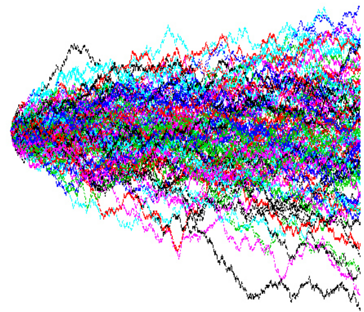
11B Lab 9: Brownian Motion and Random Walks

Introduction:



In this lab, you'll explore Brownian motion. You'll observe a micron-sized sphere under a microscope and watch as it undergoes a random walk in two dimensions. You'll then quantitatively analyze its motion and measure its diffusion constant. Using known properties of the sphere, you can then experimentally determine Boltzmann's constant and Avogadro's number, just as Einstein and Perrin did in the early 20th century (which led to Perrin's 1926 Nobel Prize in Physics). Finally, you'll get a chance to observe motion that is *not* Brownian, but rather due to self-propelled micro-organisms.

Objectives:

1.) Learn about statistical physics in a system, specifically the two-dimensional random walk
2.) Collect class data for many random walks to look for trends
3.) Understand how the motion of self-propelled organisms differs from Brownian motion

Warm-up:

First: Prepare a well slide with a 1 micron sphere solution. This is a 400:1 diluted solution containing 1-micron polystyrene spheres used for calibrating microscopes. It will be these spheres that take a random walk. Overfill the slide well with the pipette and then lower one edge of the coverslip down and then slowly lower it down. Do not trap any air bubbles. Blot out the excess water and let the slide rest.

Second: We will simulate a random walk. 10 students will line up on the centerline with a coin in hand. We will flip a coin every 5 seconds. Take a step to the right if you get a head, and a step to the left if you get a tails.

Third: Let's use a MATLAB simulator to allow us to do many trials very quickly.

After watching the MATLAB simulation answer these following questions.

1.) What is the relationship between the standard deviation and the number of coin flips
2.) If you flipped this coin until the end of time what would you expect the mean displacement to be?

Procedure

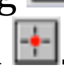
1.) Open up Logger Pro on the computer
2.) Insert a video capture for the firewire camera of 400x300 resolution. Don't worry about the sound.
3.) Place your well-rested slide into the microscope and focus on the micron spheres. Be careful not to push the objective into the slide since it will break and set you back.
4.) Set the options to video capture only and take a time-lapse film with a frame every 5 seconds. Set the duration of the film to 10 minutes.
5.) Start the capture.

In the meantime play with this random walk applet. Discuss with your group the difference between the red line and the blue line on the graph.

Note: You may need to "Reset Safari" and "Empty Cache" in the "Preferences" to get the graphs to work.

Diffusion Model

6.) IMPORTANT!! Now we want to give the video the same scaling as our objects. The spheres are 1 um large. We have provided a 50 um scale. “Insert” – “Picture Only” – Select the calibration slide. Place the slide over the video and resize it so they match. Then select the movie and click  to set the scale. Use the cursor to drag out a 50 um line in the video matching the calibration slide. Set the scale to 50 um. Now the data collected should have the correct scaling and units.

7.) After you have 120 frames of video it is time to track a few particles. Open up the tracking  window in logger pro. Select the tracking icon . Find a particle that stays in the video for a long time and track it by clicking on its center. To toggle the tracers off (making it easier to track) click . Track an object for at least 60 data points. To track a second object click .

8.) IMPORTANT!! Export Data as a CSV. You will need this for homework. Make sure the data has been scaled first (see #6). Also, you can remove any velocity data in the “data”-“data browser” since it is not needed.

9.) For each group, save at least four good runs of 60 or more contiguous points

10.) Create graphs in Logger Pro with “Insert”-“graph”. Click on the axis to change its meaning. Make a x-position vs. y-position graph.

11.) Create x vs time, and delta x vs time graphs. Calculate the delta x data with “data”-“new calculated column”-“function-delta”-“variable x”. This creates a calculated columns of the changes in x.

12.) Create a histograms of the delta x motions. Select the best bin widths and curve fit using the 11B Gaussian model.

Data Analysis

1.) Calculate the diffusion constant from your data, using the relation: $\sigma^2=2Dt$. (The origin of this equation will be made clear in the next lectures of 11b)
2.) Find the corresponding value of the Boltzmann constant, k, using the relation (again, see lecture notes): $D=kT/6\pi\eta r$,
where T is the temperature in Kelvin, η the viscosity of water (10^{-3} in mks units), and r the radius of the sphere.
3.) Export your data to *.csv files. Each file should have three columns: t, X, and Y. For each group, save at least 4 good runs of 60 or more contiguous points.
4.) Upload your data where you can access it in the future for problem sets. Load your data onto a memory stick so that we can analyze the whole class's data together.

Lab Write-up: We expect to see

1.) An example of each graph produced.
2.) A value for the diffusion constant (show all work).
3.) A value for the Boltzmann constant (show all work).
4.) A conclusion statement based on the class results and final discussion.