University of Leipzig

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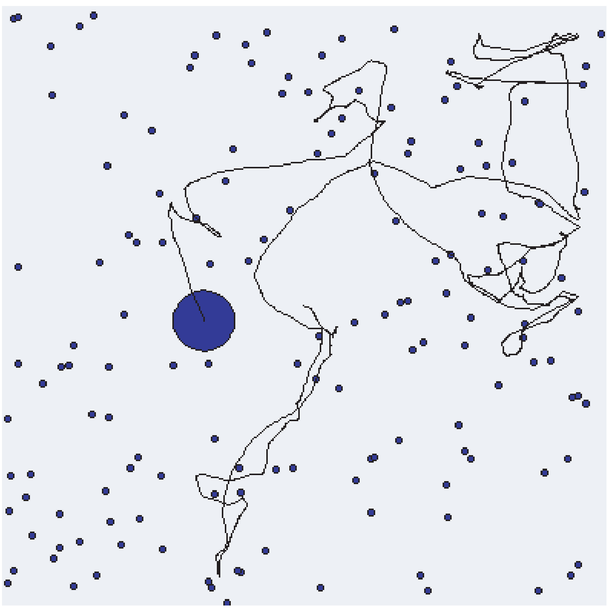
Brownian motion and Molecular diffusion

Soft Matter Physics Lecture - Experiment 1



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Chapter 1

Introduction

Soft Matter Physics examines the variety of physical states that are easily deformed by thermal stresses or thermal fluctuations. Thus, effects like Brownian motion and Molecular diffusion are of fundamental importance and particles on micrometer or even nanometer scales show a strong dependence on thermal energy. The aim of this experiment is to visualize microscopic effects influencing particle motion and calculate their magnitude to give a first impression of this area of expertise.

1.1 Thermal motion

Thermal motion is the base for the kinetic theory. Already in the 17th and 18th century physicists suggested that heat is a form of motion, but they were ignored until 1850, when Clausius, Maxwell and Boltzmann found experimental evidence and developed theories explaining macroscopic effects like temperature and pressure due to motion of particles within the system. This concept of moving particles under thermal energy was verified in many experiments and leads to a variety of effects like diffusion, Brownian motion or thermal fluctuations, which play a crucial role in nature.

1.1.1 Brownian motion

The Brownian motion is an effect which is especially apparent at the microscopic scale. It describes a random movement of particles which are suspended in a liquid or a gas. Jan Ingenhousz originally found this appearance when he studied the movement of powdered charcoal on the surface of ethanol. But it took until 1827, when Robert Brown rediscovered the effect by studying pollen particles floating in water under the microscope. He described a zig zag movement of the pollens, but could not describe an origin of the motion.
Einstein picked up this phenomena in 1905 and indicated that the thermal motion of atoms and molecules might cause the movement of suspended particles as well. He and Smoluchowski ([1],[2]) showed that Brownian motion is a result of collisions between a suspended particle and particles from the solution. Smoluchowski, using probability calculations, showed that those collisions create an effective force and causing a movement of the suspended particle in the range of the observed Brownian motion. He put

an end to the discussion, if these collision average out or not and opened a new scientific field by using stochastic processes. E.g. polymers are influenced by Brownian motion as well, therefore the concept of stochastic analysis and random walk are also applied in polymer physics. Polymers, like proteins in a cell, can be described as a suspended particle in a solution as well and hence they show Brownian motion. To create a simple reproducible experiment to show this effect, a regular shape of the suspended particle is preferable. Therefore, the employment of spherical colloids (typically polystyrene beads) seems likely due to their almost perfect round shape.

1.1.2 Diffusion

Molecules of a particle surrounding medium are moving in random directions due to the principle of equipartition of energy. Each degree of freedom of these molecules has the same mean energy $\frac{1}{2}k_BT$. The solvent molecules collide with suspended particles within the solution, causing a form of random motion of these particles characterized by frequent, abrupt changes in velocity and direction.
Due to probability the particles can move from their initial position and the average randomly moving particles move from areas of higher concentration to lower concentration. The rate of motion per unit area is called the flux J(x) and is proportional to the concentration gradient. This connection is described by Fick's first law of diffusion:

$$J(x) = -D\frac{\partial c}{\partial x}, \tag{1.1}$$

where D is the diffusion coefficient, c the concentration and x the position. By introducing the continuity equation $\frac{\partial c}{\partial t} = -\frac{\partial J}{\partial x}$ into the first law, Fick's second law of diffusion can be derived:

$$\frac{\partial c}{\partial t} = -\frac{\partial}{\partial x}J = \frac{\partial}{\partial x}\left(D\frac{\partial}{\partial x}c\right) = D\frac{\partial^2 c}{\partial x^2} \tag{1.2}$$

In cases of a constant diffusion coefficient D, the order of the differentiating can be exchanged (right side of equation 1.2). Einstein connected the drag coefficient γ with the diffusion coefficient,

$$D = \frac{k_BT}{\gamma} \tag{1.3}$$

and for a spherical particle of radius r, with a constant velocity v in an unbound fluid, Stoke's law defines the drag force

$$\gamma = 6\pi\eta r, \tag{1.4}$$

with η as the viscosity. Combining 1.3 and 1.4 leads to the Einstein- Stokes equation:

$$D = \frac{k_BT}{6\pi\eta r} \tag{1.5}$$

With the sphere size and the viscosity of the medium, the diffusion coefficient can be determined. D is related to mean square displacement $\langle r_d^2 \rangle$ of a diffusing particle and depends on the geometry of the system. By using the random walker model the mean square displacement can be expressed as $\langle r_d^2 \rangle = 2 \cdot d \cdot D \cdot t$, where d is the number of dimensions. The presented equations are idealized and are just approximations for sphere-like suspended particles and do not account for any obstacles within the solution.

Chapter 2

Experiment

To accomplish the experiment an adequate theoretical background knowledge about the main topics is mandatory. Thus, questions may be ask to test the applicability of the experimenter. Furthermore, every student has to be familiar with the safety provisions.

2.1 Preview

For an adequate preparation the experimenter has to present the following points in the preview section:

- Thermal fluctuations
- Brownian motion
- Diffusion
- Fick's laws of diffusion
- Derivation of the Einstein- Stokes equation
- Equipartition theorem
- Mean square displacement
- Random walk model
- Fluorescence microscopy
- Confocal microscopy

2.2 Experimental procedure

The main task in the preparation part is to create an appropriate experiment to investigate Brownian motion and molecular diffusion and to calculate certain properties of suspended particles. Therefor, thermal fluctuations of suspended polystyrene beads (Ø 2μm) on a glass slide should be observed in various solutions with differing viscosities. It has to be mentioned that a picture analysis program for bead detection will be provided.
For the accomplishment, the following equipment will be available:

- Fluorescence microscope
- Polystyrene beads (Colloids Ø 2μm)
- Methyl Cellulose
- Glass slides applicable with the microscope
- Vacuum crease
- Distilled water
- Pipettes

2.3 Data analysis

The collected data should be used to determine several properties like:

- Mean square displacement
- Viscosity
- Diffusion coefficient

Additionally, the protocol should include diagrams of the course of the particle, the distribution and the time dependence of the mean square displacement. Further instructions will be given during the experimental procedure.

Chapter 3

Safety provisions for workers

Some general rules concerning safety at work

- before start: design of experiments, preparation, check of used equipment and chemicals
- knowledge about potential danger of the chemicals and adequate precaution (see safety data sheets)
- wearing of appropriate protective clothing
- doors and windows must be closed during the experiments
- no food, no drink, no smoke
- freezers for chemicals are not for food
- keep the labs clean, dispose wrapping immediately
- experimental equipment is signed clearly (person in charge, time of experiments)
- after finishing the experiments cleaning up, disposing waste
- scalpels, cannulas and glass waste in the concerning signed boxes
- only authorized persons have entrance in the labs

Storage, transport and handling of chemicals

- store chemicals in the original package (clear labeling, safety and danger advice)
- when using other boxes attend to clear and durable labeling
- when decanting of chemicals use adequate device (funnels ,pipettes...)
- when chemicals toxic or corrosive use extractor hood

- no needless supply inventory of chemicals
- transport of chemicals (glass bottles) in racks or buckets - possible risk of breakage

Handling with liquid nitrogen

- wear safety glasses
- the filled liquid nitrogen tank must be transported in the elevator by oneself (risk of suffocation in emergency case!)

Some Special Rules S1 / S2 Labs

S1 and S2 are safety levels for genetic engineering labs and defined in the Gentechnikgesetz as:

S1 - no risk for human health and environment due to genetically modified organisms

S2 - minor risk for human health and environment due to genetically modified organisms

(the classification is resulted from Zentrale Kommission für biologische Sicherheit
http://www.bvl.bund.de/DE)
S1 labs are 131a/b (AFM), 309 (bong lab) and 310 (sample prep.) S2 labs are 116 (cell culture lab) and 311 (stretcher lab)

In principle

- apply the instructions on how to do genetical operations (S1/S2 level)
- follow the instructions of the hygiene plan

(both are published in every lab)

General

- wear protective clothing
- protective clothing must not be worn outside the labs
- workings of the following kind require nitril-protective gloves:
- passaging of transfected or virus-infected cell lines

- preparation with potentially infectious cells or tissue from animals and when dealing with human blood or tissue
- caustic, poisonous or mutagene material and material combinations
- mouth-pipetting is strictly prohibited
- syringes and canulaes should only be used if it cannot be avoided
- after every single working step or when leaving the S1/S2 lab, hands are to be washed and disinfected (see hygiene plan)
- disinfect work spaces after working with genetically modified organisms or pathogenic germs
- all equipment that had contact with genetically modified organisms has to be disinfected or has to be autoclaved
- lock the door when leaving the lab

Waste disposal

- collect contaminated material separately, non-fluid and liquid lab waste in different boxes
- waste that could contain genetically modified orgamisms or pathogenic germs must be autoclaved before disposing
- collect organic solvents and poisonous substances separately

In case of an accident

- if an accidental release of genetically modified organisms has happend, please inform all employees and superior authorities immediately (Prof. Käs, Undine)
- spilled biological material must be adsorbed at once and disinfected according to the rules of the hygiene plan
- if an extensive contamination of equipment or working spaces cannot be avoided, please turn off the device, ensure that nobody gets close to the site of accident and decontaminate the space carefully
- contaminated protective clothing must be taken off and be put into the autoclave
- contaminated skin must be medicated with a special disinfectant
- injuries should bleed properly (give off dangerous substances)
- after contamination of the mucous membranes - clean with water (eye shower room 310, 178)
- every injury / accident has to be register

Disinfectants

- equipment: Descosept, 80% ethyl alcohol
- tables: Descosept, 80% ethyl alcohol
- hands: Sterilum

Bibliography

[1] A. Einstein. *Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen.* Annalen der Physik, 17:549–560, 1905.

[2] M. von Smoluchowski. *Zur kinetischen Theorie der Brownschen Molekularbewegung und der Suspensionen.* Annalen der Physik, 21:756–780, 1906.