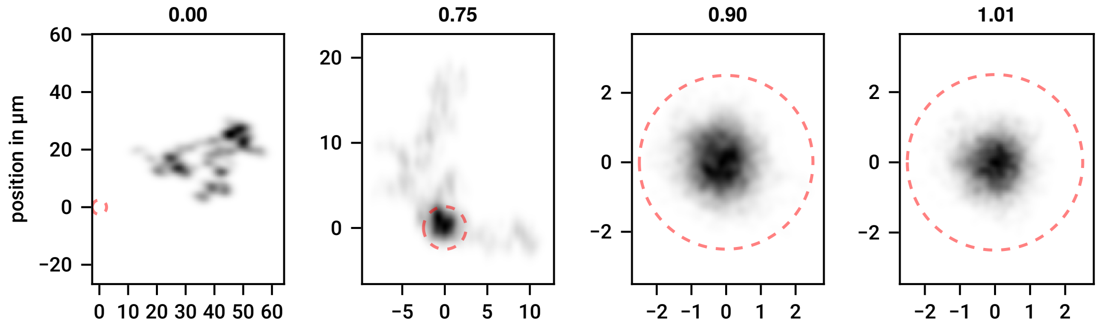

Figure 2 Density of recorded particle positions, grouped by optical trap stiffness. The red circle indicates the approximate radius of the optical trap 2.5 µm.

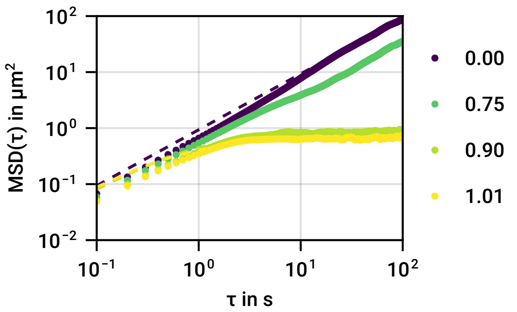

Figure 3 Mean Square Displacement for different optical trap stiffnesses, fit: Equation 8

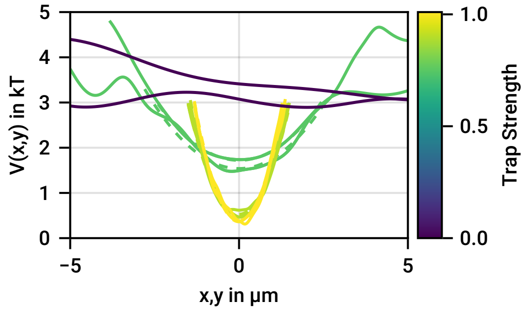

Figure 4 Grouped by axis, relative to mean.

Mean Square Displacement

A method to describe the trajectory of a random walk is the mean square displacement (MSD) [1]. This is defined as the average of the squared distance of the particle from the starting point:

$$\mathrm{MSD}(t) = \left\langle \Delta r^2(t) \right\rangle = \frac{1}{N} \sum_i^N (x_i(t) - x_i(0))^2 \quad (6)$$

Here a different implementation using the autocorrelation of the velocity was used, to achieve a more stable result. This was implemented by [2]. The resulting MSD for different optical trap stiffnesses is shown in Figure 3.

This can be described as

Model for the MSD with $k = \alpha P \cdot k_B T / \mathrm{MSD}(\infty)$ with the optical tweezer power P in arbitrary units:

$$\frac{1}{\mathrm{MSD}(\tau, k)} = \frac{1}{D_0 \tau} + \frac{1}{\mathrm{MSD}(\infty)} \quad (7)$$

$$= \frac{1}{D_0 \tau} + \frac{1}{(k_B T \cdot P)_i} \quad (8)$$

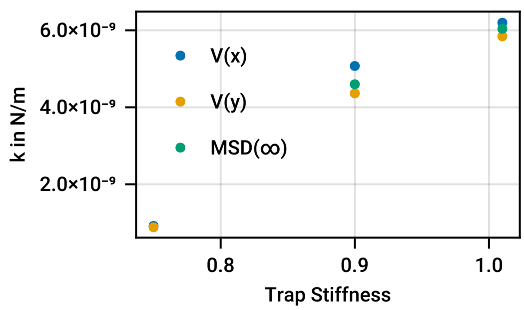

Figure 5 Differently measured spring constants.

For the i-th measurement.

4.2 Total Internal Reflection Microscopy

$$P(\Delta z) = N(0, \sigma^2) = N\left(0, \frac{\Delta T}{\langle T_s \rangle} \sigma_s^2\right) \tag{9}$$

$$\Delta I = -I_0 \beta \exp\left(-\frac{z}{\beta}\right) \Delta z \tag{10}$$

$$P(\Delta I) = P(\Delta z) \left| \frac{d\Delta z}{d\Delta I} \right| \tag{11}$$

$$= N(0, \sigma^2) \frac{1}{I_0 \beta} \exp\left(\frac{z}{\beta}\right) \tag{12}$$

5 Discussion

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References

[1] Wikipedia. *Mittlere quadratische Verschiebung — Wikipedia*. 2023. URL: https://de.wikipedia.org/w/index.php?title=Mittlere_quadratische_Verschiebung&oldid=234078066.

[2] Riccardo Foffi. *MeanSquaredDisplacement*. 2023. URL: https://github.com/mastrof/MeanSquaredDisplacement.jl.