Diffusion

Fick's first law

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The most intuitive fact that rules diffusive processes is that freely moving matter tends to go from higher to lower concentration. In reality, moving particles in the absence of any external force wander in space in any direction. Moving back and forth, left to right, up and down, they go everywhere. If there was any sort of gradient or accumulation of these particles in any region, this random dance will result in the homogenization of the concentration of particles throughout all accessible space. This simple vision is the core of Fick's first law.

Adolf Fick's first law established that the rate of transfer of matter in space is proportional to local differences in the concentration of particles, or, as it is commonly known, concentration gradients. This means that in order to have a net movement, a gradient of particles must exist. However, the First law is referring to a population of particles rather than to each of them individually. In other words, every single diffusing particle will move around within the space which contains it, independently of how many other particles of its species are there.

This requires us to understand more intimately Fick's first law, which mathematically is

$$F = -D\frac{\partial C}{\partial x}$$

where F is the flux of a particle through a single unit of area. D is the diffusion coefficient and C is the concentration of particles. Let me explain this in more detail. Suppose we are looking at a pipe. Then, let's divide the pipe into identical parts. Each part has a certain length, let's say *dx*. Now, the amount of matter crossing from one section of the pipe to the other is proportional to the difference in concentration between them. In terms of the individual particles, the probability of a particle's crossing will be independent of which section it is contained in. Let's assume that the concentration of particles in the left part of the pipe is higher than in the right part of the pipe. Following this idea, the chance of getting a particle to cross from left to right will be greater than the chance of having a particle come from the right section of the pipe and enter the left one. This idea is represented in the expression with the term

$$-D\frac{\partial C}{\partial x}$$

If the reason for the negative sign is not clear yet, I will extend this explanation a little further. Mathematica $\frac{\partial C}{\partial x}$ lly,represents the change in concentration (∂C) with respect to distance (∂x). Suppose we are located in one place that we will call our starting point or $\boldsymbol{x0}$, which happens to be in a rain forest close to a tropical beach. Let's say that the amount of mosquitoes in this place is very high. Then we walk toward the beach. We notice that the amount of mosquitoes remains unchanged. This means that at this point, $x0+dx$, the change in concentration is 0, in other words,

$$\frac{\partial C}{\partial x}=0$$

Notice that the gradient of mosquitoes ($\frac{\partial C}{\partial x}$) is zero even if the concentration ($\boldsymbol{C}$) of them is high, over the distance ($\boldsymbol{x}$). Soon, we are very close to the beach and happily, we see how the amount of mosquitoes decreases noticeably because of the breeze. Now, there is a gradient of mosquitoes which decreases as we walk toward the beach. In math, $\frac{\partial C}{\partial x}<0$, because C gets lower as x , with respect to the origin ($x0$), increases. In other words, $\frac{\partial C}{\partial x}$ is negative.

But, this is not the end of the story. After enjoying a great afternoon at the beach, we notice that the breeze, which was keeping the mosquitoes in the forest, fails to blow any longer. Later, the red sky of the sunset attracts mosquitoes to the beach. At that time, we observe a positive net flux ($F>0$) from the forest to the beach. In other words, the mosquitoes start "diffusing" from the forest to the beach ($F>0$) downhill along the gradient of concentration ($\frac{\partial C}{\partial x}$ <0).

During diffusion, the mosquitoes found a lot of obstacles along their way to the beach (trees, leaves, spider webs, etc). The higher the number of obstacles, the smaller the flux would be. In fact, if we could wrap the whole forest with a huge screen, mosquitoes would never get to the beach. Therefore, the flux is also determined by how mobile the particles are inside the space (medium) that contains them. The mobility of the particles, represented by D in the equation above, depends on the nature of the interaction between each particle and the components of the medium.

If you have any question about Fick's first law, don't hesitate to contact us. Send a message to consult@mesoscopia.net.