**Brownian Motion**

**Objectives**. The objectives of this laboratory are

* to conduct a numerical simulation of a 2D and 3D Brownian Motion.
* to conduct a quantitative observation of a 2D Brownian Motion.
* to calculate Boltzmann constant and Avogadro number based on the statistical analysis of an observed Brownian Motion.

**Theory**. Brownian motion is named after the botanist Robert Brown and describes the apparent random movement of small particles suspended in a fluid which Brown observed in 1827 while looking through a microscope at pollen of the plant Clarkia pulchella immersed in water. The movement of the small particles was due to molecules of water hitting them. Because the molecules were not visible, it seemed that the larger visible particles were moving on their own. In 1905, almost eighty years later, theoretical physicist Albert Einstein published a paper where he modeled the motion of the pollen as being moved by individual water molecules, making one of his first major scientific contributions. This explanation of Brownian motion served as convincing evidence that atoms and molecules exist and was further verified experimentally by Jean Perrin in 1908. Perrin was awarded the Nobel Prize in Physics in 1926 "for his work on the discontinuous structure of matter". The direction of the force of atomic bombardment is constantly changing, and at different times the particle is hit more on one side than another, leading to the seemingly random nature of the motion.

The important implication of Einstein’s theory for subsequent experimental research was that he identified the diffusion constant D in terms of certain measurable properties of the particle (its radius) and of the medium (its viscosity and temperature), which allowed one to make predictions and hence to confirm or reject the hypothesized existence of the unseen molecules that were assumed to be the cause of the irregular Brownian motion.

Where is the diffusion constant, is the average of the square of the displacement of the particle in the x direction during the time is the dynamic viscosity of distilled water at temperature T (in Kelvins), r is the radius of the particle, and is the particle’s mobility in the fluid. Stokes showed that

Here the first equality follows from the first part of Einstein's theory, the third equality follows from the definition of Boltzmann's constant as kB = R / NA, and the fourth equality follows from Stokes's formula for the mobility. By measuring the mean squared displacement over a time interval along with the universal gas constant R, the temperature T, the viscosity η, and the particle radius r, the Avogadro constant NA can be determined.

**Apparatus and experimental procedures**.

* Equipment.
  1. Polystyrene microspheres, 1μm.
  2. Distilled water.
  3. Microscope with a Motic X camera.
  4. Pipette.
  5. Small beaker.
* Experimental setup. A figure for the experimental setup will be provided by the student.
* Capabilities. Capabilities of the equipment items listed above will be provided by the student.
* Procedures. Detailed instructions are provided below.

**Requirements**.

* In the laboratory.
  1. Your instructor will introduce you to the equipment and software to be used in the experiment.
  2. Record the motion of the microshperes by using Motic X camera.
  3. Track the motion of a microsphere (you can track more than one) by using the Tracker program. Export the tracks as a text file.
  4. Read the track data (your instructor will assist you in obtaining data files for your calculations).
  5. Your instructor will discuss methods to be used to prepare your data for plotting and analysis.
* After the laboratory. The notebook with the completed items listed below will be turned in through D2L by the beginning of the next laboratory period. A complete laboratory report is not required for this experiment.

**Apparatus and experimental procedures**.

1. Provide a figure of the experimental apparatus.
2. Provide descriptions of the capabilities of equipment used in the experiment.

**Data**. Use Annex A for aalyzing data taken in the laboratory. The notebook will include:

1. Histograms of the displacements of a particle in x- and y- directions.
2. Calculations of the mean, median, and standard deviation for the displacement in the x- and y- directions.
3. Calculations of the diffusion coefficient, Boltzmann's constant and Avogadro number.
4. Calculation of the percent discrepancy for the Avogadro number.
5. Plot of the particle's trajectory.

**Results and Conclusions**.

* **Results**.
  1. A statement providing the measured value of the Boltzmann's constant.
  2. A statement providing the measured value of the Avogadro number.
  3. A statement providing the percent discrepancy of the Boltzmann's constant and the Avogadro number.
* **Conclusions**.
  1. Assess the accuracy of your experiment.
  2. List the sources of error in the experiment.