ETH zürich

Bioengineering FS22
Week 01/02

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About me & the exercise

- BSc Health Sciences & Technology (D-HEST), 6th Semester
  - Biomedical Engineering
  - Neurology
  - Molecular Life Sciences

- TA in Bioengineering & Biomechanik I

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- You can decide what serves you best:
  - Summary
  - Solving the exercise
  - Q&A

Agenda

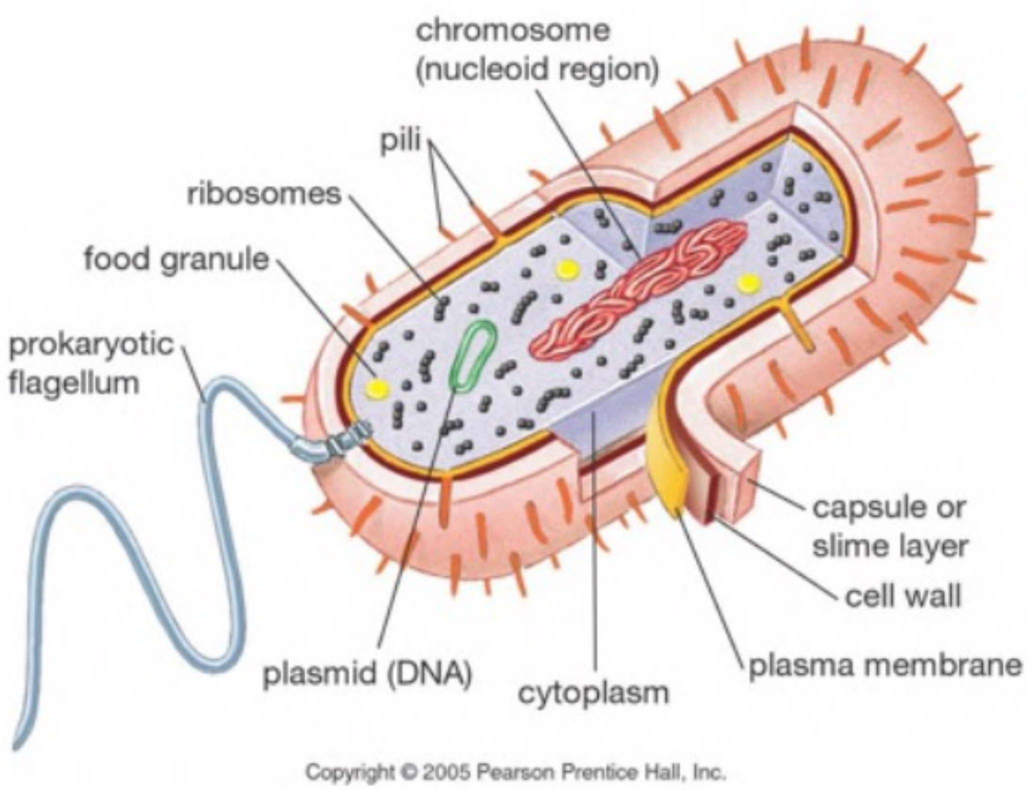
1. Cells
2. Chemical Bonds
3. Functional Groups
4. Macromolecules
    1. Lipids & Carbonic acids
    2. Proteins
    3. Carbohydrates
    4. Nucleic Acids

Cell Types

Cell Types - Prokaryotes

- DNA in cytoplasm
- NO nucleus
- NO organelles
- NO compartimentalisation
  - No internal sub-structures
  - No internal membranes

- INCLUDES:
  - Nucleoid – bacterial chromosome
  - Ribosomes
  - Flagellum
  - Capsule

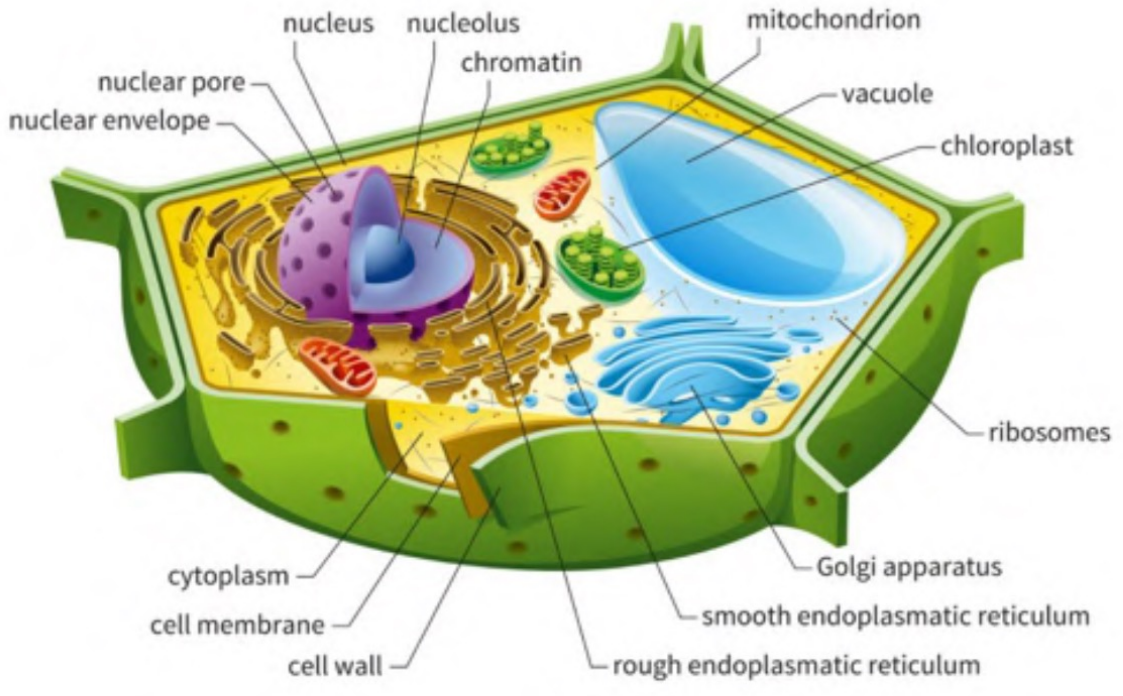


Cell Types - Eukaryotes

- Much larger than Prokaryotes
- Compartimentalisation
  - Organelles and nucleus surrounded by membranes

  → Division of reaction and work spaces with specific milieus!!!

- INCLUDES:
  - Nucleus (DNA)
  - Nucleolus (Synthesis of ribosome sub-units)
  - Organelles (mitochondria (ATP prod.); ER; Golgi; etc.
  - Ribosomes (essential for protein biosynthesis) → discussed later on regarding translation



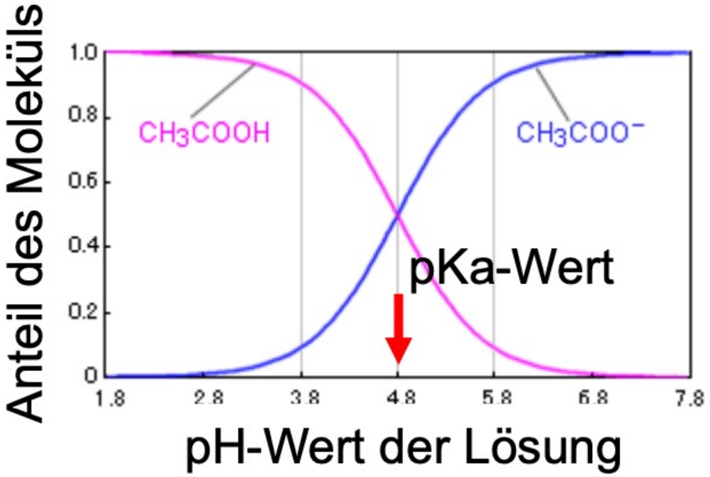
Basics in chemistry – pH and pKa

pH

- Used to characterise the H^+ concentration in a solution.
- $pH = -\log_{10}[H^+] = -\log_{10}[H_3O^+]$
- pH = 1 – very acidic solution
  pH = 7 – neutral solution
  pH = 14 – very basic solution
- At pH = 7, the concentration of $[H^+]$ and $[OH^-]$ are the same. (10^{-7}M)

pKa = acid dissociation constant

- pKa → pH value where 50% of the acid is protonated



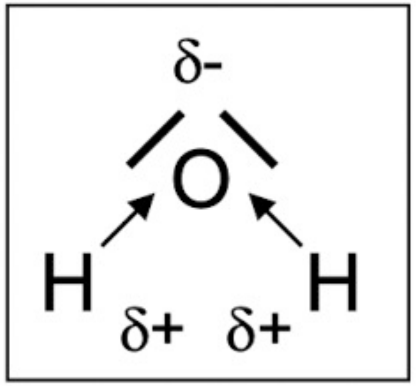
- The lower the pKa the stronger the acid!
- # pKa's = # H-atoms a substance can bind
  - Eg. H_3PO_4 → 3 pKa's

Chemical Bonds

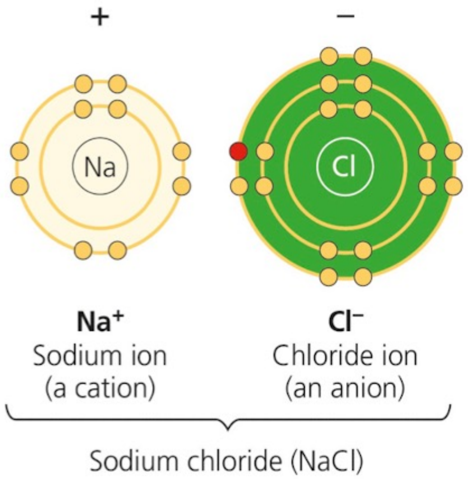
Chemical Bonds – Strong Bonds

- **Covalent bonds → form molecules**
  - Electrons shared (always in pairs) → single, double and tripple bonds
  - If the two atoms are different (H_2O) → shared electrons unevenly distributed:
    - More electronegative atom (here Oxygen) wants the electron more badly

    → «negative Partialladung»
    - Electrons mostly near Oxygen → Hydrogen seems positively charged
    - Molecules has pos. and neg. pole → a dipole
    - The bonds are polar → thus often reactive



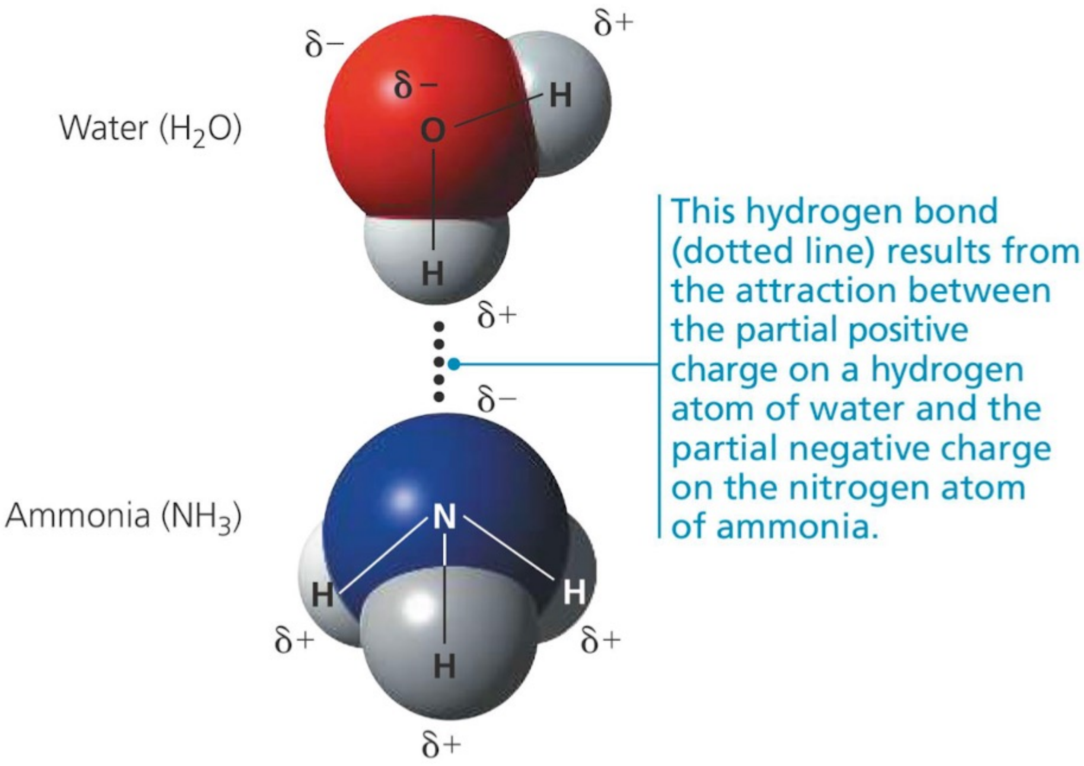
- **Ionic Bonds → form salts in grids, not molecules**
  - Electrons taken by more electronegative atom → formation of ions
  - Cations – positively charged
  - Anions – negatively charged
  - In biological environment: ions surrounded by «Hydrathülle» & seperated from their counter-ion
  - In solids: ions build salt crystals with grid structures



Chemical Bonds – Weak Interactions

- **Hydrogen Bonds**
  - Ineractions between dipole molecules (between «Partialladungen»)

  → Much weaker and more transient than ionic bonds
  - But particularly strong for Hydrogen Bonds if:
    - 1st molecule: Hydrogen bound to very electronegative atom (F, O, N) → pos. «Partialladung» stronger
    - 2nd molecule: free electron pair at strongly electronegative atom (typically N, O)



Chemical Bonds – Weak Interactions

- **Van der Waals interactions**
  - Weak interactions due to asymmetric ever changing distribution of electrons within two interacting molecules
  - Distance max. 3-4 Å between molecules

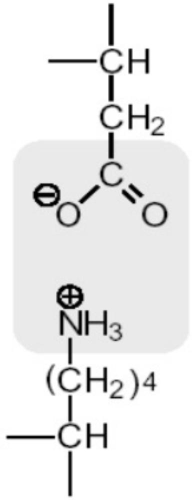
- **Hydrophobic interactions – energy optimization**
  - Goal: to minimize interactions between hydrophobnic and hydrophilic molecules (eg. H_2O)
  - Strategy: Apolar/hydrophobic molecules drawn together to minimize surface area of hydrophobic molecuels having to interact with the hydrophilic/polar water
  - Result: stabile energetic minimum
  - Seems like a bond to the outside

Basics in chemistry – chemical bonds

Strong chemical bonds

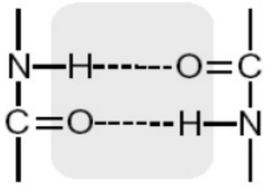
- **Covalent bonds**

- **Ionic bonds**

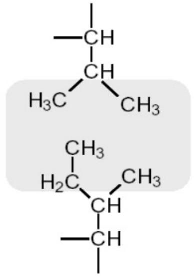


Weak chemical interactions

- **Hydrogen bonds**



- **Van der Waals interactions & Hydrophobic interactions**



Chemical Bonds – Weak Interactions

Hydrogen bonds, VdW and hydrophobic interactions

- Are essential for chemical processes in the cell and in biology
- Formed and dissociated quickly -> high turnover rate!
- Responsible for the stability of large molecules and their interactions

Hydrogen bonds

- responsible for the solublility of organic molecules in water!

→ Weak interactions are essential for molecular processes inside a cell!

Functional Groups

Functional Groups – Know how to draw the structures!

- Give molecules specific chemical and biophysical properties (reactivity, polarity, etc.)

Functional Group Name	Structure (written)	Molecuels	Properties
Hydroxyl	R-OH	"Alkohole"	Polar & reactive
Carbonyl	R-CHO or R-CO-R	"Aldehyde oder Ketone"	Polar and very reactive
Carboxyl	R-COOH	"Carbonsäuren"	Acidic (weak) and charged (-)
Amino	$R\text{-}NH_2$	"Amine & Aminoverbindungen"	Polar bound, basic and charged (+)
Sulfhydryl	R-SH	"Thiole"	Polar
Phosphate	$R\text{-}PO_4^{3-}$	Phosphates	Acidic, charged (-) Very energy rich (ATP)

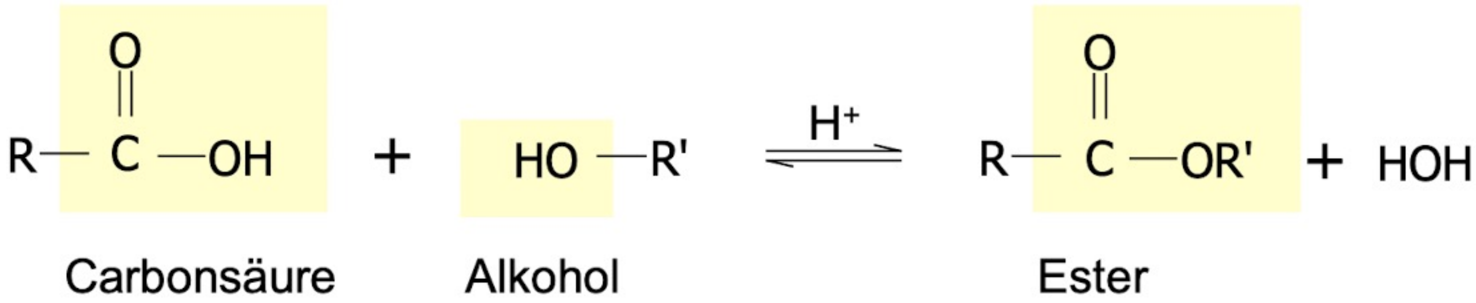
Macromolecules

Macromolecules – Content of cells

• Wasser		▸ 77%
• Hydratisierte Ionen		▸ 3%
• Lipide	Verbindungen des Kohlenstoffs	▸ 2%
• Proteine		▸ 14%
• Kohlenhydratartige		▸ 1%
• Nukleinsäuren		▸ 3%

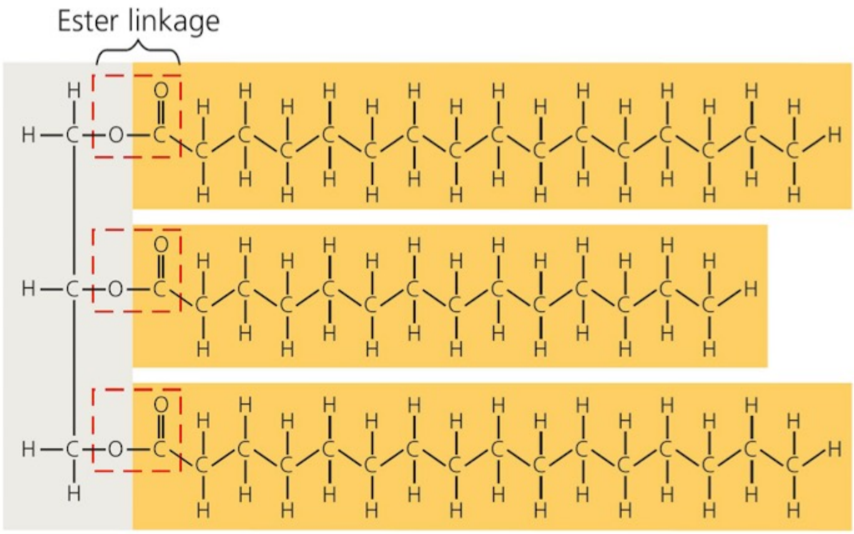
Macromolecules - Lipids

- Consist of alcohols and carboxylic acids (“Carbonsäuren”)
- Glycerine (alcohol) is often the backbone of the lipid and hydrophilic
- “Carbonsäuren”/fatty acids (long amphiphilic chains) are the tails
- Ester bonds link the –OH groups of both molecules, producing water



Macromolecules - Lipids

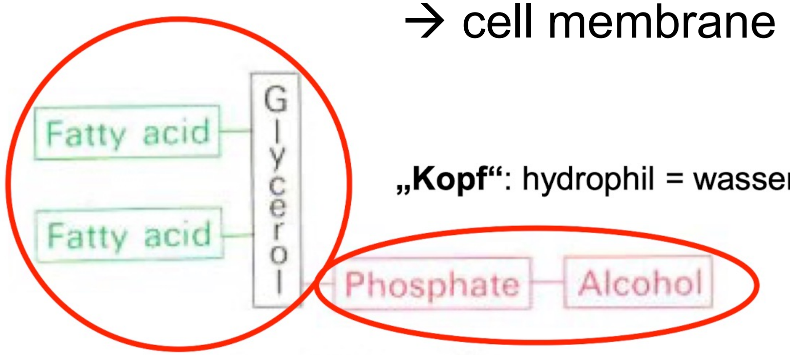
- Gylcerins with long fatty acid chains → Lipids
- Hydrophilic head and hydrophobic tail
- Lipids - lipophilic substances (soluble in fat) → normally hydrophobic



„**Schwanz**“: hydrophob = wasserabweisend

Phospholipid
→ cell membrane

„**Kopf**“: hydrophil = wasserliebend

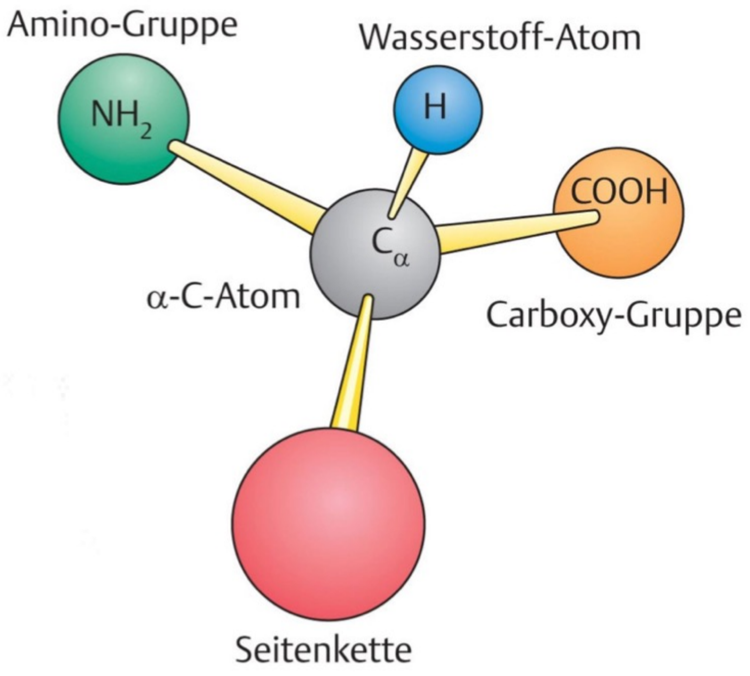


Components of a phosphoglyceride

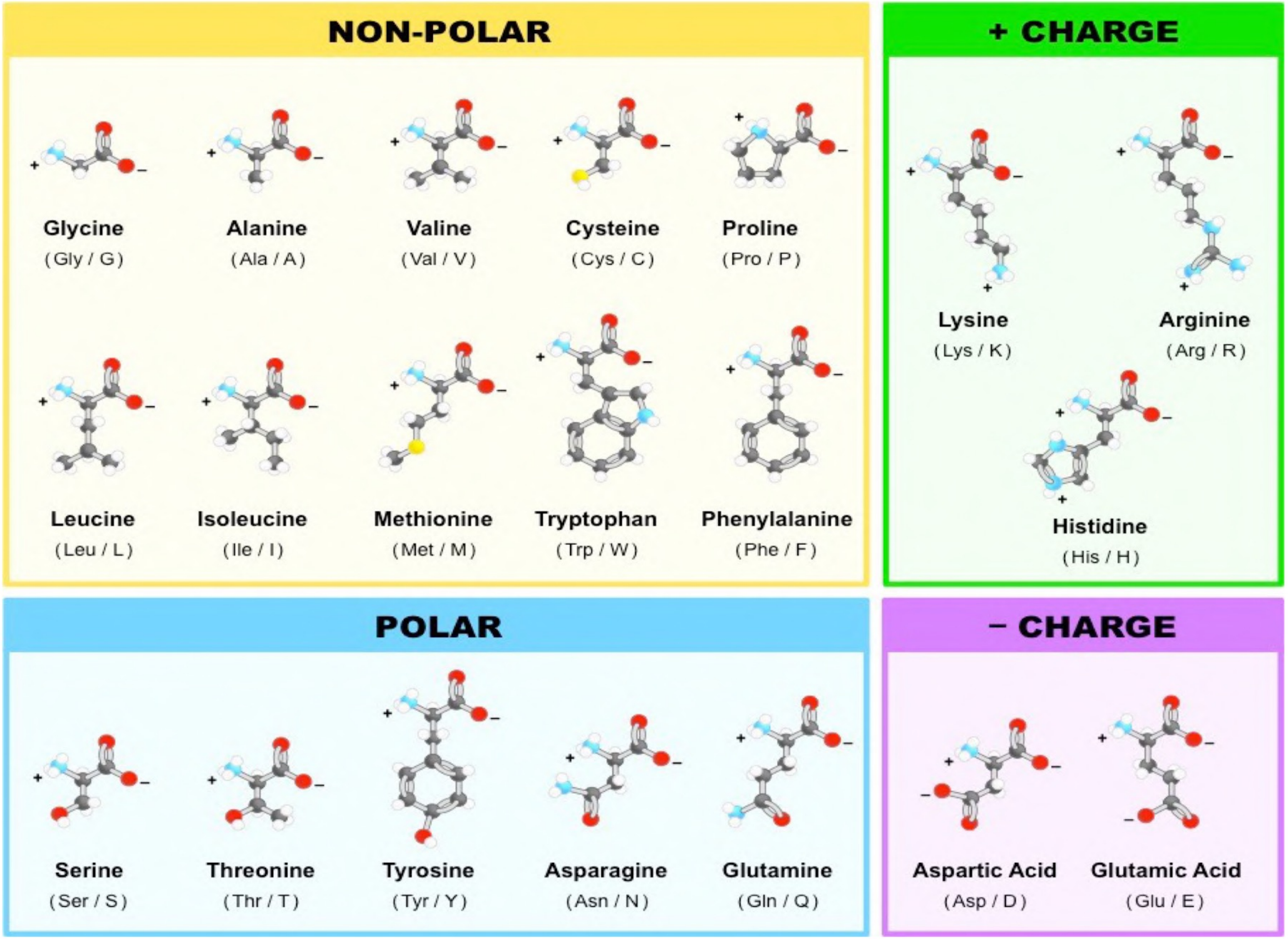
- If you have many phospholipids in a polar environment (such as water), how are they going to be organised and which of the previously discussed chemical interactions are responsible for said organisation?

Macromolecules - Proteins

- Building blocks: Amino acids (ca. 20)
- **Amino acid:** consists of a central C atom which (usually) has four different bonding partners. Three of them are fixed, while the fourth determines the properties and qualities of the amino acid.
  - Amino-group (NH2)
  - Carboxy-group (COOH)
  - Hydrogen atom
  - Side chain (non-polar, polar, + charged, - charged)



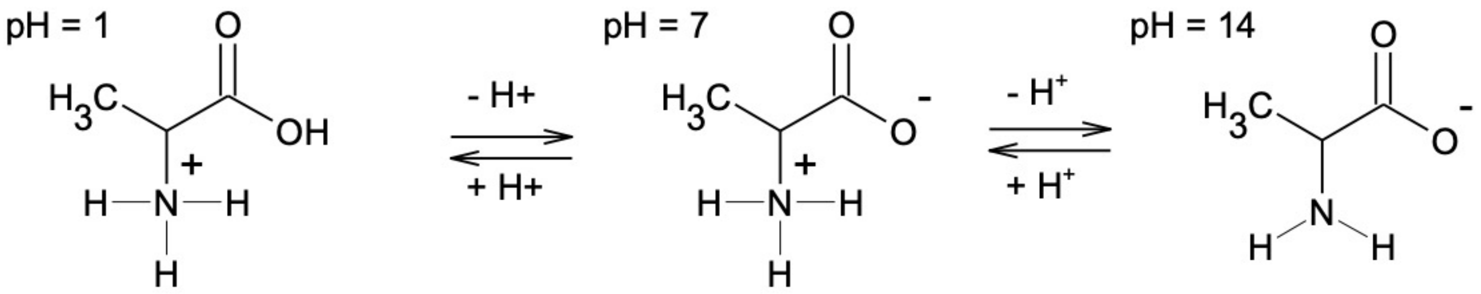
- Amino acids are Enantiomers → Its mirror image is not the same molecules and thus has different properties.
  - For amino acids we have D- and L-types (more generally R & S)
  - Most organisms use L-type Amino acids


NON-POLAR
Glycine
(Gly / G)
Alanine
(Ala / A)
Valine
(Val / V)
Cysteine
(Cys / C)
Proline
(Pro / P)
Leucine
(Leu / L)
Isoleucine
(Ile / I)
Methionine
(Met / M)
Tryptophan
(Trp / W)
Phenylalanine
(Phe / F)
+ CHARGE
Lysine
(Lys / K)
Arginine
(Arg / R)
Histidine
(His / H)
POLAR
Serine
(Ser / S)
Threonine
(Thr / T)
Tyrosine
(Tyr / Y)
Asparagine
(Asn / N)
Glutamine
(Gln / Q)
– CHARGE
Aspartic Acid
(Asp / D)
Glutamic Acid
(Glu / E)

Macromolecules - Proteins

Side Note to amino acids

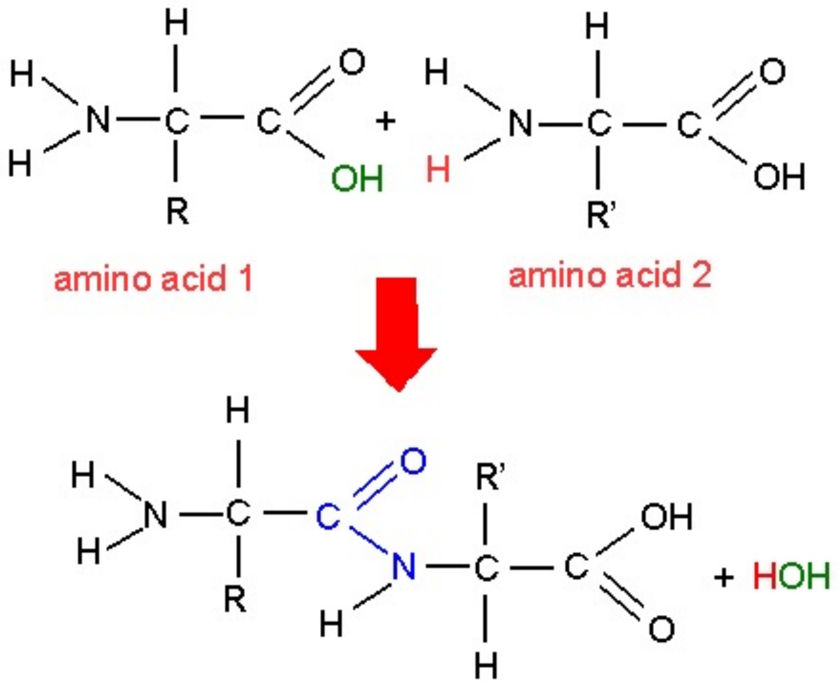
- The physicochemical properties of the amino acid depend on the pH of the environment.
  - If the pH is low (=1), the amino acid is fully protonated (+ charge).
  - At neutral pH (= 7), the amino acid is partially protonated (no charge due to compensation).
  - If the pH is high (= 14), the amino acid is fully deprotonated (- charge)



Macromolecules - Proteins

Formation

- In proteins, the amino acids form the backbone of the structure. The amino-group and the carboxy-group are linked together in a condensation reaction – one molecule of H_2O is released with every bond formation.
  → Primary structure of the polypeptide
- Amino Acid side chains start to interact with each other causing the polypeptide chain to fold in a 3D structure

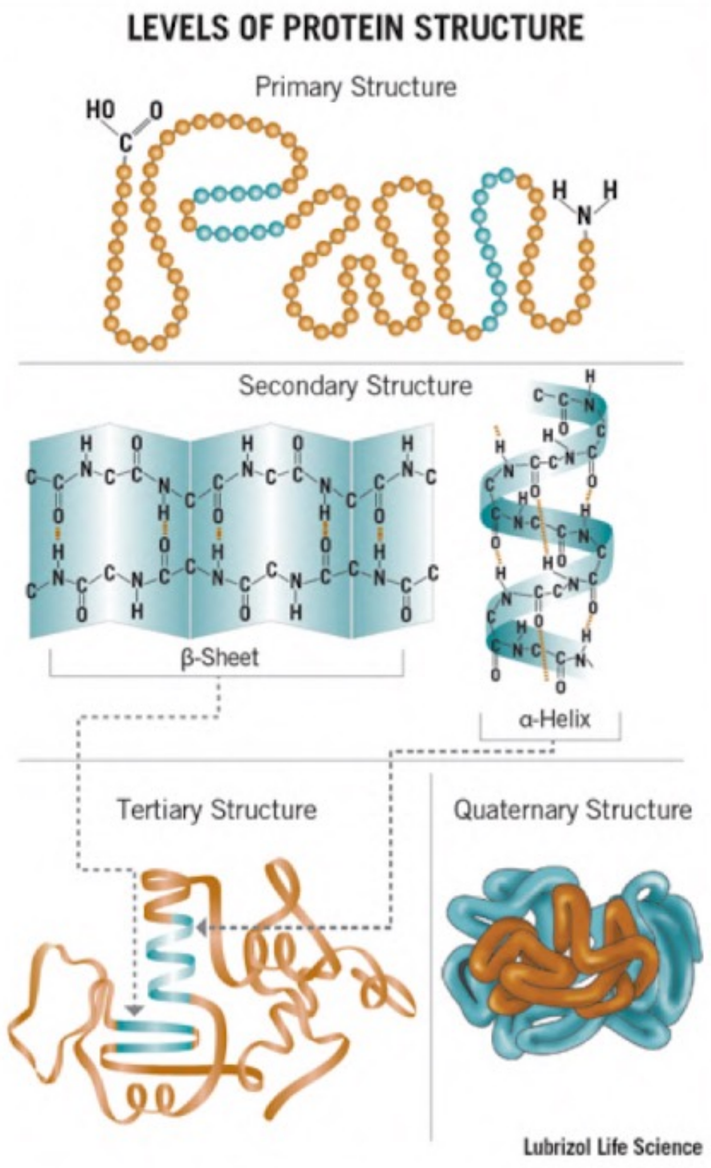


Macromolecules - Proteins

Structure

- <u>Primary structure</u>: Sequence of amino acids
- <u>Secondary structure</u>: alpha helix or beta sheet (primary structure is "formed" into these structures by hydrogen bonds between the backbone)
- <u>Tertiary structure</u>: folded up, functional arrangement of secondary structure (due to interactions between the amino acid side chains!)
  If you have a part with primarily non-polar side chains, do you think these will be presented on the outside of the protein in an aqueous environment or on the inside? Why?
- <u>Quaternary structure</u>: composed of multiple protein domains (several strands of amino acids) – eg. Haemoglobin

→ Only when the polypeptide is correctly folded and has a function we call it a protein!



Macromolecules - Proteins

Cellular functions

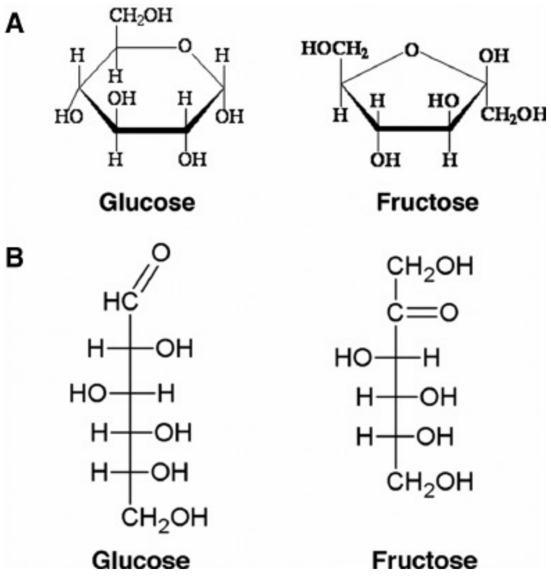
- Structure protein
- Catalysator (enzymes)
- Membrane proteins (eg. Pores, or ion channels)
- Locomotion apparatus (Myosin)
- Antibodies

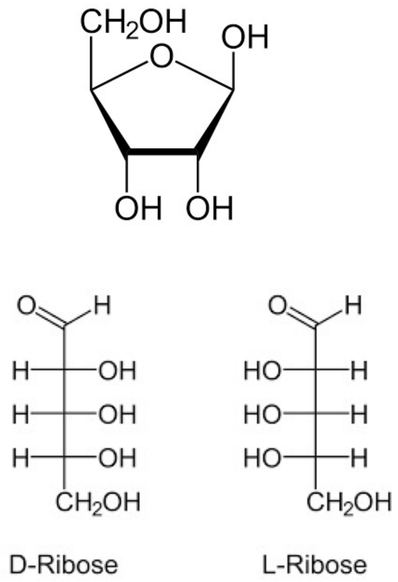
→ Wherever something actively happens within a cell and the body, there are proteins involved!

Macromolecules - Carbohydrates

- Linear and/ or circular molecules consisting of C, H and O atoms, additional functional groups are possible. The common formula for carbohydrates is $(CH_2O)_x$
- C atoms have four valence electrons and thus can enter up to four bonds with other atoms. C atoms are the backbone of carbohydrates, OH-groups and H-atoms are attached to them.
- Saccharides are circular carbohydrate molecules. They are grouped first and foremost by the amount of linked circular carbohydrate molecules. Their chemical properties depend on the placement of the OH-groups in space.

Macromolecules - Carbohydrates

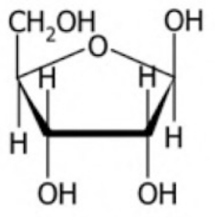




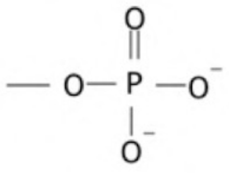
- **Monosaccharides**
  - Hexose: 6 C-atoms
    - Glucose and Fructose
  - Pentose: 5 C-atoms
    - Ribose
- **Disaccharides**
  - Two monosaccharides linked together via a condensation reaction
  - Sucrose: Glucose + Fructose
- **Polysaccharides**
  - Multiple monosaccharides linked together
  - Depending on linkage of monosaccharides the polysaccharide will have different properties: α-linked monomers (spiral form, more soluble but less stiff) will create a starch while ß-linked (stiffer but not as soluble) monomers will create cellulose

Macromolecules - Nucleic acids

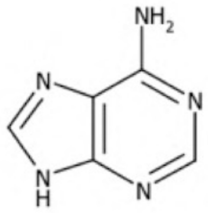
- Carriers of genetic information
- Important in the whole process of Proteinbiosynthesis
- Building Blocks (Monomers): Nucleotides
  - Pentose
  - Phosphate-rest (at 5th C of the Pentose)
  - Base (at 1st C of Pentose)



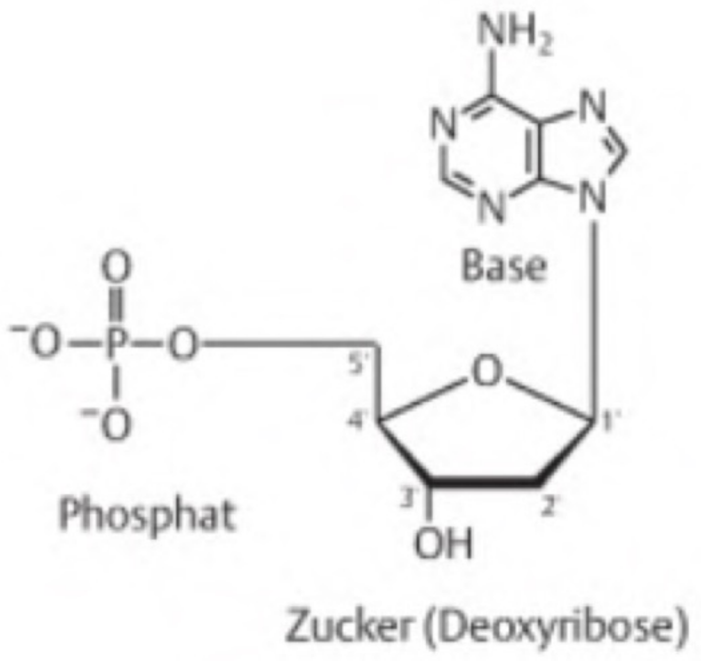
Pentose (Ribose)



Phosphat-Rest

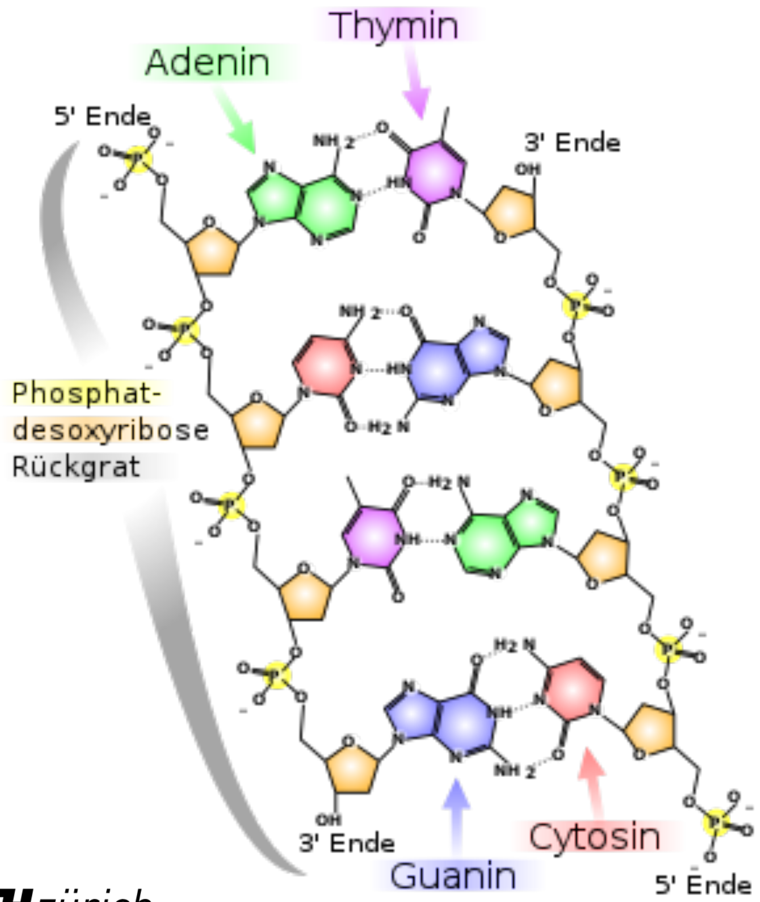


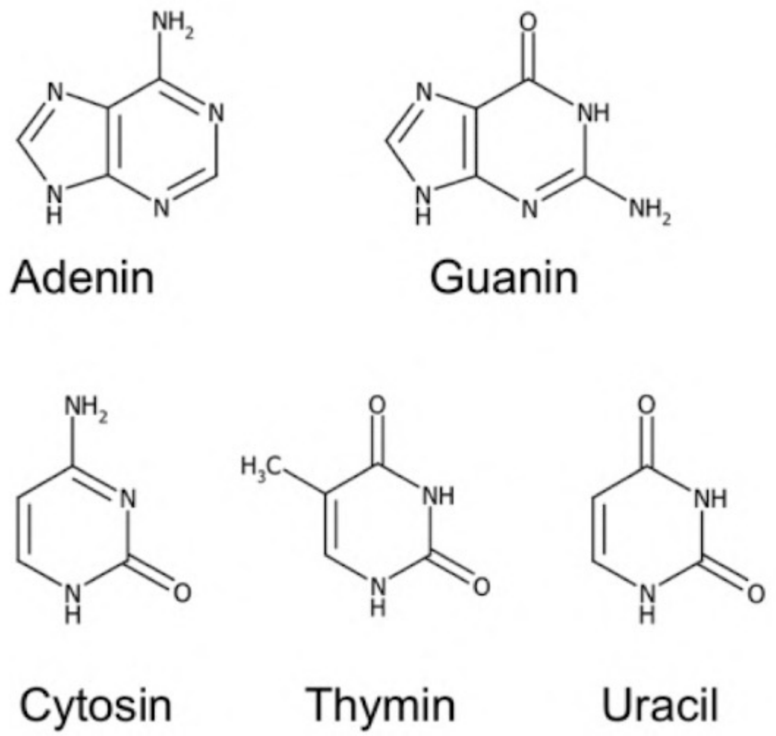
Base (Adenin)



Macromolecules - Nucleic acids

- 5 Bases
- A, G, C, T → DNA
- A, G, C, U → RNA





Doppelringsystem „Purinbasen“

Einfachringsystem „Pyrimidinbasen“

Macromolecules - Nucleic acids

Formation

- Nucleotides bind and build a nucleic acid chain via Phosphate-Bridge between the Phosphate group (On the 5^{th} C) and the 3^{rd} C of the next nucleotide
- → gives nucleic acid a direction (5' and 3')
- Elongation always on the 3' end of the nucleic acid chain. (Synthesis: 5' to 3')

Types of Nucleic acids

- Ribonucleic Acid (RNA) – containing ribose and bases: AGCU
- Deoxyribonulceic Acid (DNA) - containing deoxyribose and bases: AGCT
  - Forms double helix, G-C and A-T bind via Hydrogen bridges between the two backbones

Roles of nucleic acids

- Genetic material – long term storage (DNA)
- Replicating material, mediator/short-term storage (RNA)
- Carry out own function (protein-like); eg. In ribosomes
- Energy exchanger/carrier and chemical activator