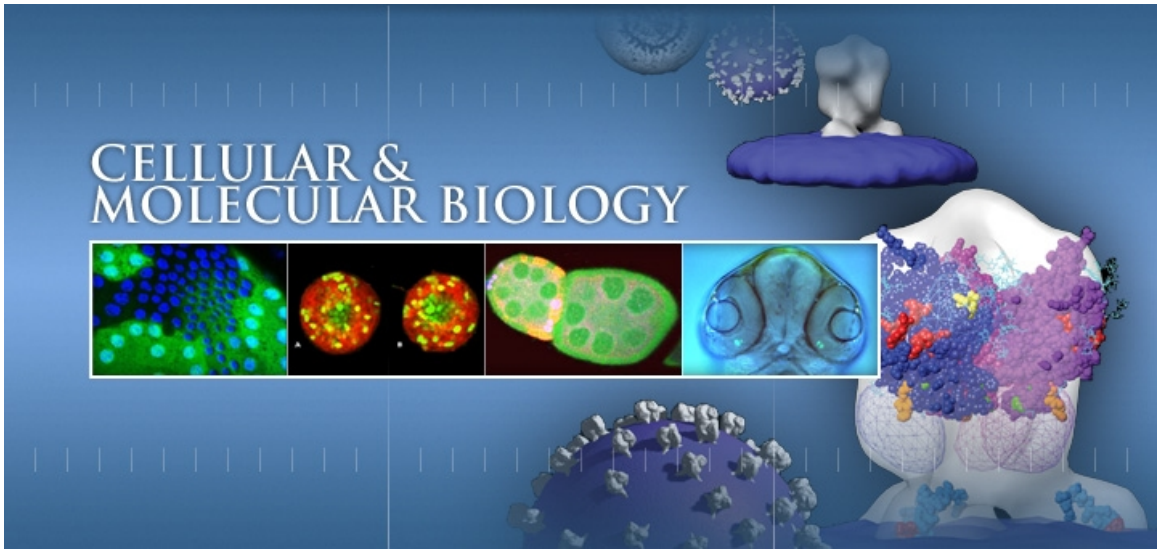
Summer term 2016
Nanobiophysics Module

Introduction to

Molecular and Cellular Biology



PLAN OF THE COURSE: OVERVIEW

Basics:

- **Organic chemistry and biochemistry of biomolecules**
- **Structure of biomolecules**
- **Principles in molecular and cell biology**
- **Cellular organization (compartmentalization)**
- **Protein networks in cellular structure and function**
- **Regulation of cell growth, differentiation and tissue-development**
- **Methods**

PLAN OF THE COURSE: TIMEFRAMES

2016 CALENDAR

DAYS:

APRIL		MAY		JUNE		JULY		AUGUST
Wed.	Thu.	Wed.	Thu.	Wed.	Thu.	Wed.	Thu.	FRI
6	7	4	-	-	2	6	7	5
13	14	11	12	8	9	13	14	
20	21	-	-	15	16			
27	28	25	26	22	23			
				29	30			

(-) official holidays

LECTURES & SEMINARS:

APRIL		MAY		JUNE		JULY		AUGUST
Wed.	Thu.	Wed.	Thu.	Wed.	Thu.	Wed.	Thu.	Friday 5th
L1	L2	L9	-	-	l14 + S4	L23	l24 + S9	ORAL EXAM
L3	L4	L10	l11 + S2	L15	l16 + S5	L25	l26 + S10	
L5	L6	-	-	L17	l18 + S6			
L7	l8 + S1	L12	l13 + S3	L19	l20 + S7			
				L21	l22 + S8			

L = Lecture 90 min. (2 x 45 min.)
l = Lecture 45 min.
S = Seminar 45 min. (2 student presentations x 20 min. each)

TIMES & Location:

- *Lectures (Wed.): 9:00 –10:30 (Room E05)*
- *lectures (Thu.): 9:20 - 10:05 (Room E05)*
- *Seminars (Thu.): 10:10 – 10:50 (Room E05)*

EXAMINATION: **Oral examination (20')**
5.08.2016

PLAN OF THE COURSE: TIMEFRAMES

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5.08.2016

Cancelled: 9.06, 15.06, 16.06 **Substitution: 23.06, 30.06, 07.07 (11:10-12:40)**

PLAN OF THE COURSE: LECTURES

- Introduction to cell chemistry and biosynthesis I-III (L1-L6)
- Cell organization I-III (L7 + I8 + L9 + L10 + I11)
- Cellular nucleus (L12 + I13)
- Cell membrane (I14 + L15 + I16)
- Vesicular transport (L17 + I18)
- Cellular signaling (L19 + I20)
- Cell cycle I-II (L21 + I22 + L23 + I24)
- Cell junctions & adhesion

PLAN OF THE COURSE: SEMINARS

- **Research papers related to lectures**

- **Presentation of the paper: MAX 15'+5'**
  - Introduction (Motivation)
  - Methodology
  - Results + Conclusions
  - *Critics: strong/weak points

- **Questions and discussion**

LITERATURE

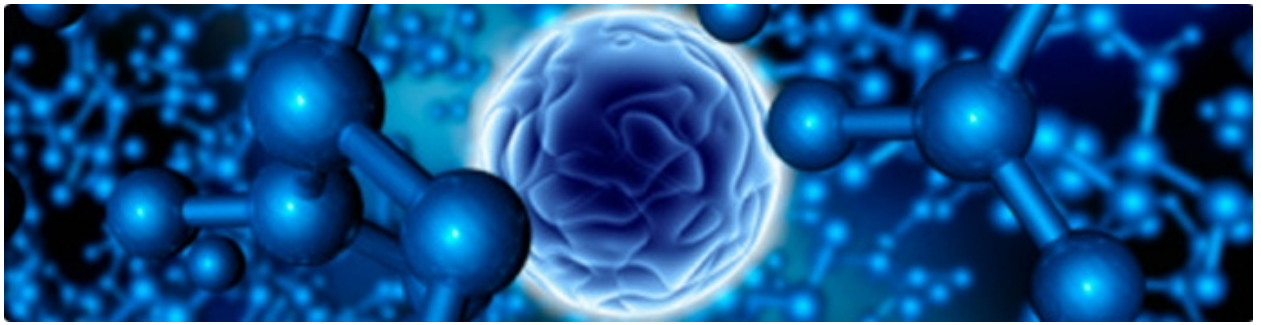
- Molecular Biology of the Cell (Alberts)
- Principles of Biochemistry (Lehninger)
- Essentials of Glycobiology (Cummings)
- Proteins, structure and function (Whitford)
- Protein-lipid interactions (Tamm)
- Nucleic acid in chemistry and biology (Blackburn)
- Protein-nucleic acid interactions (Rice & Correll)
- PubMed, Wikipedia etc.

Summer term 2016
Nanobiophysics Module

Introduction to Molecular and Cellular Biology

LECTURE 1:

Introduction to cell chemistry and biosynthesis I

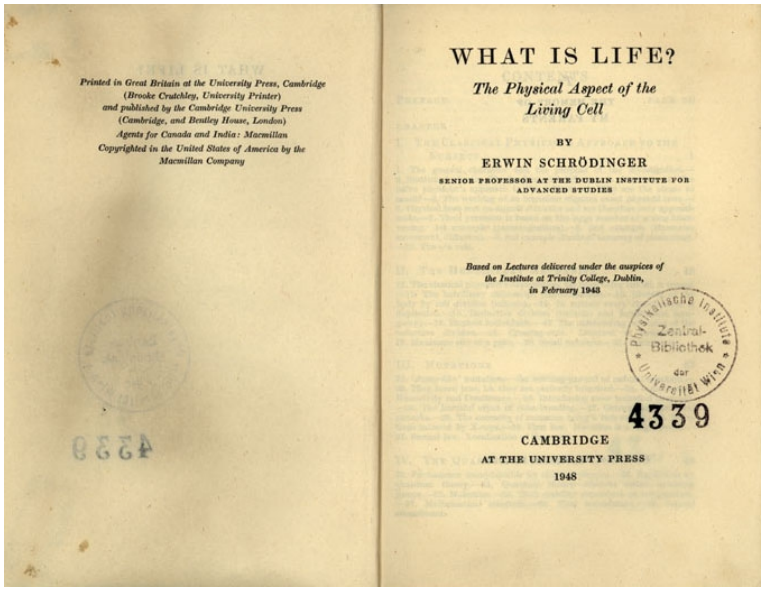


LECTURES 1: INTRODUCTION TO CELL CHEMISTRY AND BIOSYNTHESIS I

- Living vs. non-living systems: what is life?
- Chemistry of living systems
- Levels of organizations in biology:
  - atom: their basic properties, elements in living systems
  - molecule: covalent bonds and non-covalent interactions
  - macromolecules in living systems and the role of wat
  - organelle: types and properties
  - cell
  - tissue: types and properties
  - organ
  - organism

WHAT IS LIFE?

Erwin Schrödinger (1887-1961)



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(Brooke Crutchley, University Printer)
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WHAT IS LIFE?

The Physical Aspect of the Living Cell

BY

ERWIN SCHRÖDINGER

SENIOR PROFESSOR AT THE DUBLIN INSTITUTE FOR ADVANCED STUDIES

Based on Lectures delivered under the auspices of the Institute at Trinity College, Dublin, in February 1943

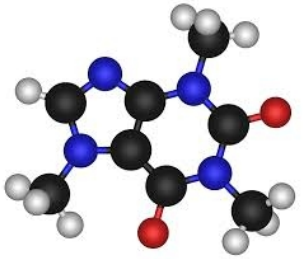
CAMBRIDGE
AT THE UNIVERSITY PRESS
1948

Cambridge University Press, 1944

"How can the events in space and time which take place within the spatial boundary of a living organism be accounted for by physics and chemistry?"

- **Order from disorder**
- **Hereditory rules vs. classical physics**
- **A molecule carrying information in evolution, 'atypical crystal'**
- **'Other physics'**
- **Free will, quantum chemistry and determinism**
- **Schrödinger's paradox**

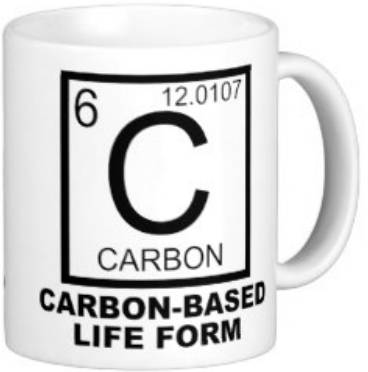
LIVING vs. NON-LIVING



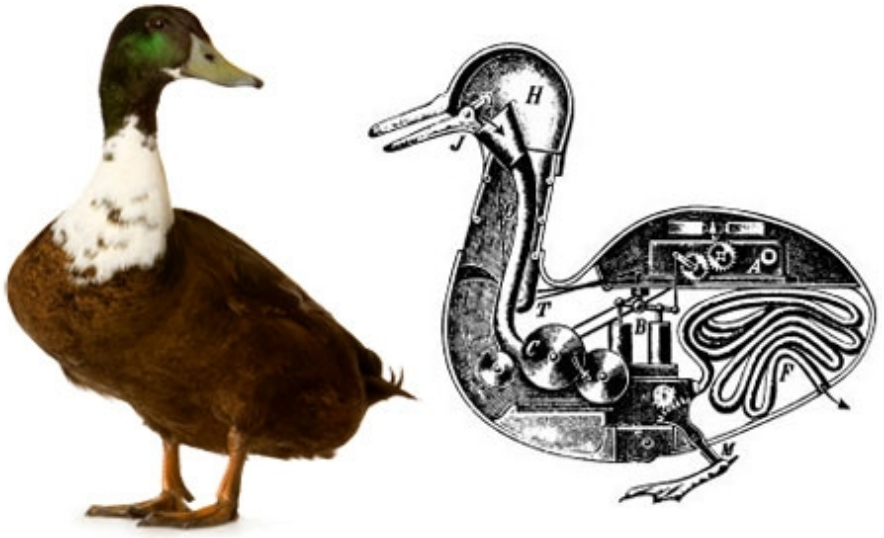
- Different levels of structured orders
- Consumation of the energy from outside (open systems)
- Reaction to the changes in the environment
- Evolution
- Reproduction
- Protein-based existance
- Self-regulation
- Movement towards order (minimum of entropy)
- Exchange of the substances with the environment

CHEMISTRY OF LIVING SYSTEMS

- The life is carbon-based
- All processes are carried out aqueous solution
- Enormous complexity
- Dominance of polymeric molecules



REDUCTIONISM



Decartes, 1662: automata

- **Ontological reductionism**
- **Methodological reductionism**
- **Theory reductionism**

LEVELS OF ORGANIZATION IN BIOLOGY

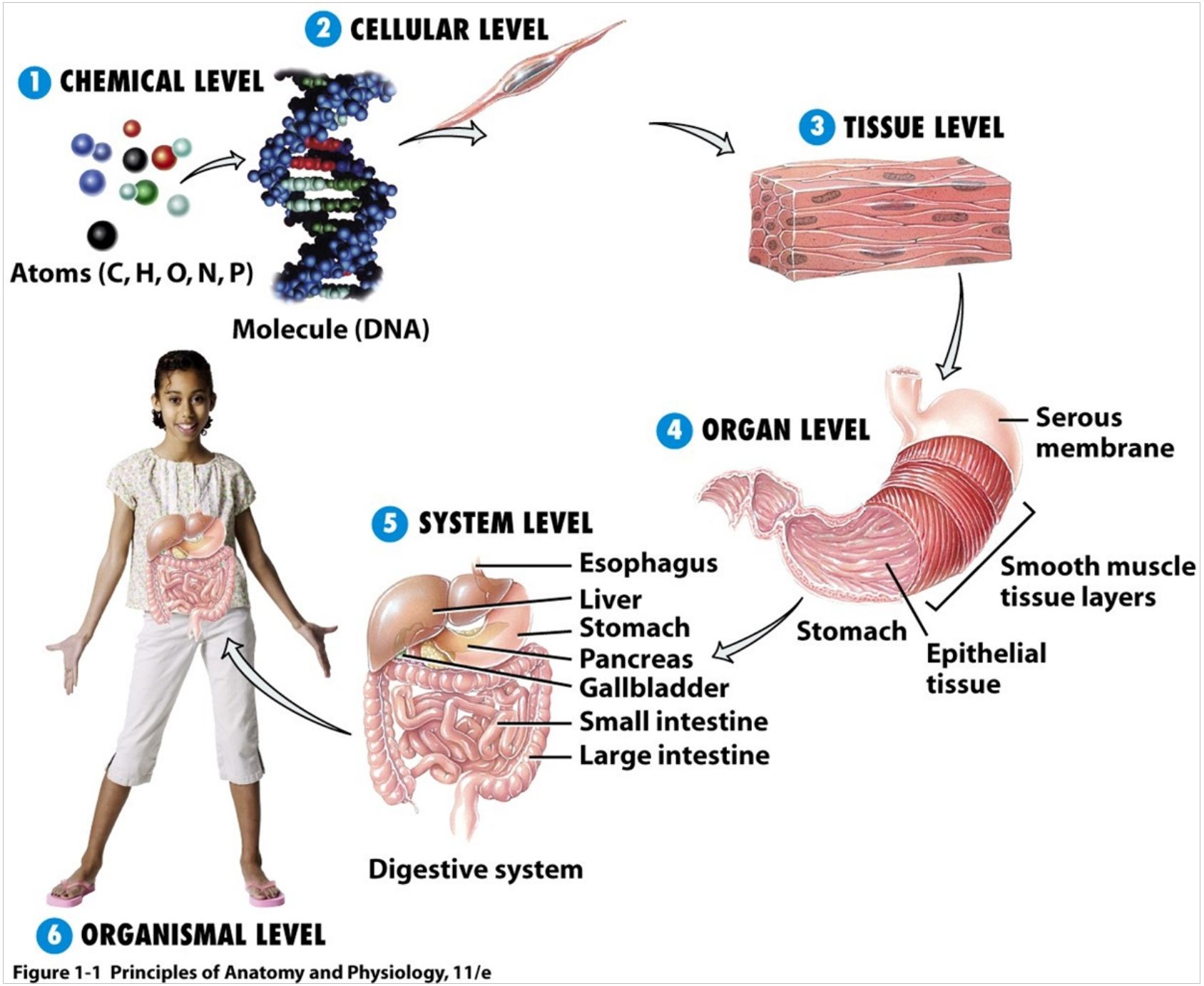
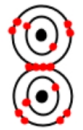
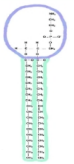
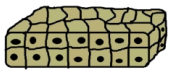


Figure 1-1 Principles of Anatomy and Physiology, 11/e

LEVELS OF ORGANIZATION IN ORGANISM

- Atoms
- Molecules
- Macromolecules
- Organelles
- Cells
- Tissue
- Organ
- Organ system
- Organism
- ...




LEVELS OF ORGANIZATION IN ORGANISM

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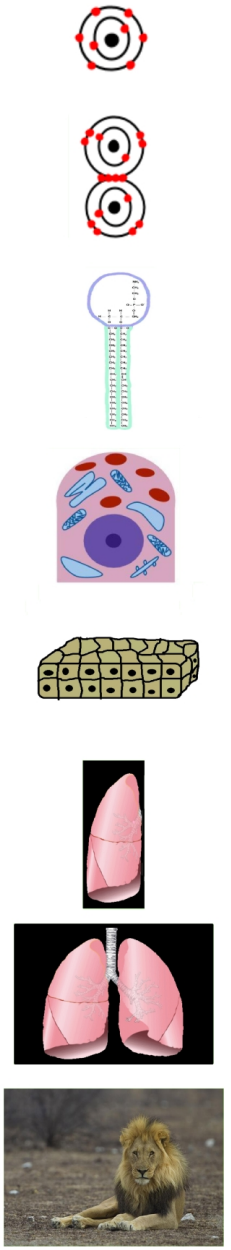


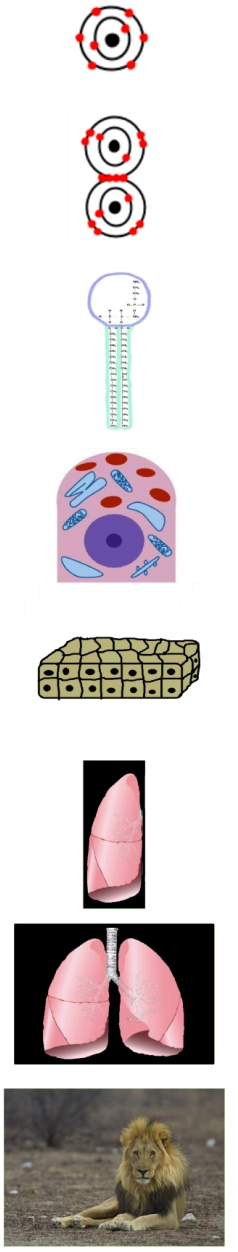
Focus of the course

LEVELS OF ORGANIZATION IN ORGANISM

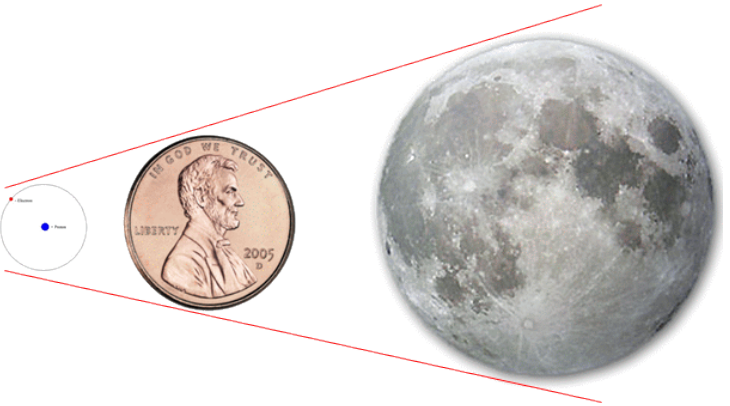
- **Atoms** ~ 10^{-10}-10^{-9} m
- **Molecules** ~ 10^{-9} – 10^{-8} m
- **Macromolecules** ~ 10^{-8} – 10^{-7} m
- **Organelles** ~ 10^{-7} – 10^{-5} m
- **Cells** ~ 10^{-5} – 10^{-4} m
- **Tissue**
- **Organ**
- **Organ system**
- **Organism**

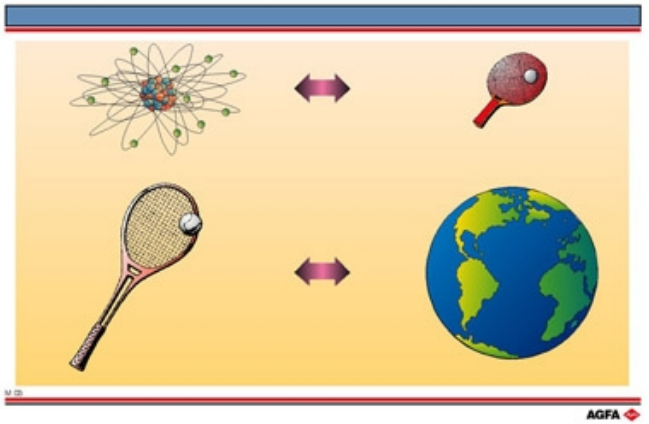
} ~ 10^{-3} – 10^{1} m

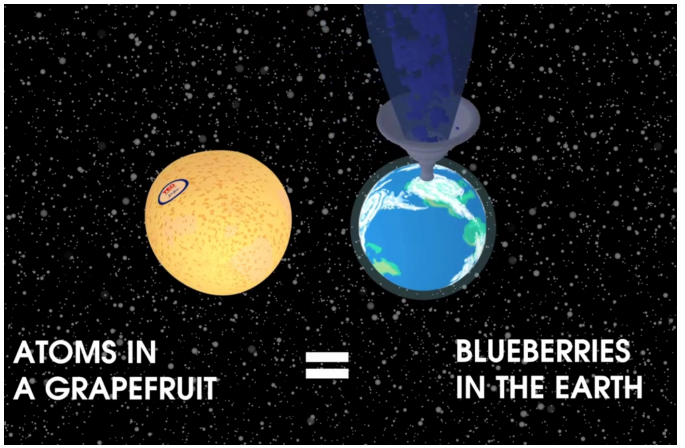
- **...**



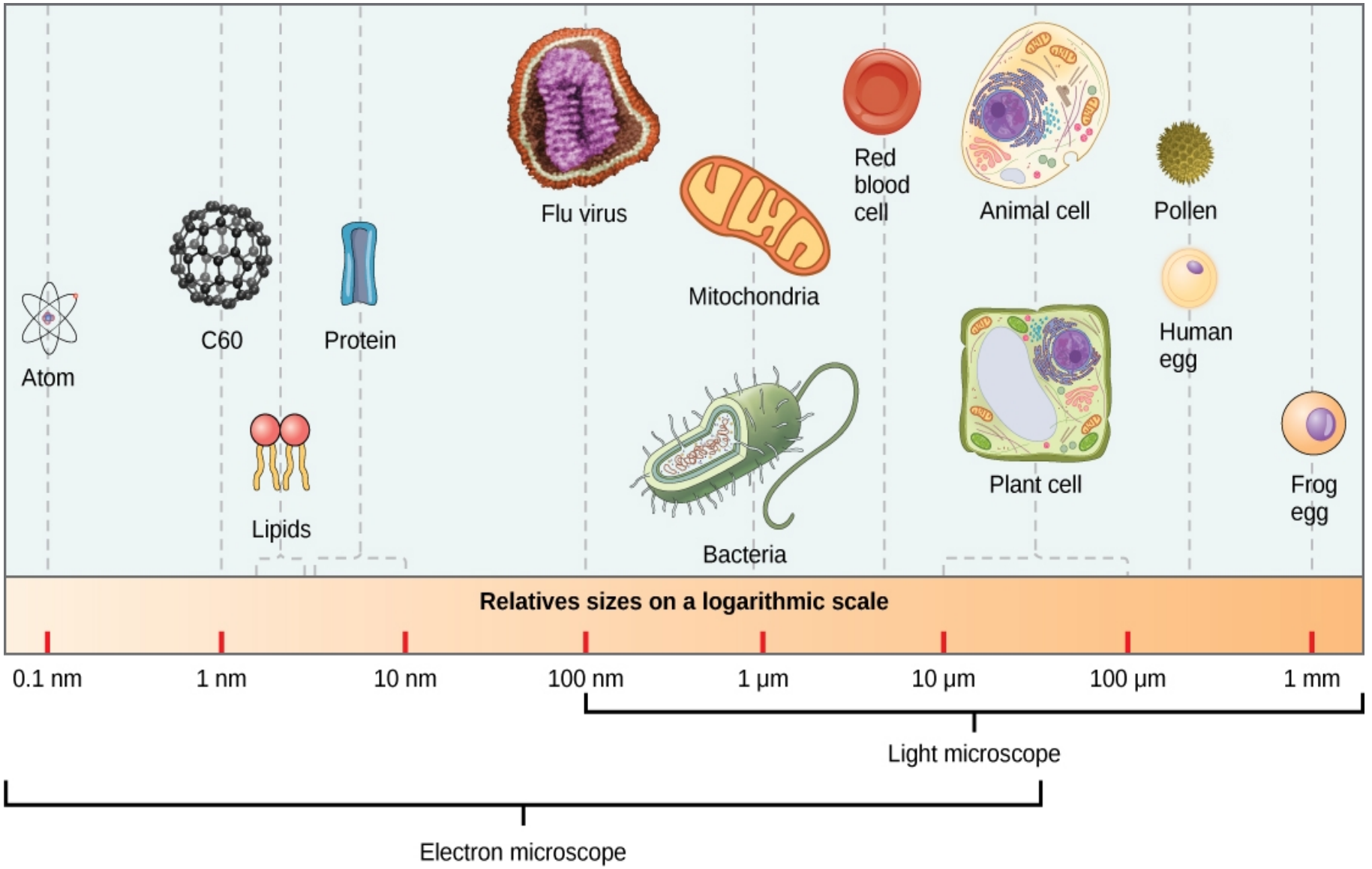
DISTANT SCALES COMPARISON



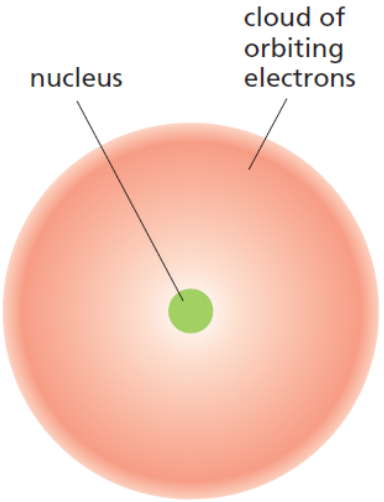




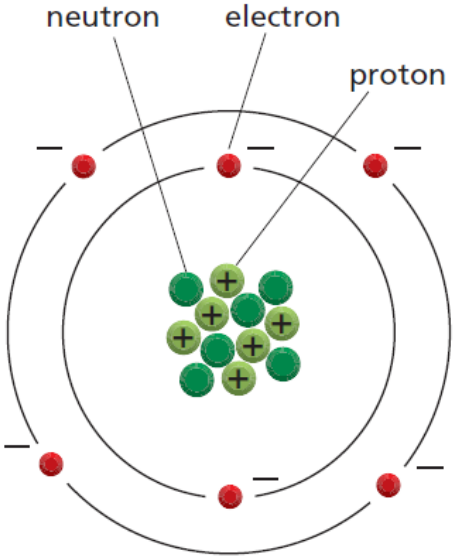
LEVELS OF ORGANIZATION IN ORGANISM



ATOMS

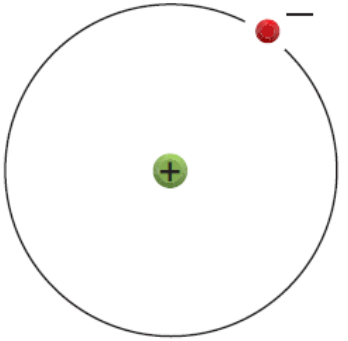


Nucleus ~ 10^{-14} m



carbon atom

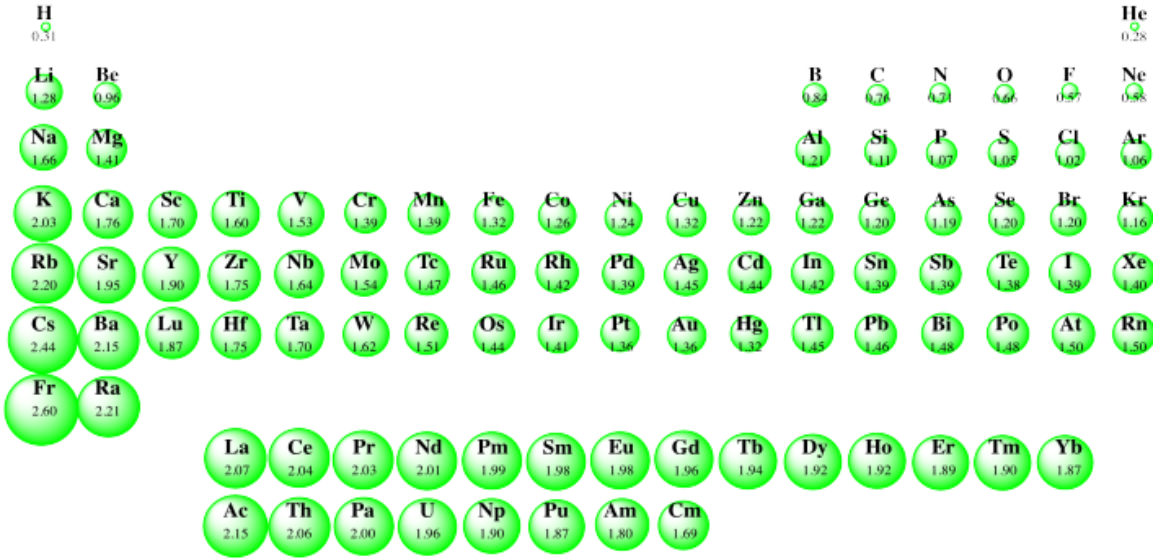
atomic number = 6
atomic weight = 12



hydrogen atom

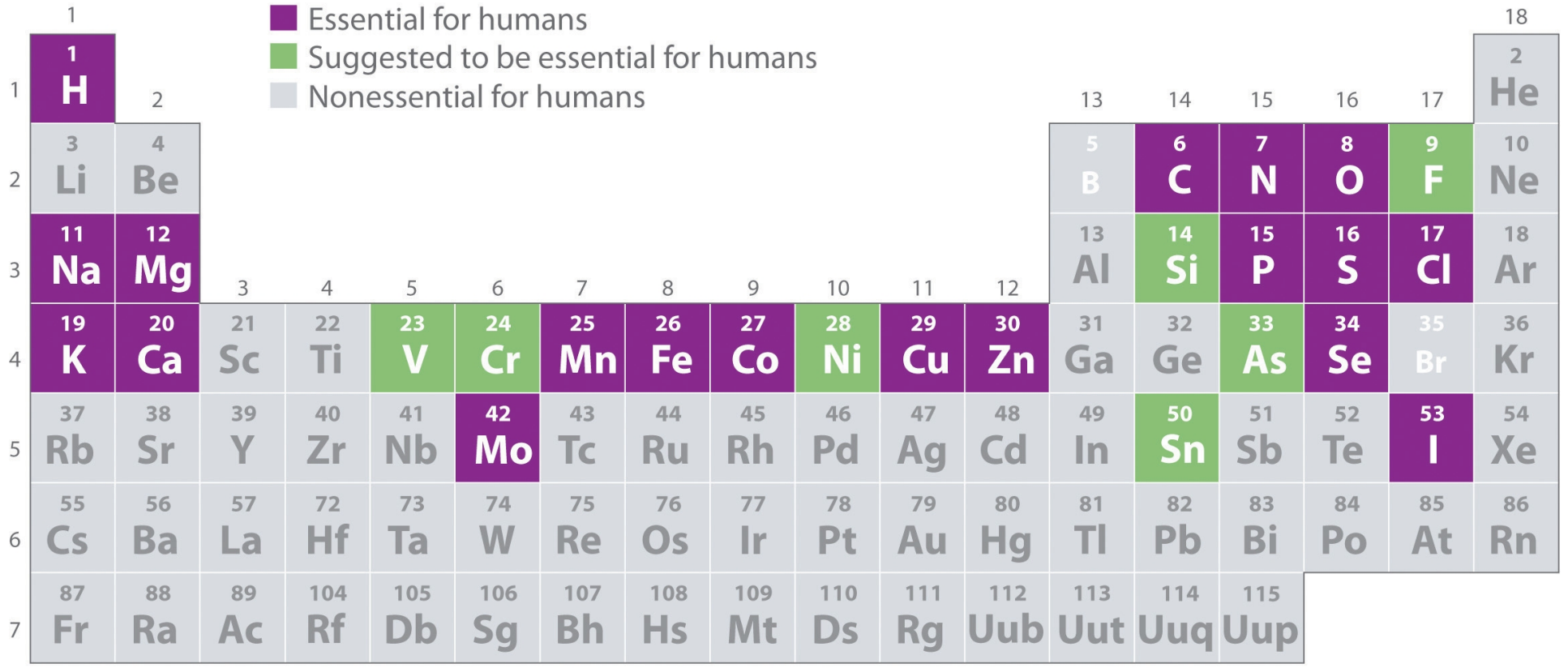
atomic number = 1
atomic weight = 1

Periodic Table of the Elements



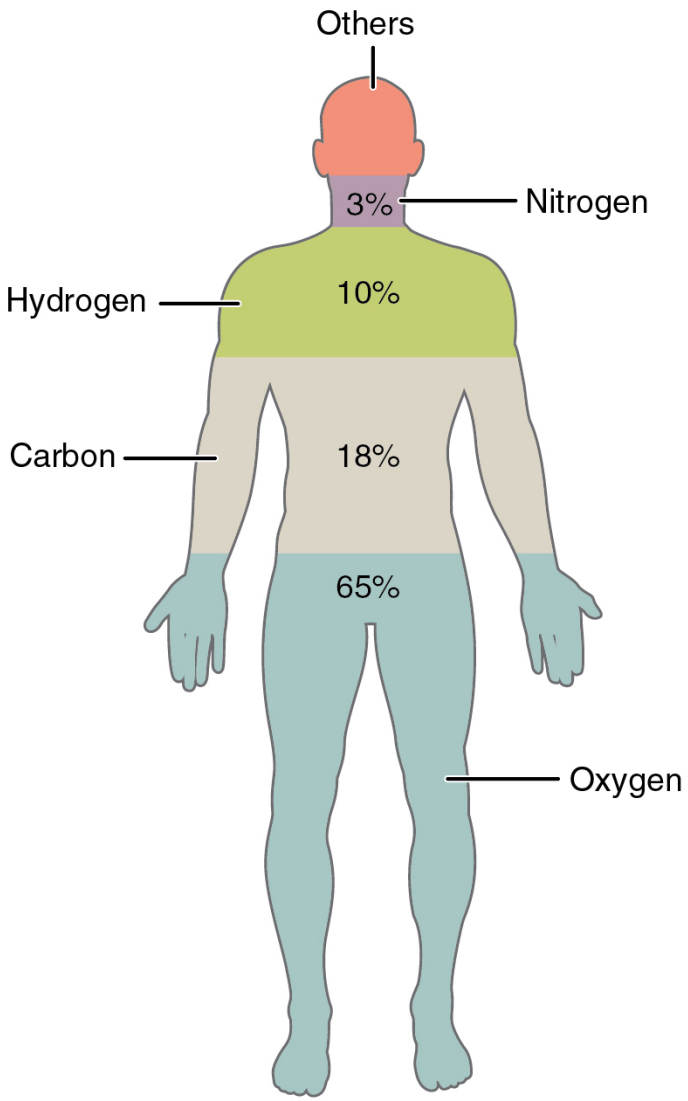
Atom radius ~ 10^{-10} m

ELEMENTS IN BIOLOGICAL SYSTEMS



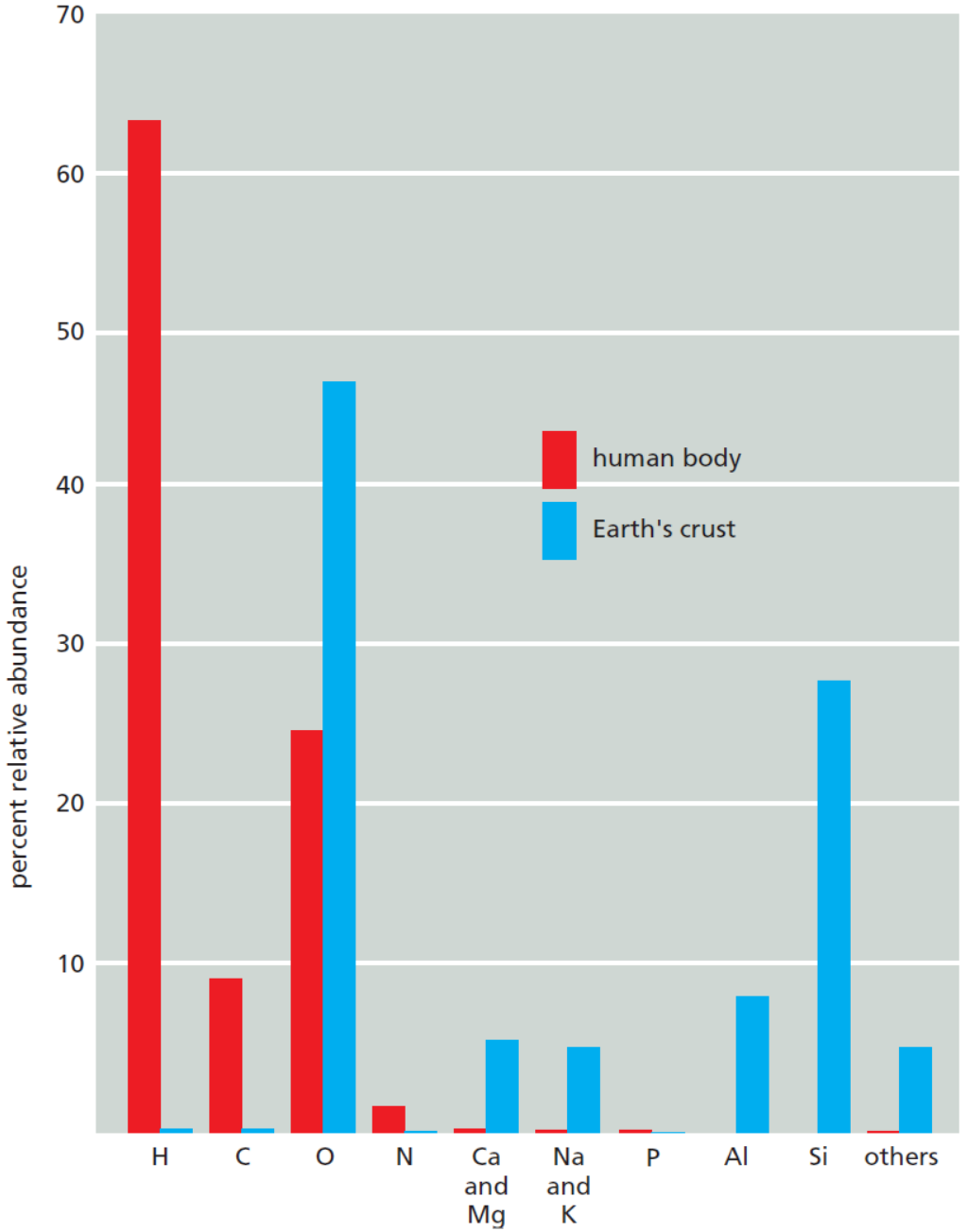
96.5%: C, H, N, O

ELEMENTS IN BIOLOGICAL SYSTEMS

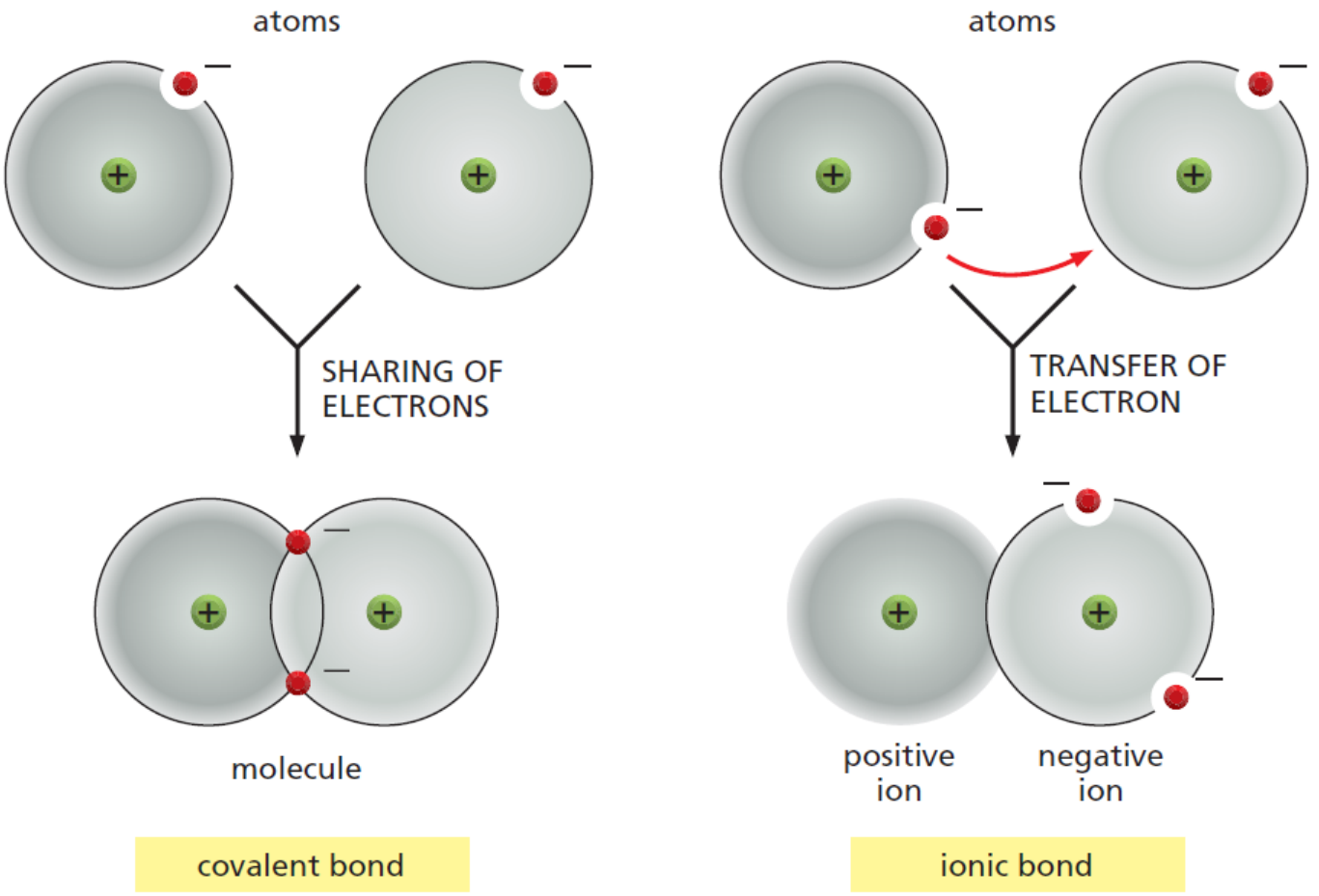


Element	Symbol	Percentage in Body
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.2
Calcium	Ca	1.5
Phosphorus	P	1.0
Potassium	K	0.4
Sulfur	S	0.3
Sodium	Na	0.2
Chlorine	Cl	0.2
Magnesium	Mg	0.1
Trace elements include boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).		less than 1.0

ELEMENTS IN BIOLOGICAL SYSTEMS vs. TOTAL



COVALENT AND IONIC BONDS

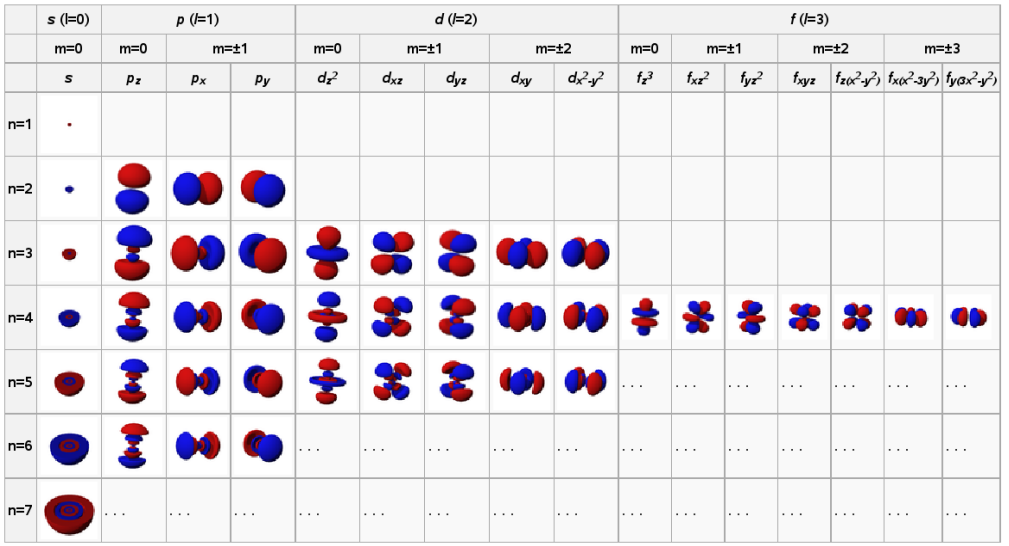


COVALENT BONDS

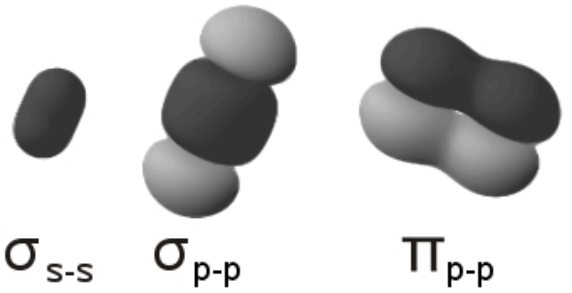
atomic number ↓

electron shell

	element	I	II	III	IV
1	Hydrogen	●			
2	Helium	●●			
6	Carbon	●●	●●●●		
7	Nitrogen	●●	●●●●●		
8	Oxygen	●●	●●●●●●		
10	Neon	●●	●●●●●●●●		
11	Sodium	●●	●●●●●●●●	●	
12	Magnesium	●●	●●●●●●●●	●●	
15	Phosphorus	●●	●●●●●●●●	●●●●●	
16	Sulfur	●●	●●●●●●●●	●●●●●●	
17	Chlorine	●●	●●●●●●●●	●●●●●●●	
18	Argon	●●	●●●●●●●●	●●●●●●●●	
19	Potassium	●●	●●●●●●●●	●●●●●●●●	●
20	Calcium	●●	●●●●●●●●	●●●●●●●●	●●



- **Atomic orbitals => molecular orbitals**



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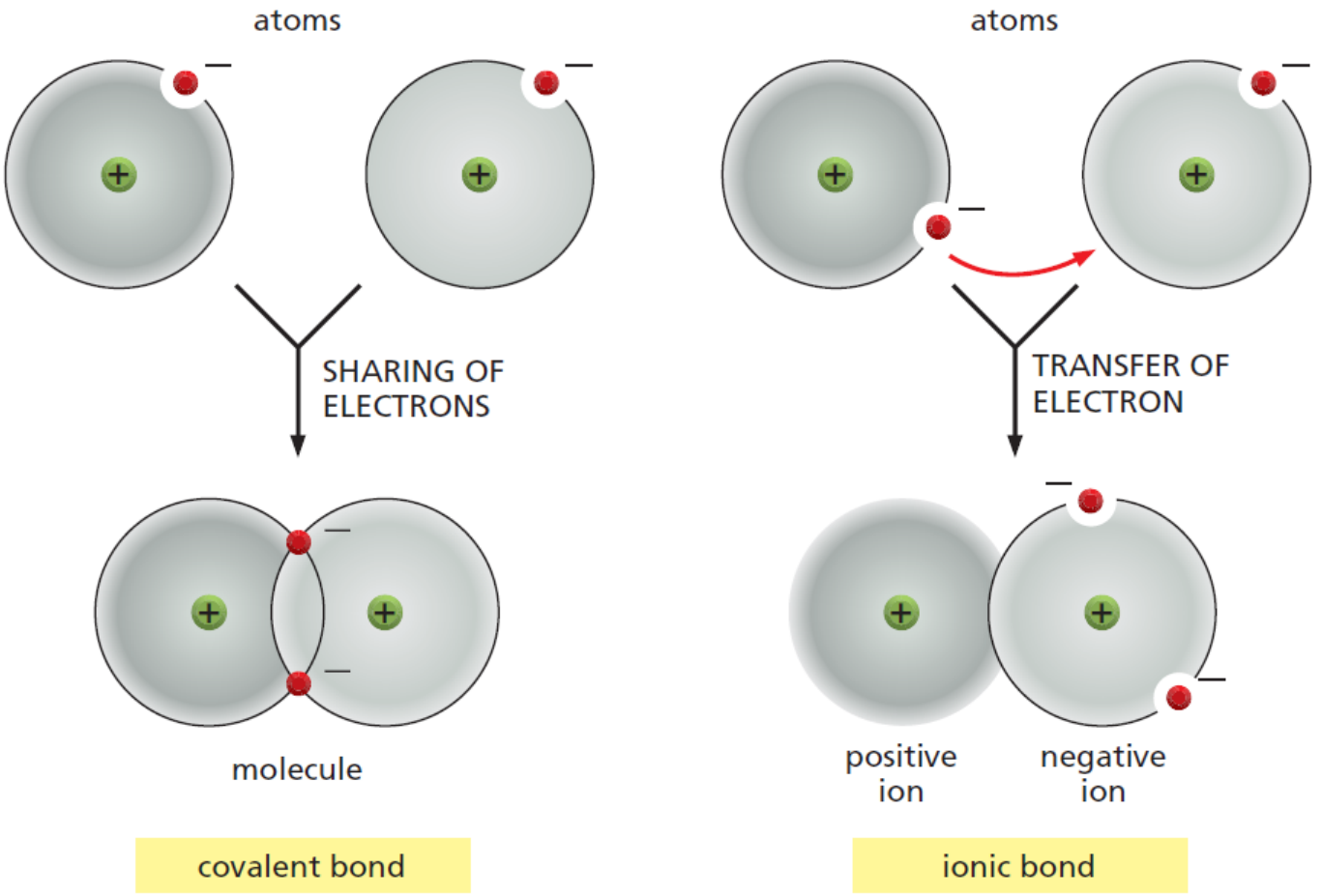
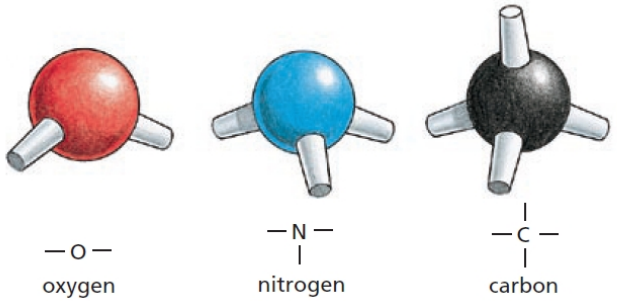
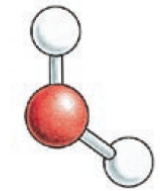


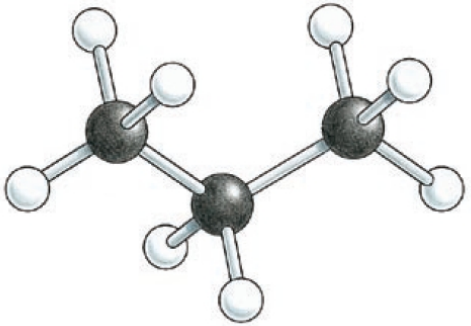
- **Electronegativity**
- **Valence**

TYPES OF COVALENT BONDS

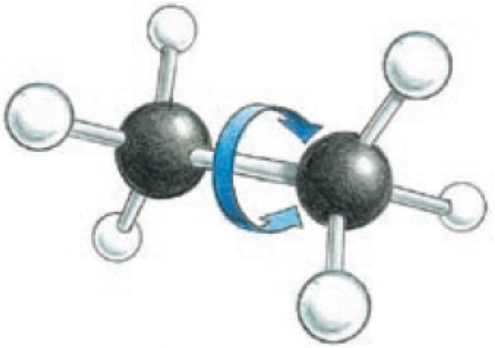




water (H_2O)

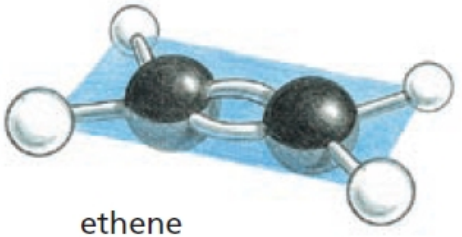


propane (CH_3-CH_2-CH_3)



ethane

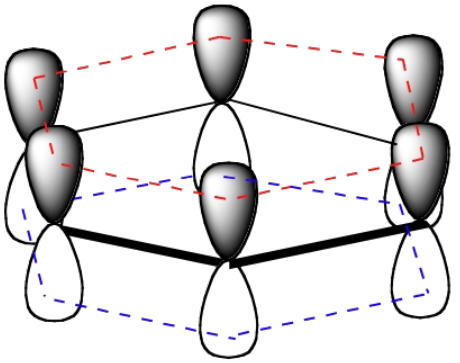
2 common electrons



ethene

4 common electrons

- **Single/double/aromatic**
- **Polar/non-polar**

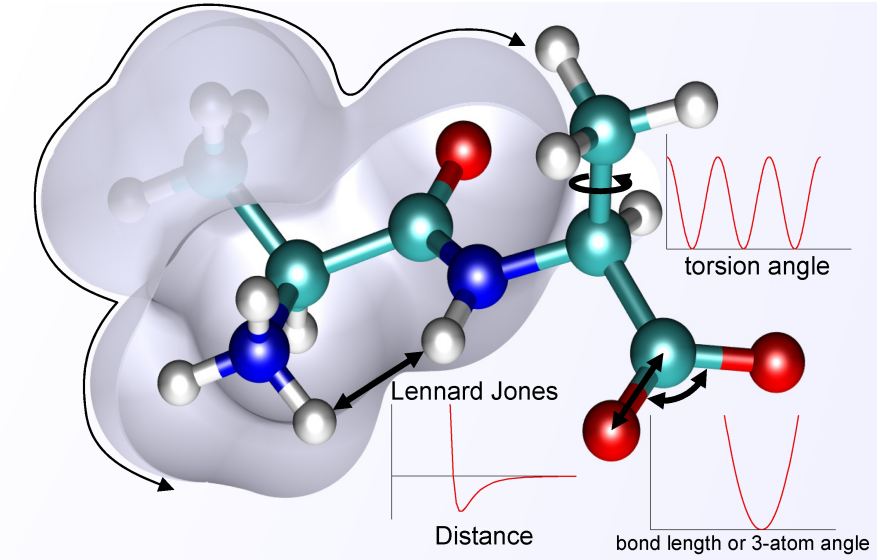


π electrons delocalized around the ring, above and below the plane

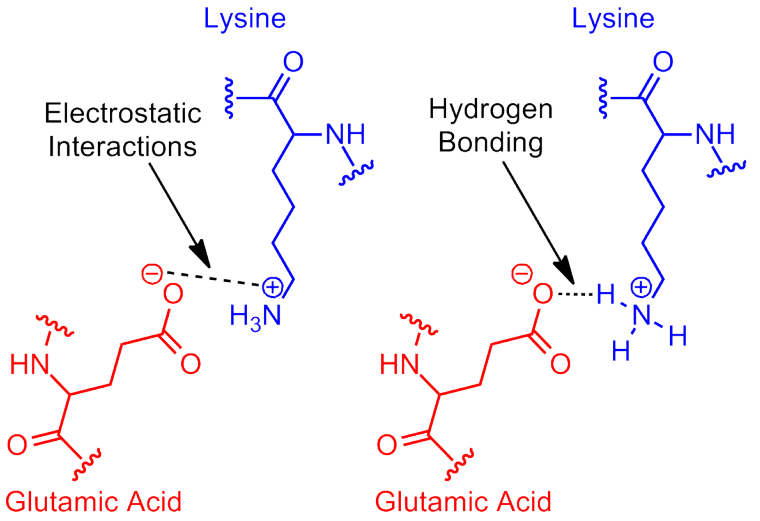
INTERATOMIC INTERACTIONS

$$V(\vec{r}) = \sum_{bonds} K_r (r - r_{eq})^2 + \sum_{angles} K_\theta (\theta - \theta_{eq})^2 + \sum_{dihedrals} \frac{V_n}{2}(1 + \cos[n\phi - \gamma]) + \sum_{i<j}^{atoms} \left(\frac{A_{ij}}{R_{ij}^{12}} - \frac{B_{ij}}{R_{ij}^{6}}\right) + \sum_{i<j}^{atoms} \frac{q_i q_j}{\epsilon R_{ij}}$$

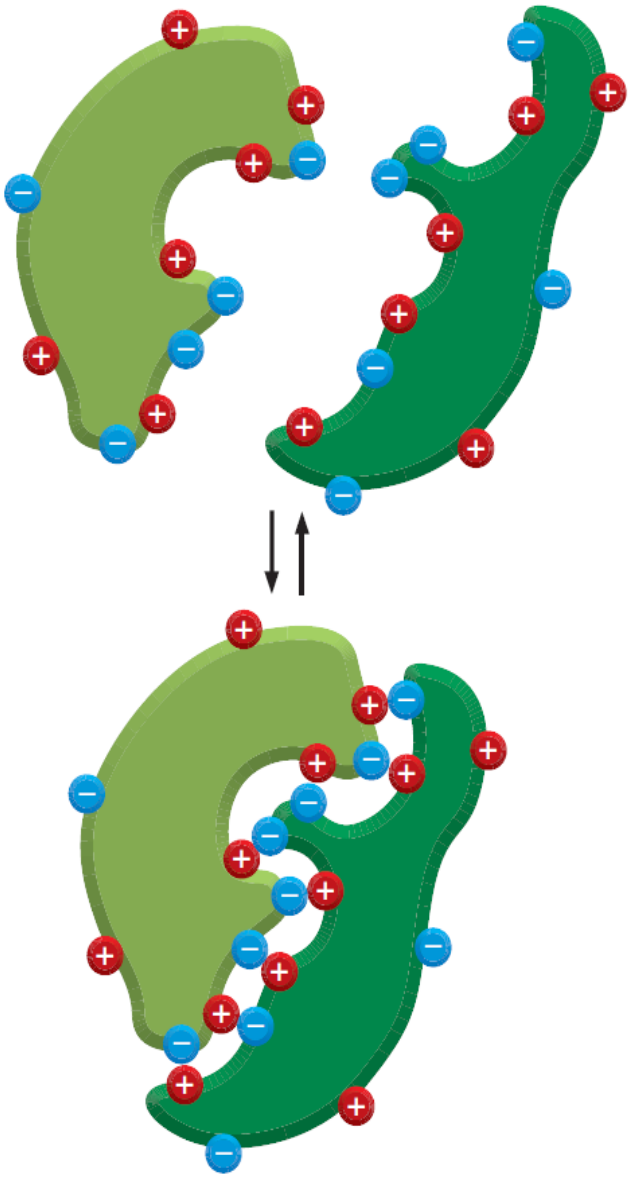
$$\vec{F}_i = \frac{-\delta V}{\delta \vec{r}_i}$$



- **Covalent bonds**
- **Non-covalent bonds:**
  - **electrostatic = ionic bonds + H-bonds**
  - **van der Waals**
- **Hydrophobic**



SCHEME OF INTERMOLECULAR INTERACTION



STRENGTH OF INTERATOMIC INTERACTIONS

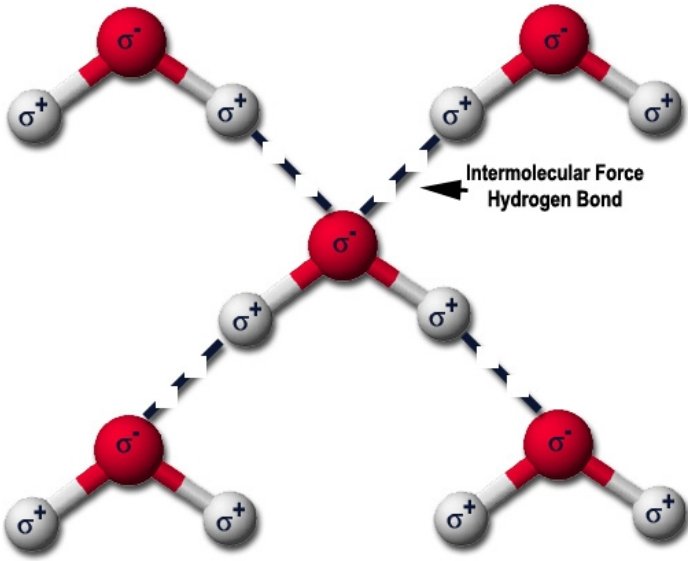
			STRENGTH IN kcal/mole	
BOND TYPE		LENGTH (nm)	IN VACUUM	IN WATER
Covalent		0.15	90 (377)**	90 (377)
Noncovalent:	ionic bond*	0.25	80 (335)	3 (12.6)
	hydrogen bond	0.30	4 (16.7)	1 (4.2)
	van der Waals attraction (per atom)	0.35	0.1 (0.4)	0.1 (0.4)

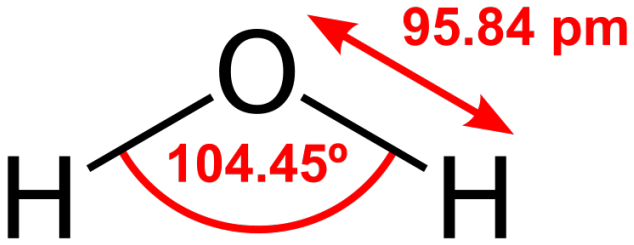
*An ionic bond is an electrostatic attraction between two fully charged atoms.
**Values in parentheses are kJ/mole. 1 calorie = 4.184 joules.

kT~0.6 kcal/mol (T= 300 K)

WATER: UNIQUE PROPERTIES

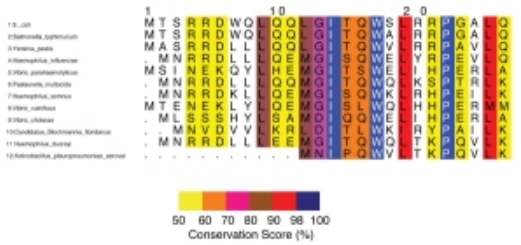
- Three-dimensional tetrahedral H-bonding networks
- High boiling and freezing temperatures, vaporization enthalpy, surface tension
- Fluidity increases with increased pressure
- High dielectric constant (~80)
- Different crystal forms
- Volumetric anomalities (ice density < liquid water density)
- $2H_2O \leftrightarrow H_3O^+ + OH^-$; $K_w = 10^{-14}$ at 25ºC
- 1.52% of Earth, 70% of cell, 90% of human

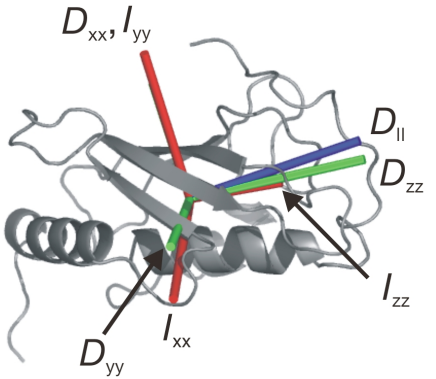


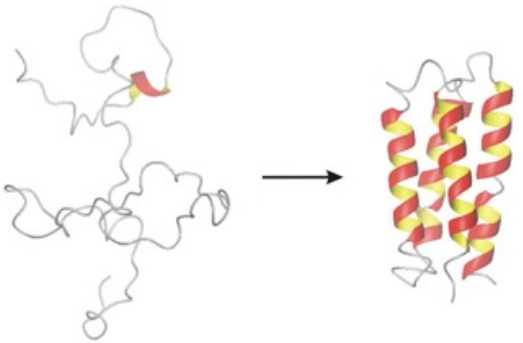


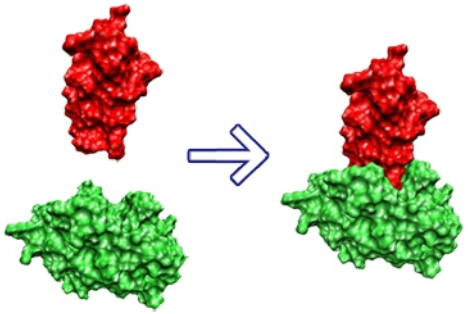
WATER: FUNCTION IN CELL

- Environment
- Structural conservation
- Dynamics
- Folding
- Molecular recognition
- Catalytic activity

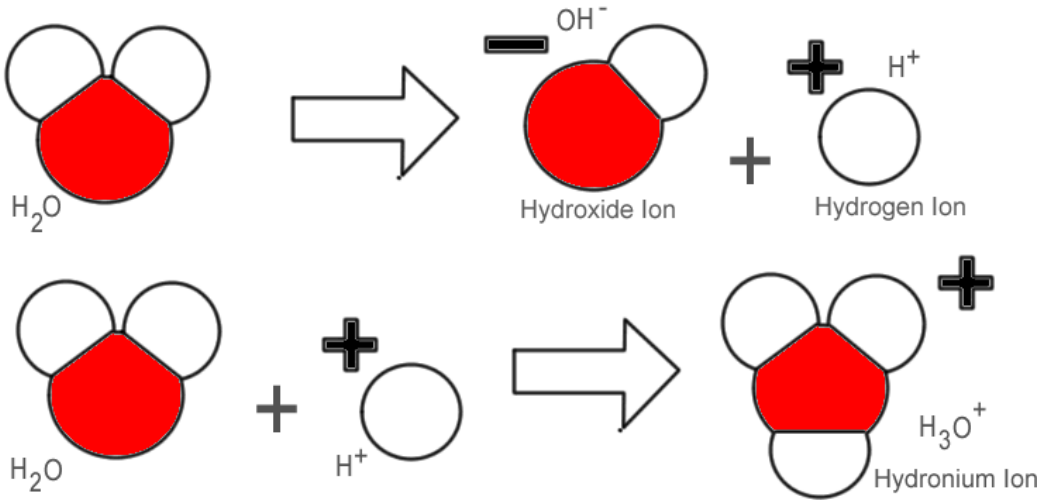




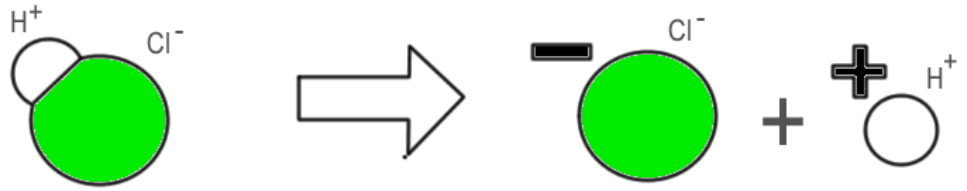




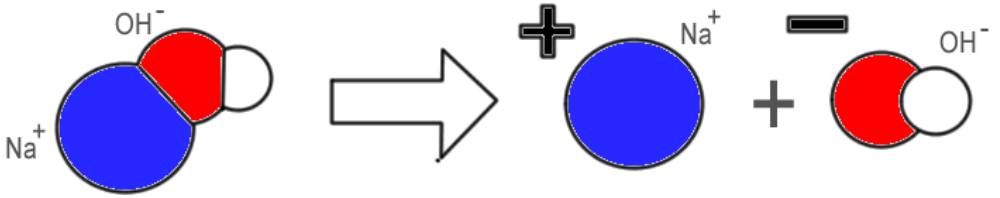
POLAR MOLECULES IN WATER



Hydrochloric Acid



Sodium Hydroxide



$$HA + H_2O \rightleftharpoons A^- + H_3O^+$$

$$K_a = \frac{[A^-][H_3O^+]}{[HA][H_2O]}$$

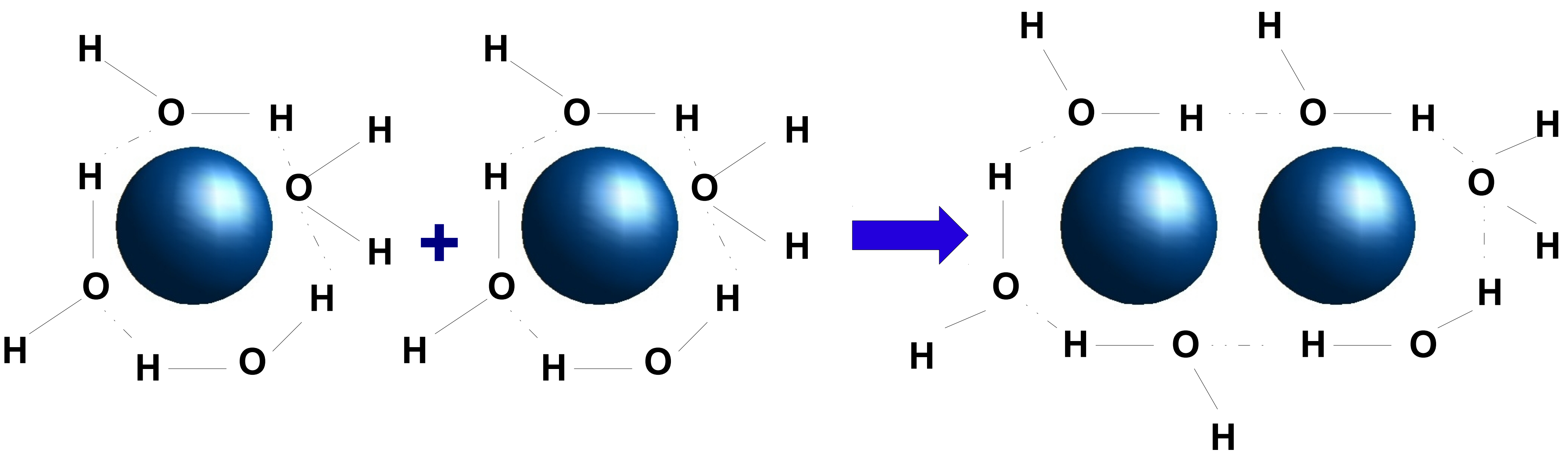
$$HA \rightleftharpoons A^- + H^+ : K_a = \frac{[A^-][H^+]}{[HA]}$$

$$pK_a = -\log_{10} K_a$$

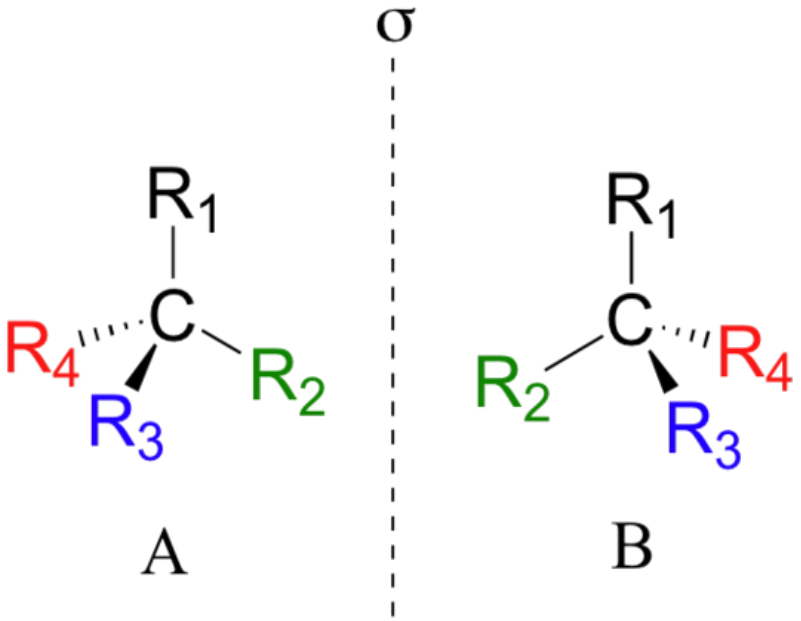
HYDROPHOBIC EFFECT

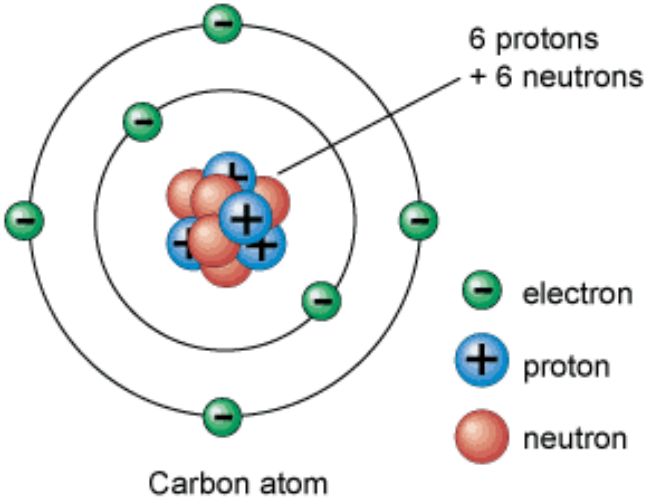
- [CH_4] above water surface = 10 [CH_4] in water
- 90% of work spent on protein folding
- Hydrophobic molecules:
  - disturb H-bonds
  - do no create H-bonds themselves

→ **Entropic nature**



CARBON-BASED MOLECULES





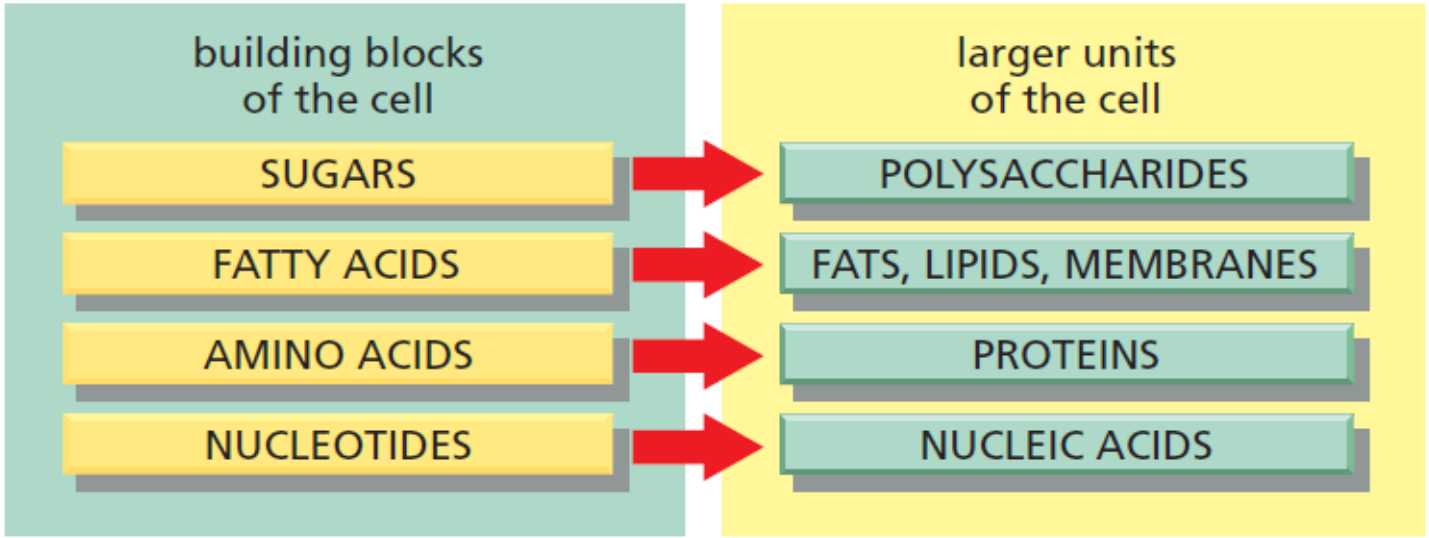
- **Bonds**
  - **Singel**
  - **Double**
  - **(Triple)**
  - **Aromatic**
- **Tetrahedrality => chirality**

^{12}C

MOLECULES IN CELL

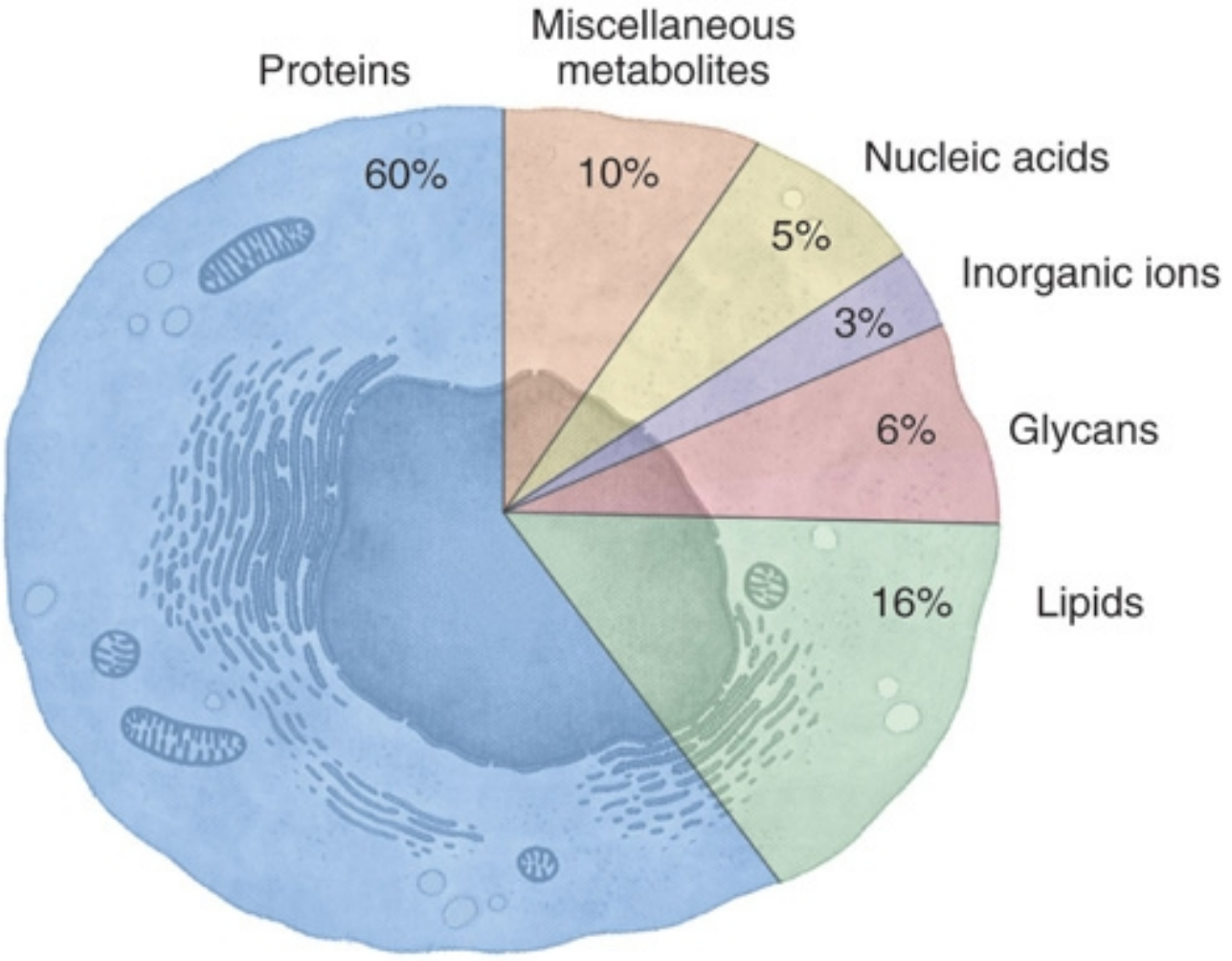
- Chemical classes
- Periodicity
  - Monomers
  - Oligomers
  - Polymers
- Localization
- Function
- Pathways

	PERCENTAGE OF TOTAL CELL WEIGHT	NUMBER OF TYPES OF EACH MOLECULE
Water	70	1
Inorganic ions	1	20
Sugars and precursors	1	250
Amino acids and precursors	0.4	100
Nucleotides and precursors	0.4	100
Fatty acids and precursors	1	50
Other small molecules	0.2	~300
Macromolecules (proteins, nucleic acids, polysaccharides, and phospholipids)	26	~3000



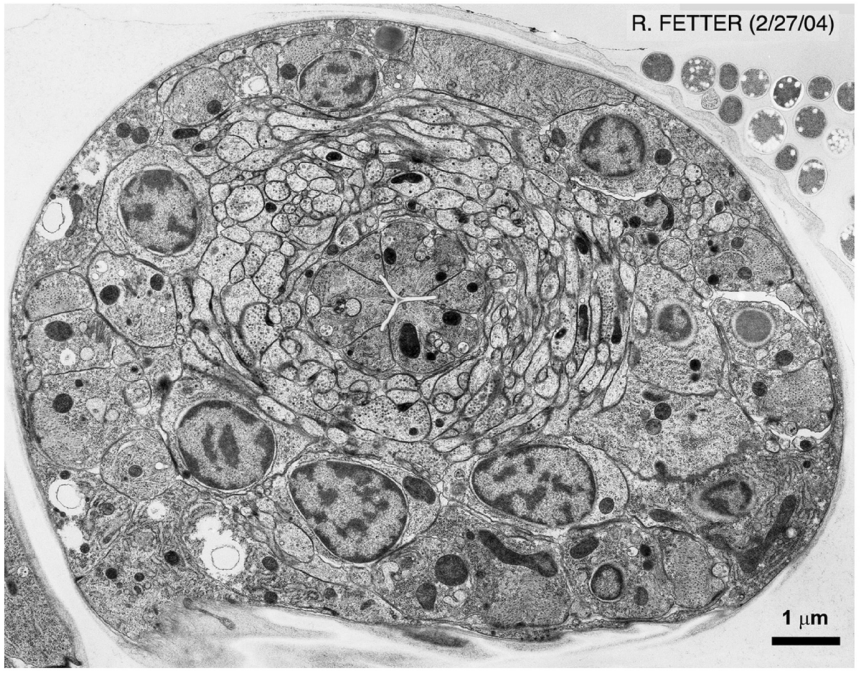
Molecules **Macromolecules**

MACROMOLECULES

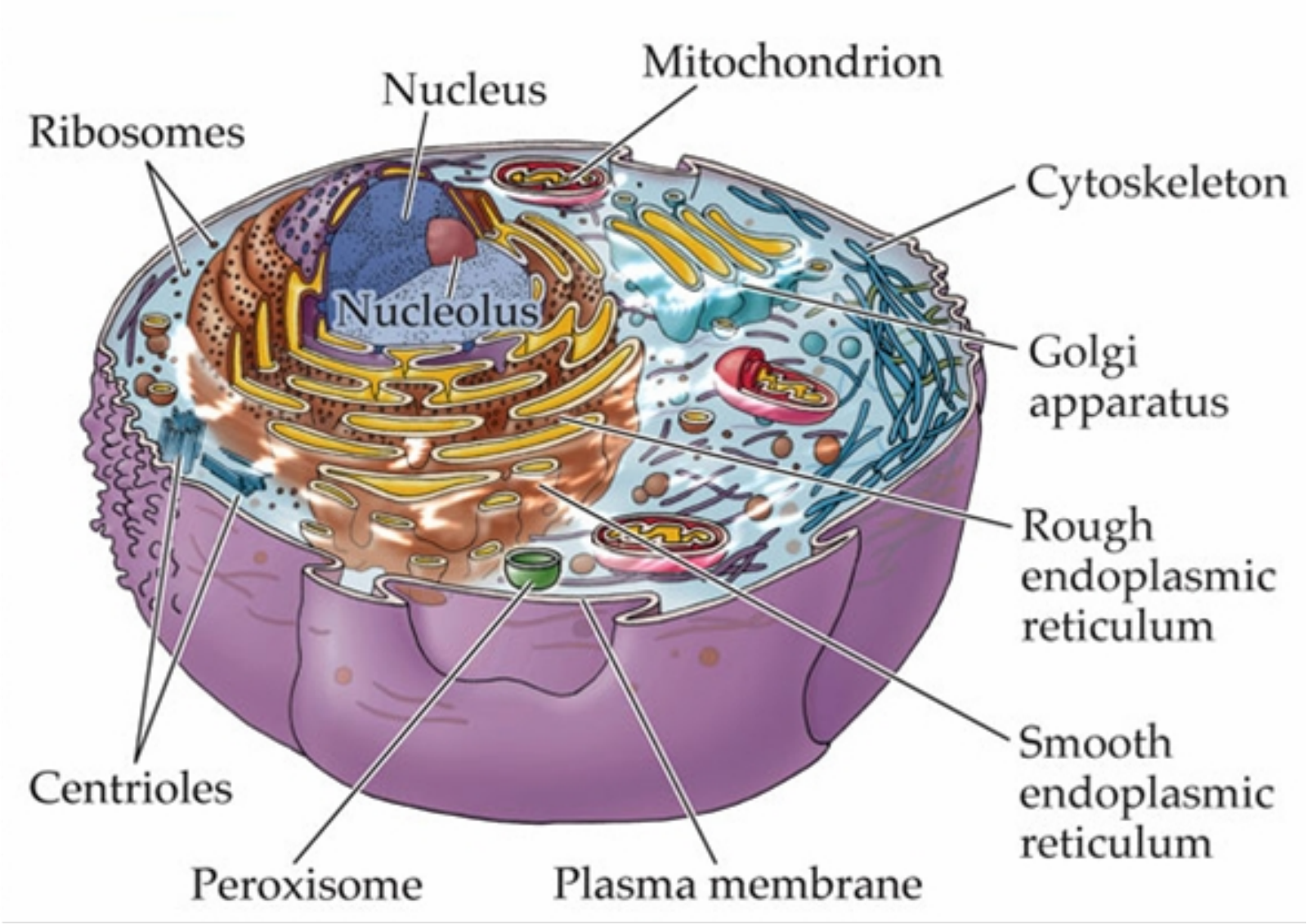


ORGANELLES

- Specialized subunit of the cell with the particular function
- Separation by a lipid bilayer
- Can be purified by cell fractionation
- Classification:
  - contain own DNA or not
  - membrane-bound/non-membrane-bound
  - eukariotic/prokariotic
  - visible/invisible by microscopy
- Organelles vs. compartalization

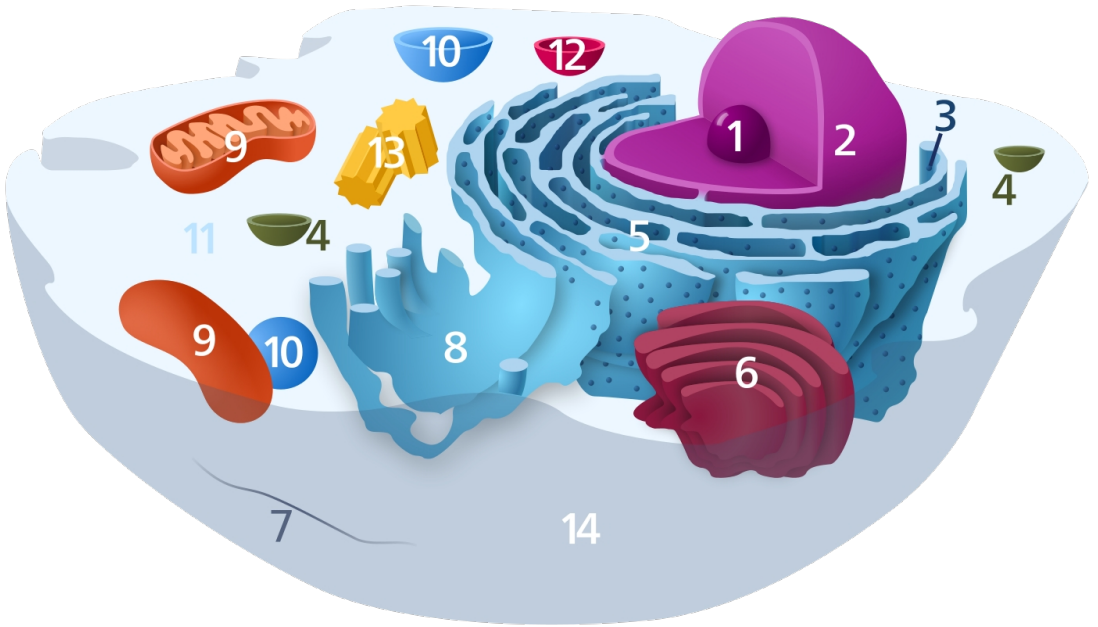


MAJOR ORGANELLES



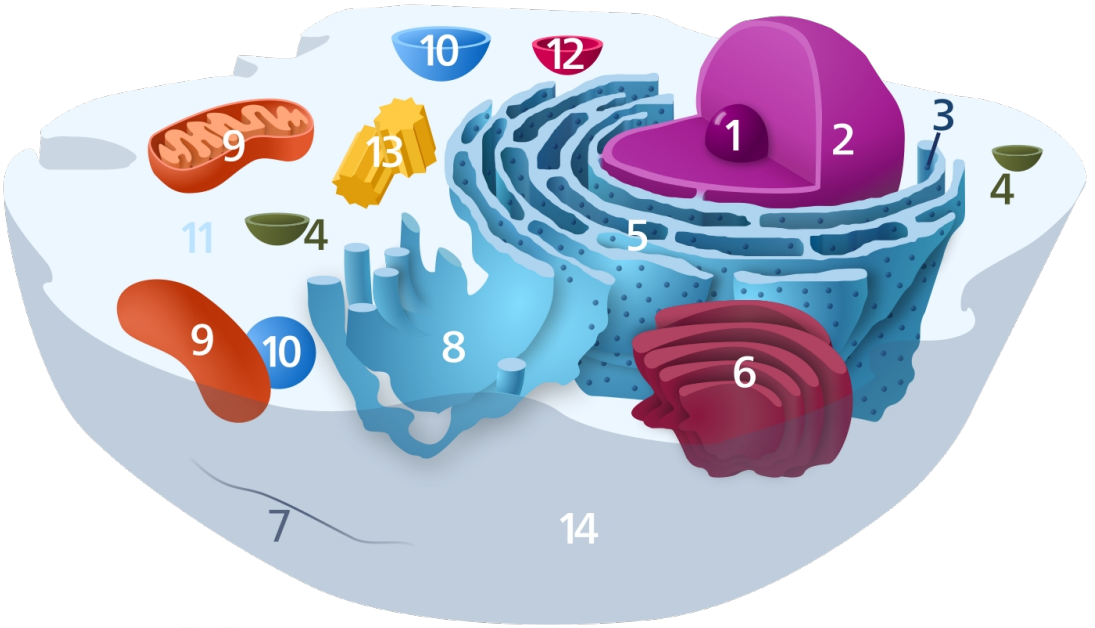
MAJOR (EUKARIOTIC) ORGANELLES

Organelle	Function	Membrane	Size, m
Nucleus	DNA involved processes, cell activity control, RNA transcription	Double	~ 10^{-6}
Endoplasmatic reticulum	Translation and folding of new proteins, lipids expression	Single	Depth ~ 10^{-7}
Golgi apparatus	Sorting, packaging, processing and modification of proteins	Single	Depth ~ 10^{-7}
Mithochondria	Energy/ATP production	Double	~ (5-10)·10^{-6}
Chloroplast	Photosynthesis	Double	~ (4-6)·10^{-6}
Vacuole	Storage, transport	Single	-
Flagellum	Locomotion, sensoric activity	-	-



NUCLEUS

2


10
12
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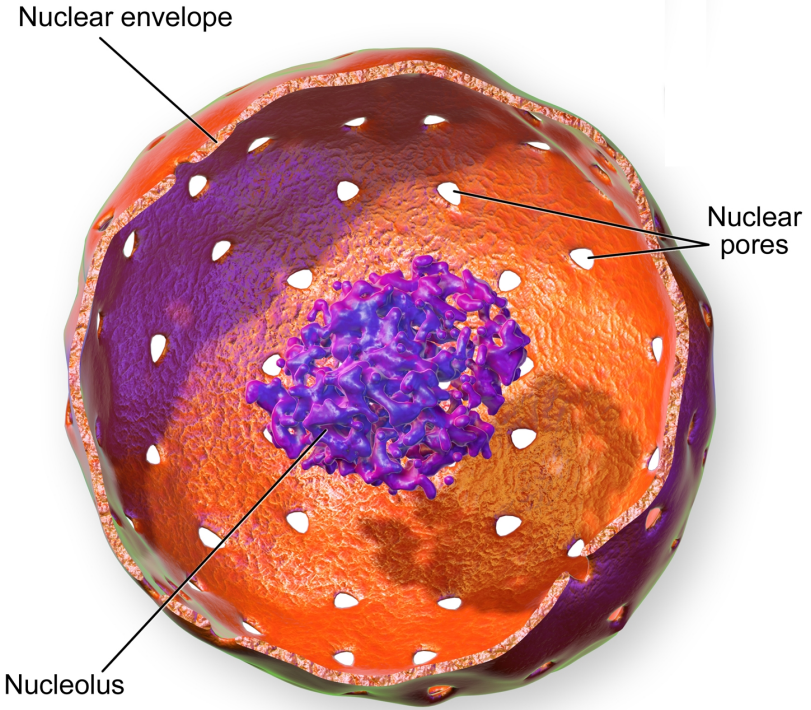
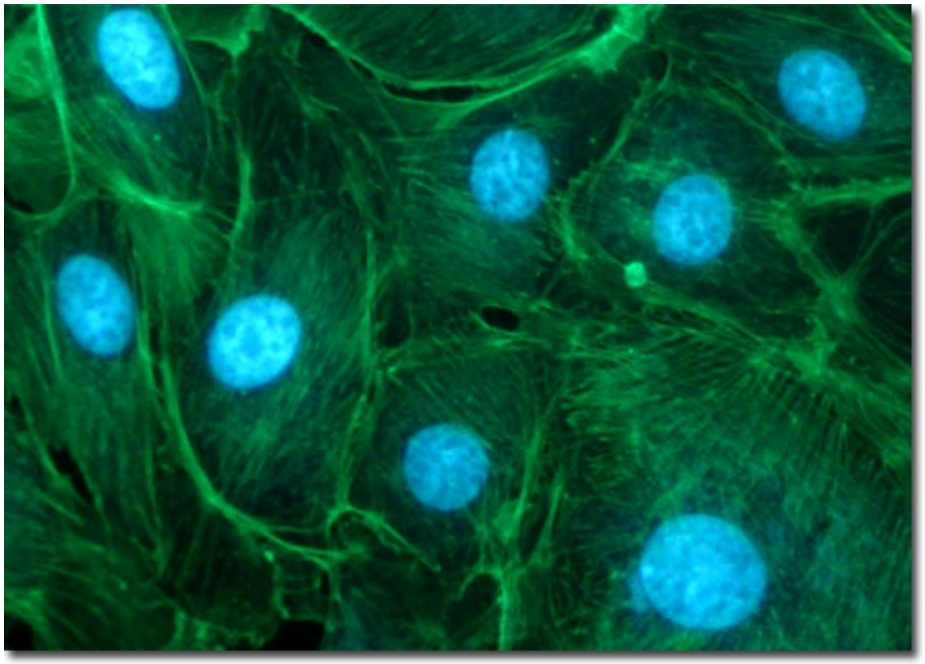
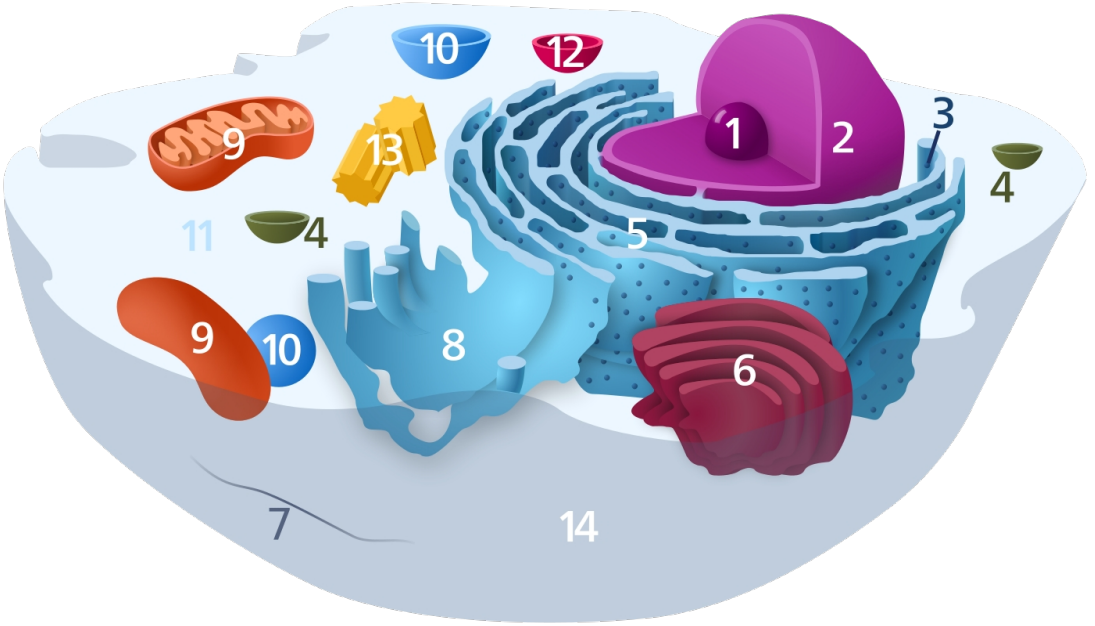
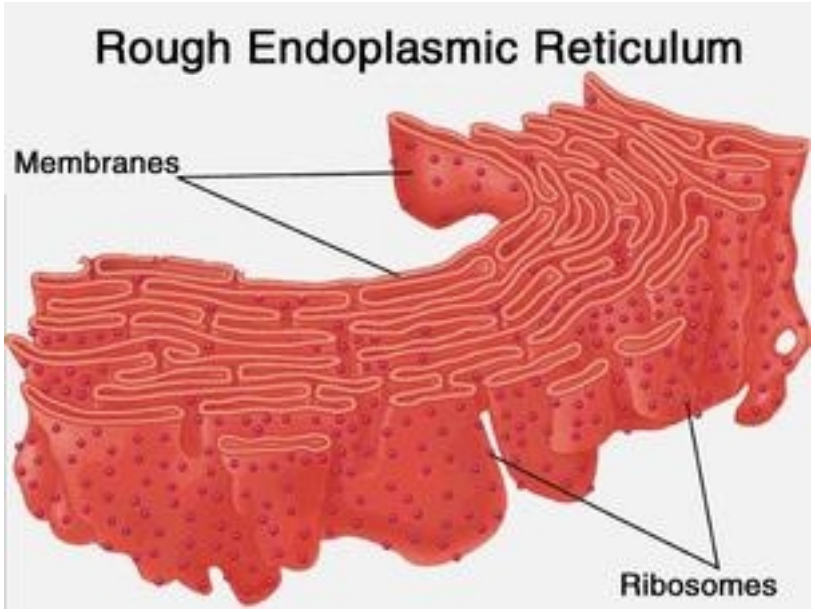

Nuclear envelope
Nuclear pores
Nucleolus

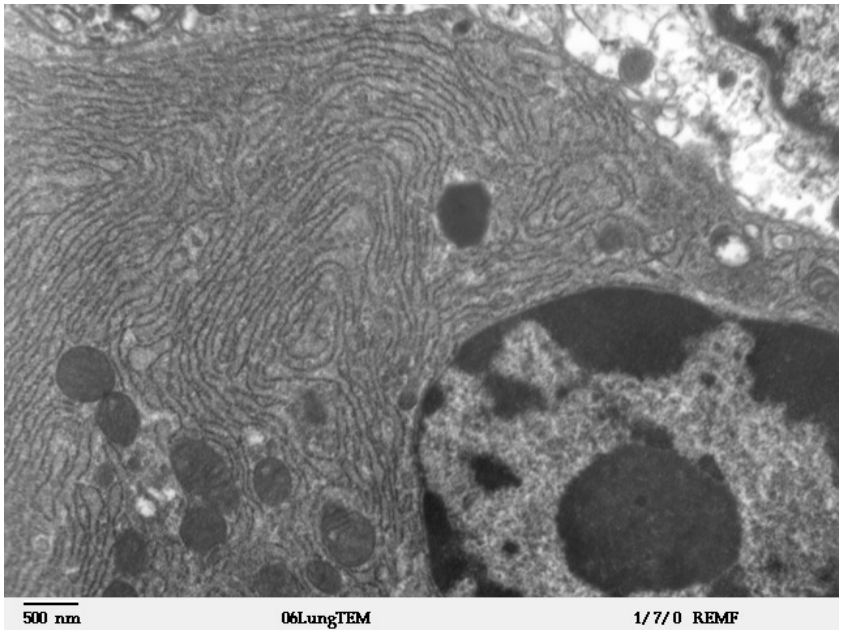


ENDOPLASMATIC RETICULUM

5,8

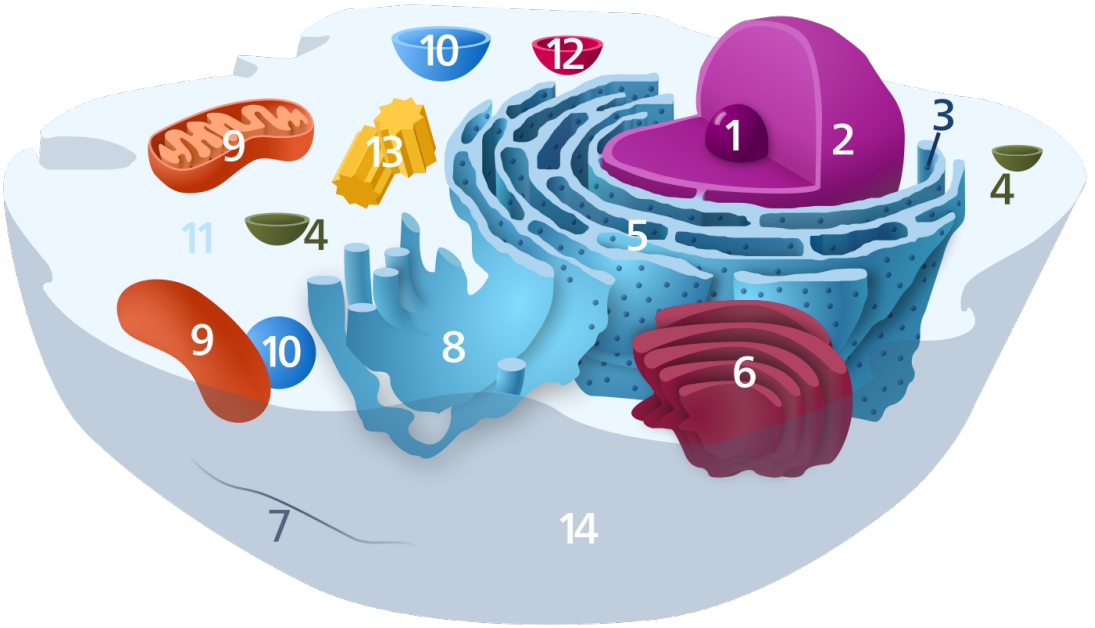


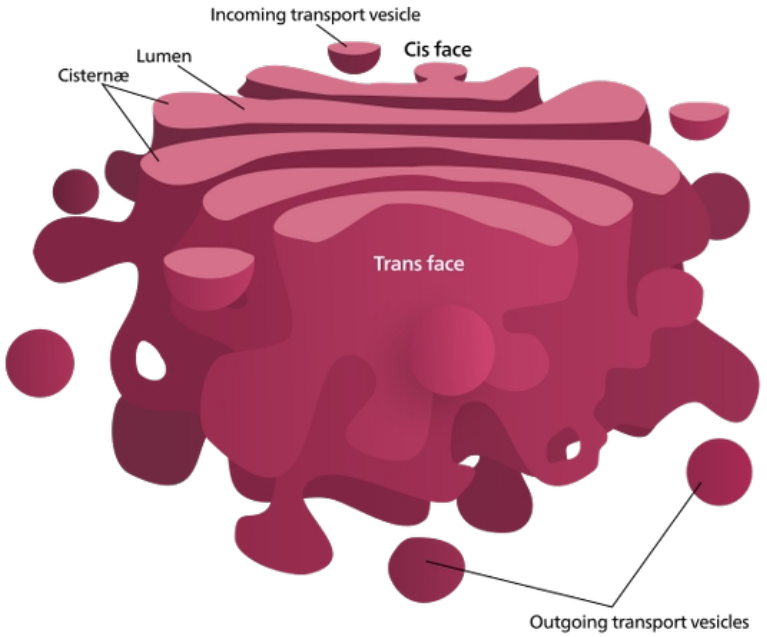




GOLGI APPARATUS

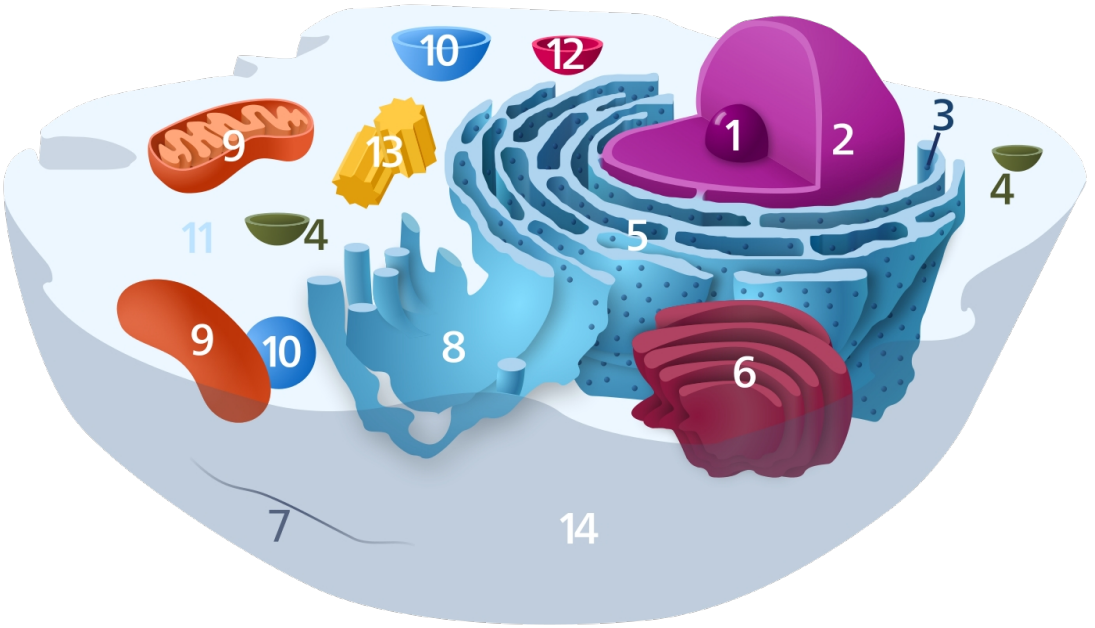
6

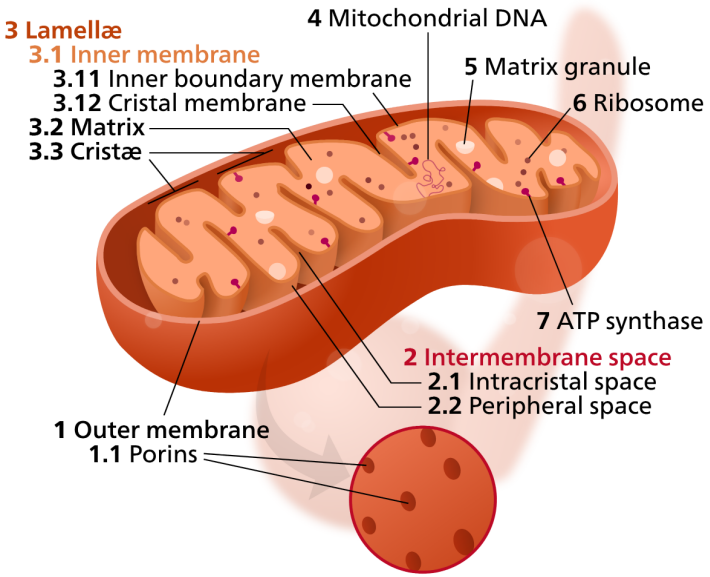


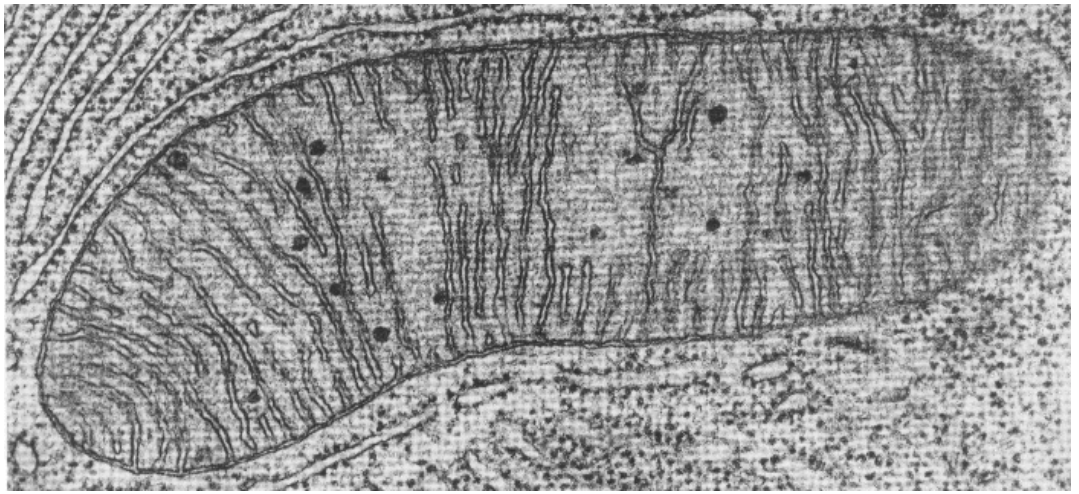


MITOCHONDRIA

9

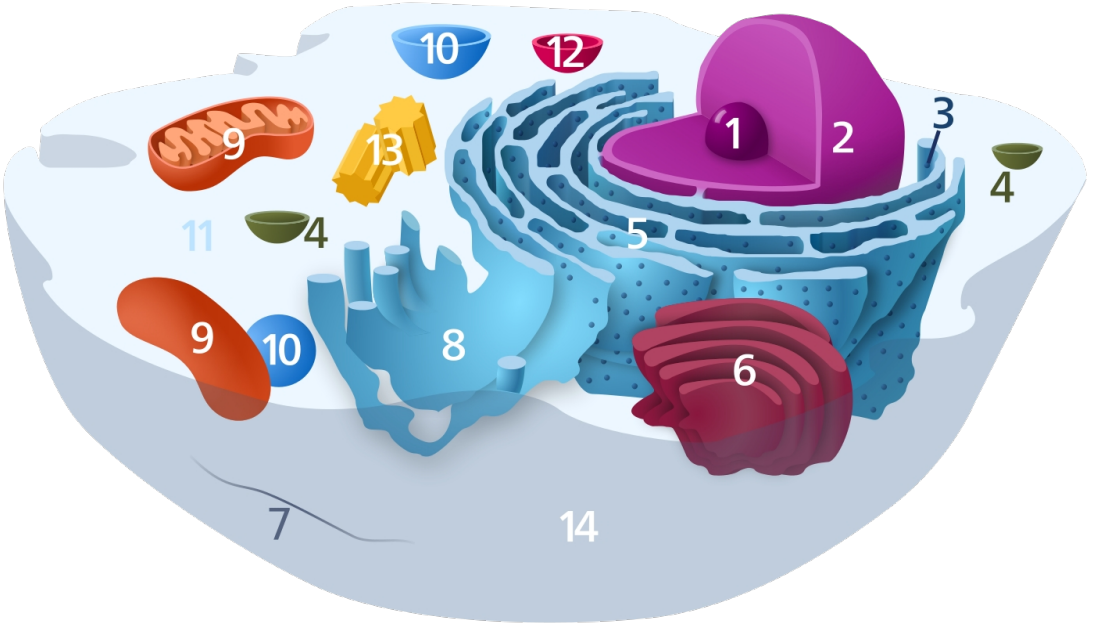


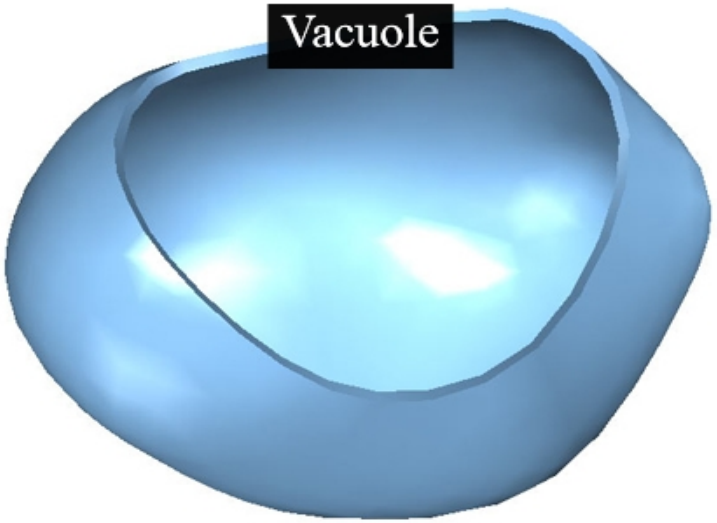


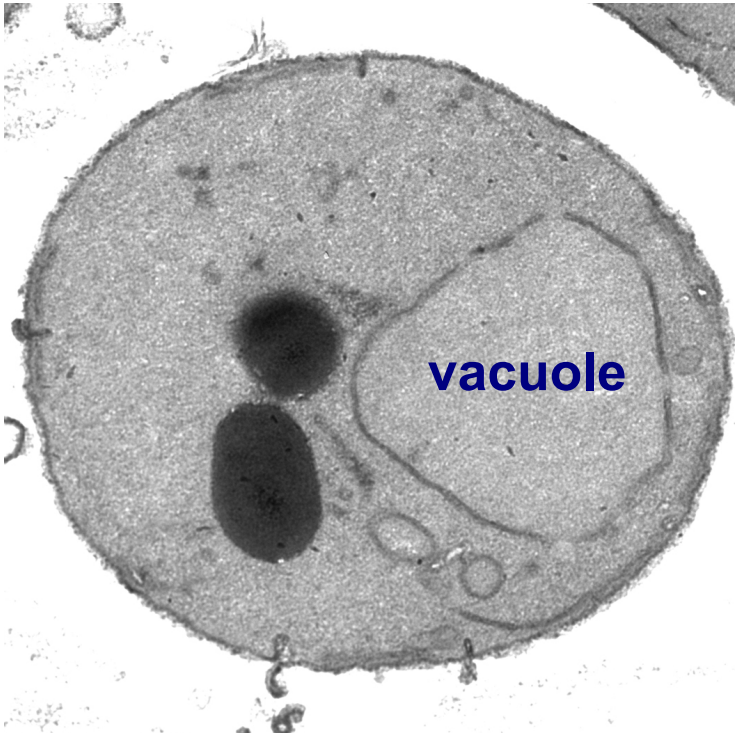


VACUOLE

10

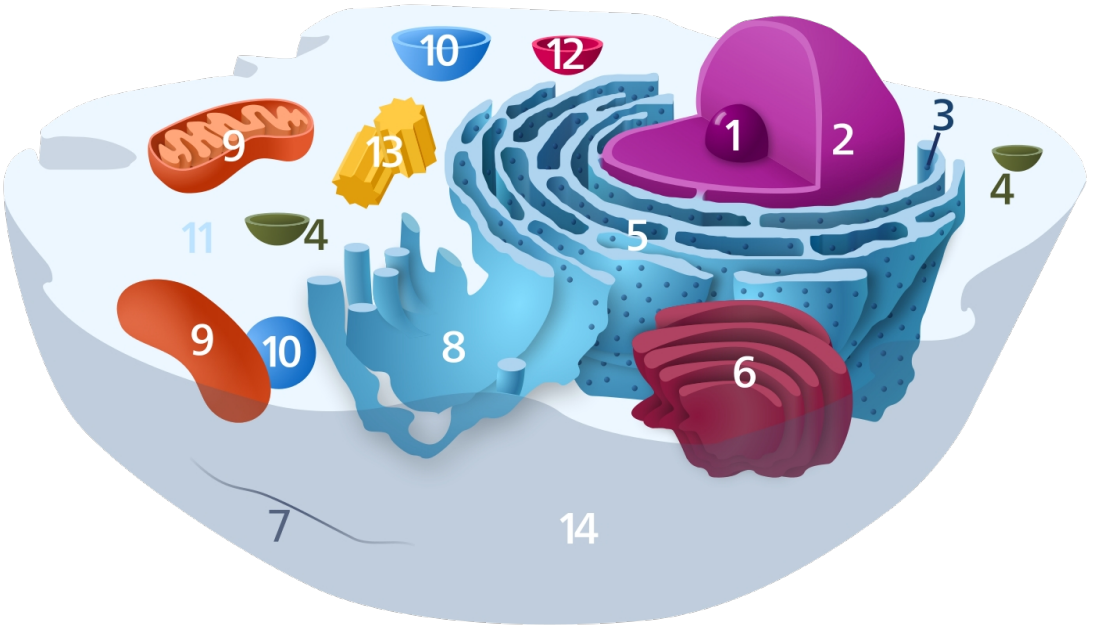


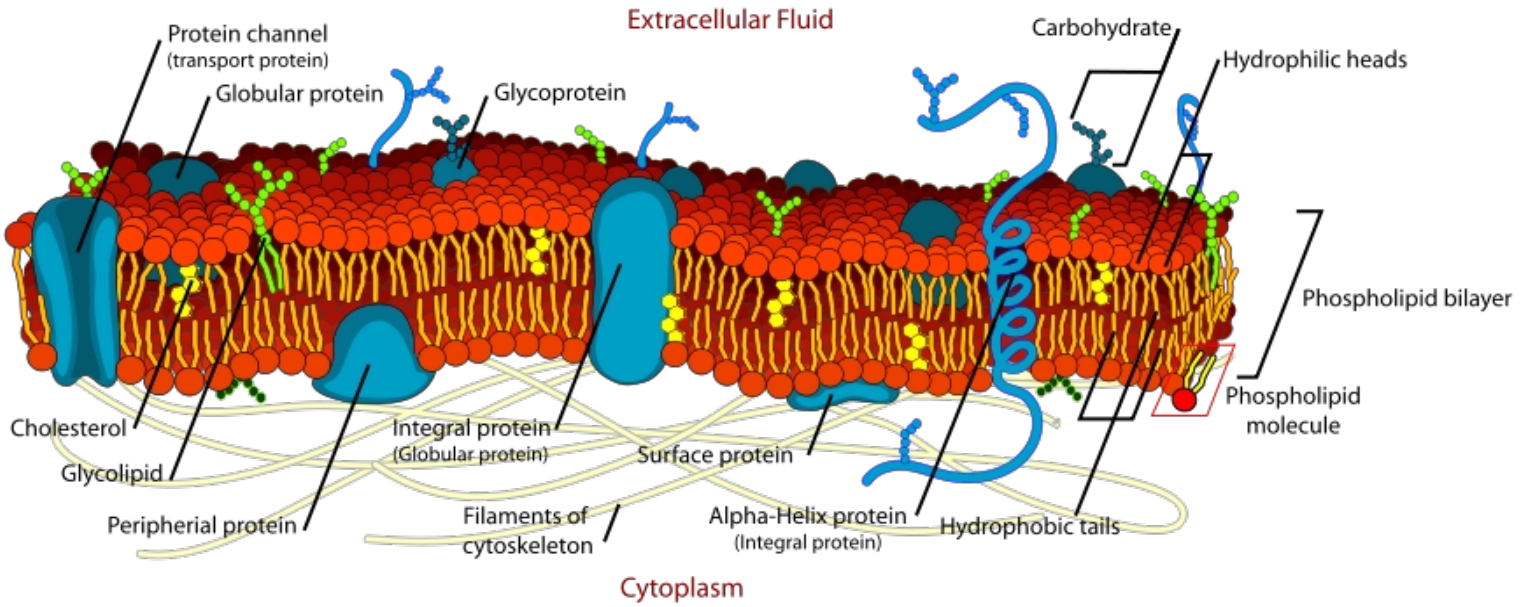




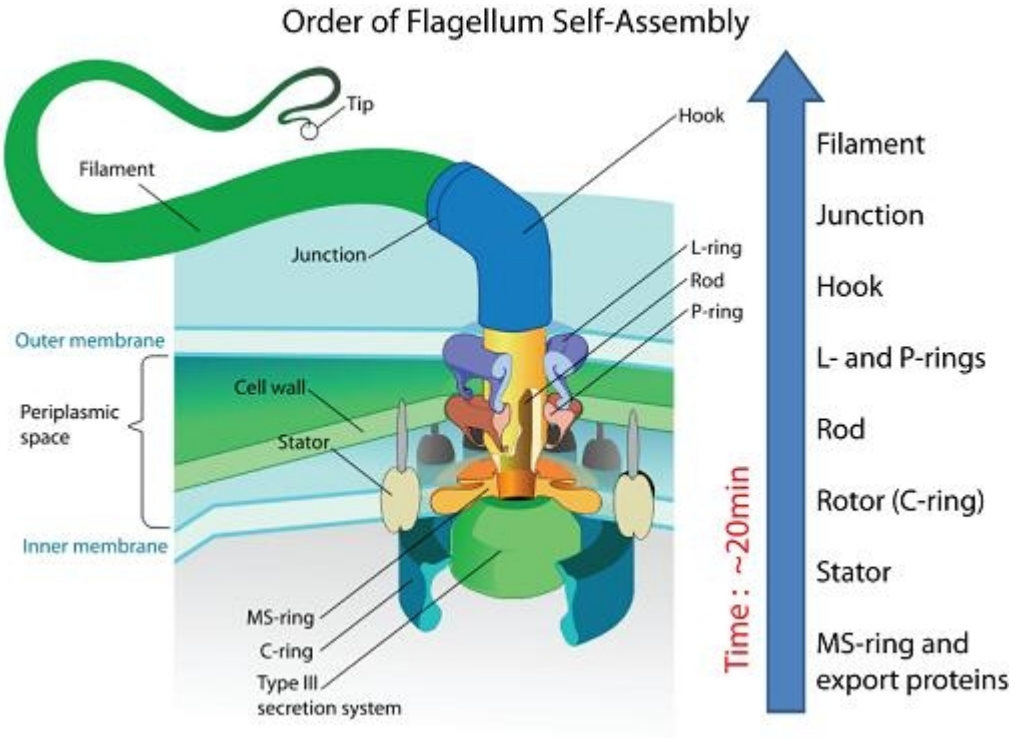
CELL MEMBRANE

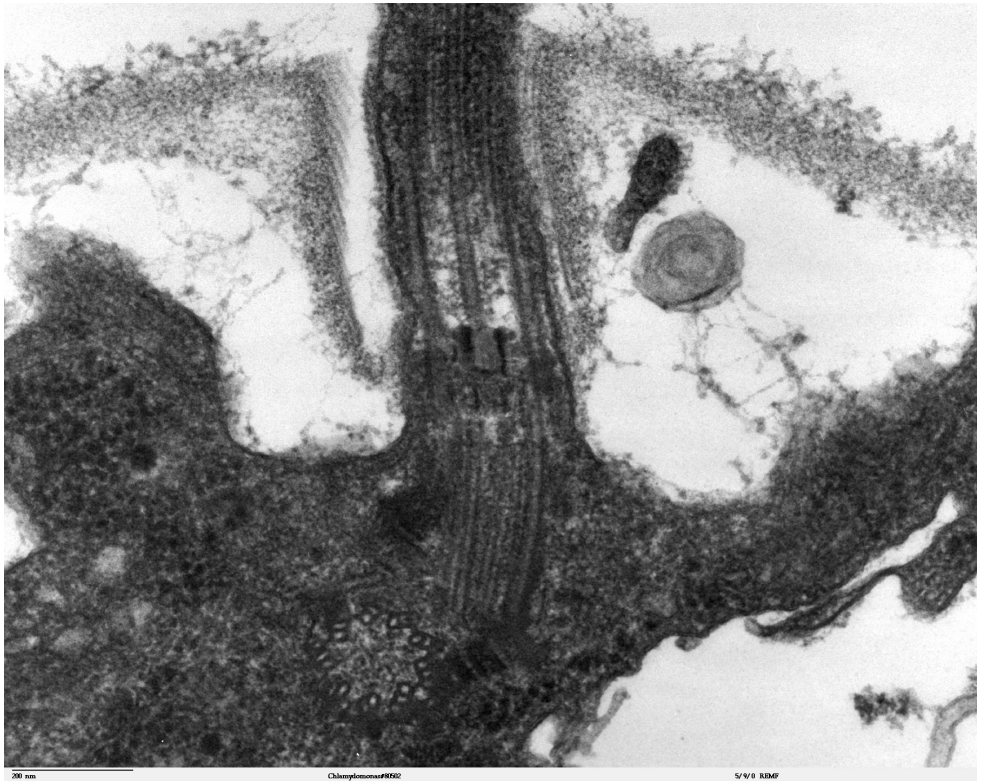
7



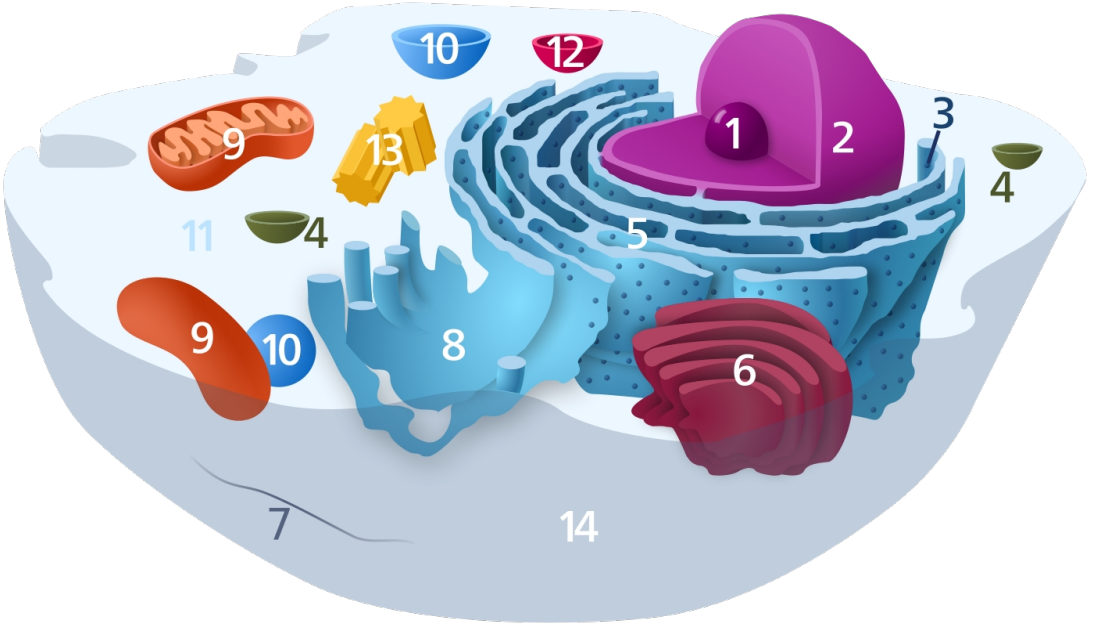


FLAGELLUM


Order of Flagellum Self-Assembly
Tip
Filament
Hook
Junction
L-ring
Rod
P-ring
Outer membrane
Periplasmic space
Cell wall
Stator
Inner membrane
MS-ring
C-ring
Type III secretion system
Time : ~20min
Filament
Junction
Hook
L- and P-rings
Rod
Rotor (C-ring)
Stator
MS-ring and export proteins



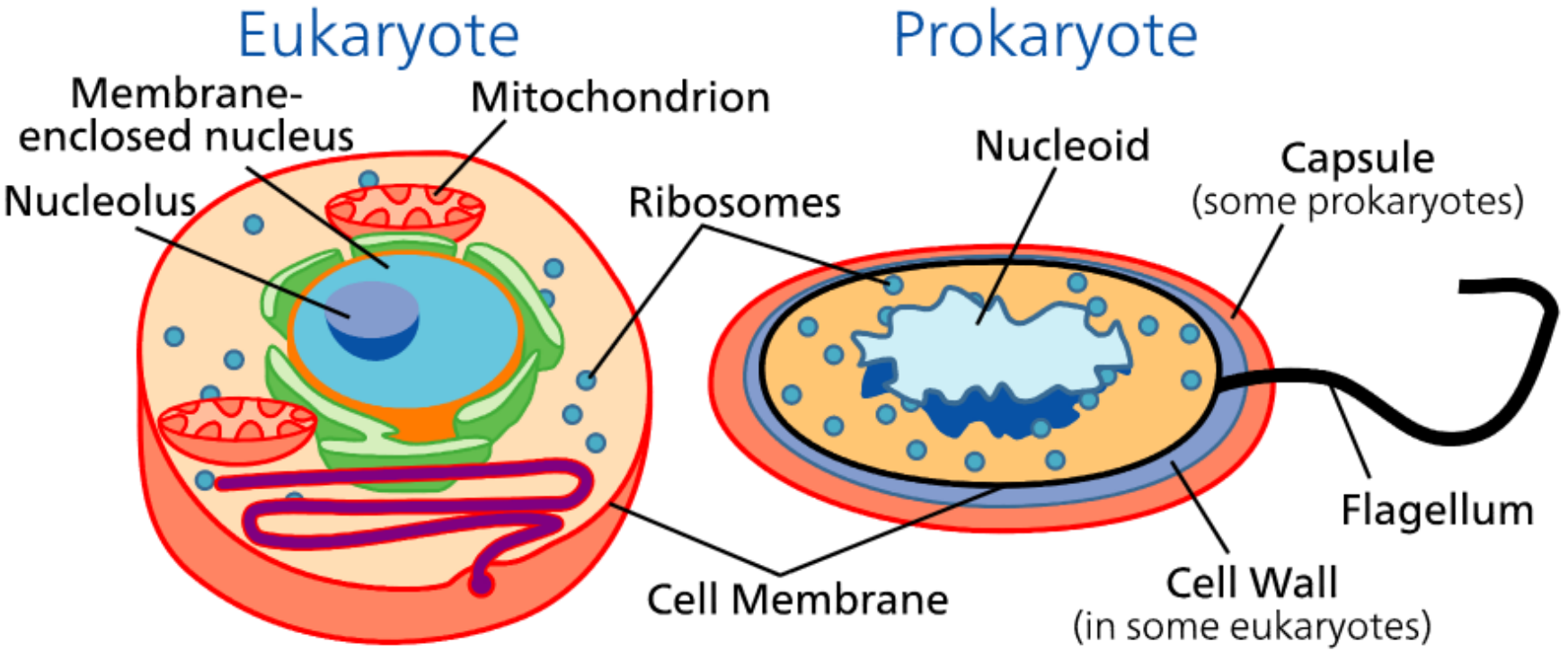
MINOR (EUKARIOTIC) ORGANELLES



Number	Organelle	Function	Size, m
3	Ribosome	Translation RNA=>protein	~ 10^{-8} m
4	Vesicles	Molecular transport	-
7	Cytoskeleton	Structural and transport	-
11	Cytosole	Environment	-
12	Lysosome	Degradation of molecules	~ 10^{-6} m
13	Centrosome	Cell cycle regulator	~ 10^{-7} m
14	Cell membrane	Separation, structure, transport	-

CELL

The basic structural, functional and biological unit

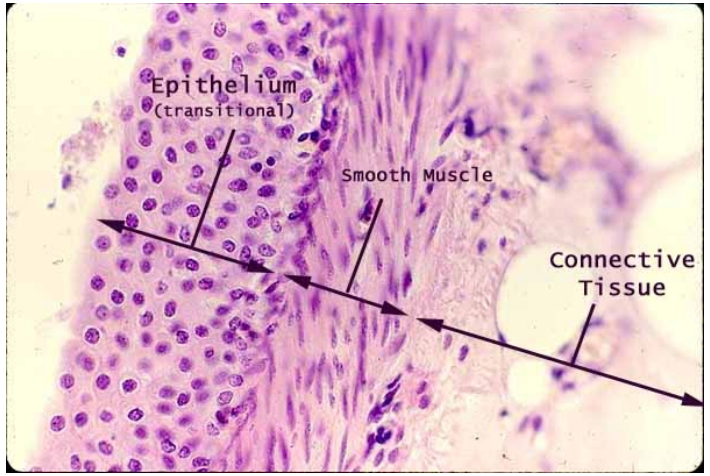


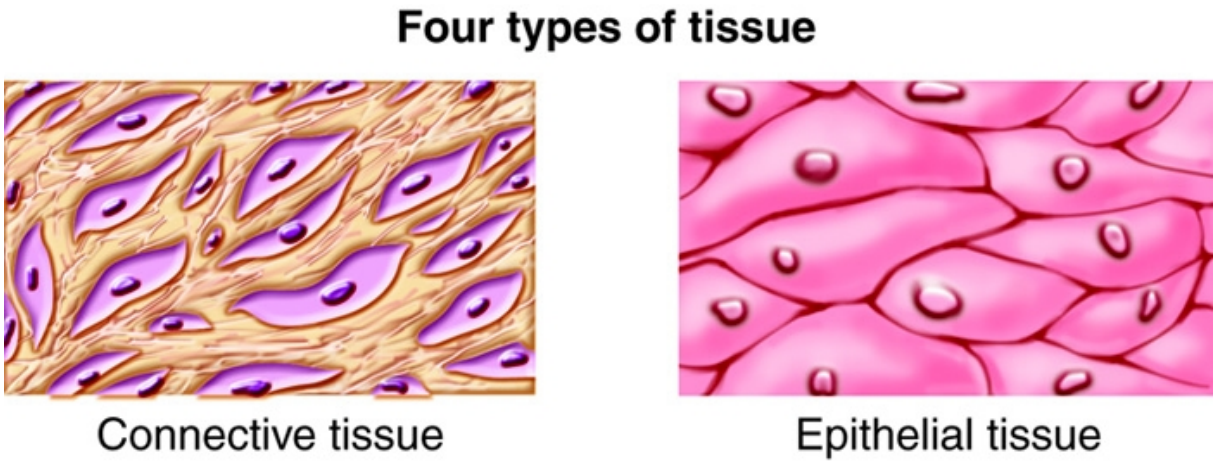
TISSUE

CELL => TISSUE => ORGAN

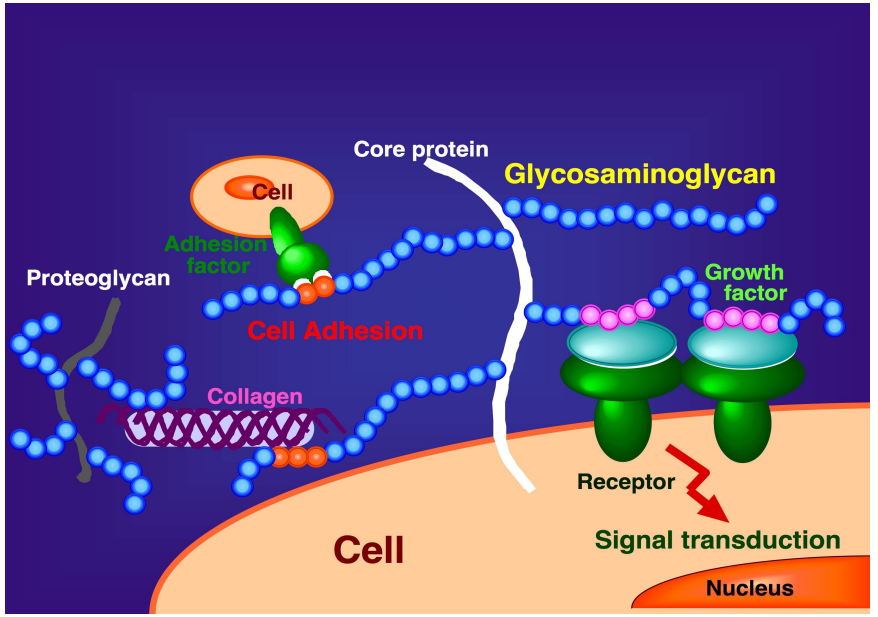
Group of similar cells with the same origin carrying out common functions

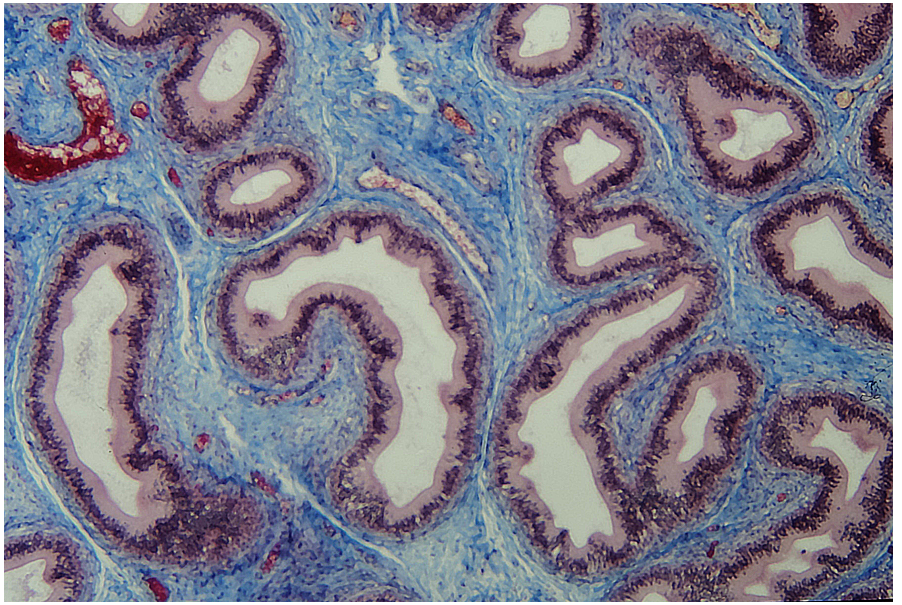
- **Connective**
- **Muscle**
- **Nervous**
- **Epithelial**





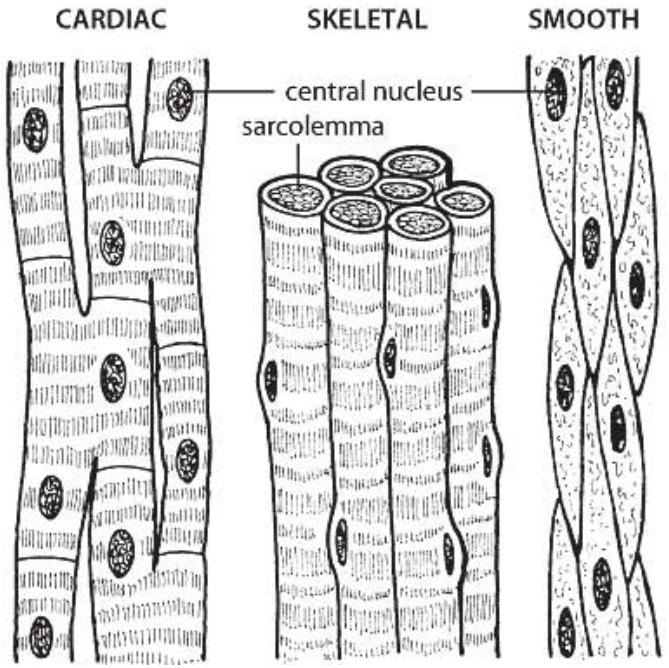
CONNECTIVE TISSUE

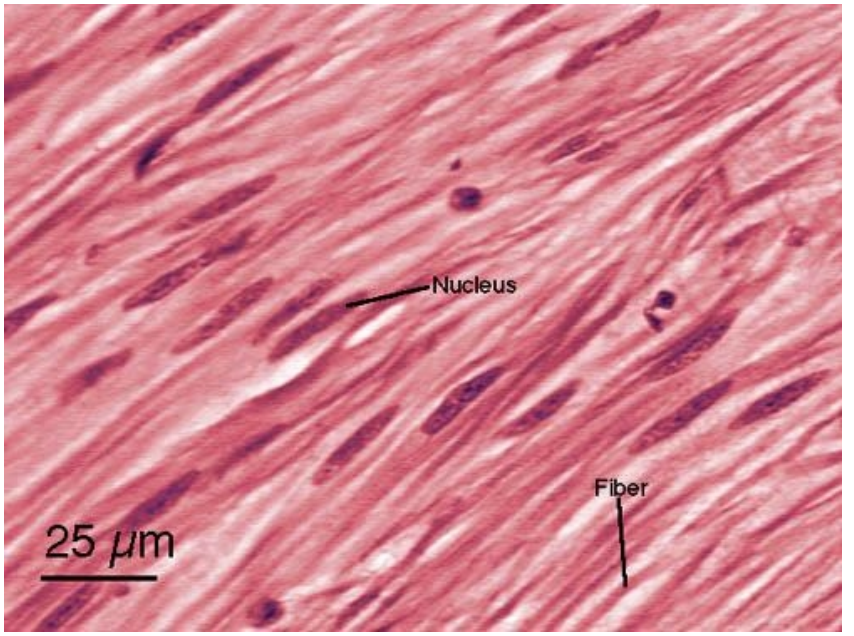




- Function: support, connection and separation of other tissues
- Content: fibers, ground substance, cells
- Cell types: fibroblasts, adipocytes, macrophages, mast cells, leucocytes
- Types: special (bone, skin, cartilage, blood etc.) and loose

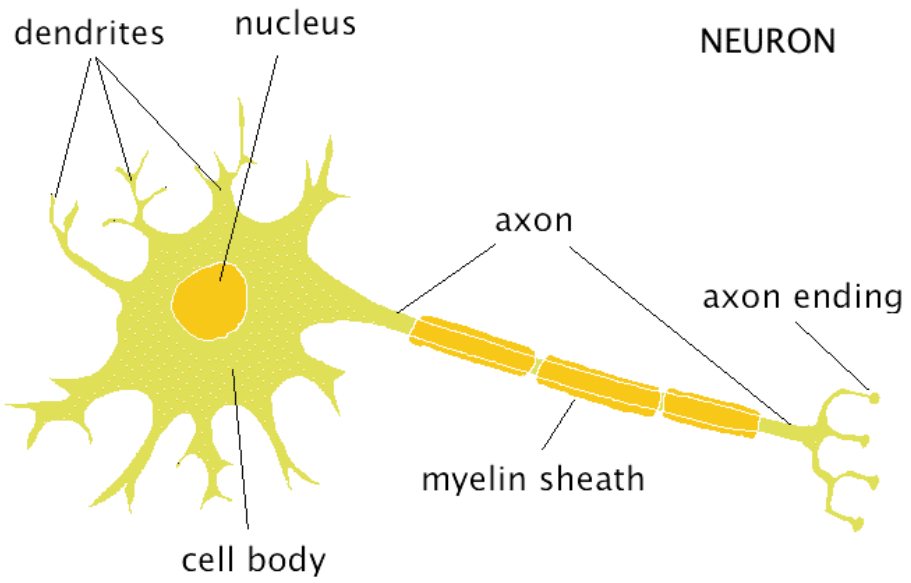
MUSCLE TISSUE





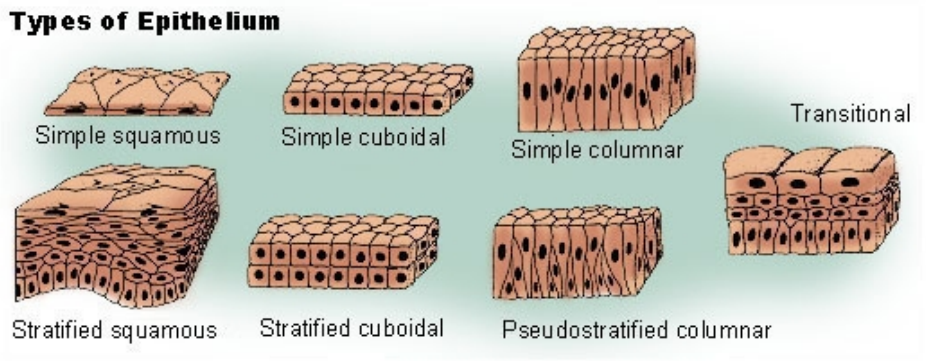
- **Function: contraction (movement, support, maintenance of posture)**
- **Content: myocytes and myofilaments**
- **Cell types: myocytes**
- **Types: cardiac, skeletal, smooth**

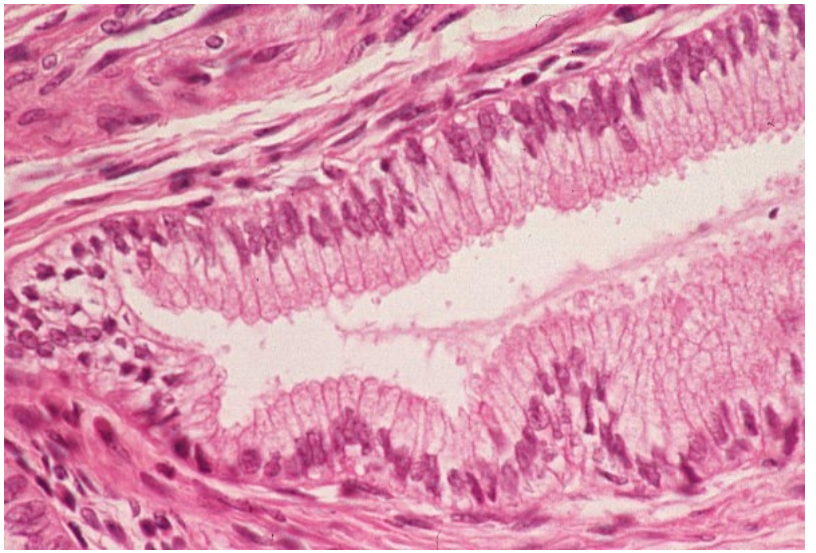
NERVOUS TISSUE



- **Function: establishming the communication network of the nervous system**
- **Cell types: neurons and glia cells**
- **Types: central neural system (grey matter, white matter), peripheral neural system (ganglion and nerves)**

EPITHELIAL TISSUE





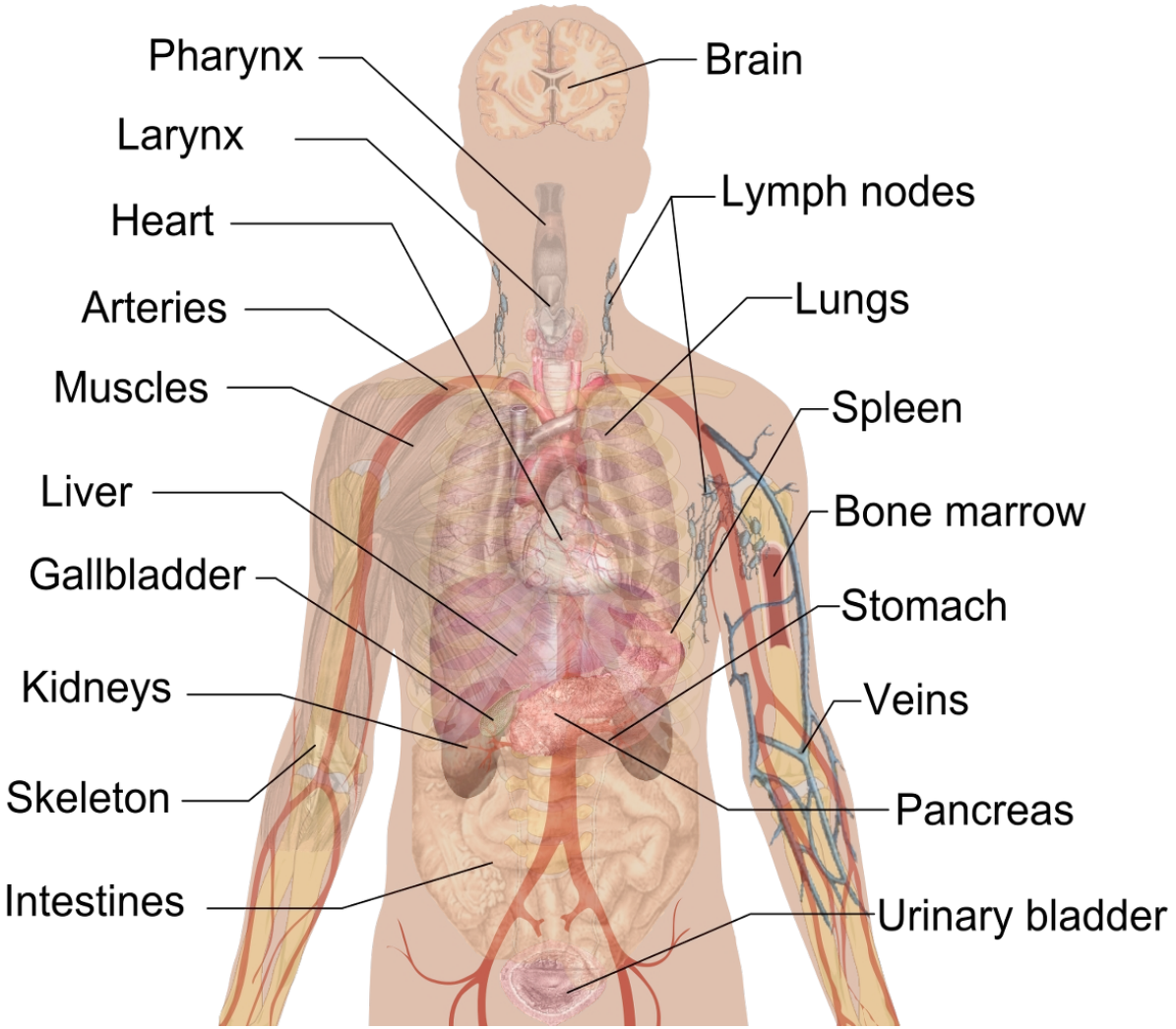
- **Function: protection, regulation/transport, secretion of hormones**
- **Cell types: many types of polar cells**
- **Types: morphological classification**

ORGANS

A collection of different tissues structurally asssembled

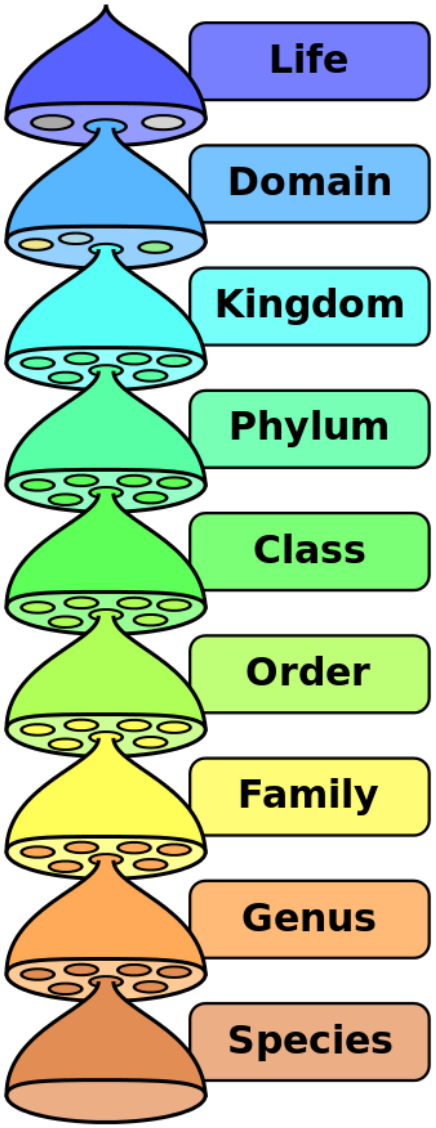
to carry out a common function

Internal organs



ORGANISM

Any living structure, such as a plant, animal, fungus or bacterium, capable of growth and reproduction



Eukaryota, *bacteria, archea*

Animals

Vertebrates

Mammals

Primate

Hominidae

Homo

Homo sapiens

LECTURES 1: INTRODUCTION TO CELL CHEMISTRY AND BIOSYNTHESIS I

- Living vs. non-living systems: what is life?
- Chemistry of living systems
- Levels of organizations in biology:
  - atom: their basic properties, elements in living systems
  - molecule: covalent bonds and non-covalent interactions
  - macromolecules in living systems and water role
  - organelle: types and properties
  - cell
  - tissue: types and properties
  - organ
  - organism