Domain 2: Matter

2.1: Organisms must exchange matter with the environment to grow, reproduce and maintain organization.

1. MATTER EXCHANGE

Matter Cycles

The atoms in living systems are common on this planet.

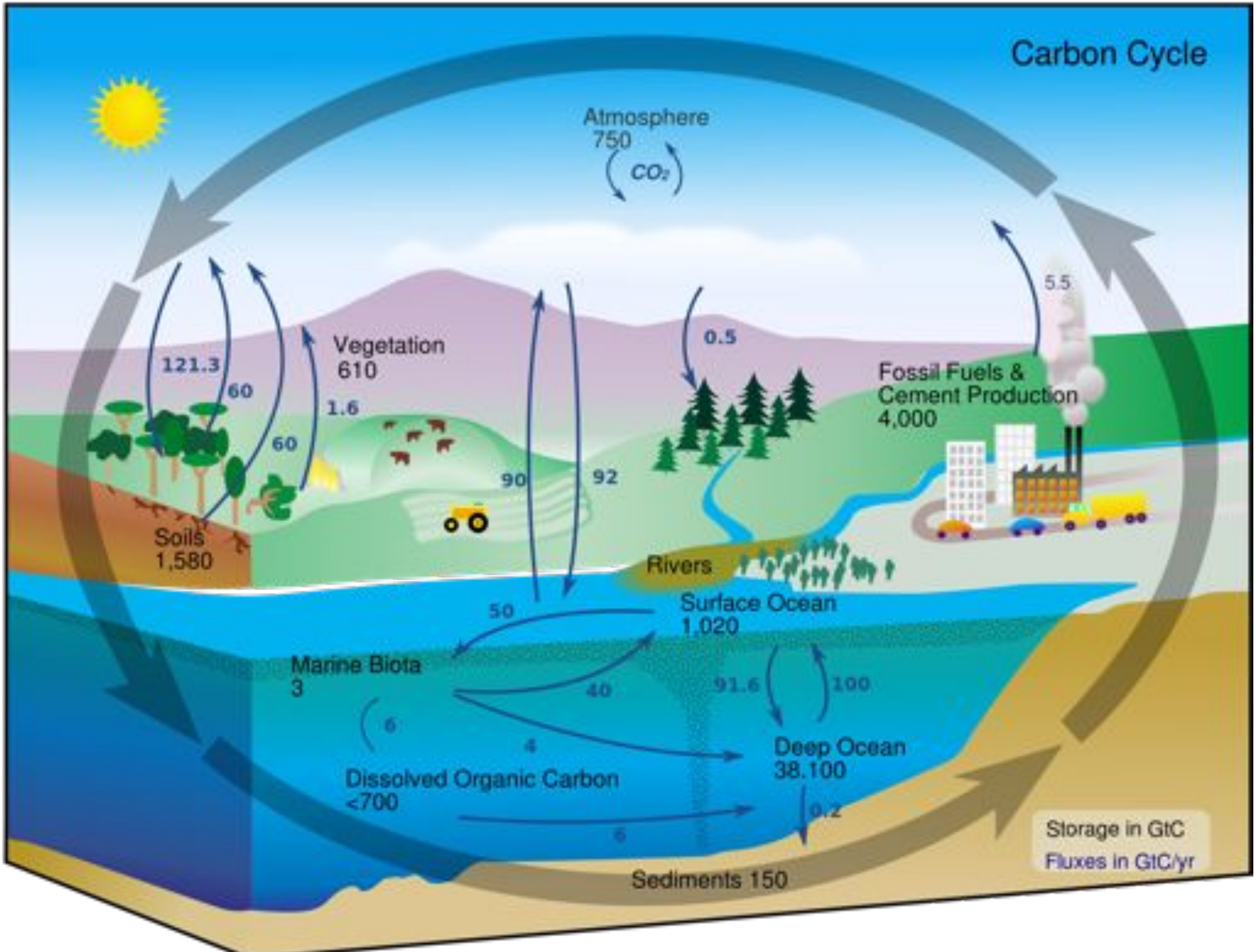
Living systems are mostly made of 6 elements (**CHNOPS**) and a handful of other “**trace**” elements.

Carbon

Role: The major structural atom in all organic molecules.

Major abiotic source: The atmosphere (as CO_2).

Major biotic processes: Incorporated in to producers through **photosynthesis**, returned back to the environment through **cellular respiration**, and **decomposition**.


Carbon Cycle
Atmosphere
750
CO_2
121.3
60
60
1.6
Vegetation
610
90
92
0.5
5.5
Fossil Fuels &
Cement Production
4,000
Soils
1,580
Rivers
Surface Ocean
1,020
50
Marine Biota
3
40
91.6
100
6
4
Deep Ocean
38,100
Dissolved Organic Carbon
<700
0.2
6
Sediments 150
Storage in GtC
Fluxes in GtC/yr

Oxygen

Role: A major component of all organic molecules.

Major abiotic source: The atmosphere (as O_2).

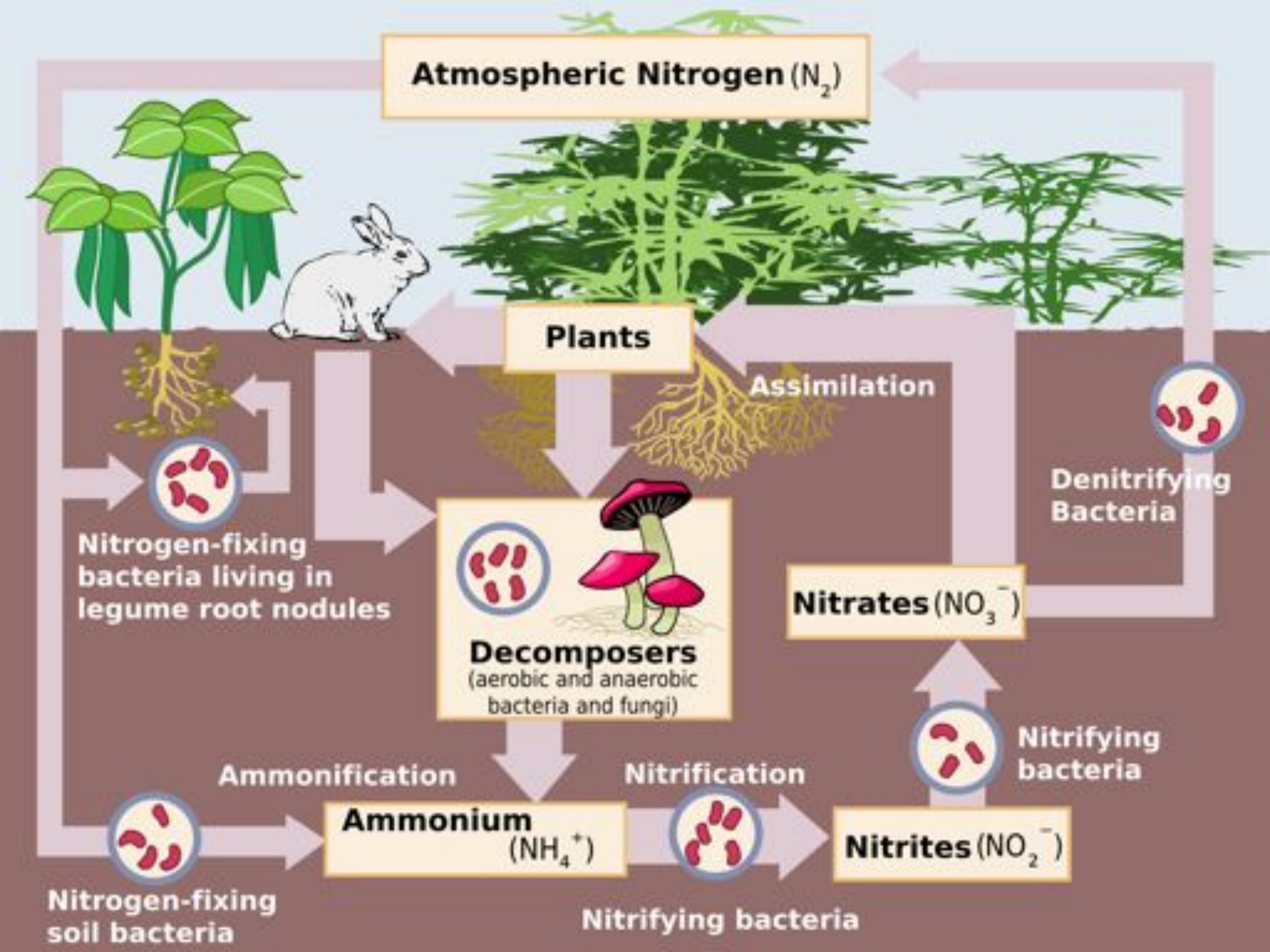
Major biotic processes: Used in cellular respiration. Released in photosynthesis.

Nitrogen

Role: A major component of proteins and nucleic acids

Major abiotic source: The atmosphere (as N_2).

Major biotic processes: Incorporated in to food chains by **nitrogen-fixing** bacteria. Released through decomposition ("**denitrification**")

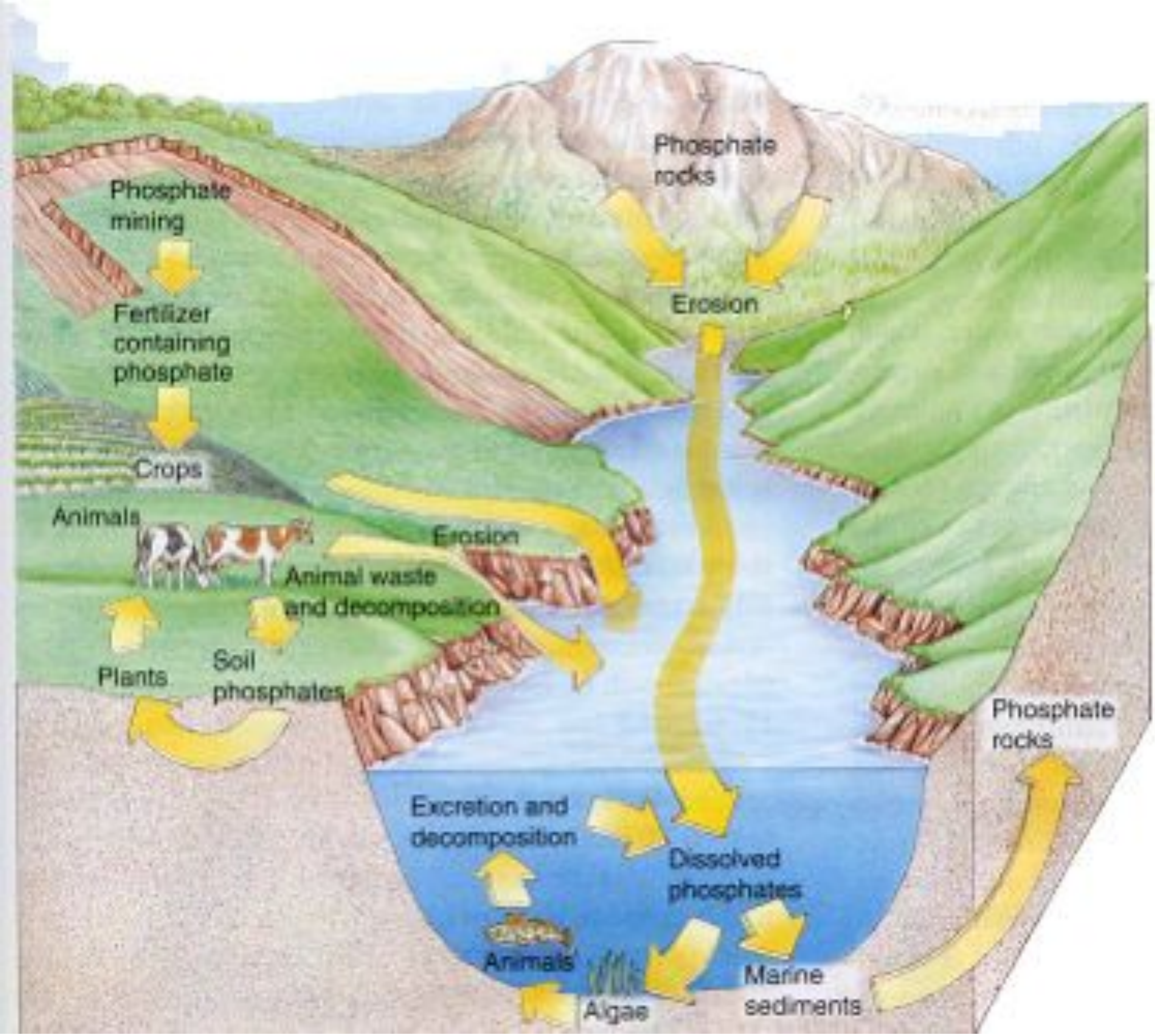

Atmospheric Nitrogen (N_2)
Plants
Assimilation
Denitrifying Bacteria
Nitrogen-fixing bacteria living in legume root nodules
Decomposers
(aerobic and anaerobic bacteria and fungi)
Nitrates (NO_3^-)
Nitrifying bacteria
Ammonification
Nitrification
Ammonium (NH_4^+)
Nitrites (NO_2^-)
Nitrogen-fixing soil bacteria
Nitrifying bacteria

Phosphorous/Sulfur

Role: A major component of proteins (sulfur) and nucleic acids (phosphorous). **Phosphate groups** are also used in energy storage and release.

Major abiotic source: The lithosphere (in rocks). Released in **weathering** processes.

Major biotic processes: Incorporated in to food chains from soil. Released by decomposition.



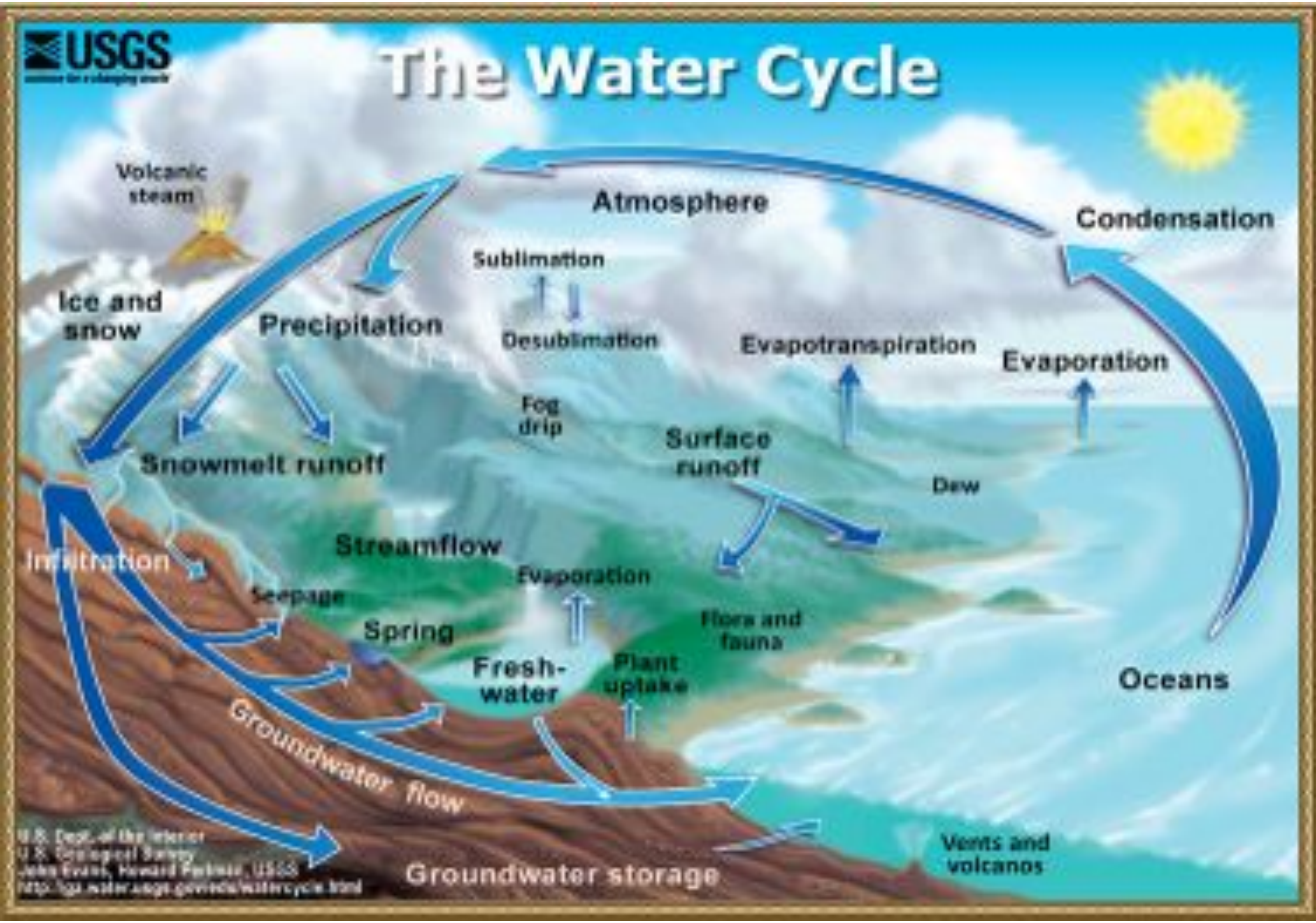
Phosphate rocks
Erosion
Phosphate mining
Fertilizer containing phosphate
Crops
Animals
Erosion
Animal waste and decomposition
Plants
Soil phosphates
Phosphate rocks
Excretion and decomposition
Dissolved phosphates
Animals
Algae
Marine sediments

Hydrogen

Role: A major component of all biological molecules. Does not exist freely in nature.

Major abiotic source: The hydrosphere (in H_2O).

Major biotic processes: Incorporated in to food chains along with water. Released through decomposition/water release.


USGS
The Water Cycle
Volcanic steam
Atmosphere
Condensation
Sublimation
Desublimation
Ice and snow
Precipitation
Evapotranspiration
Evaporation
Fog drip
Surface runoff
Snowmelt runoff
Dew
Streamflow
Infiltration
Evaporation
Seepage
Spring
Flora and fauna
Fresh-water
Plant uptake
Oceans
Groundwater flow
Vents and volcanos
Groundwater storage
U.S. Dept. of the Interior
U.S. Geological Survey
John Evans, Howard Perlman, USGS
http://ga.water.usgs.gov/edu/watercycle.html

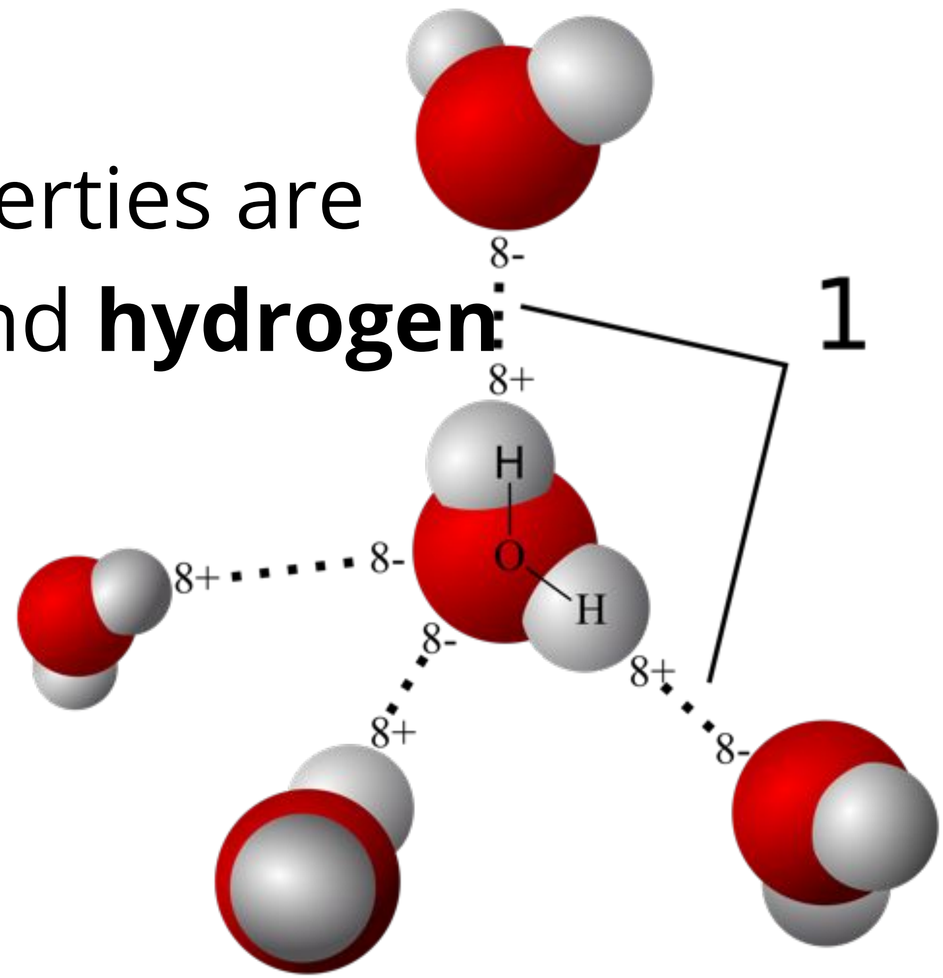
2.1: Organisms must exchange matter with the environment to grow, reproduce and maintain organization.

2. PROPERTIES OF WATER

Organisms are mostly water

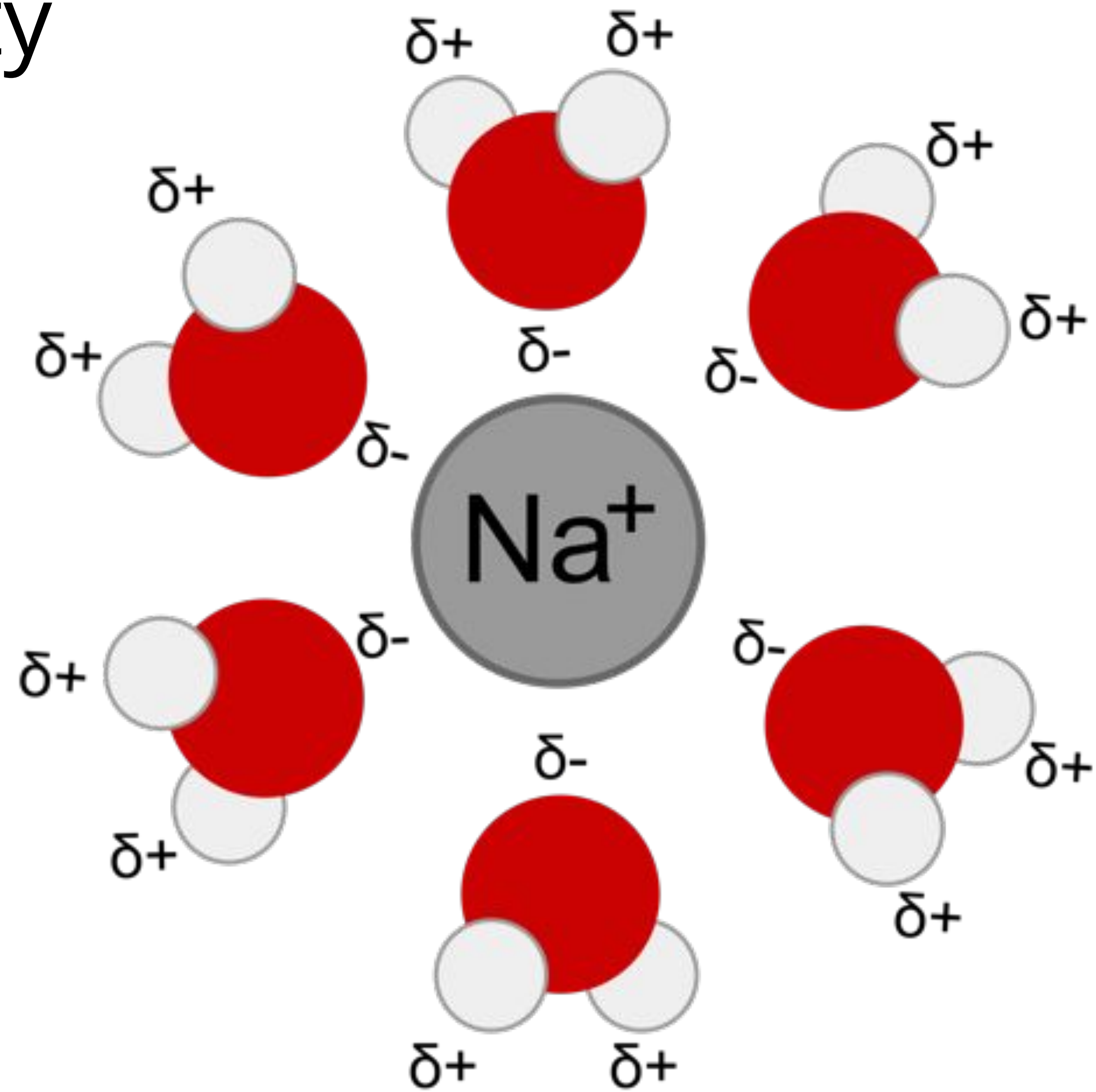
Water has major properties that allow for life processes.

Most of water's properties are due to its **polarity** and **hydrogen bonding** (H-Bonds).

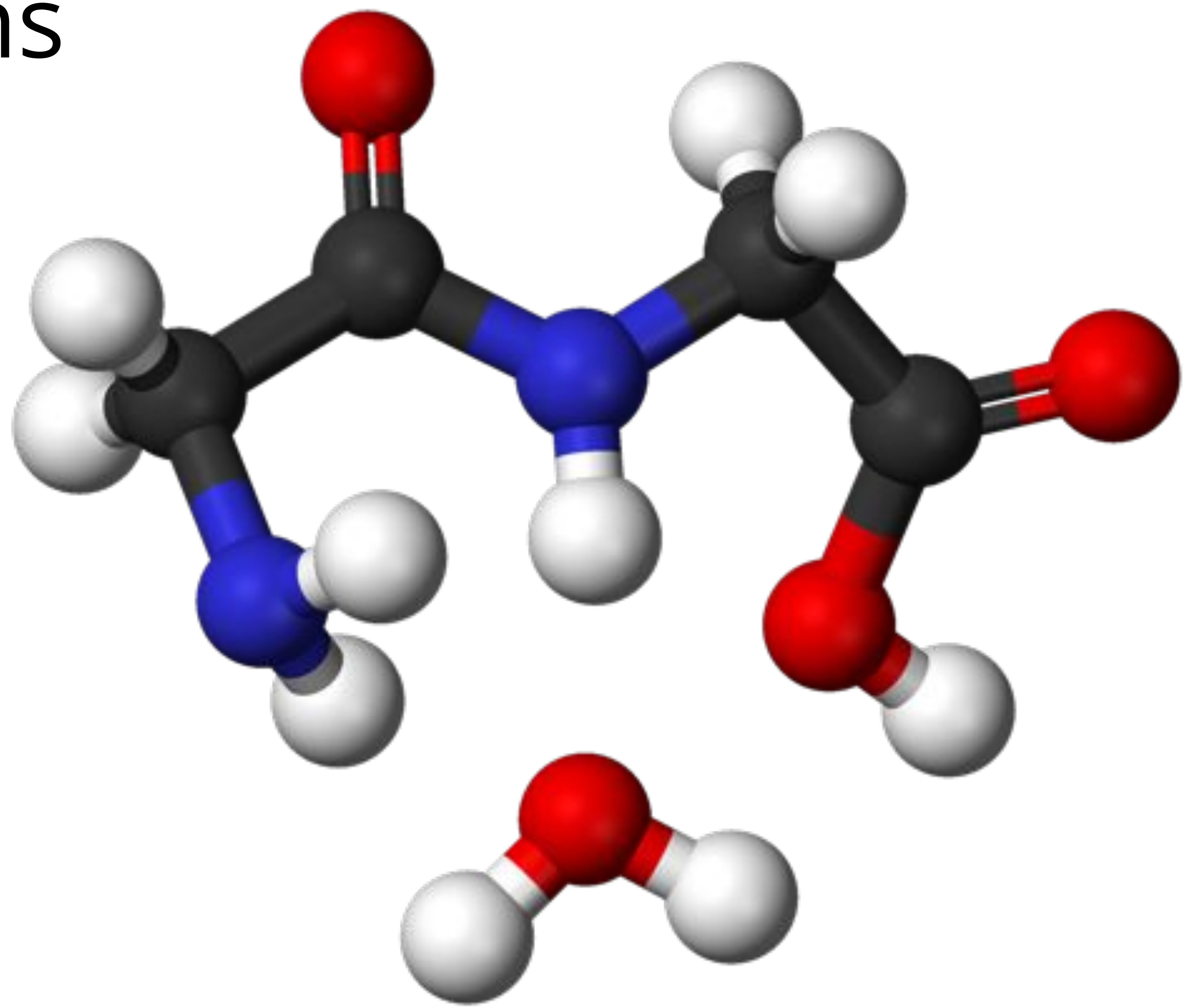


Adhesional/Cohesional forces

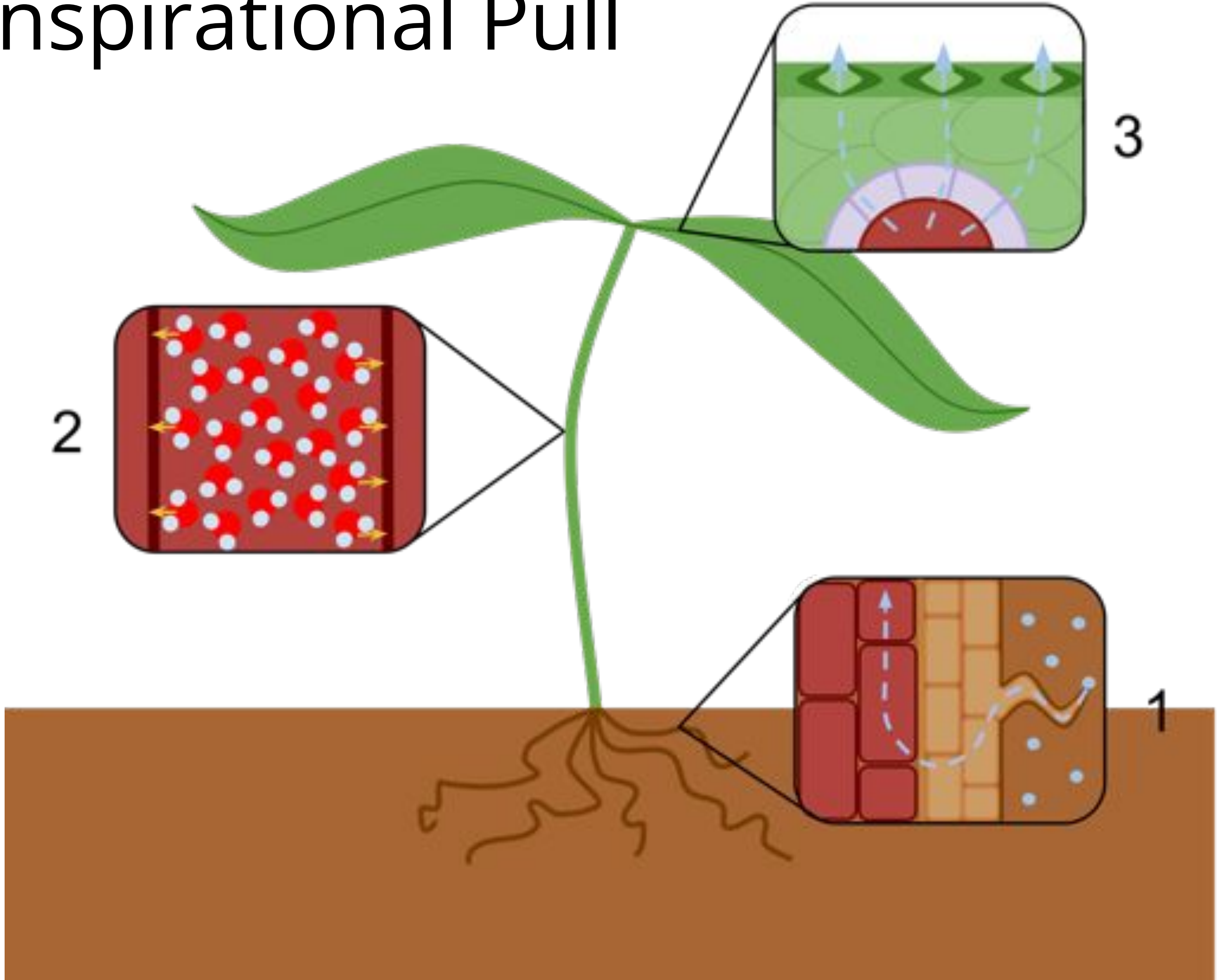
Solubility



Condensation/Hydrolysis Reactions



Transpirational Pull



Water is a Temperature Buffer

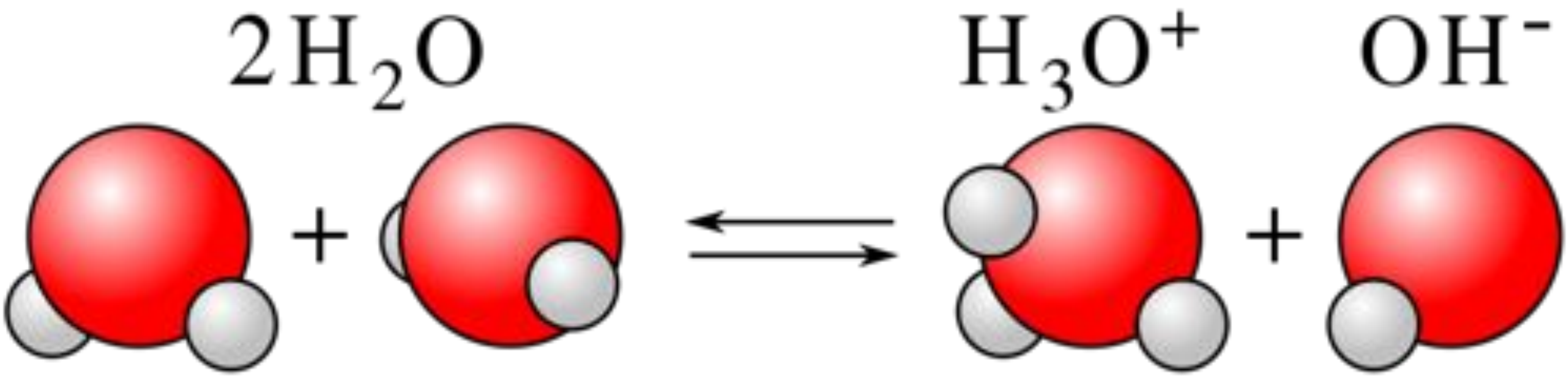
2.1: Organisms must exchange matter with the environment to grow, reproduce and maintain organization.

3. MATH SKILLS- PH

Water Dissociates

A water molecule can be pulled apart into a **proton (H^+/H_3O^+)** and a **Hydroxide ion (OH^-)** by other water molecules.

This happens ~ once for every 10,000,000 (10^7) water molecules.



In pure water, the concentrations of H^+ and OH^- are each **10^{-7}** (one in 10 million).

Acids: substances that increase the amount of H^+ ions in an aqueous solution. This will cause the concentration of OH^- ions to decrease.

Bases: Substances that decrease the amount of H^+ ions in an aqueous solution. This will cause the concentration of H^+ ions to increase.

pH

a measurement of the concentration of H + ions in a solution.

$$\mathbf{pH = - \log [H^+]}$$

The negated exponent of the pH concentration (make it positive) is the pH.

Acids have a pH lower than 7. **Bases** have a pH higher than 7.

pH is a logarithmic scale

Each whole number on the pH represents **a power of 10**.

A solution with a pH of 5 has a [H+] that is 100 times more acidic than a solution with a pH of 7.

2.2: The subcomponents of biological molecules and their sequence determine the properties of that molecule.

1. BIOLOGICAL MOLECULES

4 Types of Macromolecules

- **Carbohydrates-** Sugars: short-term energy storage and structural support.
- **Lipids-** Fats, oils, waxes: long-term energy storage, cell membrane structure, and cell signaling.
- **Proteins-** function in all cellular processes.
- **Nucleic Acids**- DNA and RNA: information storage and expression.

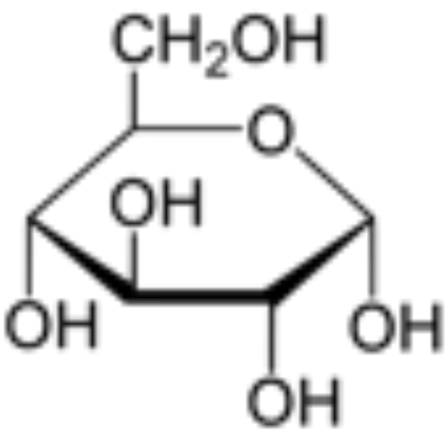
All macromolecules are synthesized via condensation reactions and decomposed via hydrolysis reactions.

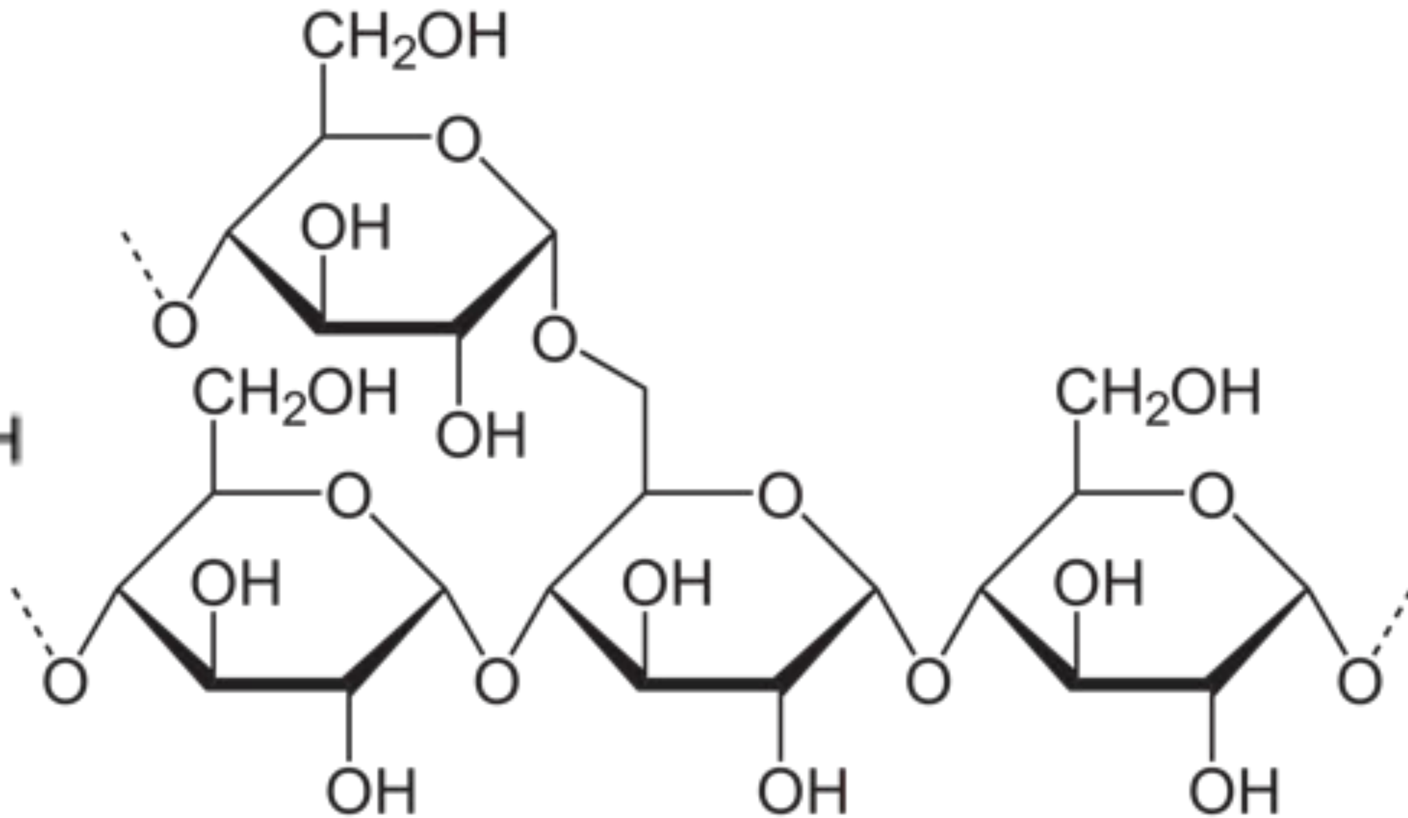
Most macromolecules are **polymers.**

Carbohydrates

Monomer: Monosaccharide

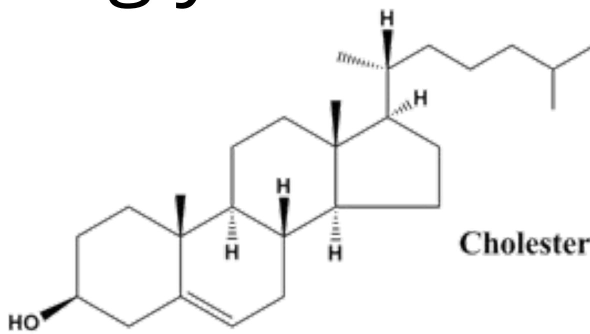
Polymer: Polysaccharide



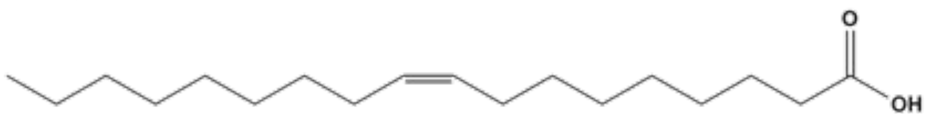


Lipids

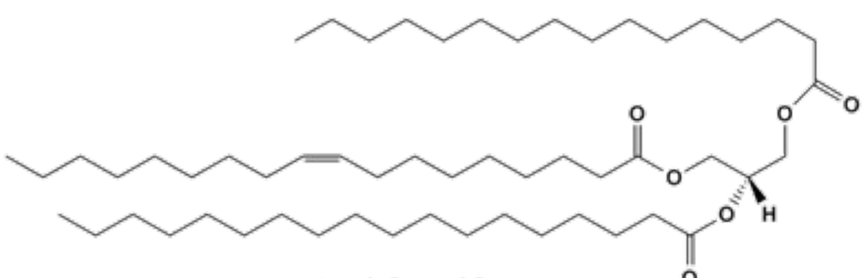
Steroids, triglycerides, and phospholipids



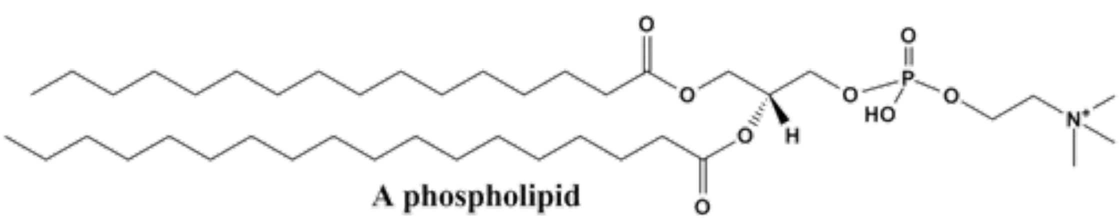
Cholesterol



A free fatty acid



A triglyceride

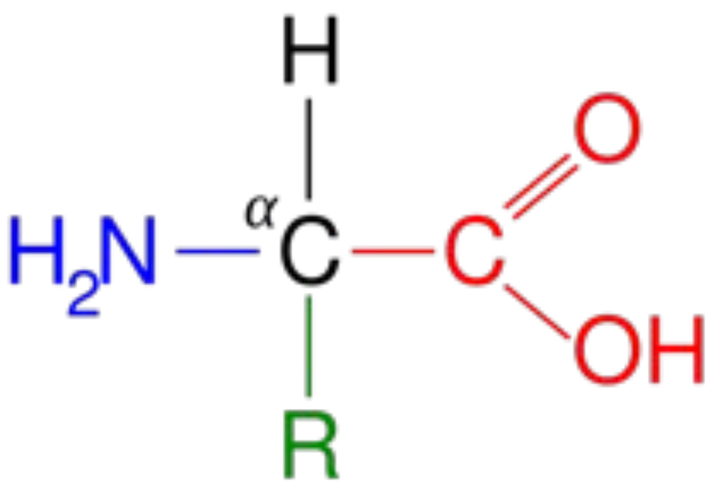


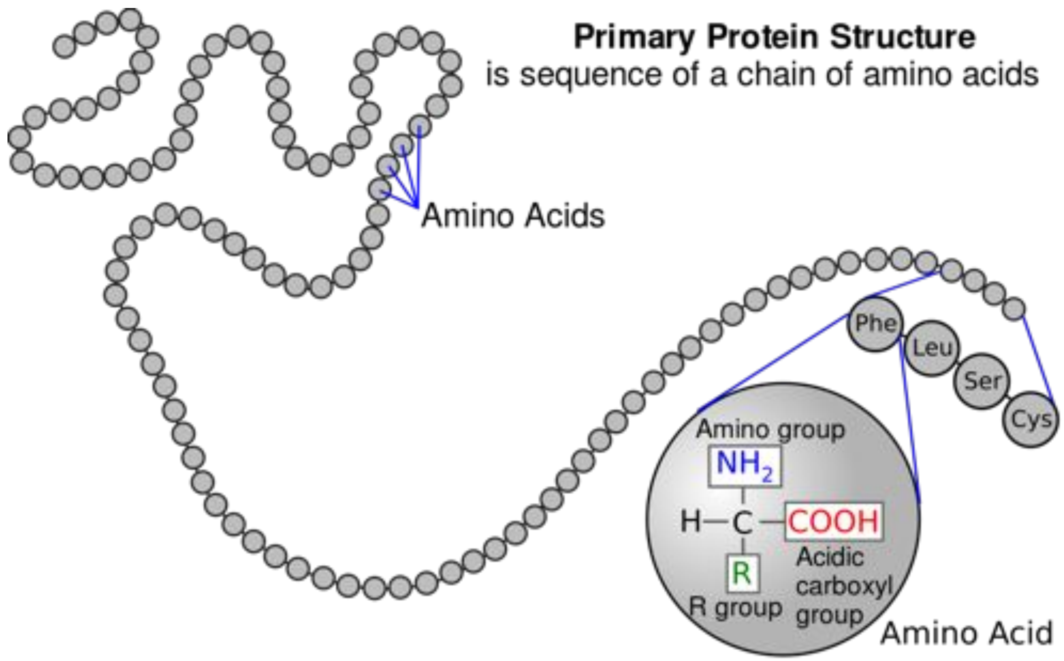
A phospholipid

Proteins

Monomer: Amino Acids (20 kinds)

Polymer: Polypeptide

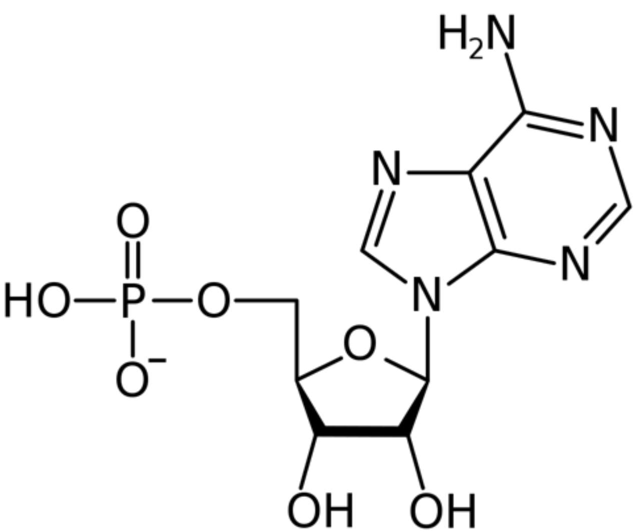


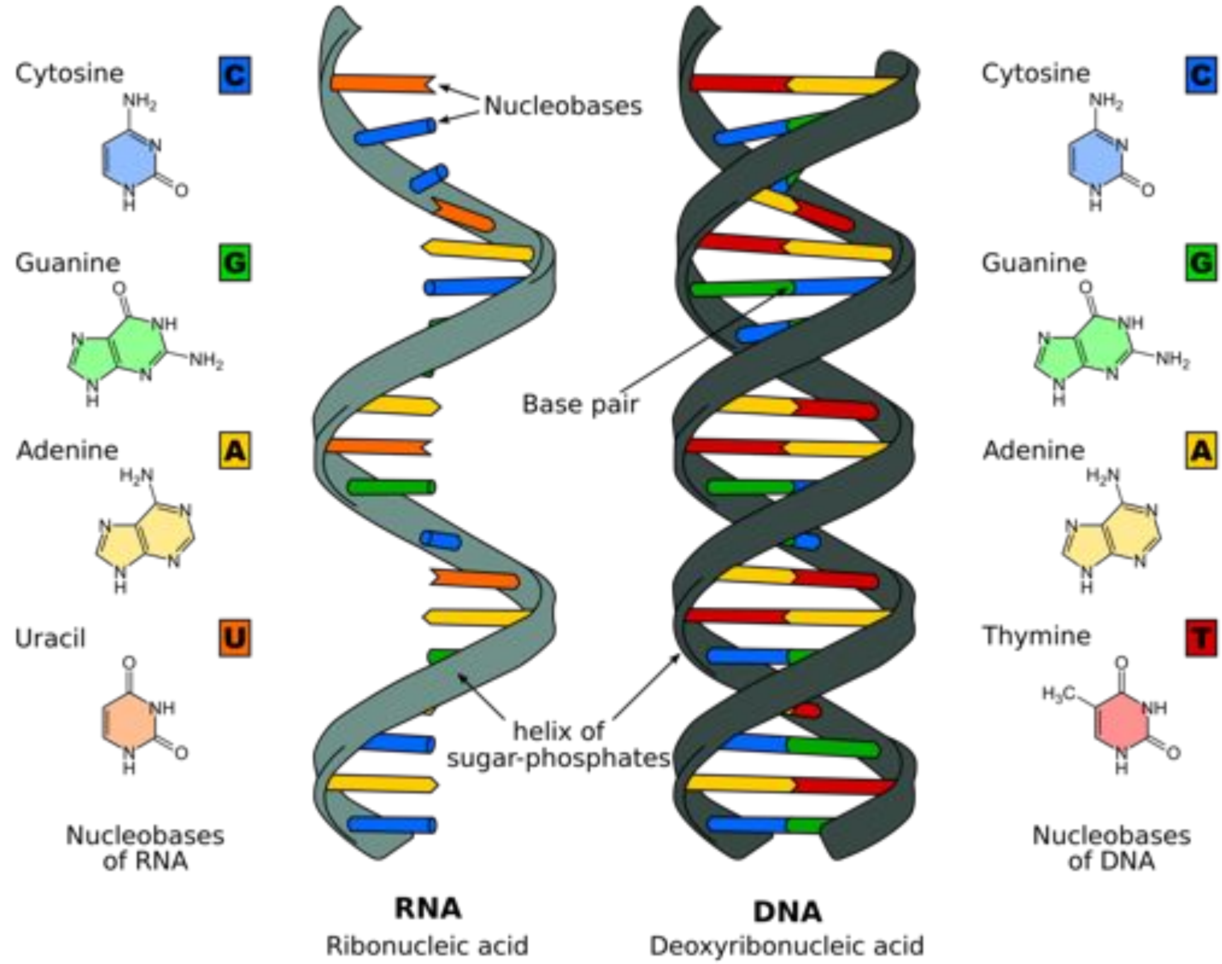


Nucleic Acids

Monomer: Nucleoside

Polymer: Nucleic Acid (DNA or RNA)





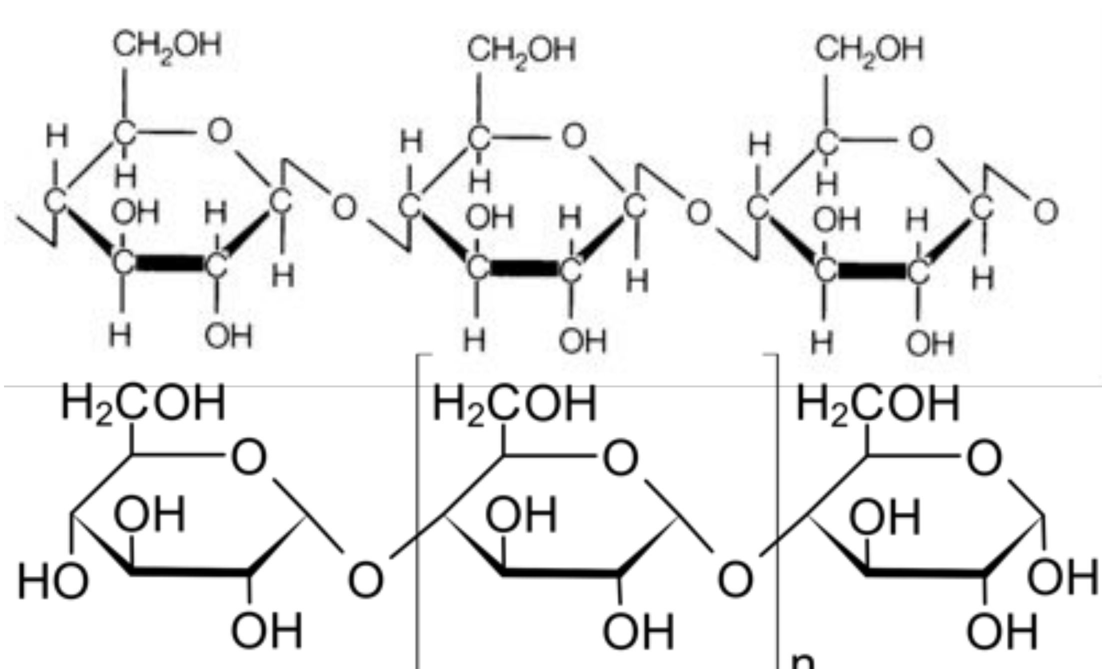
2.3: Variation in molecular units provides cells with a wider range of functions.

1. VARIATION IN BIOLOGICAL MOLECULES- CARBOHYDRATES AND LIPIDS

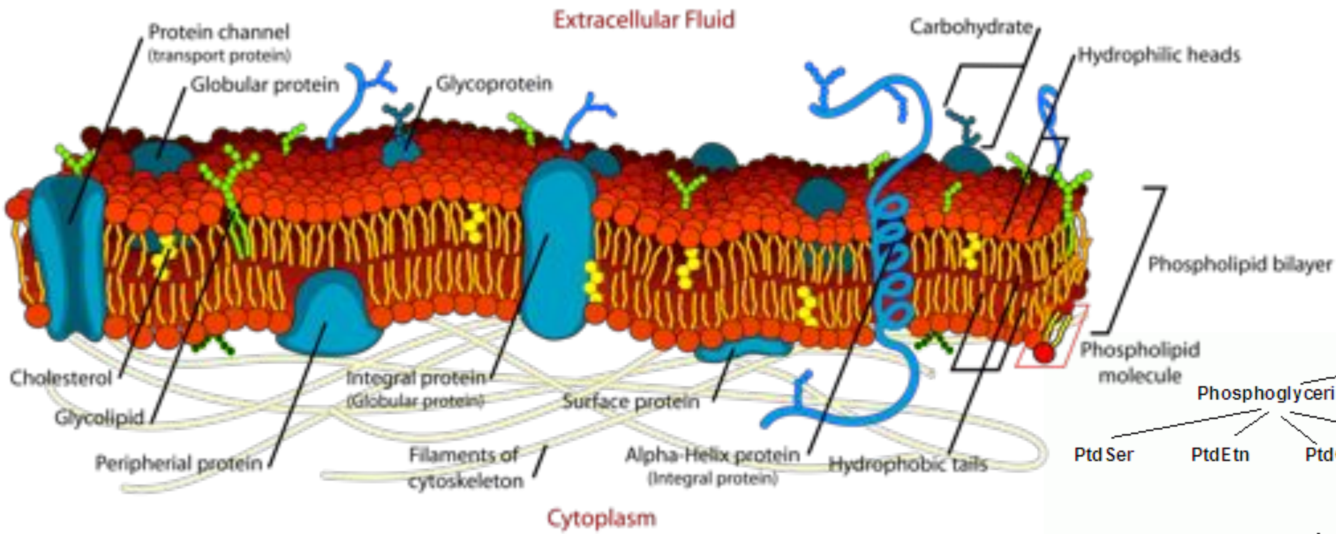
Structure Determines Function

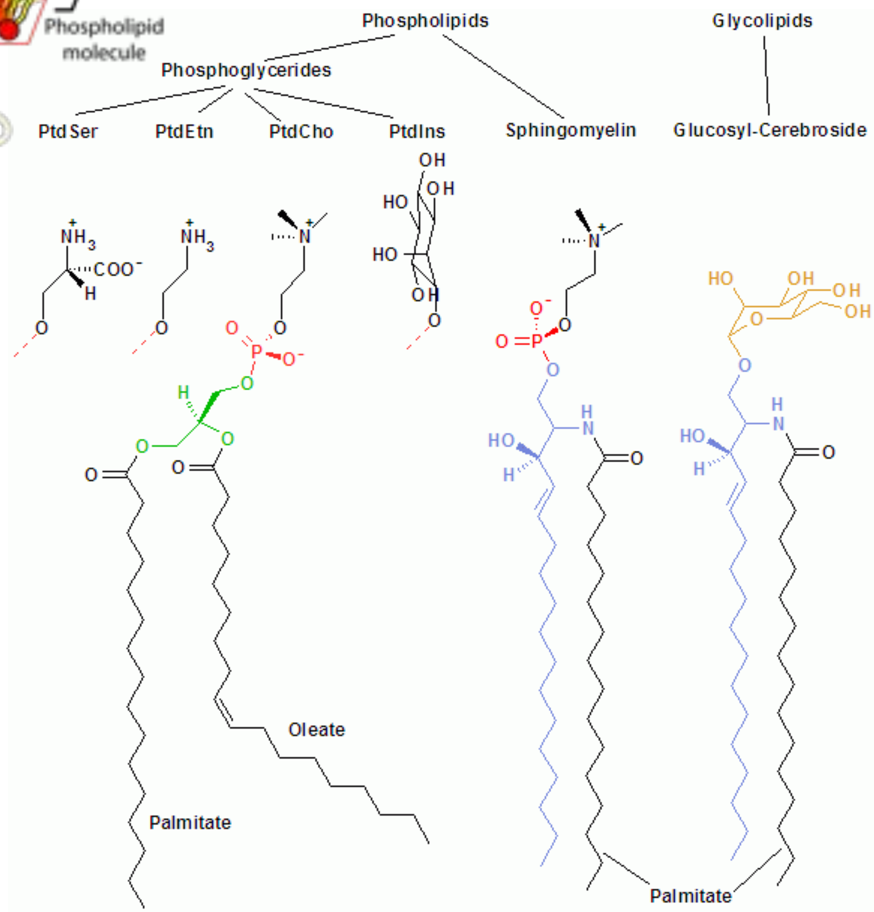
The structure of a molecule enables its function.

Ex: Cellulose vs. Amylose



Ex. lipid composition in cell membranes.





2.3: Variation in molecular units provides cells with a wider range of functions.

2. VARIATION IN BIOLOGICAL MOLECULES- PROTEINS

Structure Determines Function

The structure of a molecule enables its function.

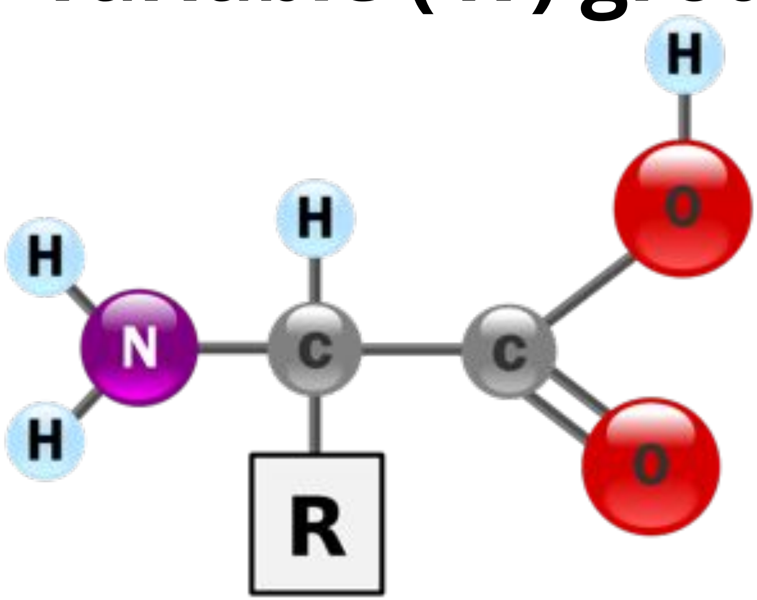
Proteins are responsible for all cellular processes.

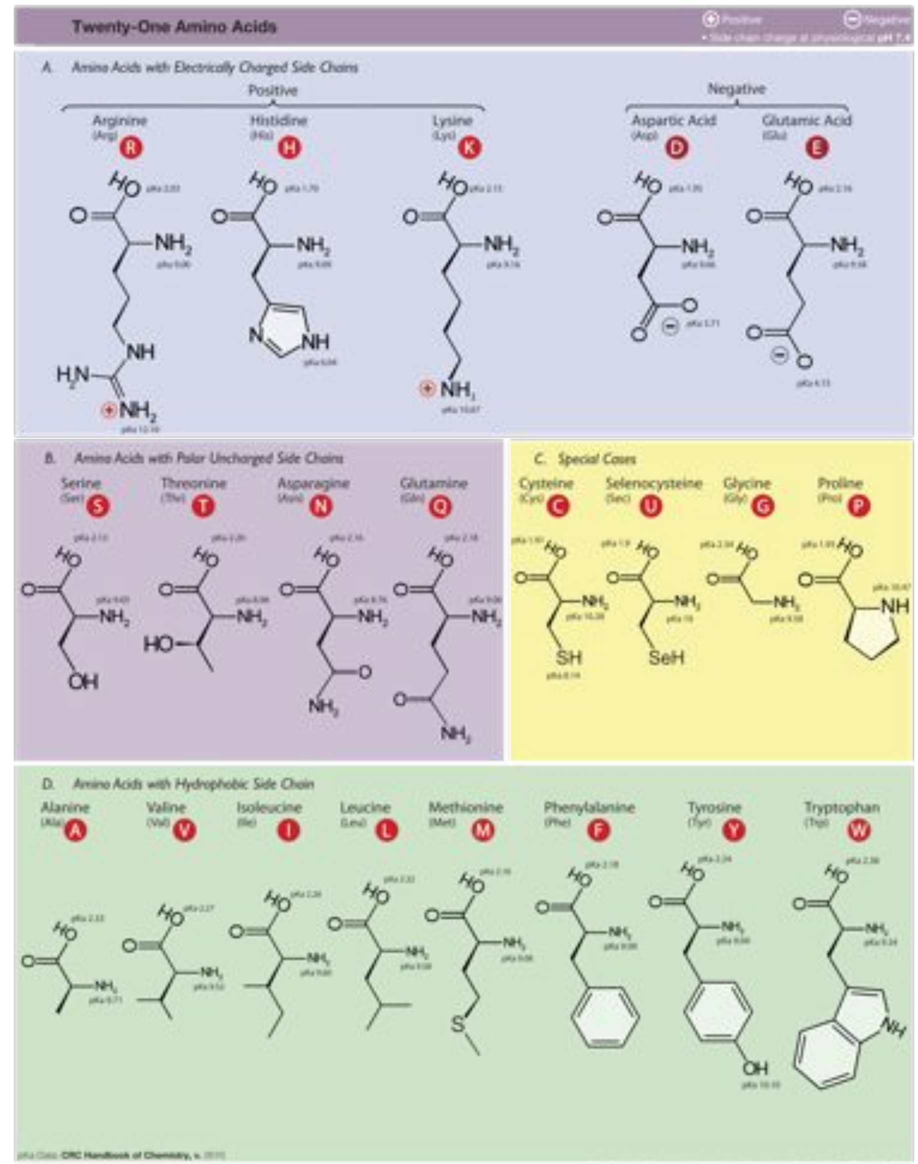
They have a wide diversity of structures.

Amino Acids

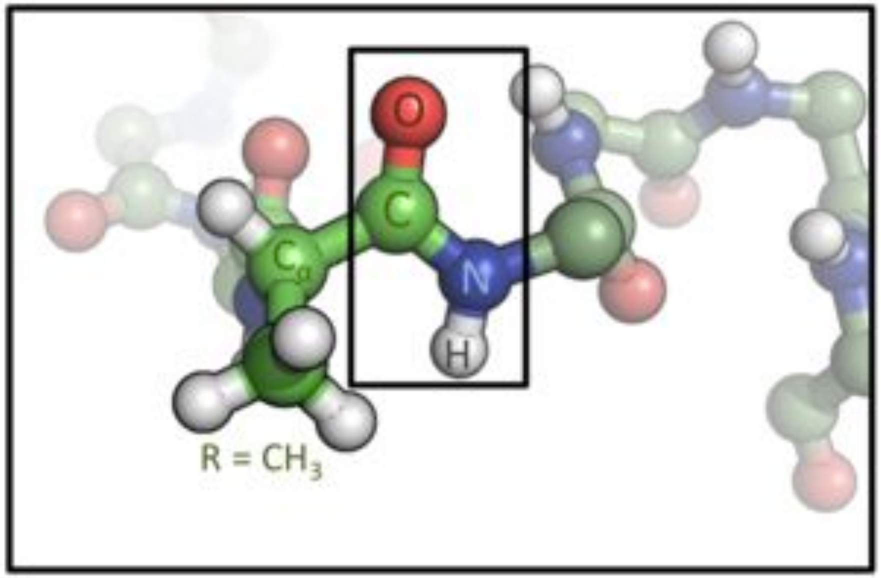
20 different types in most biological systems.

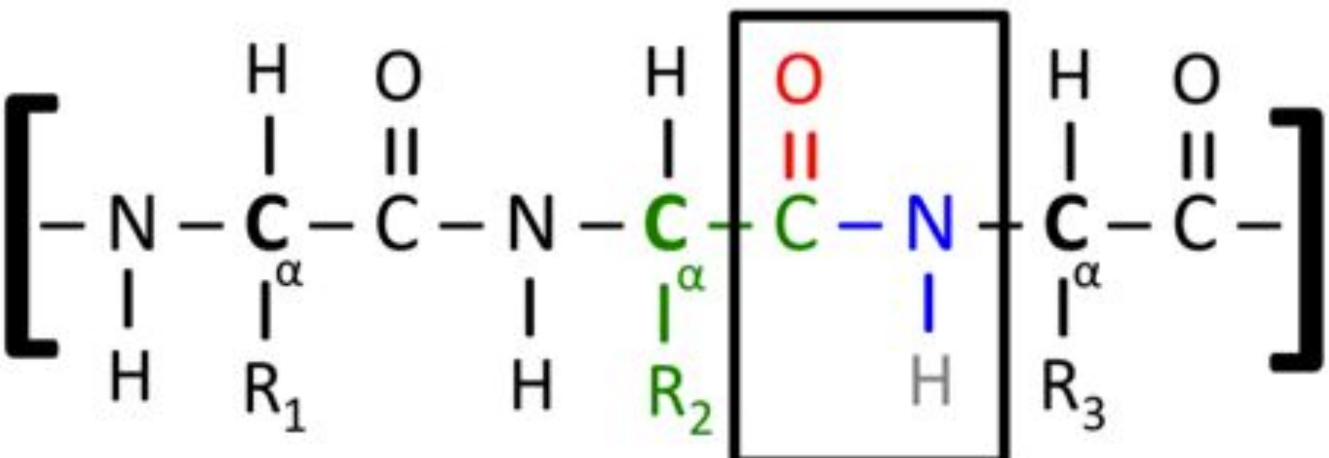
Same general structure with a **variable ('R') group.**





Amino Acids are joined via **Peptide Bonds**

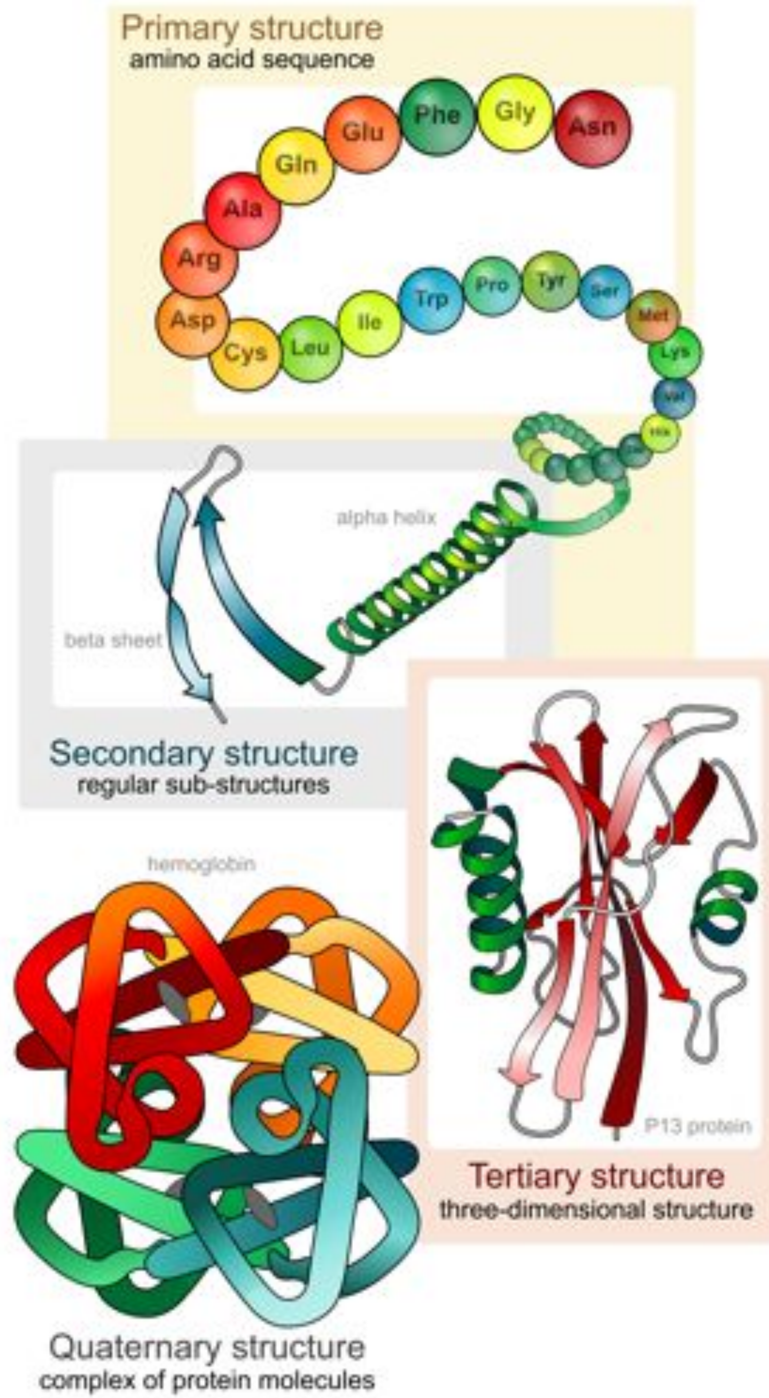




4 levels of protein structure

Because proteins have such complex structures, their organization is considered at 4 levels of resolution.

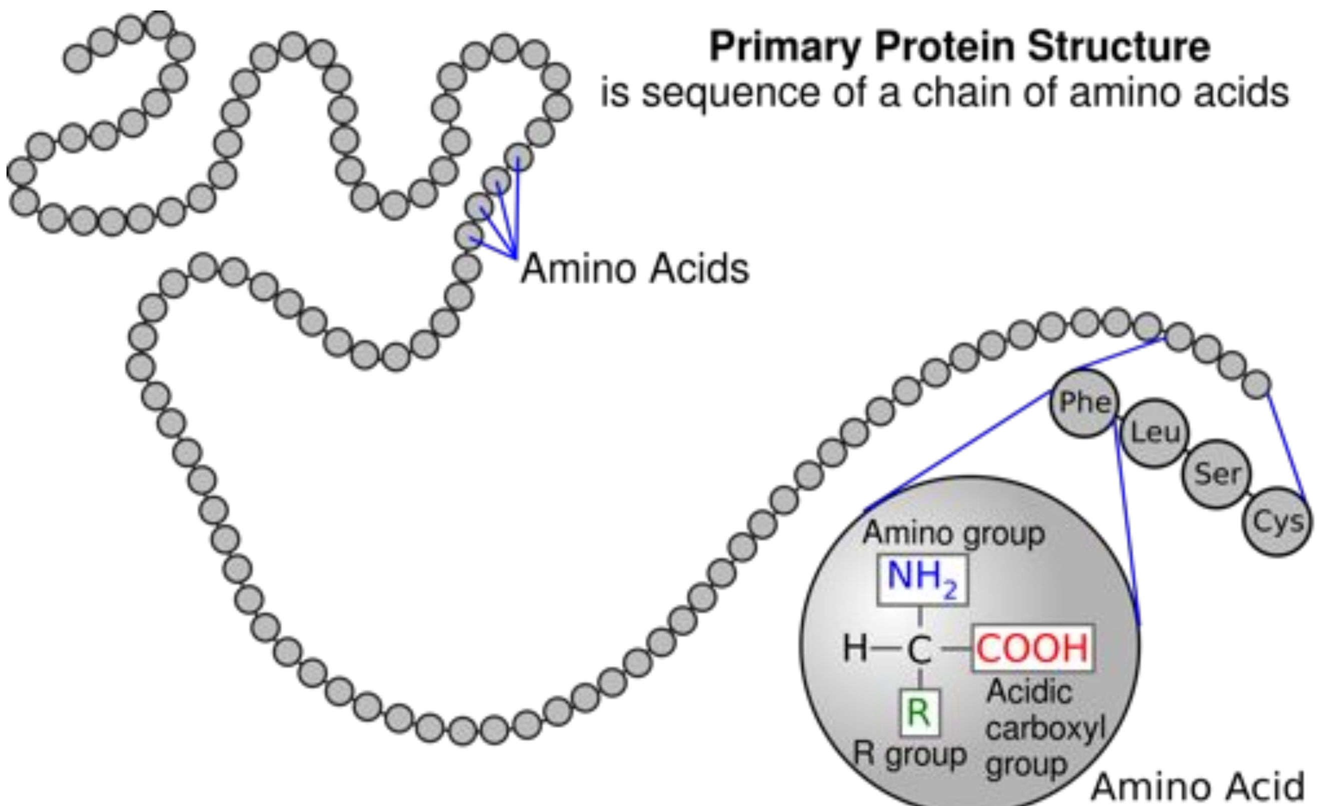
Each level is due to different interactions among amino acids.



Primary Structure

The sequence of amino acids in a polypeptide chain.

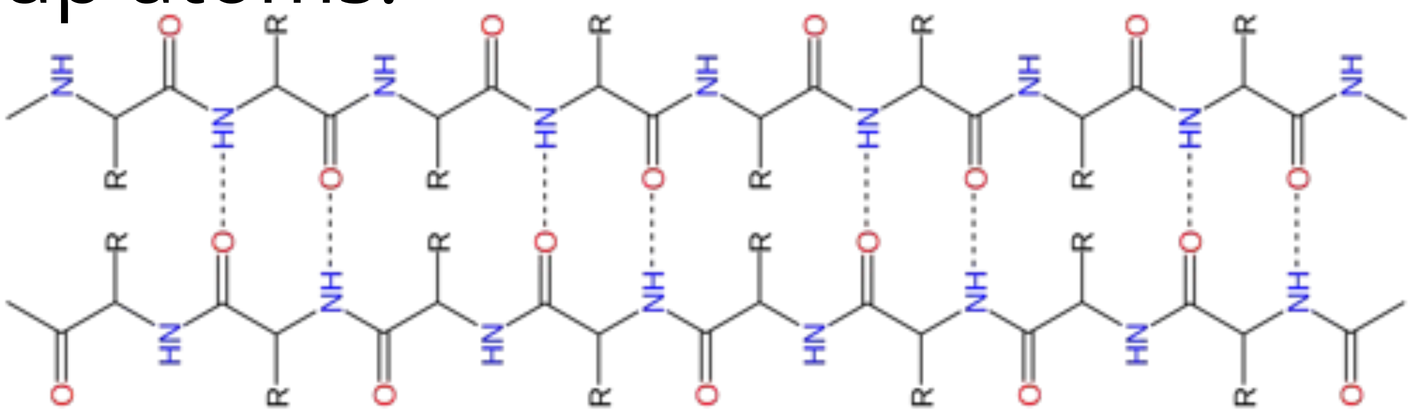
Interactions: Peptide bonds

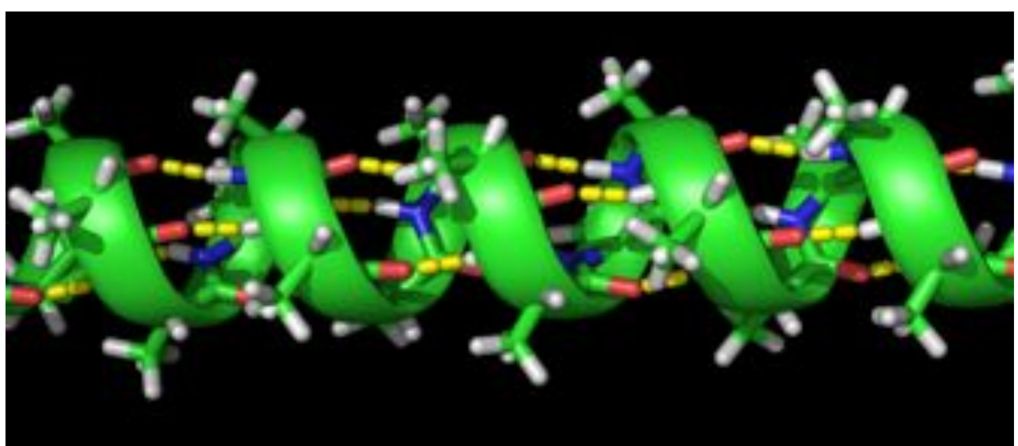


Secondary Structure

Regular 3D structures found in most proteins.

Interactions: H-Bonds among non-R group atoms.

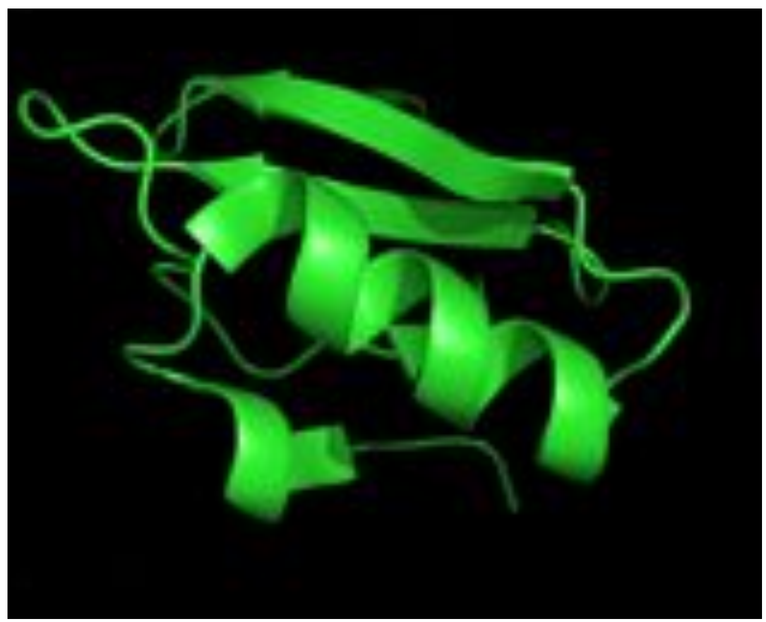




Tertiary Structure

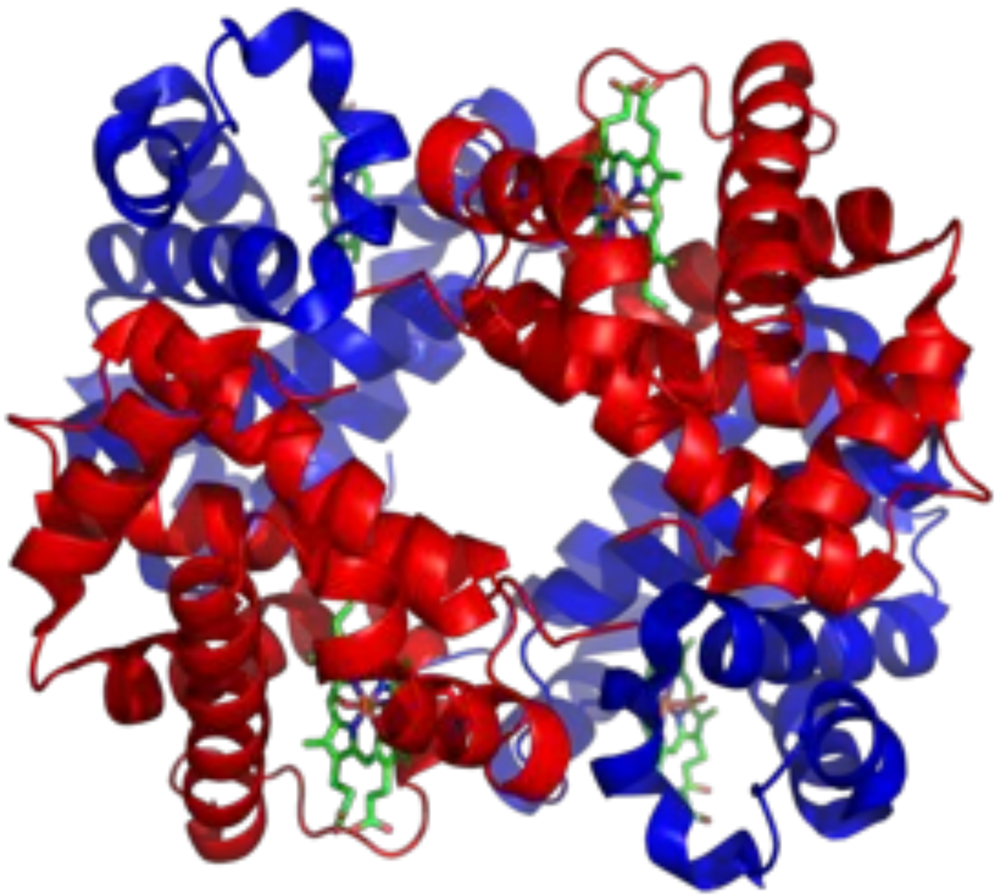
Specific, unique 3D structure ("**conformation**") of a polypeptide chain.

Interactions: R-group interactions between each other and the environment

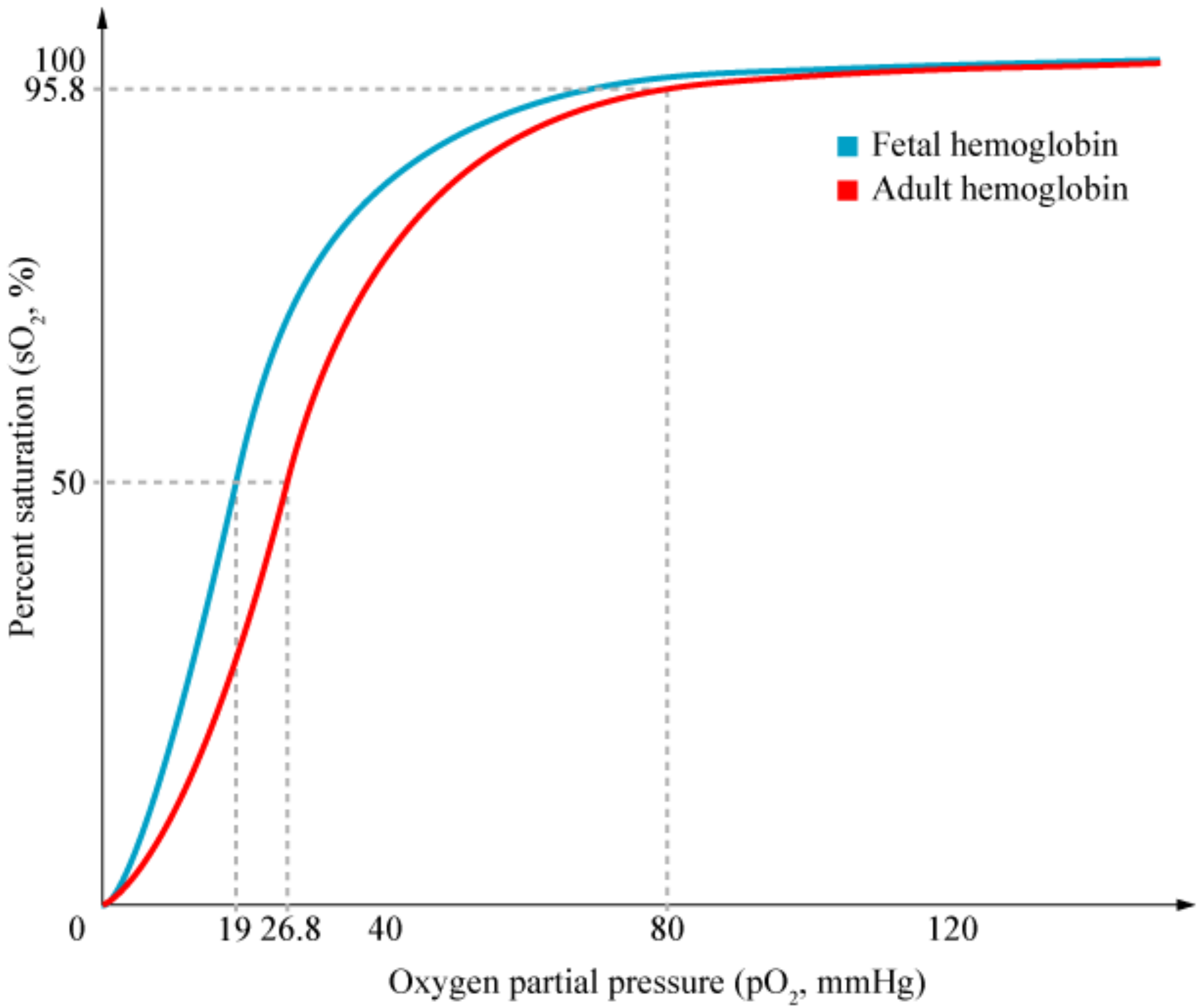


Quaternary Structure

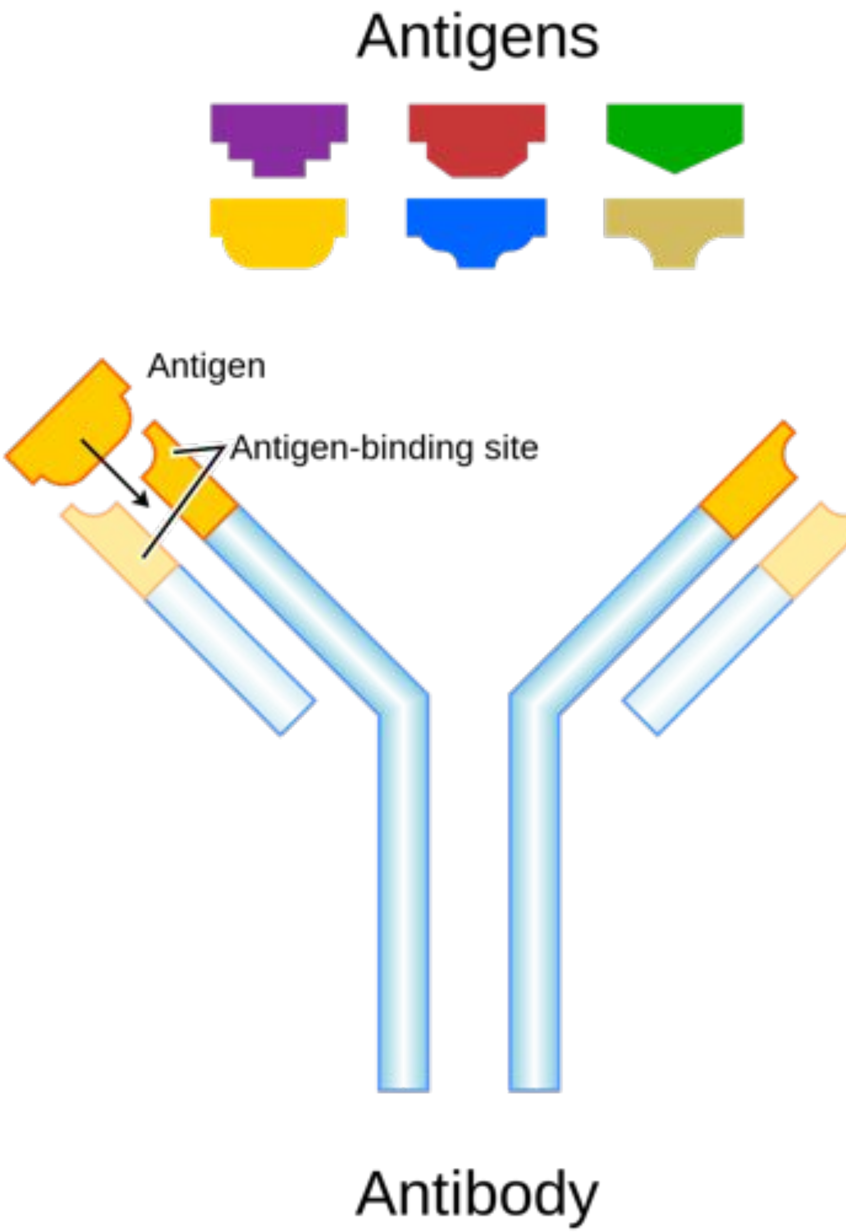
Structure that results from multiple polypeptide chains interacting.

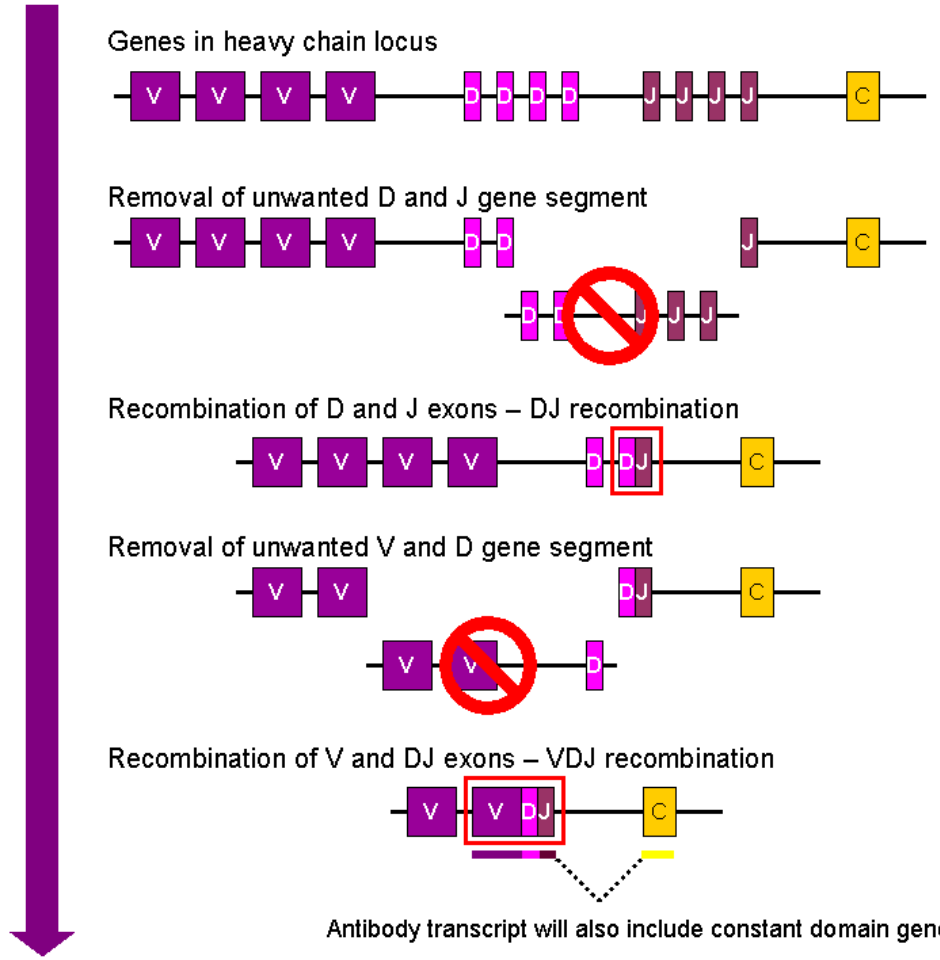


Ex. Fetal Hemoglobin vs. Adult Hemoglobin



Ex. Antibody Variation





Denaturation

Changes in the 3D structure of a macromolecule.

Caused by changes to the environment of the molecule.

Disrupts function.

2.3: Variation in molecular units provides cells with a wider range of functions.

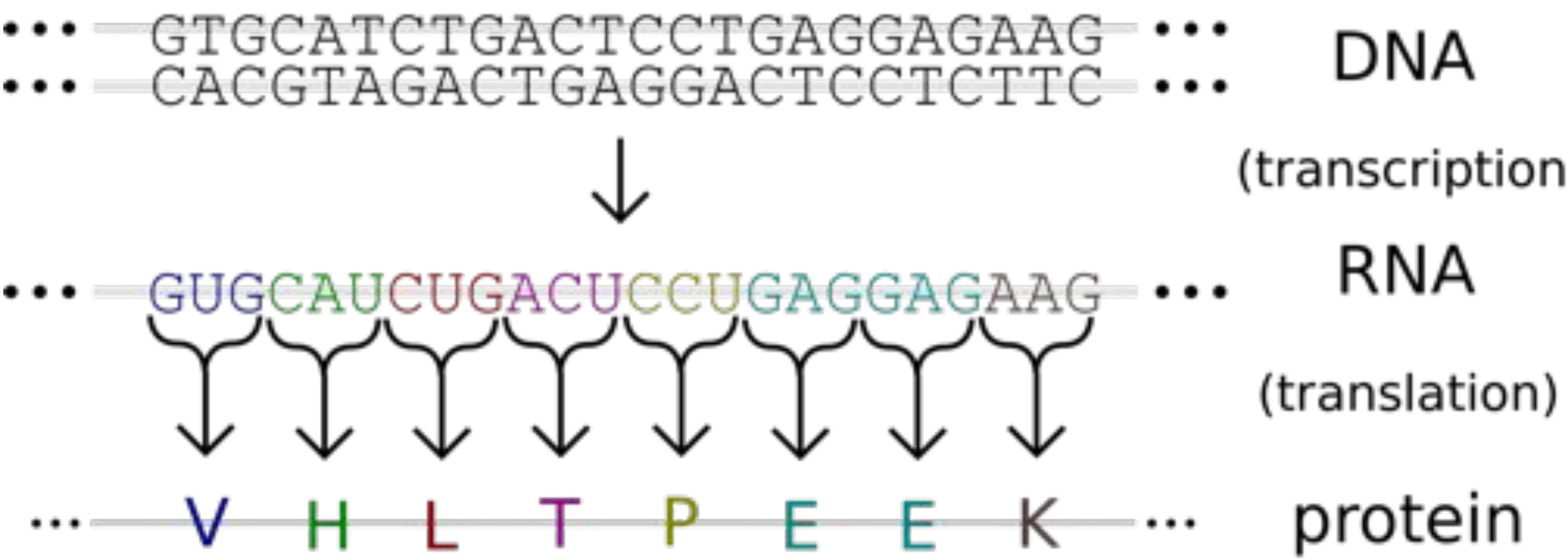
3. VARIATION IN BIOLOGICAL MOLECULES- NUCLEIC ACIDS

Structure Determines Function

The structure of a molecule enables its function.

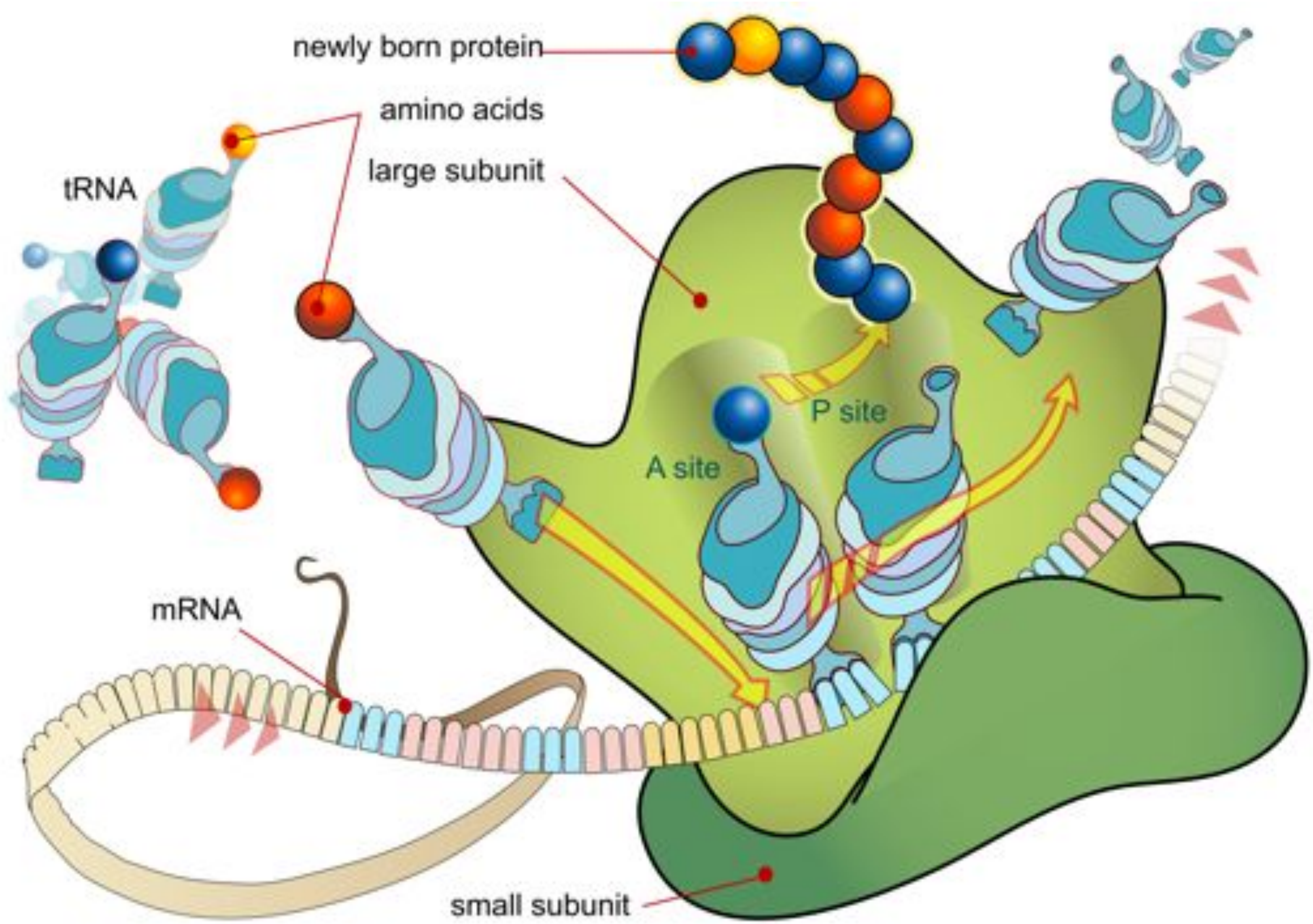
Nucleic Acids are responsible for storing and expressing genetic information.

DNA sequence determines protein sequence.



A change in DNA sequence can affect all levels of organism function.

DNA → RNA → Protein



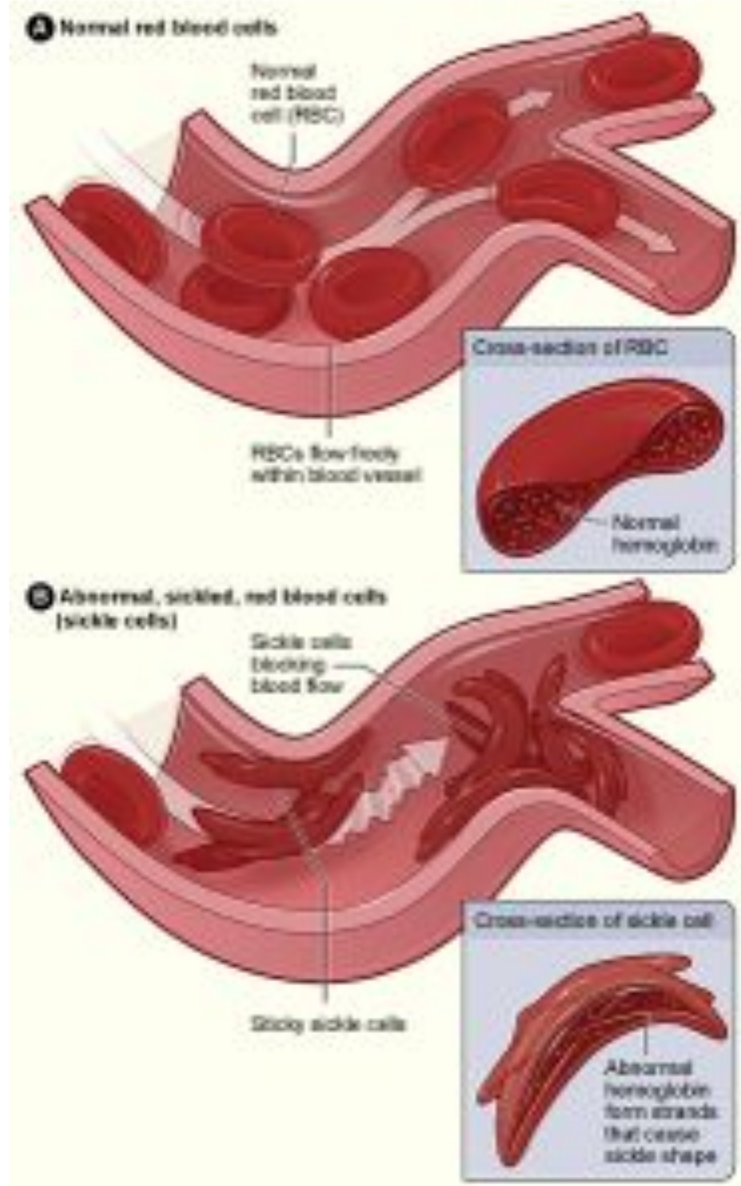
Ex. Sickle Cell Anemia

Sequence for Normal Hemoglobin

ATG	GTG	CAC	CTG	ACT	CCT	GAG	GAG	AAG	TCT	GCC	GTT	ACT
START	Val	His	Leu	Thr	Pro	Glu	Glu	Lys	Ser	Ala	Val	Thr

Sequence for Sickle Cell Hemoglobin

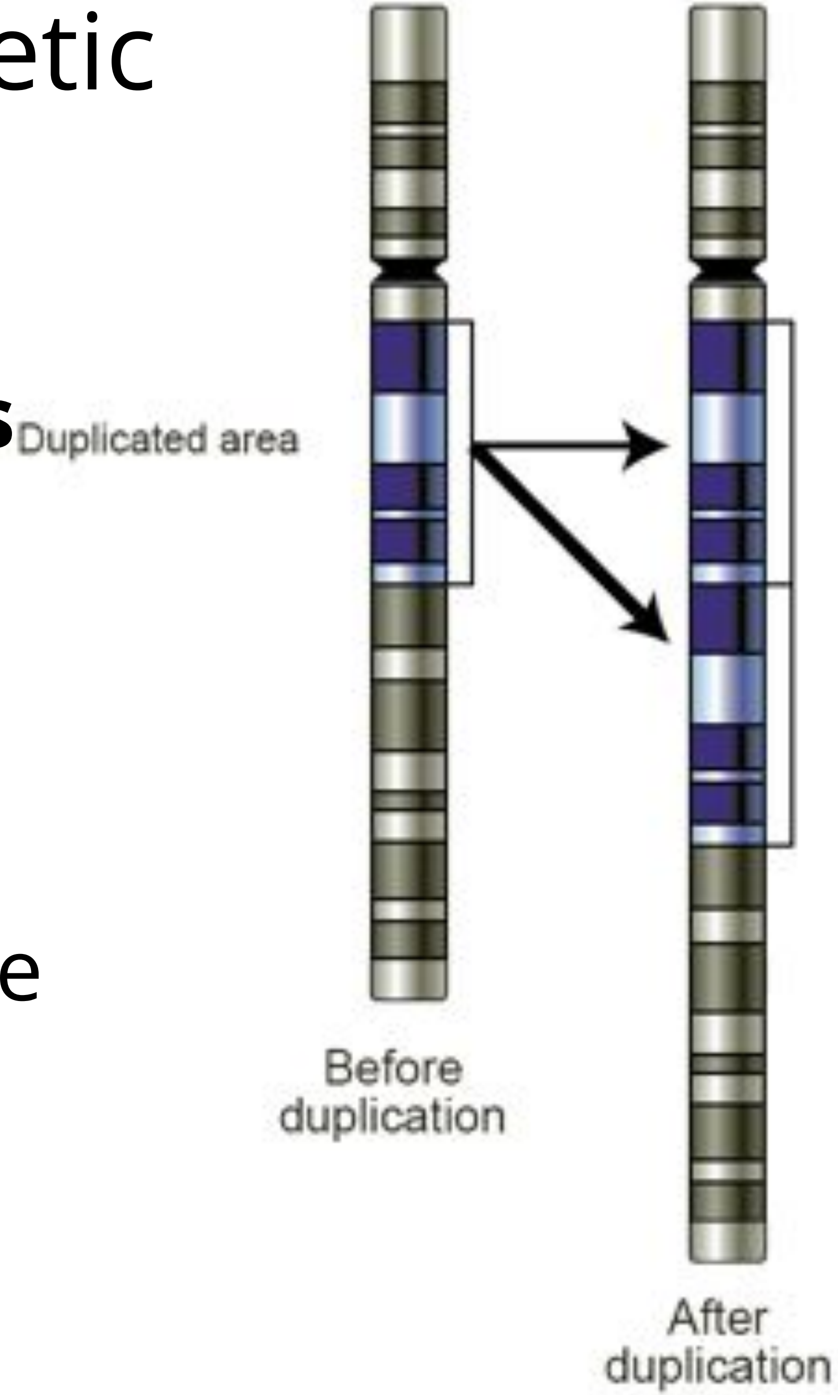
ATG	GTG	CAC	CTG	ACT	CCT	GtG	GAG	AAG	TCT	GCC	GTT	ACT
START	Val	His	Leu	Thr	Pro	Val	Glu	Lys	Ser	Ala	Val	Thr

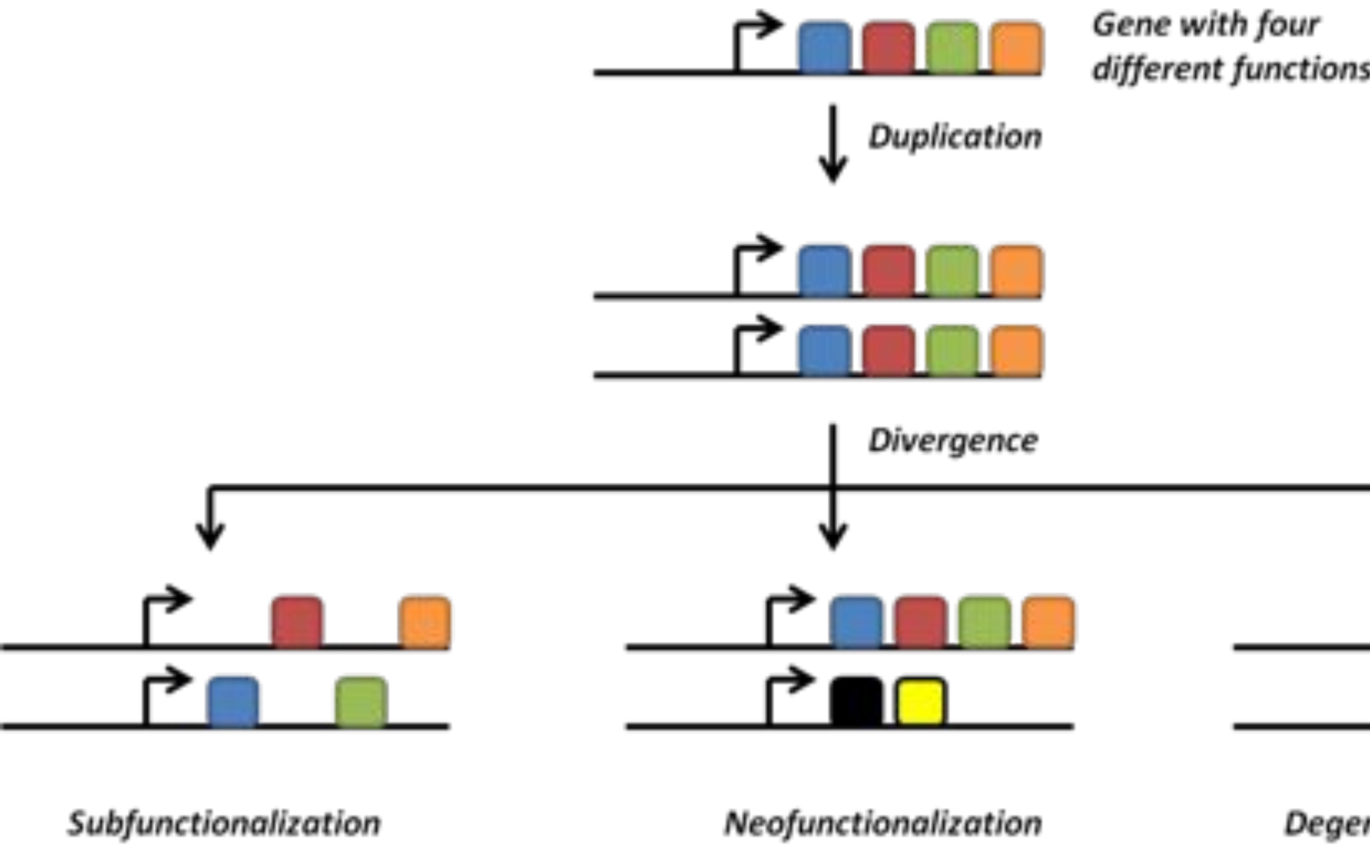


Increases in Genetic Information

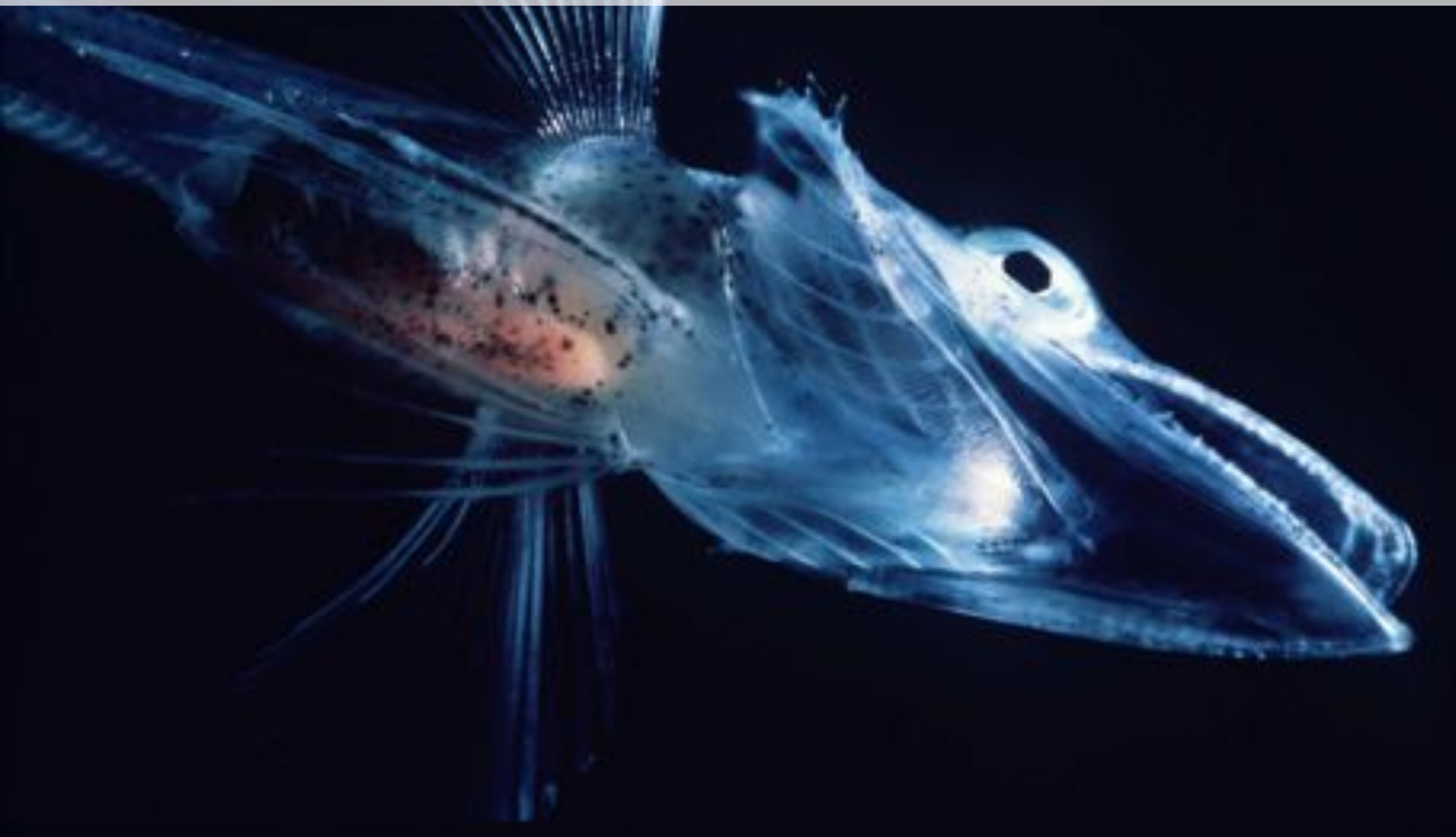
Genetic Duplications can lead to increased genetic information.

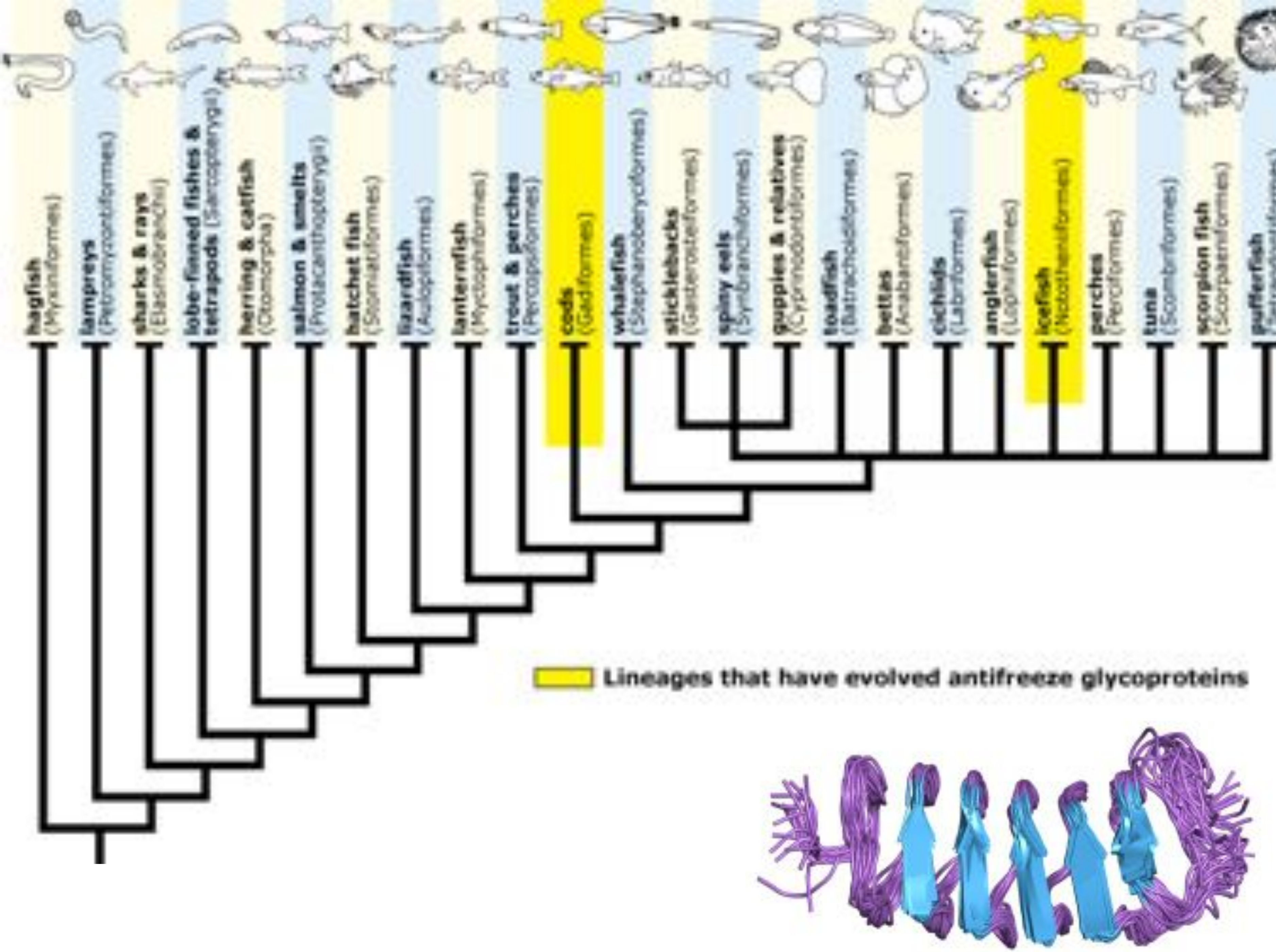
This duplicated information can evolve to allow for novel functions.




Gene with four
different functions
Duplication
Divergence
Subfunctionalization
Neofunctionalization
Degeneration/Gene loss

Ex. Antifreeze Gene in Cold-Water Marine Fish





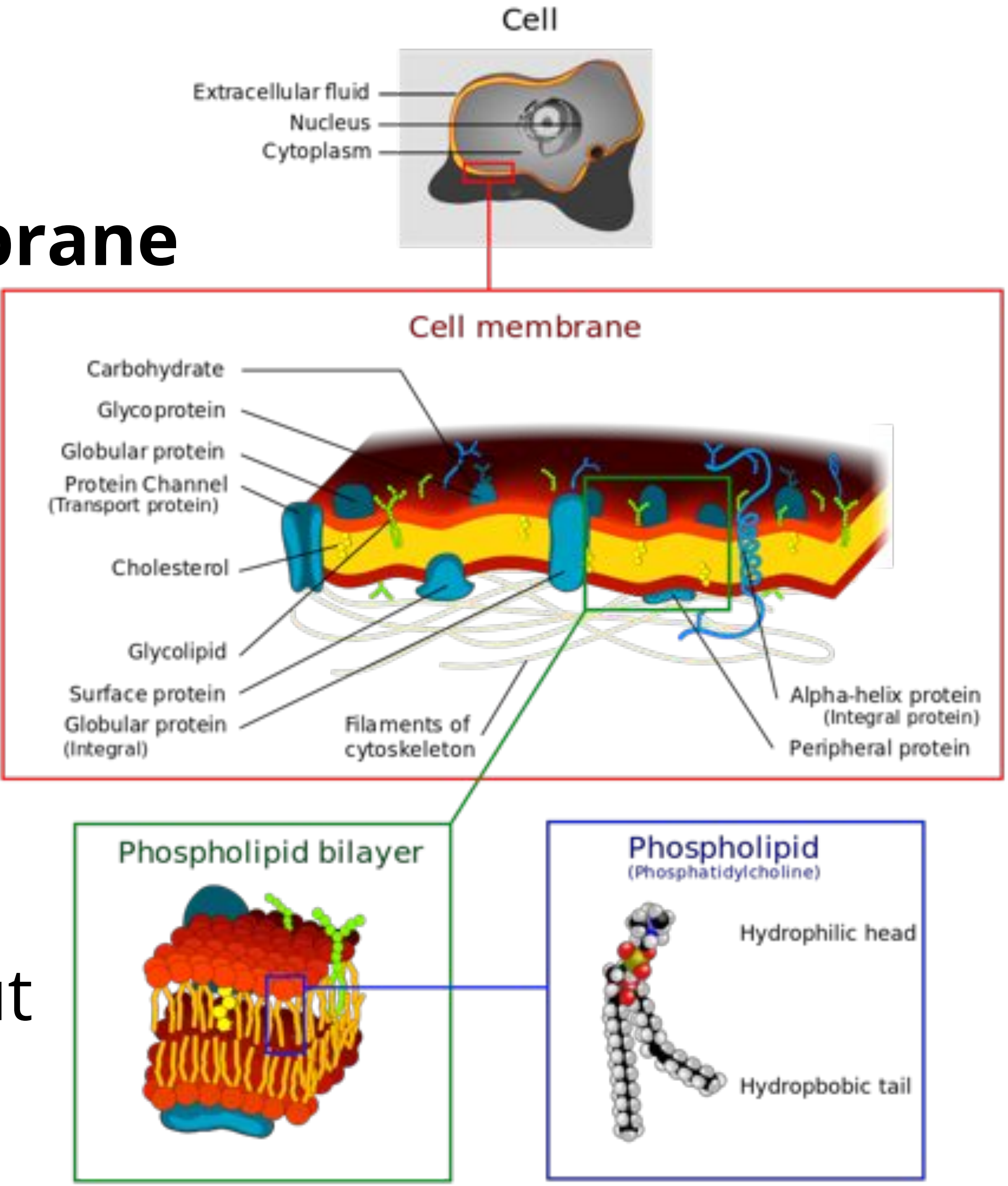
hagfish (Myxiniformes)
lampreys (Petromyzontiformes)
sharks & rays (Elasmobranchii)
lobe-finned fishes & tetrapods (Sarcopterygii)
herring & catfish (Otomorpha)
salmon & smelts (Protacanthopterygii)
hatchet fish (Stomiatiformes)
lizardfish (Aulopiformes)
lanternfish (Myctophiformes)
trout & perches (Percopsiformes)
cods (Gadiformes)
whalefish (Stephanoberyciformes)
sticklebacks (Gasterosteiformes)
spiny eels (Synbranchiformes)
guppies & relatives (Cyprinodontiformes)
toadfish (Batrachoidiformes)
bettas (Anabantiformes)
cichlids (Labriformes)
anglerfish (Lophiiformes)
icefish (Notothenioiformes)
perches (Perciformes)
tuna (Scombriformes)
scorpion fish (Scorpaeniformes)
pufferfish (Tetraodontiformes)
Lineages that have evolved antifreeze glycoproteins

2.4: Cell membranes are selectively permeable due to their structure.

1. CELL MEMBRANE STRUCTURE

The **cell membrane** is a boundary between the cell and the environment.

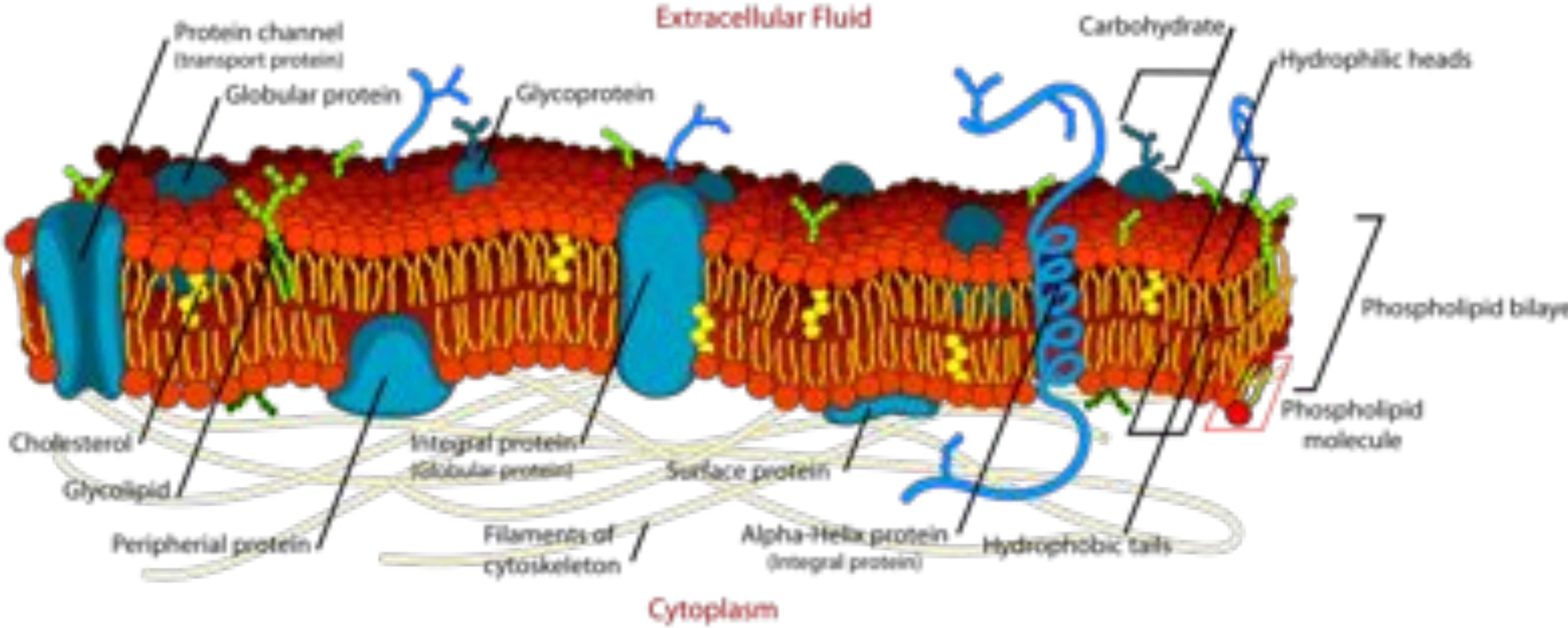
It controls the **transport** of materials in/out of the cell.



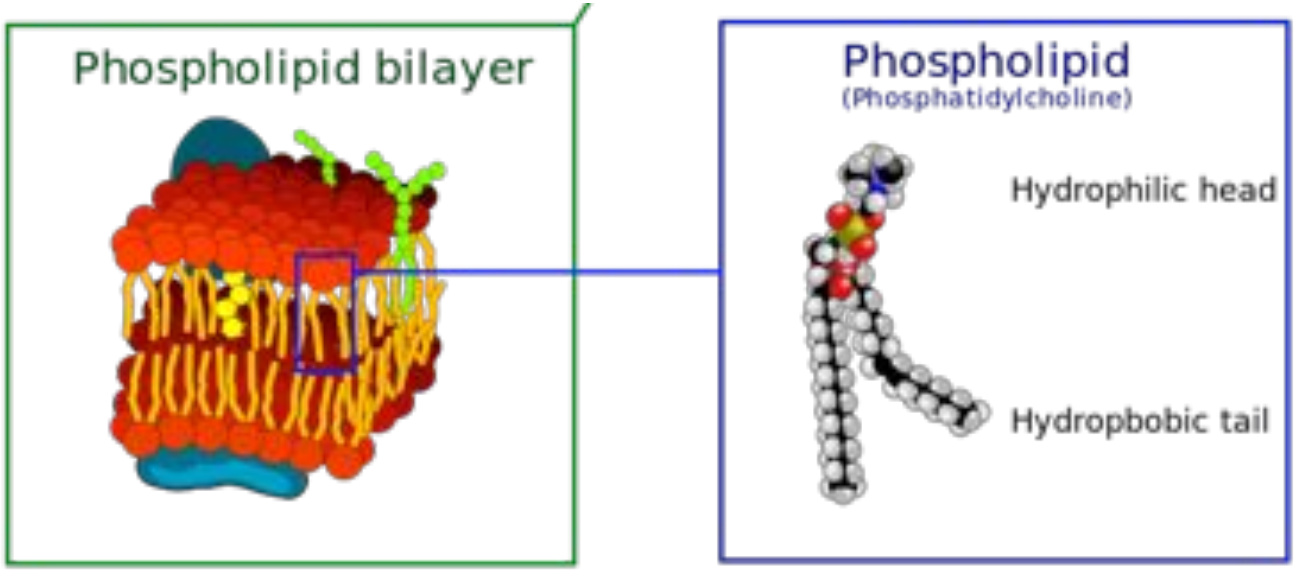
The Fluid Mosaic Model

Connects membrane structure to function.

2 components: phospholipids and proteins



Phospholipids



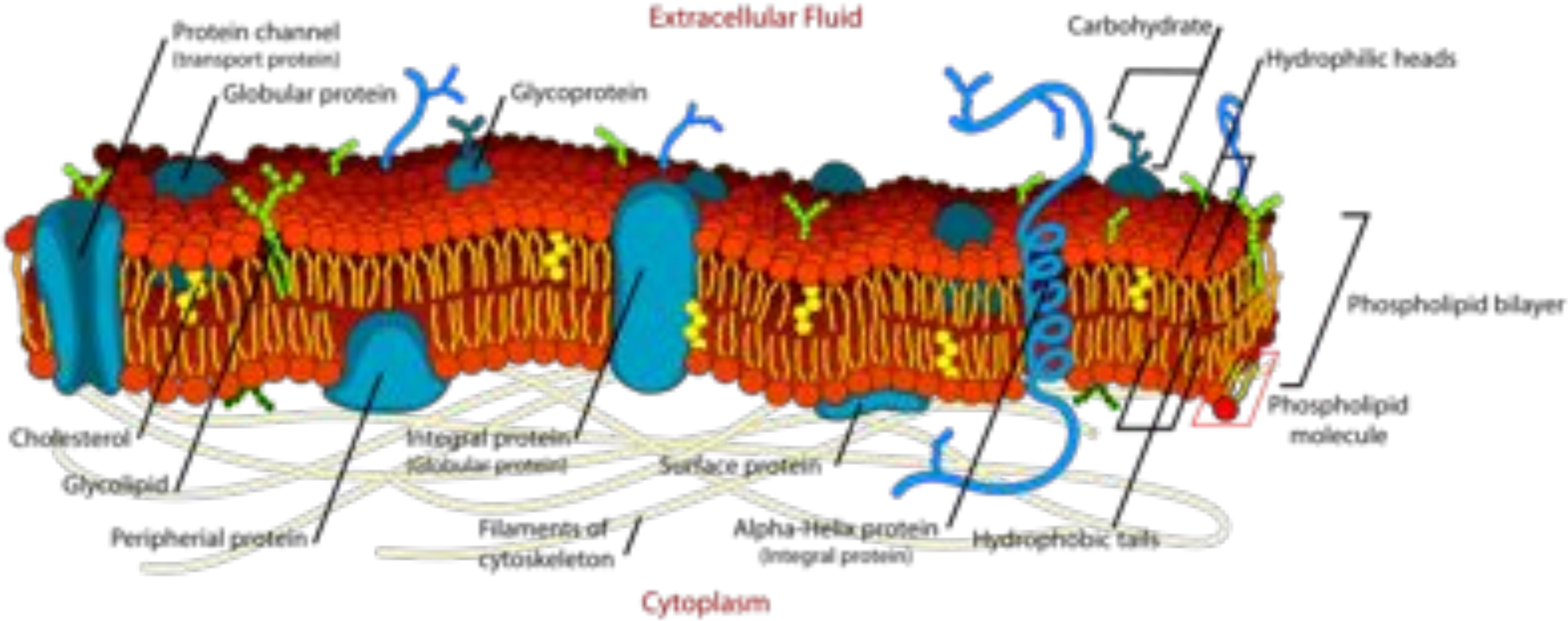
Phospholipids are **amphipathic**.

They spontaneously form a **bi-layer** in aqueous environments.

The inside of the bi-layer is **hydrophobic**.

Membrane Proteins

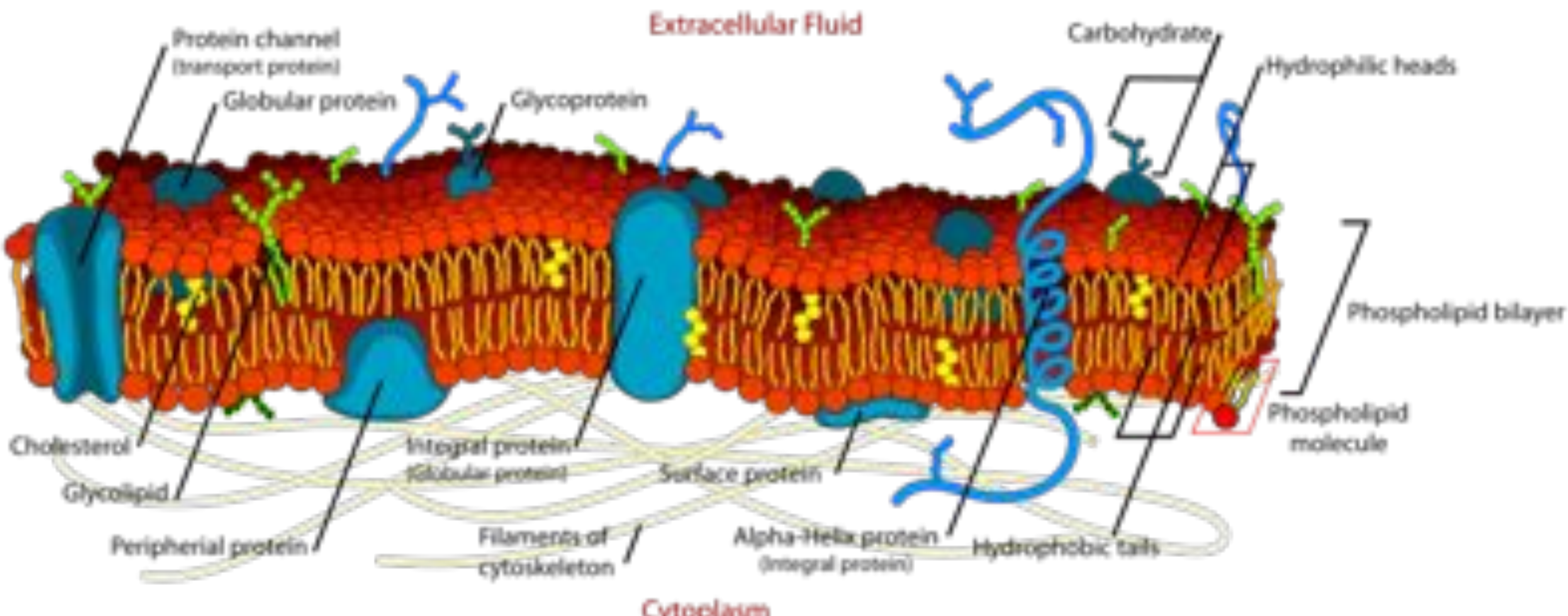
Membrane proteins serve a variety of functions for the cell.



Selective Permeability

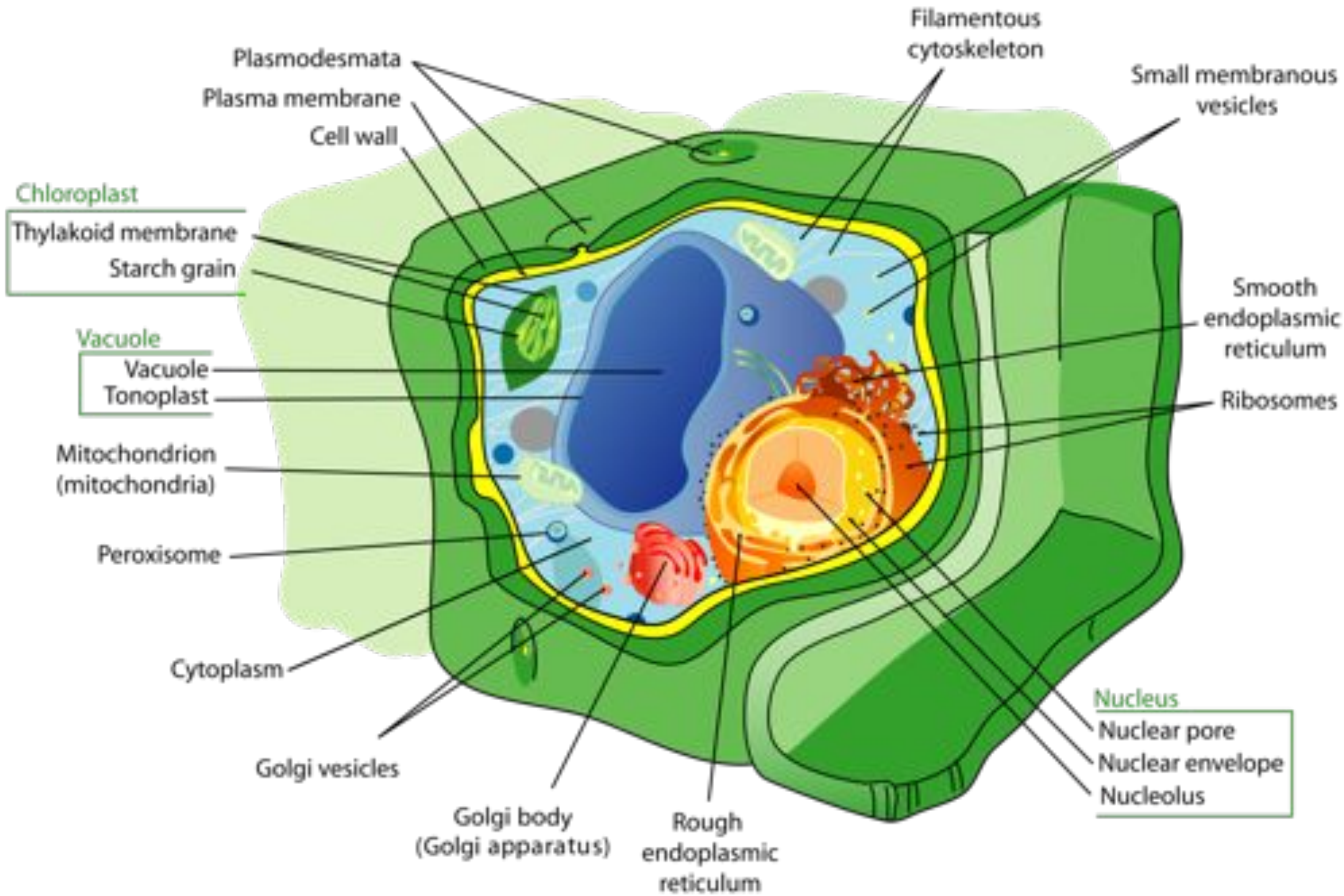
Only small, non-polar molecules move through the bi-layer.

All other material must move through protein **pores**



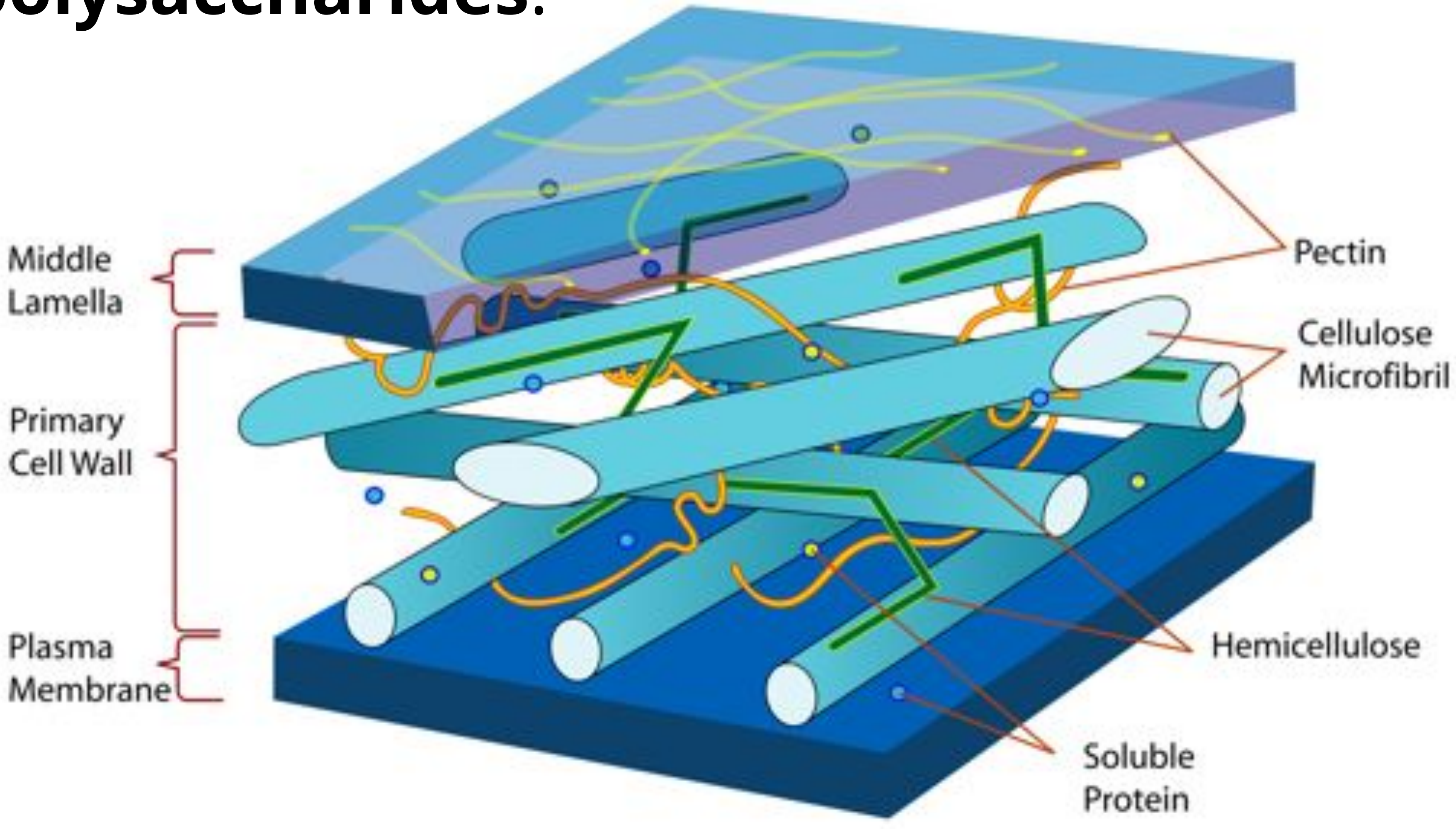
Cell Walls

Many cells are surrounded by **cell walls**, which are inactive structural supports.



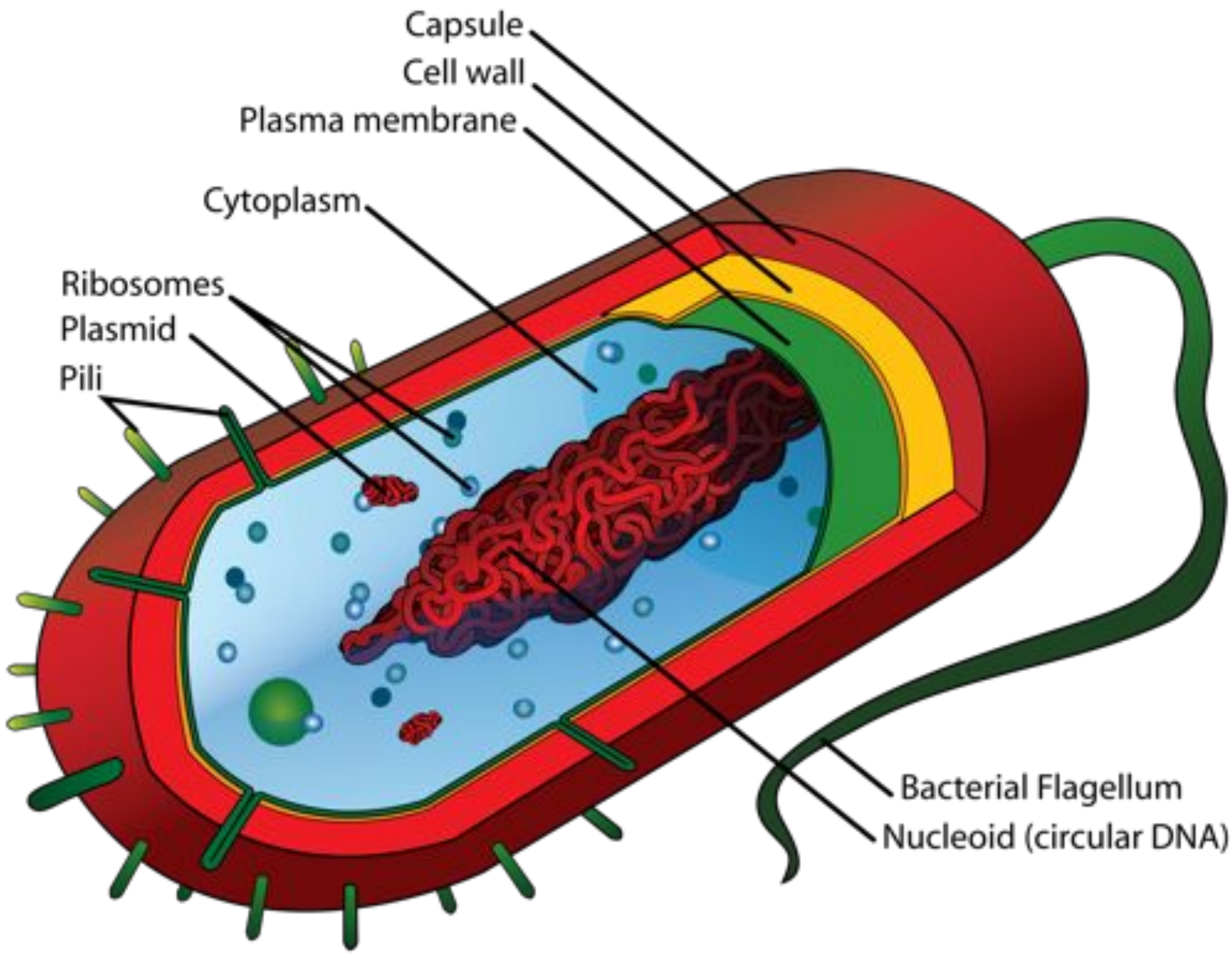
Cell Wall Structure

All cell walls are fibers of **structural polysaccharides**.



Plant-like, fungal, and prokaryotic cells all have cell walls (of different polysaccharides).

Animal-like cells do not.



2.4: Cell membranes are selectively permeable due to their structure.

2. MATH SKILL- CONSTRAINTS ON CELL SIZE

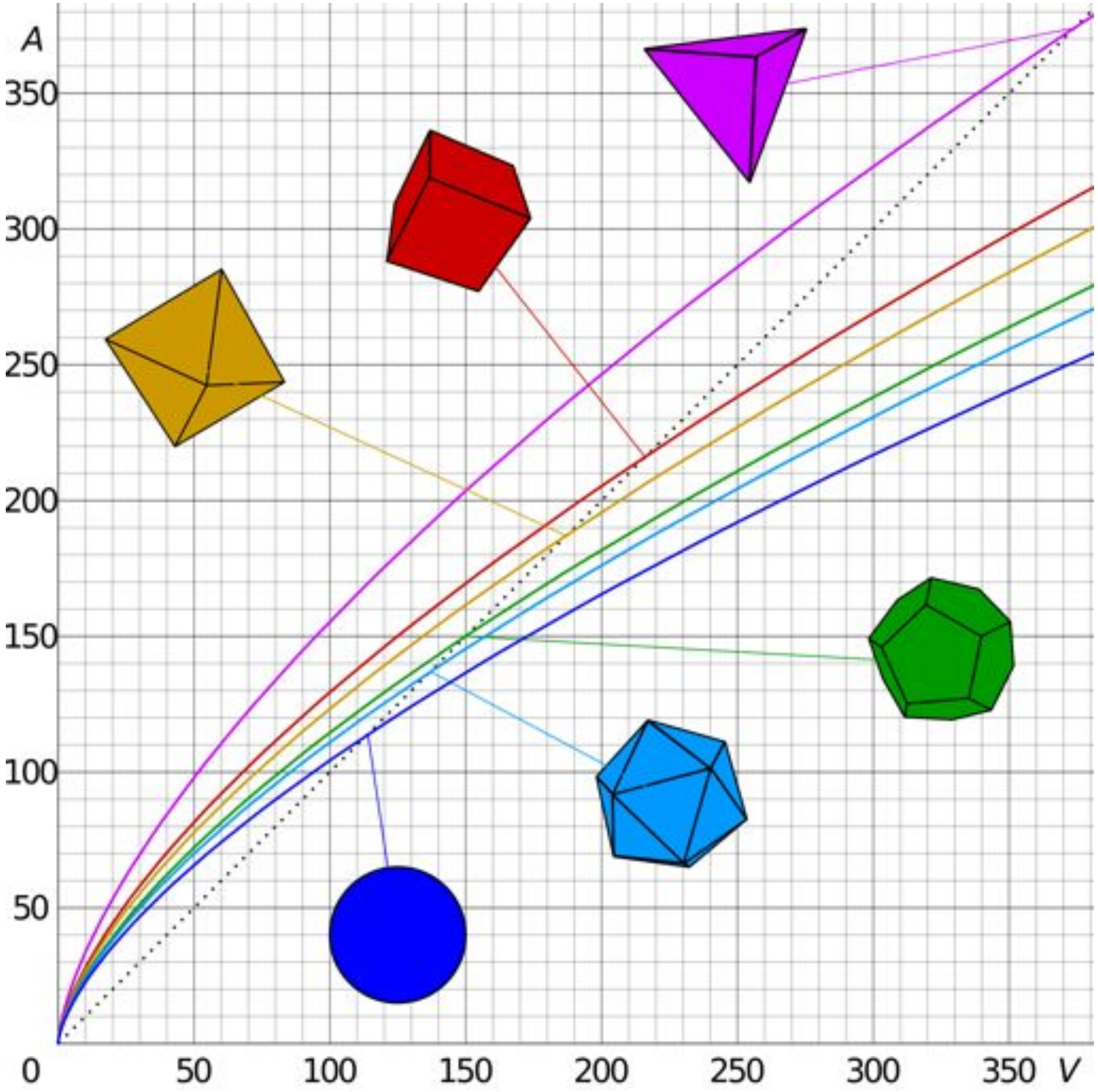
Living Systems are Constrained by the Environment

The need to efficiently exchange material with the environment limits cell size.

Lower limit: due to materials required to be a functional cell.

Upper limit: Surface area: Volume ratio- volume increases as a cubic function of size, while surface area increases as a squared function.

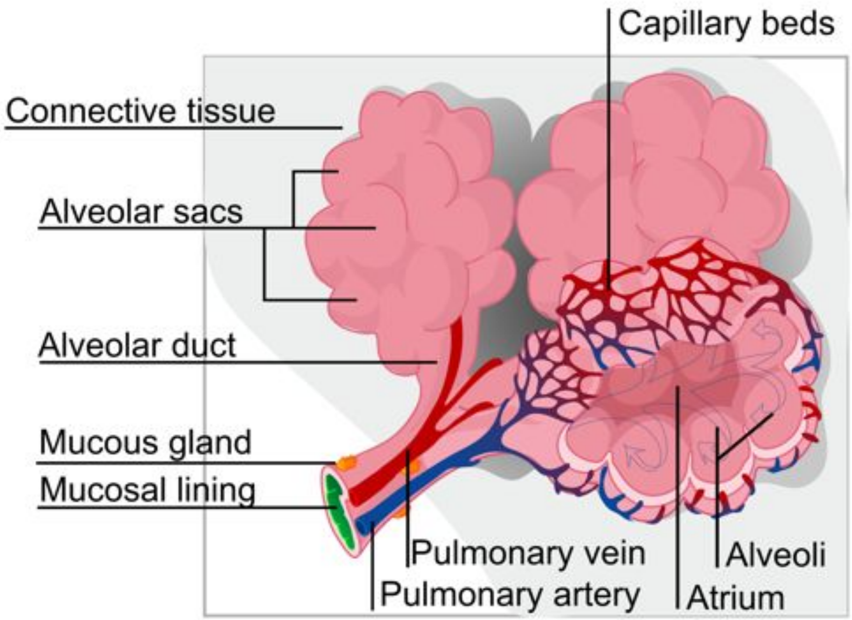
As volume increases, exchange efficiency decreases

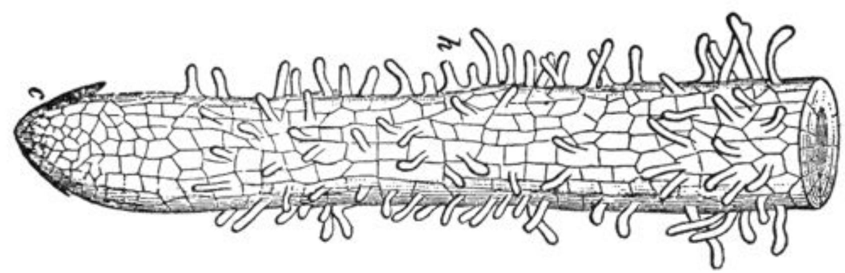


Surface Area Adaptations

Cells have adapted to maximize surface area when material exchange needs to be maximized.

Ex. Lung alveoli, and plant root hairs





2.1: Organisms must exchange matter with the environment to grow, reproduce and maintain organization.

5. MATH SKILLS- SURFACE AREA: VOLUME RATIO

What you need to do.

Be able to calculate the surface area and volume of a 3D cell and determine the relative efficiency of material exchange.

The formula sheet has formulas for surface area and volume for a variety of 3D shapes.

Sample Problem

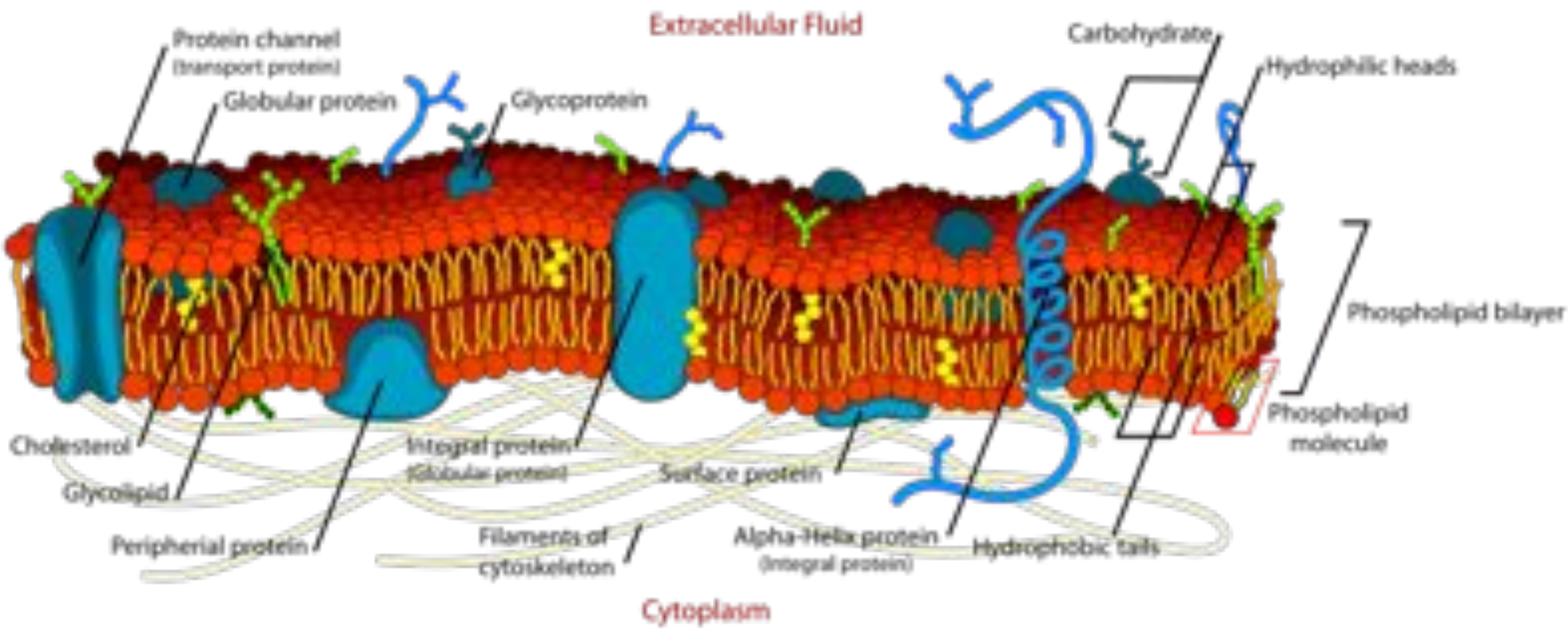
Determine the relative efficiency of material exchange for a spherical cell with a radius of 10 µm, and a cubic cell with a side length of 10 µm.

2.5: Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes.

1. MECHANISMS OF CELLULAR TRANSPORT

Transport is controlled by the cell membrane.

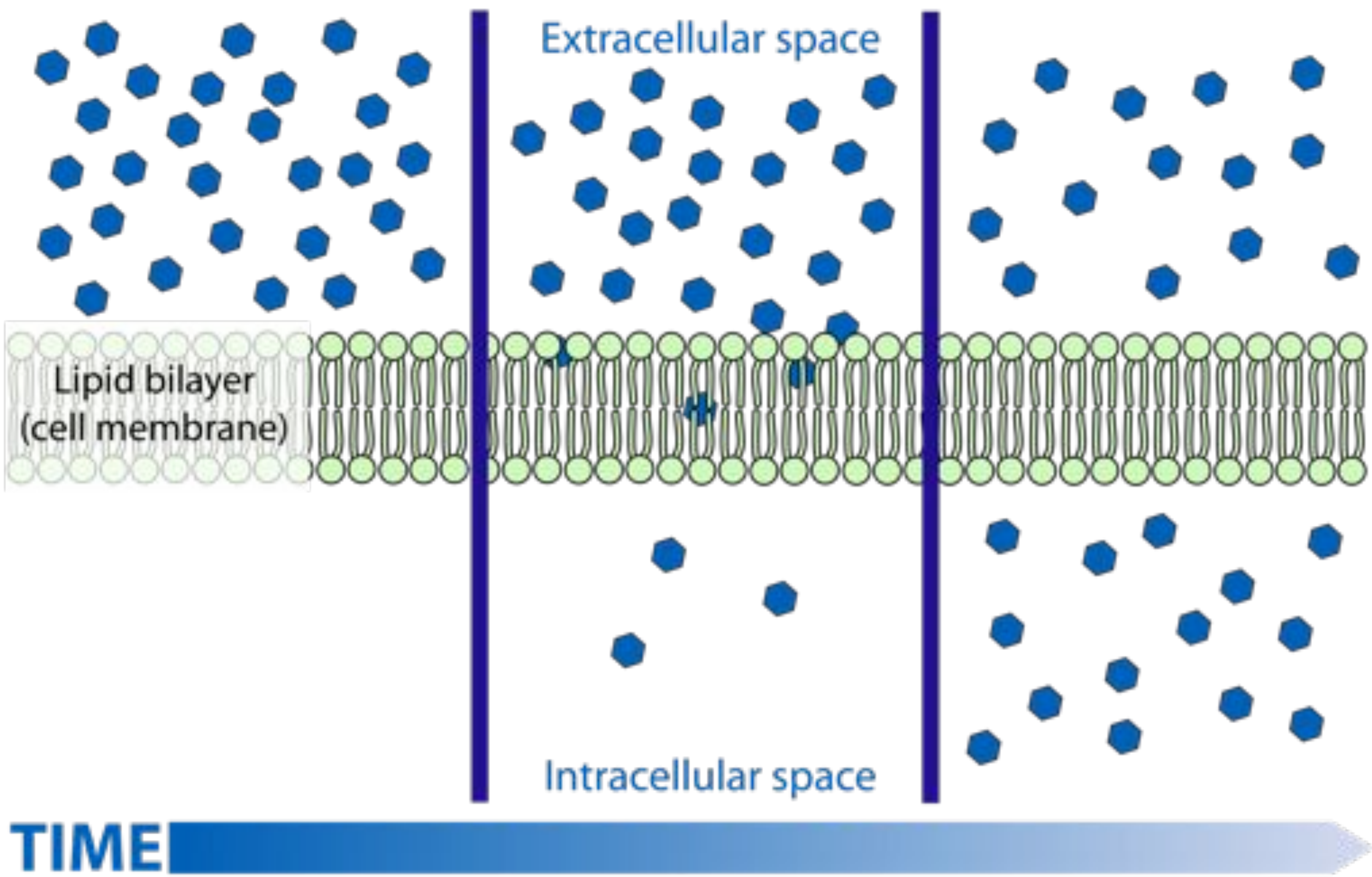
Transport can be **active** or **passive**.



Passive Transport

Does not require energy, moves with the concentration gradient.

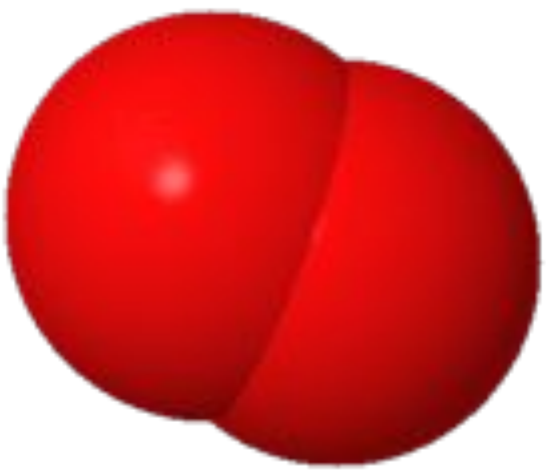
Passive Transport is called "**Diffusion**"



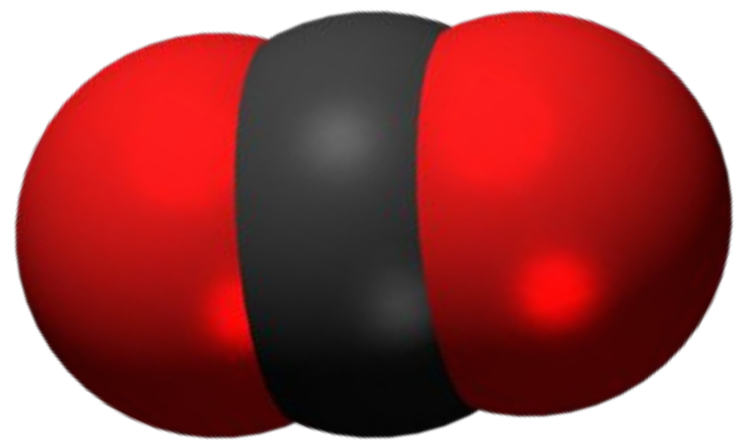
Simple Diffusion

Small, non-polar molecules are able to diffuse across the phospholipid bi-layer.

Cells control simple diffusion by controlling the concentrations of these molecules.



Oxygen (O_2)

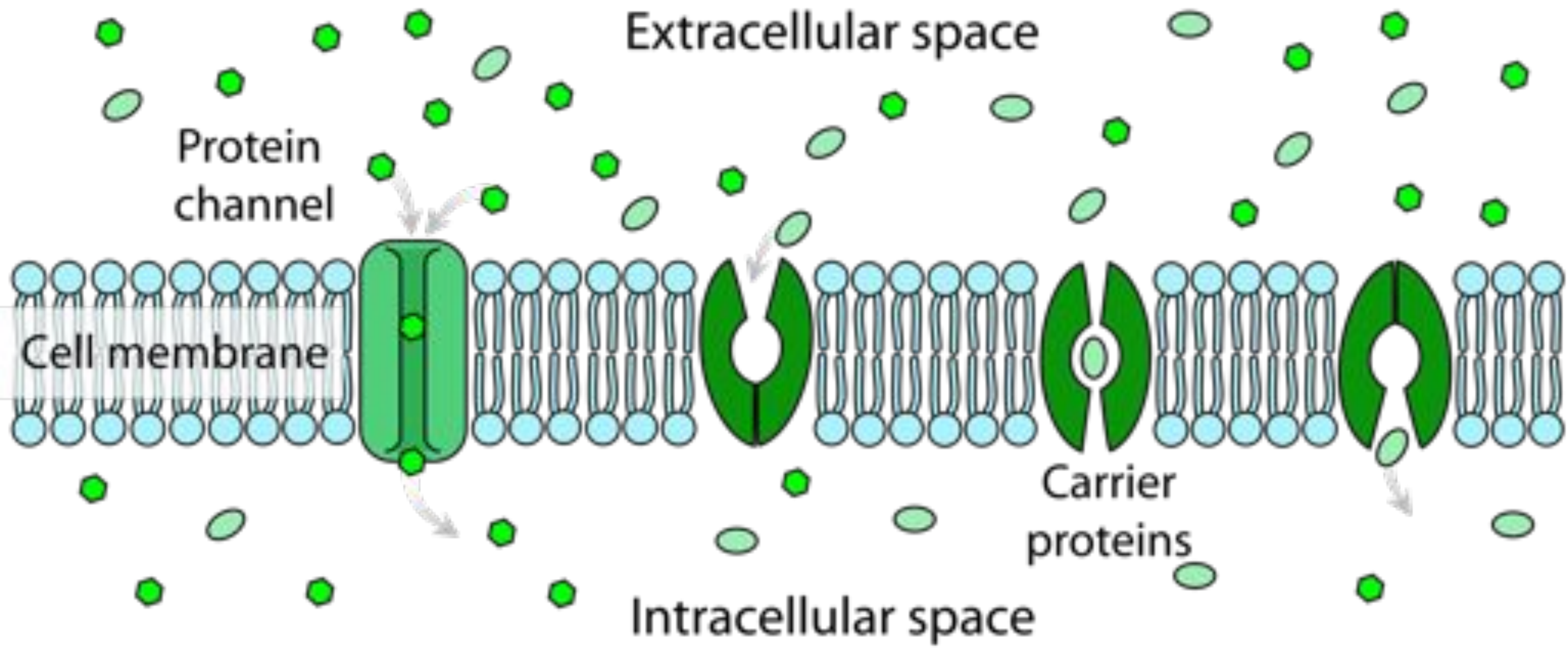


Carbon Dioxide (CO_2)

Facilitated Diffusion

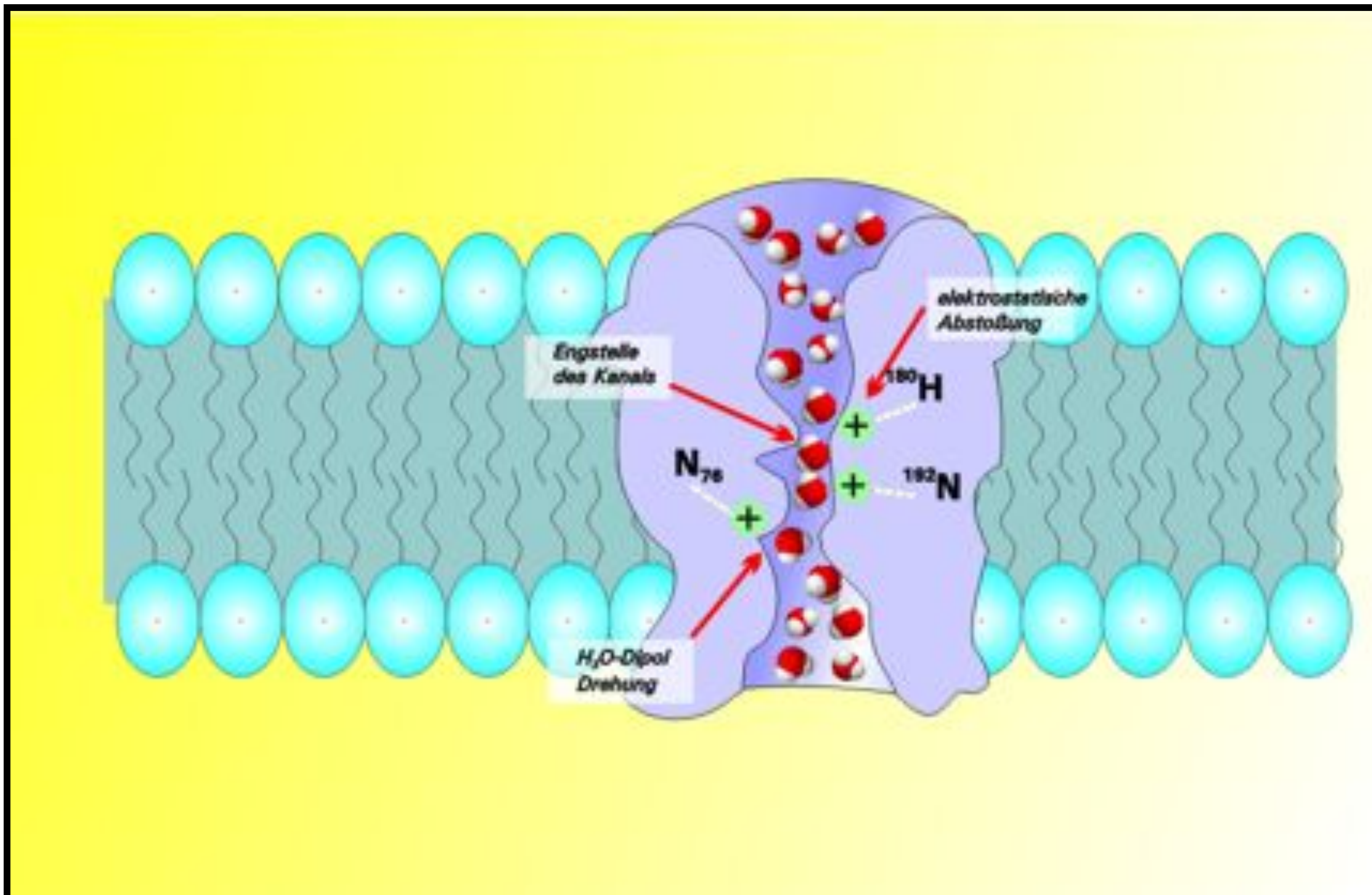
Molecules that are polar/charged, must diffuse through protein pores in the cell membrane.

Pores are specific for specific molecules.



Ex. Aquaporins

Channels that allow water to diffuse (“**osmosis**”)

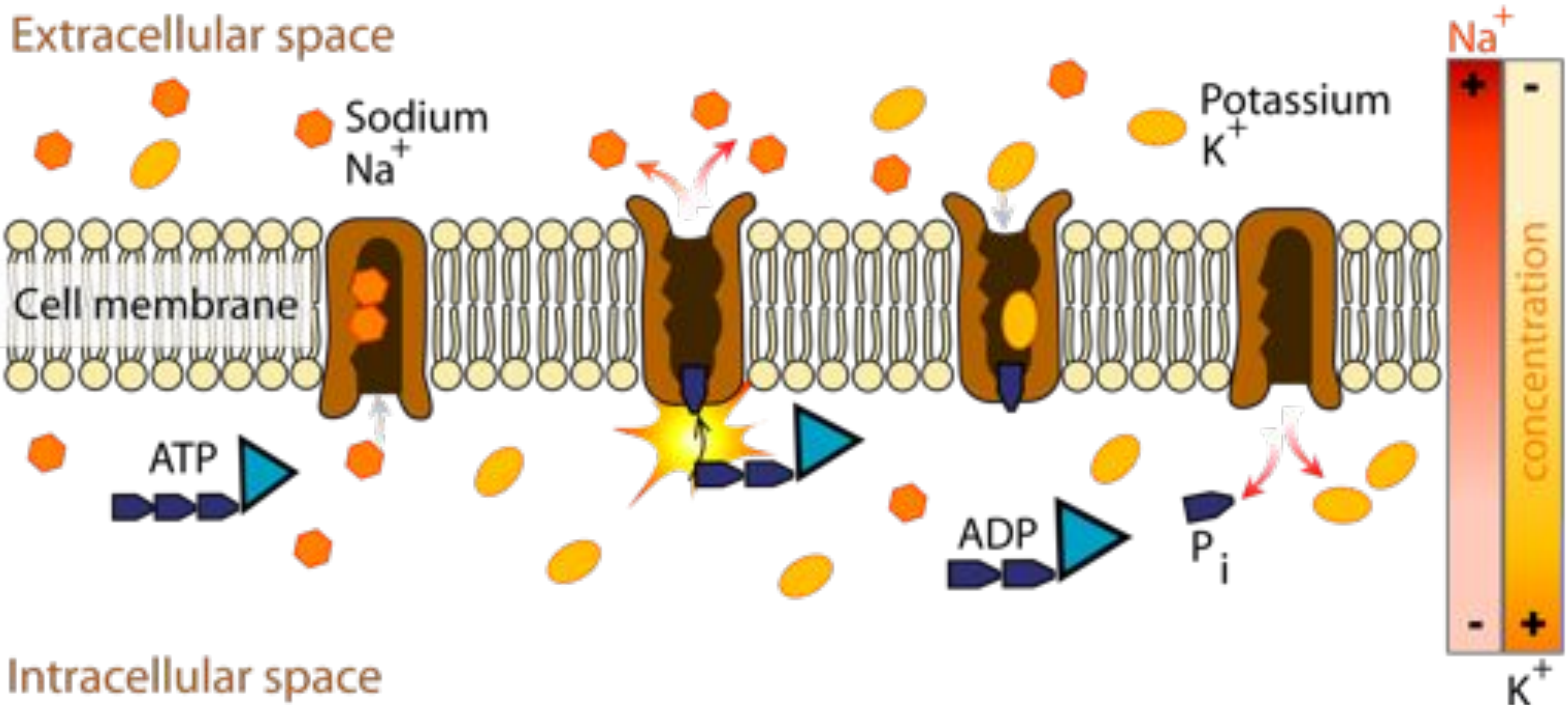


Active Transport

Cells move molecules against the concentration gradient by using energy.

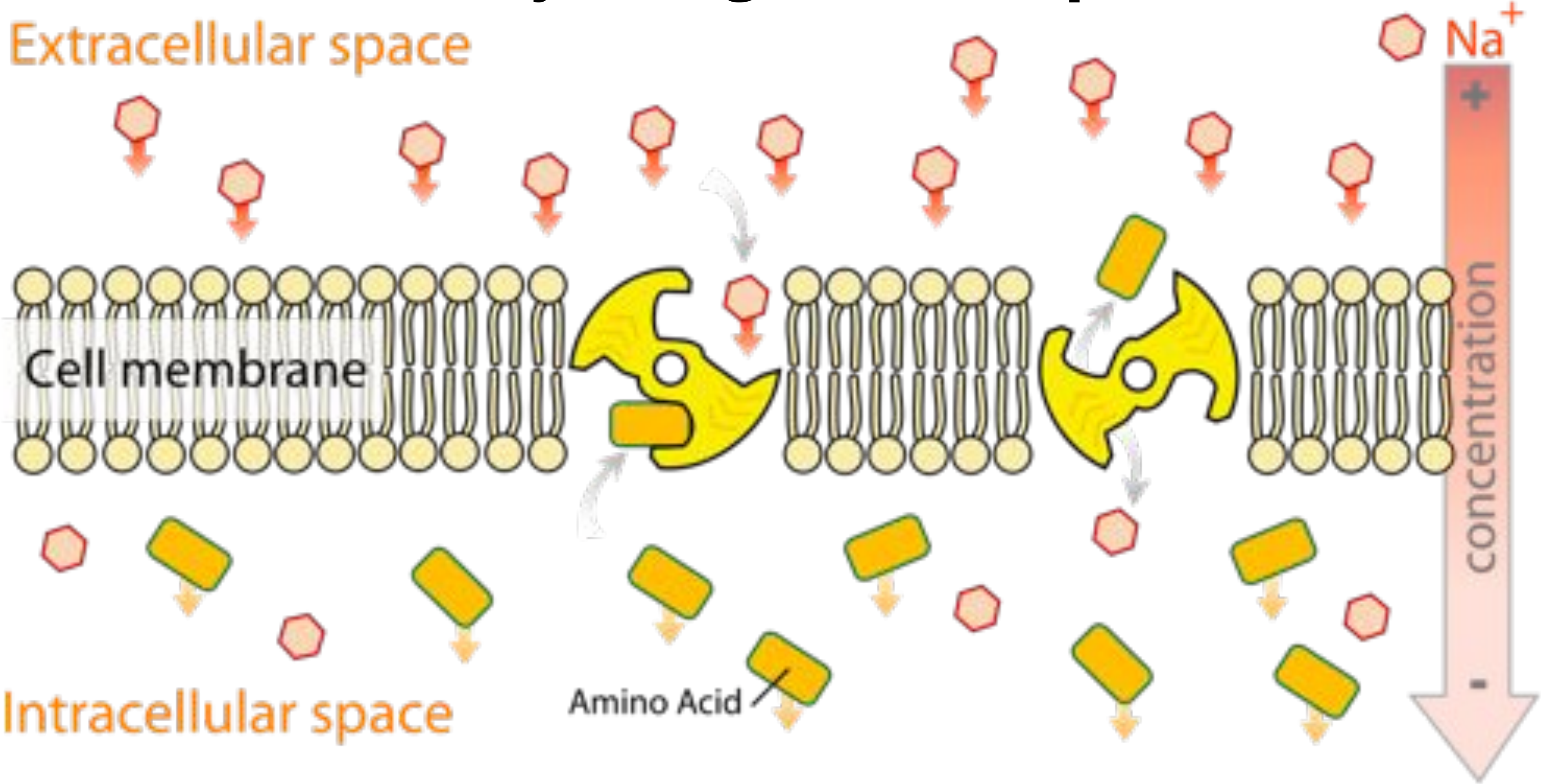
The energy is used to operate **"pump proteins"**.

Ex. Sodium-Potassium Pump



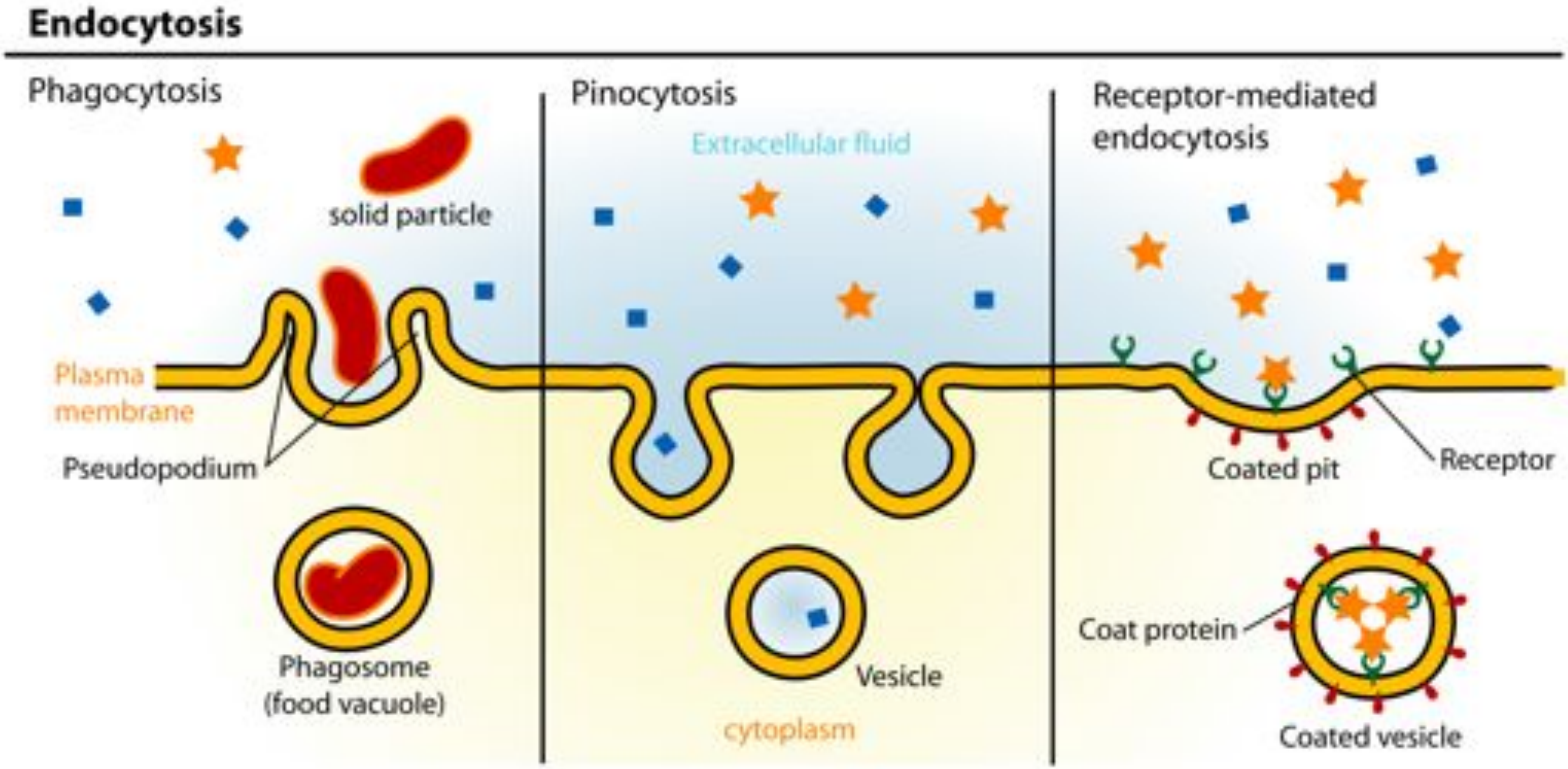
Co-Transport

Cells can transport multiple molecules simultaneously using **co-transporters**.



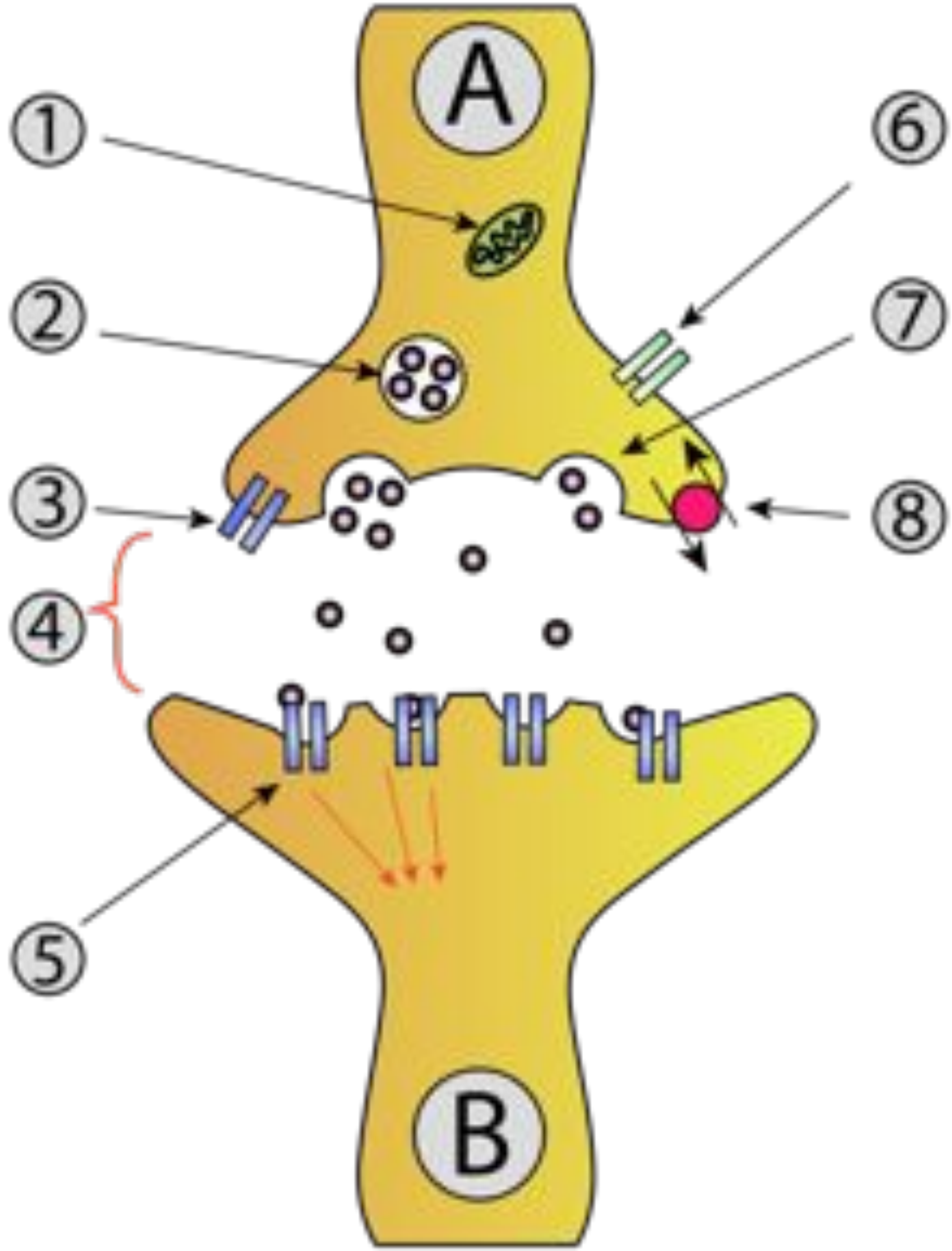
Bulk Transport

Cells transport bulk molecules by surrounding them with membrane ("**vesicles**")



Vesicular transport can be internal ("**endocytosis**") or external ("**exocytosis**")

Shown: Release of molecules from cell A to cell B.



2.5: Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes.

2. ANALYZING TRANSPORT

Tonicity

A measurement of the relative concentrations of solute between two solutions (inside and outside of cell).

Hypertonic: More solute/less solvent.

Hypotonic: Less solute/more solvent

Isotonic: Equal concentrations.

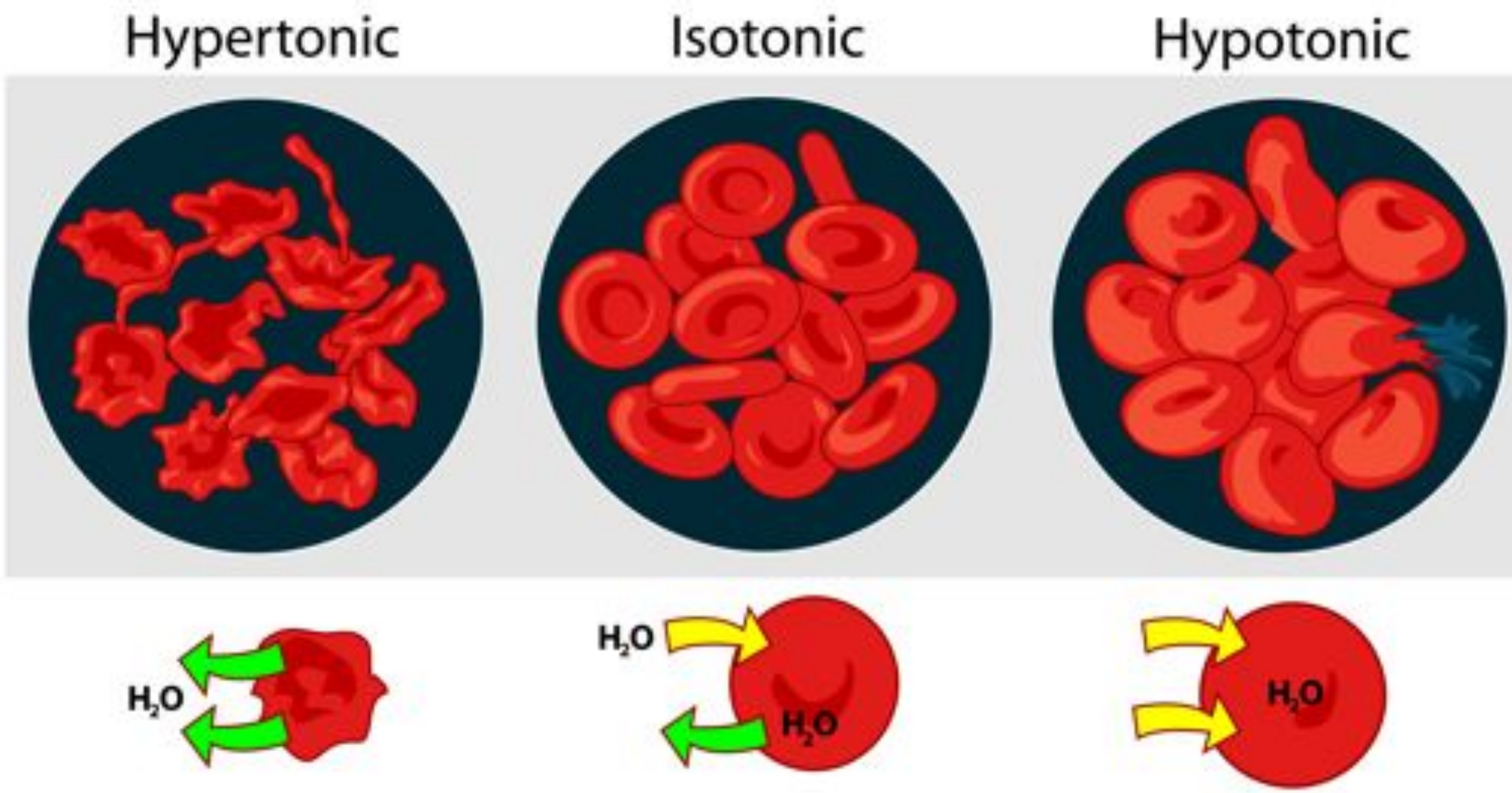
These terms are comparative.

The solvent is always water.

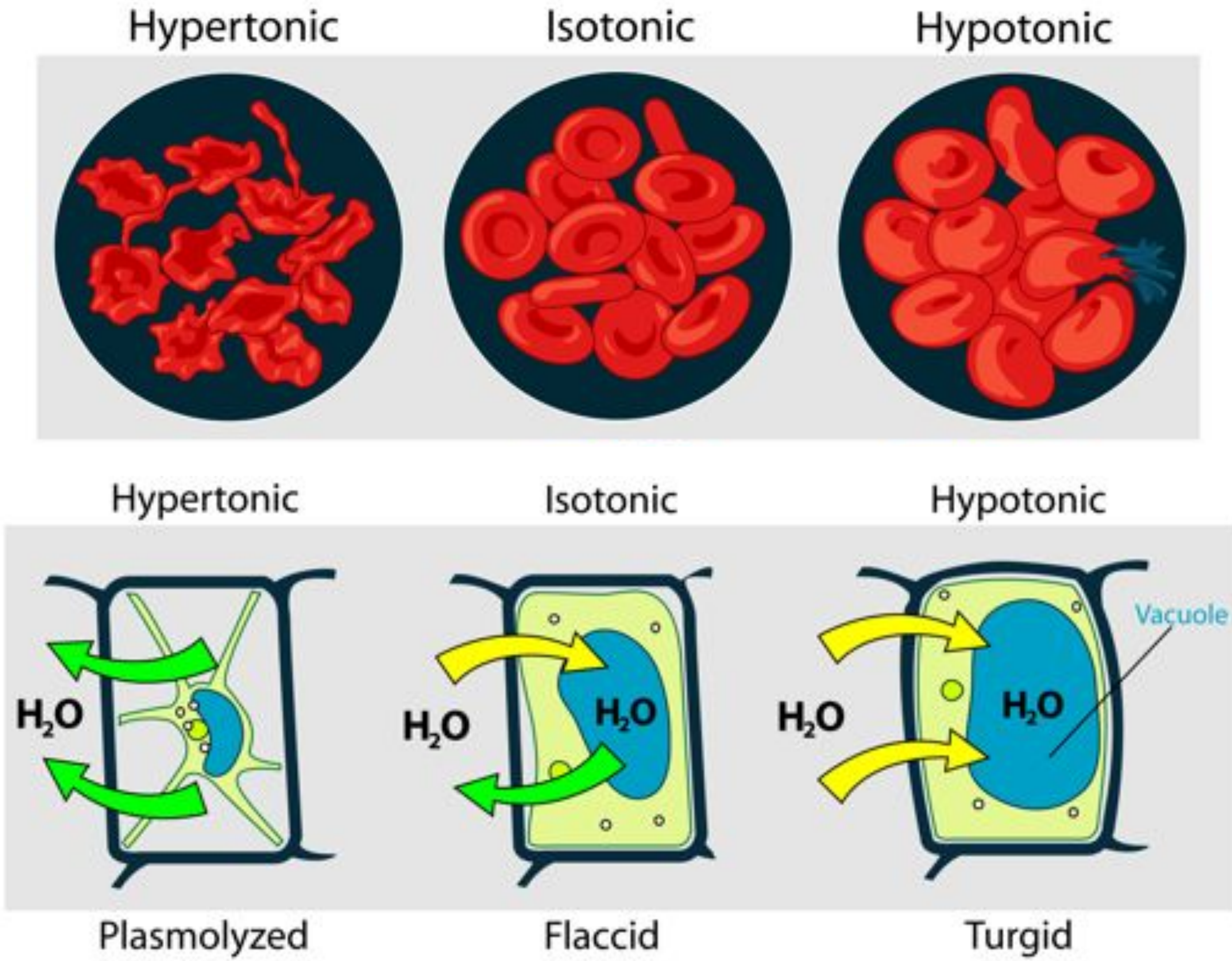
Tonicity effects cell physiology.

Solute moves from hypertonic to hypotonic solutions IF it is able to.

Solvent (water) moves from hypotonic to hypertonic solutions.



Different cell types are adapted to different tonicity relationships.



2.5: Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes.

3. MATH SKILLS- WATER POTENTIAL AND SOLUTE POTENTIAL

What You Have To Do

Be able to calculate water potential and use it to determine how likely it is that water will move in to or out of a cell.

Water Potential (Ψ): A measurement of how likely it is that water will move in/out of a solution. Pure water is assigned a potential of 0.

The more negative the potential, the more likely water will move in to the area.

Ψ

$$\Psi = \Psi_p + \Psi_s$$

Ψ_p = pressure potential (external force).
Ψ_s = solute potential (tonicity).

The units for Ψ are pressure units. Typically bars (aka torr, mmHg)

If a system is at amospheric pressure, Ψ_p is 0

Solute Potential

$$\Psi_s = -iCRT$$

- i = ionization constant for the solute (1.0 for sucrose, 2.0 for NaCl, etc.)
- C = molar concentration of the solute
- R= pressure constant 0.0831 liter bars/ mole K
- T= temperature in Kelvin (C + 273)

Sample Problem

Determine which of the following solutions will gain the most water if placed in to a sample of pure water in a piece of dialysis tubing at the temperature indicated:

Solution:	Solute:	Tonicity:	Temperature
A	Sucrose	2M	298K
B	NaCl	1M	290K
C	Glucose	1M	300K

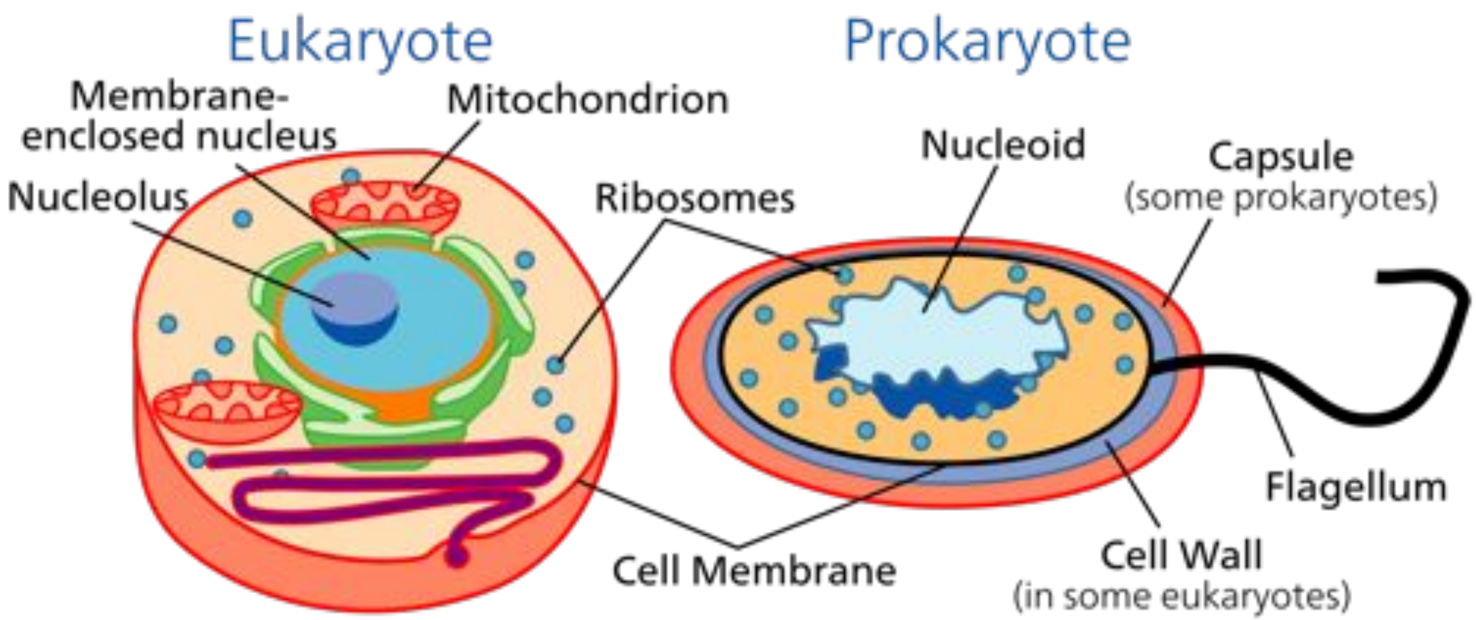
2.6: Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.

1. CELLULAR COMPARTMENTALIZATION

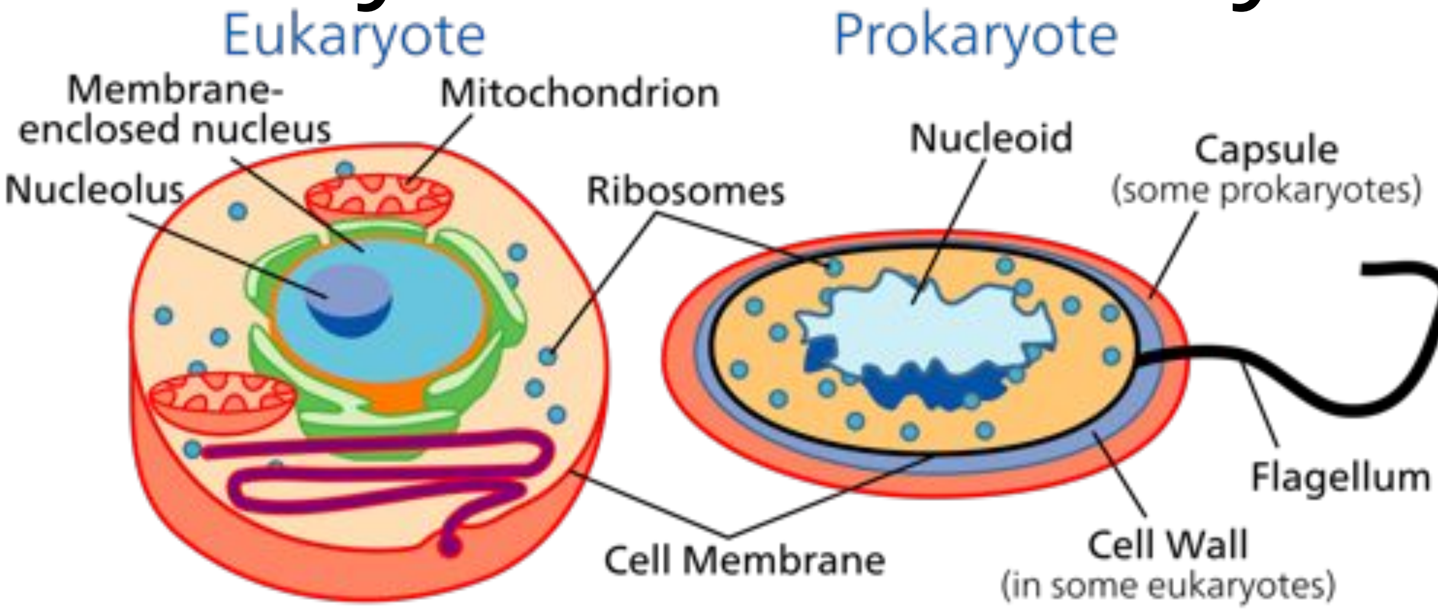
Cells are Compartmentalized

Compartmentalization allows for increased control and efficiency of cellular processes.

Different areas of the cell can be specialized for different metabolic tasks.



Prokaryotes and Eukaryotes



The major dividing line in cellular organization.

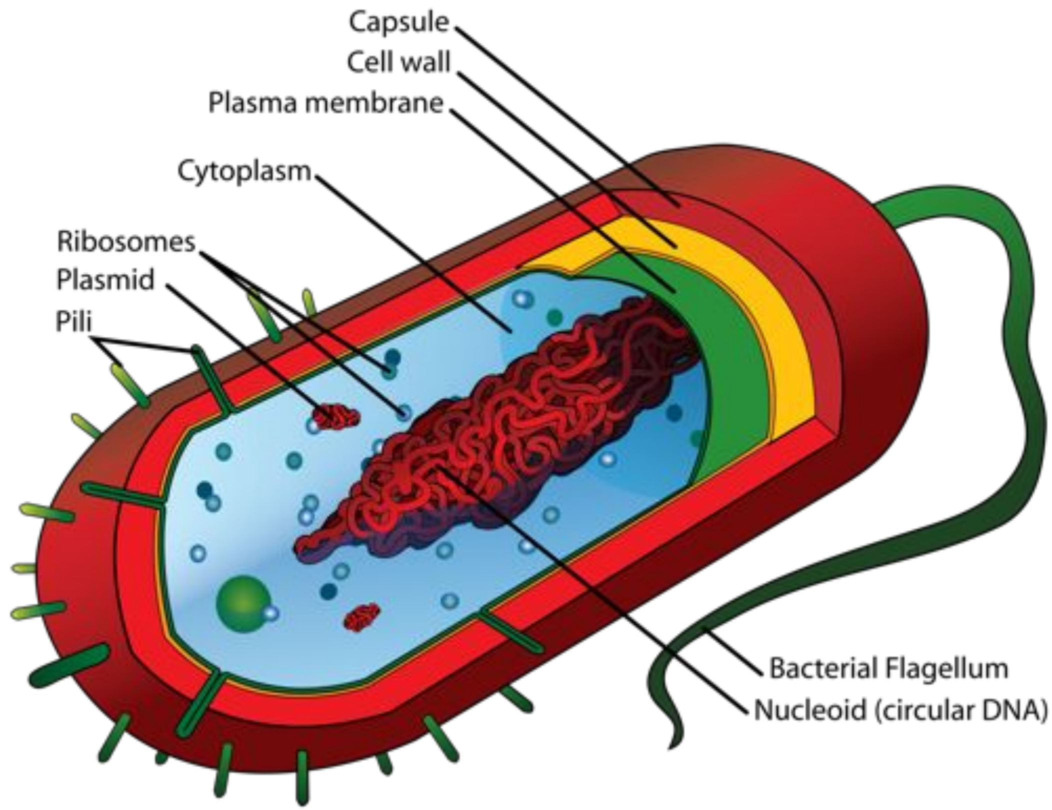
Prokaryotes: No internal compartments.

Eukaryotes: Many internal compartments ("**organelles**")

Prokaryotes

AKA “**Bacteria**”.

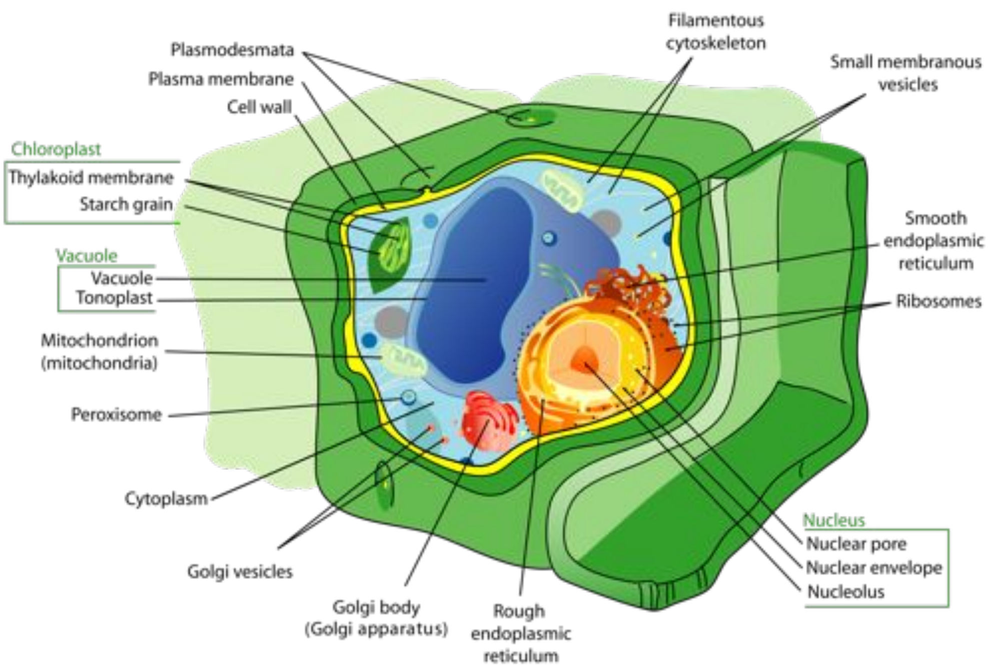
The vast majority of life on Earth. Always unicellular, contain less DNA, and generally smaller than Eukaryotes.

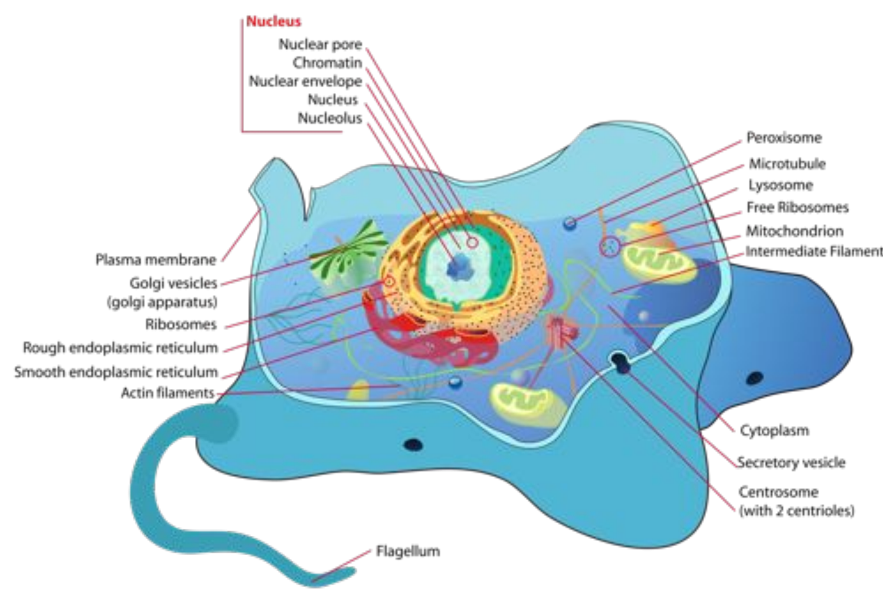


Eukaryotes

Protists, Plants, Fungi, and Animals.

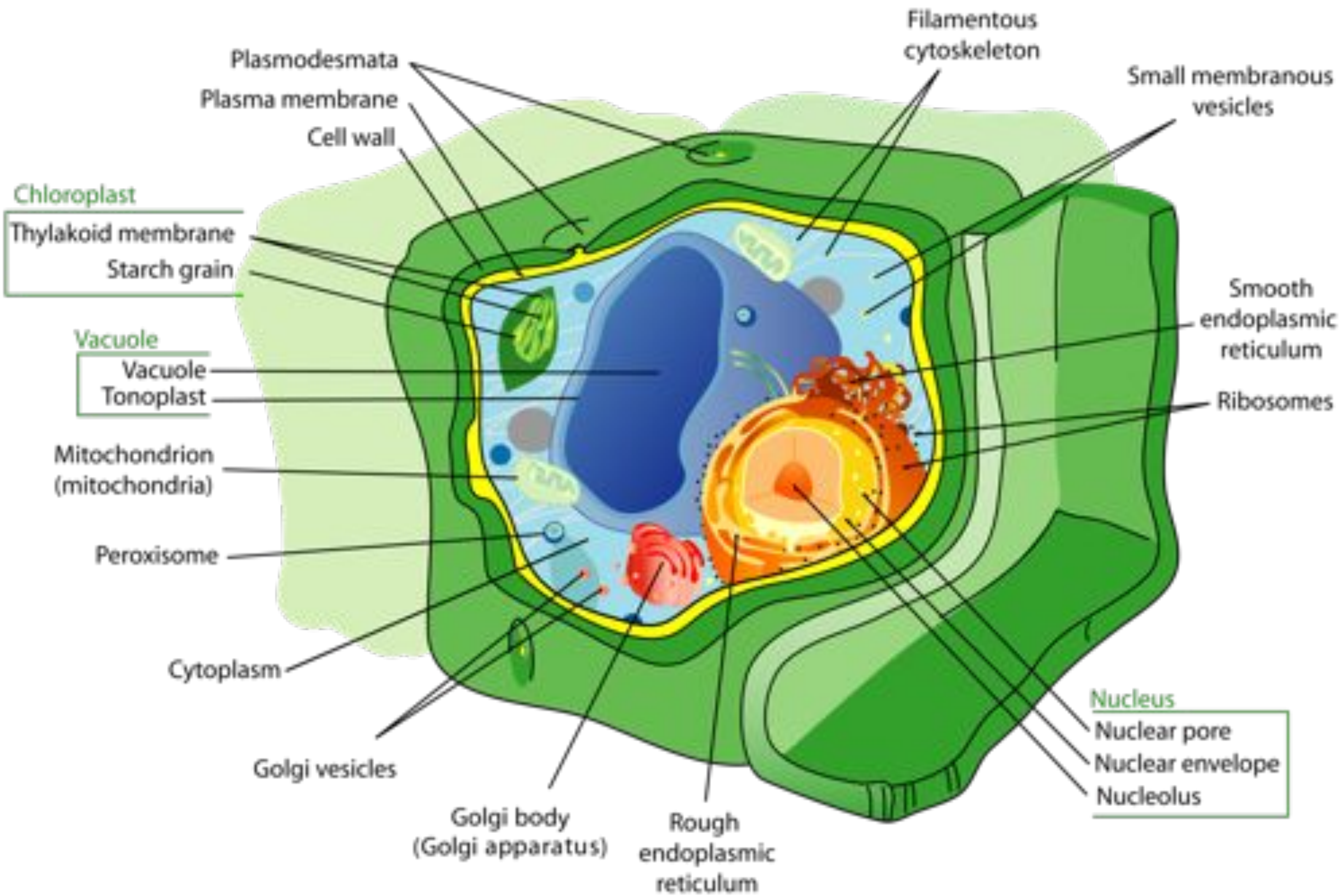
Unicellular and multicellular. Generally larger cells than prokaryotes.





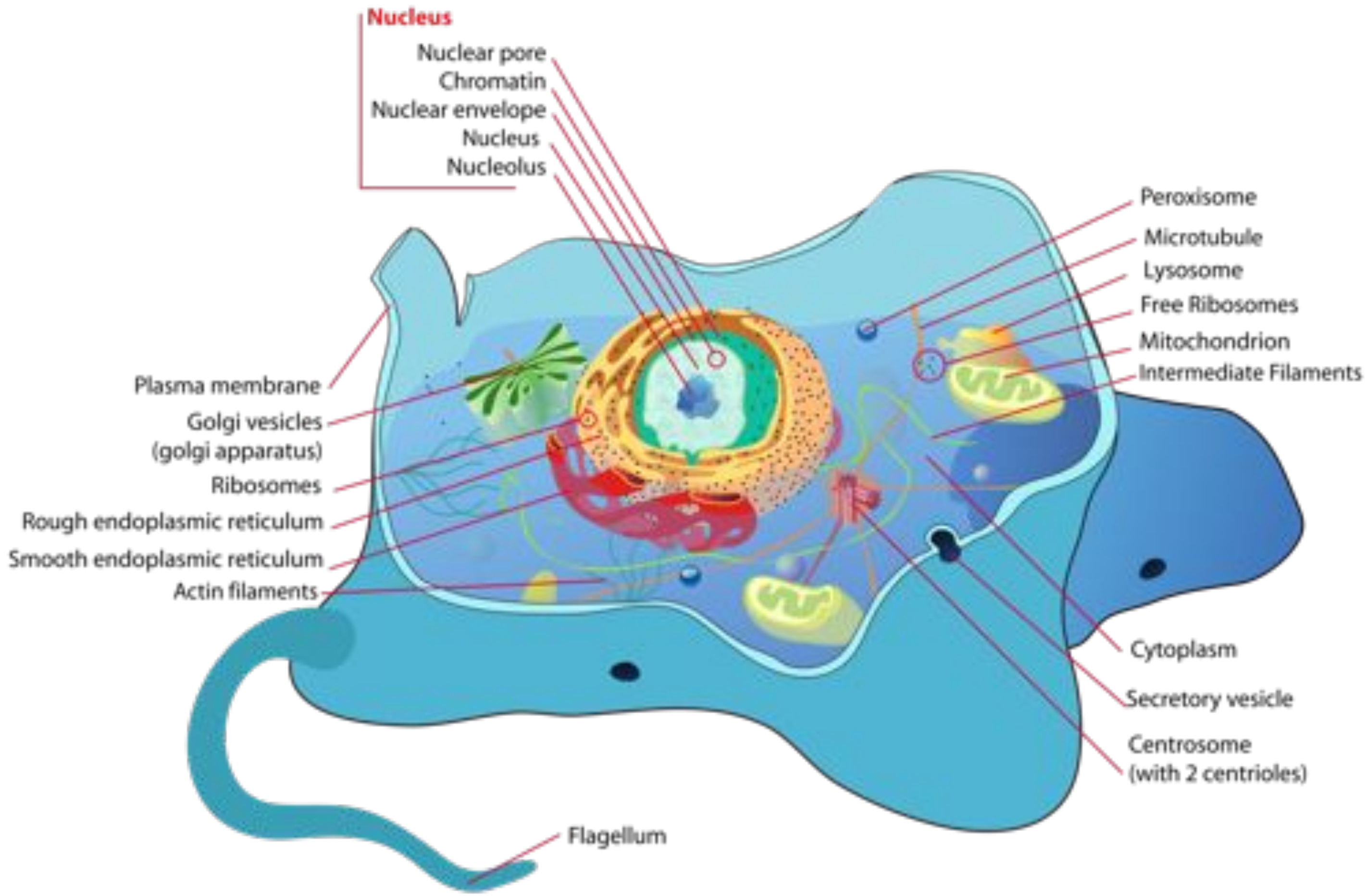
“Plant-Like” Eukaryotes

Adapted for **autotrophic nutrition**.
Plants and photosynthetic protists.



“Animal-Like” Eukaryotes

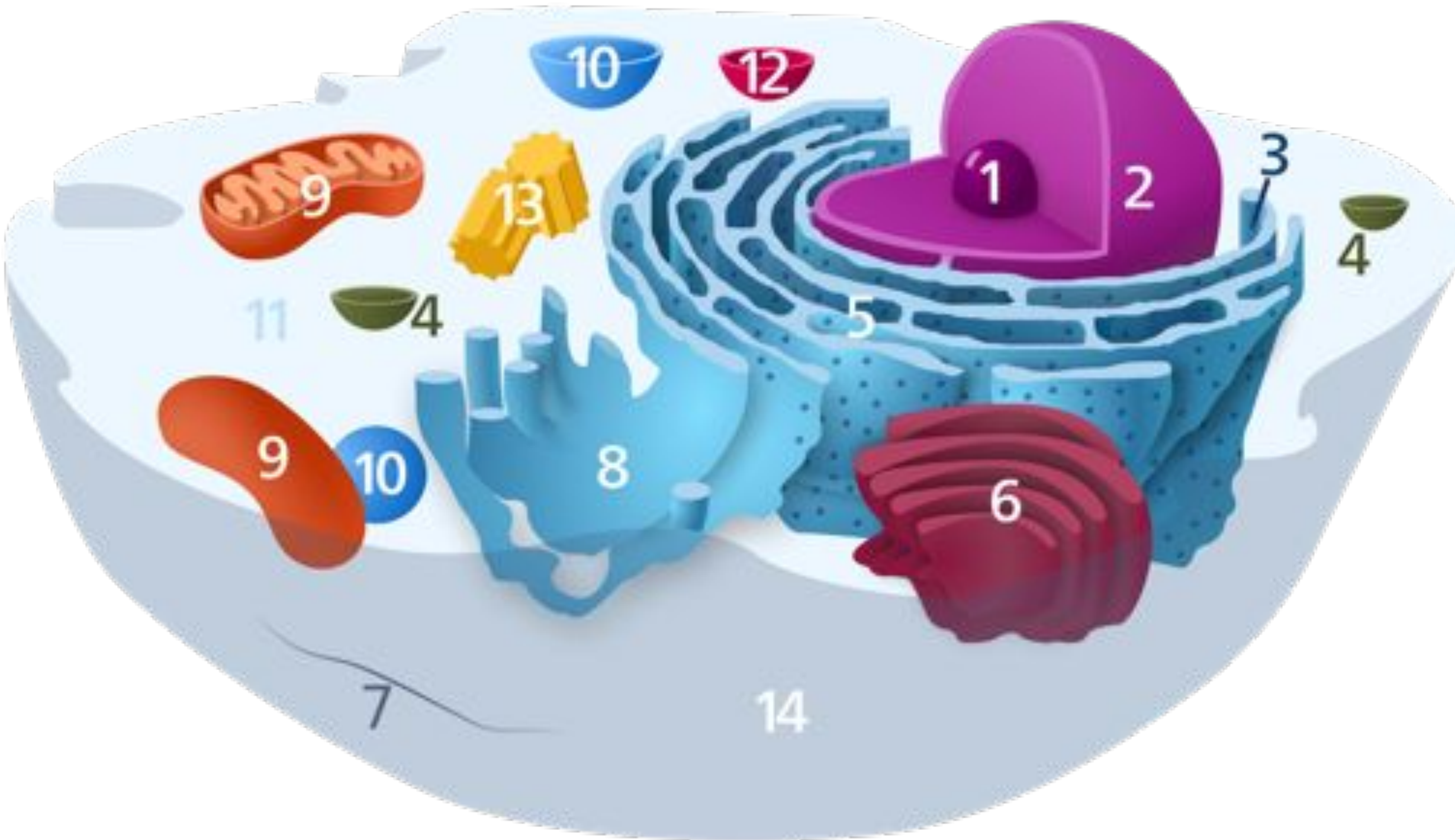
Adapted for **heterotrophic nutrition**.
Animals, Fungi, and heterotrophic Protists.



2.6: Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.

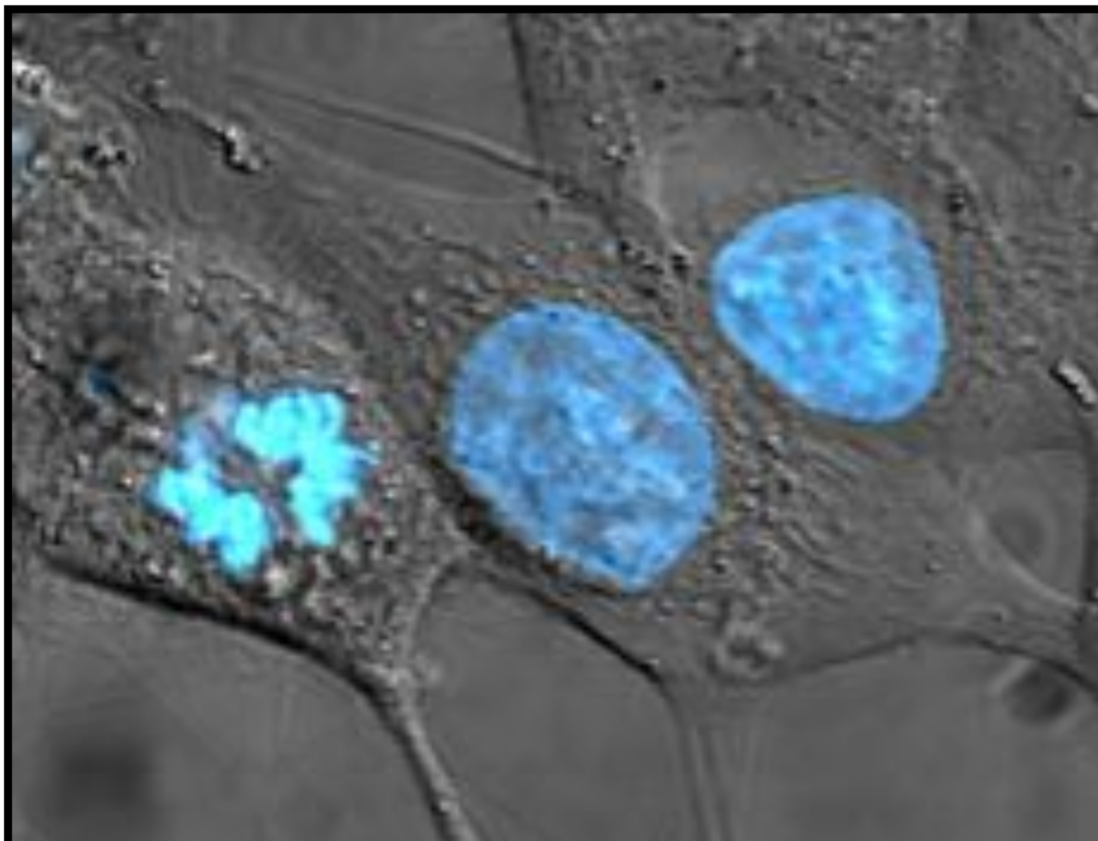
2. MAJOR EUKARYOTIC ORGANELLES

Organelles Increase Efficiency

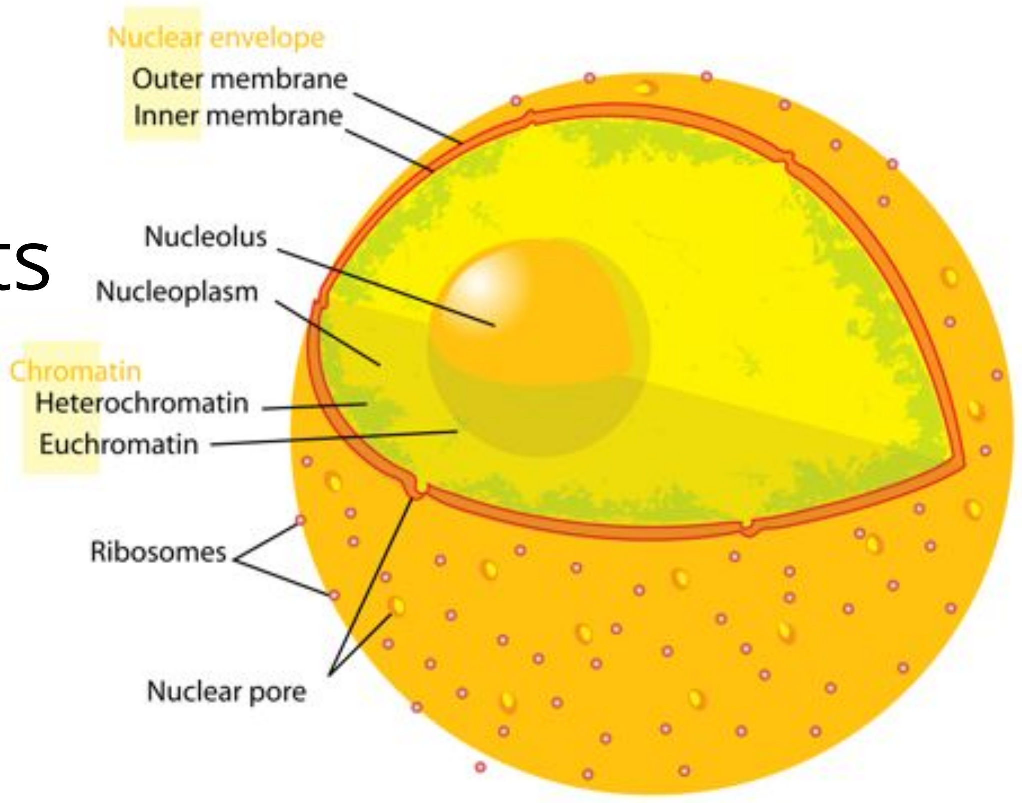


The Nuclear Membrane

Porous membrane that separates the cell's **DNA genome** from the rest of the cellular environment.



The nuclear membrane is structured to allow its function in storing cellular information and allowing information to flow from the nucleus to ribosomes in the cytoplasm.

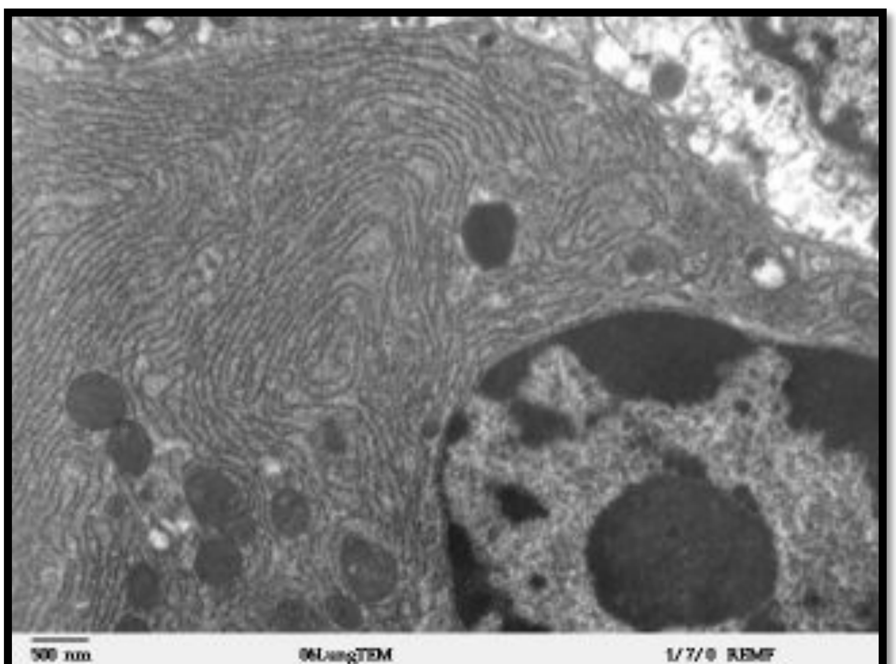


Endoplasmic Reticulum

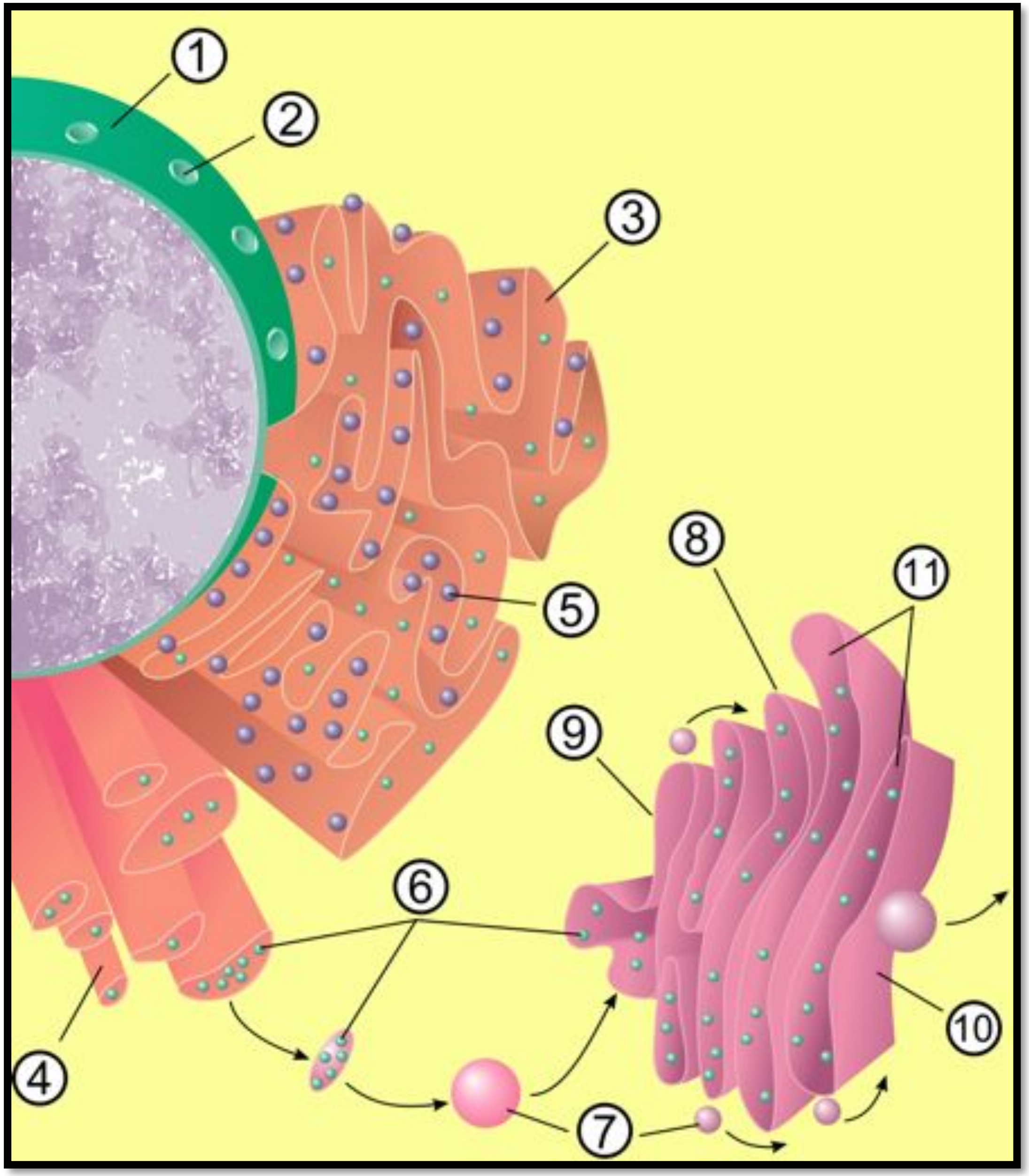
Membranous channels that run throughout the cell. Produce membrane and transport proteins.

Rough ER: covered in “**bound**” ribosomes.

Smooth ER: not covered in ribosomes

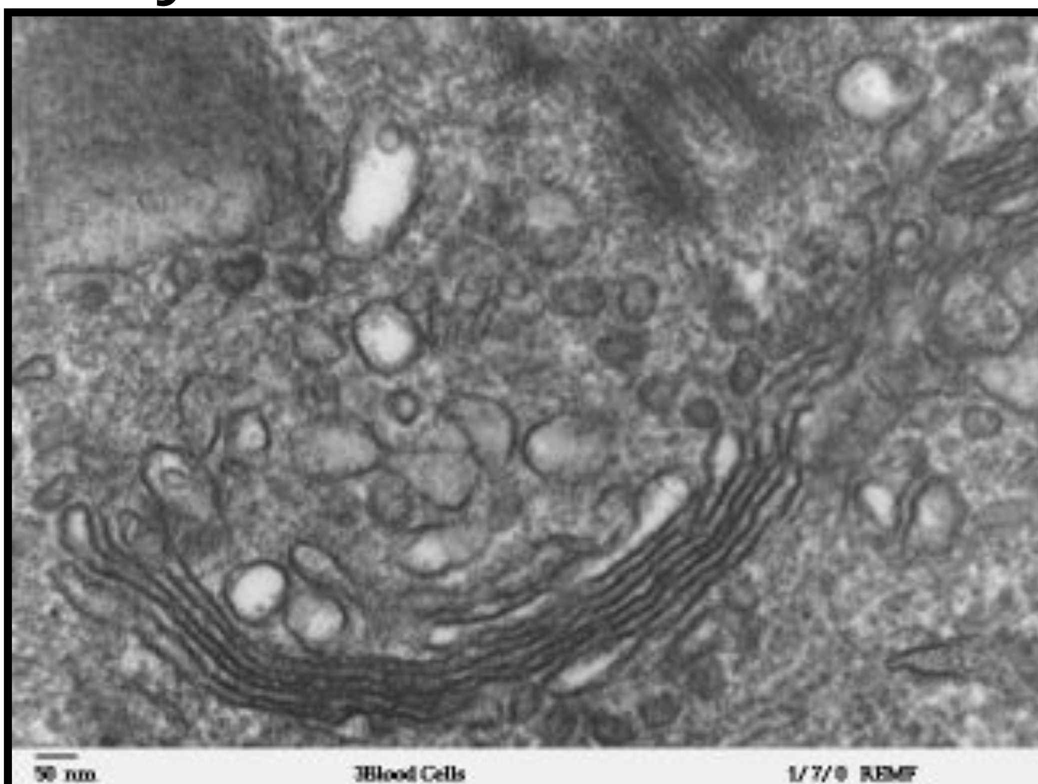


The ER (#3, #4) is part of the cell's "**endomembrane system**", which is involved in production and transport of membrane and membrane proteins.

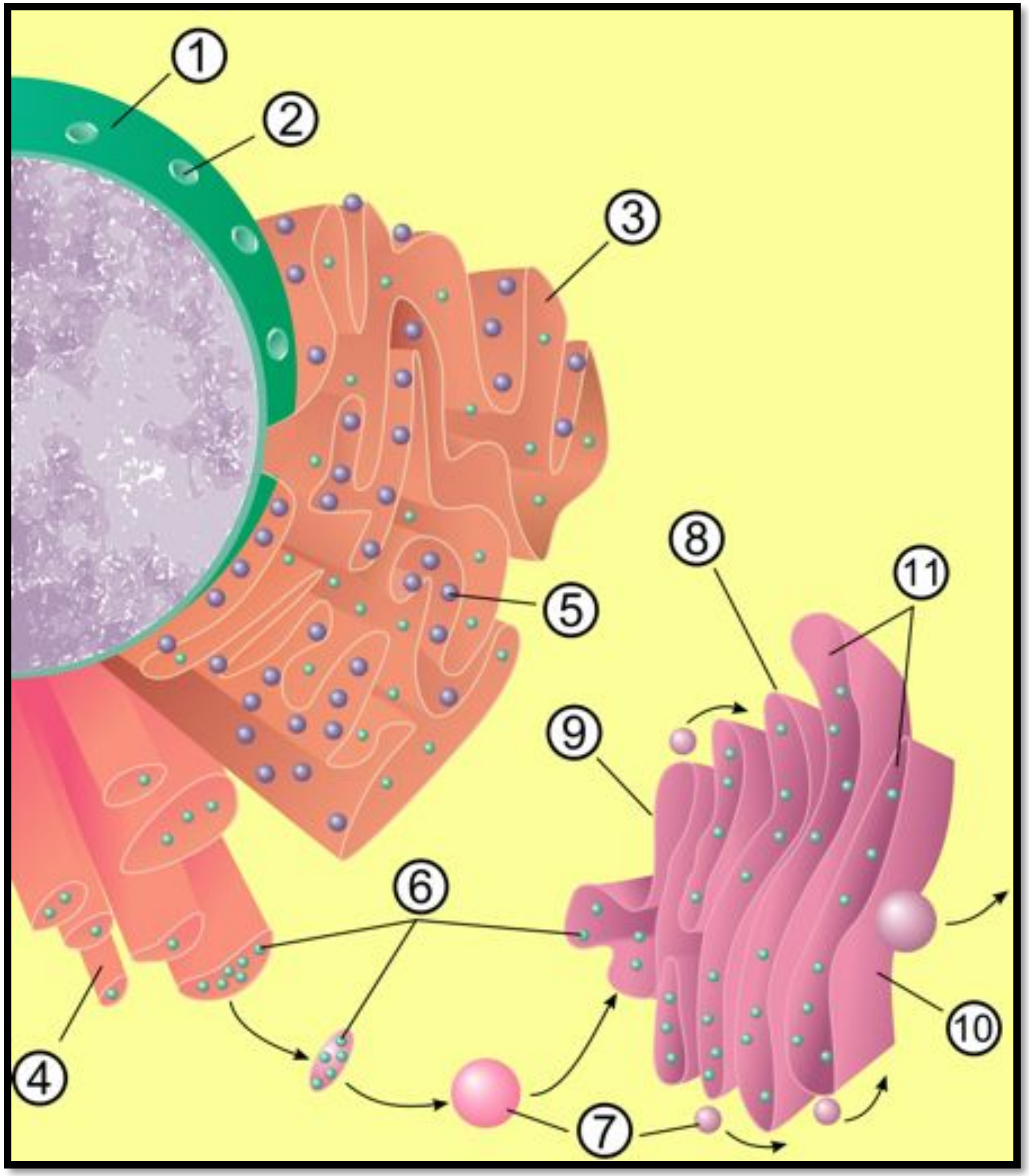


Golgi Apparatus

A series of flattened membranous compartments that receive material from the ER, and modify it before targeting it for delivery to other areas of the cell.



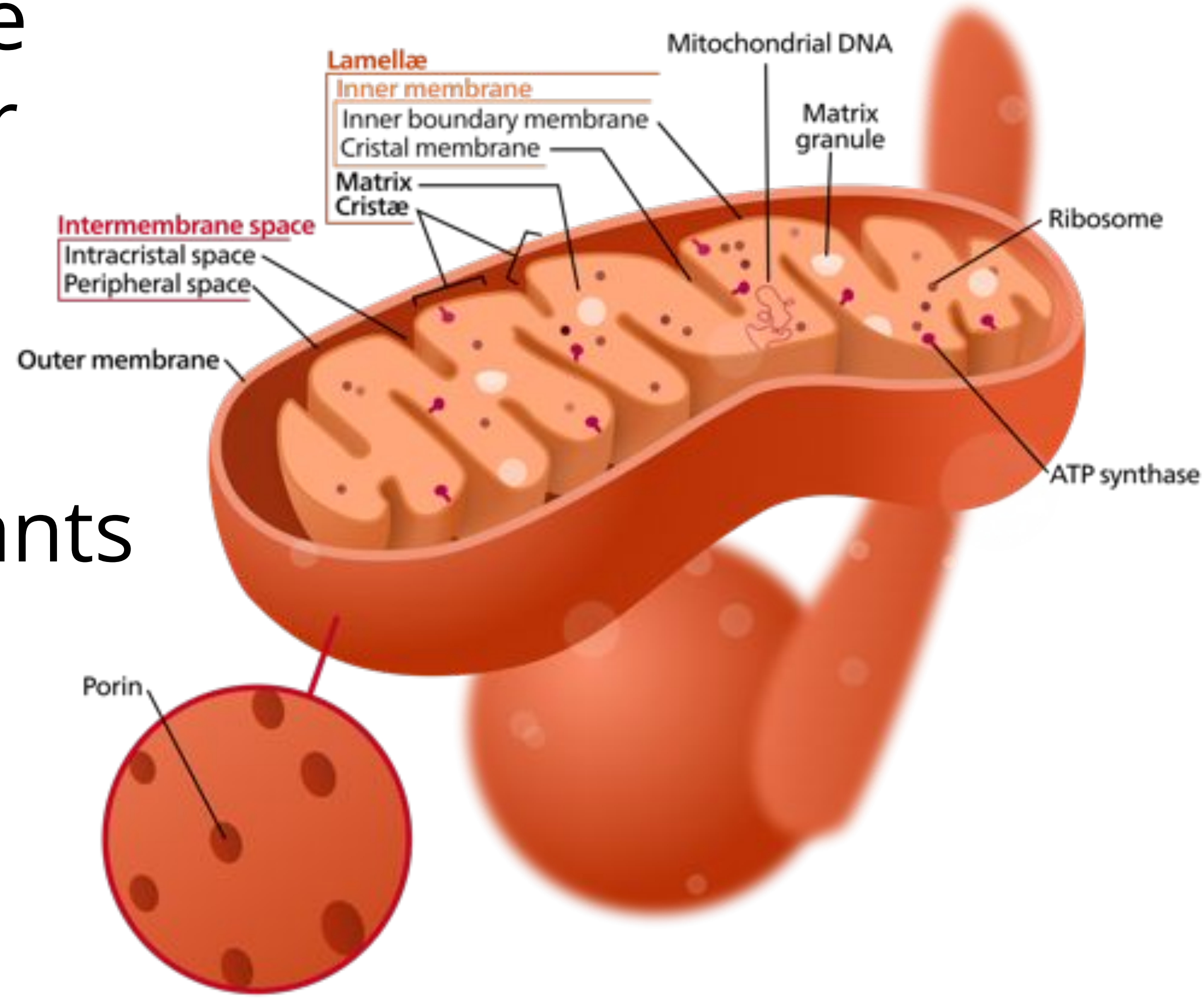
The Golgi Apparatus (#9 - #11) is also a major part of the endomembrane system, receiving material from the endoplasmic reticulum before sending it elsewhere in the cell.



Mitochondria

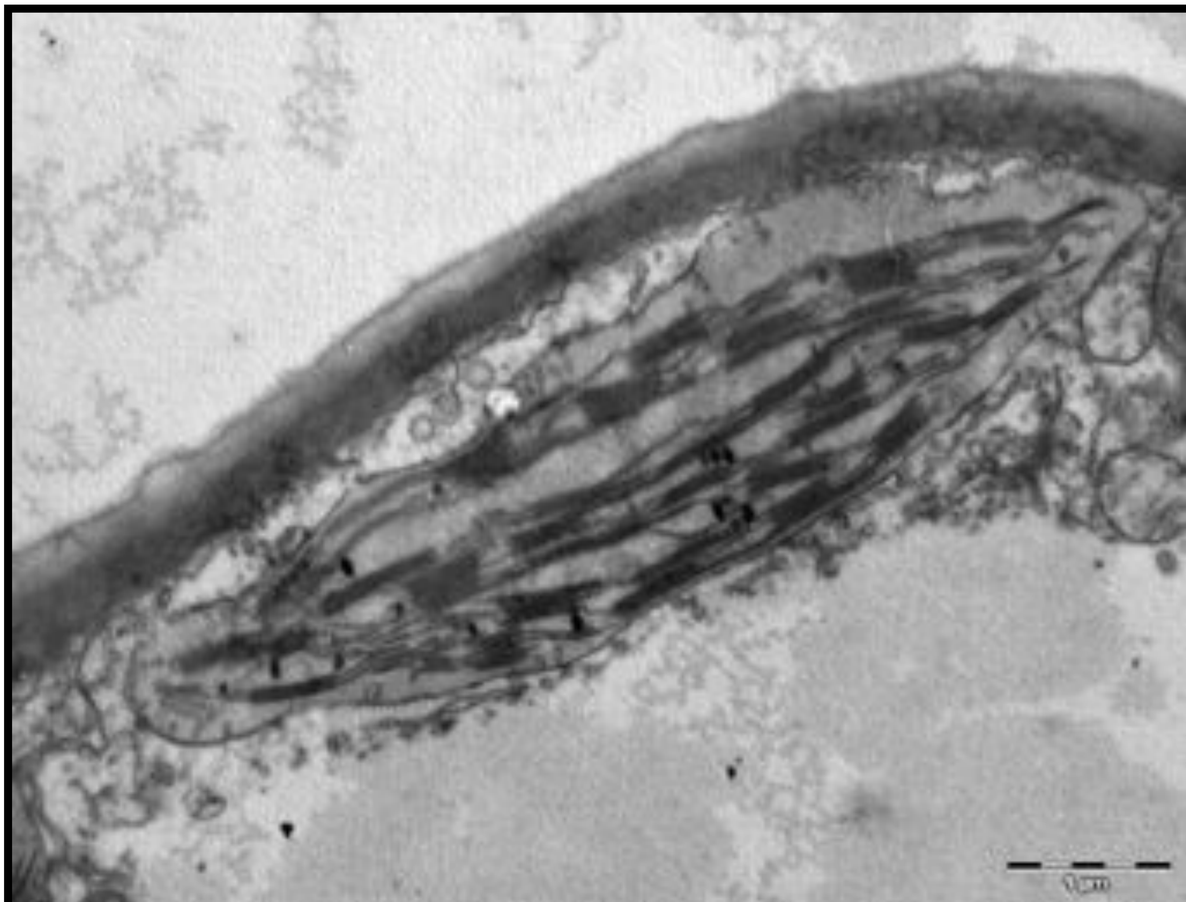
The site of **Aerobic Cellular Respiration**. Double membrane. Highly folded inner membrane (a surface area adaptation)

Mitochondria are adapted for their role in cellular metabolism and also posses structural remnants of their endosymbiotic origin

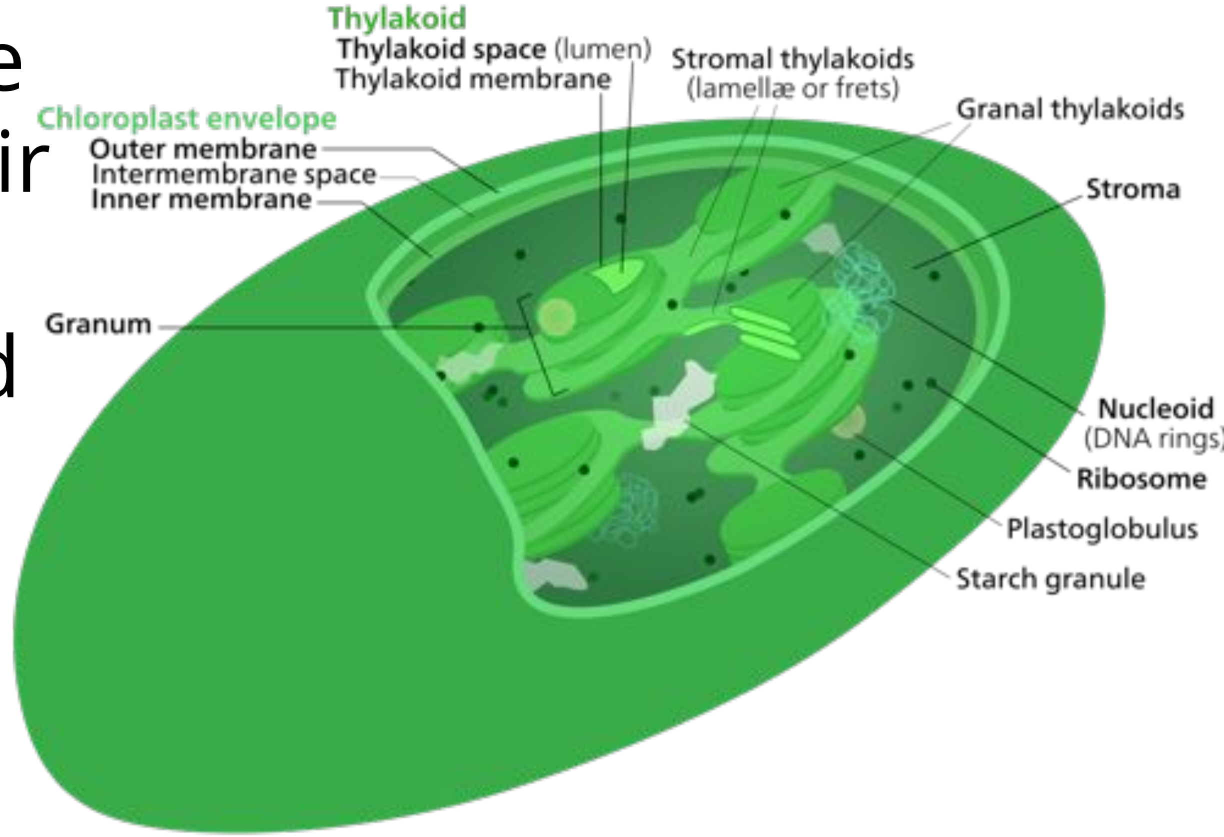


Chloroplasts

The site of **Photosynthesis**. Double membrane. Inner membrane is stacked (a surface area adaptation)



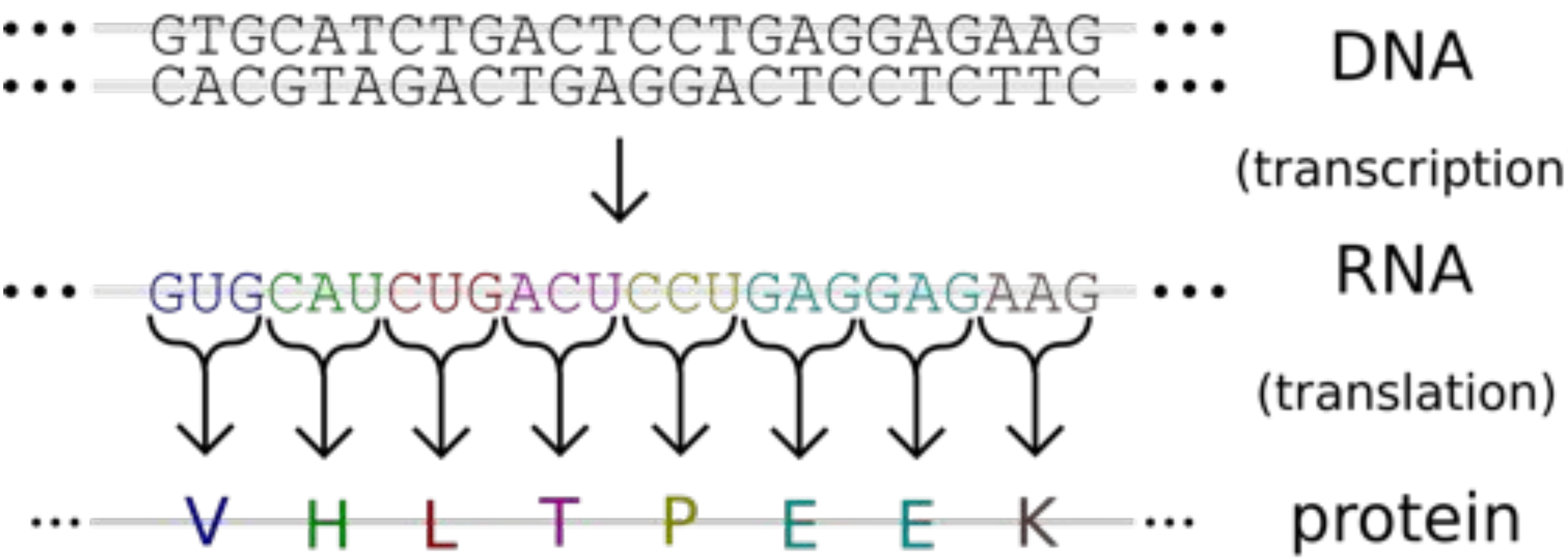
Chloroplasts are adapted for their role in cellular metabolism and also posses structural remnants of their endosymbiotic origin



2.7: The structure and function of subcellular components, and their interactions, provide essential cellular processes.

1. ORGANELLE STRUCTURE AND FUNCTION- INFORMATION PROCESSING

Cellular Information Flow



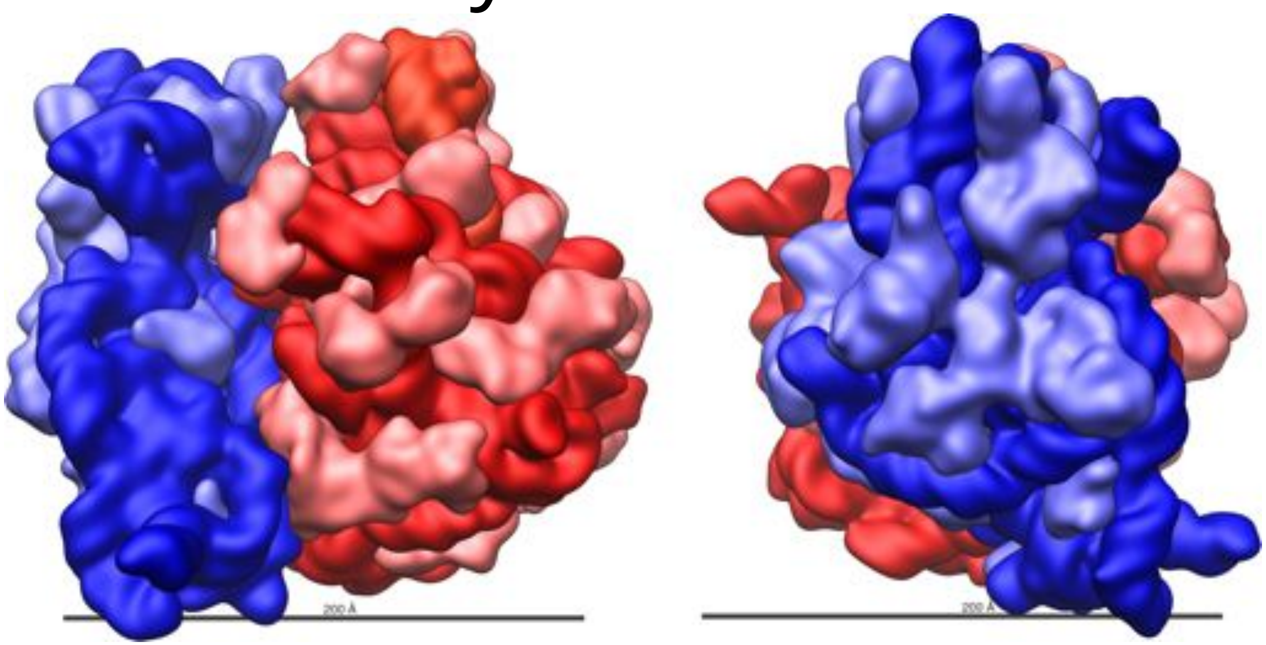
A change in DNA sequence can affect all levels of organism function.

Ribosomes

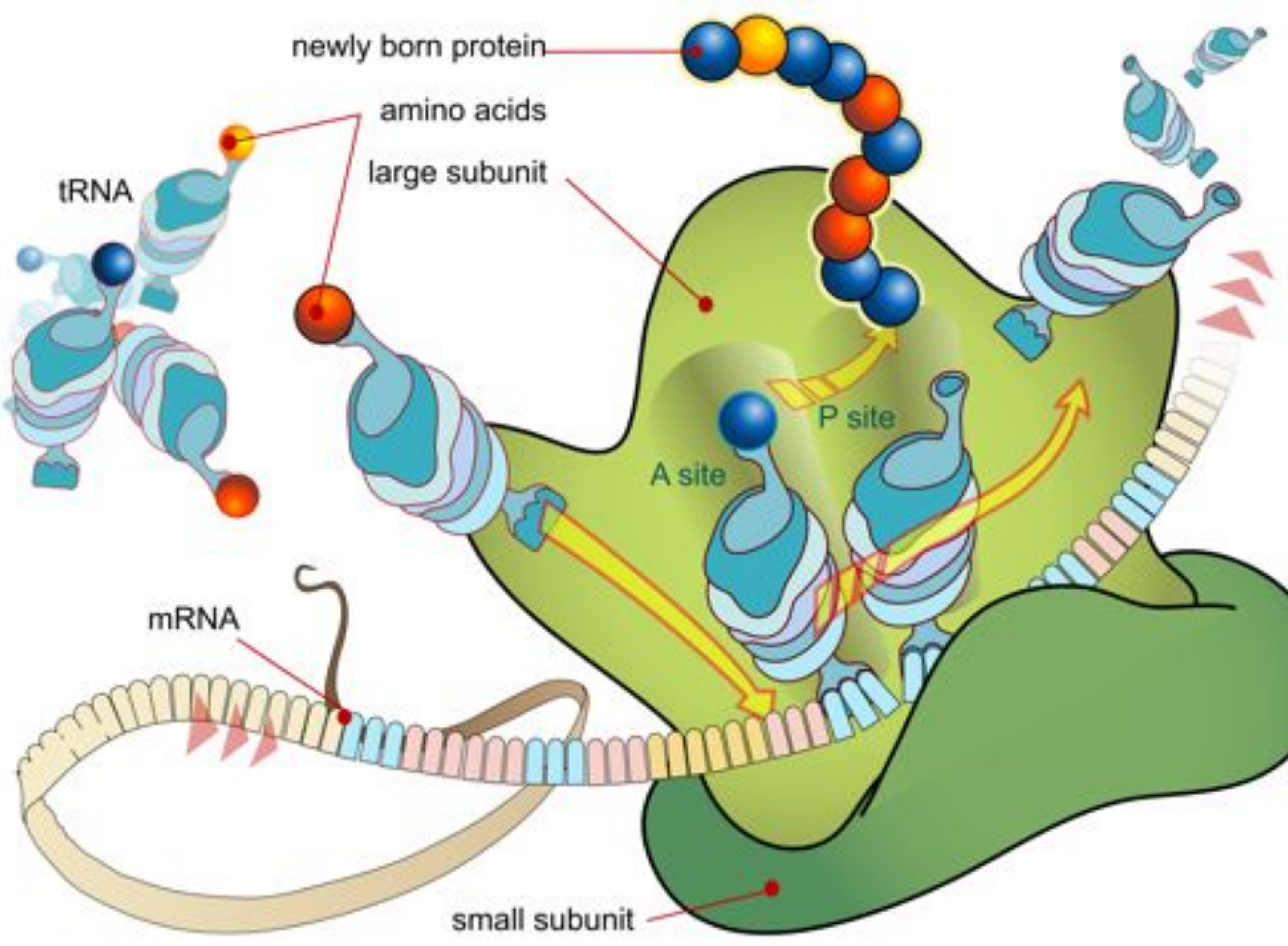
Universal in all cells.

Two subunits made of RNA and protein.

Exist "**free**" in cytoplasm, and "**bound**" to the ER in eukaryotes.



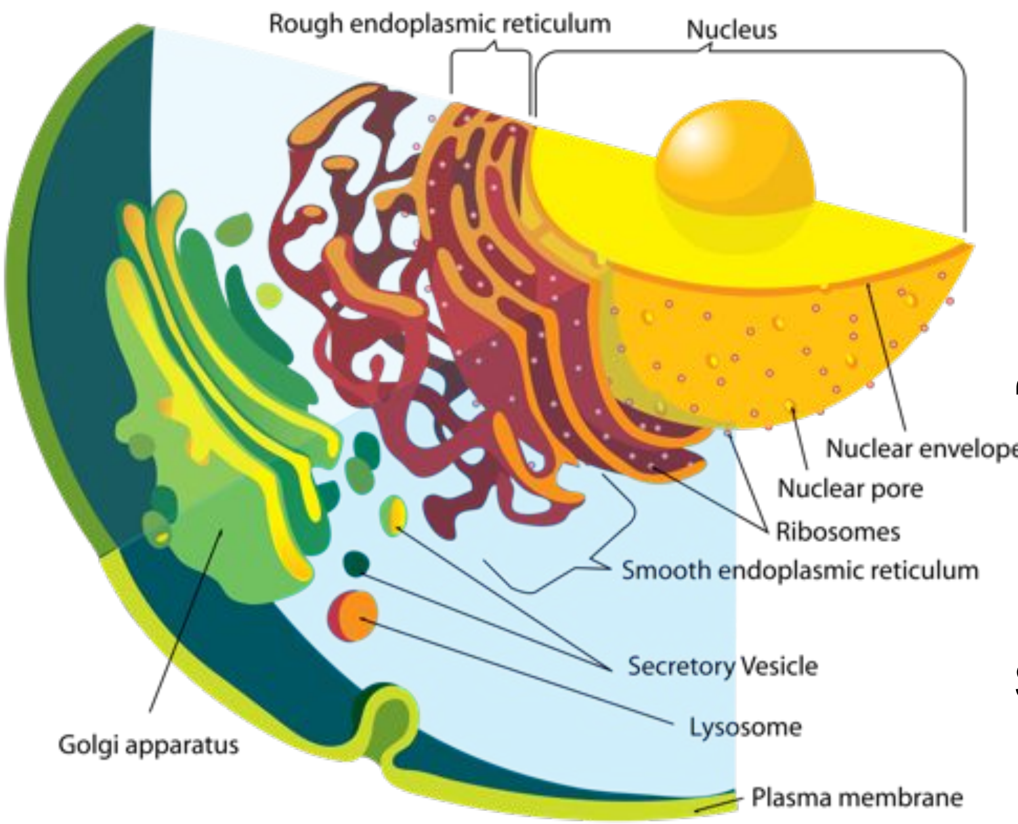
Ribosomes convert nucleic acid information into polypeptide chains



The Endomembrane System

The flow of information from the nucleus to proteins.

Nucleus → ER → Golgi → Final Destination



Note: Cytoplasmic proteins are made by “free” ribosomes and may not move into the ER/ endomembrane system.

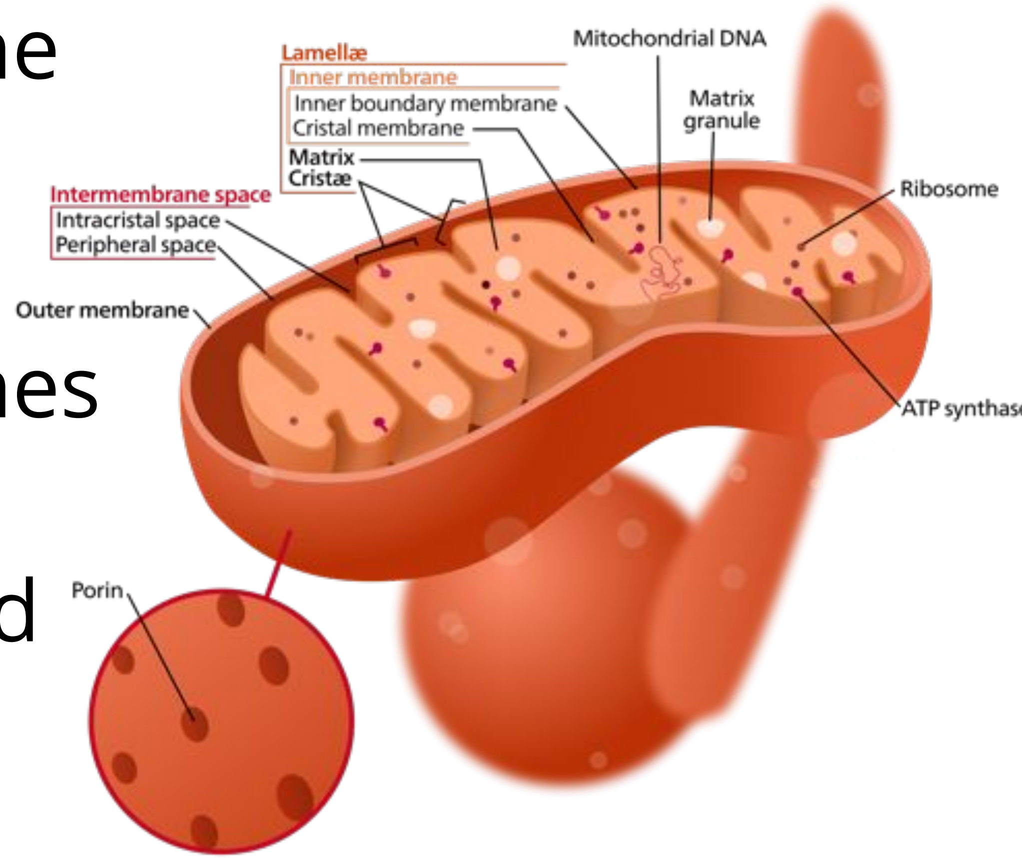
2.7: The structure and function of subcellular components, and their interactions, provide essential cellular processes.

2. ORGANELLE STRUCTURE AND FUNCTION- MATTER AND ENERGY PROCESSING

Mitochondrial Anatomy

A double membrane which allows for separation of different processes.

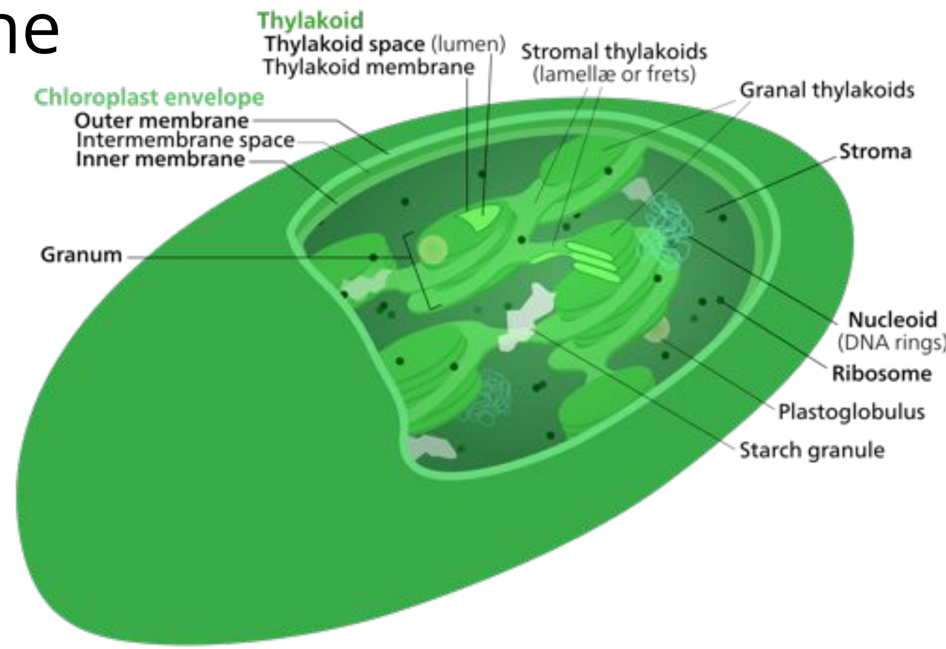
The inner membrane (the "**cristae**") contains many copies of the enzymes needed to produce ATP, with maximized surface area.



Chloroplast Anatomy

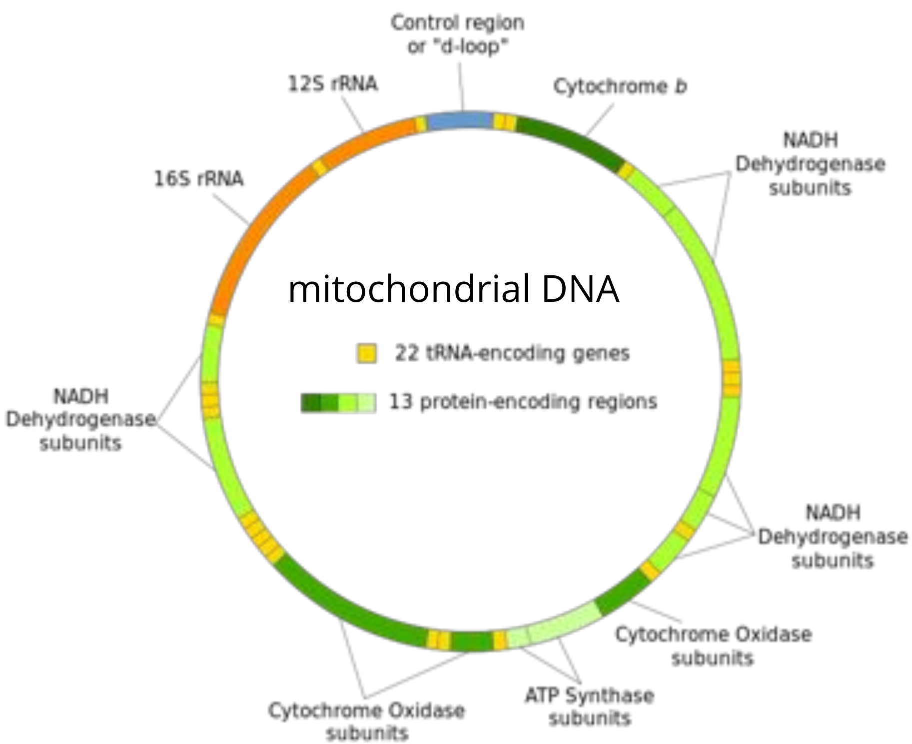
A double outer membrane with inner membranous stacks called “**thylakoids**”

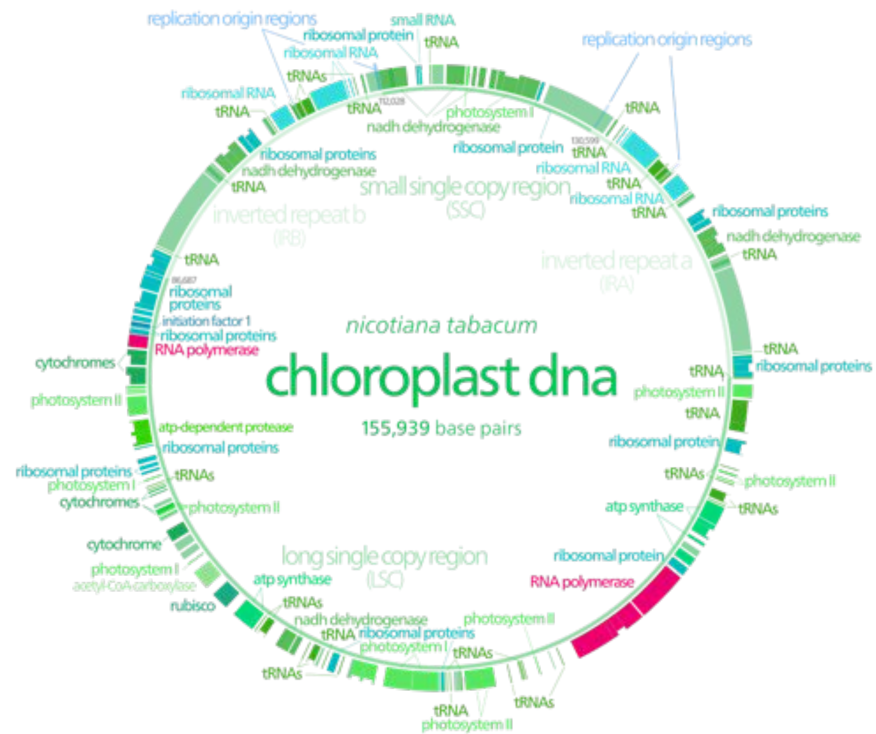
The thylakoid membrane contains many copies of the enzymes and chlorophyll needed to produce chemical energy from solar radiation.



The stroma contains the enzymes needed to produce organic compounds

Mitochondria and chloroplasts contain their own circular DNA, and their own ribosomes.

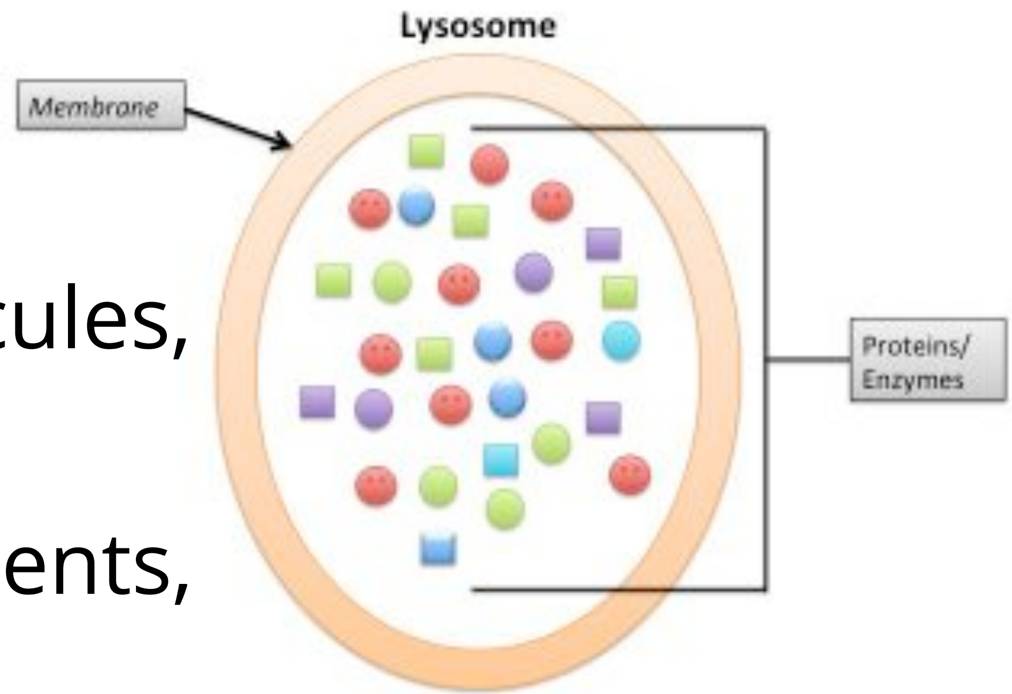




Lysosomes

Membrane-enclosed sacs that contain collections of digestive, **hydrolytic** enzymes.

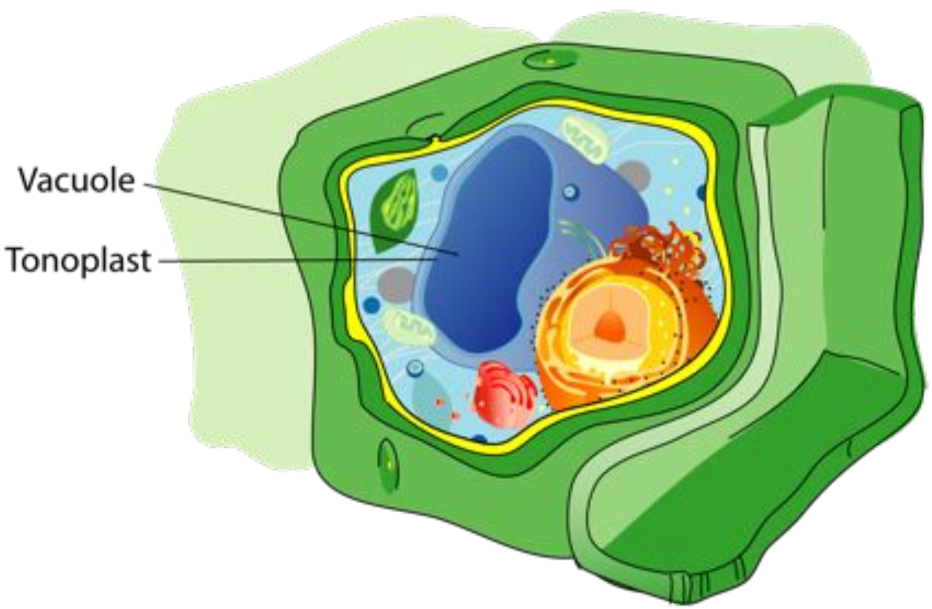
Have roles in digestion of molecules, recycling a cell's damaged components, and programmed cell death.

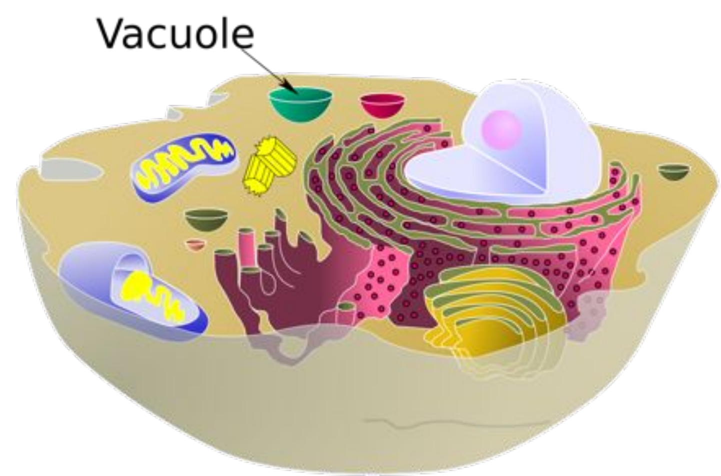


Vacuoles

A membrane-bound sac that stores material.

Plants have a large central vacuole that increases the cells surface area: volume ratio by decreasing the active volume





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