PHYS 107 - Week 12 - Wednesday

* Laminar flow versus turbulence

Video Laminar Flow

laminar flow: no mixing, streamlined

↓

turbulent flow: eddies, swirls, caused by - swift flow
- obstacles, corners

Where is the transition? How do we know when flow will be turbulent or laminar?

Define Reynolds number $N_R = \frac{2 \rho v r}{\eta}$ (for tube of radius r)
(units: none)

If $N_R > 3000$: turbulent
If $N_R < 2000$: laminar
} in between: ill-determined, unstable

Flow will be more turbulent when:
- density higher
- velocity higher
- characteristic length scale larger
- viscosity smaller

Scaling up or down: if N_R is the same for a scaled up or scaled down version of geometry, system, then the flow will behave similarly

Example: At what speed will blood flow turn turbulent in an artery that has $r = 2\ mm$?
$\rho = 1030\ kg/m^3$, $\eta = 2.08 \times 10^{-3}\ Pa \cdot s$

$N_R = 3000$ if $v = \dfrac{N_R \eta}{2 \rho r} = 3.0\ m/s$

Note that the calculated blood flow is $1.9\ m/s$ in pulmonary artery. Obstruction of half diameter → turbulence!

* Generally $N_R = \dfrac{\rho v L}{\eta}$ where L = characteristic length
$L = 2r$ for tube or sphere

Example: Tacoma Narrows bridge:
When, at what wind speed, will a cable of a suspension bridge cause turbulence?

$$v = \frac{\eta N_R}{\rho L} = \frac{(10^{-3}\ Pa \cdot s)(3000)}{(1.29\ kg/m^3)(21\ inch)} = 4\ m/s$$
$\parallel$
9 mph

Phenomenon called "vortex shedding" causes the bridge to vibrate "in resonance" (see later).

Video Tacoma Narrows

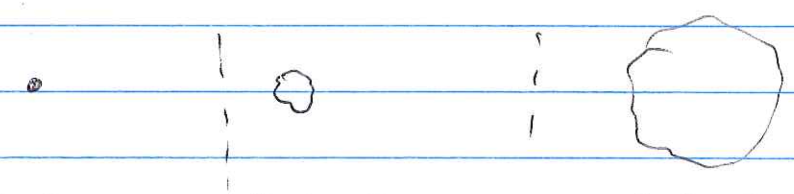
* Diffusion, random walk, Brownian motion

Brownian motion of nano-particles in water
→ water molecules collide with nano-particles → move the nano-particles around   Video Brownian Motion

Position x is a random variable that changes randomly over time, but $\langle x \rangle = \bar{x}$ = average position remains zero.

Root-mean-square $\sqrt{\langle x^2 \rangle} = x_{RMS}$ is not zero but describes how widely the particles disperse from their original position

*Diffusion of ink on paper



$\langle x \rangle = 0$	$\langle x \rangle = 0$	$\langle x \rangle = 0$
$\sqrt{\langle x^2 \rangle}$ = small	$\sqrt{\langle x^2 \rangle}$ = larger	$\sqrt{\langle x^2 \rangle}$ = largest

Diffusion law: $x_{RMS} = \sqrt{2Dt}$ with D = diffusion constant in units $\frac{m^2}{s}$

D depends on the molecule and the medium it is in

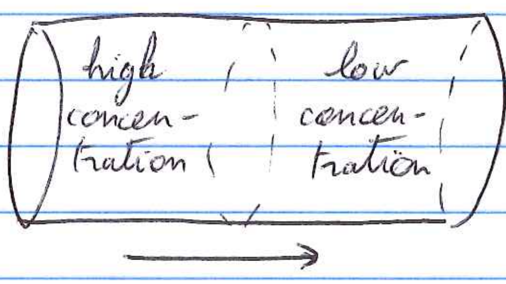
D for	O_2 in H_2O	$1.0 \times 10^{-9} \frac{m^2}{s}$
	$C_6H_{12}O_6$ in H_2O (glucose)	$0.7 \times 10^{-9} \frac{m^2}{s}$
	hemoglobin in H_2O	$0.07 \times 10^{-9} \frac{m^2}{s}$
	DNA in H_2O	$0.0013 \times 10^{-9} \frac{m^2}{s}$

larger molecules $\left\{ \begin{matrix} \text{diffuse} \\ \text{move} \end{matrix} \right.$ more slowly

How far will O_2 diffuse in H_2O during 1 second breathing cycle?

$$x_{RMS} = \sqrt{2Dt} = \sqrt{2\left(1.0 \times 10^{-9} \frac{m^2}{s}\right)(1s)}$$
$$= 45 \ \mu m$$

* Direction of diffusion is <u>isotropic</u>, in all directions



net diffusion direction

but different concentrations will cause diffusion from high to low, because "there is more to diffuse" on the high side.

* Diffusion defines the size of cells and their time scale

Amoeba: how long does it take for O_2 to diffuse?
500 μm

$$x_{RMS} = \sqrt{2Dt} \rightarrow t = \frac{x_{RMS}^2}{2D} \approx 100\,s$$

Red blood cell: $t = \dfrac{x_{RMS}^2}{2D_{hemoglobin}} \approx \underline{0.5\,s} \rightarrow$ breathing rate
8 μm

Chromosome: $t = \dfrac{x_{RMS}^2}{2D_{DNA}} \approx 20\,s$
7 μm

How long would it take for DNA to diffuse through an amoeba? $t = 27$ hours

Diffusion determines the <u>short</u> distance travel in cells

For <u>longer</u> distances, cells need active mechanism: flagella, molecular motors, ATP

* Osmosis : diffusion will happen until the concentrations are equal

If membrane does not allow one type of molecules through
→ pressure builds up