

BIOL/PHYS 438

Zoological Physics

- **Logistics** & **CAP Exam** announcement
- Introducing Ch. 4: "Fluids in the Body"
 - Diffusion
 - Chemical Potential
 - Single-Cell Size Limit
 - Hæmoglobin

More Logistics

- **People Database**
 - Please [log in](#), *Update your Profile* (especially your Email address!) and participate.
 - Few received my Email notice about the fabulous Harvard video on cellular nanoprocesses. :-)
- **Projects**
 - **Draft proposals due today!**
 - How about a *Web Database of Project Ideas?* (like the [Quips](#) database - anyone can contribute)

Logistics

Assignment 1: login, update, Email anytime!

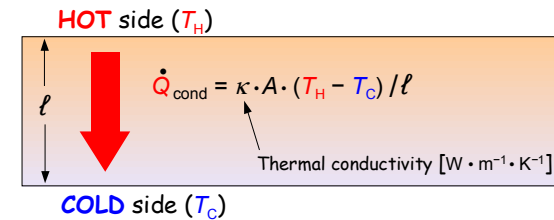
Assignment 2: due Tuesday

Assignment 3: Tuesday → Thursday 15 Feb

Assignment 4: Thu 15 Feb → Tue after Break

Spring Break: 17-25 Feb: work on Project too!

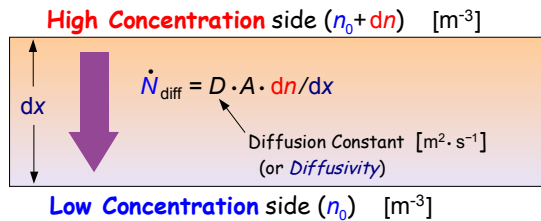
Conduction of Heat



For an infinitesimal region in a thermal gradient,

$$\mathbf{J}_U = \kappa \vec{\nabla} T$$

Diffusion



For an infinitesimal region in a concentration gradient,

$$\mathbf{J}_N = D \vec{\nabla} n \quad (\text{Fick's First Law})$$

Using the Chemical Potential

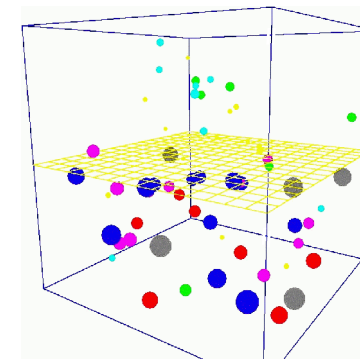
$\mu = -\tau d\sigma/dN$ is used like a **potential energy** [J] in that **particles tend to move "downhill"** from **high μ** to **low μ** . For ideal gases (and even for concentrations of solutes in water!) we have $\mu_G = \tau \log(n/n_Q)$ where n_Q is a constant. In thermal equilibrium, we require $\mu_{tot} = \mu_G + \mu_{ext} = \text{constant}$, where μ_{ext} is some "external" potential energy per molecule, like mgh or the binding energy of an O_2 molecule to haemoglobin.

Example: 100% humidity at roots vs. 90% at leaves will raise H_2O molecules **1.5 km!** (but only as vapor)

Chemical Potential

A little more **Statistical Mechanics**: we have defined **temperature τ** by $1/\tau = d\sigma/dU$ where U is the internal **energy** of "the system" and σ is its **entropy**. By similar logic we can define the system's **chemical potential μ** by $\mu/\tau = -d\sigma/dN$ where N is the **number of particles** of a given type that it contains. (There is a different μ for each type of particle.) Like τ , the chemical potential μ has units of **energy** [J]. **Entropy increases** when **particles move from** a region of **high μ** into a region of **low μ** ... so they do!

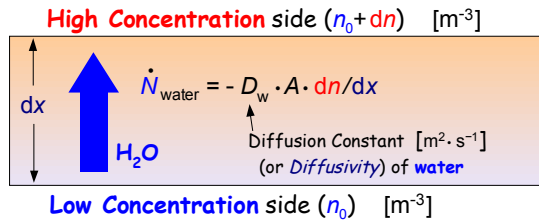
Osmosis



(image from Wikipedia)

Little molecules (like H_2O) can get through the "screen" but big solute molecules can't. If the solute "likes" to be dissolved in water, it will create a **chemical potential** to draw H_2O molecules through the membrane, creating an effective "**osmotic pressure**".

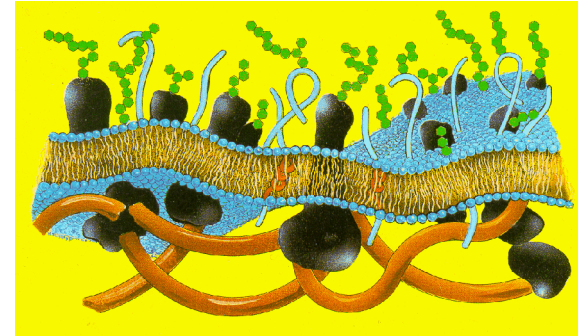
Osmotic Diffusion



For an infinitesimal region in a concentration gradient,

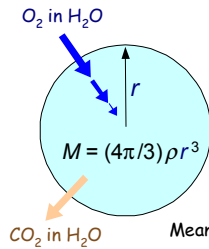
$$\mathbf{J}_{\text{water}} = -D_w \nabla n_{\text{solute}} \quad (\text{Fick's First Law})$$

Cell Wall



Courtesy of Myer Bloom & CIAR Program on Soft Surfaces

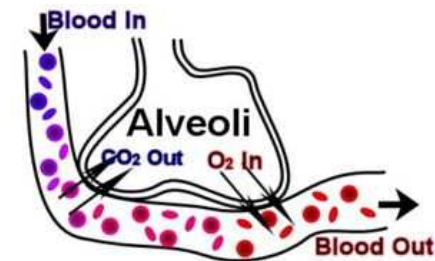
Model of a Single Cell



$\dot{N}_{\text{diff}} = D \cdot A \cdot dn/dr$ where $A = 4\pi r^2$
and $D \approx 1.8 \times 10^{-9} \text{m}^2 \cdot \text{s}^{-1}$ = Diffusivity of O_2 in H_2O .
If $n_w \approx 0.03 n_{\text{air}} \approx 1.62 \times 10^{23} \text{m}^{-3}$ = Concentration of O_2 in H_2O and we assume that n decreases steadily to zero at $r = 0$, then $dn/dr = n_w/r$, giving $\dot{N}_{\text{diff}} = 3.66 \times 10^{15} r$, so the specific supply $s = \dot{N}_{\text{diff}}/M = 0.88 \times 10^{12} r^{-2}$, in SI units.

Meanwhile, the specific demand of $d = \dot{N}_{\text{req}}/M$ comes to $d = 2.21 \times 10^{18} b I_0/M = 0.88 \times 10^{17} M^{-1/4} b_s$. Since M increases as r^3 , d decreases as $r^{-3/4}$. The supply decreases faster than the demand, so eventually if a cell gets too big, it cannot get enough oxygen via diffusion alone.

Lungs & Alveoli



Hæmoglobin

$\mu = -\tau d\sigma/dN$ is like a **potential energy** [J]: **oxygen molecules tend to move "downhill"** from **high μ** to **low μ** . For concentrations of solutes in water we have $\mu_{IG} = \tau \log(n/n_Q)$ where n_Q is a constant. In thermal equilibrium, we require $\mu_{tot} = \mu_{IG} + \mu_{ext} = \text{constant}$, where μ_{ext} is the binding energy of an O_2 molecule to **hæmoglobin (Hb)**. The stronger the binding, the more "downhill"! The density n is proportional to the *partial pressure* p . Oxygen occupies all Hb sites for $p > 10$ kPa (~ 0.1 atm) and is released when $p < 2$ kPa (~ 0.02 atm). *What happens when CO competes with O_2 for Hb?*