Schedule

[Fundamentals]

1. 4/15 Basic chemical and biochemical concepts
2. 4/22 Basic biophysical concepts
3. 4/29 Basic bioelectrochemical concepts1
4. 5/13 Basic bioelectrochemical concepts2

[Applications]

5. 5/20 Cancel (Homework1 and 2)
6. 5/27 Biosensors and bioelectronics1
7. 6/03 Cancel (Homework3 and 4)
8. 6/10 Student seminar
9. 6/17 Biosensors and bioelectronics2
10. 6/24 From bioelectronics (electron) to iontronics (ion)1
11. 7/01 From bioelectronics (electron) to iontronics (ion)2
12. 7/ 8 Wearable applications1
13. 7/15 Wearable applications2
14. 7/22 Student seminar

Homework2

生物に存在するbuilding blocksの例(図を含む)を示し，
その説明をまとめよ.

Confirm a journal paper regarding an example of building blocks
in Nature, and then summarize as the following contents
(any pages, including the figures and references).

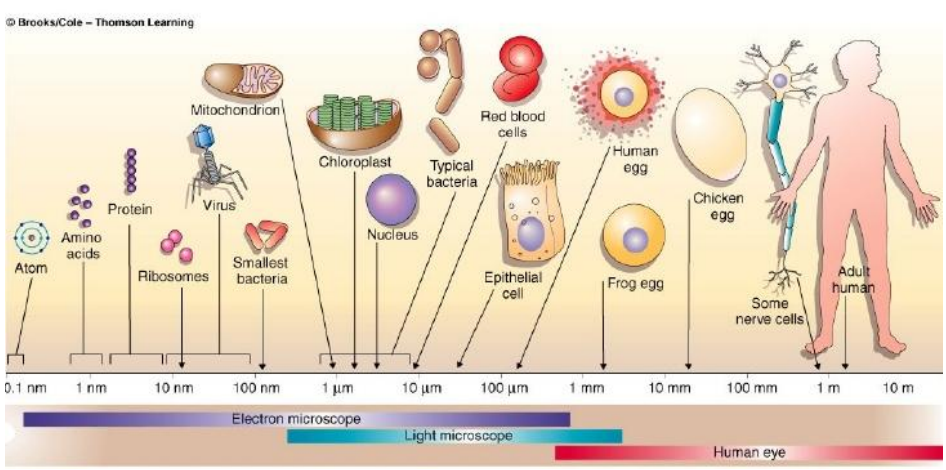
1. Reason why you choose the paper (なぜその文献を選んだのか？)
2. Purpose of the paper (その文献の目的は？何が新しいのか？)
3. Results of the paper (結果の説明，図を含む)
4. Conclusions and future perspective (結論と将来性)

Deadline: May 6 2025

✓ Upload electrical file (MS word or pdf)to this lecture in MyWaseda

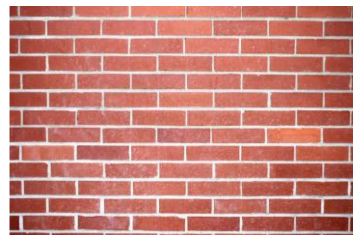
Cells (<u>their components</u>)
and their basic building blocks

Biological size and cell diversity



Building blocks
(Bottom-up)

(monomer)



(polymer)

Monomers

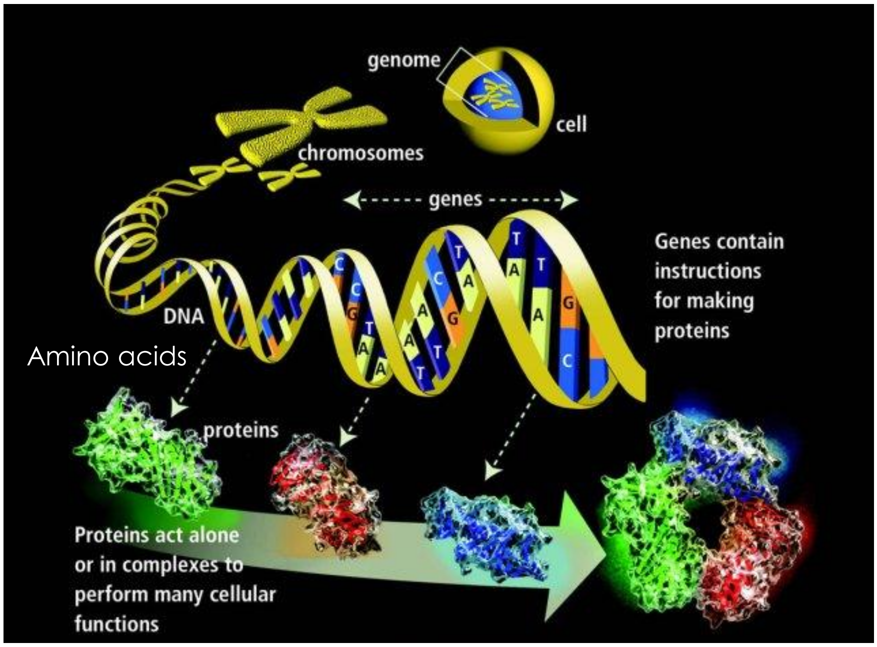
Polymers

Building blocks of the cell		Large units of the cell
Amino acids	⇨	**Proteins**
Sugars	⇨	**Polysaccharides**
Nucleotides	⇨	**Nucleic acids**

Self-assembly
Static interaction

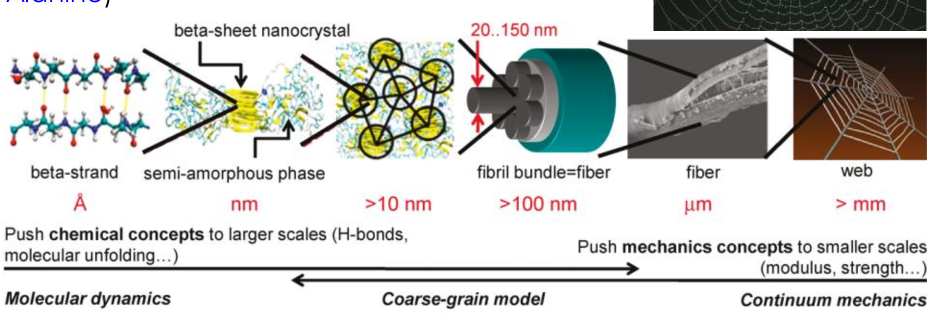
Fatty acids	⇨	**Fats, Lipids, membrane**

Genome

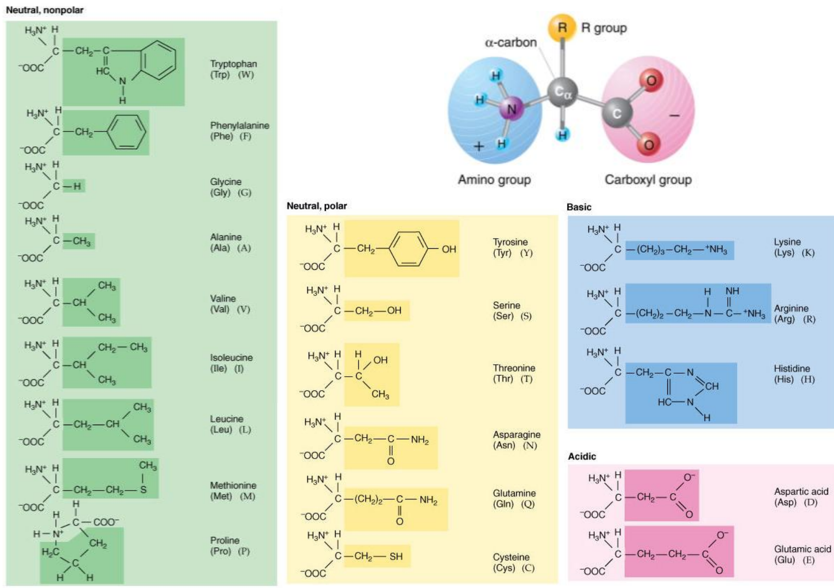


Spider silk

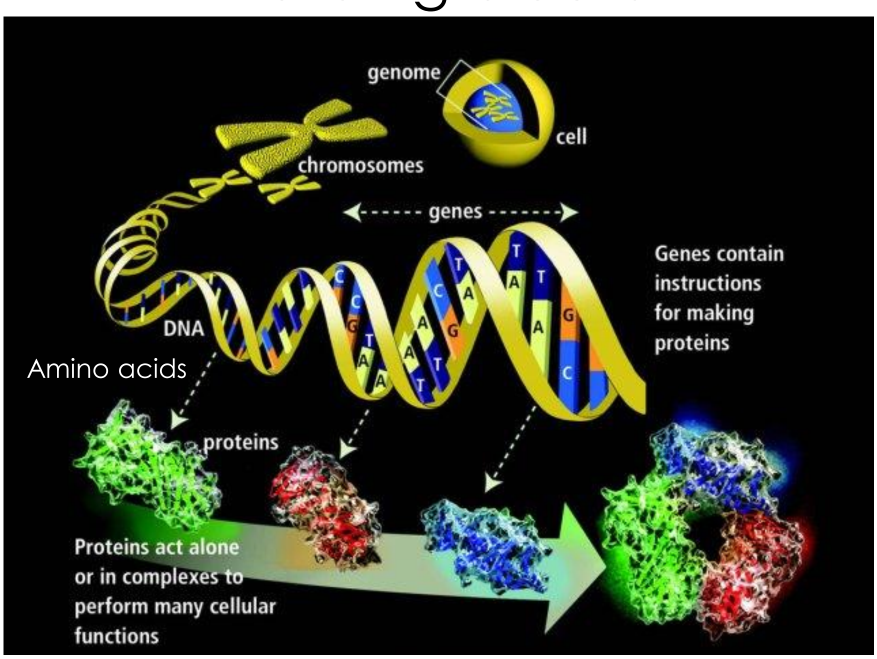
Monomer: amino acids
(90% components: Glycine, Serine and Alanine)



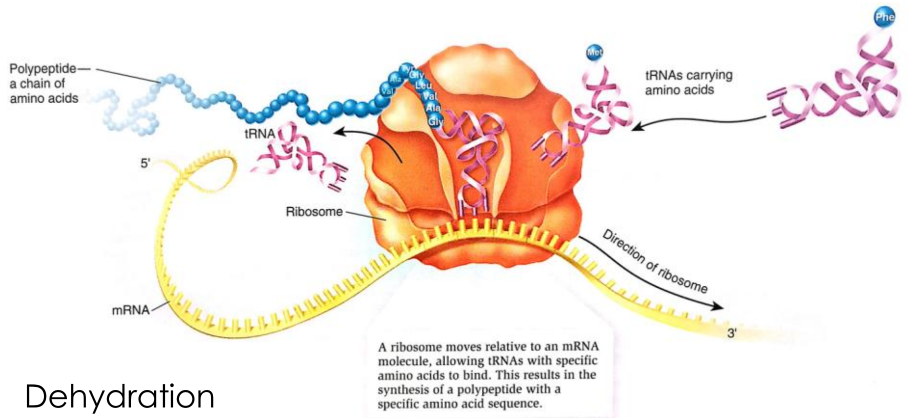
20 amino acids



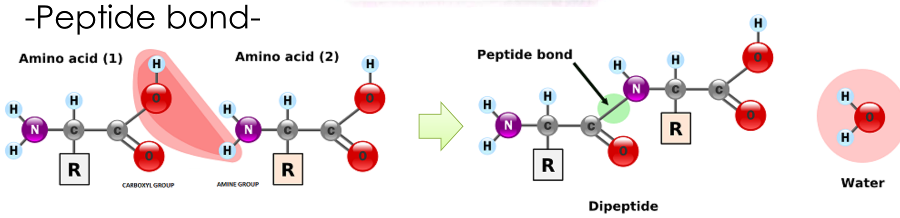
Building blocks



Protein synthesis

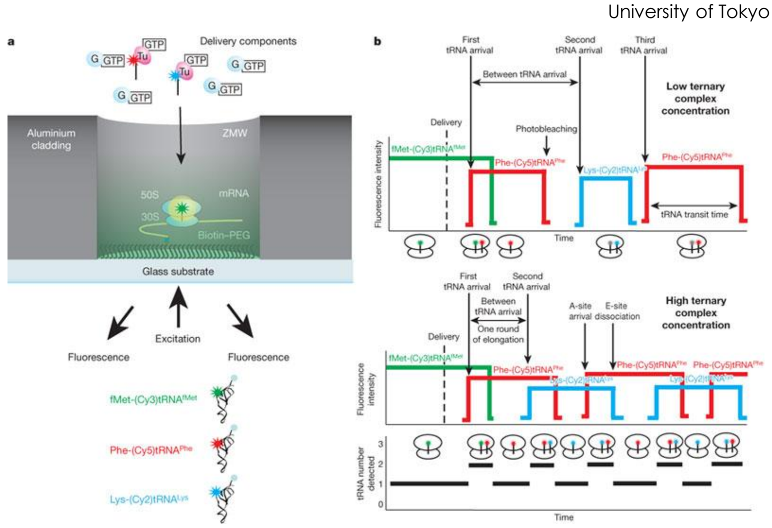


Dehydration
-Peptide bond-



Single molecule imaging of protein synthesis

S.Uemura
University of Tokyo

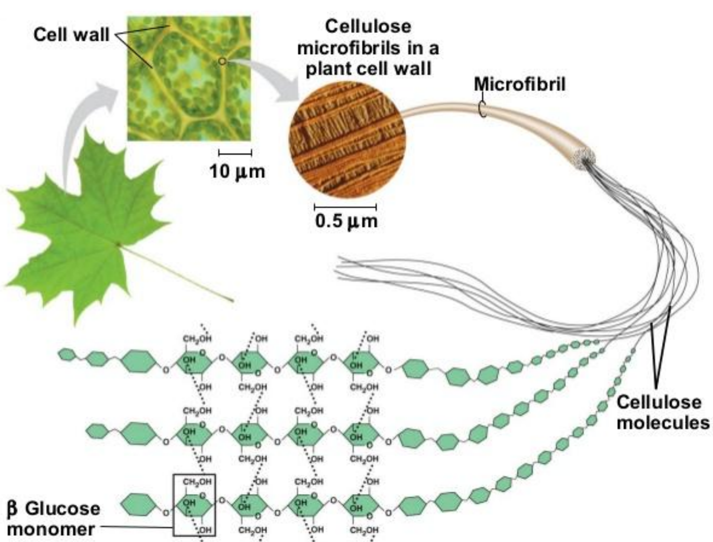


Monomer	Polymers
Building blocks of the cell	Large units of the cell
Amino acids →	**Proteins**
Sugars →	**Polysaccharides**
Nucleotides →	**Nucleic acids**

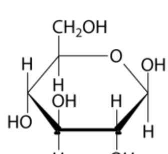
Self-assembly
Static interaction

Fatty acids → **Fats, Lipids, membrane**

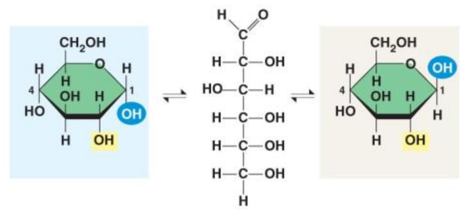
Polysaccharides: glucose to cellulose



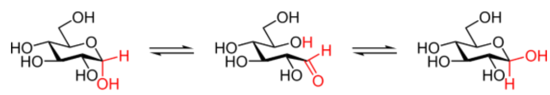
C: Carbon
H: Hydrogen
O: Oxygen

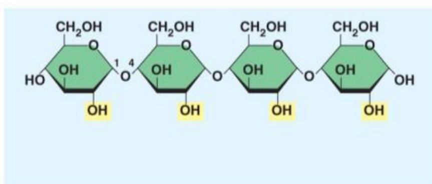


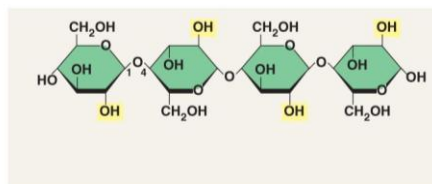
a-glucose β-glucose

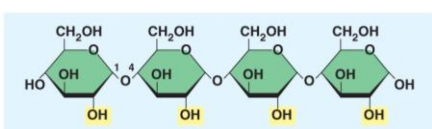


38% 62%

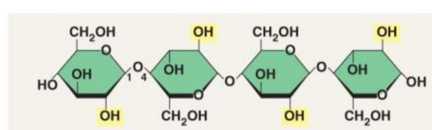






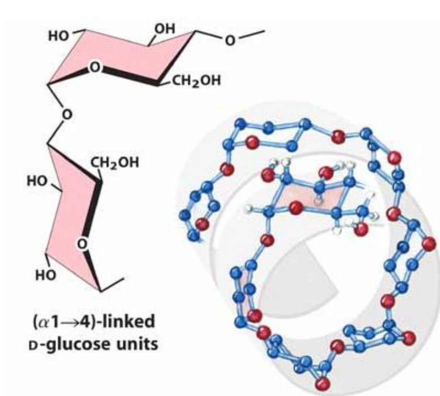


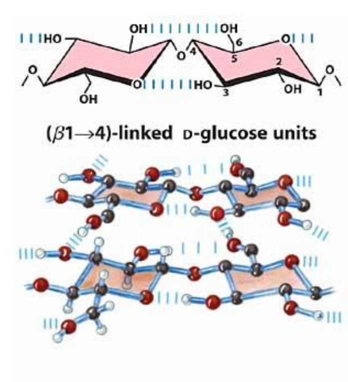
(a) Starch: 1-4 linkage of a-glucose monomers



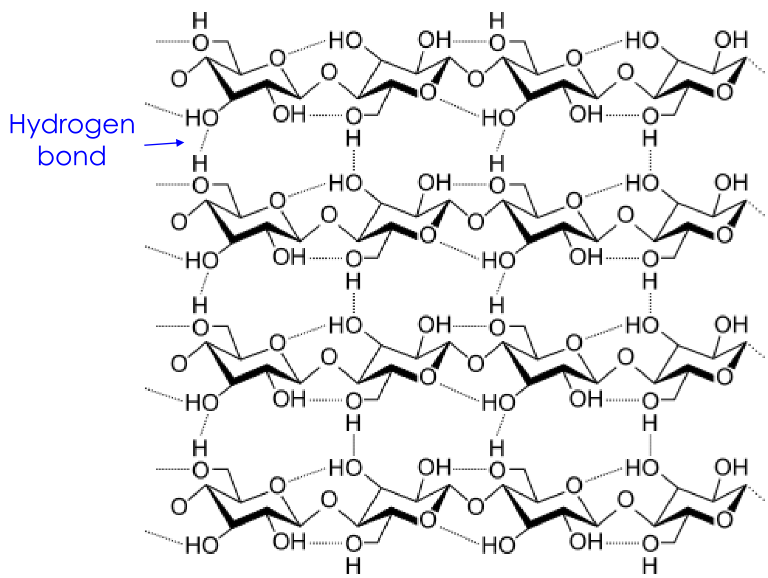
(b) Cellulose: 1-4 linkage of β-glucose monomers

Helical Straight





Why β-glucose in cellulose



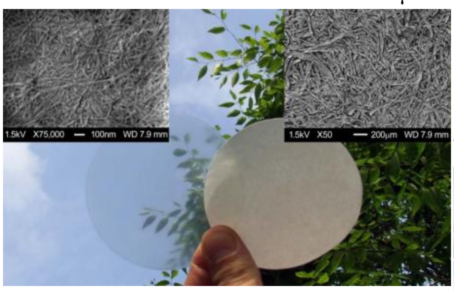
Natural Materials vs Synthetic Materials

Materials	Young's Modulus (GPa)	Density (g/cm^3)	Specific Stiffness ($GPa.cm^3/g$)
Steel	200	7.9	25
Titanium Alloys	112	4.5	25
Aluminum	69	2.7	26
Cellulose	138	1.5	92
Chitin	3-92	1.4	2-66
Mollusk Shell	80	3	26

Ritchie, et. al., "Bioinspired Structural Materials", Nature Materials, 2015.
Ashby, et. al., "On the Engineering Properties of Materials", Acta metall, 1989.

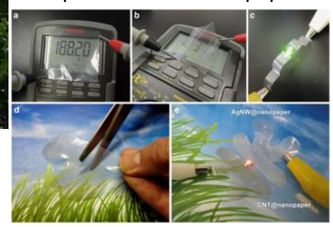
Transparent cellulose nanofiber films

Φ4-15 nm Φ15-50 μm

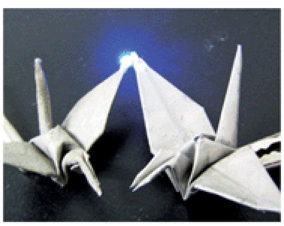


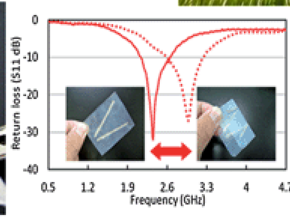
Prof. Nogi,
Osaka University

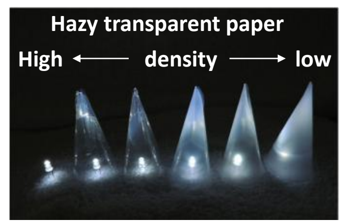
Transparent conductive papers



Foldable nanopaper antennas for origami electronics

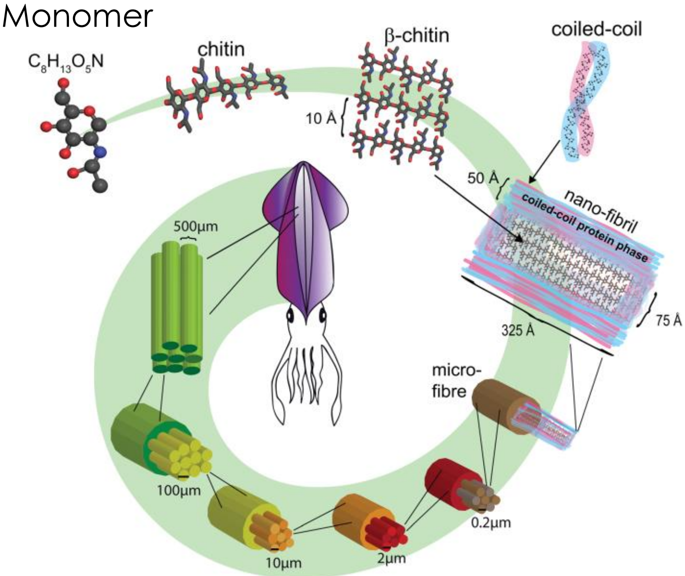






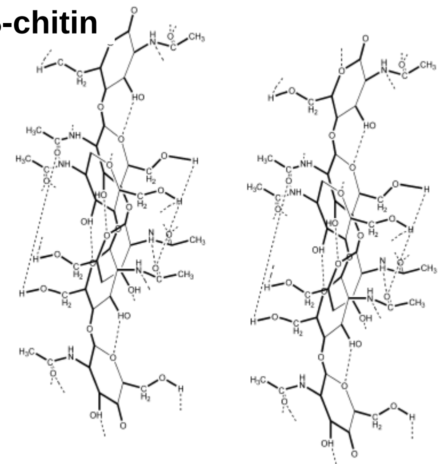
Squid Pen

Monomer

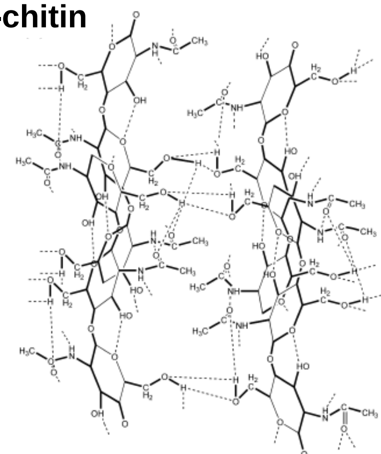


Rheinstadter, et.al., "Hierarchical, self-similar structure in native squid pen", Soft Matter, 2014.

β-chitin

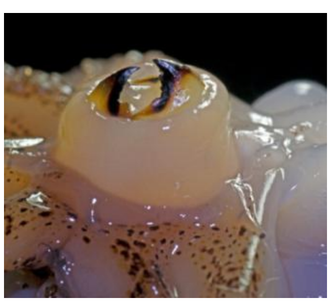


α-chitin

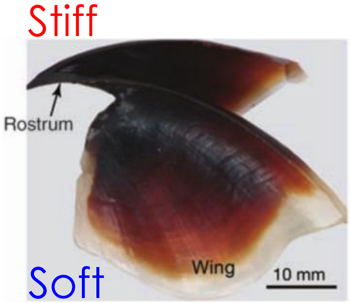


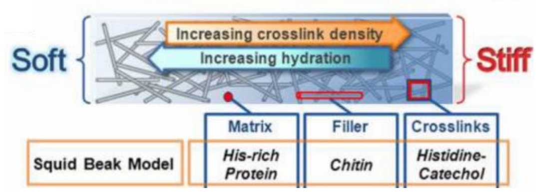
C. Pillai, Paul, Sharma, **2009**, *34*, 641

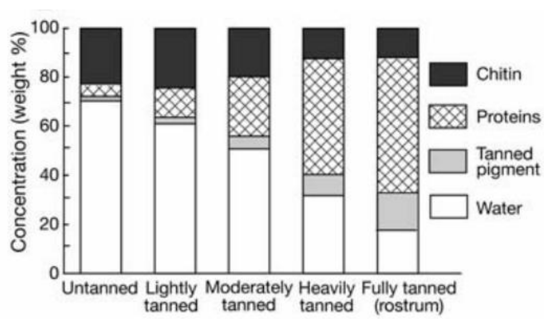
Squid beak

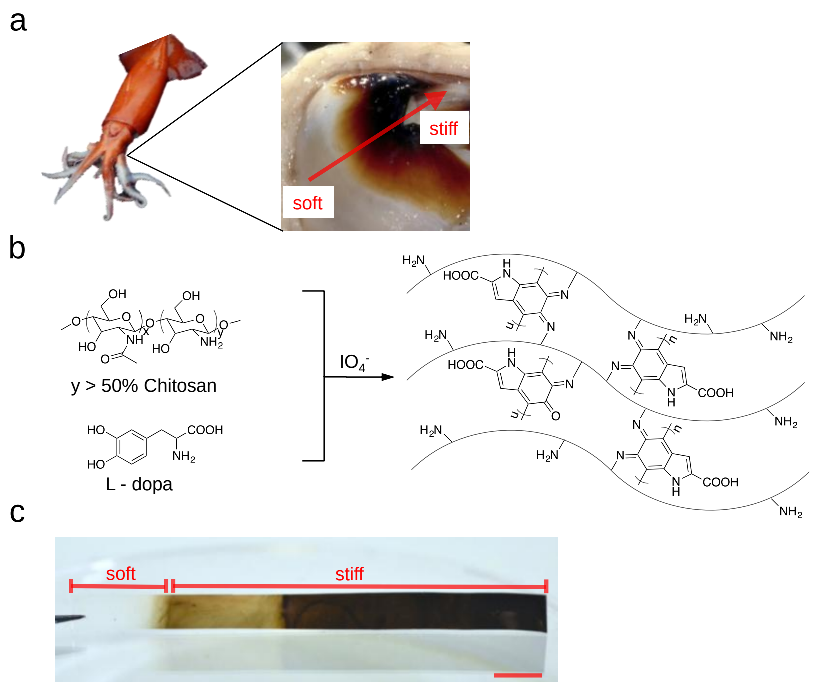


Stiff









J. Mater. Chem. B, 4, 2273-2279 (2016)

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Building blocks of the cell		Large units of the cell
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Sugars	⇨	**Polysaccharides**
Nucleotides	⇨	**Nucleic acids**

Self-assembly
Static interaction

Fatty acids	⇨	**Fats, Lipids, membrane**

Examples of lipids

Oils, fats, phospholipids, steroids

https://www.haikudeck.com/condiments-one-cannot-live-without-travel-and-lifestyle-presentation-JgoAzjoUE2

http://irongangsta.blogspot.com/2013/05/layne-norton-and-steroids-life-built-on.html

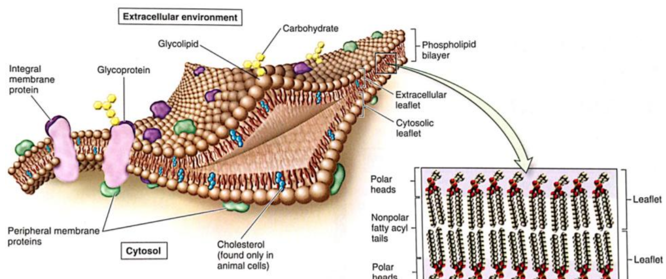


Figure 5.1 Fluid-mosaic model of membrane structure.

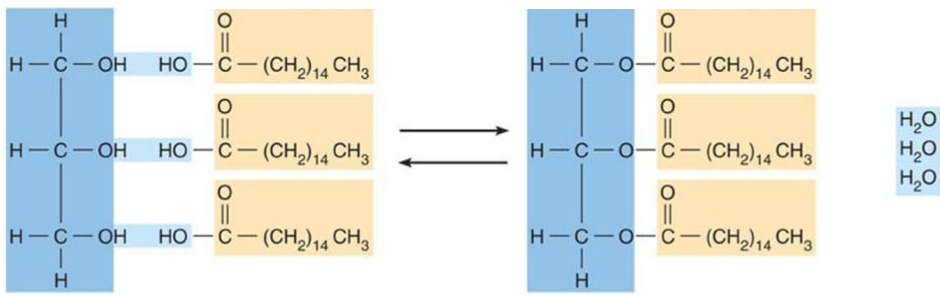
lipids

Lipid = a compound that is insoluble in water, but soluble in an organic solvent (e.g., ether, benzene, acetone, chloroform)

"lipid" is synonymous with "fat",
but also includes phospholipids, sterols, etc.

chemical structure: glycerol + fatty acids

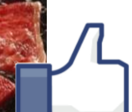
Lipid molecule



Glycerol + 3 fatty acid molecules ⇌ Fat molecule (triglyceride) + 3 water molecules

Raw tuna vs. Raw beef

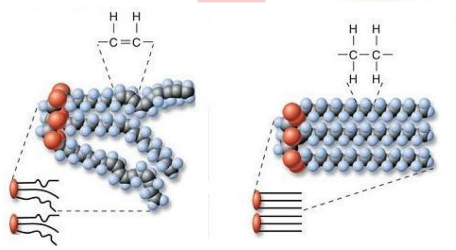
Heat ↓



Melting point of lipids
(in our mouth)

More than one double bond in chain

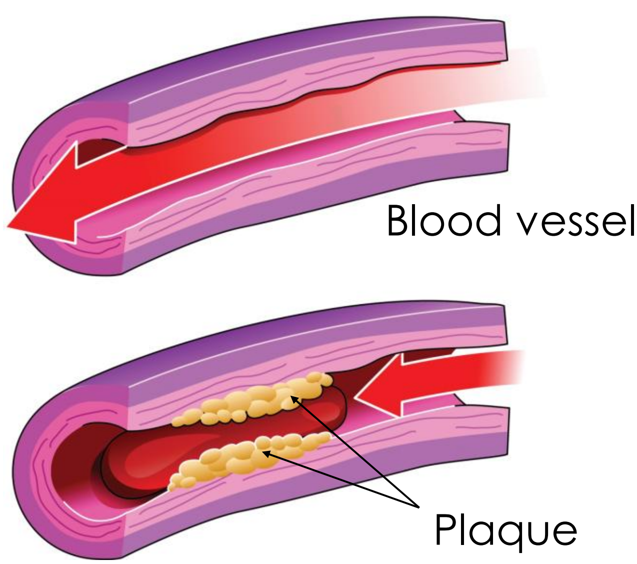
Low melting point



No double bonds between carbons in chain

High melting point

Why so bad for us?



Phospholipids

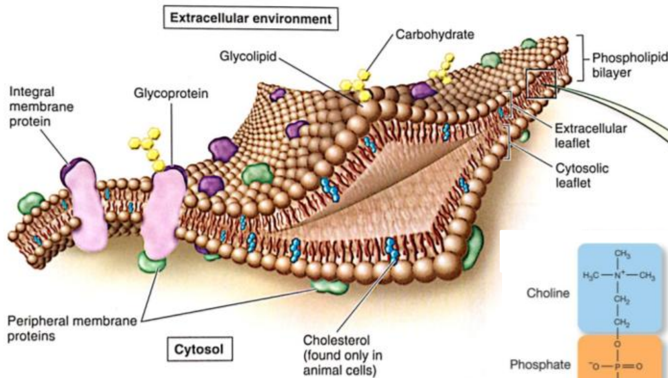
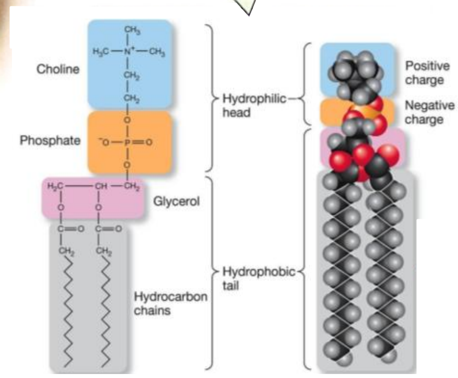
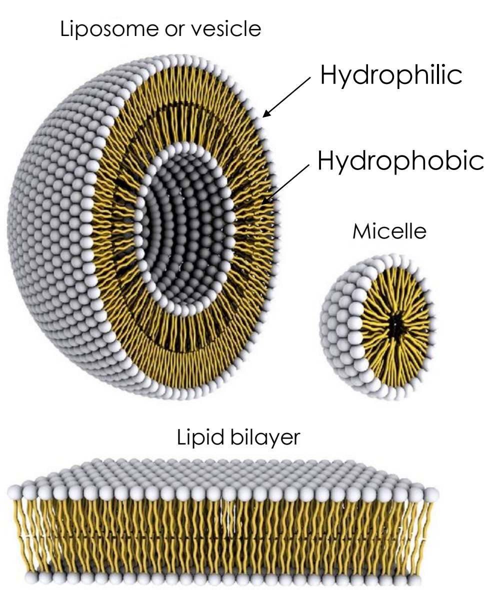
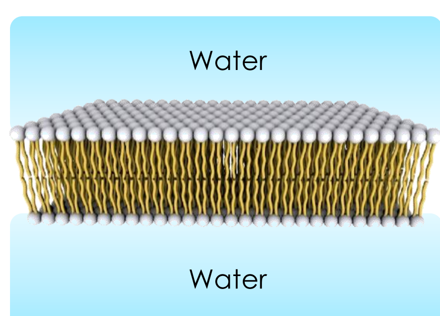


Figure 5.1 Fluid-mosaic model of membrane structure.



Phospholipids





Permeability

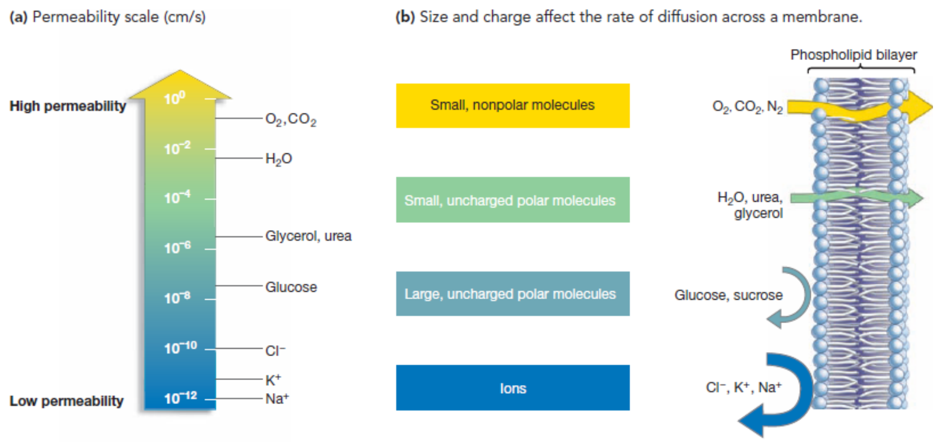
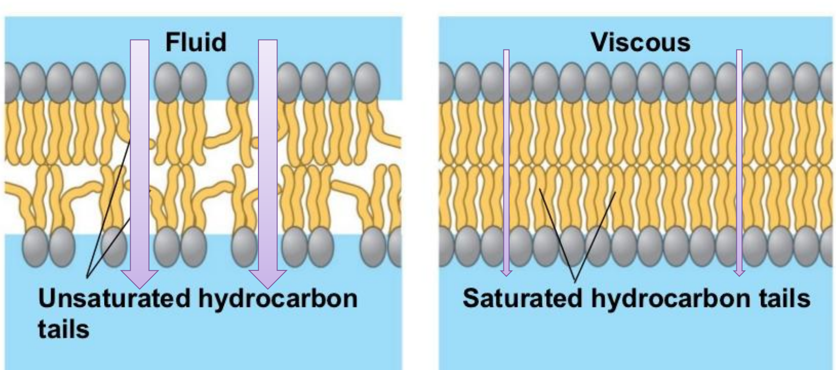


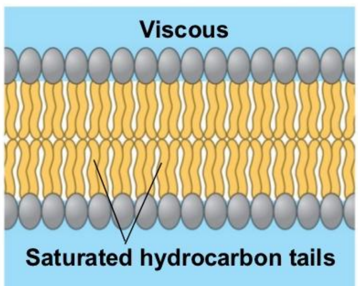
FIGURE 6.8 Selective Permeability of Lipid Bilayers. **(a)** The numbers represent "permeability coefficients," or the rate (cm/s) at which an ion or molecule crosses a lipid bilayer. **(b)** The relative permeabilities of various molecules and ions, based on data like those presented in part (a).

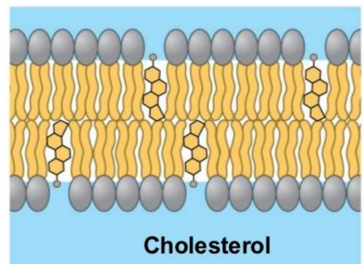
Permeability depends on the types of the lipids in the membrane

Higher permeability | Lower permeability



Question: Does adding cholesterol to a membrane affect its permeability?

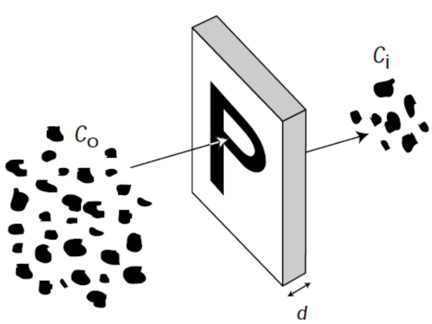




How small molecules across membranes

Fick's law

$$J = P(C_0 - Ci)$$



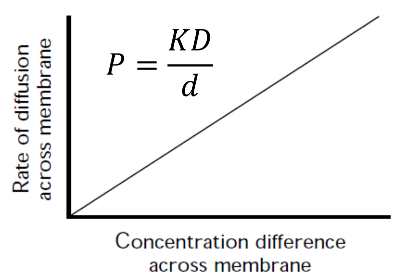
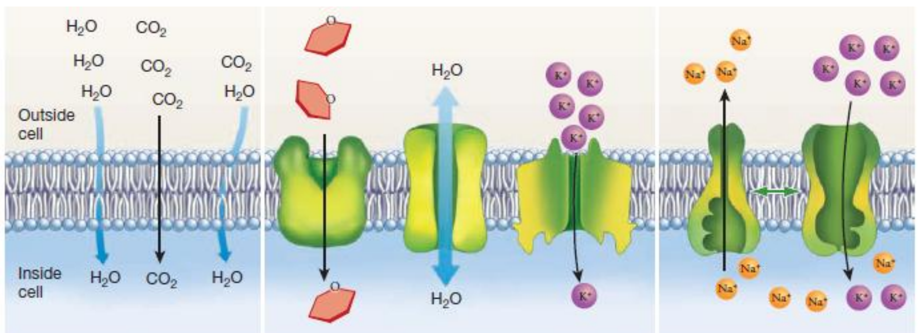


Figure 18. Passive diffusion of an uncharged molecule across a membrane. Abbreviations used: C_o, concentration outside (mol·cm^{-3}); C_i, concentration inside (mol·cm^{-3}); P, permeability coefficient (cm·s^{-1}); K, partition coefficient (ratio of the solubilities of the diffusing material in lipid and water; no units); D, diffusion coefficient (cm^2·s^{-1}); *d*, membrane thickness (cm). The negative sign means that the flow is downhill.

Different types of membrane transport

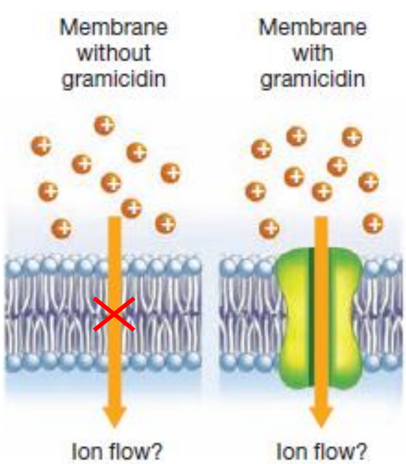
Passive transport **Active transport**

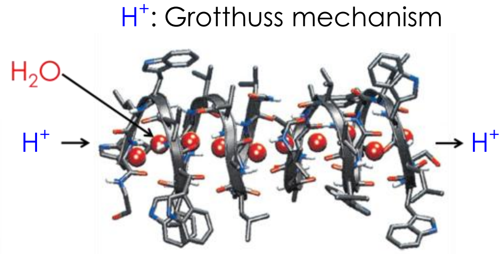
Diffusion Facilitated diffusion

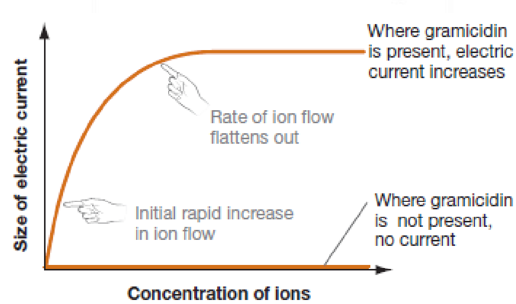


Cation permeability in gramicidin channel

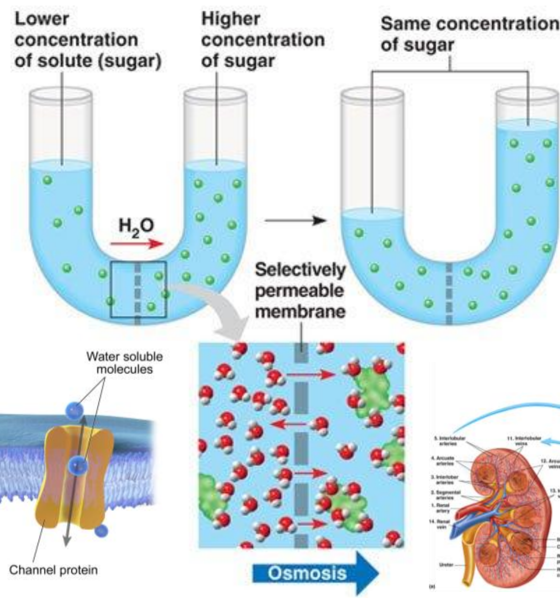
Cation: Diffusion
H^+: Grotthuss mechanism

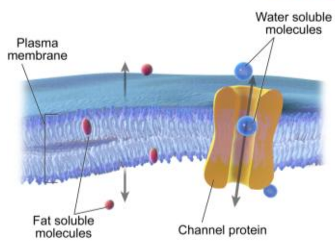




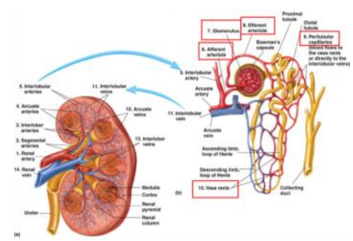


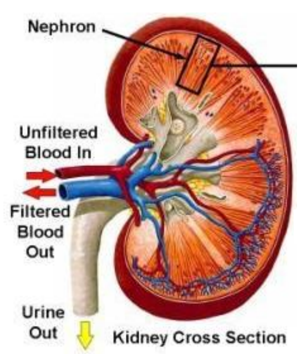
Osmosis: Water permeability in membrane

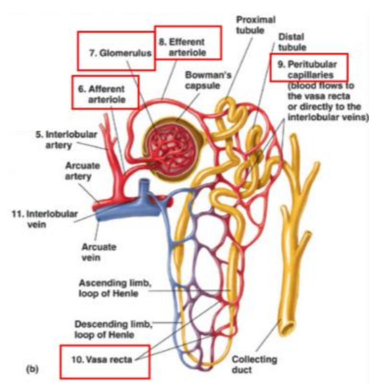


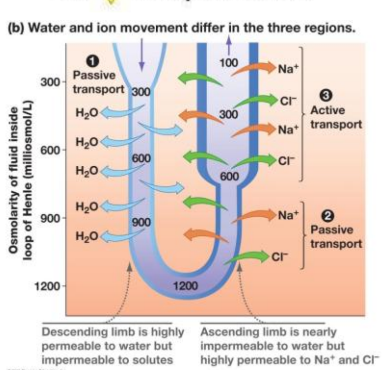


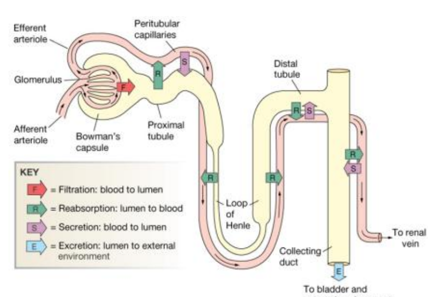
Kidney



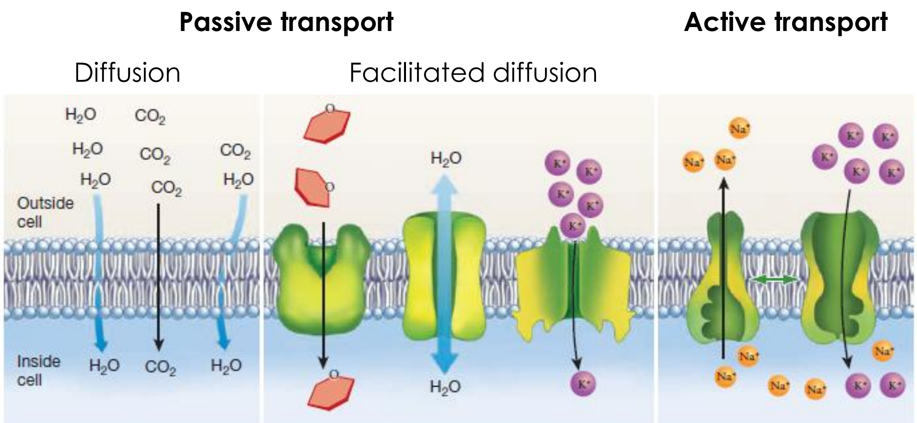




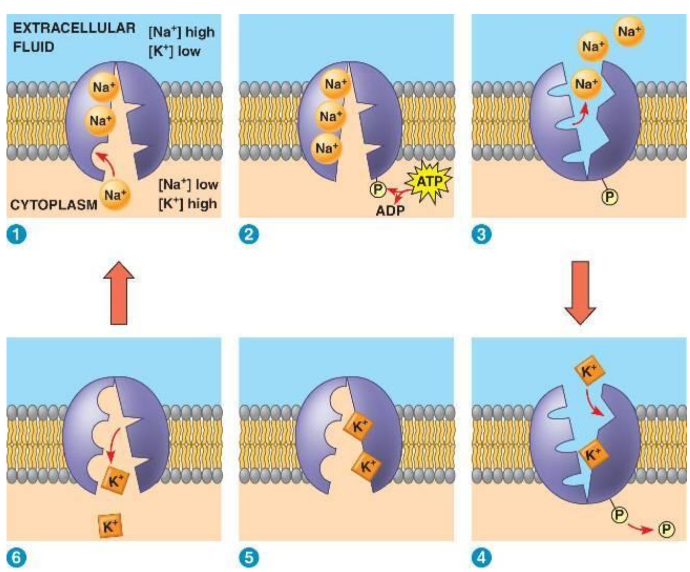




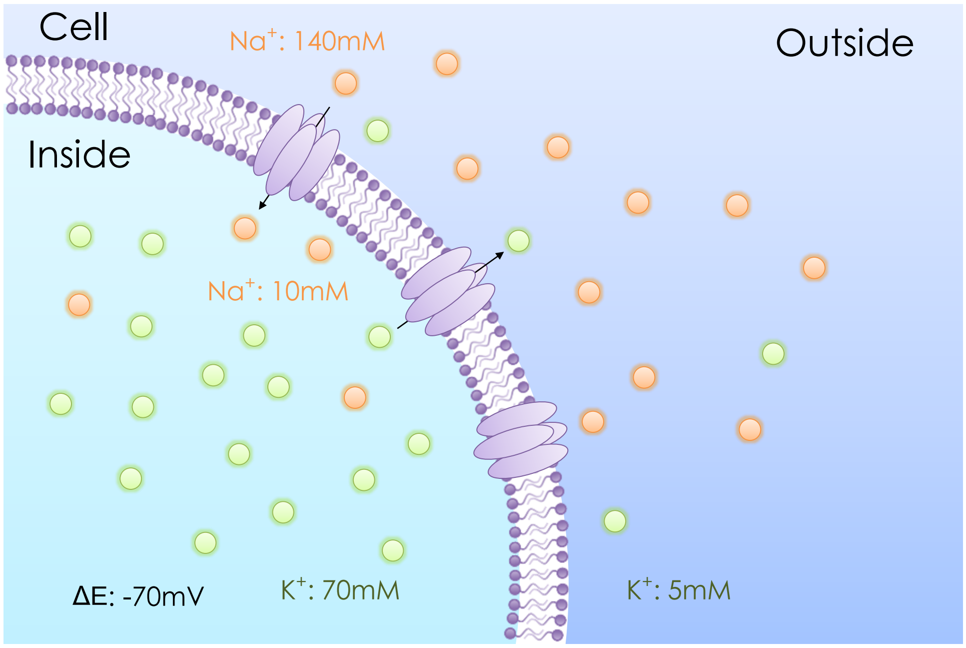
Different types of membrane transport



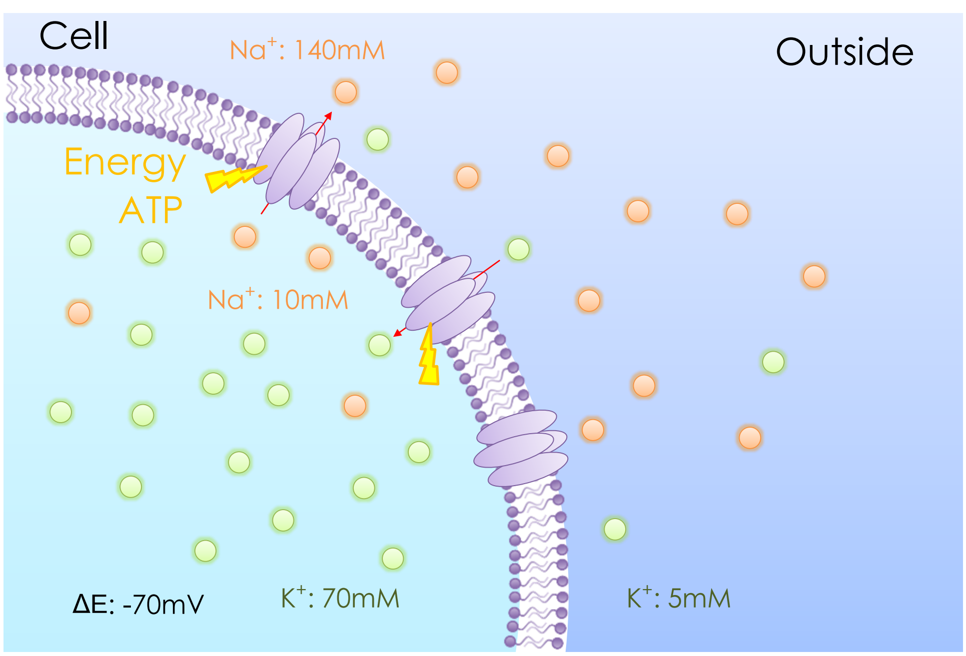
Active transport



Active transport



Active transport



Active transport

$$ATP + H_2O + 3Na^+{}_{in} + 2K^+{}_{out} \rightarrow 2K^+{}_{in} + 3Na^+{}_{out} + ADP + P_i$$

	n	$\Delta\mu$	$\Delta G (kJ\ mol^{-1})$
$Na^+{}_{in} \rightarrow Na^+{}_{out}$	3		
$K^+{}_{out} \rightarrow K^+{}_{in}$	2		
$ATP + H_2O \rightarrow ADP + Pi$			

$$ATP + H_2O + 3Na^+{}_{in} + 2K^+{}_{out}$$
$$\rightarrow ADP + Pi + 3Na^+{}_{out} + 2K^+{}_{in}$$

Active transport

$$\Delta\mu = ZFV + RTln\frac{a_{in}}{a_{out}}$$

$Na^+{}_{in} \rightarrow Na^+{}_{out}$ $J\ mol^{-1}$

$$\Delta\mu = 1 \times 96485.3 \times -0.007 + 8.31447 \times 310 \times ln\frac{10}{140} = \quad J\ mol^{-1}$$

$K^+{}_{out} \rightarrow K^+{}_{in}$ $J\ mol^{-1}$

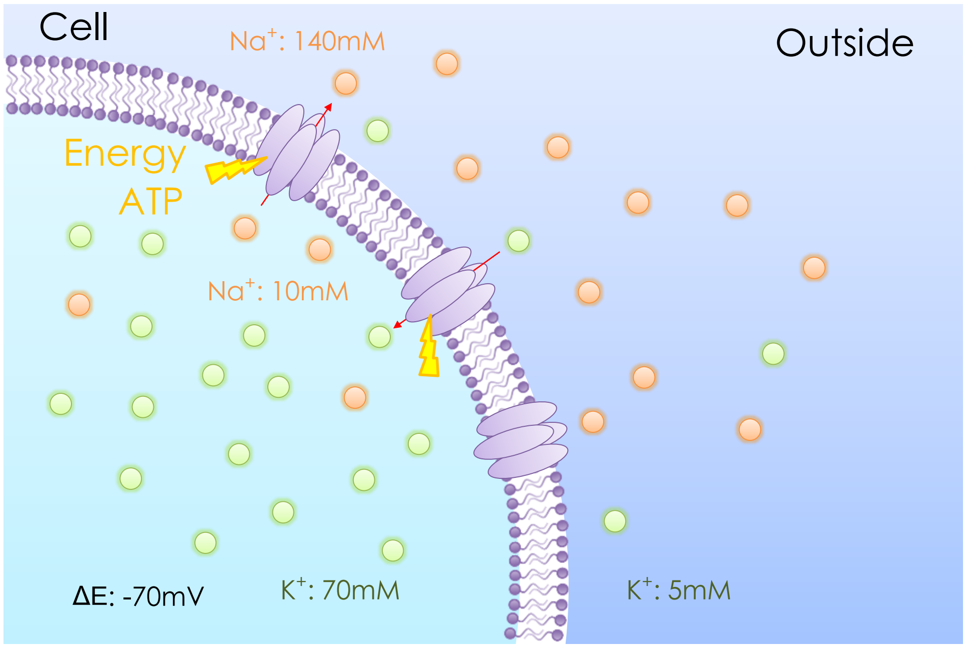
$$\Delta\mu = 1 \times 96485.3 \times -0.007 + 8.31447 \times 310 \times ln\frac{100}{5} = \quad J\ mol^{-1}$$

$$\Delta\mu = \Delta\mu^{\circ} + RTln\frac{[ADP][Pi]}{[ATP]}$$

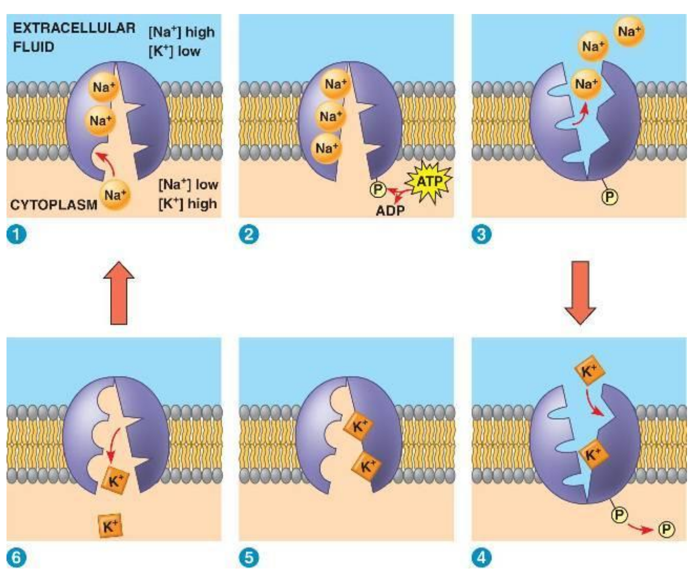
$ATP + H_2O \rightarrow ADP + Pi$ $J\ mol^{-1}$

$$\Delta\mu = -31300 + 8.31447 \times 310 \times \ln(0.001) = \quad J\ mol^{-1}$$

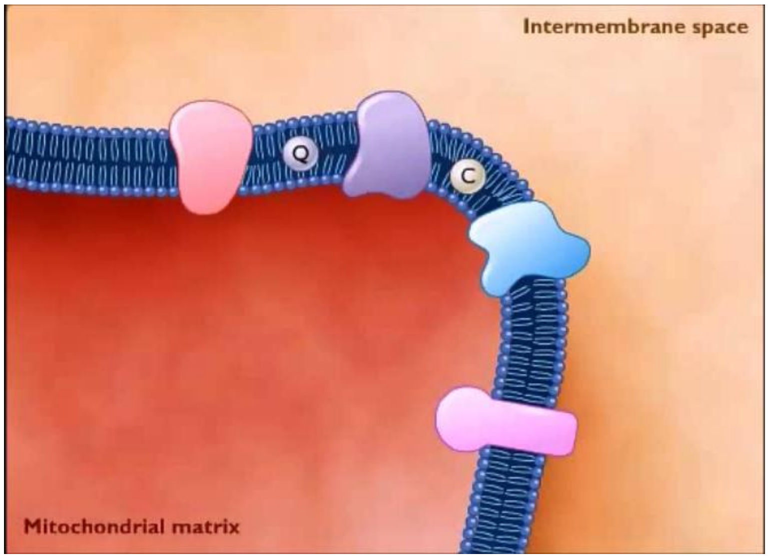
Active transport



Active transport



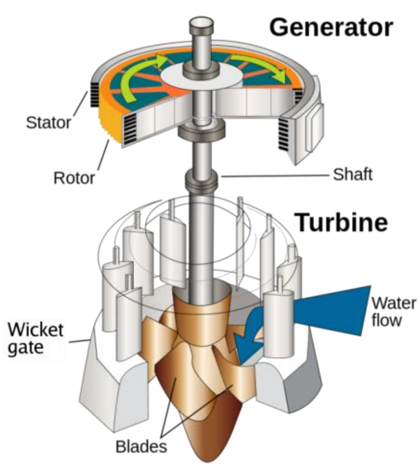
ATP synthesis in mitochondria



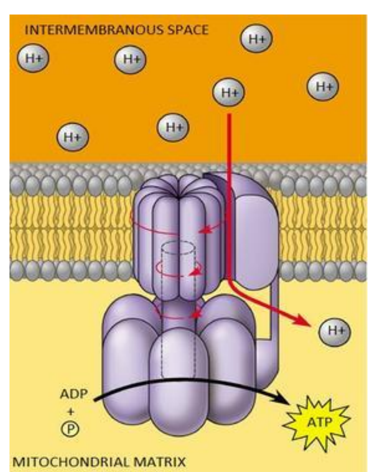
https://www.youtube.com/watch?v=6W-7FG9KlpA

Water turbine vs. ATP synthase

Potential energy (water)
Mechanical energy
Electrical energy



Potential energy (proton)
Mechanical energy
Chemical energy (ATP synthesis)



ATP synthase

$$ADP + Pi + 3\,{}^{1}/_{3}\,H^{+}{}_{out}$$
$$\rightarrow ATP + H_2O + 3\,{}^{1}/_{3}\,H^{+}{}_{in}$$

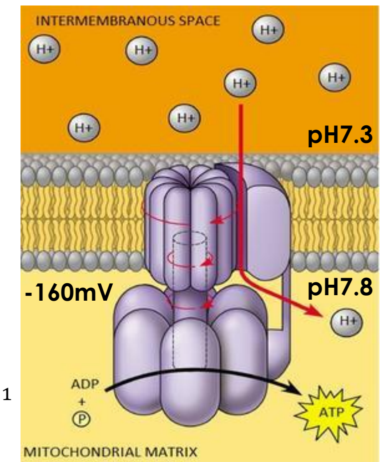
Potential energy (proton)
Mechanical energy
Chemical energy (ATP synthesis)

$$\Delta\mu = ZFV + RT\ln\frac{a_{in}}{a_{out}}$$
$$= ZFV - 2.303RT\Delta pH$$

$H^{+}{}_{out} \rightarrow H^{+}{}_{in}$ $\quad -18292\,J\,mol^{-1}$

$$\Delta\mu = 1 \times 96485.3 \times -0.16$$
$$-8.31447 \times 298.15 \times 2.303 \times 0.5$$
$$= -18292\,J\,mol^{-1}$$

$ADP + Pi \rightarrow ATP + H_2O$ $\quad 49133\,J\,mol^{-1}$



ATP synthase

$$ADP + Pi + 3\,{}^{1}/_{3}\,H^{+}{}_{out} \rightarrow ATP + H_2O + 3\,{}^{1}/_{3}\,H^{+}{}_{in}$$

	n	$\Delta\mu$	$\Delta G\,(kJ\,mol^{-1})$
$H^{+}{}_{out} \rightarrow H^{+}{}_{in}$			
$ADP + Pi \rightarrow ATP + H_2O$			
$ADP + Pi + 3\,{}^{1}/_{3}\,H^{+}{}_{out} \rightarrow ATP + H_2O + 3\,{}^{1}/_{3}\,H^{+}{}_{in}$			