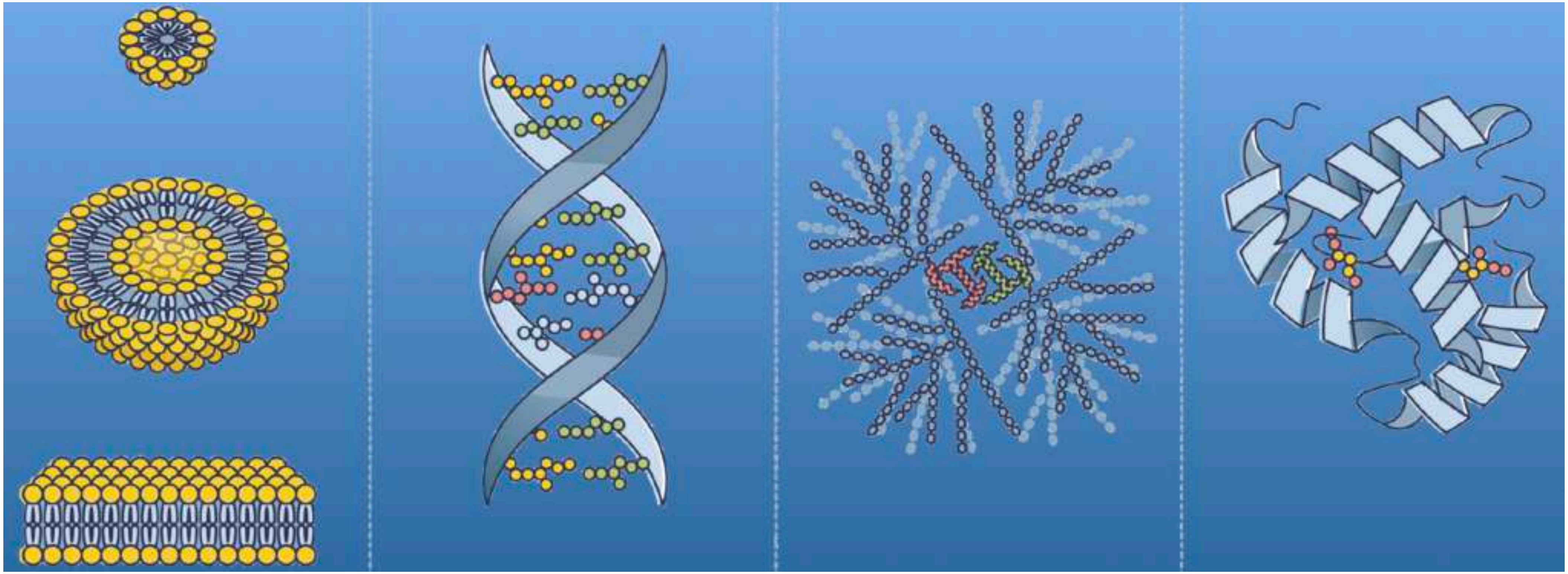
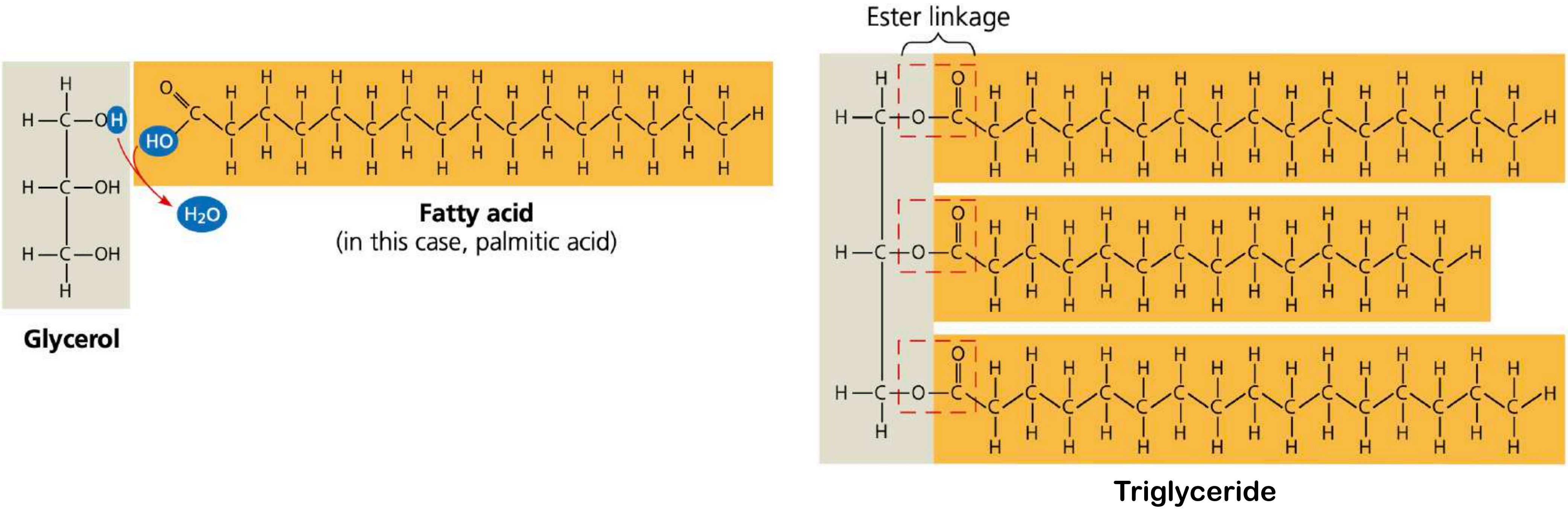
The molecular logic of life

Small molecules (building blocks) common to all organisms are ordered into unique macromolecules or polymers (biomolecules)



Lipids (Fat) | Nucleic Acids (DNA or RNA) | Carbohydrates (Sugars, Starches and Fibers) | Proteins

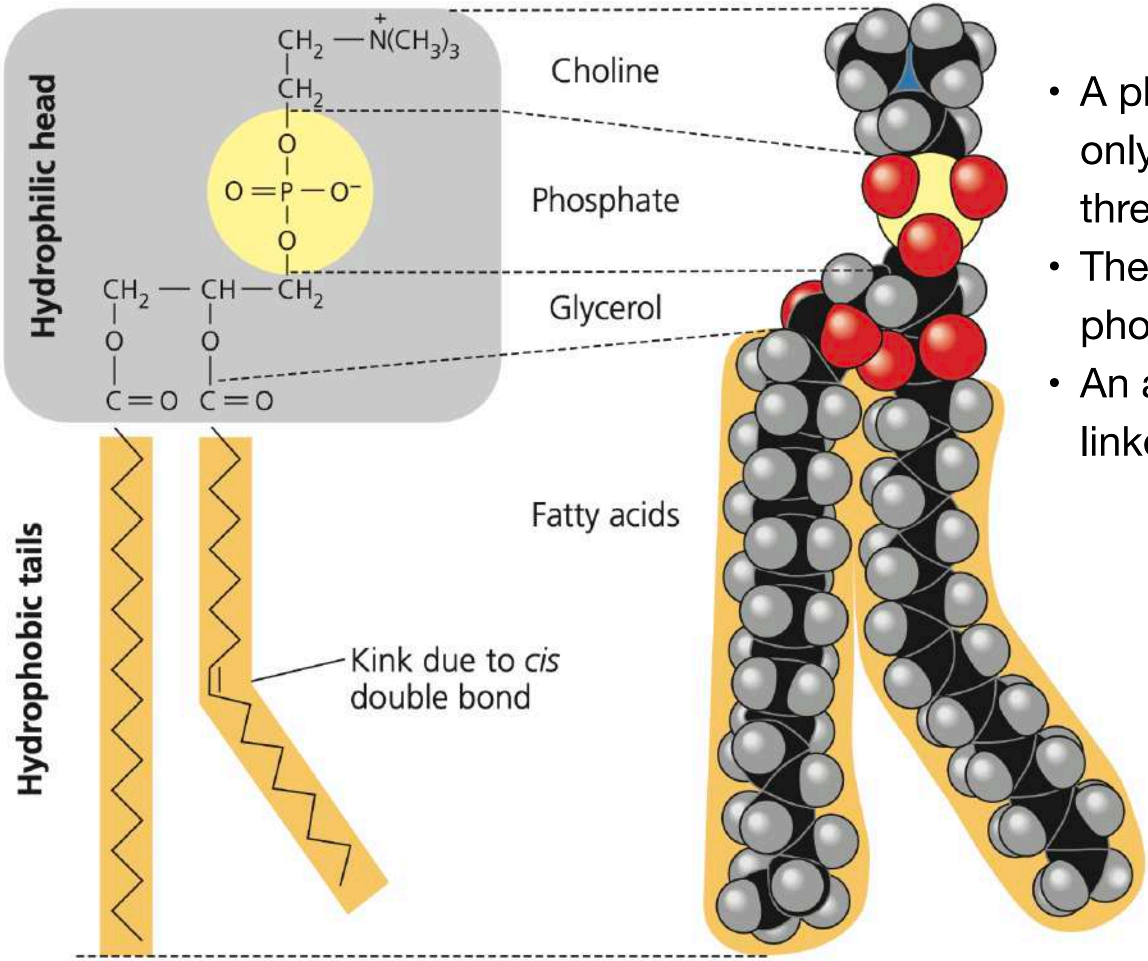
Lipids (fats)



- Not true polymers
- Large biomolecules assembled from two kinds of smaller molecules: glycerol and fatty acids
- Instead of glycerol, lipids can also have Sphingosine = sphingolipids
- One lipid molecule is three fatty acid molecules joined to glycerol by an ester linkage = Triacylglycerol or Triglyceride

Figure 5.9 of Campbell's Biology: a global approach

Phospholipids



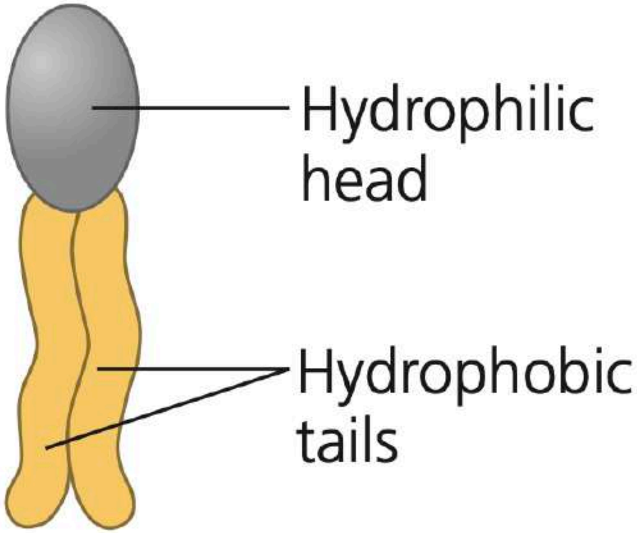
- A phospholipid is similar to a fat molecule but has only two fatty acids attached to glycerol instead of three
- The third hydroxyl group of glycerol is joined to a phosphate group
- An additional small charged or polar molecule is also linked to the phosphate group - e.g. choline

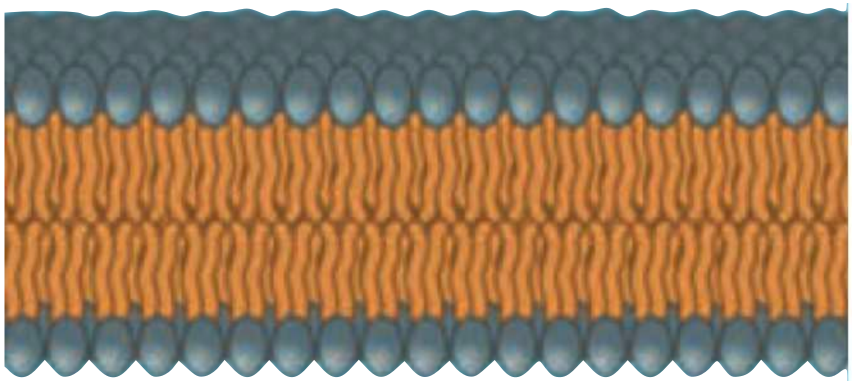
Phospholipids have a phosphate "head" and a lipid "tail"

- The "head" is hydrophilic and "tail" is hydrophobic
- Due to this property, when phospholipids are added to water, they self assemble into biomolecules

Figure 5.11 of Campbell's Biology: a global approach

What will phospholipid self-assembly in water look like?





These self-assembled structures are known as lipid bilayers
They are the “envelope” for enclosures known as “cells”

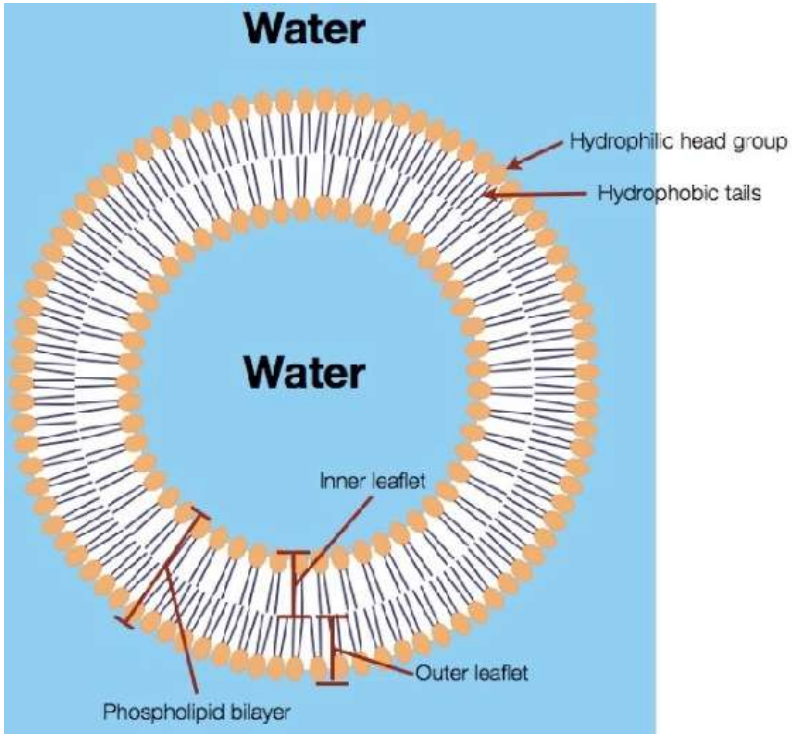
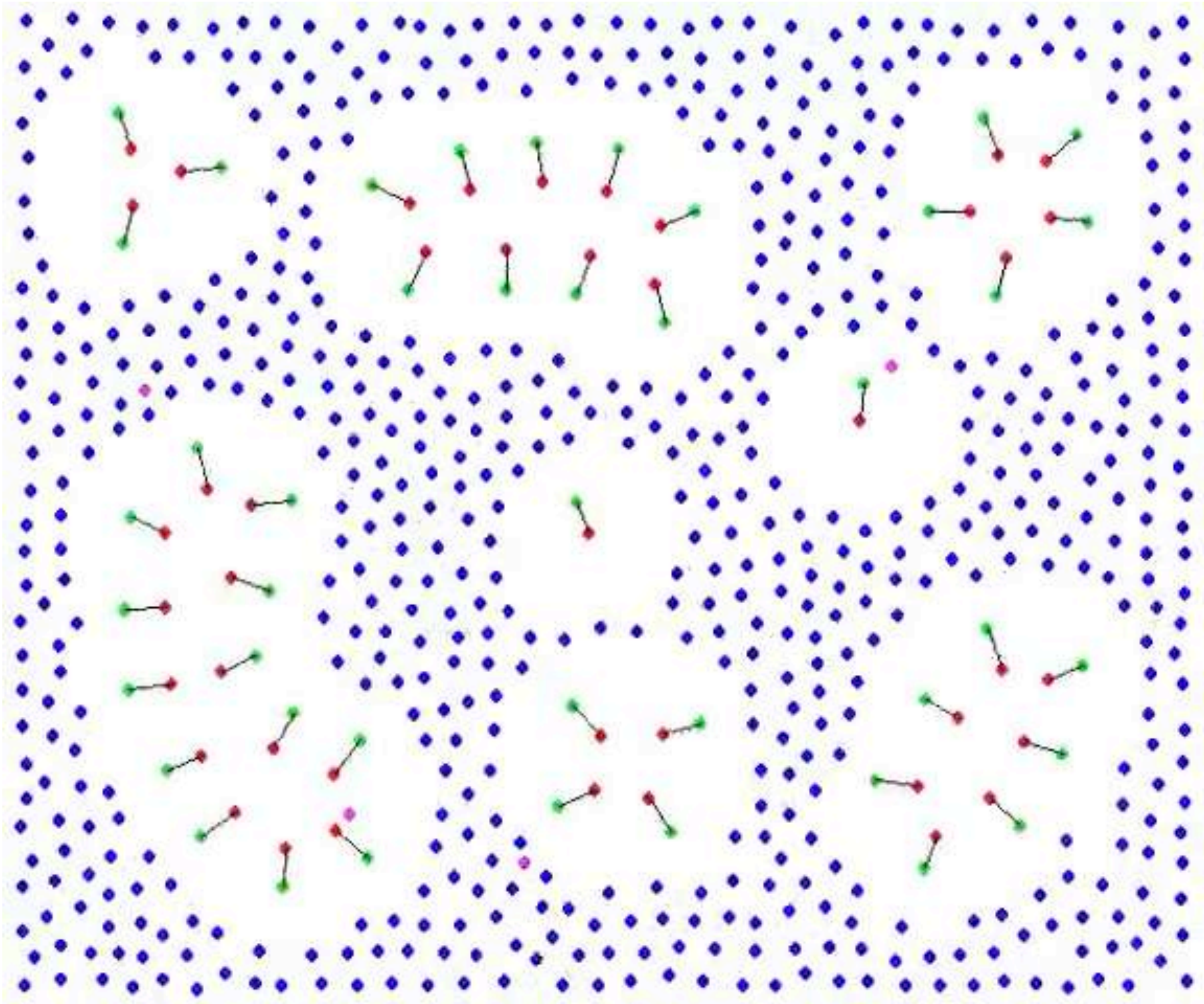


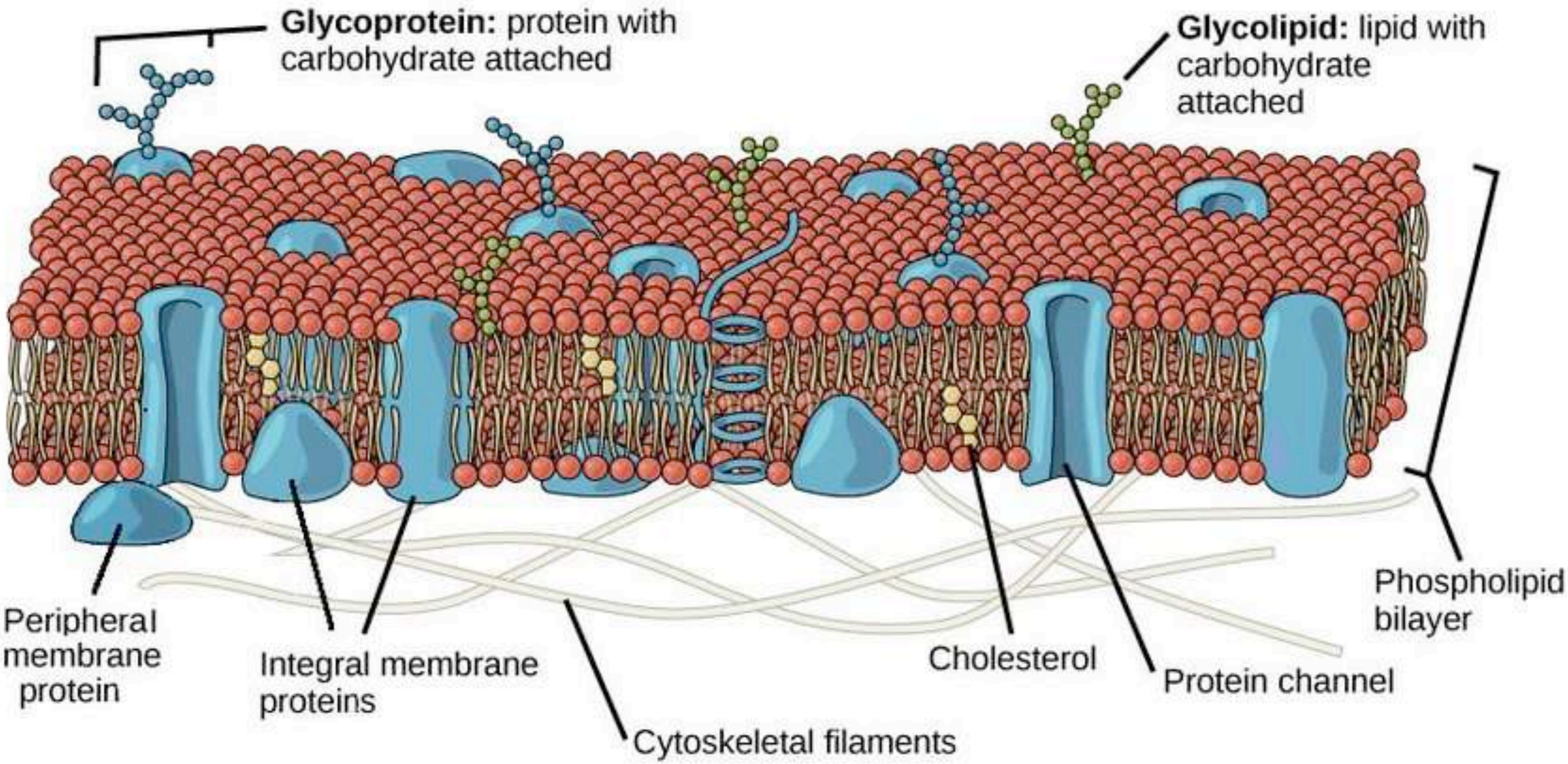
Figure 5.11 of Campbell’s Biology: a global approach

A 2D model of lipid bilayers self-assembling in water



Code for the animation: https://www.openprocessing.org/sketch…

The fluid mosaic model of the cell membrane



- Singer-Nicolson Fluid Mosaic model for cell membranes proposed in 1972
- Cell membrane is discontinuous - biomolecules interspersed with lipids, embedded and spanning the bilayer
- It is a barrier with variable mechanical properties - depends on composition of the phospholipids, types of proteins, etc
- Phospholipids can “flip” across the bilayer

Figure from DOI: 10.1007/978-3-319-65960-2_10

size balance between the head group and hydrophobic tails of lipids affect membrane spontaneous curvature

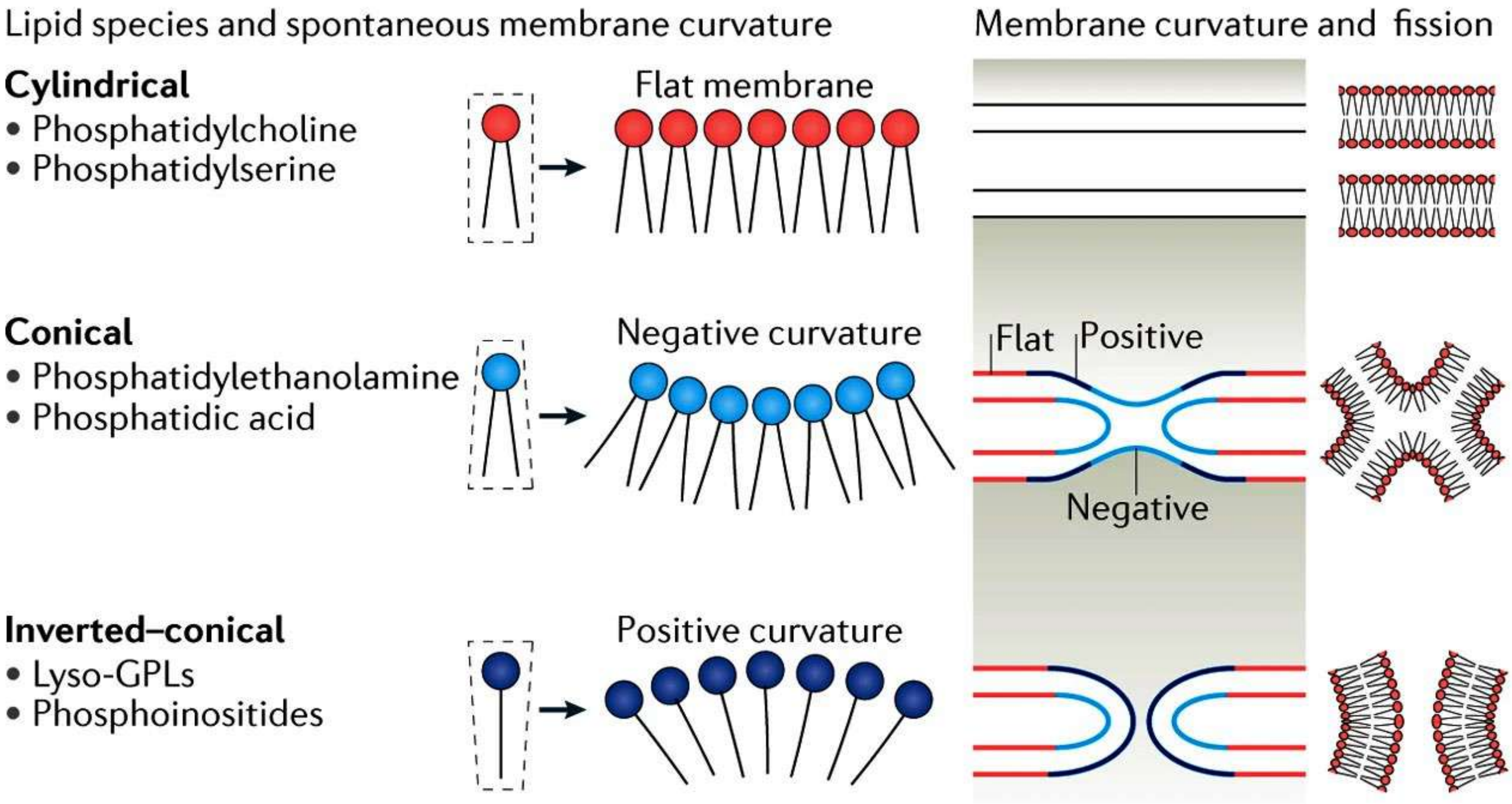
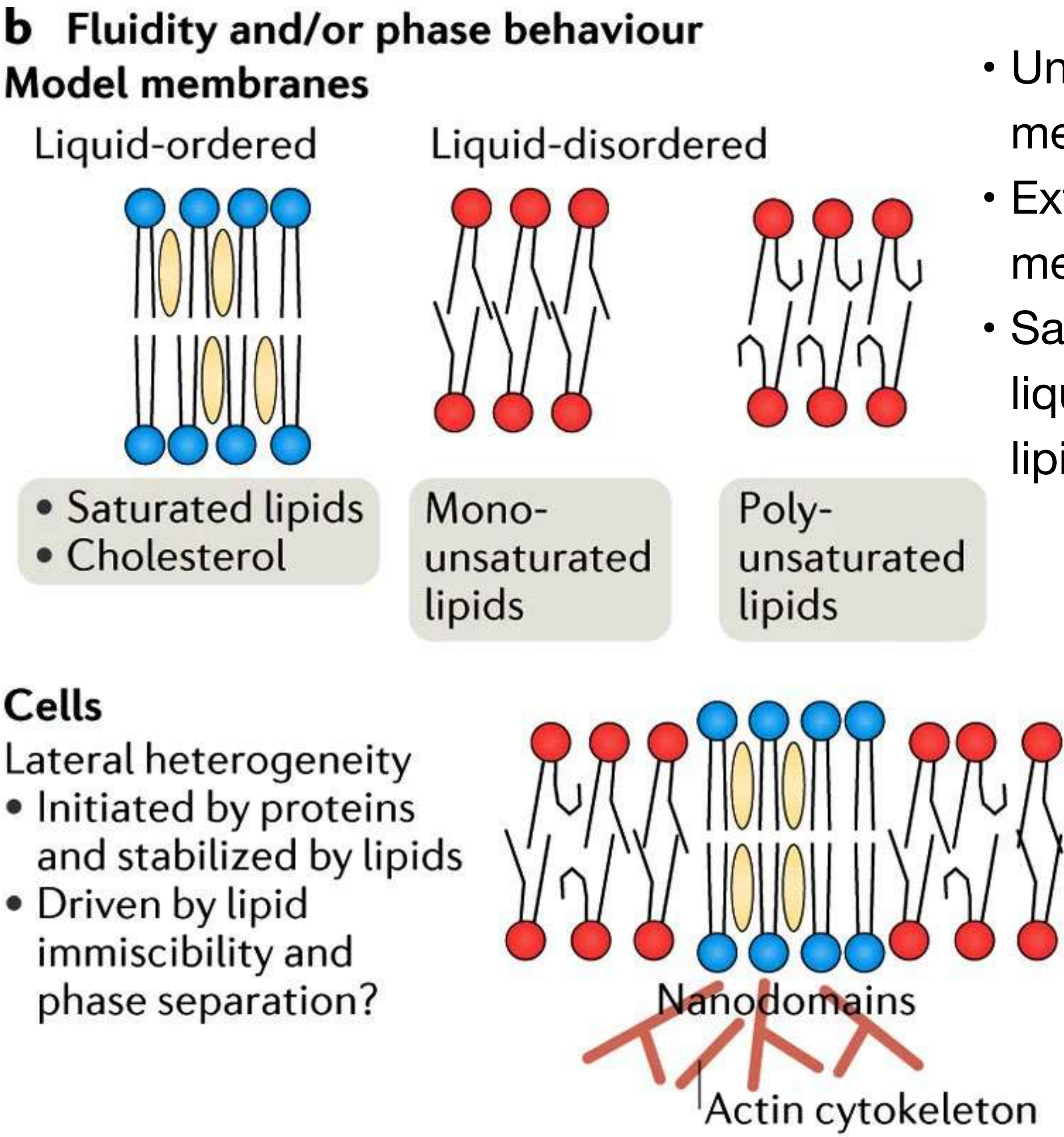


Figure from doi: 10.1038/s41580-019-0171-x

Type of lipids in the cell membrane affect membrane contours and mechanical properties

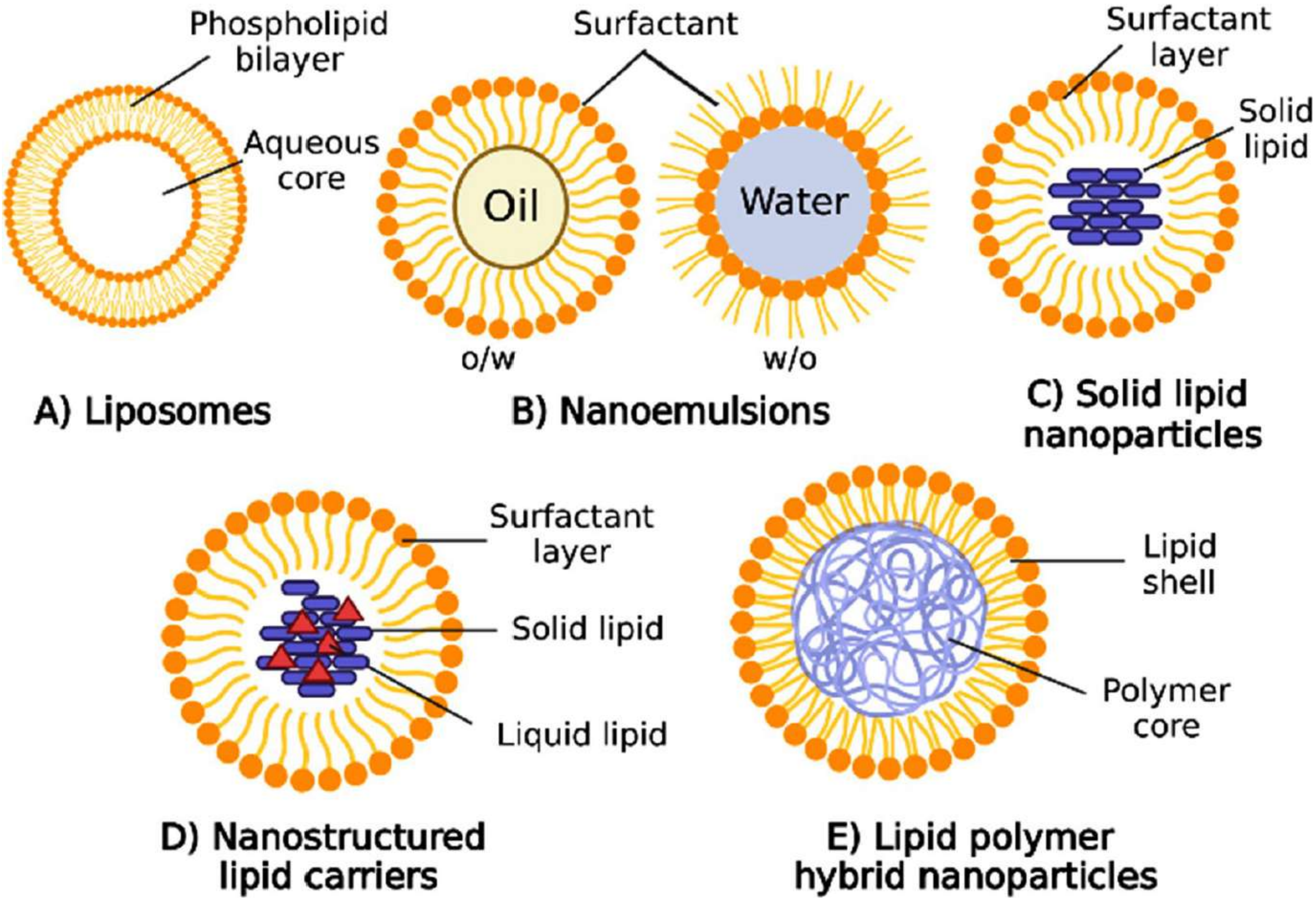


- Unsaturated lipid tails increases membrane fluidity.
- Extent of unsaturation of lipids in the membrane might affect its organization.
- Saturated lipids and cholesterol generate liquid-ordered phases, and unsaturated lipids generate liquid-disordered phases

Lateral heterogeneities in membrane fluidity generating distinct nanodomains - special areas where different types of activity can occur

Figure from doi: 10.1038/s41580-019-0171-x

Lipids for drug delivery - Lipid Nano Particles



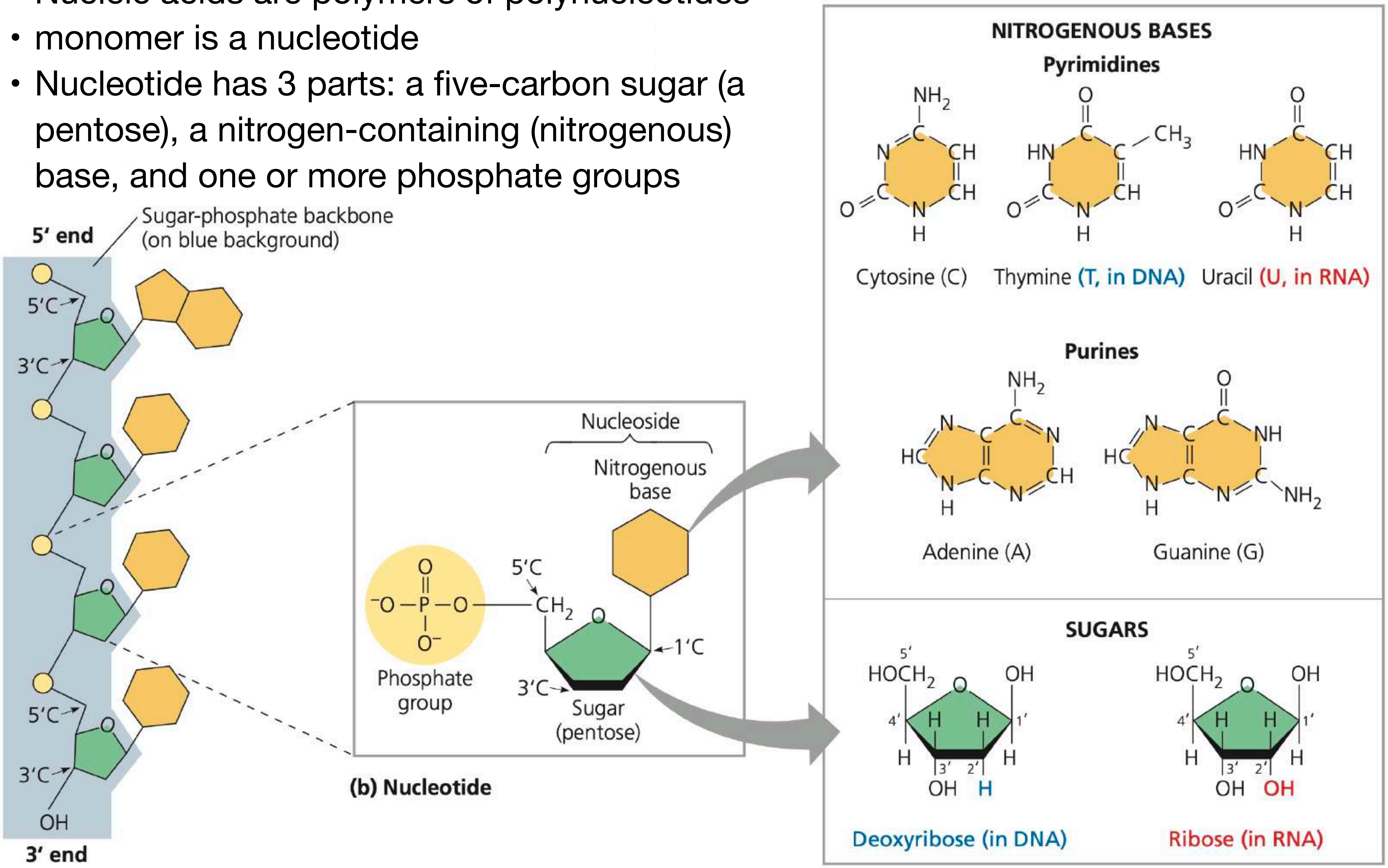
Used for targeted and contained drug delivery

Figure from doi: 10.1021/acsmaterialsau.3c00032

Sreelaja Nair

Nucleic Acids (DNA and RNA)

- Nucleic acids are polymers of polynucleotides
- monomer is a nucleotide
- Nucleotide has 3 parts: a five-carbon sugar (a pentose), a nitrogen-containing (nitrogenous) base, and one or more phosphate groups



(a) Polynucleotide, or nucleic acid

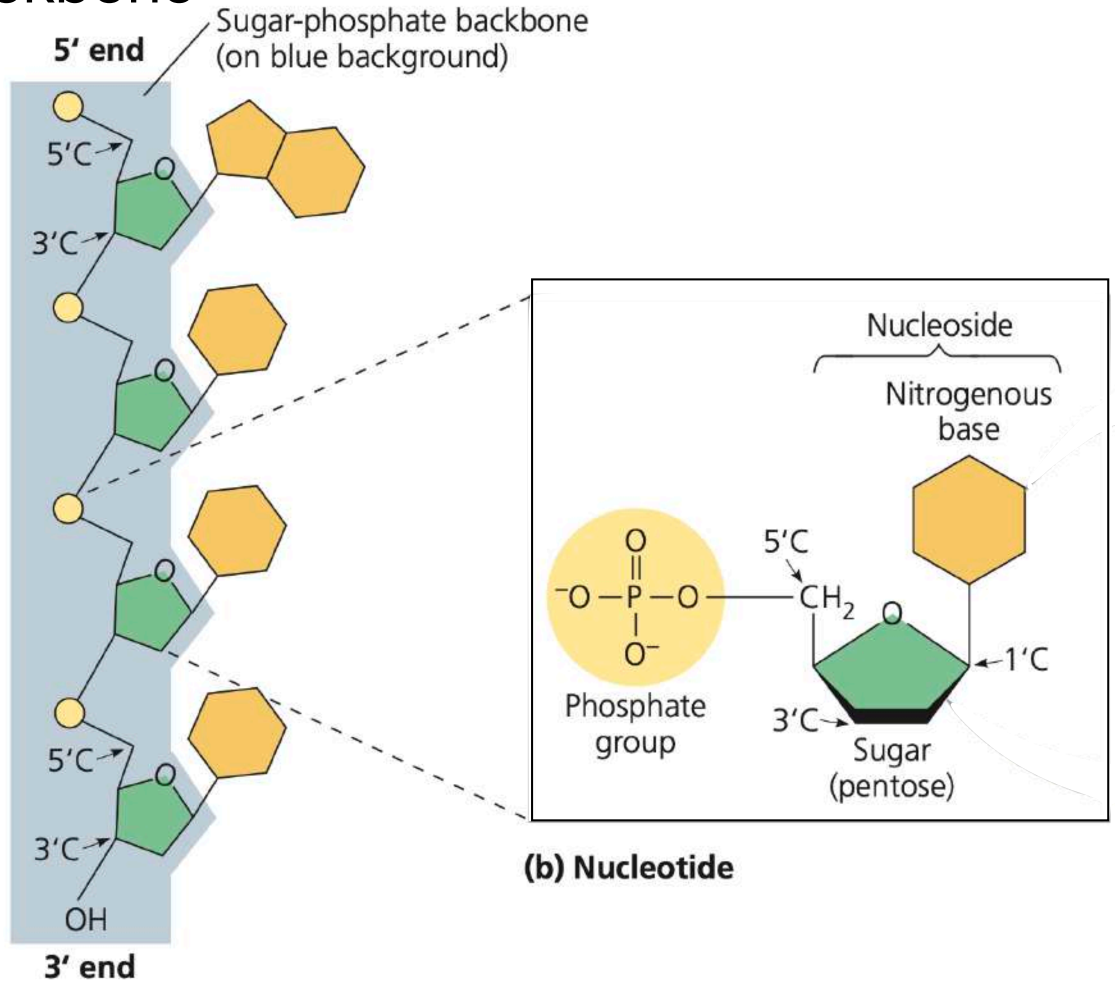
(b) Nucleotide

(c) Nucleoside components

Figure 5.24 of Campbell's Biology: a global approach

- Nucleotides are joined by a phosphodiester linkage = a phosphate group linking sugars of two nucleotides.
- This bonding results in a repeating pattern of sugar-phosphate units called the sugar-phosphate backbone

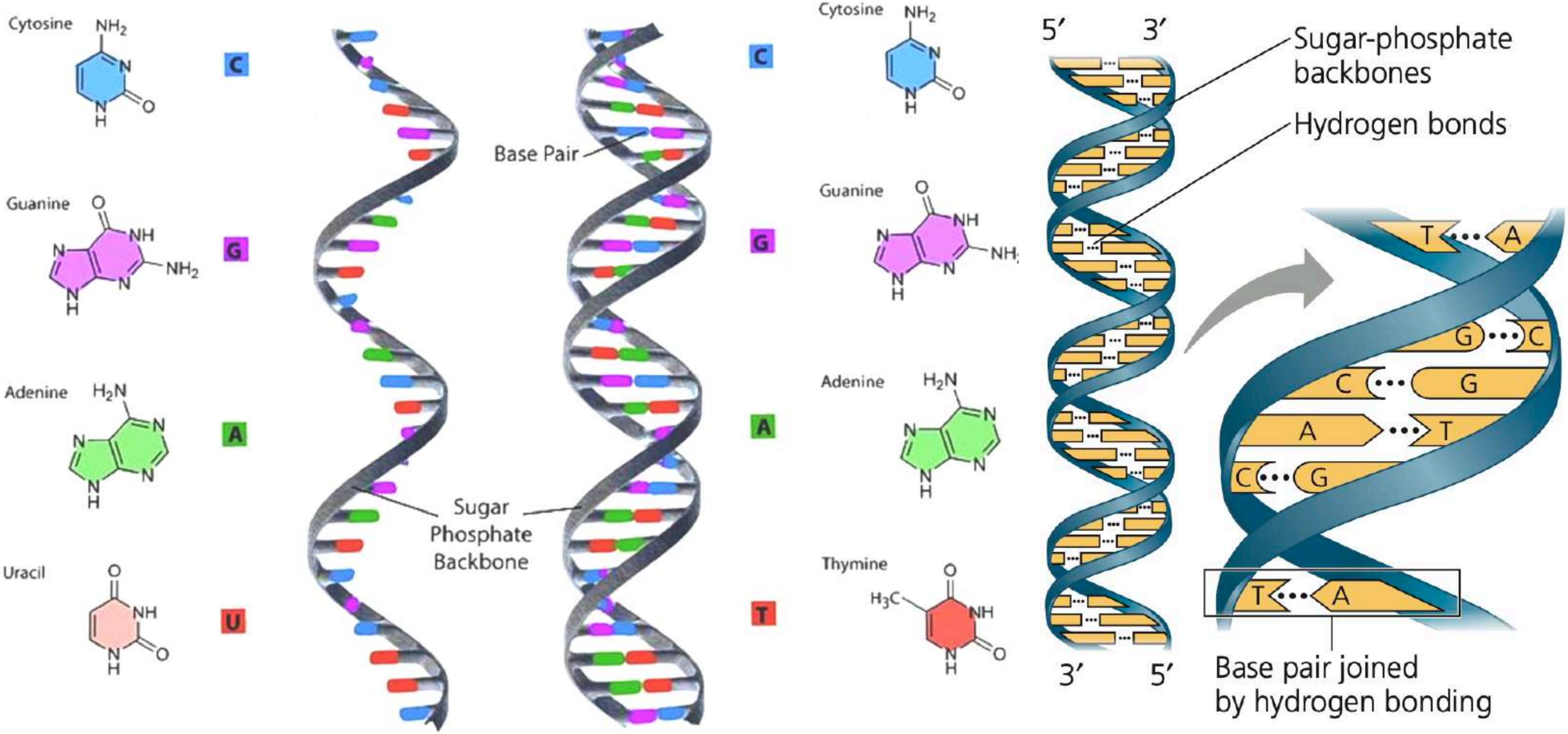
- The two free ends of the polynucleotide are distinct - one end has a phosphate attached to a 5′ carbon, and the other end has a hydroxyl group on a 3′ carbon
- These are known as the 5′ end and the 3′ end, respectively, giving the polynucleotide a built-in directionality along its sugar-phosphate backbone, from 5′ to 3′



(a) Polynucleotide, or nucleic acid

(b) Nucleotide

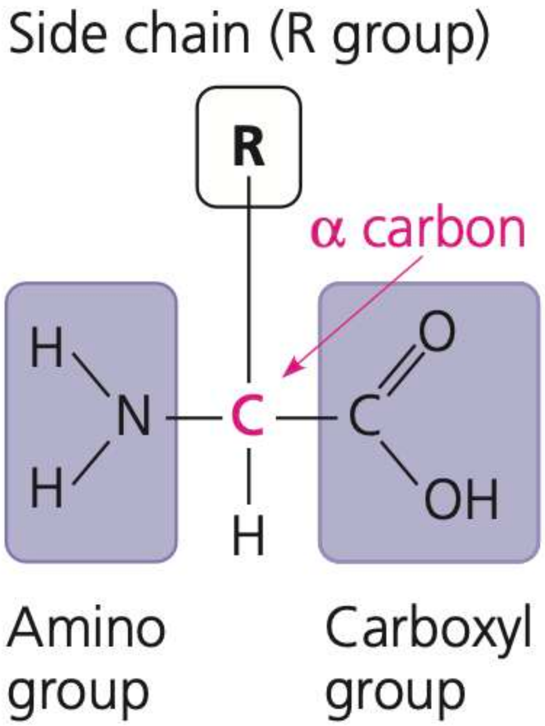
Deoxyribonucleic acid and Ribonucleic acid

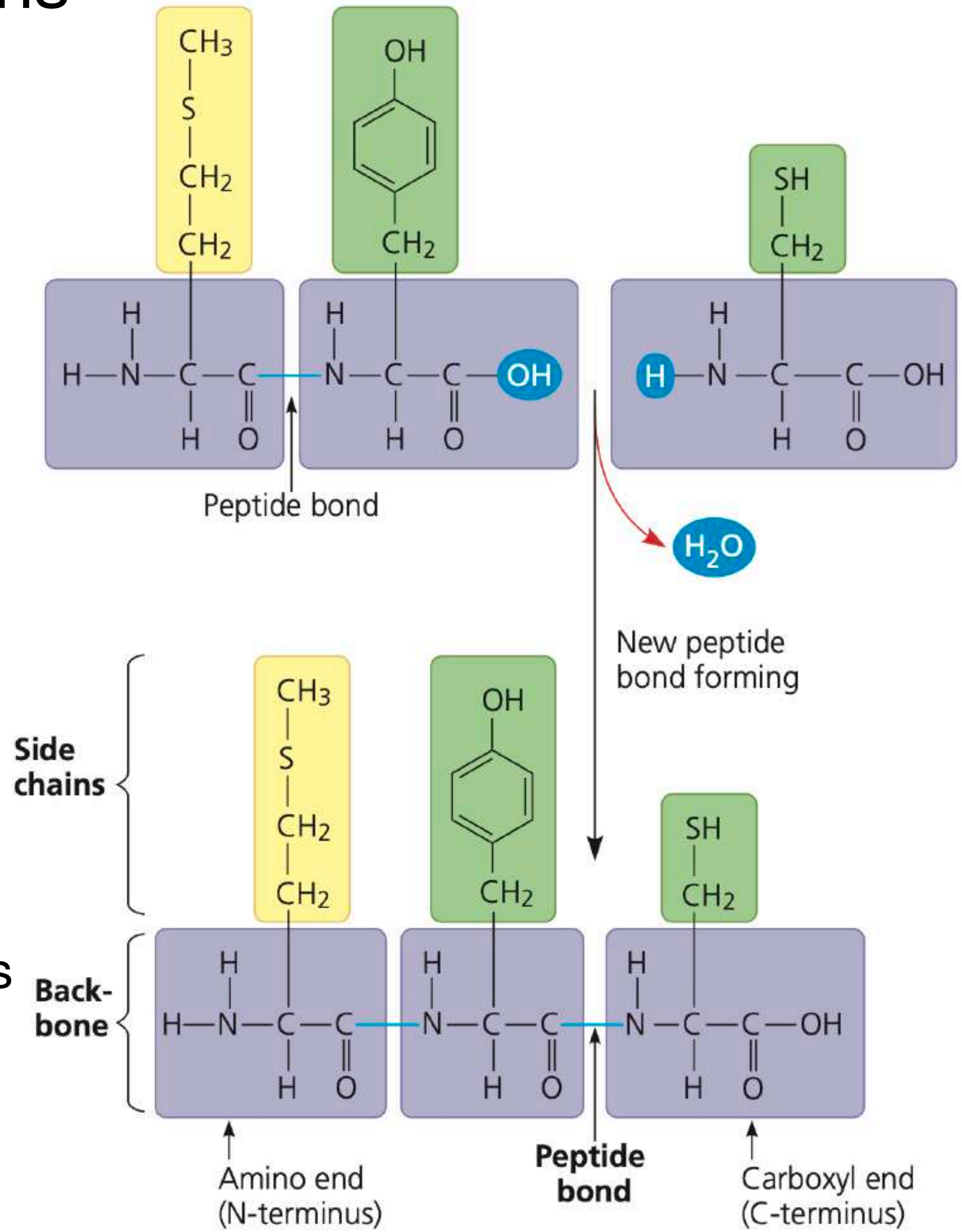


- Base complementarity between A-T/U and G-C
- If you know one, you can predict the other half of a pair of nucleotides
- If you know information in one strand - you can predict the information in the other
- If you know the information in DNA - you can predict the information in the RNA
- If you know the information in RNA - you can predict the information in the DNA

Figure 5.25 of Campbell's Biology: a global approach

Proteins

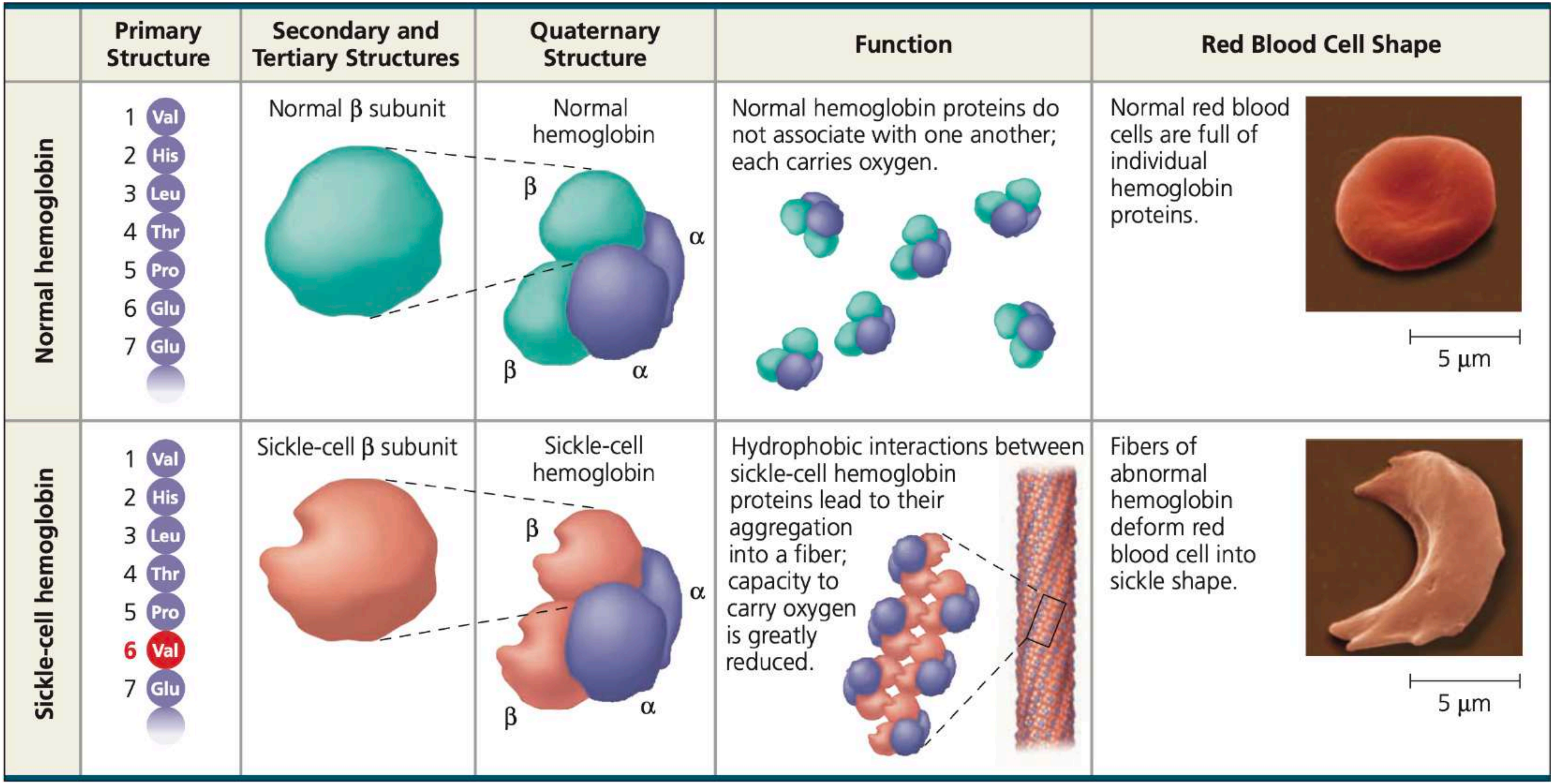




- An amino acid is an organic molecule with both an amino group and a carboxyl group
- The R group, also called the side chain, differs with each amino acid
- Amino acids are joined by a covalent (called a peptide bond) to form polymers known as proteins

Figure 5.14 and 5.15 of Campbell's Biology: a global approach

Protein sequence, structure and function

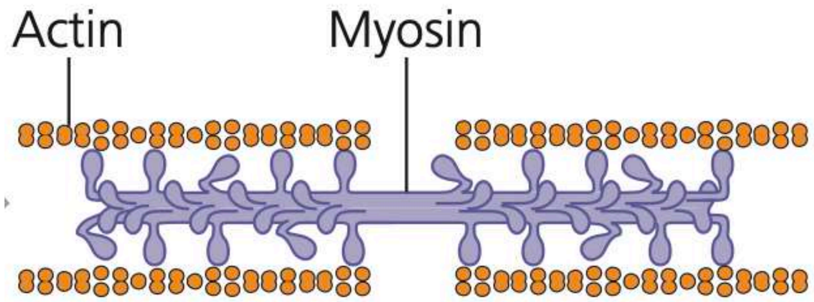


- Protein sequence is the primary structure
- The protein adopts secondary, tertiary and quaternary structures based on interactions amongst amino acids and cellular environment
- Protein structure is important for function

Figure 5.19 of Campbell's Biology: a global approach

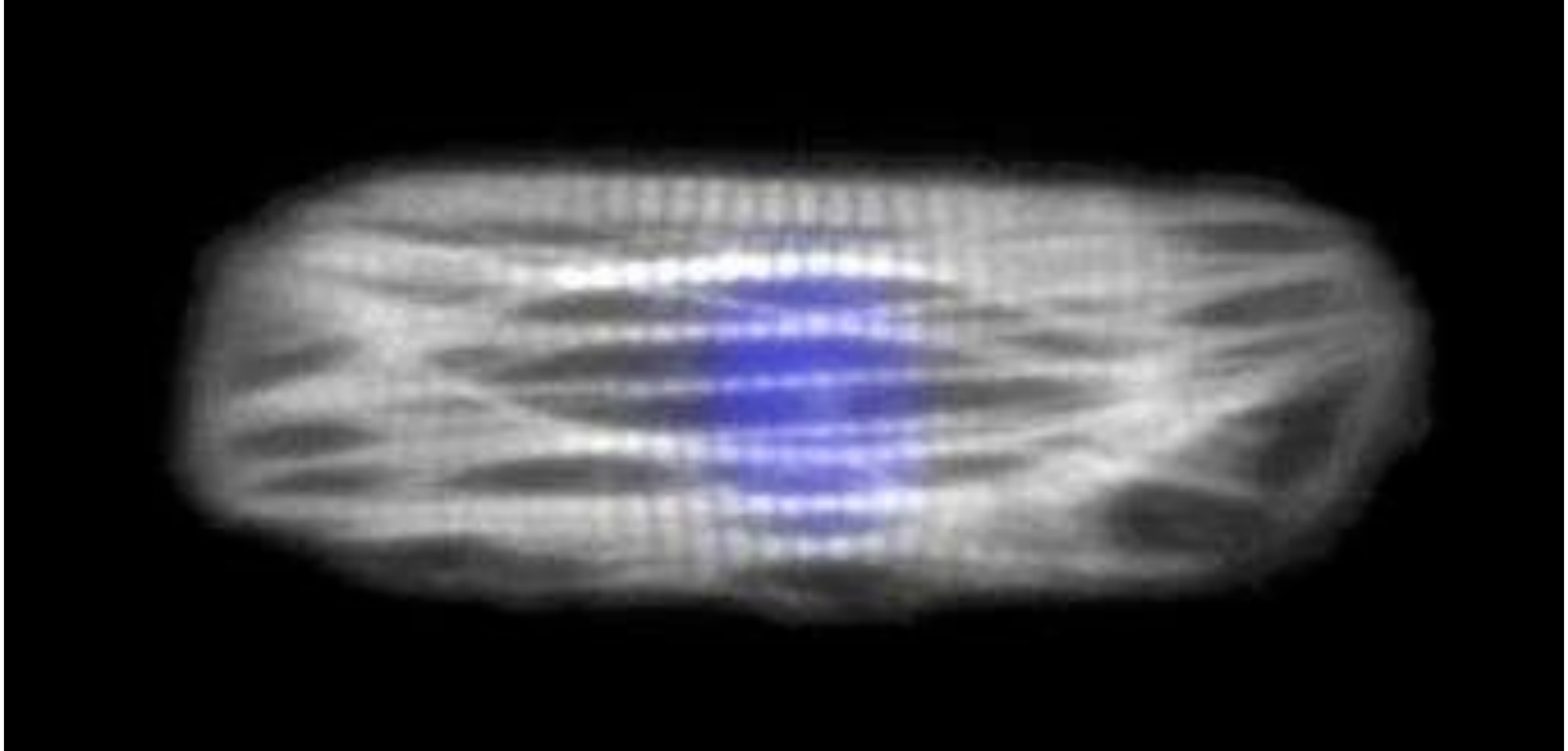
Protein function example: movement

Visible at the level of entire cell or at sub-microscopic levels inside cells



Cardiac muscle cell contraction: result of interactions between two proteins - actin and myosin inside cardiomyocytes of the heart

Single cardiomyocyte (from human iPSCs) exhibiting actomyosin driven contractility



Movie from doi: 10.1073/pnas.1508073112

Figure 5.13 of Campbell's Biology: a global approach

Protein function example: movement

Visible at the level of entire cell or at sub-microscopic levels inside cells

Some bacteria have "flagella" which help in their movement
Flagella is an organelle made of multiple proteins

Animation code and additional examples: https://github.com/callumsmits/rt1

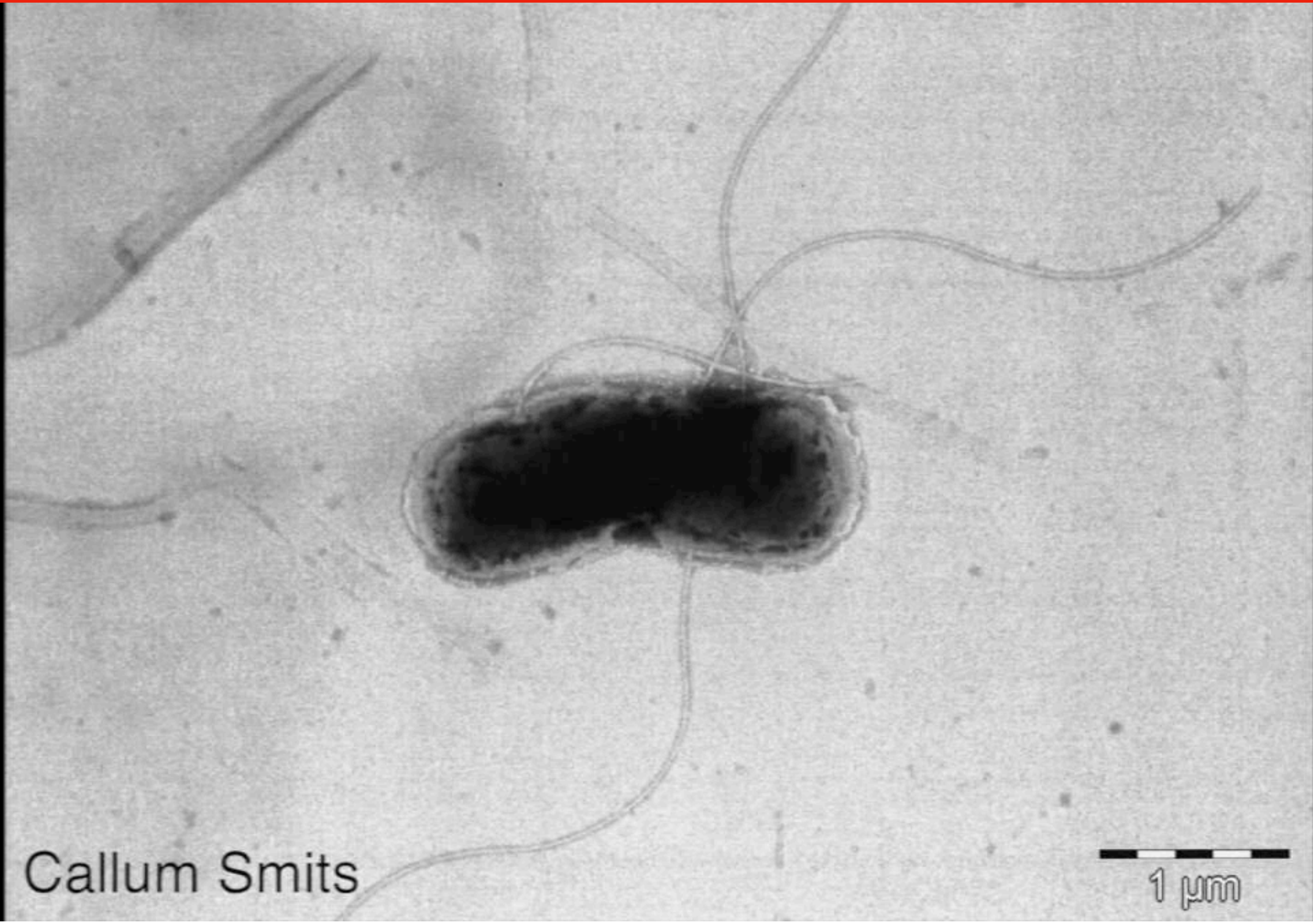


Figure 5.13 of Campbell's Biology: a global approach

Protein function example: movement

Visible at the level of entire cell or at sub-microscopic levels inside cells

- Cells have “roads” - microtubules and actin on which “motors” - kinesin, dynein, myosin “walk”
- This system is responsible for all transport inside cells

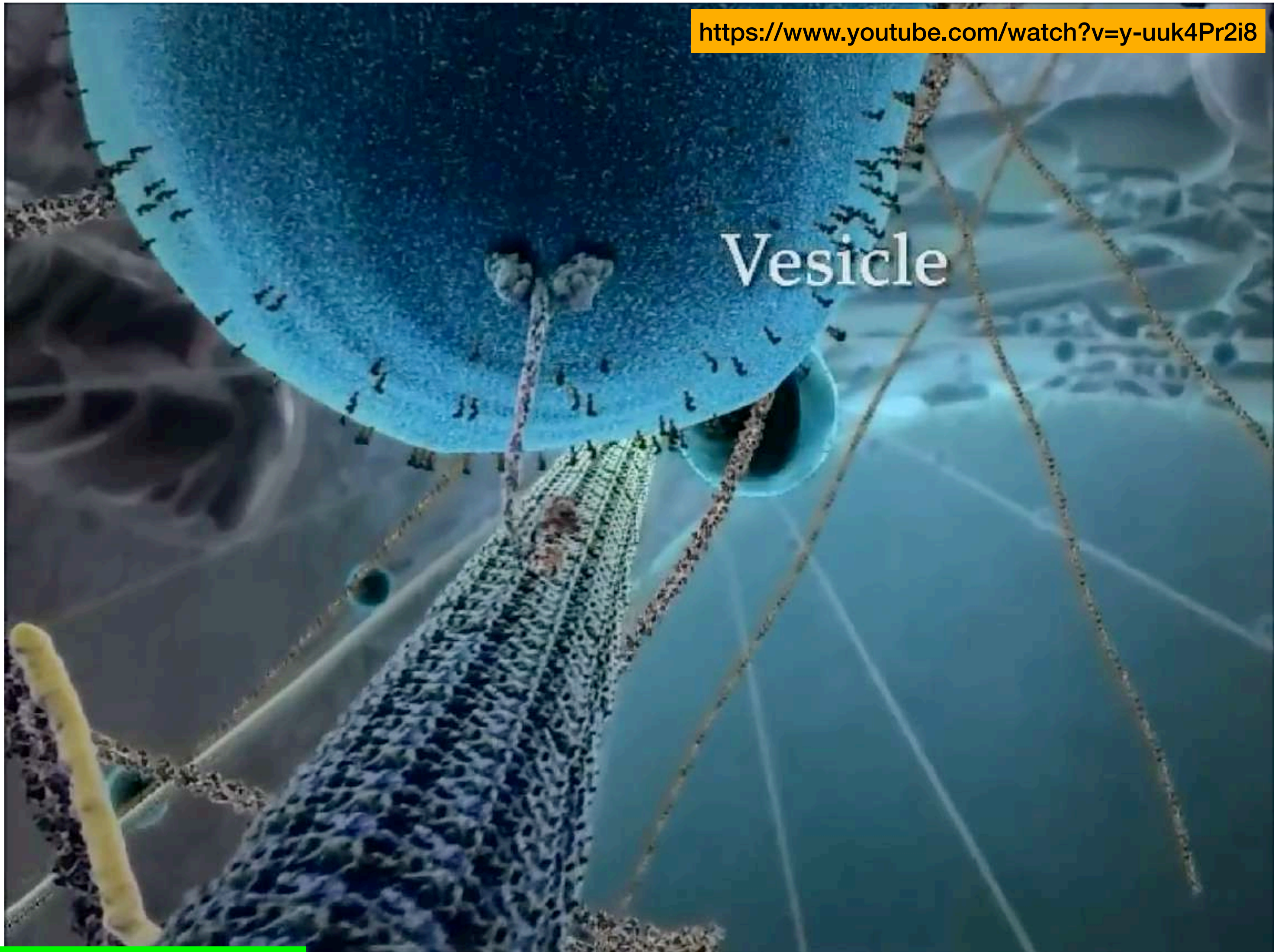


Figure 5.13 of Campbell’s Biology: a global approach

Protein structure

Primary structure

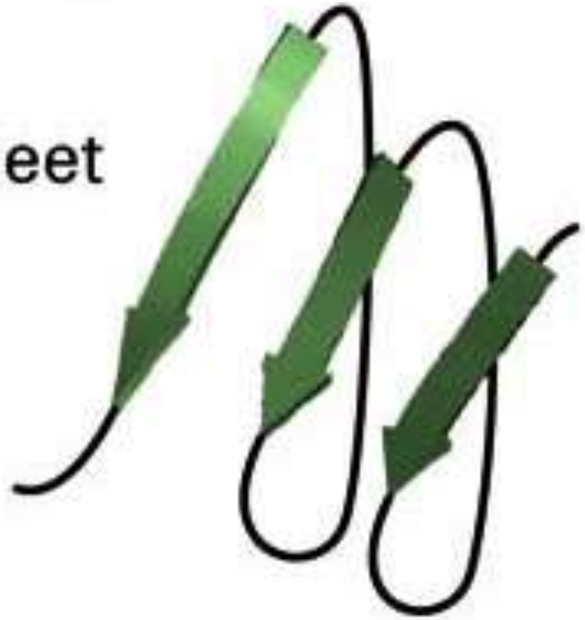
–Ala–Glu–Val–Thr–Asp–Pro–Gly–

↓

Secondary structures (examples)

α helix

β sheet



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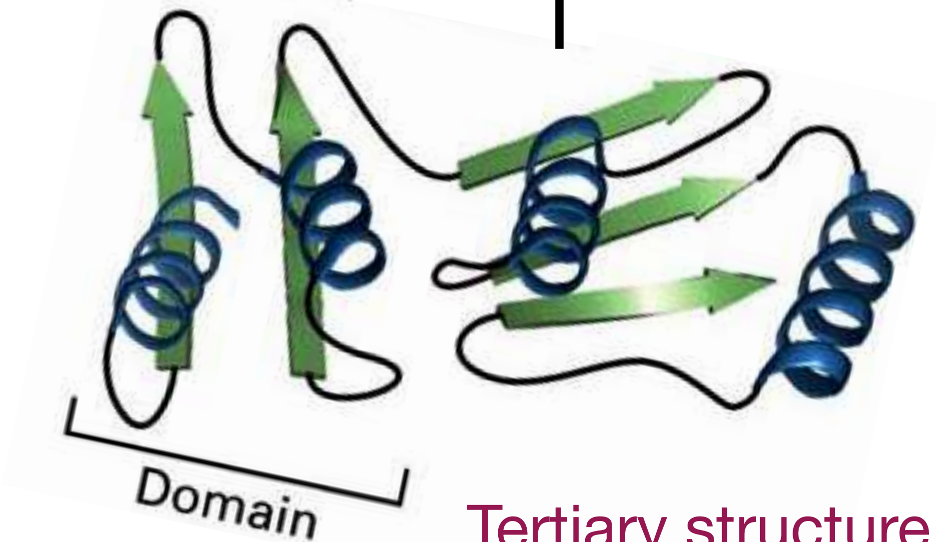
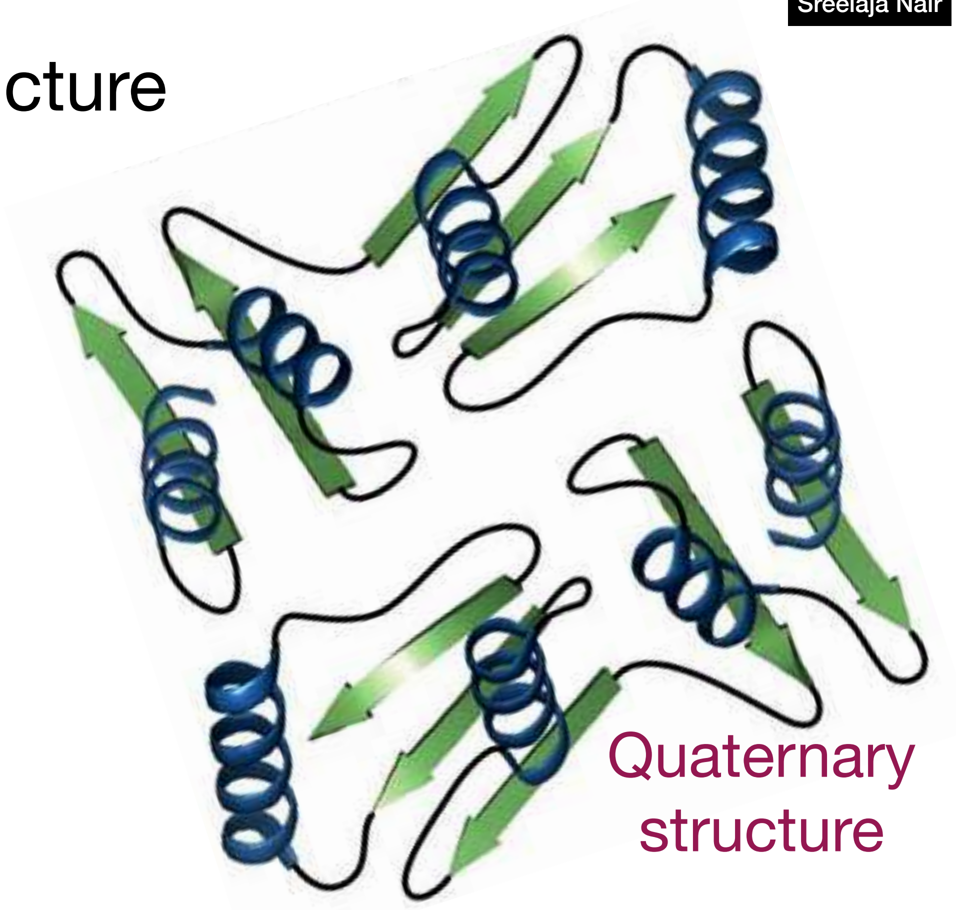


Tertiary structure

↑



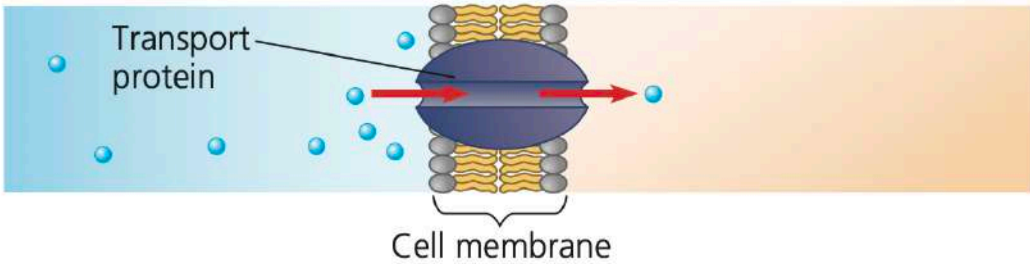
Quaternary structure

Examples of function of proteins

Transport proteins

Function: Transport of substances

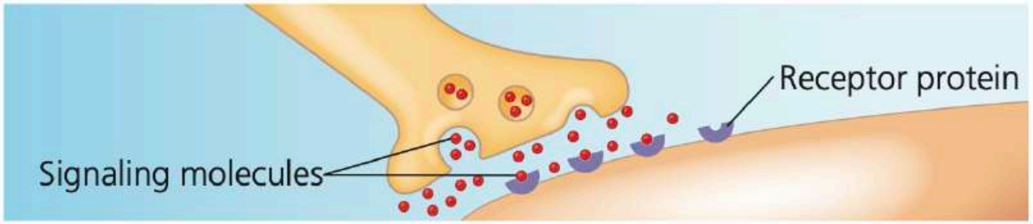
Examples: Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across membranes, as shown here.



Receptor proteins

Function: Response of cell to chemical stimuli

Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.



Enzymatic proteins

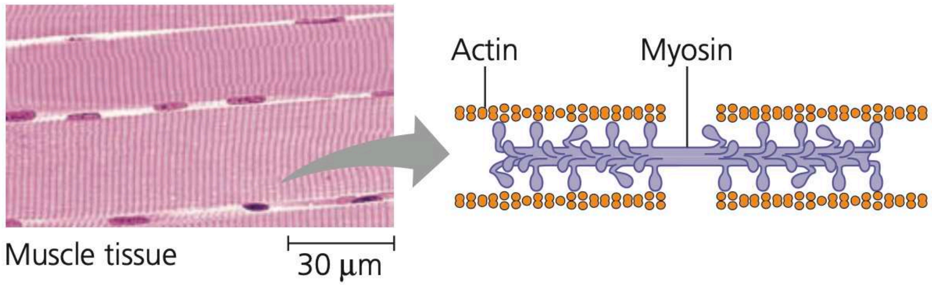
Function: Selective acceleration of chemical reactions

Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.

Contractile and motor proteins

Function: Movement

Examples: Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.



Structural proteins

Function: Support

Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.

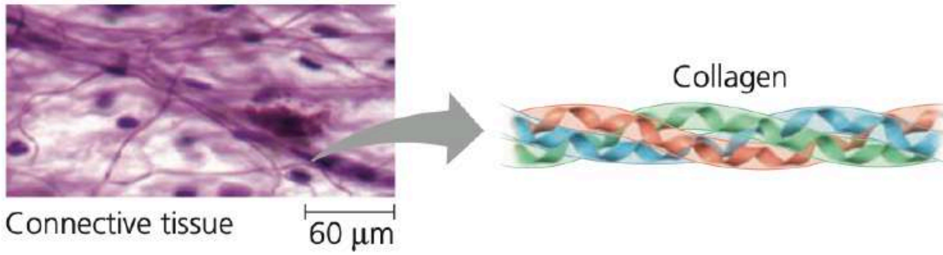
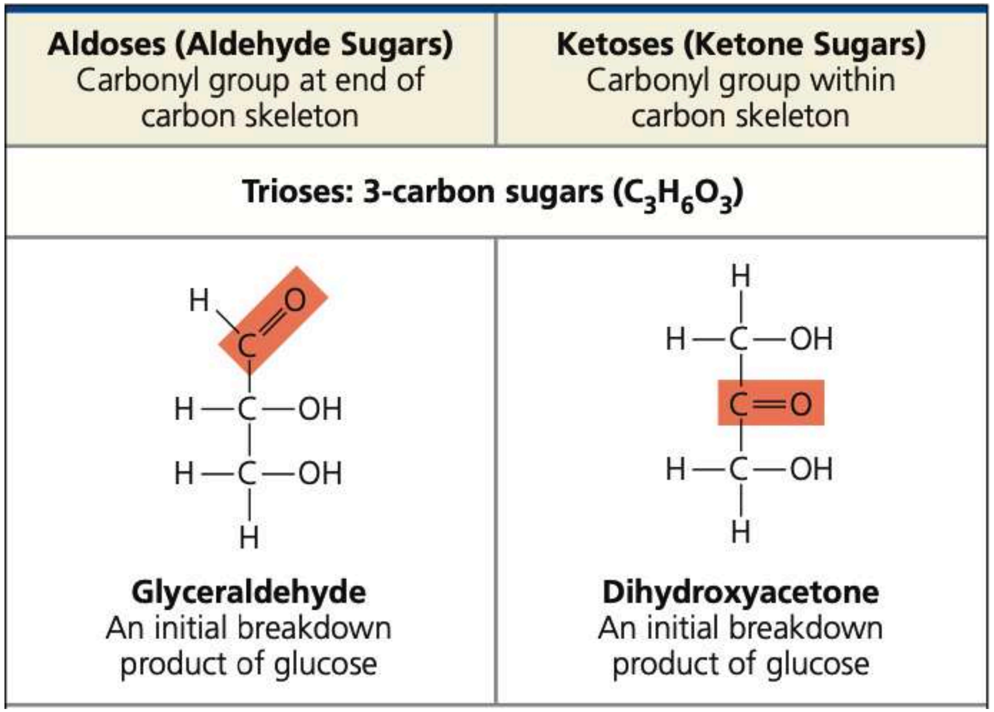
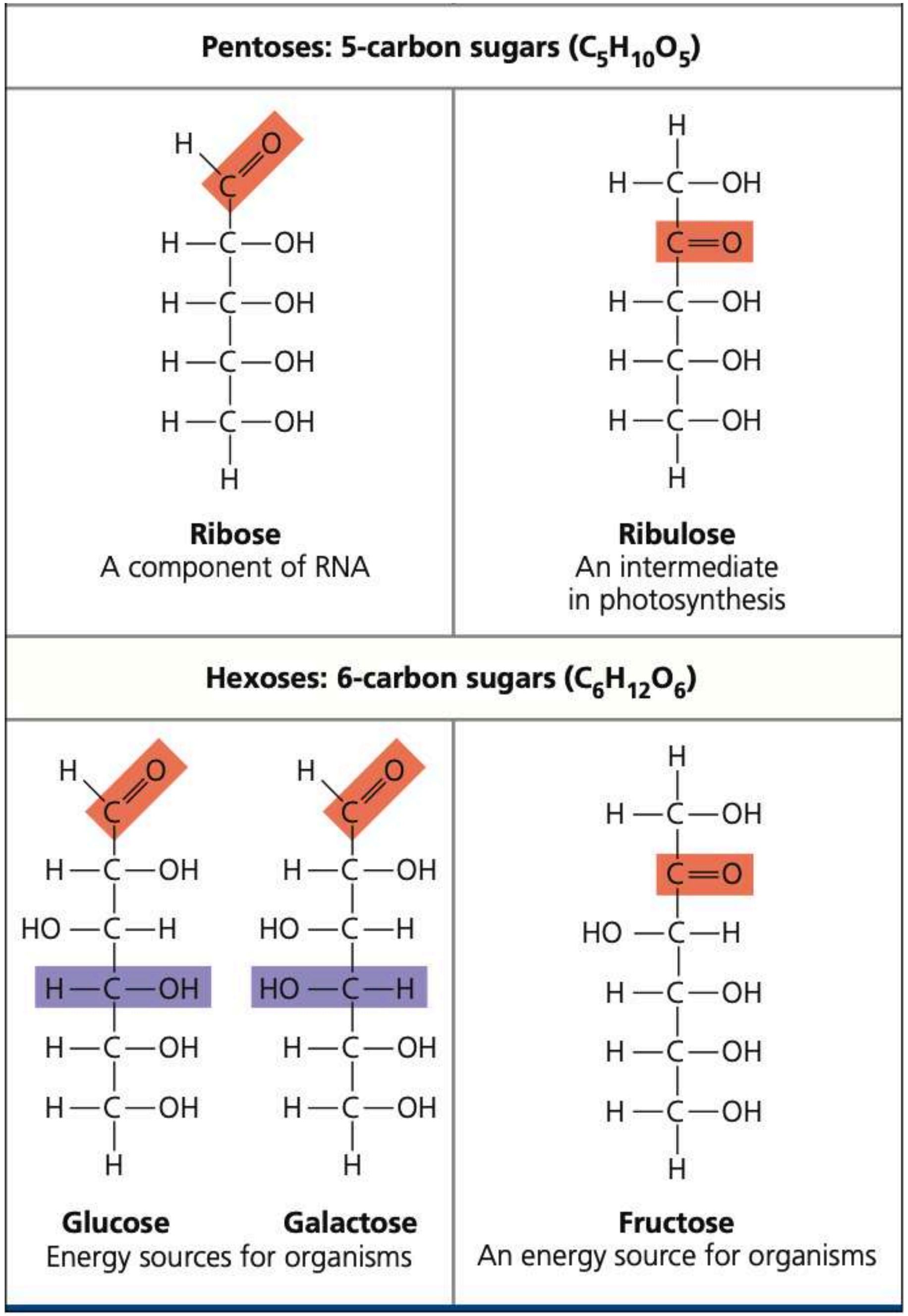


Figure 5.13 of Campbell's Biology: a global approach

Carbohydrates





- Carbohydrates include sugars
- polymers of sugars - polysaccharides
- Usually reserves of energy in cells
- Can also provide structural support - e.g. cellulose in plant cells
- In aqueous solutions, most pentose and hexose sugars form rings

Figure 5.3 of Campbell's Biology: a global approach

Polysaccharides in plants and animals

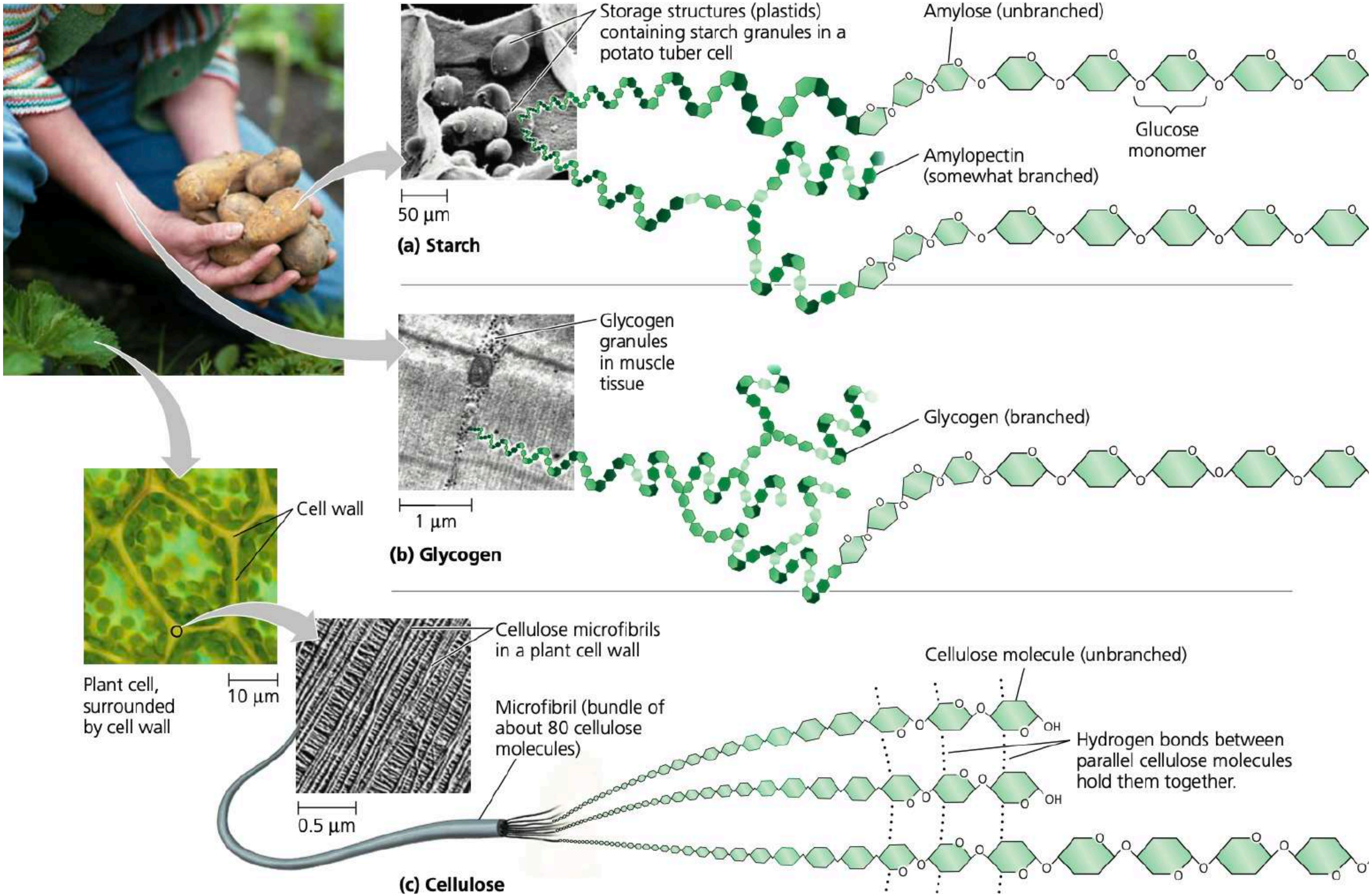
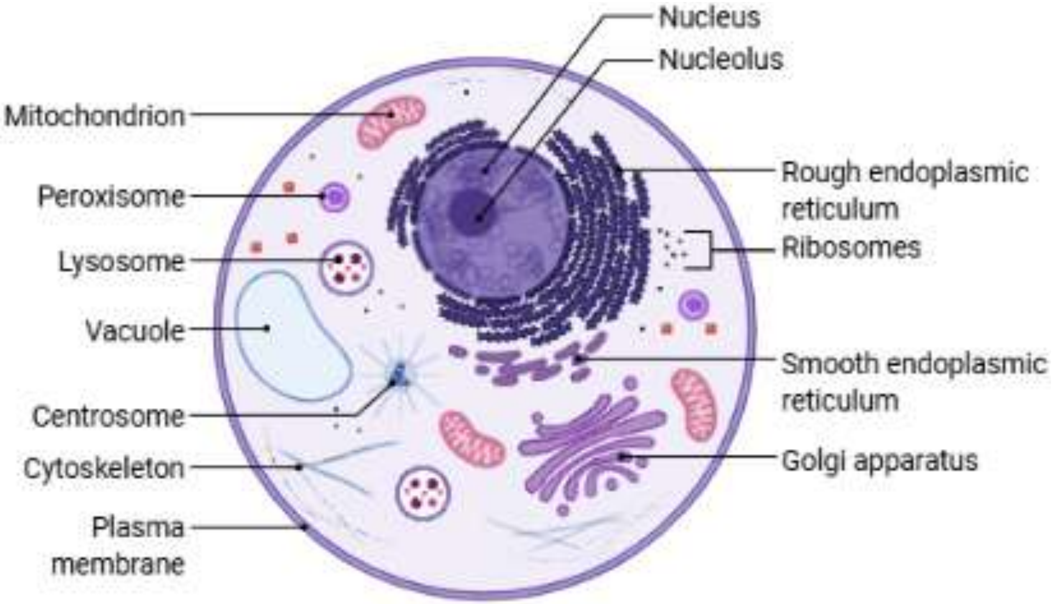


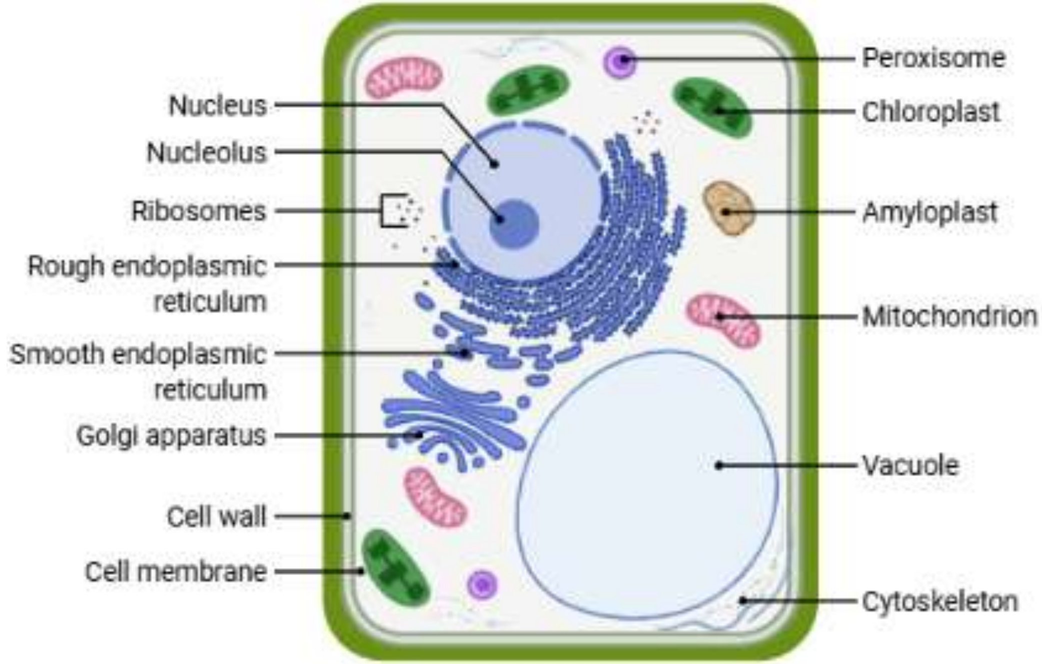
Figure 5.6 of Campbell's Biology: a global approach

Eukaryotic cells

Animal cell



Plant cell



Compartments → "rooms" in which different activities can occur

Organized → "layout" decides the optimal sequence in which activities can occur

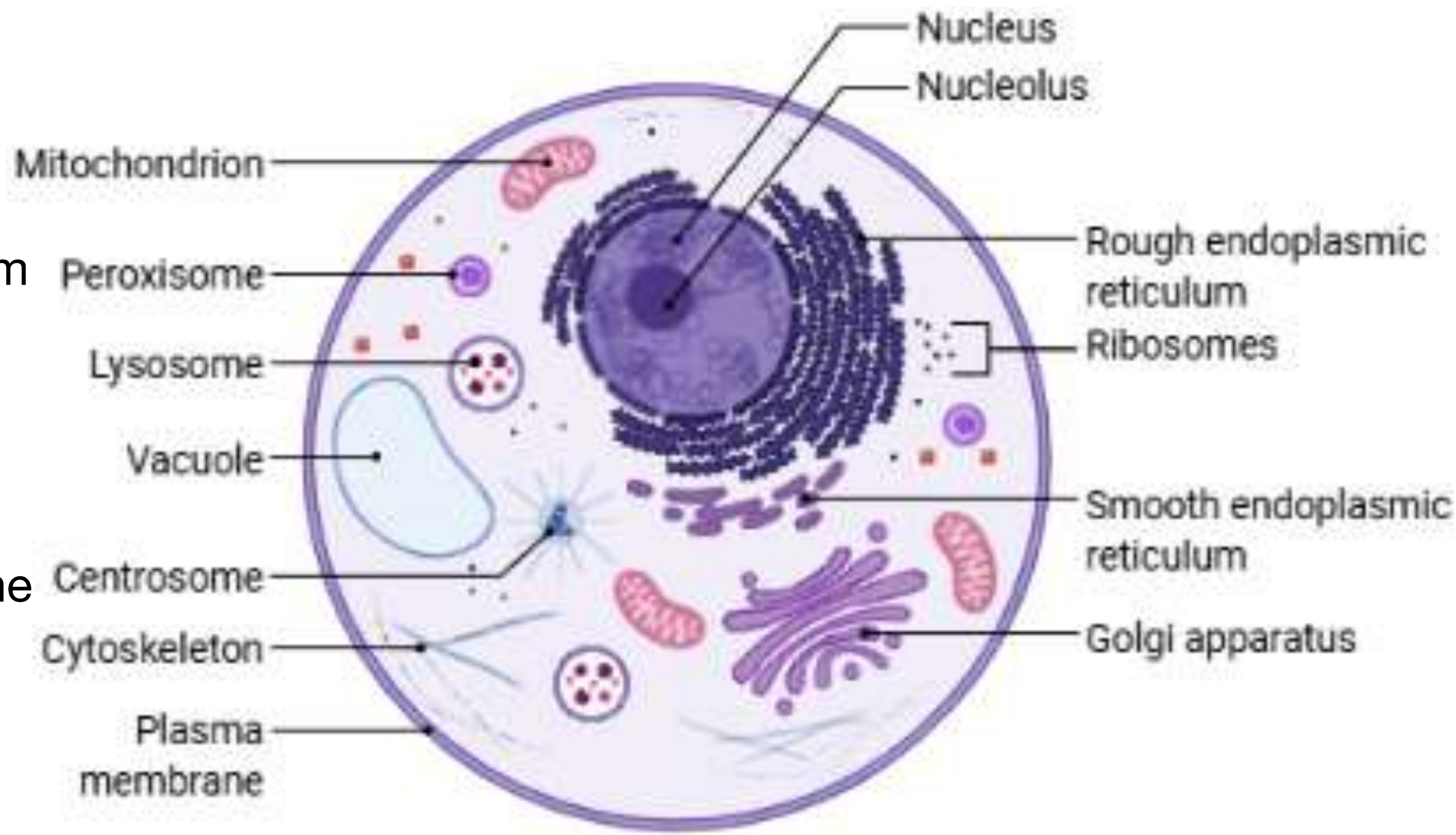
Figure 6.8 of Campbell's Biology: a global approach

Biorender

Eukaryotic cells and apartments

Endomembrane system in cells

- Nuclear envelope
- Endoplasmic reticulum
- Golgi apparatus
- Lysosomes
- Vesicles
- Vacuoles
- The plasma membrane



- Membranes of this system are related either through direct physical continuity or by the transfer of membrane segments as tiny vesicles (sacs made of membrane)
- Allows exchange of materials between compartments
- Allows stuff to get in and get out of cells
- Exists in prokaryotes, animal and plant cells

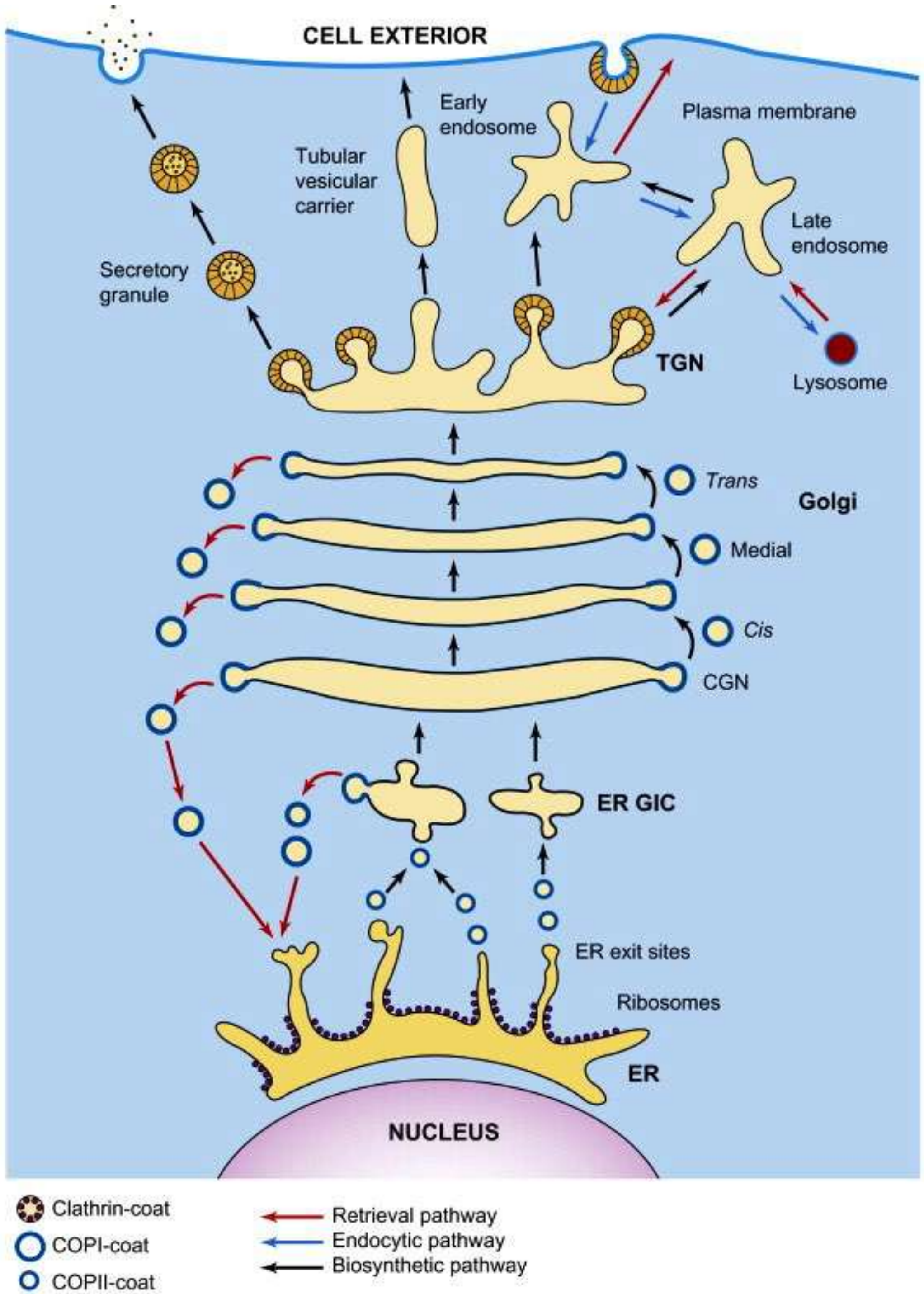
Lecture 3: lipids and membranes

Entry and Exit routes in cells

ER-Golgi secretory pathway

Allows cells to send out information
Allows cells to receive information

Also makes cells
vulnerable to hijacks



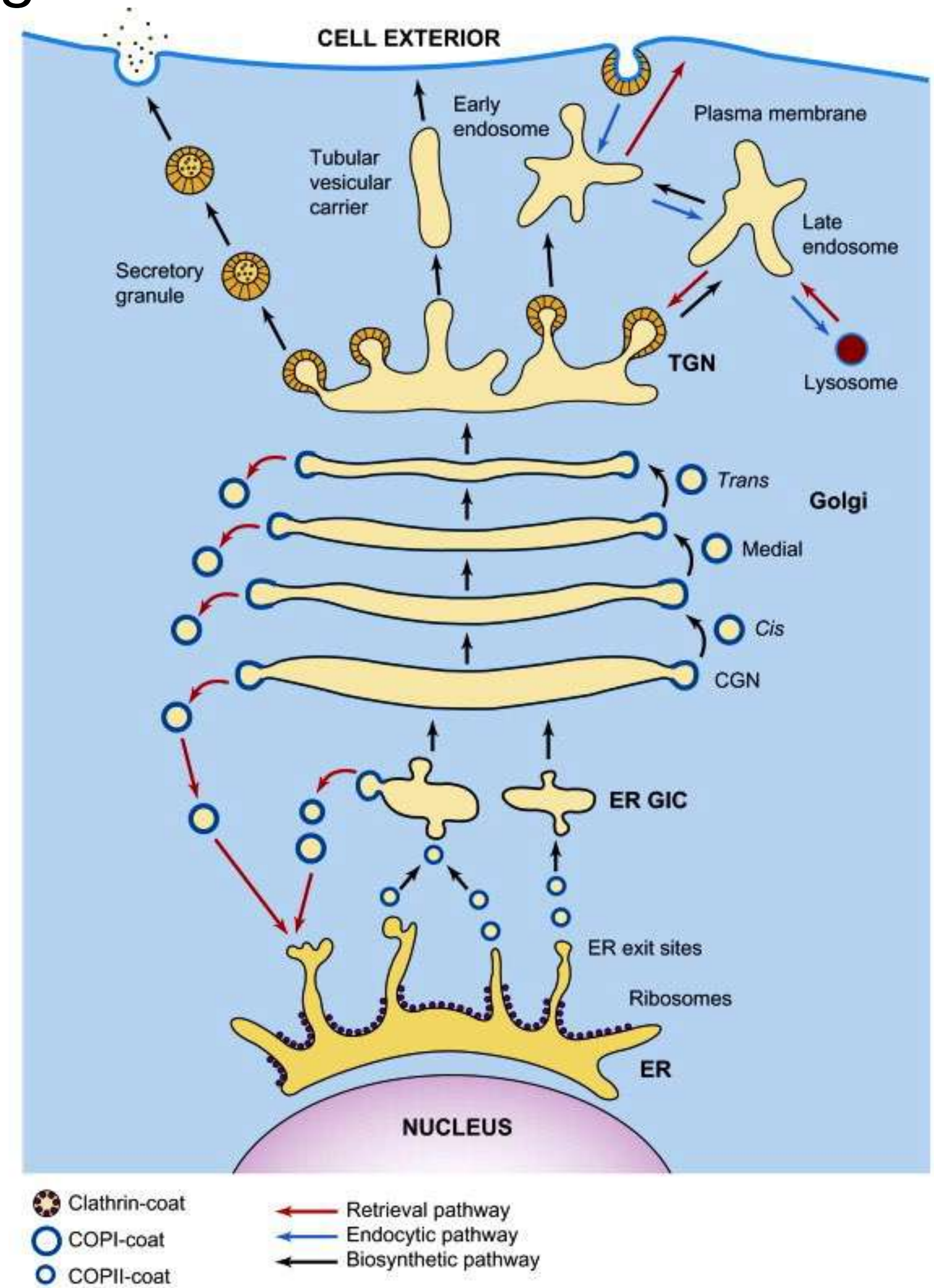
Concept 6.4 of Campbell's Biology: a global approach

Hijacking a cell

- Need a “key” to get in
- “Hitch a ride” with something that normally gets inside cells

- When inside:
  - “Blend in” with the background
  - “Hide” from detection systems
  - “Masquerade” as something already present in cells

- When the time is right “reveal and fight” or “escape” from the cell



Concept 6.4 of Campbell’s Biology: a global approach