Physical biology

David Caro

08-01-2024

1.1 Life

Common description uses 5 characteristics:

- made of cells
- they replicate
- they evolve
- store information (genes)
- use energy

1.2 Cellular theory

- 1665 Hook ->first microscope ->**dead cells**
- 1660-1680 Van Leeuwenhoek ->more potent microscopes ->**live cells and microorganisms**
- 1831 Brown ->**defines the nucleus**
- 1838 Schleiden (for plants), 1839 Schwann (for animals) and 1857 Virchow define the cellular theory:
  - The cell is the unit of structure for life
  - Cells retain a dual existence as individuals and building blocks
  - (Virchow 1857) All cells come from other cells

1.3 Theory of evolution

Darwin and Wallace create the theory of evolution, two main principles:

- All species are related by common ancestors.
- Characteristics of species change from generation to generation.

The key insight was their description of the process that pushes for that change: **natural selection**.
This means that you can draw a **tree of life** from the common ancestor to the current extant species.

1.4 Chromosomic theory of inheritance and central dogma

Chromosomes are made of a single DNA molecule, and some of it's segments that codify the products in the cell are called genes.
The central dogma of microbiology states that the flow of information is unidirectional:

- DNA
- -transcription->mRNA
- -traduction->protein
- ->specific trait

1.5 Taxonomy

Naming organisms, started by Carl Linnaeus, binomial system, ex:

<gender><species>: quercus robur (oak)

Added a hierarchy of taxonomical groups:

species <gender <family <order <class <phylum <kingdom

Can be drawn for all species in a phylogenetic tree, where the closest the branch, the more closely related the species.
Recent genetic studies have shown that this is obsolete, and currently life is classified in three domains:

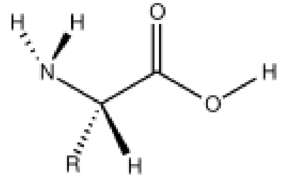
- Bacteria
- Archaea
- Eukarya (cells with well defined nucleus, plants, fungi, animals, ...)

2.0 Biomolecules

There's organic and inorganic molecules that are part of a living being, we will focus on the organic ones:

2.1 Proteins

Polymers of aminoacids joined by peptide bonds, structure of an aminoacid:



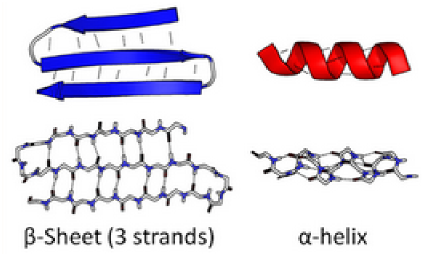
by Smokefoot - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=106539890

Note the amino group NH_2, the carboxyl acid group $COOH$, and the lateral chain with the root R, characteristic of every aminoacid.
They are joined by condensation, when the $COOH$ group creates a peptidic bind with the $NH2$ of the next.

2.2 Protein structure

There's 4 structure levels:

- Primary: peptidic bonds between single aminoacids in the protein
- Secondary: hydrogen bonds between the O of a $COOH$ group in one aminoacid and the NH_2 of another, can create two different shapes:
  - α-helix - R groups facing outwards
  - β-sheet



- Tertiary: **when R groups are involved**, there's many kind of folds, but only a few bonds that can happen:
  - **Hydrogen bonds** between $COOH$ carbonyl group and the lateral chain
  - **Hydrogen bonds** between two lateral chains or R groups
  - **Covalent bonds**, commonly di-sulfur bridge between cysteine R groups
  - **Ionic bonds** between R groups
  - **Hydrophobe interactions and van der Waals forces**, when in water, the hydrophile lateral chains push the hydrophobe R groups together, and then van der Waal forces keep them stable
- Quaternary: Combination of polypeptide, bound by similar bonds than the tertiary structures.

Folding is often facilitated by a specific type of proteins called **chaperones**. These molecules are generated in big quantities when there's a high rise in temperature. They attach themselves to the hydrophobe sections of unfolded proteins to prevent other molecules from attaching and allow the protein to re-fold itself before any unfolded aggregates get created.

2.3 Protein function

The functionality of a protein is strongly related to it's folding, two proteins with the same aminoacid sequence cat behave really differently, for example prions are proteins that when folded in a specific way, become infectious.
When a protein loses it's folding it's said it gets **denaturated**, this can happen for many reasons (heat, pH, ...).
They are the more versatile of the molecule groups, having many functions:

- **Catalytic/enzymes**: they speed up many chemical reactions.
- **Defensive**: Antibodies and other proteins attack and destroy viruses and bacteria
- **Movement**: Motor protein and contractile proteins move substances within the cell, the cells themselves and the whole body (muscles).
- **Signaling**: They are involved in the transport and reception of signals, sometimes bound to the cell membrane to interact with neighboring cells.
- **Structural**: collagen of the skin and tendons, membrane proteins.
- **Transport**: They allow that some molecules enter and leave the cell, or transport them throughout the body (hemoglobin).

2.4 Nucleic acids

Formed by **nucleotides**: a pentose sugar (ribose with OH on 2'/deoxyribose with H on 2'), a nitrogenous base (bound to the carbon 1'), and a phosphate (bound to the carbon 5').
Note that **nucleoside** is just the pentose sugar and the base.
Bases can be one of:

- Cytosine - Pyrimidine
- Uracil (RNA)/Thymine (DNA) - Pyrimidine
- Guanine - Purine
- Adenine - Purine

The nucleotides are bound with phosphodiester bonds (covalent bonds) on 5' and 3', and form a directed chain, always written from the nucleotid with the phosphate (5') free, to the one with the OH (3') free.
That is also the direction they are synthesized.
They form two main structures:

- **RNA**:
  - Sugar: ribose
  - Bases: A-U, G-C
  - Structure: simple strand
  - Function: transport, structural, etc.
- **DNA**:
  - Sugar: deoxyribose
  - Bases: A-T, G-C
  - Structure: double helix strand bound by hydrogen bonds of the bases
  - Function: carries the genetic information

In order to polymerize the nucleotides, the potential energy of the nucleotides is increased by adding phosphates, creating triphosphate nucleosides or **activated nucleotides**, then when they get polymerized they need water and generate inorganic pyrophosphate. Ex. ATP (adenine + 2 phosphates ->adenosin triphosphate)

2.5 DNA structure

The **primary structure** of the nucleic acids is just the sequence of basis it's made of.

The **secondary structure** is built by hydrogen bonds between the R groups, and for DNA is an **antiprallel double helix**, where the bases are matched only between complementary purines and pyrimidines (G-C has 3 hydrogen bonds, A-T has two hydrogen bonds).
The helix (2 nm wide) does a turn (3.4 nm) every 10 base pairs (0.34 nm), where the two strands phase is not symmetric, creating one small and one big gap between them.

The **tertiary structure** DNA is usually packed with proteins, in eucaryotes these are histones, the bundle is called **chromatin**, and it comes in two flavors, a more packed one that is not ready for transcription **heterochromatin** and a lightly packed one ready for transcription, **euchromatin**.

2.6 RNA structure

The **primary structure**: same as DNA, it's the sequence of basis.

The **secondary structure**: the most common is the stem loops (horquilla), where a single strand bends over itself to create a loop and a double helix section with itself.

The **tertiary structure**: secondary structures fold to generate a great variety of forms for RNA.

2.7 RNA types

There's three main types of RNA:

- **mRNA (messenger RNA)**:
  - Transports information from the nucleus to the cytoplasm
  - Gets translated in the ribosomes to generate proteins
  - Single strand

  TOTAL 26 TiB 21 TiB 21 TiB 1.4 GiB 67 GiB 5.2 TiB 79.97 15:43:15 TOTAL 26 TiB 21 TiB 21 TiB 1.4 GiB 67 GiB 5.3 T
- **rRNA (ribosomal RNA)**:
  - It's a structural part of the ribosomes
  - There's several types that form the small and big subunits of the ribosome along with proteins
  - Single strand with secondary structure
- **tRNA (transfer RNA)**:
  - Transports aminoacids to the ribosome
  - Simple strand with clover-like secondary structure

2.8 Carbohydrates structure

Made out of **monosaccharides**, they are composed by carbon, hydrogen and oxygen and are mainly used either as energy storage, or as structural molecules.
They have one carbonyl group ($C = O$), several hydroxyl ($-OH$) and a variable number of carbon-hydrogen bonds ($C - H$).

- **monosaccharides**: simplest of sugars, made of a single strand of carbons, with a carbonyl group and one or more hydroxyl (ex. glucose, fructose, galactose).

- **disaccharides**: formed by two monosaccharides when the hydroxyl groups bond (by condensation) to form **O-glycosidic bonds** (ex. 2 x glucose ->maltose + $H2O$, glucose + galactose ->lactose + $H2O$)
- **oligosaccharides and polysaccharides**: for groups of 2-10 monosaccharides bonded by glycosidic bonds, we call them oligosaccharides, and when they have more monosaccharides, we call them polysaccharides. (ex. starch, cellulose, chitin, glycogen).

2.9 polysaccharides

They have mainly two functions, **structural** and **energy reserve**. The main polysaccharides are:

- **Starch**
  - reserve molecule used by plants
  - amylose and amylopectin (both made of glucose)
  - amylose has a lineal helix structure
  - amylopectin has a ramified helix structure
- **Glycogen**
  - reserve molecule used by animals, fungi and some bacteria
  - very similar to amylopectin but it's even more ramified
- **Cellulose**
  - Structural support for plants and many algae
  - parallel chains joined with hydrogen bonds
- **chitin**
  - Structural support for insects and fungi
  - parallel chains joined with alternating hydrogen bonds
- **Peptidoglycan**
  - Structural for bacteria
  - parallel chains joined with peptide bonds (using a chain of 4 aminoacids)
  - alternating NAG (N-acetylglucosamine) and NAM (N-acetylmuramaic acid), with a short string of aminoacids on C-3 of Nam