BB 101 Tutorial – 1 (Batch-D1)

General comment: Assume viscosity of water and temperature of 300K whenever not specified.

Quiz question.
Please write the answer on an A4 sheet and submit it at the end of the tutorial class. Ensure your Roll number and name are on the A4 sheet. You may prepare the answer even before coming to the class.

1. Consider a thin narrow and long one-dimensional (1D) tube with water at temperature T. Imagine inserting a drop of protein at the centre of the tube (x=0), and the protein particles will diffuse. Make a rough sketch of the probability distribution (i.e., P(x) vs. x) of the protein particles for the following cases.

   (a) P(x) for T=10^0c and T=90^0c at time=10seconds. Both the curves should be plotted in the same graph so that the curves can be compared.

   (b) P(x) at time= 1 second and time = 10 seconds for T=25^0c. Both the curves should be plotted in the same graph so that the curves can be compared. **(1+1 Marks)**

Tutorial questions: Please answer the tutorial questions below in your notebook and not in the quiz A4 sheet. You do not have to submit them. It is only for your training purpose.

1. Consider a protein diffusing in a narrow one-dimensional channel. Let $C(x,t)$ be the concentration of the protein at location x at time t. Then the concentration will obey the equation:

$$\frac{\partial C(x,t)}{\partial t} \propto \frac{\partial^2 C(x,t)}{\partial x^2}$$

   The proportionality constant is the diffusion constant D. That is, $\frac{\partial C(x,t)}{\partial t} = D\frac{\partial^2 C(x,t)}{\partial x^2}$. What is the dimension of D? Compare with the dimension you get from Einstein's relation.

2. "Actin" is a globule-like protein having a radius approximately 3nm. Using Einstein relation, calculate the diffusion coefficient of actin (viscosity of water = 10^{-3}Pa s).

3. Solving the diffusion equation one can find out that the distance over which a molecule diffuses (in 3D), within a time t is

$$r_{rms} = \sqrt{\langle r^2 \rangle} = \sqrt{6Dt}.$$

   How far an actin molecule will diffuse within a minute? (Think about it in the context of the size of a cell)

4. Consider a vesicle of of radius 100nm. How long will it take for the vesicle to diffuse from the centre of a typical human cell to the end(radius=100μm)?

5. Some of the neuronal cells are very long : many centimetres to meter. How long would it take for the above vesicle to diffuse a distance of ten centimetre? Convert the answer into days and years. Can you depend on diffusion for transport in neuronal cells?

6. Diffusion is one way of transport. Another way of transport in cells is where some molecular machines carry the vesicle and travel from one end of the cell to the other end. Using energy from the food we eat (i. e., using ATP as the fuel), these molecular motors move with a velocity v. Such motion, using ATP, is called "active" motion (as opposed to diffusion which is a passive motion).

   Now, consider two cells, one has a diameter 1000 times the other. Let t_s^D and t_l^D be the times it takes for a vesicle to diffuse from the centre to the end in the smaller cell and larger cell, respectively. t_s^a and t_l^a be the times it takes for a vesicle to actively get transported from the centre to the end in the smaller cell and larger cell, respectively. Calculate t_l^D/t_s^D and compare with t_l^a/t_s^a. Think about how badly diffusion-time will scale with the size of the cell.

7. **Home work: You should attempt this later. TAs will not discuss in class. Try yourself.** An equation for fluid flow is the continuity equation, which says :
$$\frac{\partial C(x,t)}{\partial t} = -\frac{\partial J}{\partial x}$$
   where J is the current. That is number of particle crossing unit area in unit time. As we discussed in the class, there can be two kinds of currents (flows or flux). Diffusional current, or a current due to an external force. We also argued that the diffusional current
$$J_D = -D\frac{\partial C}{\partial x}$$
   and the current due to external force is
$$J_f = Cv.$$
   Substitute $J = J_D + J_f$ in the earlier differential equation. What is the resulting equation, if we assume v is a constant (independent of x)?