Biological Physics

FYS4715 2021

Some questions

Write, 5 min, read aloud the parts you want, send as email to me, helpful for me

- Why did you choose to follow FYS4715?
- What do you expect to get out of the course?
- What have you learnt previously that is relevant for the course?
- What education background do you have?

Themes this year

- General: Processes on cellular and molecular scale
  - 1nm – 100 um
  - from atomic to macroscopic: stat mech
  - small scale: atomic forces, velocities, charges
  - large scale: surface tension, stress-strain, diffusion, osmosis, electrochemistry
- Nelson ch 1-7, 11.1-2, 12.1-2 + chosen topics
- Projects:
  - Passive and active walkers
  - Nerve impulses
  - Mechanobiology
  - Morphogenesis

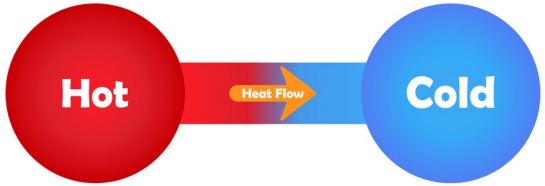
Hands on training

- Theory: Boook + research papers
- Experiments + Image analysis
- Numerical simulations

Course web pages (Vortex)

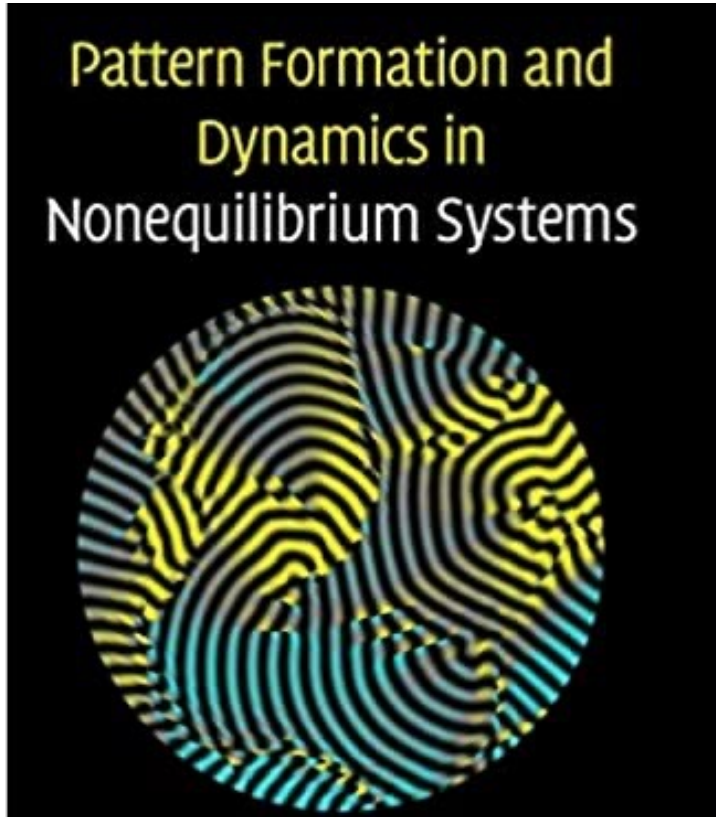
Law and order

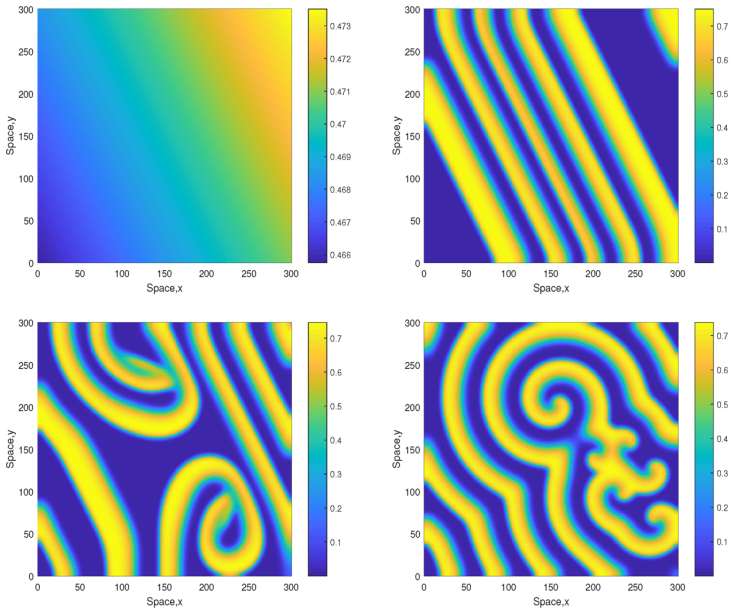
- Second law of thermodynamics?



- Non-equilibrium
  - -> equilibrium
  - -> heat death of universe
  - -> pattern formation

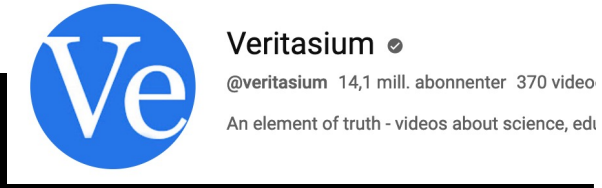
- Life is the ultimate order
  - non-equilibrium “systems”





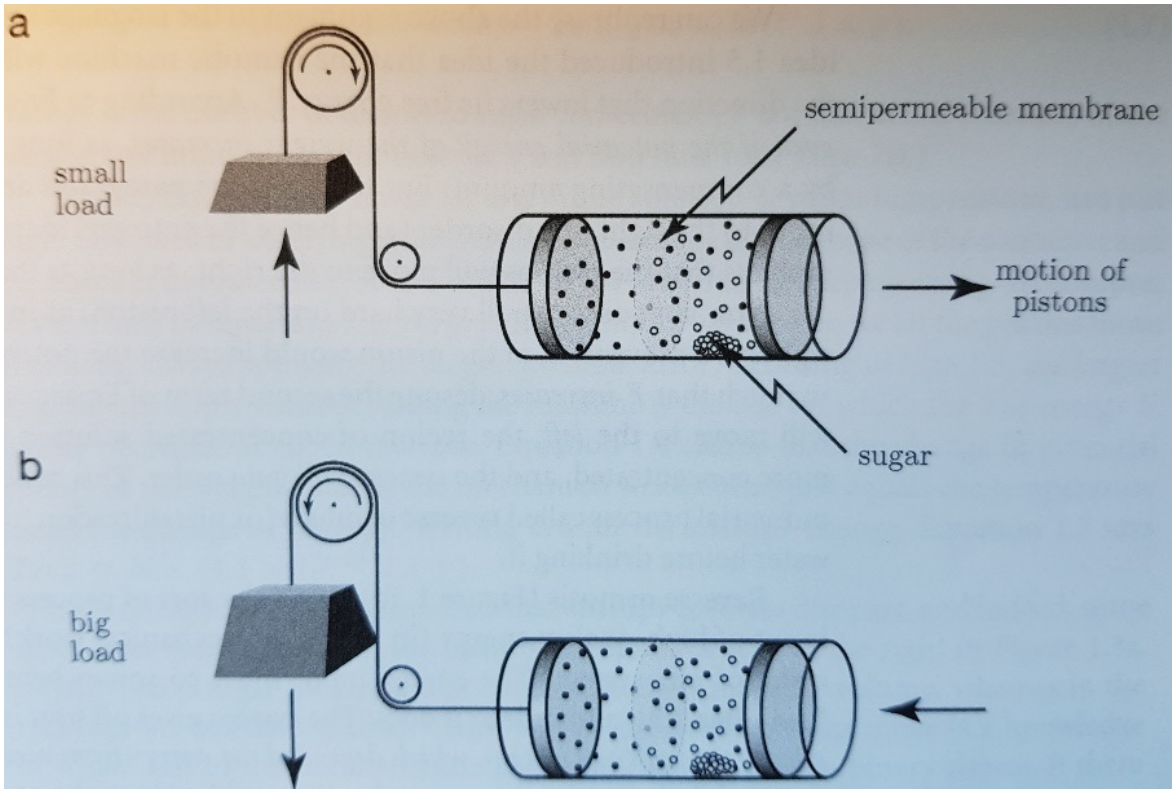
Life captures order, ultimately from the Sun. This order then trickles through the biosphere through an intricate set of transformation processes, which we will refer to generically as free energy transductions. Looking only at the biosphere, it seems as though life has created order.

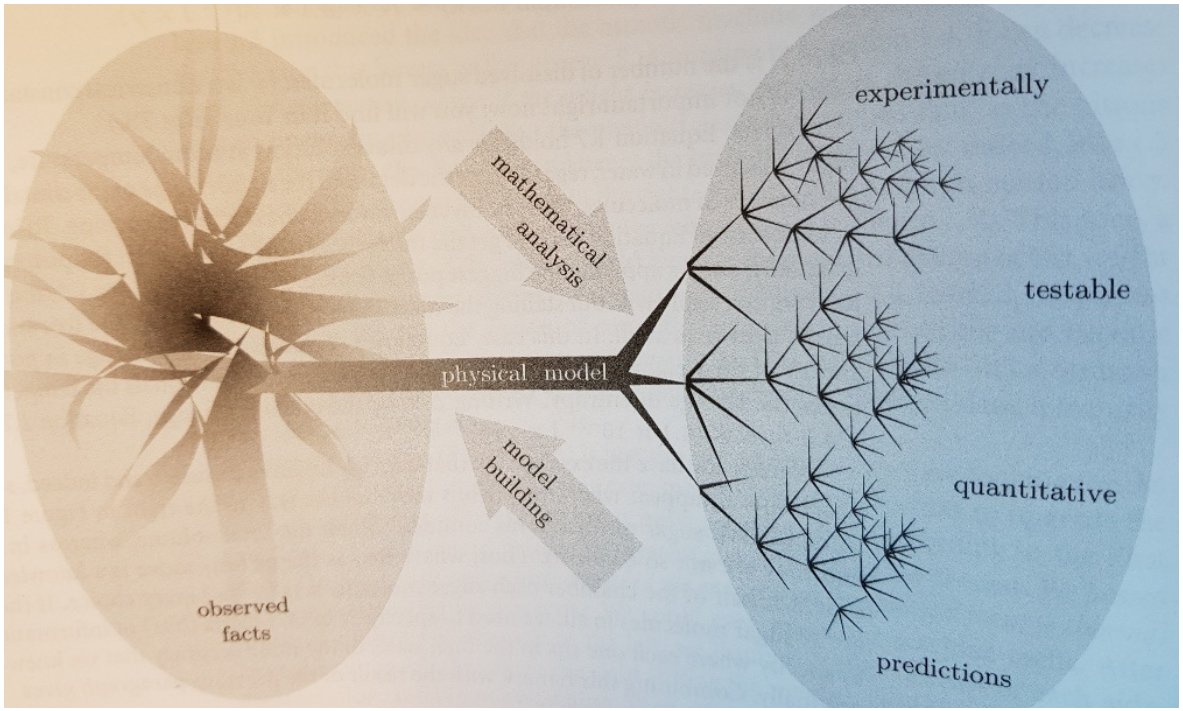




Chapter 1

- What is heat?
- Entropy
- 2nd law vs. order
- Free energy
- Osmosis, reverse osmosis (-> order)
- Physical models
  - For biologists: https://www.nature.com/articles/d41586-019-03960-z

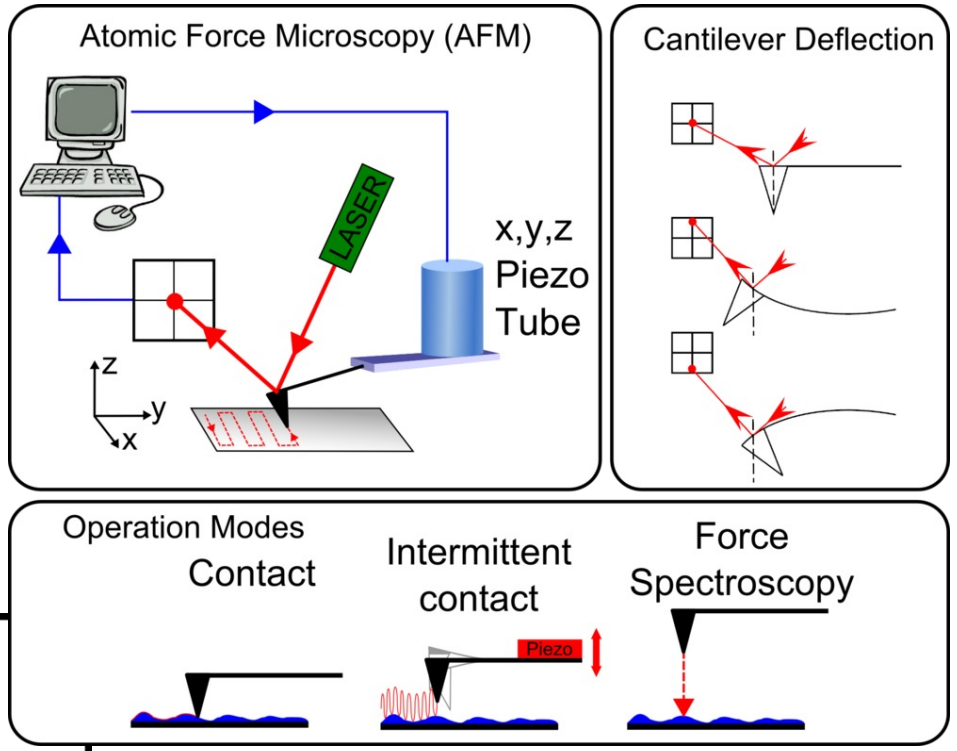


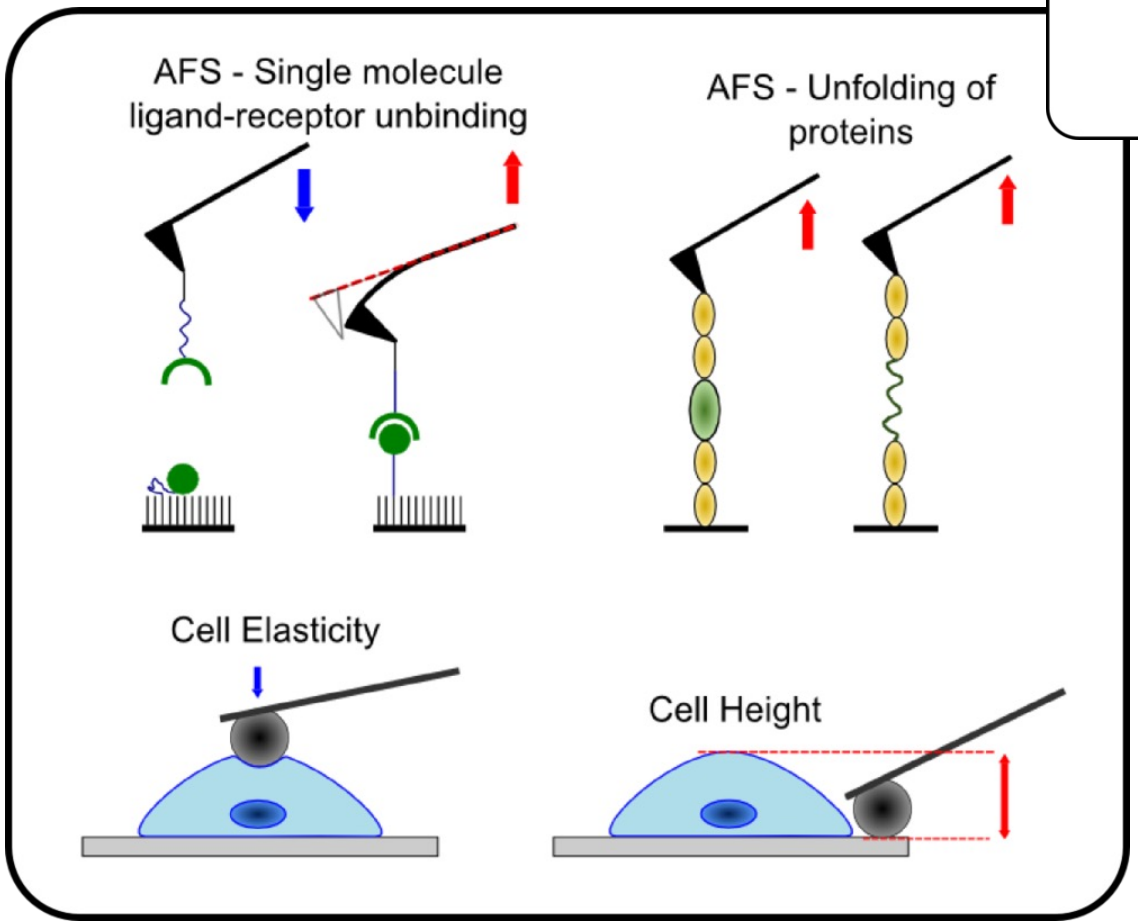


Biological Physics

- In physics we make mathematical models and calculate stuff
- What is the volume of one molecule of water?
- Most famous model: ideal gas
  - equation of state: $PV = Nk_BT$
  - What is PV?
  - How much is k_BT at room T? Express in terms of force * distance

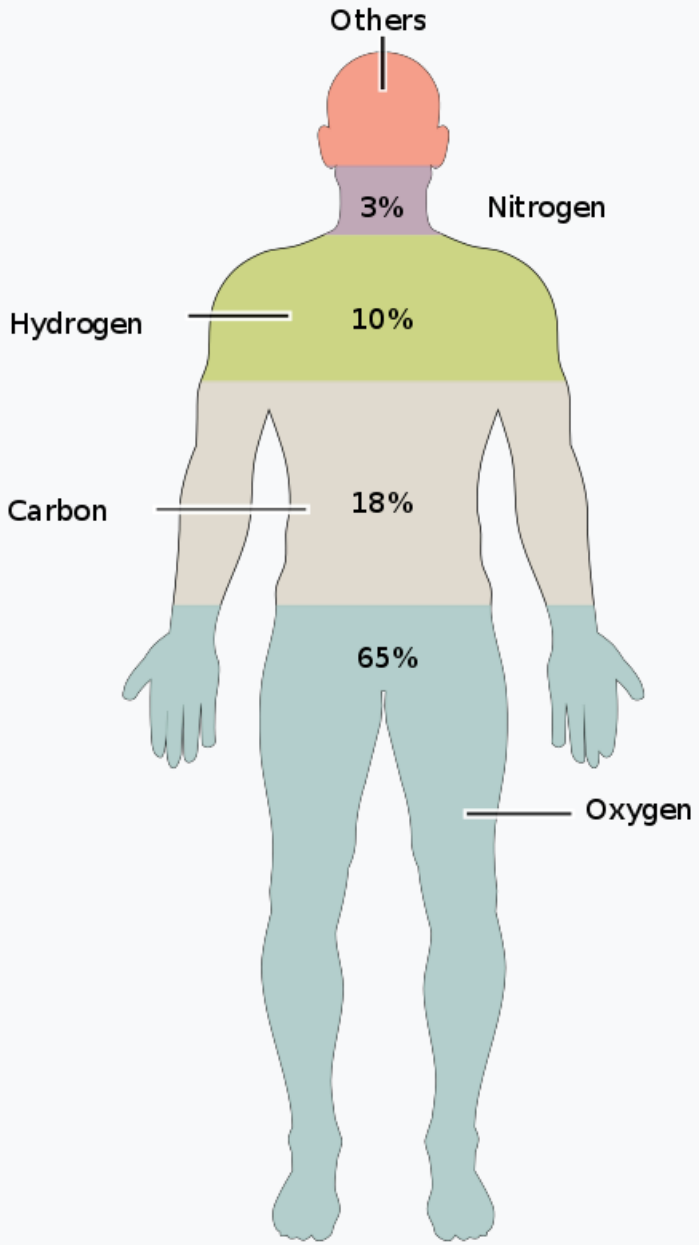
pN forces
nm distances





Chapter 2: What's inside cells

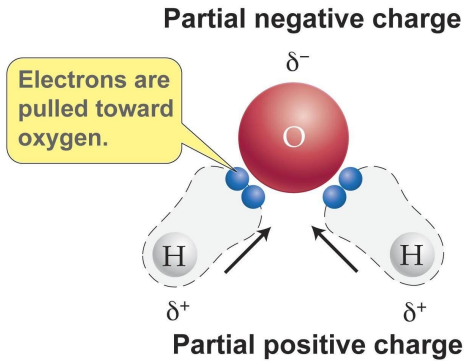
- Biological question: How do organisms organize all the chemical processes?
- Physical ideas
  - Compartmentalization
  - Active transport
  - Specific processes
  - Non-linearity -> switching in networks

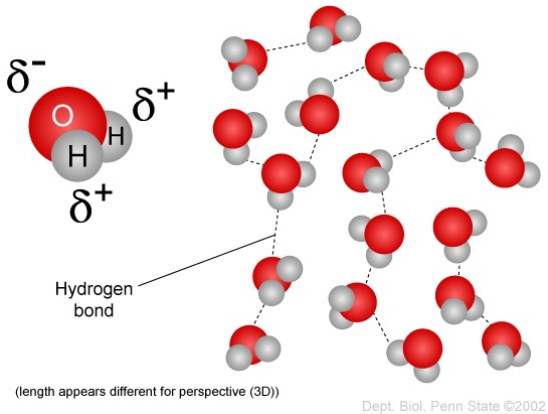


Element	Symbol	% in body
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.2
Calcium	Ca	1.5
Phosphorus	P	1.0
Potassium	K	0.4
Sulfur	S	0.3
Sodium	Na	0.2
Chlorine	Cl	0.2
Magnesium	Mg	0.2
Others		< 1.0

The main elements that compose the human body are shown from most abundant (by mass, not by fraction of atoms) to least abundant.

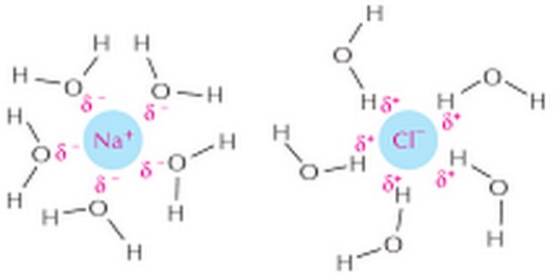
Polar – hydrophilic – water soluble



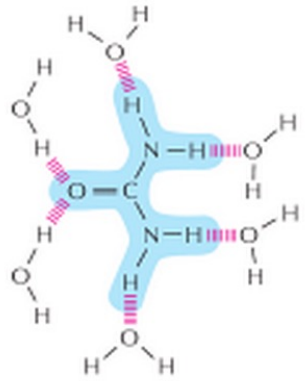


HYDROPHILIC MOLECULES

Substances that dissolve readily in water are termed **hydrophilic**. They include ions and polar molecules that attract water molecules through electrical charge effects. Water molecules surround each ion or polar molecule and carry it into solution.

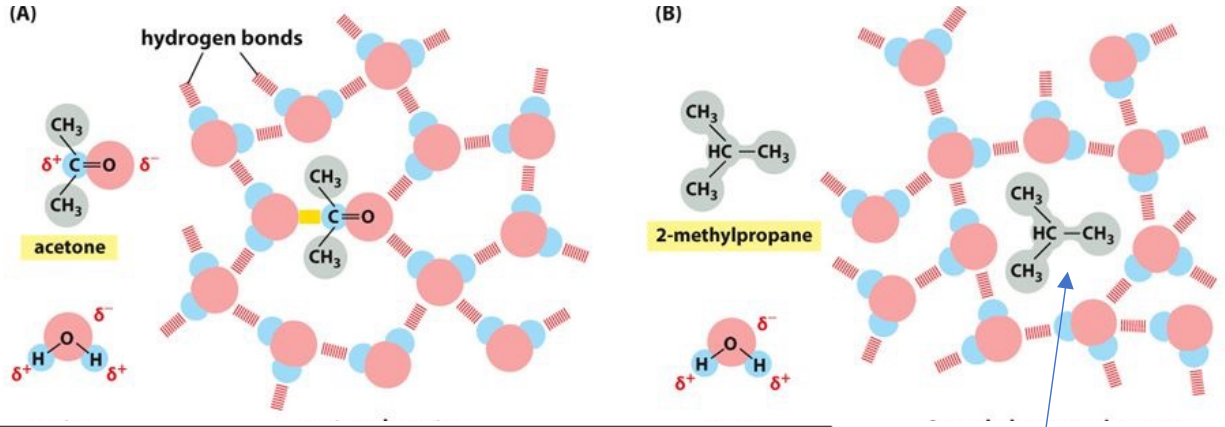


Ionic substances such as sodium chloride dissolve because water molecules are attracted to the positive (Na^+) or negative (Cl^-) charge of each ion.

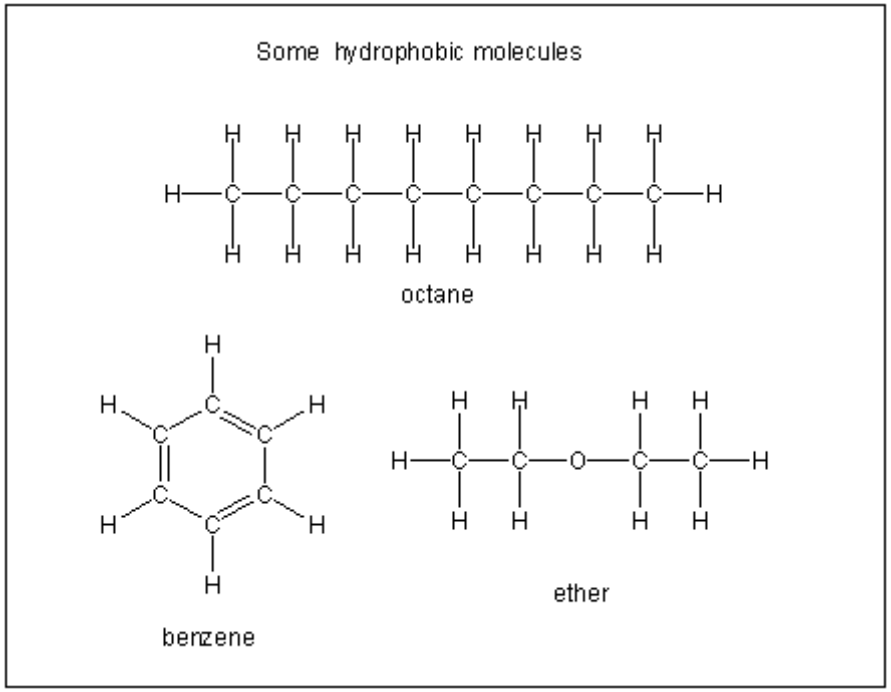


Polar substances such as urea dissolve because their molecules form hydrogen bonds with the surrounding water molecules.

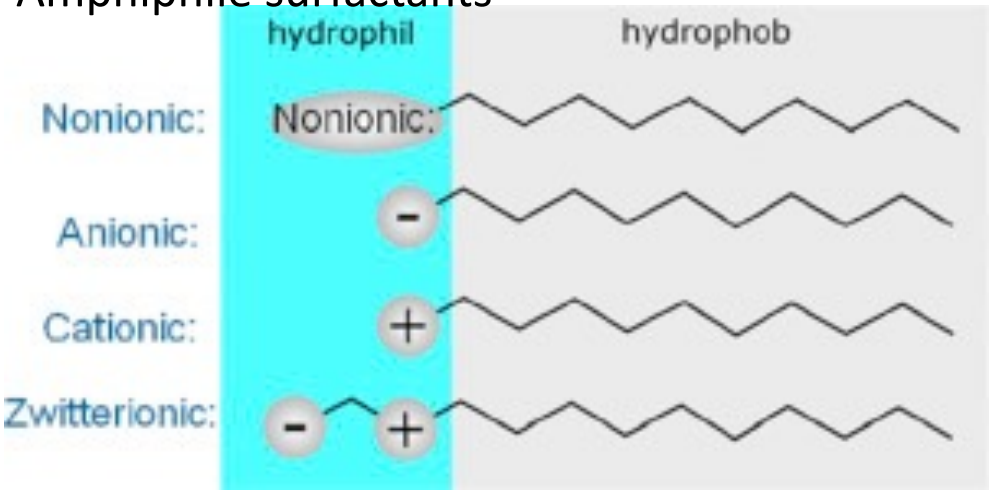
Hydrophobe & amphiphile



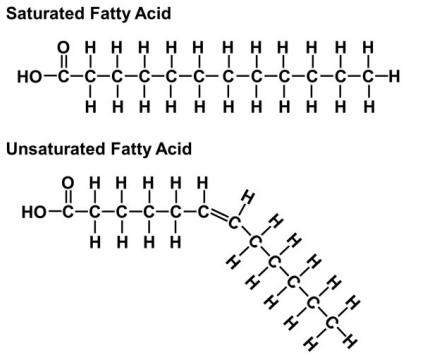
higher energy cost



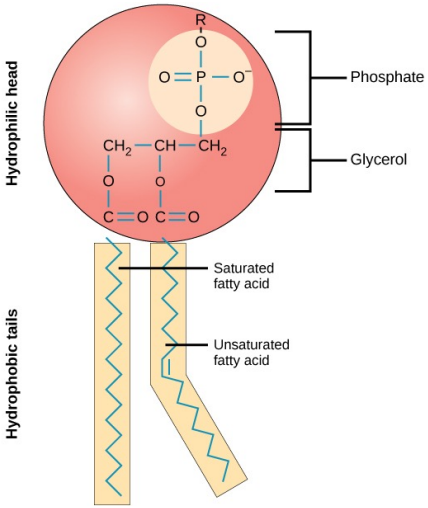
Amphiphile surfactants

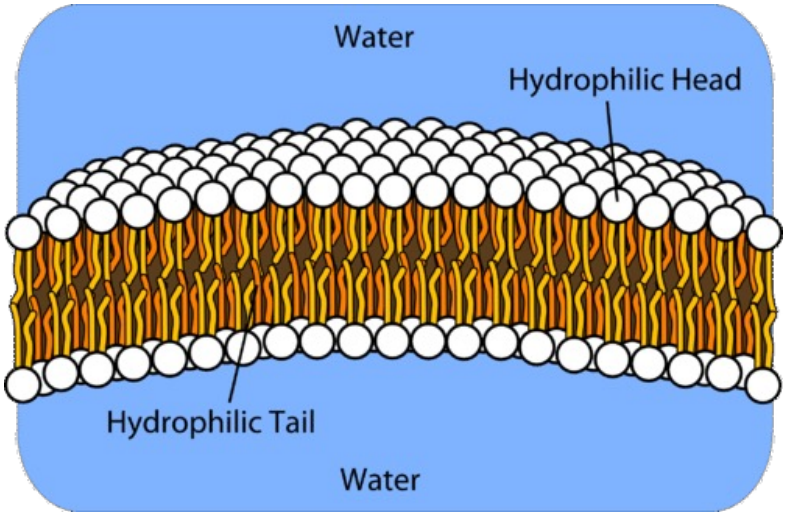


fatty acids -> phospholipid -> membranes

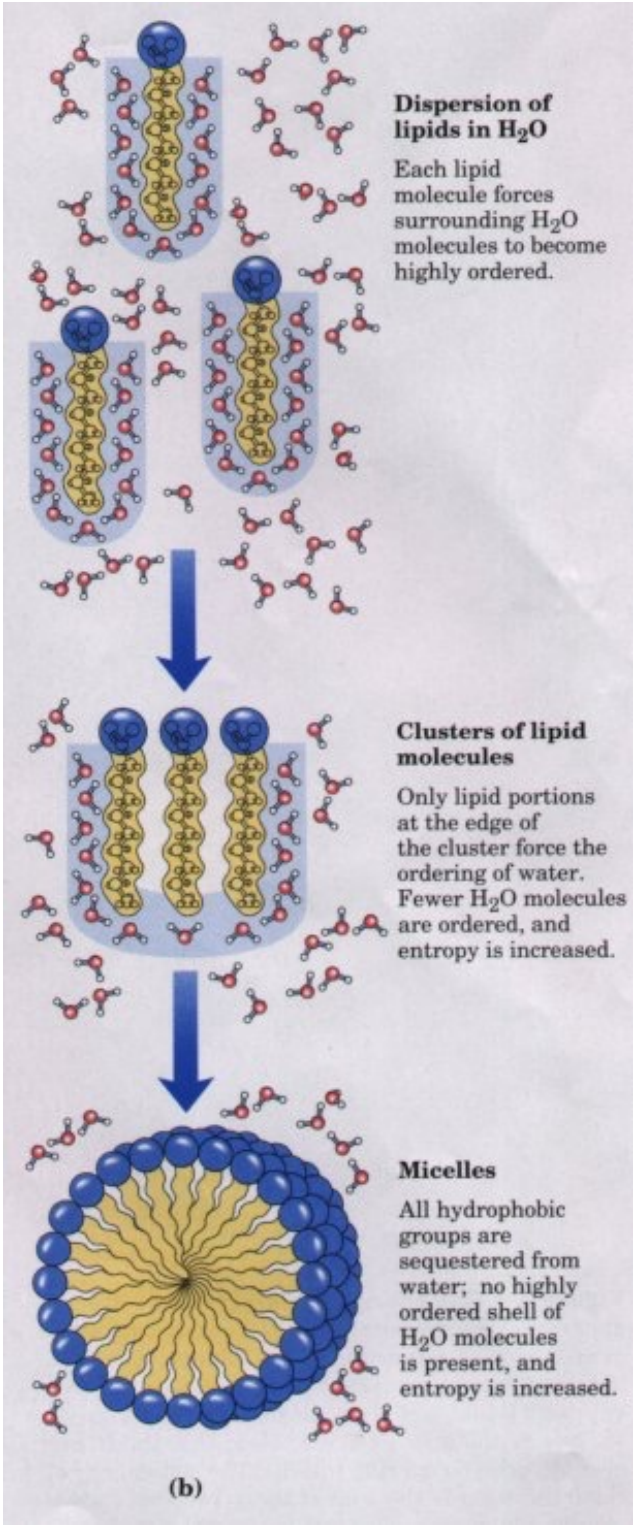


lipid:
macrobiomolecule that is
soluble in nonpolar solvents



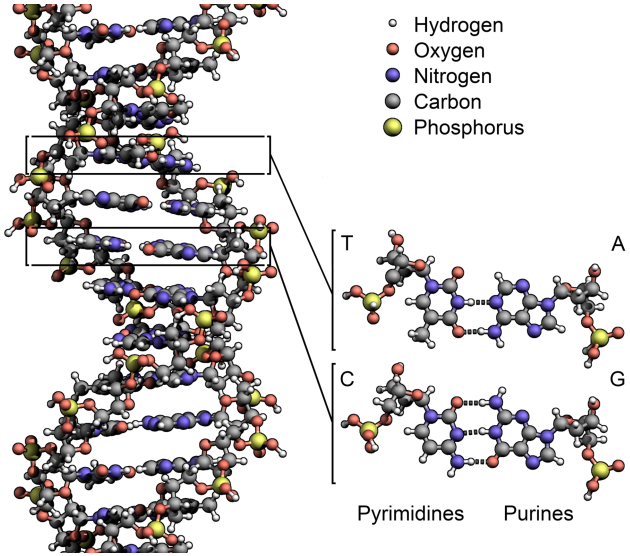


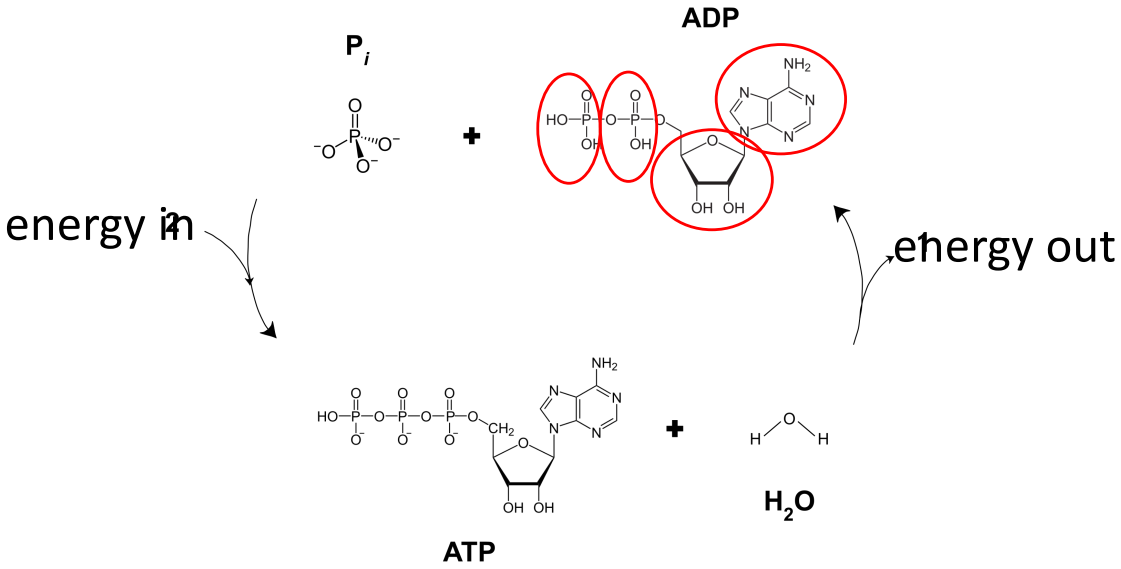
energy and entropy

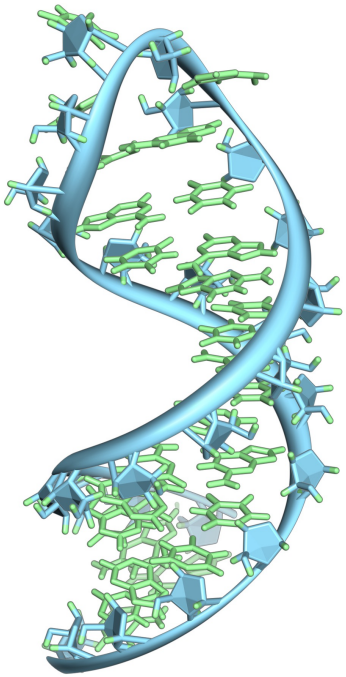


Important molecules

- Important nitrogenous bases: Adenine, Thymine, Guanine, Cytesine, Uracil
- Nucleic acids
  - DNA (DeoxyriboNucleic Acid): base pairs T-A, C-G
  - RNA (RiboNucleic Acid): single strands of G,U,A,C
- Nucleotide = (nitrogenous) base + sugar + phosphate
  - Adenine (base) + ribose (sugar) = Adenosine
  - ATP (Adenosine TriPhosphate)
  - ADP (Adenosine DiPhosphate)

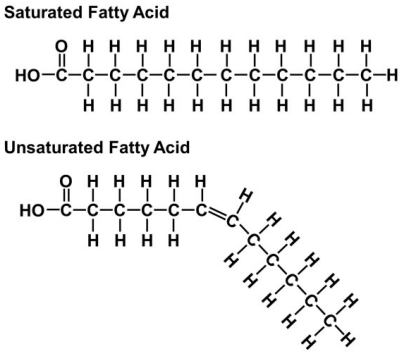


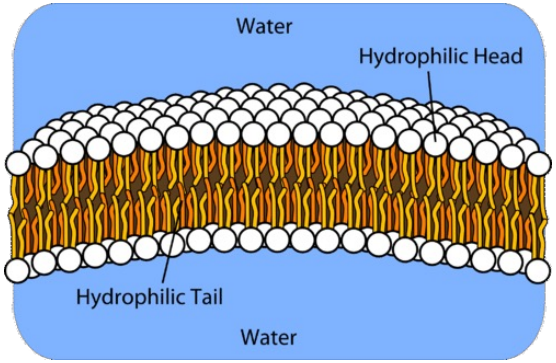




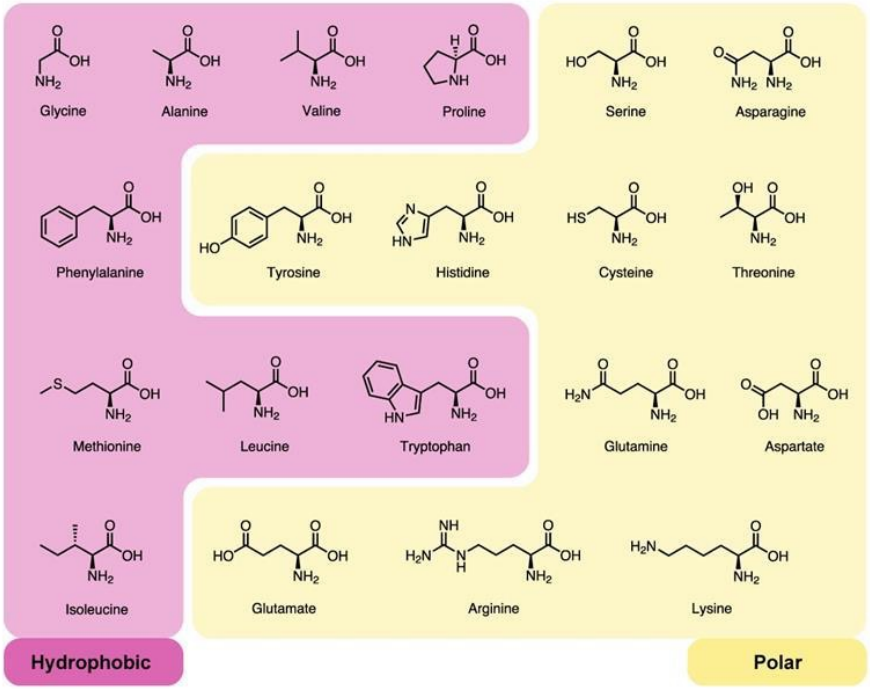
Important molecules

- fatty acids -> phospholipid -> membranes

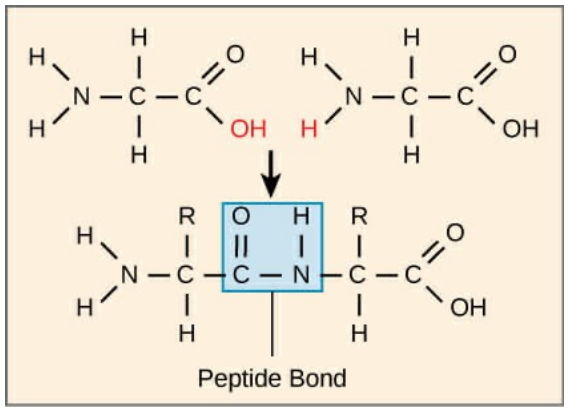




- amino acids -> polypeptides - proteins



Amino: NH2, Acid: OOH



Peptides: 2-50 amino acids

Proteins: >50 amino acids

Pro

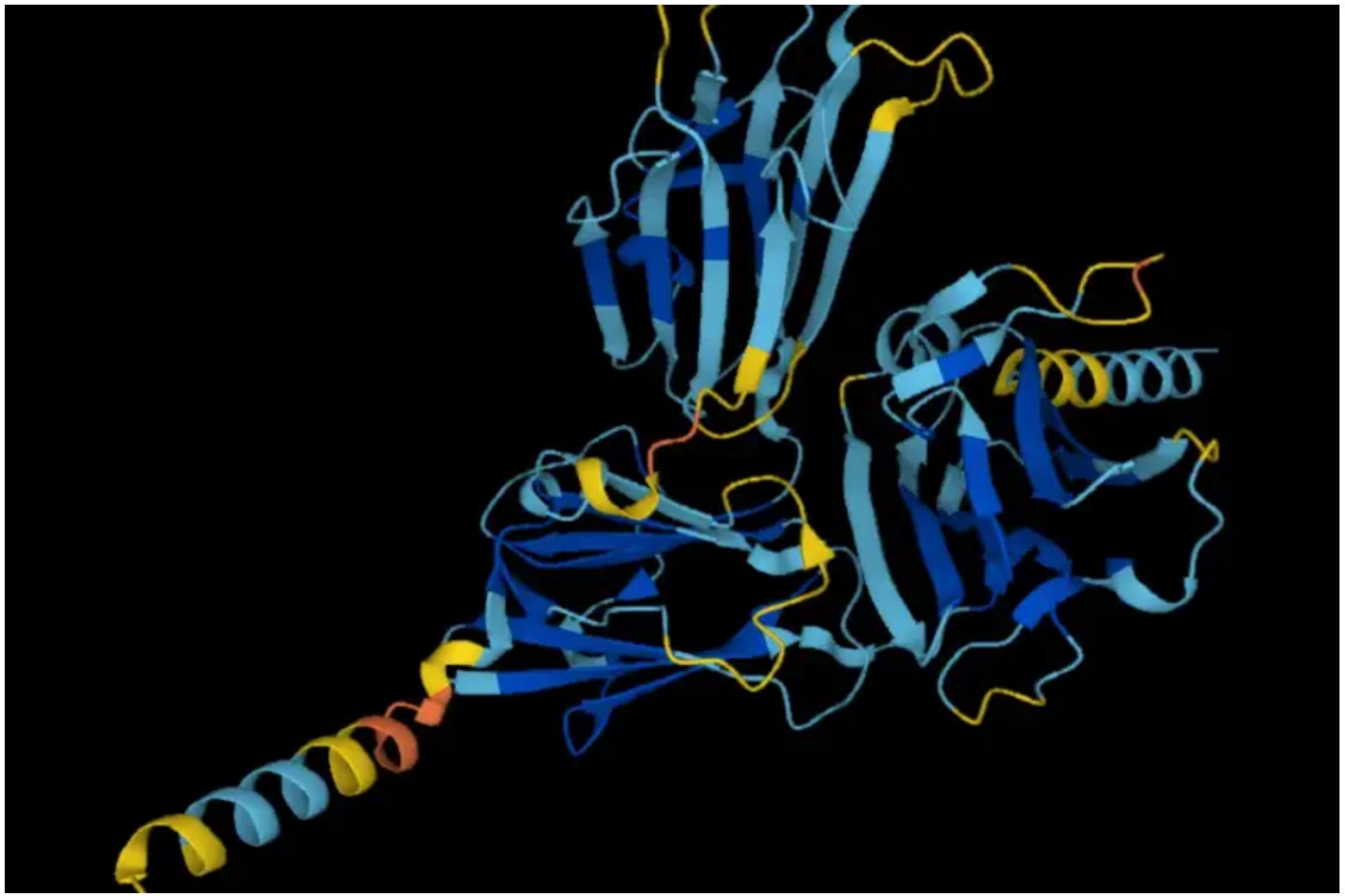
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DeepMind's protein-folding AI cracks biology's biggest problem

Artificial intelligence firm DeepMind has transformed biology by predicting the structure of nearly all proteins known to science in just 18 months, a breakthrough that will speed drug development and revolutionise basic science

TECHNOLOGY 28 July 2022

By **Matthew Sparkes**



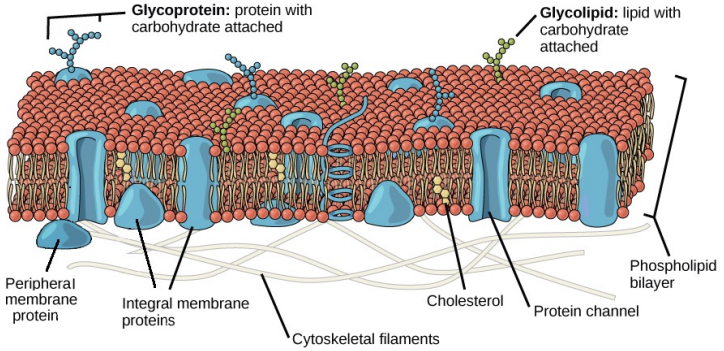
Predicting the structure of proteins is one of the grand challenges of biology
DeepMind

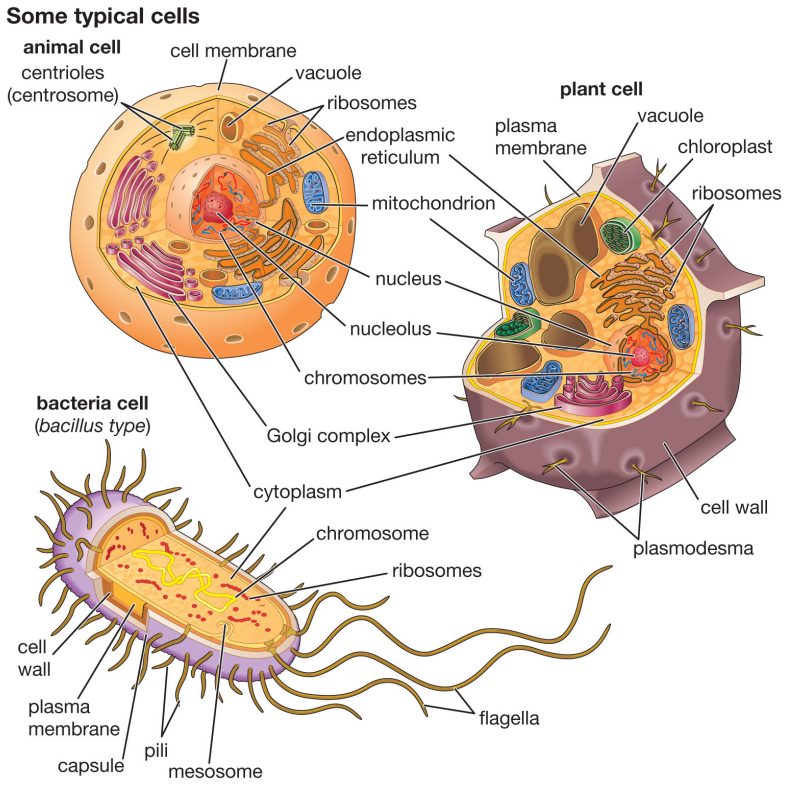
uk/

Cells – fundamental functional units of life

- enclosed by plasma membrane
- interior «soup» called cytoplasm
- organized in organelles = specialized compartments surrounded by membrane
  - nucleus: contains the genetic information necessary for cell growth and reproduction
  - mitochondria: responsible for the energy transactions necessary for cell survival
  - lysosomes: digest unwanted materials within the cell
  - endoplasmic reticulum & Golgi apparatus: organization of the cell by synthesizing selected molecules and then processing, sorting, and directing them to their proper locations

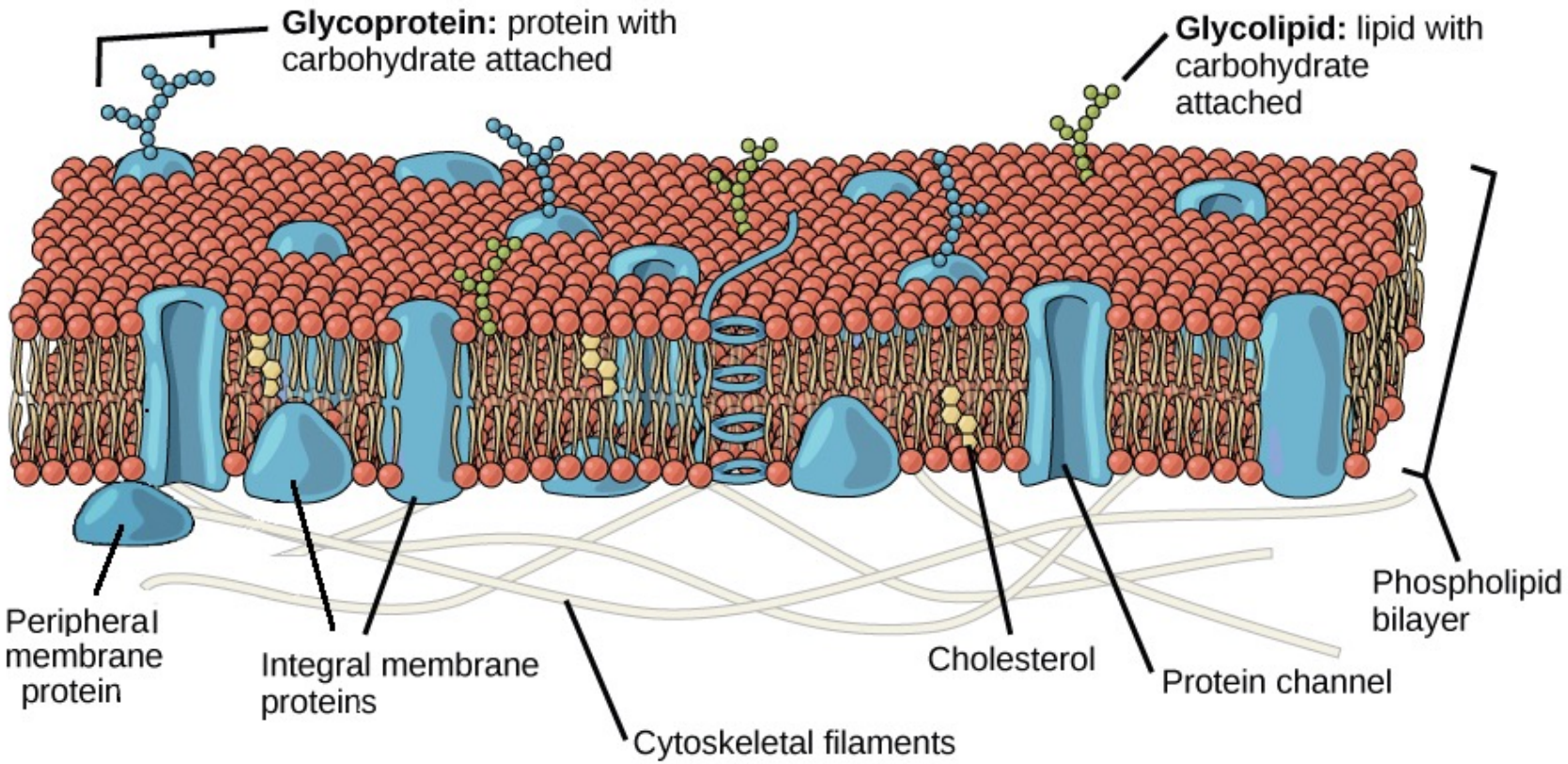
- https://www.allencell.org/





cyto- = cell

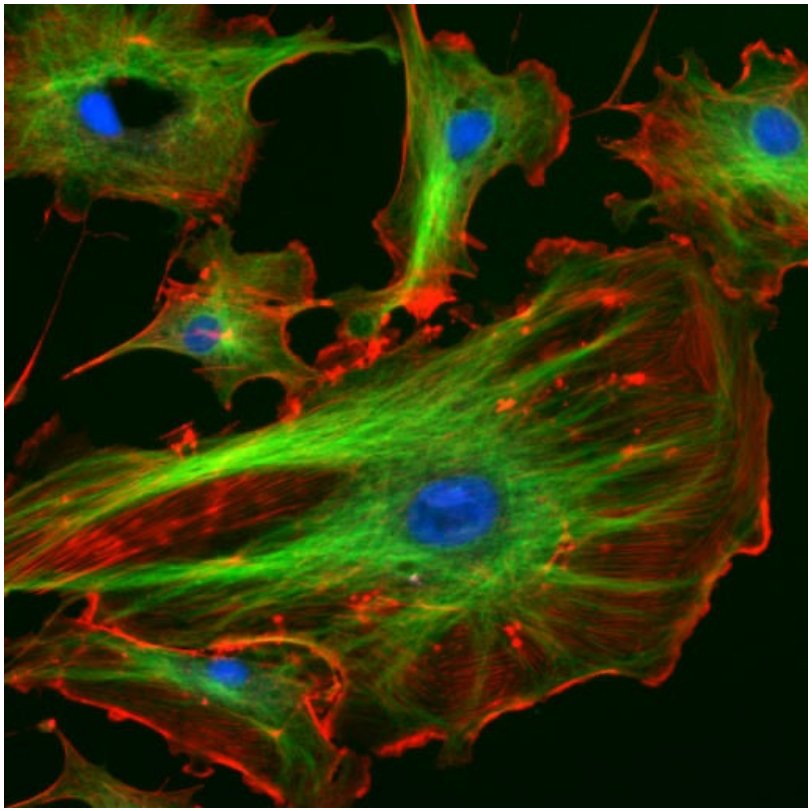
Plasma membrane



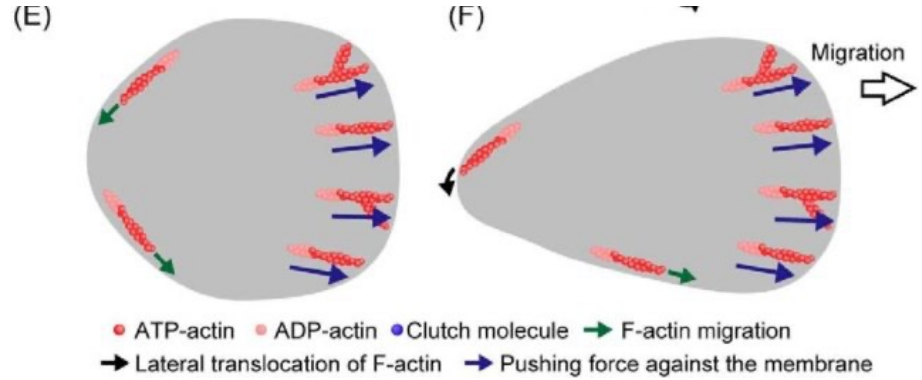
Three ways through membrane: diffusion, channels, vesicles

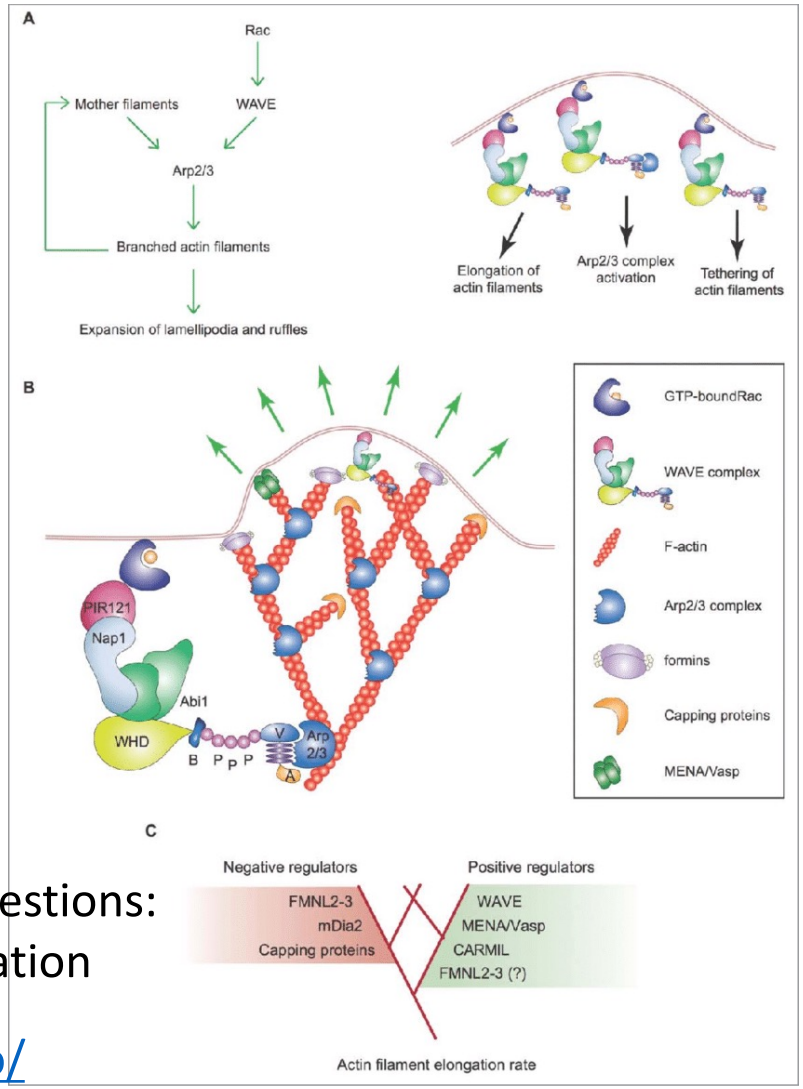
Cytosceleton

- actin filaments (7 nm Ø)
- microtubules (25 nm Ø)
- intermediate filaments (10 Ø)



The eukaryotic cytoskeleton. Actin filaments are shown in red, and microtubules composed of beta tubulin are in green.





physics questions:

- polarization
- force

G-actin monomer

F-actin polymer

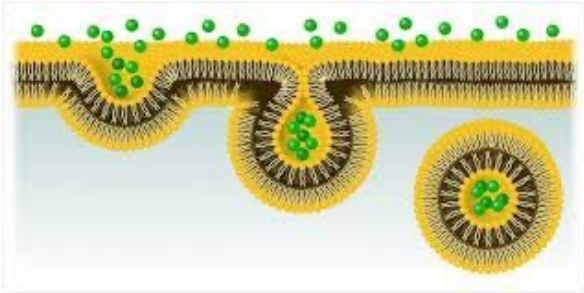
https://www.mechanobio.info/

Molecular machines

- https://youtu.be/X_tYrnv_o6A

Processes in cells: transport

- Directed transport
  - cell division
  - https://youtu.be/y-uuk4Pr2i8
  - Hemoglobin in blood flow
  - ion pumps in cell membrane
  - endocytosis
- Diffusion
  - actin monomers
  - O_2 to/from hemoglobin (size of cells)
  - signal molecules
  - permeation through cell membrane

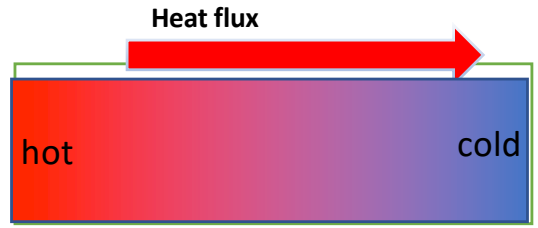


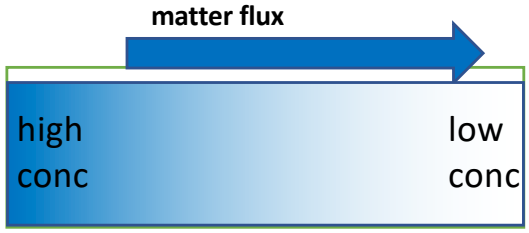
Theory:
Relaxation to equilibrium by **diffusion**

Macroscopic explanation of diffusion:

Net transport of *energy* or *particles* until thermodynamic equilibrium is reached

- $\vec{J} = -D\nabla c$ *Matter flux is proportional to gradient of concentration*
- $\vec{Q} = -\lambda\nabla T$ Heat flux is proprtional to gradient of temperature
- What are «matter» and »heat»?





I. DIFFUSION AS A MIXING PROCESS

Diffusion equation:

$$J = -D_{12}\frac{\partial \rho}{\partial y} \tag{1}$$

Divergence theorem (continuity equation)

$$\frac{\partial \rho}{\partial t} + \nabla J = 0 \tag{2}$$

Combine the two to get the partial differential equation for diffusion:

$$\frac{\partial \rho}{\partial t} + D_{12}\frac{\partial^2 \rho}{\partial y^2} = 0 \tag{3}$$

Starting with particles in $y = 0$ at time $t = 0$: $\rho(t = 0, y) = \delta(y)$, where δ is the Kroeneker delta function the diffusion equation has solution (you may easily verify this):

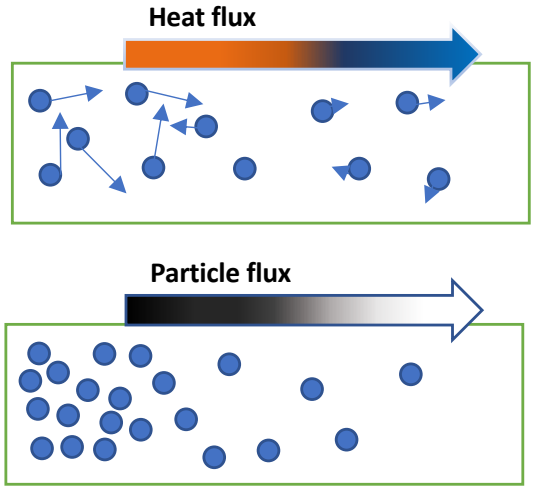
$$\rho(t, y) = \frac{1}{\sqrt{4\pi D_{12} t}} \exp(-\frac{y^2}{4D_{12}t}) \tag{4}$$

Theory: Relaxation to equilibrium by diffusion

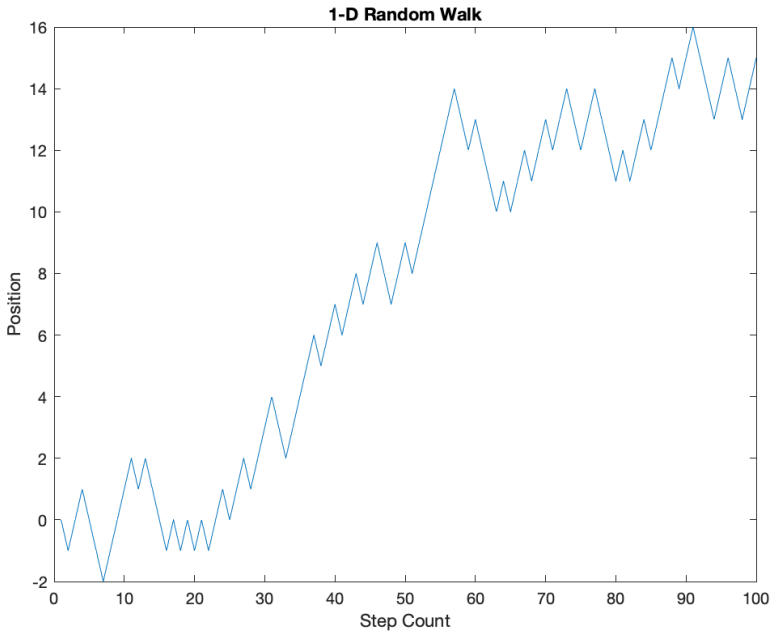
Microscopic explanation of diffusion:

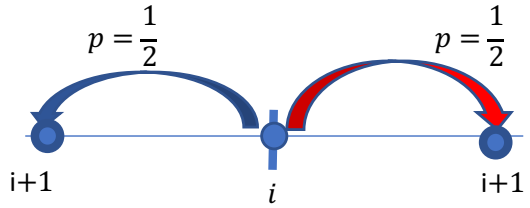
Net transport of *energy* or *particles* through random thermal motion and particle collisions until thermodynamic equilibrium is reached

- At any $T > 0$K, particles are in *thermal motion*
- Collisions between particles -> particle trajectory is a zigzag -- random *(diffusive particle)*



Random walk (RW)






```
n = 100; % number of steps
P = zeros(n,1); %position(time) vector
P(1) = 0; % Starting value
for i=2:n
  R = rand;
  if R < 0.5
    S = -1;
  elseif R > 0.5
     S = 1;
  end
  P(i) = S+P(i-1);
end
plot(1:n,P)
ylabel('Position')
xlabel('Step Count')
title('1-D Random Walk')
```

RW exercise

- Write Python or Matlab code for 2D RW
- Plot mean square displacement as function of time for 10, 100, 1000, 10000 walkers

Crash course in greek and latin:

Angio-	Vessel	Angiogenesis =production of vessels
-atomy, -otomy	cutting	
Auto-	self	
Brachy	short	
Cata- (katalysis)	dissolving	
Carcino-	tumor (crab-like)	
Centro-, -centric	centre	
-ceptor, ceptive	capere, to take	
Chromo-	color	
Chrono-	time	
-cyte, cyto-	hollow	
Diplo	double	
e-, ec-	out of	
Endo-	within, inside	
Exo-	outside	
Extra-	beyond	
Erythro-	red	
-gen, genous	descent	
-genic, -genous	birth, descent, origin	
-genic, -genous	to produce	

Carcinogenesis = Production (development)of cancer

Crash course in greek and latin:

Glia-	glue
Haem-	blood
Histo-	tissue
Homeo-	alike
Homo-	the same
Hyper-	above
Hypo-	under
Infero-	beneath
Infra-	below
Inter-	between
Intra-	within
Iso-	equal
-kinesis, -kinetic	kinesis=movement
Leuko-	white
Lipo-	fat
-lysis, -lysin	dissolving
Macro-	large
Medi-	middle

Crash course in greek and latin:

-mere, mero-	a part
Meta-	after
Metabolism	change
Micro-	small
Mito- (mitosis)	a tread
Mono-	single
Muta-	mutare=to change
Necro-	dead
Neuro-	nerve
-nomics	law
Oligo-	few
Onco-	bulk, mass
Ortho-	straight
Para-	beside
Per-	through
Peri-	around
-phage, -phagous	phagein=to eat
-phil	to love

Centromere=
middle part

telomere=
end part

Crash course in greek and latin:

-phobe	to fear
Photo-	light
Plasma-, -plasm	form
-plicate	to fold
Post-	after
Pre-	before
Pro-	before
Proto-	first
Re-	back
Retro-	backwards
Serum	whey (myse)
-some, soma-	body
Stereo-, -steric	solid
Sub-	under
Super-	over
Supra-	above
Sym-, syn-	with

Crash course in greek and latin:

-synthesis	composition
Tauto-	the same
Tele-	far
Teleo-	complete
Telo-, telio-	end
Trans-	across
Ultra-	beyond