A Study of Diffusion: Liesegang Rings

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Goal: Determine the diffusion coefficient for ions in water and observe the formation of a spatial pattern caused by countercurrent diffusion.

Strategy: Use the appearance of Liesegang rings as an indicator for the distance traveled by diffusion.

Background Reading: Atkins: 846-856.

Last semester we studied homogeneous reactions, i.e., those occurring in well-stirred reactors. This semester we consider processes in which diffusion plays a crucial role.

Transport Properties: Diffusion

Because the molecules in a gas or solution are in constant motion, uneven distributions of matter tend to even out. This is called **diffusion**.

The amount of a property passing through a unit area/unit time is called a **flux**.

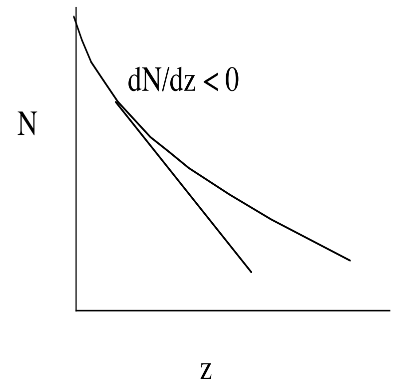
e.g. $\frac{\text{kg}}{\text{m}^2\text{s}}$

Fick's Law: The flux of matter is directly proportional to the gradient of matter.

What does this mean? Mathematically,

$J_z = -D\frac{dN}{dz}$ D is the *diffusion coefficient*, the proportionality constant and

$\frac{dN}{dz}$ is the *gradient* of matter, or how the amount of matter varies as a function of position.



For a simple gas, $D = \frac{l\bar{c}}{3}$ and has units of length^2/unit time. For simple molecules in aqueous solution, D is on the order of 10^{-5} cm^2/s.

The **Diffusion Equation** describes how the concentration at position x changes as a function of time.

$$\frac{\partial C_i(x,t)}{\partial t} = D_i \frac{\partial^2 C(x,t)}{\partial x^2}$$

The equation says that the rate of change of the concentration of the i^{th} chemical species at position x is affected by two factors. The first term describes the change from diffusion in which D_i (cm^2/s) is the diffusion coefficient that is multiplied times the rate of change of the gradient of the concentration at the position. (This second derivative with respect to position is called the one-dimensional Laplacian and is a measure of how sharply the concentration changes with position.)

Diffusion as a stochastic process

We can consider diffusion on the molecular level as a **random walk** of each molecule. Robert Brown observed that pollen grains in water continuously jiggled about. We know now that this so-called **Brownian motion** is the result of the collisions of the water molecules with the pollen grains. If you track a particle and see how long it takes to move a distance x from its initial position, you find that

$$x \propto \sqrt{Dt}$$

Purpose

Diffusion of molecules in solution is an extremely slow process. This experiment involves the observation of countercurrent diffusion (diffusion of one species into a solution of another species) of two ions that form a precipitate. The precipitation occurs in regular periodic patterns called **Liesegang Rings**.

You will use the video camera to capture an image and use the IMAGE software to determine the relationship between the spacing of the rings and the order of magnitude of the diffusion coefficient for an ionic compound in water.

PreLab Assignment

1) Write the net ionic equations for the reactions.

2) Estimate how long a potassium ion will take to diffuse 1 cm.

3) What is the purpose of the agar?

Procedure

In order for this experiment to work at all, this procedure must not be deviated from.

Heat two beakers filled with 50 mL of deionized water to 95 ˚C. After the water is 95 ˚C, add 1% agar to each beaker and stir for 15 minutes to be sure that each solution is homogeneous.

While the solutions are still at 95 ˚C, make one 0.17M in KI and the other 0.009M in $Pb(NO_3)_2$.

Pour the $Pb(NO_3)_2$ solution into the bottom half of a test tube. Stopper the tube and allow a gel to form. The gel is ready when you can turn the tube on its side and little to no liquid motion occurs.

After the gel has hardened, fill the tube with the KI solution. Stopper the tube. Place the tube in a test tube rack. Setup the video camera so that the entire tube is in the field of view. Set the IMAGE program to capture a frame every 30 minutes over 24 hours.

Data Analysis

Use the Plot Profile tool in IMAGE to plot a gray scale profile. Use the Export function to save the Plot Values. To get x values, determine how much real distance the plot corresponds to and use Kaleidagraph to plot the gray scale versus distance. Use this information to plot the distance versus the ring number. Using Kaleidagraph, determine most likely functional relationship between the ring number and the distance.

By observing the time at which ring appears and its position, prepare a plot of position of the diffusion front vs. time. Is it a straight line? Plot it versus $t^{1/2}$. The slope of the line is approximately the diffusion coefficient.

In your report discuss the mechanism of diffusion. Why doesn't the gel affect the diffusion coefficient? Why is it used?

Compare your result to the typical value for an ionic compound in water.