BROWNIAN MOTION OPTICAL TRAP

Introduction

Brownian motion originates from the observation of spontaneous movements of pollen grains in liquid, made in 1827 by the botanist Robert Brown. It is a physical description of the random motion of a particle immersed in a fluid. With arguments from statistical physics and kinetic theory of gases, this motion can be explained as the result of incessant collisions between the suspended particles and the surrounding fluid molecules. A quantitative description of the phenomenon was described by Einstein in 1905, then put into practice by Jean Perrin.
The Brownian motion can be confined in a small area using a lazer (optical tweeser). This technique was developed by Arthur Ashkin, and is very useful in microbiology, especially for moving or stretching particles.

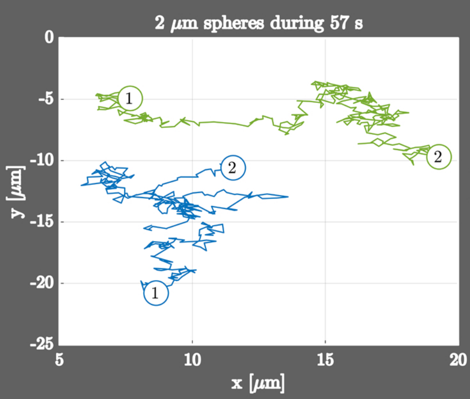
Brownian Motion

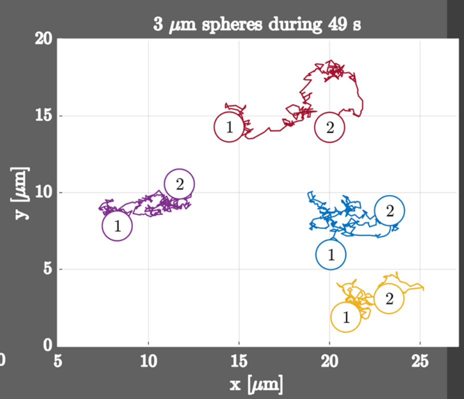
Brownian motion is described by the Langevin equation:

$$\frac{d\mathbf{v}(t)}{dt} = -\lambda\mathbf{v}(t) + \beta(t) \qquad (1)$$

- v : particle velocity
- λ : braking coefficient
- β : a rapidly fluctuating force (correspond to collisions with molecules of the fluid)

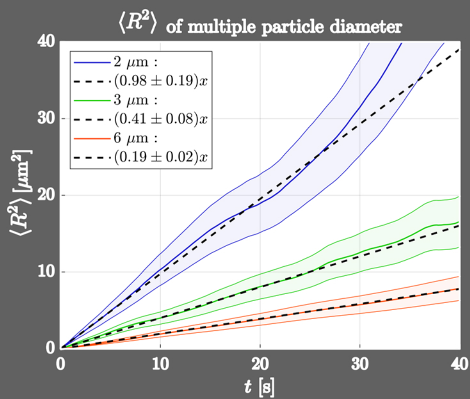
This equation can be solved to obtain the speed, but the main focus of this experiment will be to find the Diffusion Coefficient. For this, some transparent microsphere are put in water, under a microscope, and the trajectories are recorded.
It is possible to see here some brownian trajectories for microsphere of radius a=2 μm and a=3 μm. For larger particles, the motion becomes smaller.





Also, the mean square displacement $\langle R^2\rangle$ can be useful as an indication of particle deviation from its mean position over time. It is defined as:

$$\langle R^2\rangle = \langle(\mathbf{x}(t'+t) - \mathbf{x}(t'))^2\rangle_{t'}$$



Now, according to Einstein's theory, the mean square displacement described above corresponds to a diffusion process, and then:

$$\langle R^2\rangle = 2dD \cdot t$$

- d = 2 : the number of dimensions used to calculate Ripsum dolor sit
- D : the diffusion coefficient
- t : the time

The theoretical diffusion coefficient D_{th} is known by solving Langevin's equation (1).

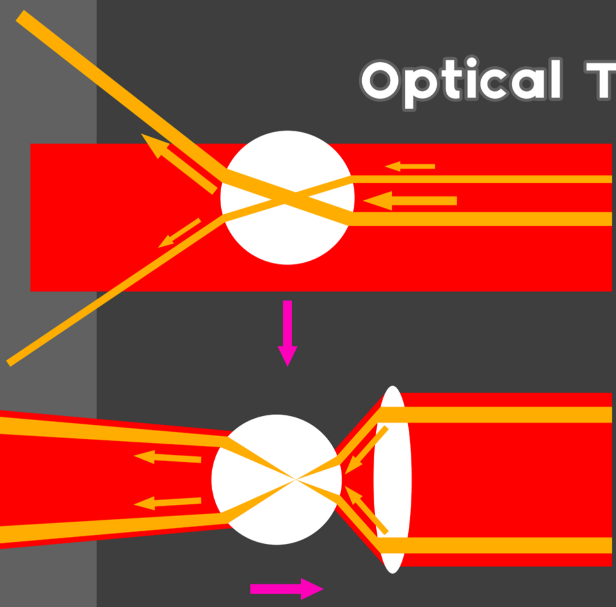
$$D_{exp} = \frac{\langle R^2\rangle}{2d \cdot t} \qquad D_{th} = \frac{k_B T}{6\pi\eta a}$$

- η : viscosity of water
- a : the radius of particle
- k_B : Boltzmann constant
- T : temperature

Particle Diameter [μm]	D_{exp} [m²/s]	D_{th}	error
2±0.05	$(2.5\pm0.5)\cdot10^{-13}$	$2.17\cdot10^{-13}$	15 %
3±0.05	$(1.0\pm0.2)\cdot10^{-13}$	$1.45\cdot10^{-13}$	31 %
6±0.05	$(0.48\pm0.04)\cdot10^{-13}$	$0.72\cdot10^{-13}$	50 %

TABLEAU 1 – Diffusion coefficient for different particle diameters

Optical Trap



The transparent nanoparticle are trapped, using the conservation of momentum and the refraction (snell law) of the light rays coming from the laser.

Indeed, the light is more intense at the center of the lazer beam. Thus, when the light rays are deflected, the total LIGHT MOMENTUM will be pointing up.
Then, by conservation of momentum of the total system particle + lasez beam, the RESULTING MOMENTUM of the particle wil be pointing down. Thus, the particle will stay on the axis of the laser.

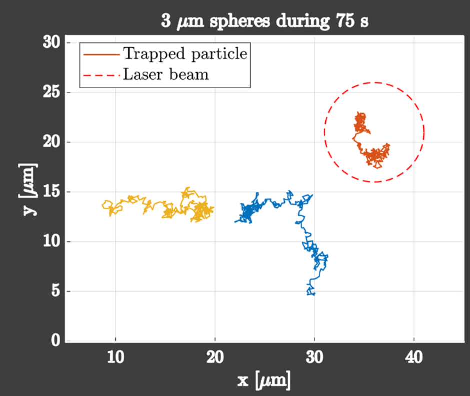
Also, to avoid the particle moving on the axis of the lazer, a lens is added. And with the same analysis, the particle will stay on a precise point of the laser's axis.

: LIGHT MOMENTUM
: PARTICLE MOMENTUM
: Laser Beam
: Microparticle
: Lens

The potential applied by the laser can be approximated by:

$$V = \frac{1}{2}k(x^2+y^2) = \frac{1}{2}kr^2$$

- k : the trap stiffness
- r : norm of position on the plane

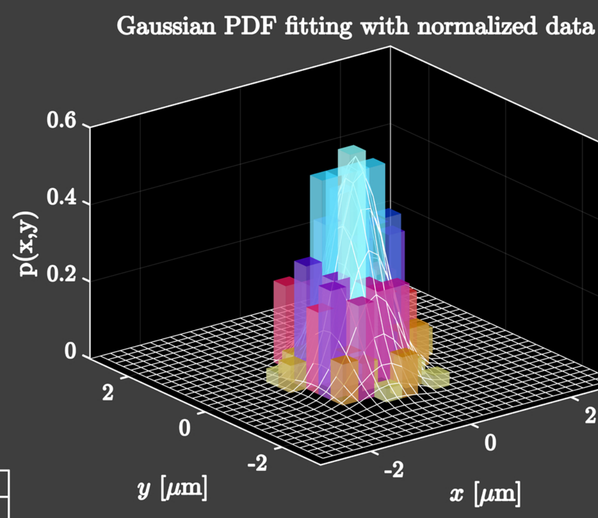


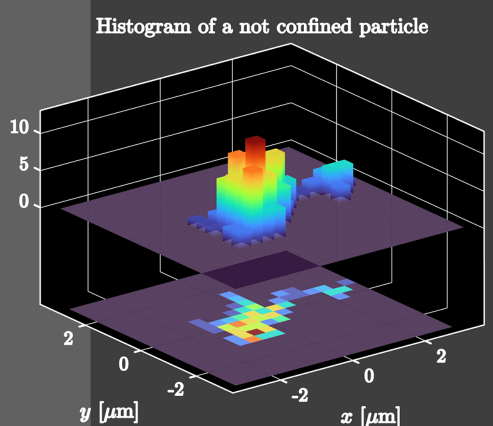
k can be calculated using the equipartition theorem, or using the shape of the potential (and the probability density of the particle's position):

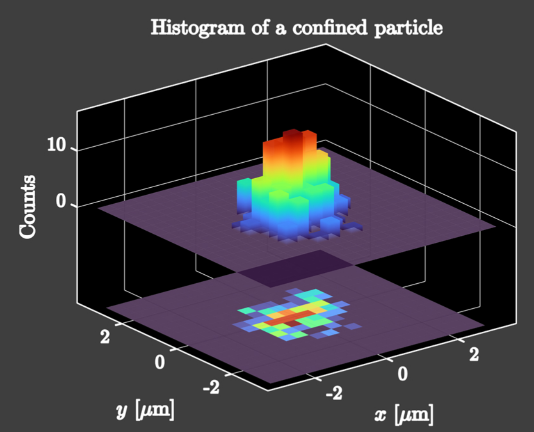
$$k_1 = \frac{k_B T}{\langle r^2\rangle} \qquad k_2 = \langle\frac{2V(r)}{r^2}\rangle$$

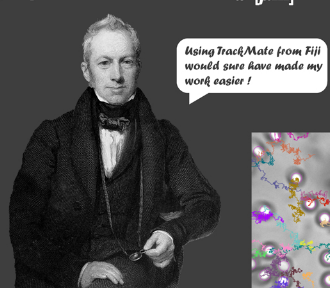
Using the renormalised histogram for the confined particle, and a gaussian fit, it is possible to obtain both k :

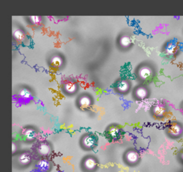
k_1 [N/m]	k_2 [N/m]
$(2\pm1)\cdot10^{-8}$	$(6.8\pm0.7)\cdot10^{-8}$











Conclusion

The brownian motion was observed. Larger particles have smaller Diffusion coefficient. The big particles almost not moved.
The optical trap was performed. Due to some problem with the experiment and the focus of the laser, the effect was not very important, but it was still possible to see the particles stay in the laser beam radius.