VIBE PROJECT

Virtual Biomedical and STEM/STEAM Education

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The structure of eukaryotic cells

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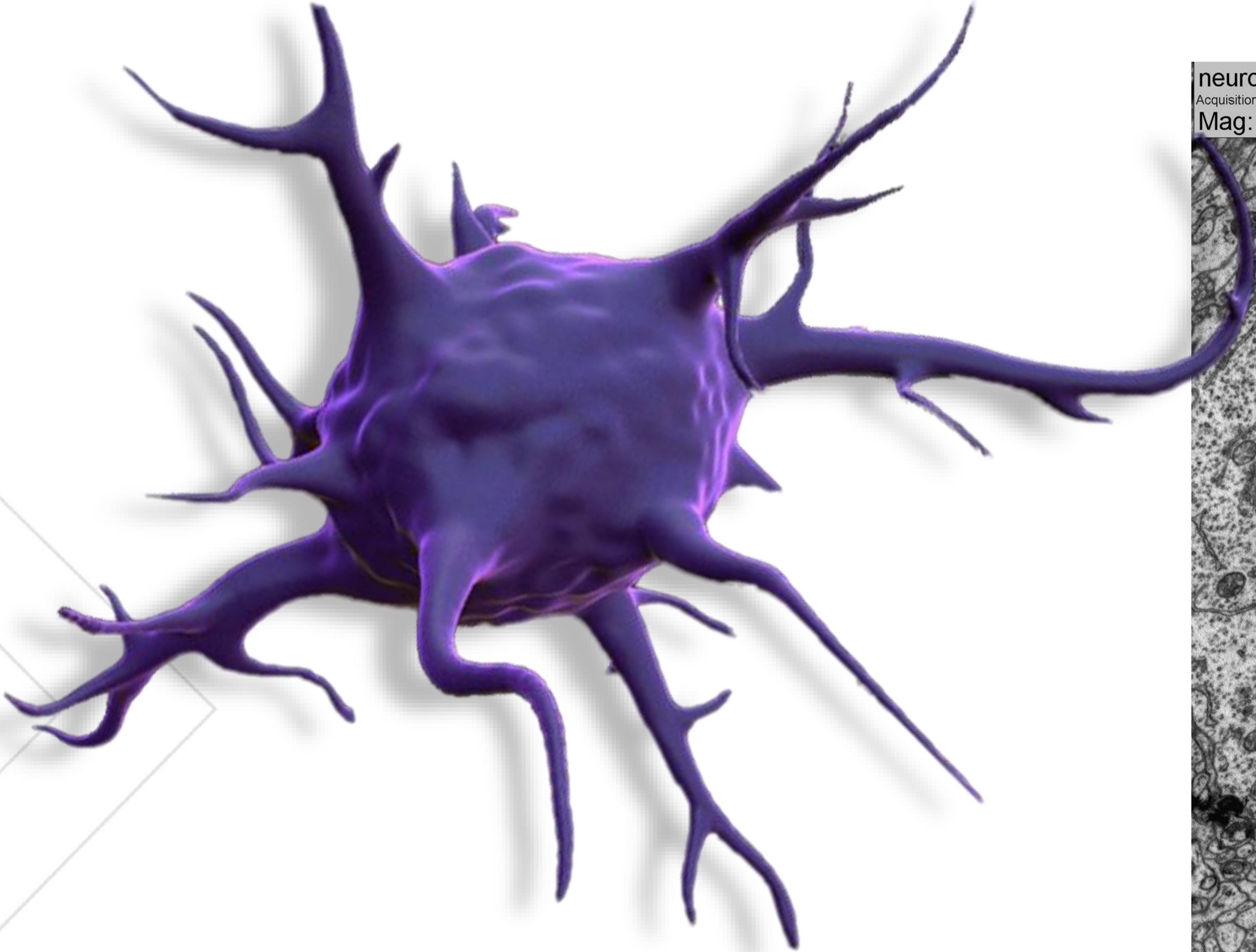
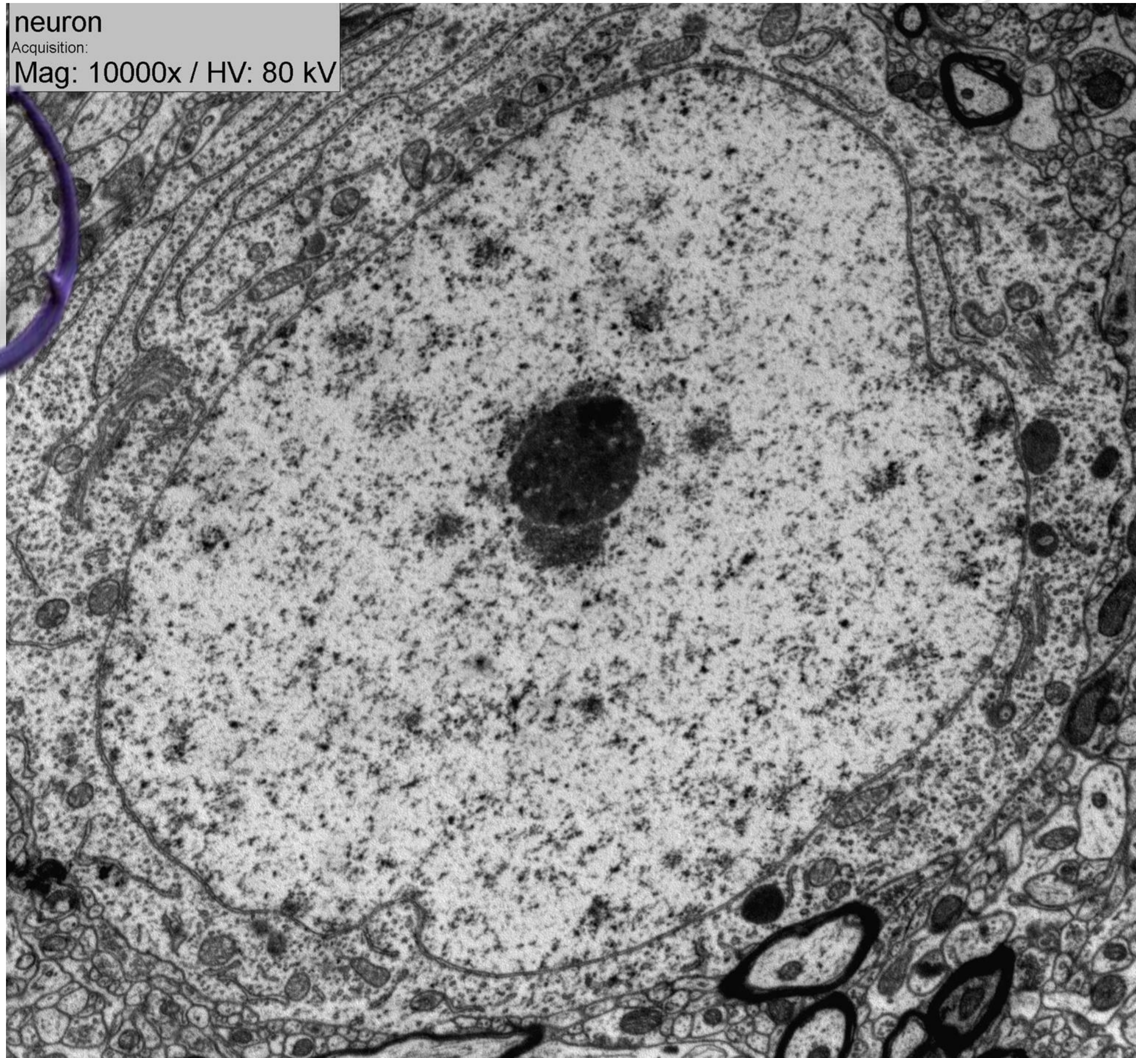
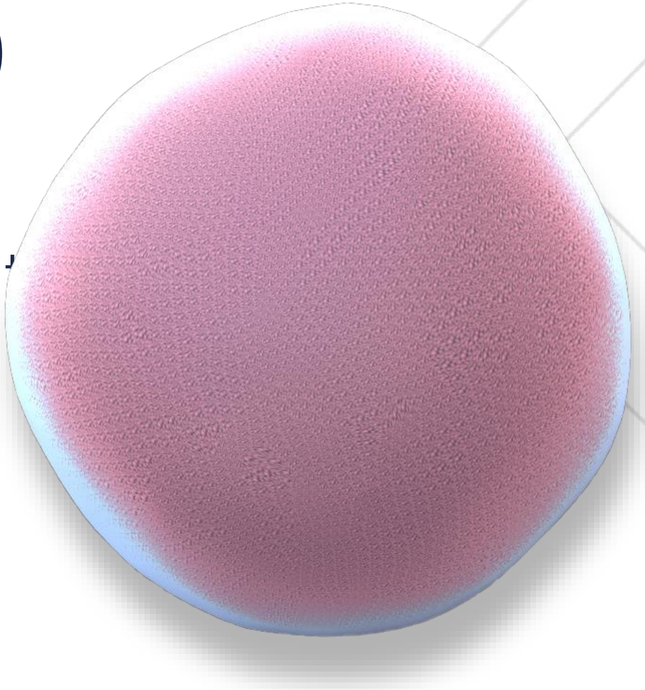
The structure of a neuron

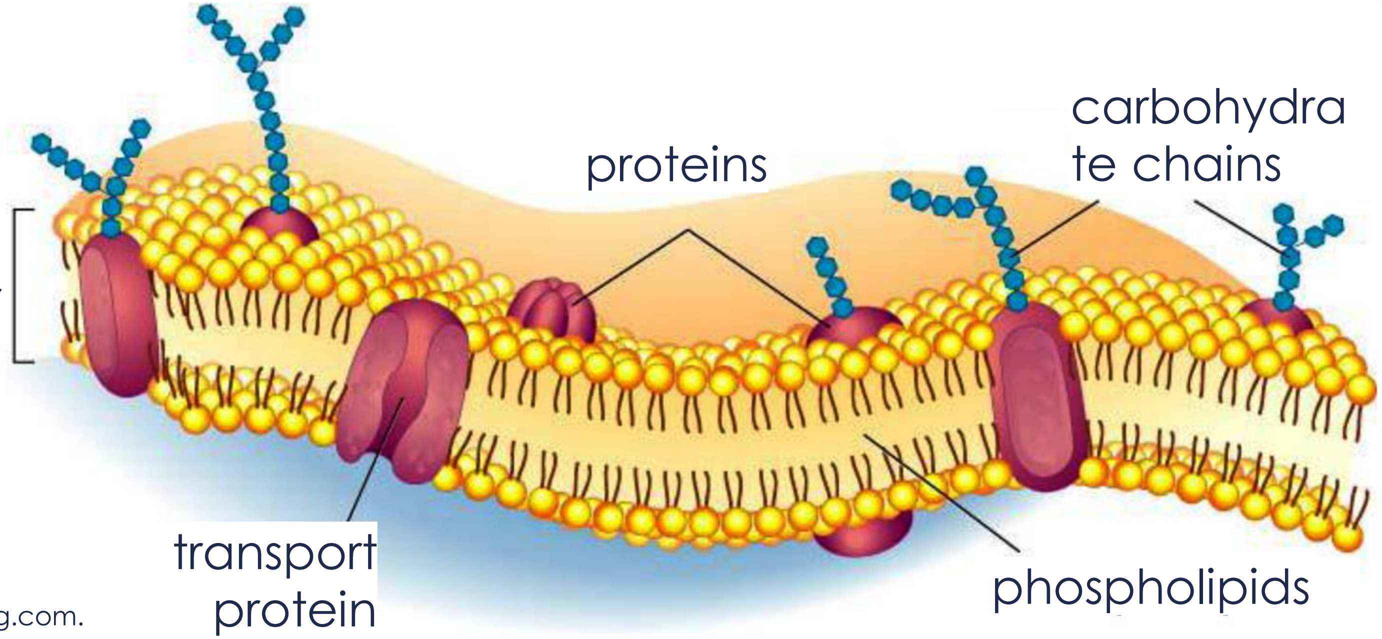




The cell membrane and biological membranes of intracellular organelles

- Phospholipid bilayer with embedded proteins (ratios approx.50-50%)
- fluid mosaic model
- glycoproteins and glycolipids contain carbohydrate chains
- membranes allow selective transport, separate but also connect to environment (via receptors involved in signaling)





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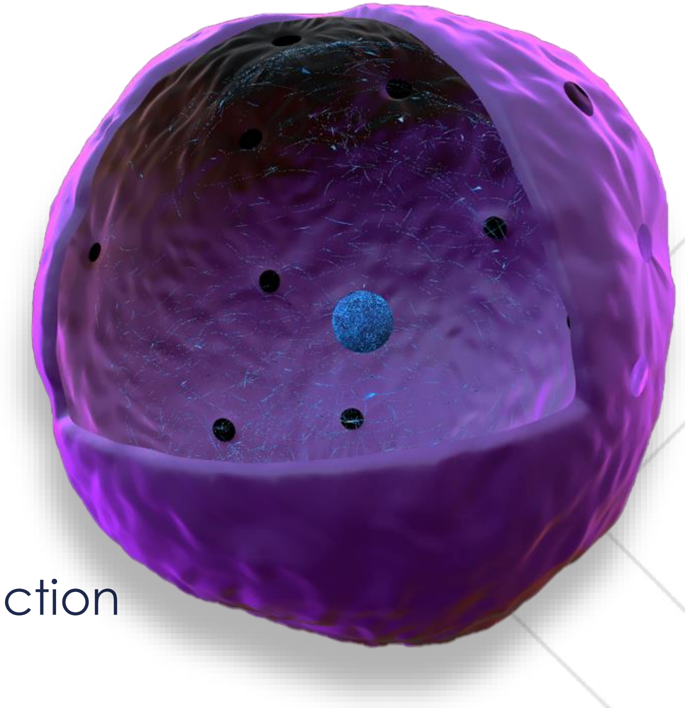
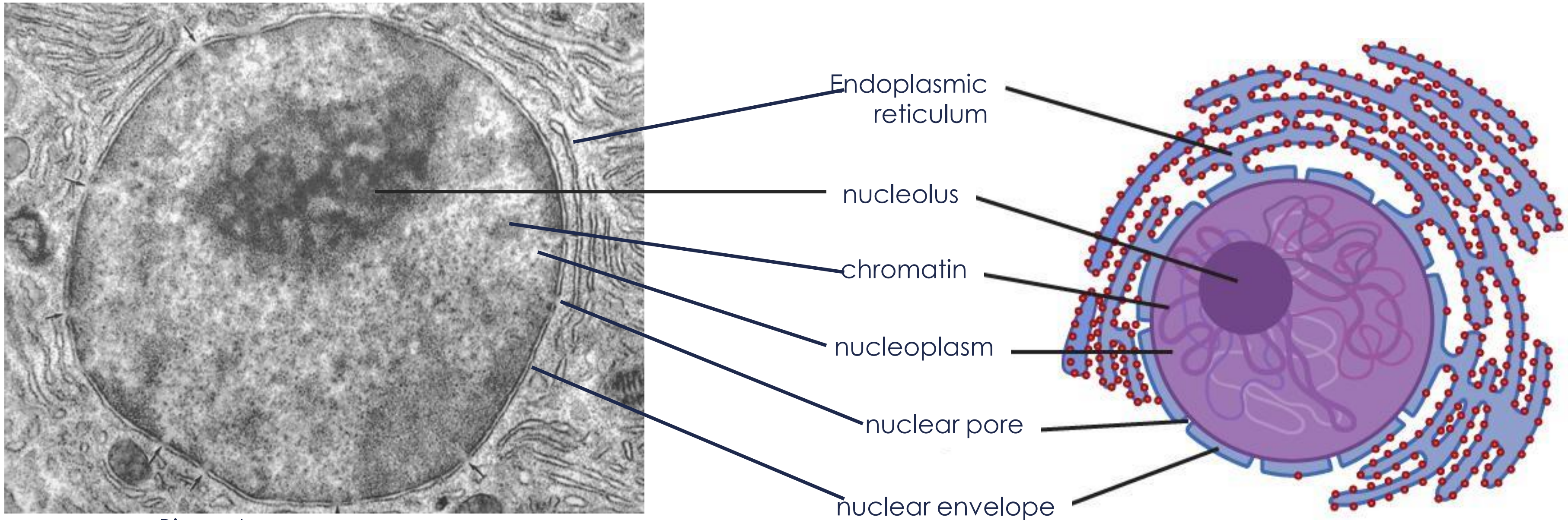
The nucleus



- The largest organelle
- Its shape can be round, flat, rod or a string
- Size: 5-10 μm
- It stores most of the cell's DNA, i.e. the genetic material
- It is the cell's control center: gene expression→ cellular structure and function
- It is the site of DNA replication, transcription (= RNA synthesis) and RNA processing



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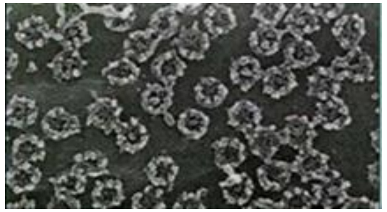
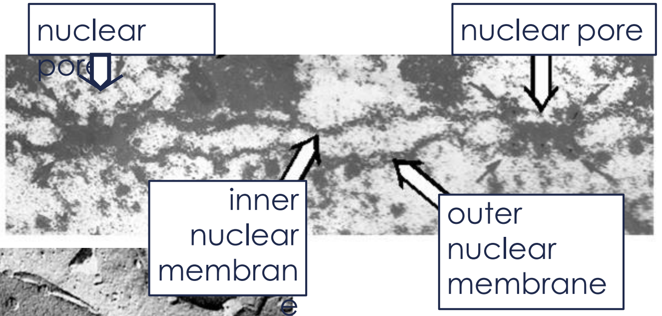
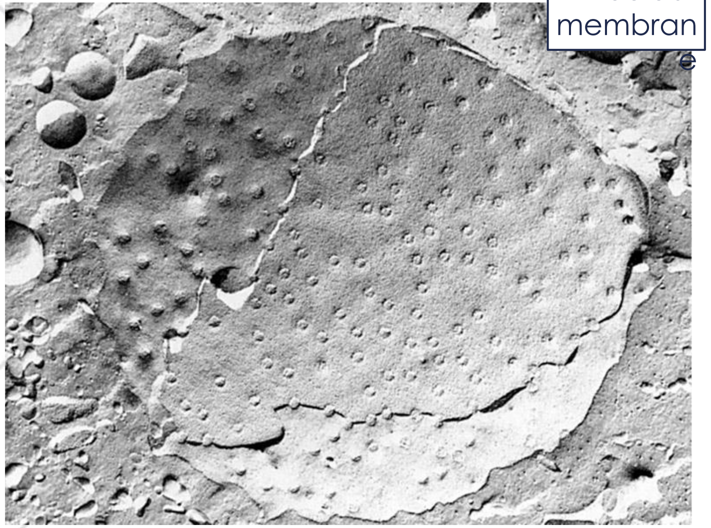
The nuclear envelope

- Consists of an outer and inner membrane + perinuclear space
- Abounds in nuclear pore complexes: intensive transport (e.g. protein import, RNA export)
- Nuclear lamina: a protein layer lining the inner surface of the inner nuclear membrane







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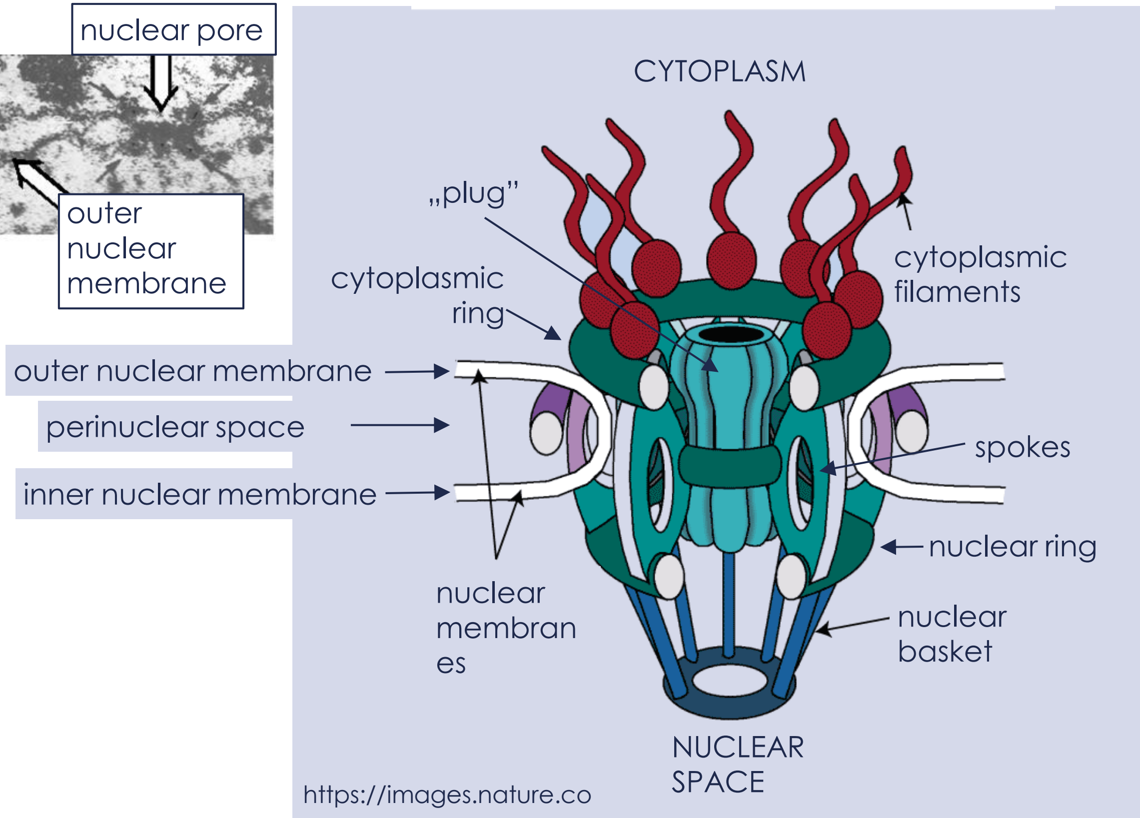

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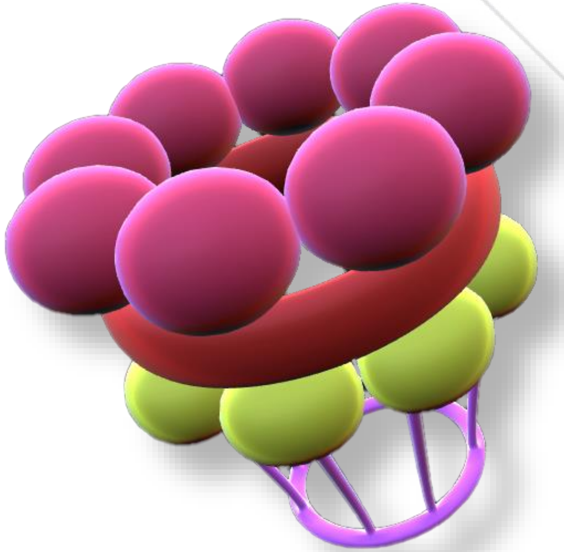
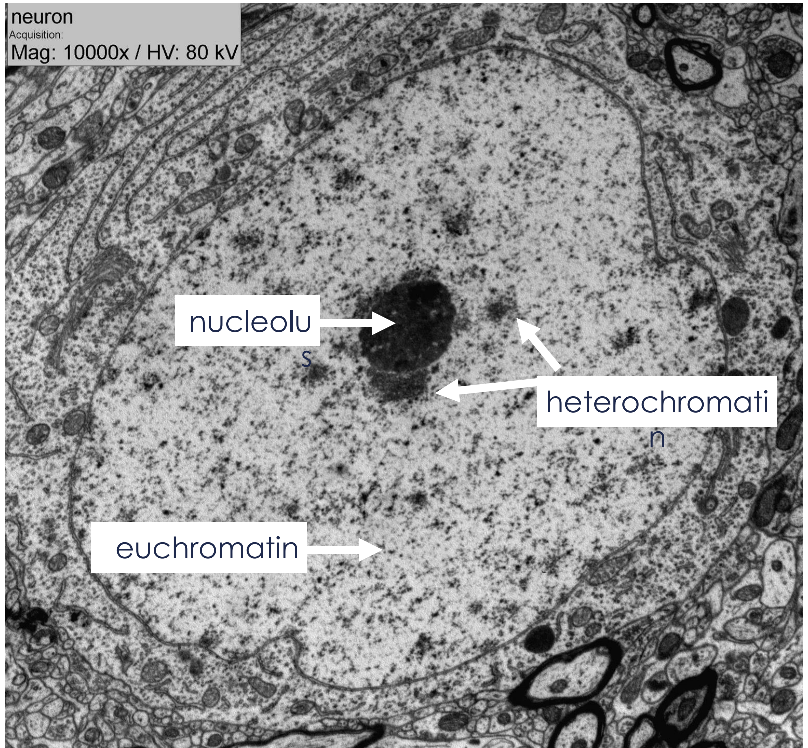


The structure of the nucleus

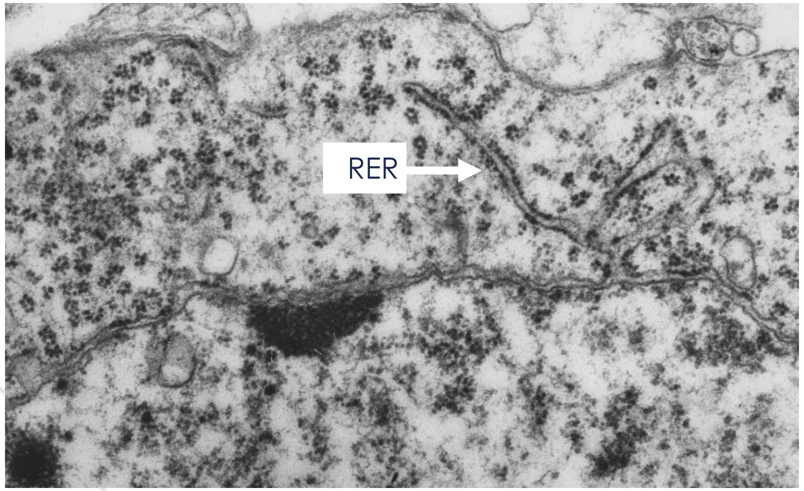
- Chromatin: DNA + proteins + RNA + ions
- Histone and nonhistone proteins bind to DNA
  - Euchromatin: looser structure, transcription takes place in it
  - Heterochromatin: more condensed structure, inactive regarding transcription

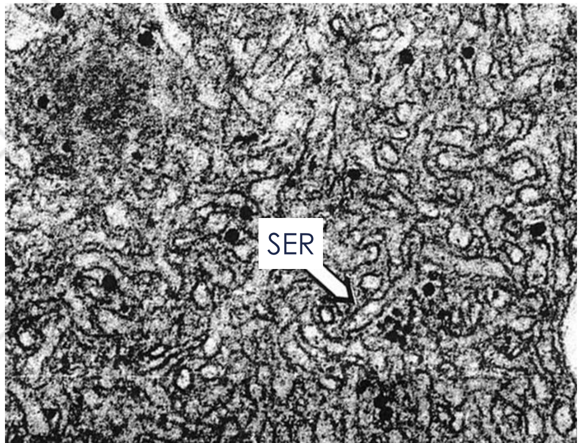
- Nucleolus: manufactures ribosomal subunits
- Nucleoplasm: the inner substance of the nucleus



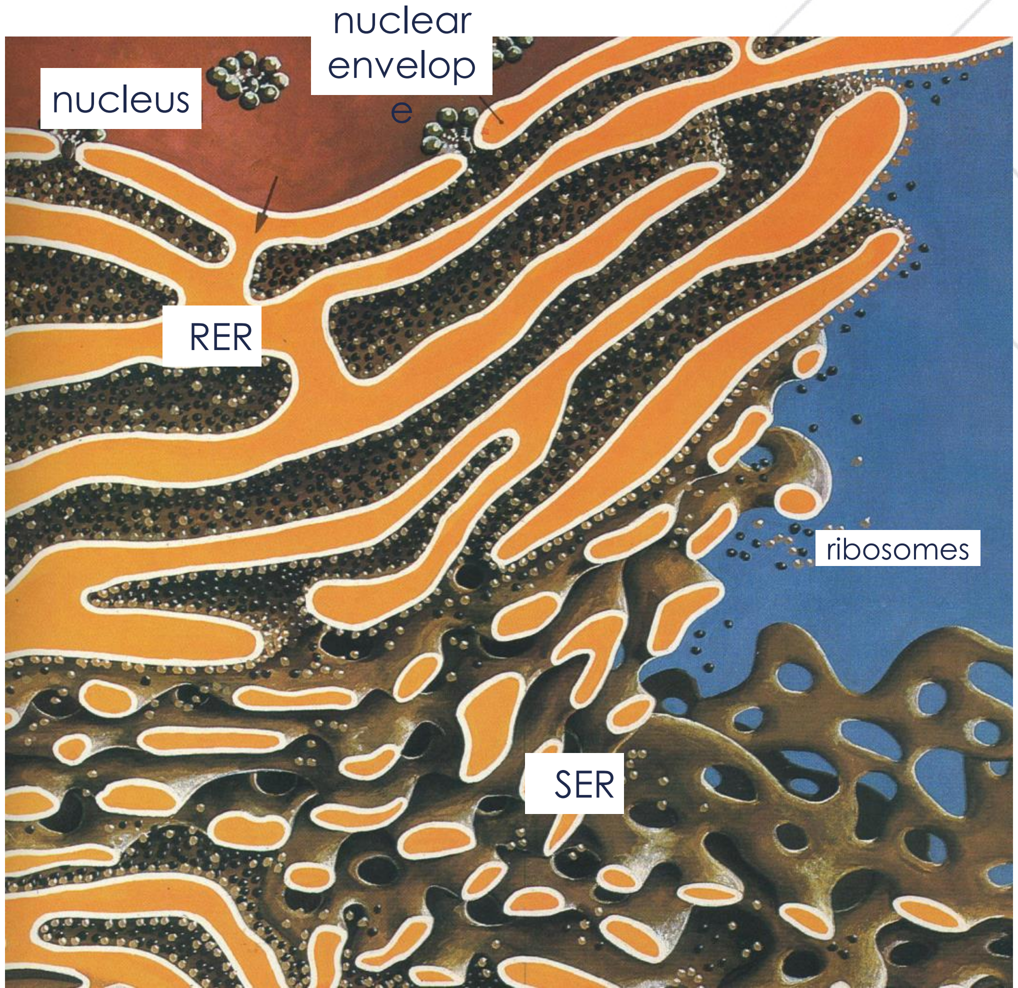
The endoplasmic reticulum

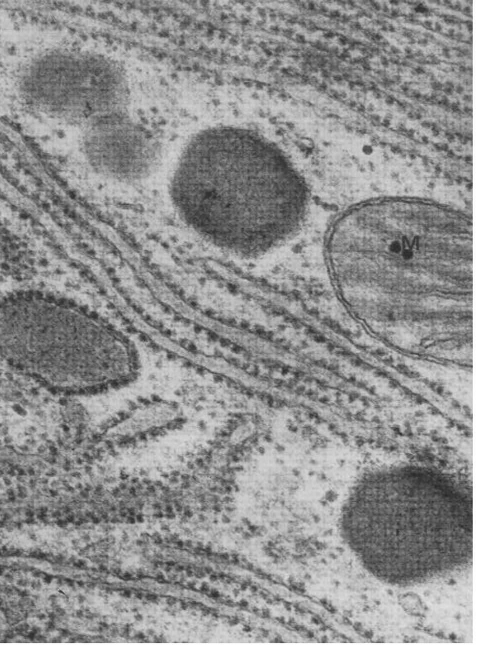
- An extensive membrane system connected to the outer nuclear membrane



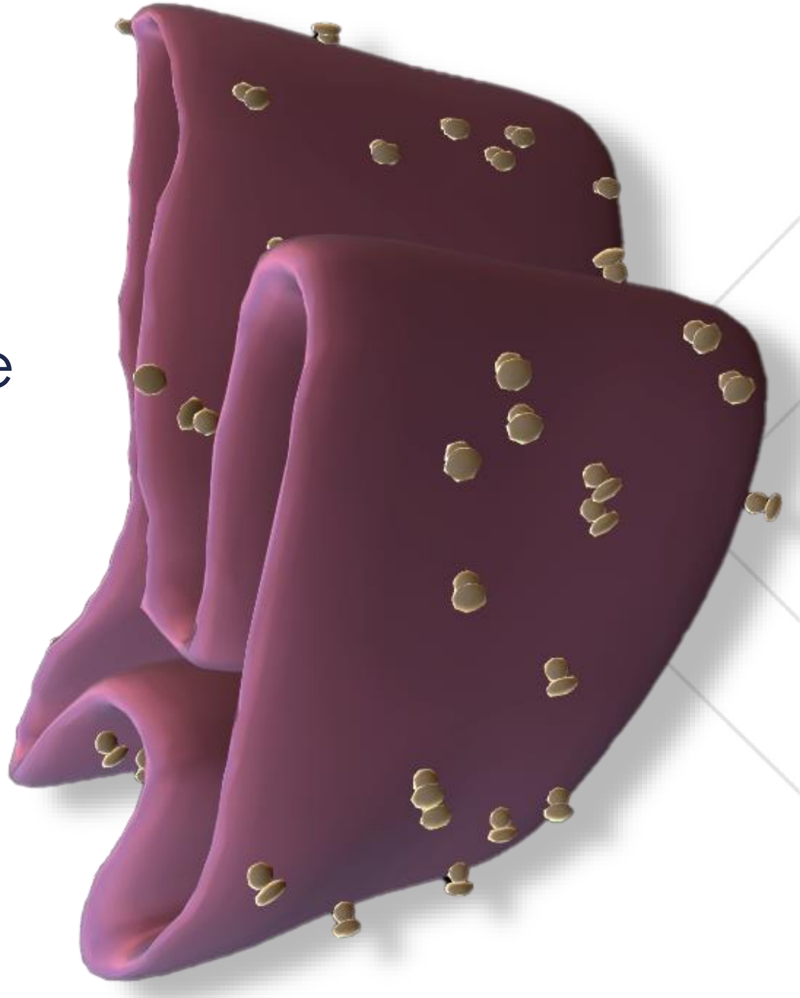


- ➢ Rough endoplasmic reticulum (RER)
- ➢ Smooth endoplasmic reticulum (SER)





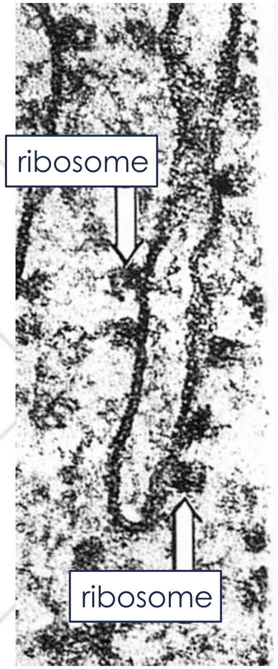
Rough ER



There are bound ribosomes on its surface

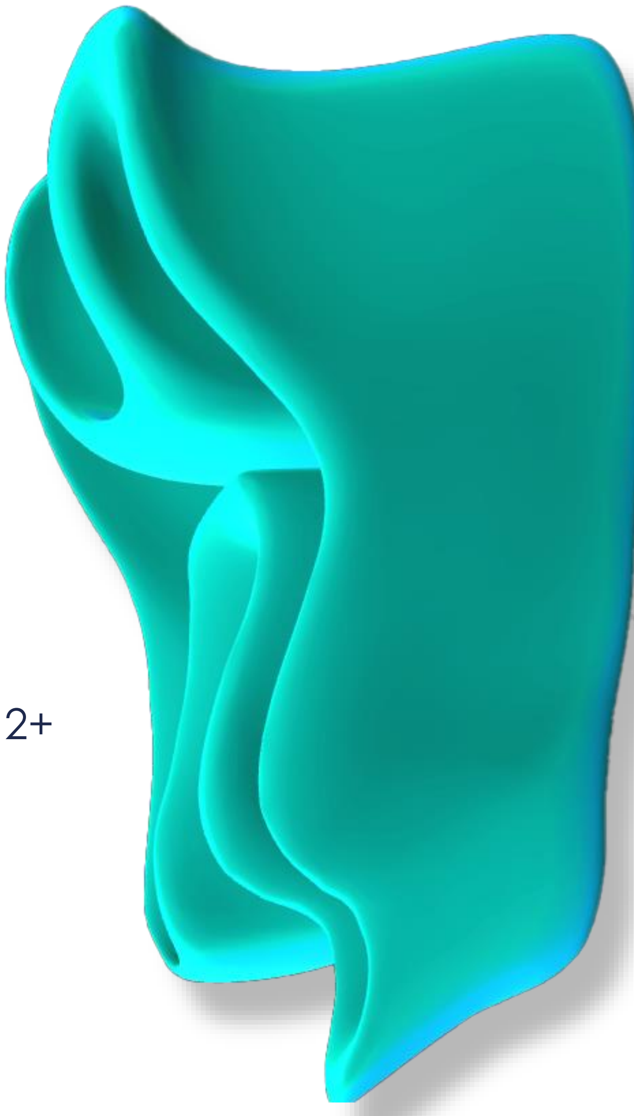
Functions:

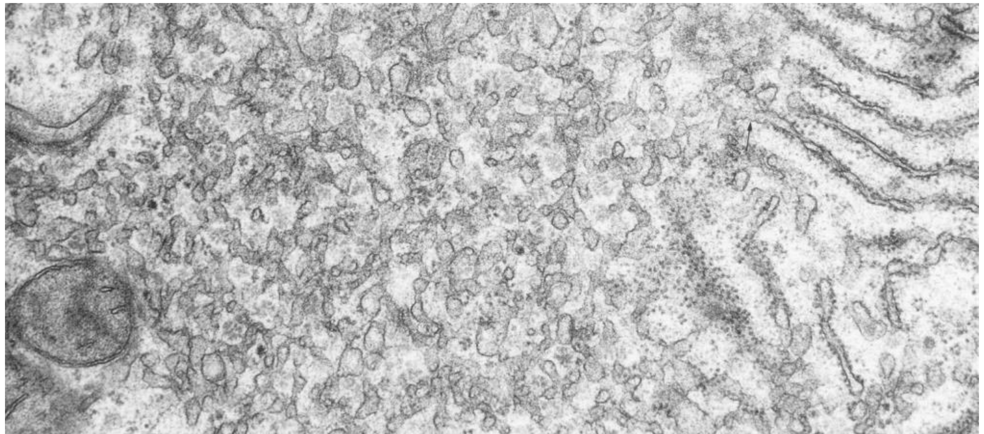
- Protein synthesis, for various organelles:
  - RER
  - Golgi apparatus
  - cell membrane
  - lysosomes
  - secretory proteins
- Protein processing (maturation):
  - Folding: formation and stabilization of conformation – with the help of chaperone proteins
  - Disulfide bond formation
  - Chemical modifications e.g. glycosylation (addition of carbohydrates)
- Quality control of proteins

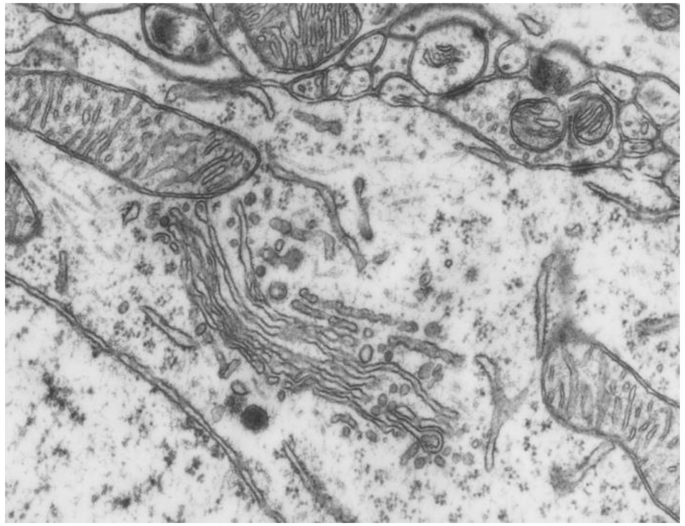


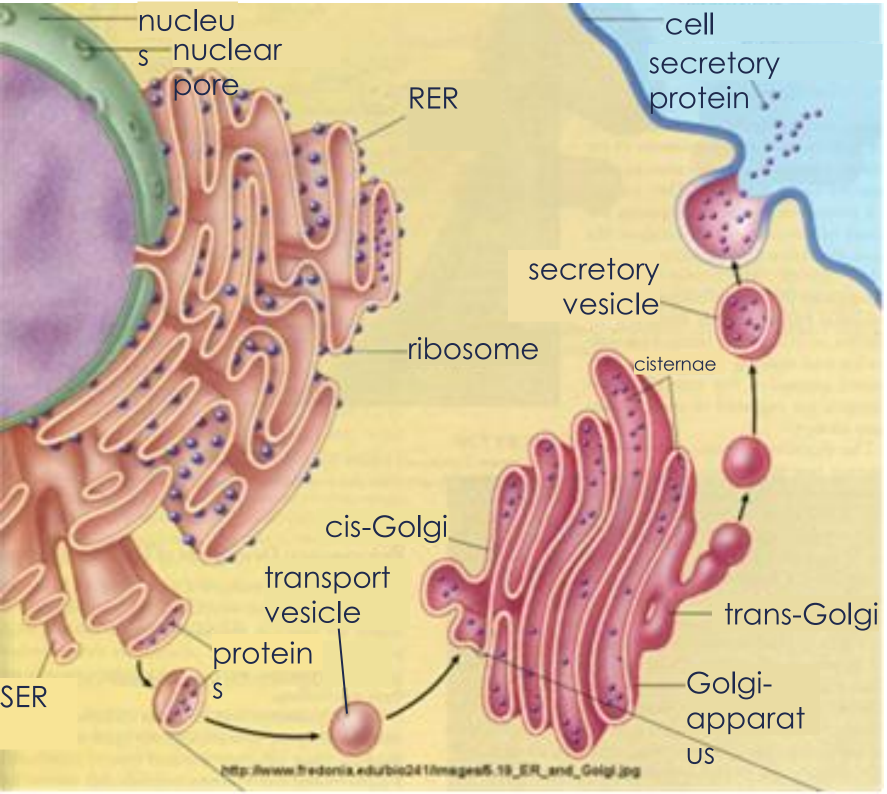
Smooth ER

- There are no ribosomes on its surface
- Its structure is not as well-ordered as that of the RER
- Functions:
  - Synthesis of lipids (e.g. phospholipids, steroids)
  - Ca^{2+} storage
  - Detoxification: biotransformation of foreign molecules
- In muscle: sarcoplasmic reticulum (a special SER): Ca^{2+} release from it → muscle contraction









Golgi apparatus

- is the next station of intracellular protein transport (along the „secretory pathway")
- It is composed of flat compartments (cisternae)
  - ➢ cis-Golgi
  - ➢ median-Golgi
  - ➢ trans-Golgi

Functions:

- ➢ protein maturation (e.g. glycosylation)
- ➢ sorting, and packaging of proteins into transport vesicles (by the trans-Golgi)

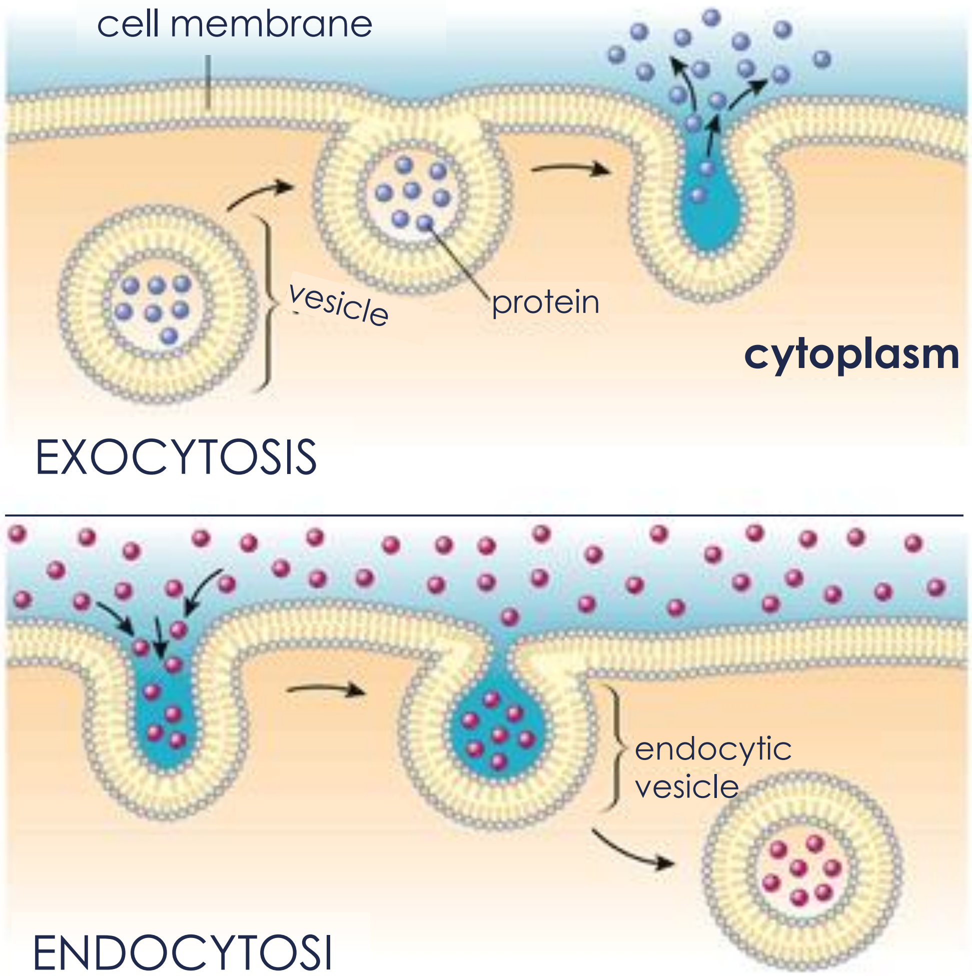
Vesicular transport

- The transport of materials (proteins, lipids, liquids, etc.) between the RER, Golgi apparatus, and SER is performed via transport vesicles (membrane-enclosed sacs)
- Along 2 major pathways:
  - endocytic pathway

    endocytosis: materials are taken up from the outside of the cell by a membrane invagination process

    - phagocytosis (e.g. leukocytes engulf bacteria)
    - pinocytosis (liquid uptake, „cell drinking")
    - receptor-mediated endocytosis (e.g. uptake of LDL particles)

    Endocytosis → endosome → merging with primary lysosomes → secondary lysosome (or alternatively storage, exocytosis)
  - Secretory pathway → exocytosis (secretion): transport of materials into the extracellular space: RER → transport vesicle → Golgi-apparatus → transport (secretory-) vesicle → exocytosis



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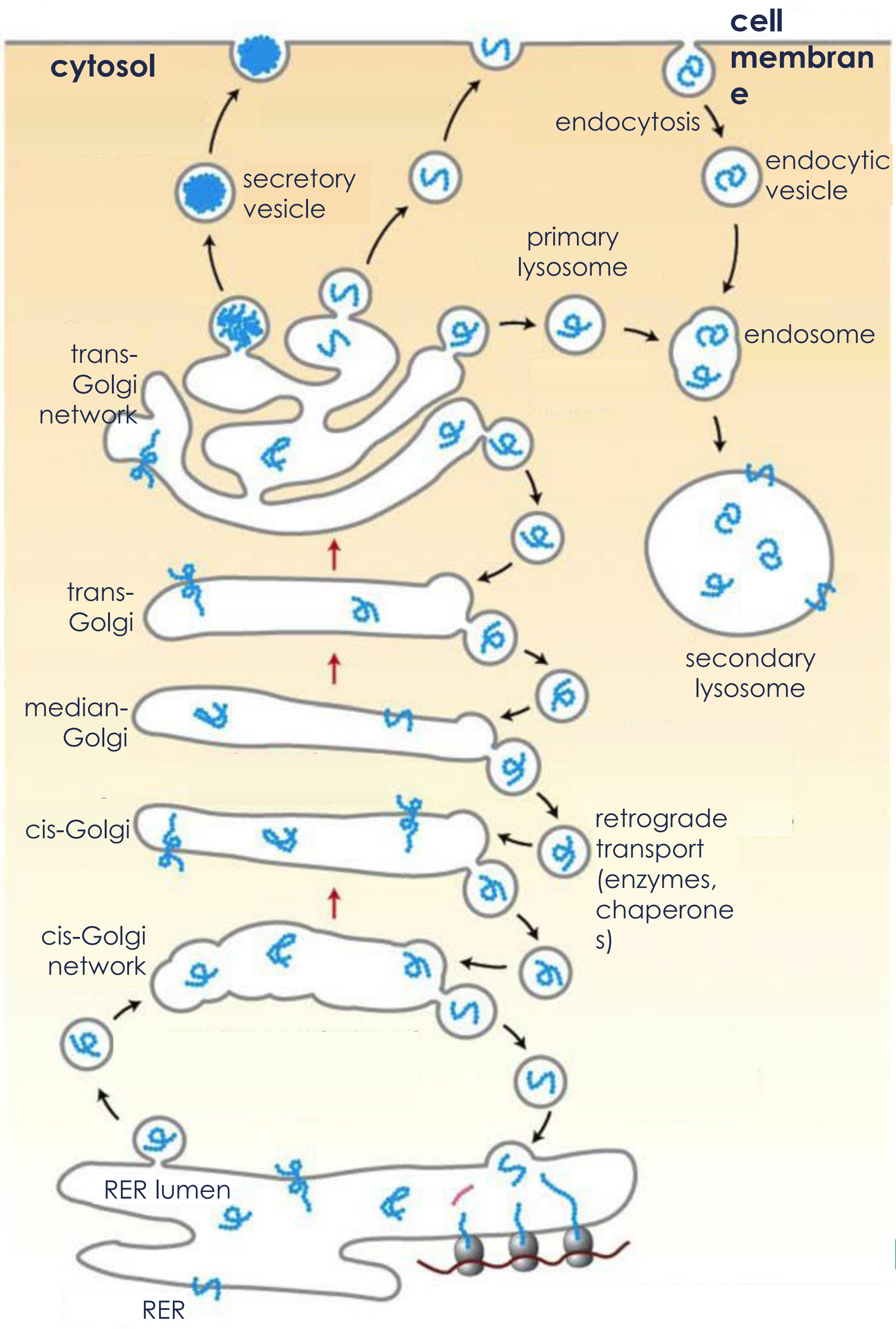

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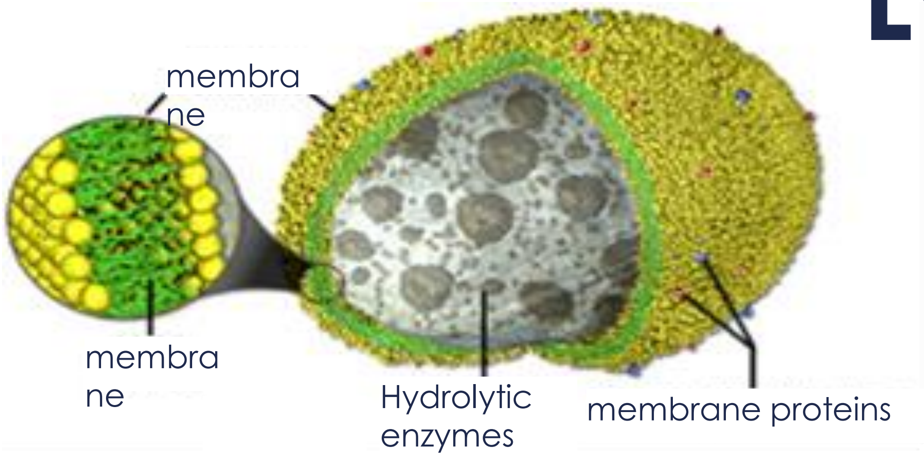
Lysosome

- Organelles of degradation and digestion. A single biomembrane surrounds a special content:
  - primary lysosomes: low pH (approx. 5), degradative enzymes (acid hydrolases). They originate form the trans-Golgi by budding.
  - secondary lysosomes: formed when primary lysosomes are fused to other vesicles. They contain materials which are being degraded (and are usually bigger in size).
- Degradation of molecules from different sources:
  - taken up from the cell's surroundings (by endocytosis, phagocytosis): heterophagy
  - intracellular molecules: e.g. worn out/damaged organelles (autophagy)

Lysosome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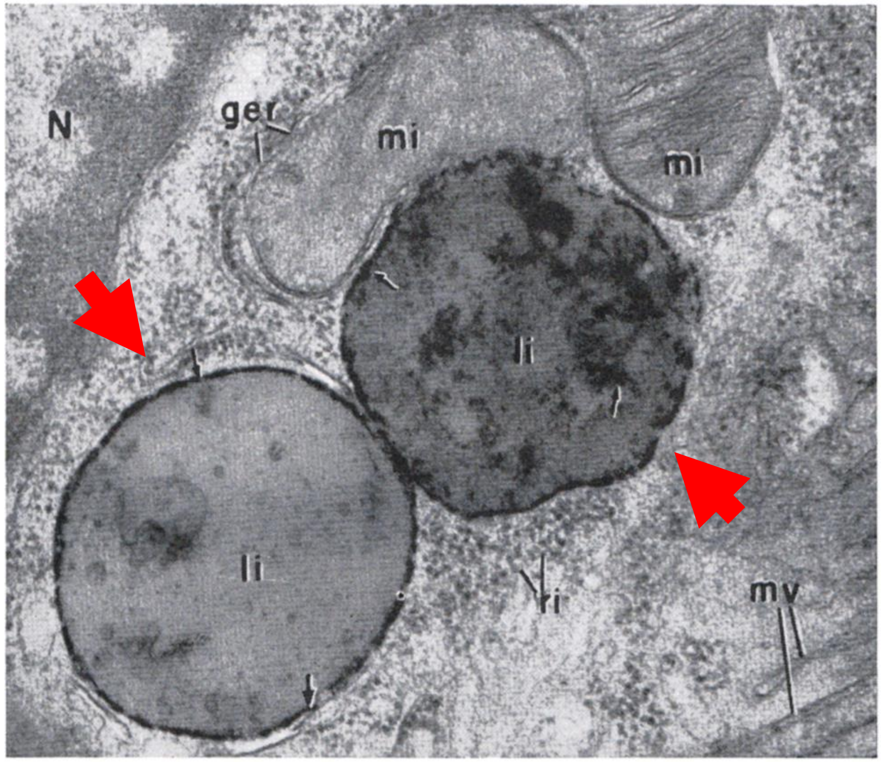
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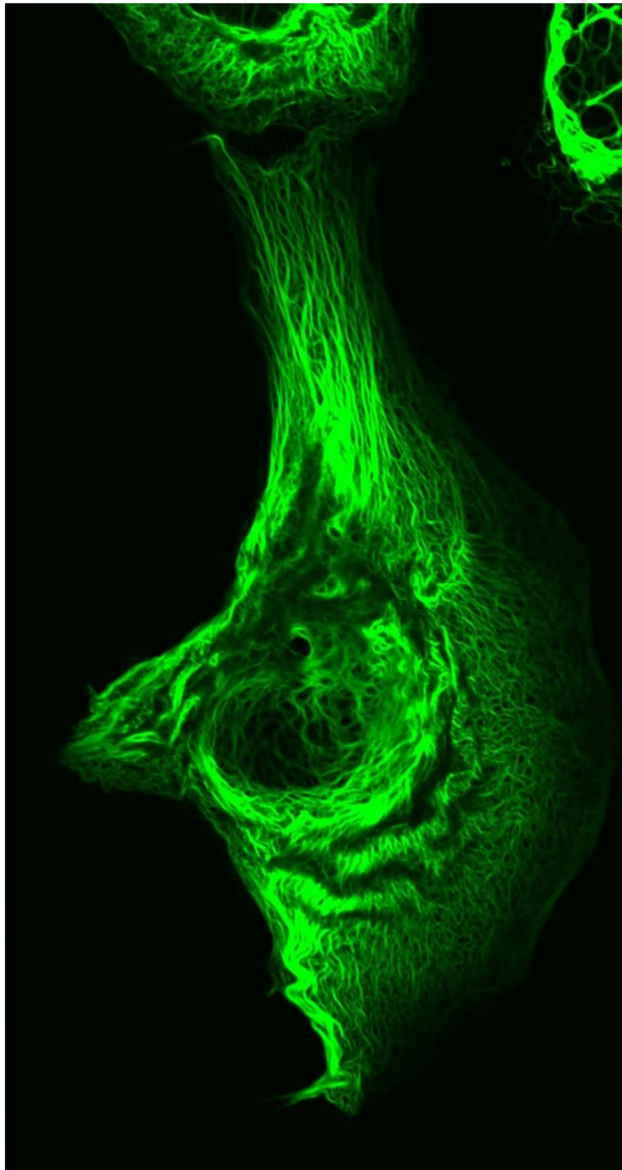
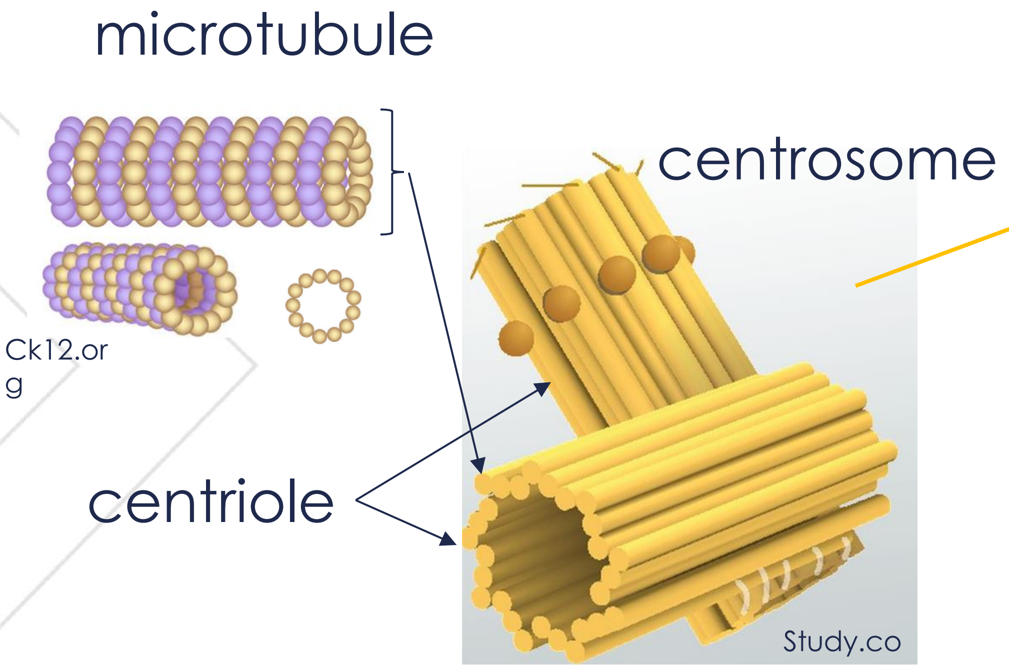
Cytoskeleton

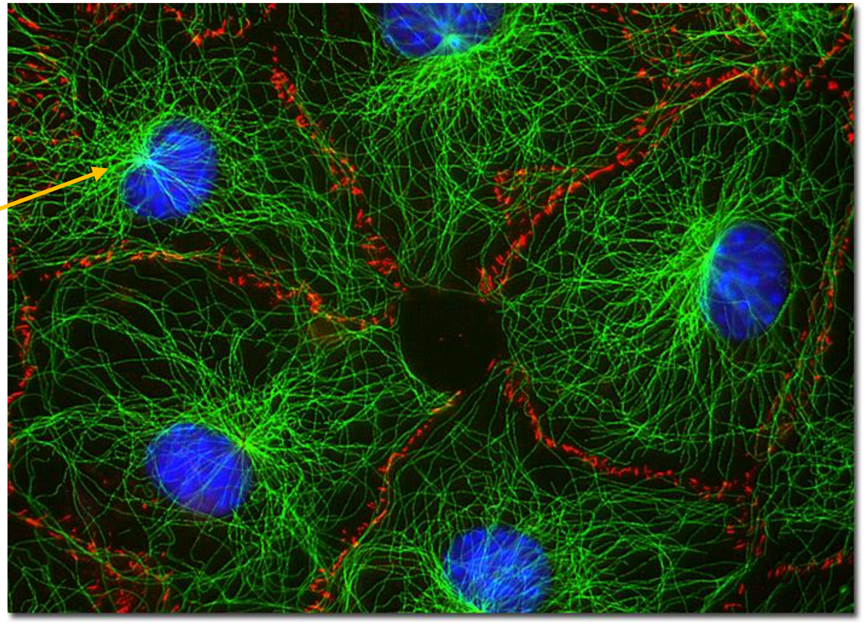
- Secondary bonds are formed between protein monomers during a polymerization process → filaments
- Roles:
  - determines cell shape
  - provides mechanical support
  - cell movement, shape alterations
  - chromosome movement during cell division
  - intracellular transport (movement of vesicles)
  - roles in intracellular signaling
  - 3 types: - **microfilaments**,
    - **intermediate filaments** and
    - **microtubules**



Centrosome

- The organizing center of microtubules
- composed of 2 centrioles
- in a centriole, 9 microtubule triplets form a cylinder
- microtubules are small tubes, composed of 13 paralel protofilaments of tubulin proteins





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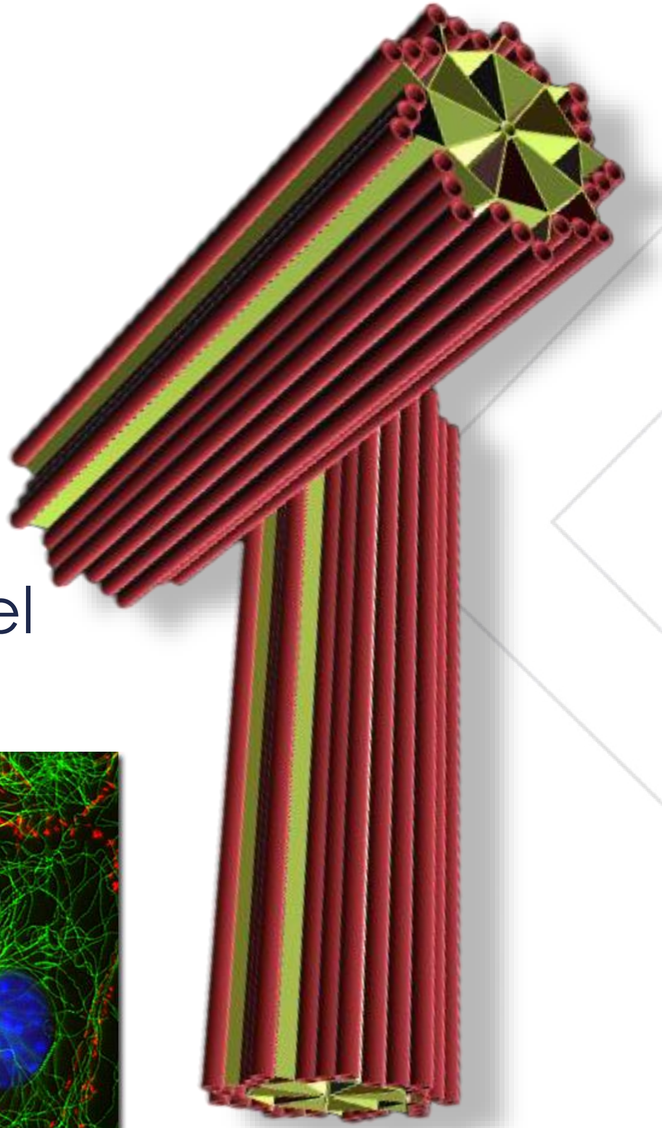
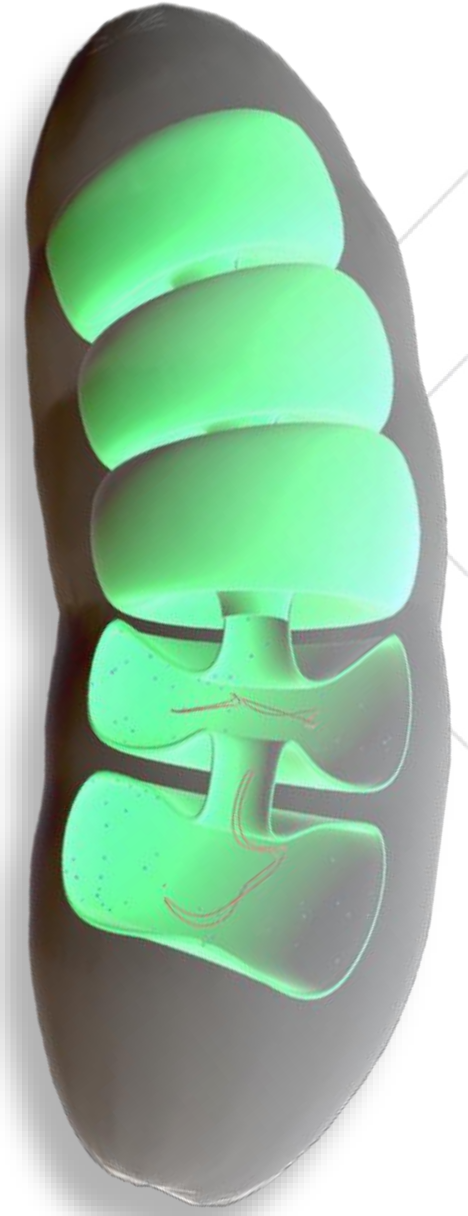
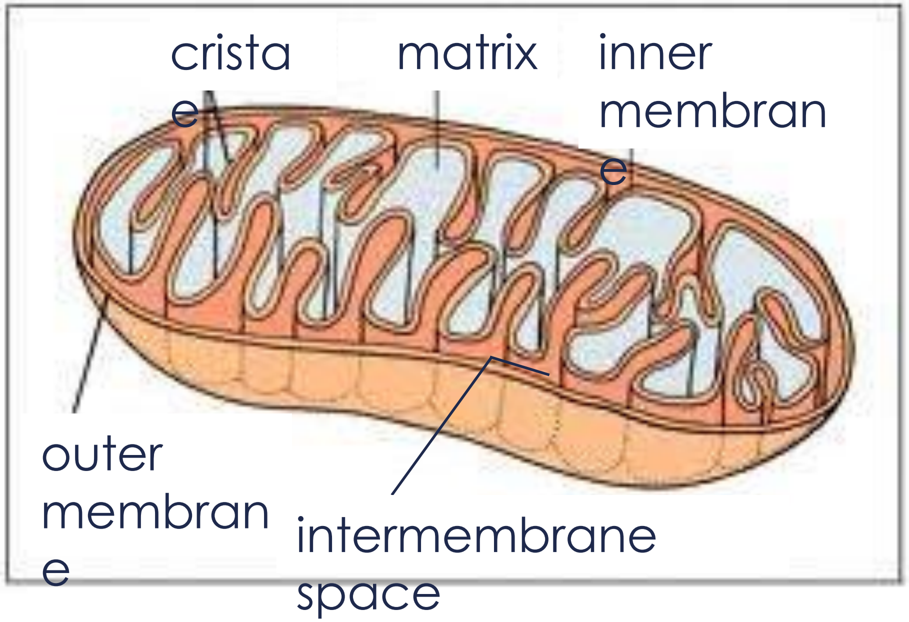


Mitochondrion

- Size ~ 0,5-1 µm
- Wide range in numbers: 1 – thousands of mitochondria /cell
- Role: „power plant of the cell", has a major role in ATP synthesis
- Cristae can show a laminar or tubular structure

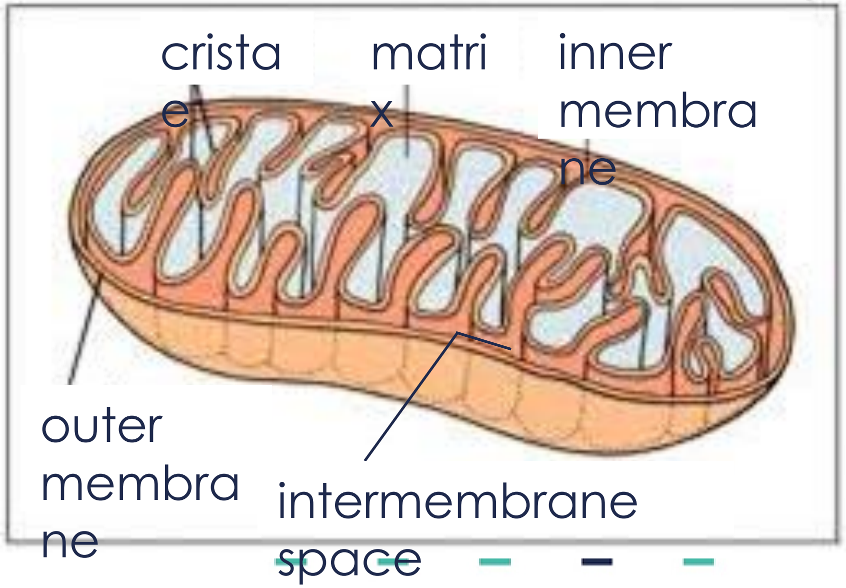




The structure of mitochondria

- **Outer membrane**: highly permeable
- Therefore, the **Intermembrane space** has a composition similar to that of the cytosol
- **Inner membrane**: highly impermeable, it contains important proteins:
  - transport proteins (e.g. H^+/pyruvate symporter, ADP/ATP antiporter) necessary due to the high degree of impermeability
  - Respiratory chain (electron transport chain) proteins
  - ATP synthase

  cristae are to increase the surface area
- **Matrix**: contains a lot of enzymes and also the mitochondrial DNA



The function of mitochondria

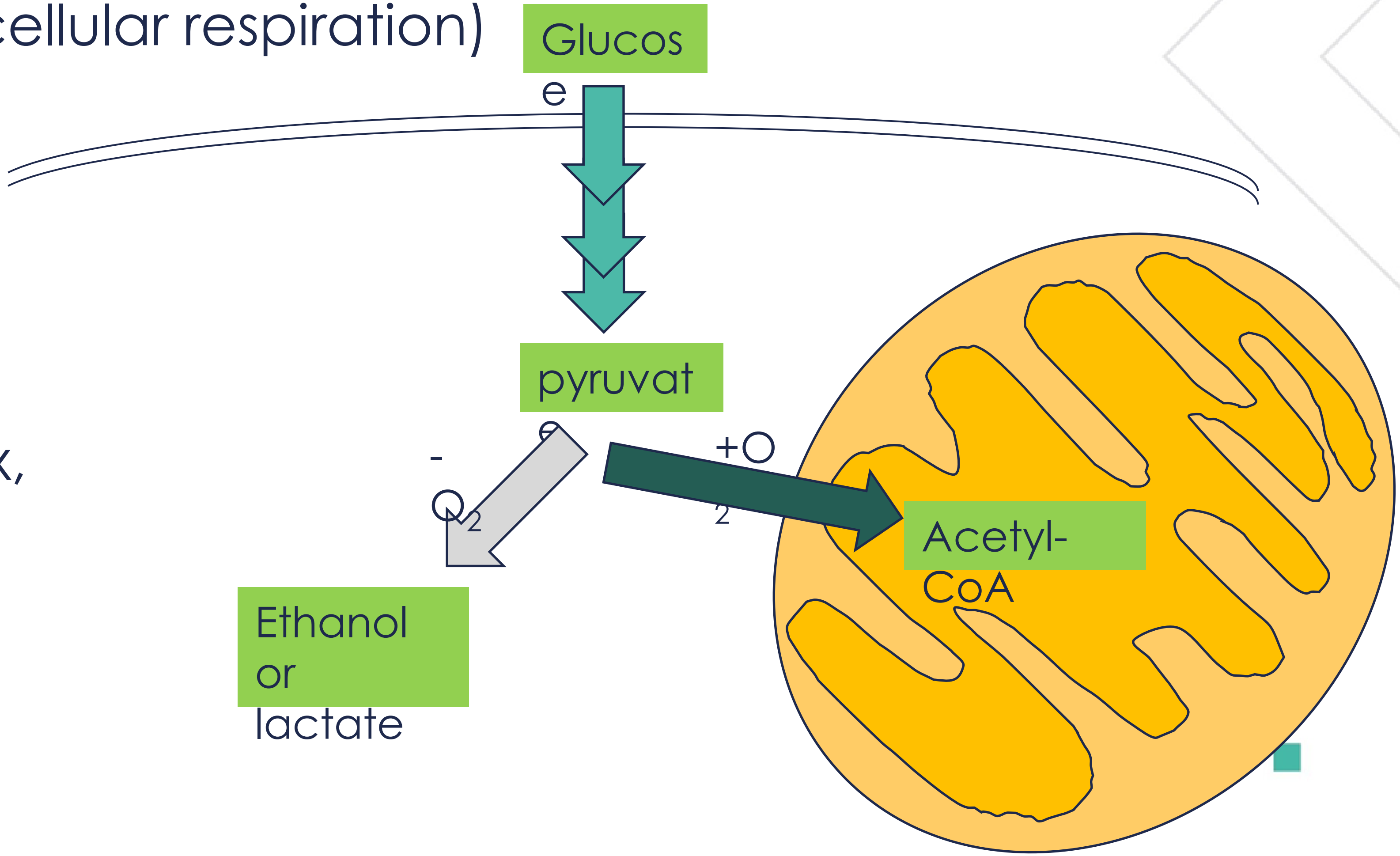
- ATP synthesis through aerobic cellular respiration, in the breakdown process of glucose:

$$1\ C_6H_{12}O_6 = 6\ CO_2 + 6\ H_2O \text{ and } 36\ ATP$$

- 3 phases:
  - Glycolysis in the cytoplasm
  - Citric acid cycle in the mitochondrial matrix
  - Terminal oxidation along the inner mitochondrial membrane

Glycolysis

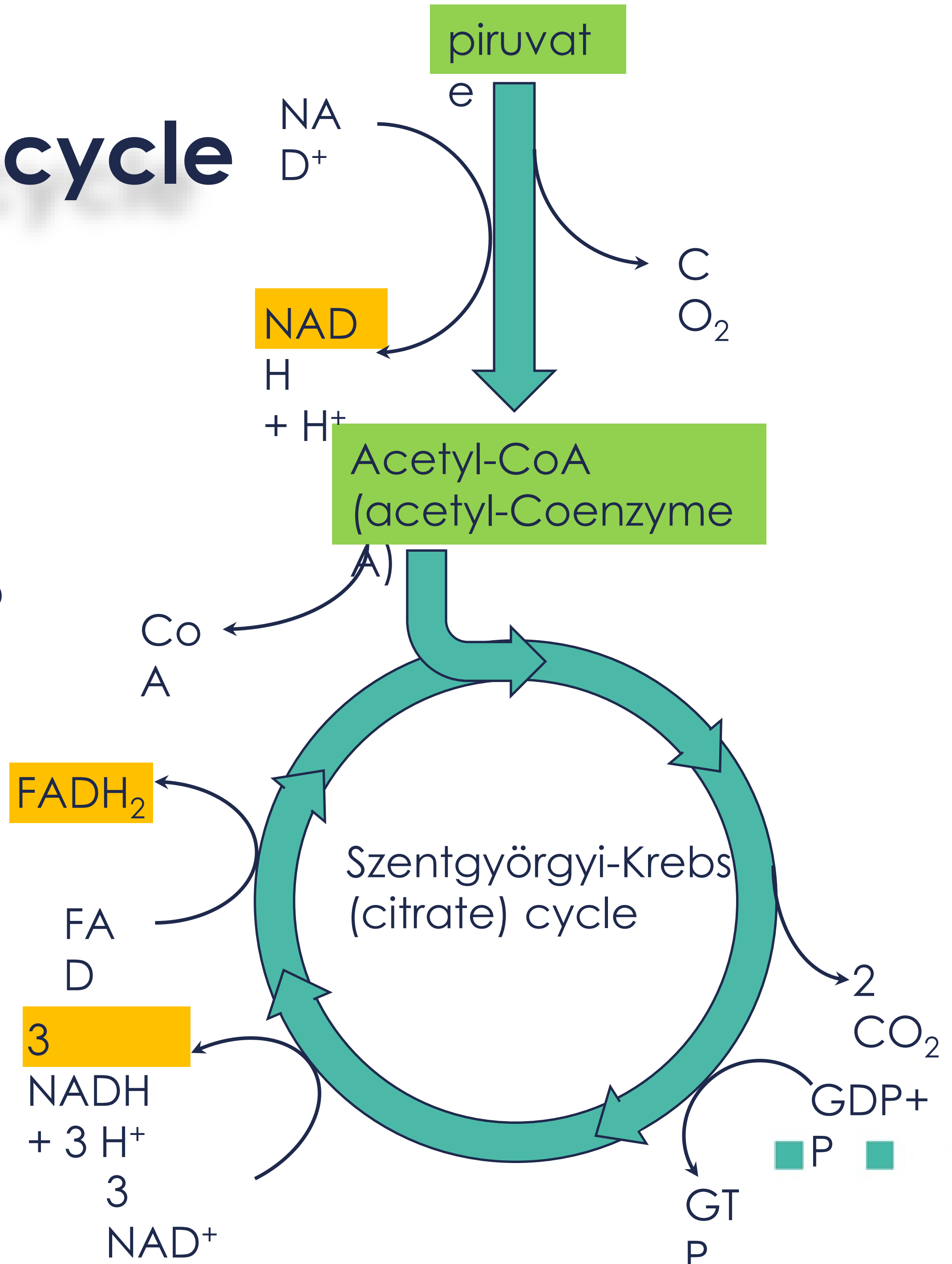
- Glucose (with 6 carbons)→ 2 pyruvates (with 3 carbons each)
- In the absence of oxygen: e.g. lactic acid (lactate) is produced (fermentation, anaerobic cellular respiration)



- A small amount of ATP molecules, and reduced coenzymes (NADH) are also produced
- In the mitochondrial matrix, pyruvate is turned into acetyl groups (2 carbons), which are bound to Coenzyme A (CoA)

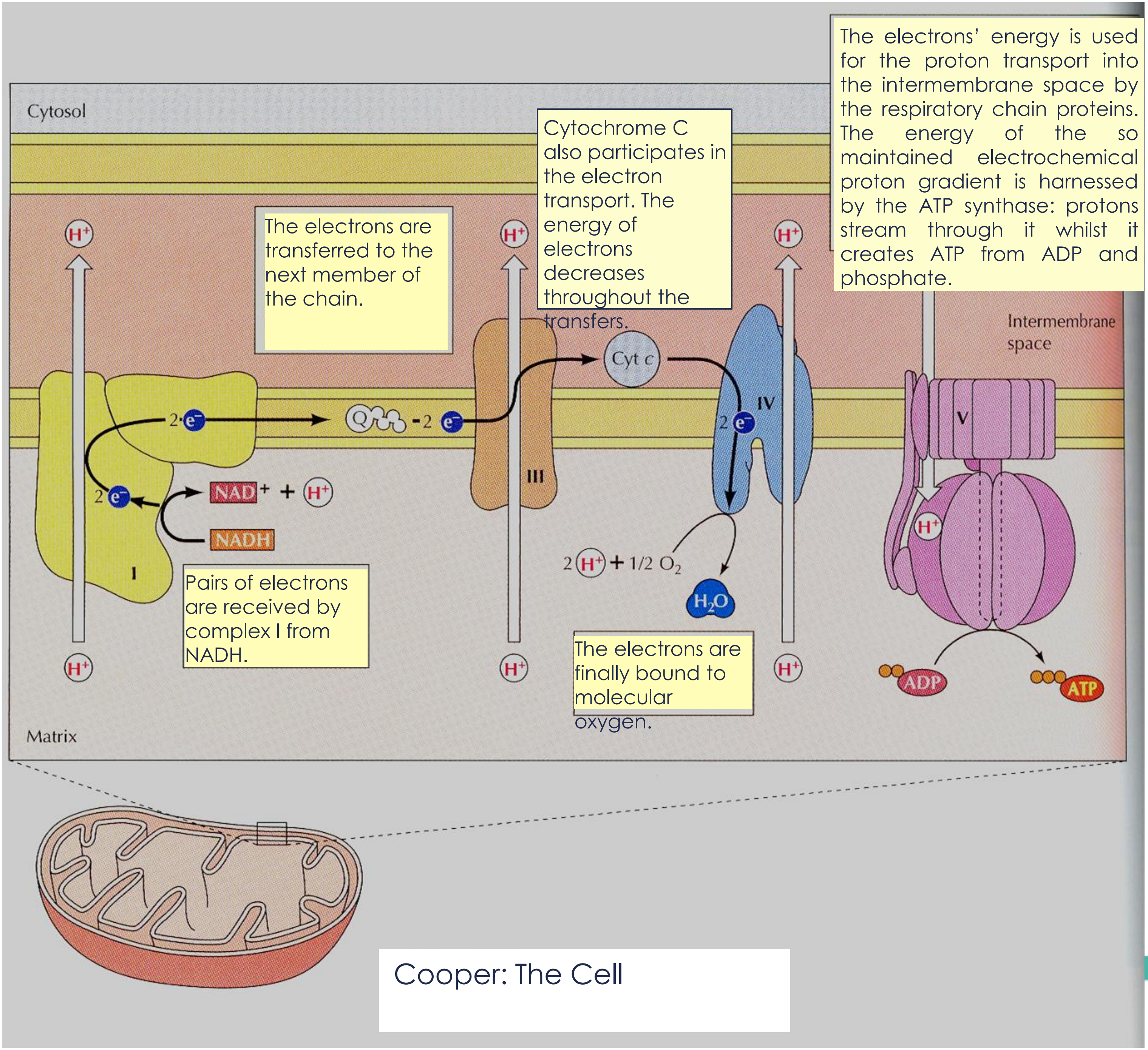
The citric acid cycle

- Also called Szentgyörgyi-Krebs or citrate cycle
- Oxaloacetate (4 C-atoms) + acetyl group (2 C-atoms) → citric acid (6 C-atoms)
- products:
  - 2 CO_2
  - GTP
  - Reduced coenzymes: NADH, $FADH_2$ (they contain high energy electrons)



Terminal oxidation

- NADH, $FADH_2$ →electrons → respiratory chain (electron transport chain) proteins
- Respiratory chain members I. →II. →III. →IV.
- Cytochromes participate: they contain iron (Fe^{2+} or Fe^{3+})
- Respiratory chain proteins transport protons from the matrix into the intermembrane space
- This maintains a H^+ concentration difference: electrochemical proton gradient
- The energy of this gradient is harnessed by the ATP synthase protein in the inner membrane: protons are streaming back into the matrix, whilst ADP + P → ATP
- Peter D. Mitchell: chemiosmosis theory



The electrons' energy is used for the proton transport into the intermembrane space by the respiratory chain proteins. The energy of the so maintained electrochemical proton gradient is harnessed by the ATP synthase: protons stream through it whilst it creates ATP from ADP and phosphate.

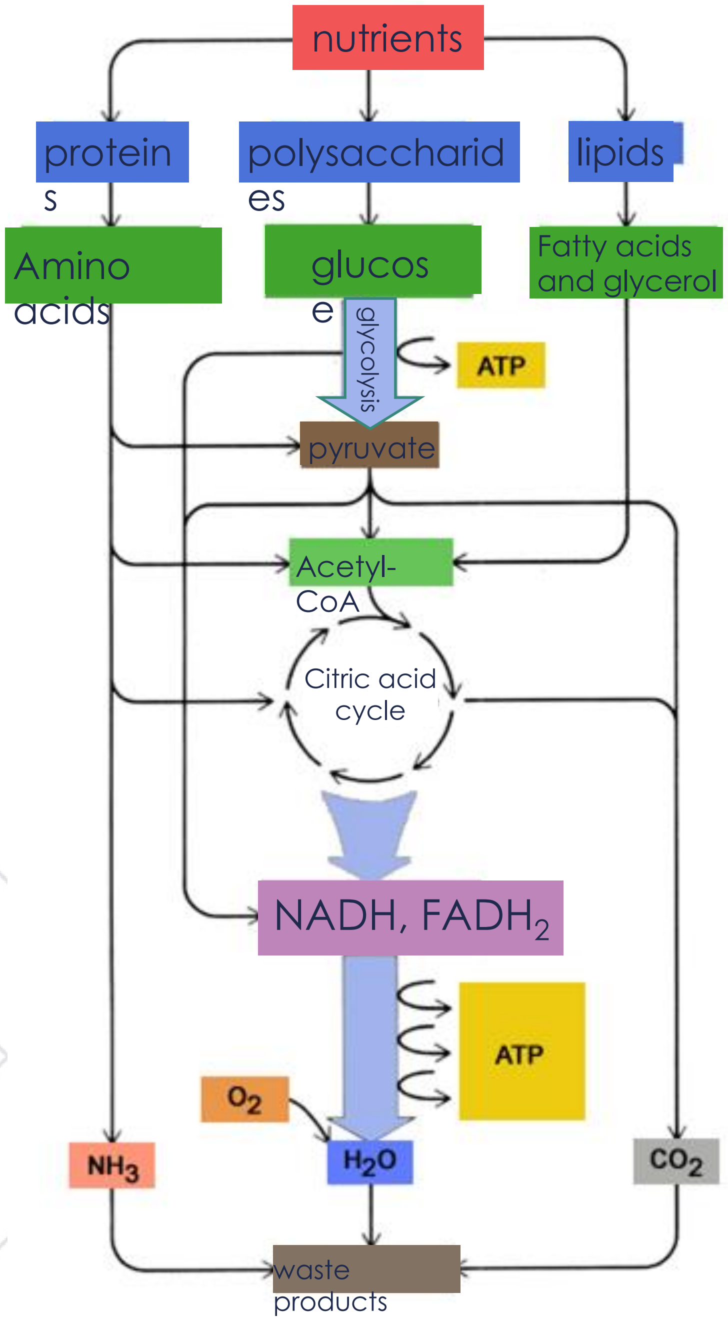
Cytochrome C also participates in the electron transport. The energy of electrons decreases throughout the transfers.

The electrons are transferred to the next member of the chain.

Pairs of electrons are received by complex I from NADH.

The electrons are finally bound to molecular oxygen.

Cooper: The Cell

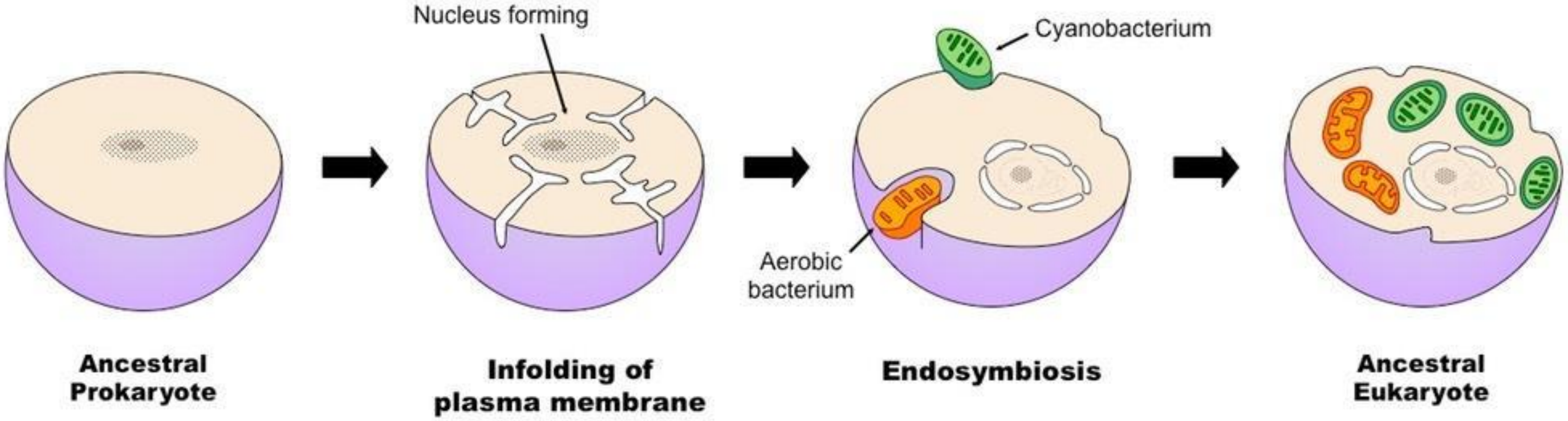


Summary: breakdown of glucose and other nutrients with the help of mitochondria

Mitochondrial DNA

- Small, circular
- Codes for: mRNA, tRNA, rRNA molecules of mitochondria
- But most mitochondrial proteins are imported from the cytosol (synthesized on free ribosomes)
- The presence of DNA is supportive of endosymbiosis:
- Mitochondria derived from ancient prokaryotes

Endosymbiosis theory



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