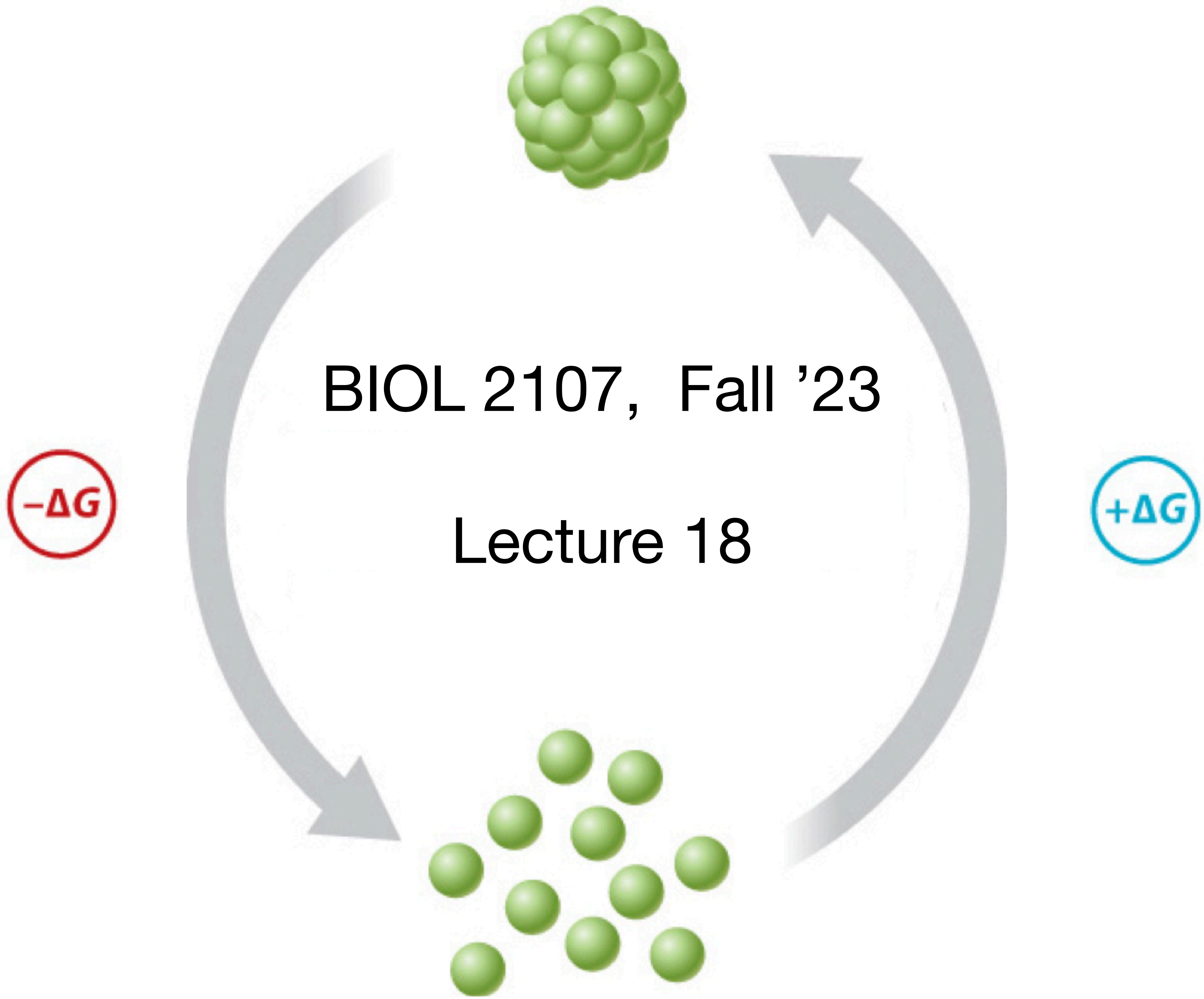
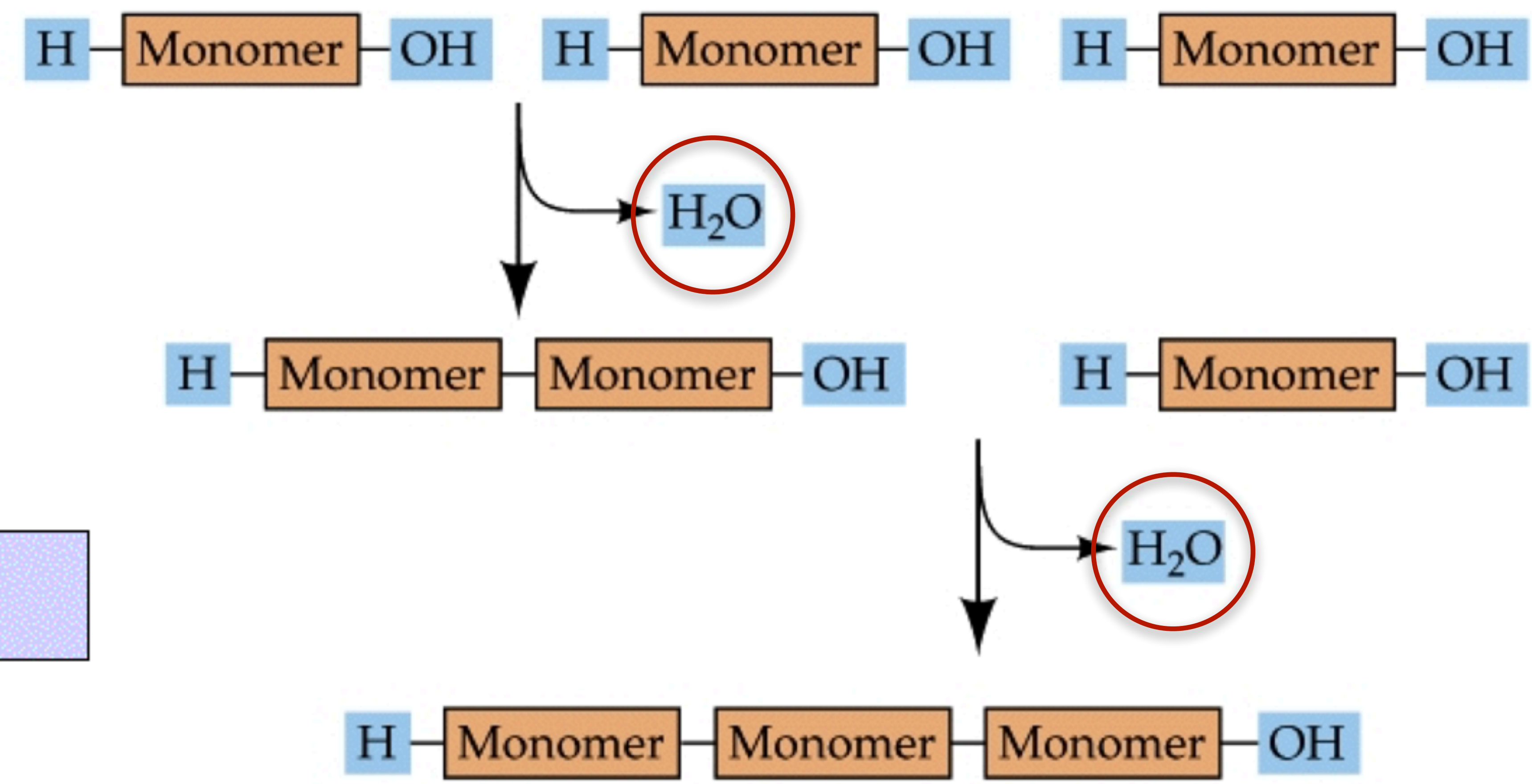
BIOL 2107, Fall '23

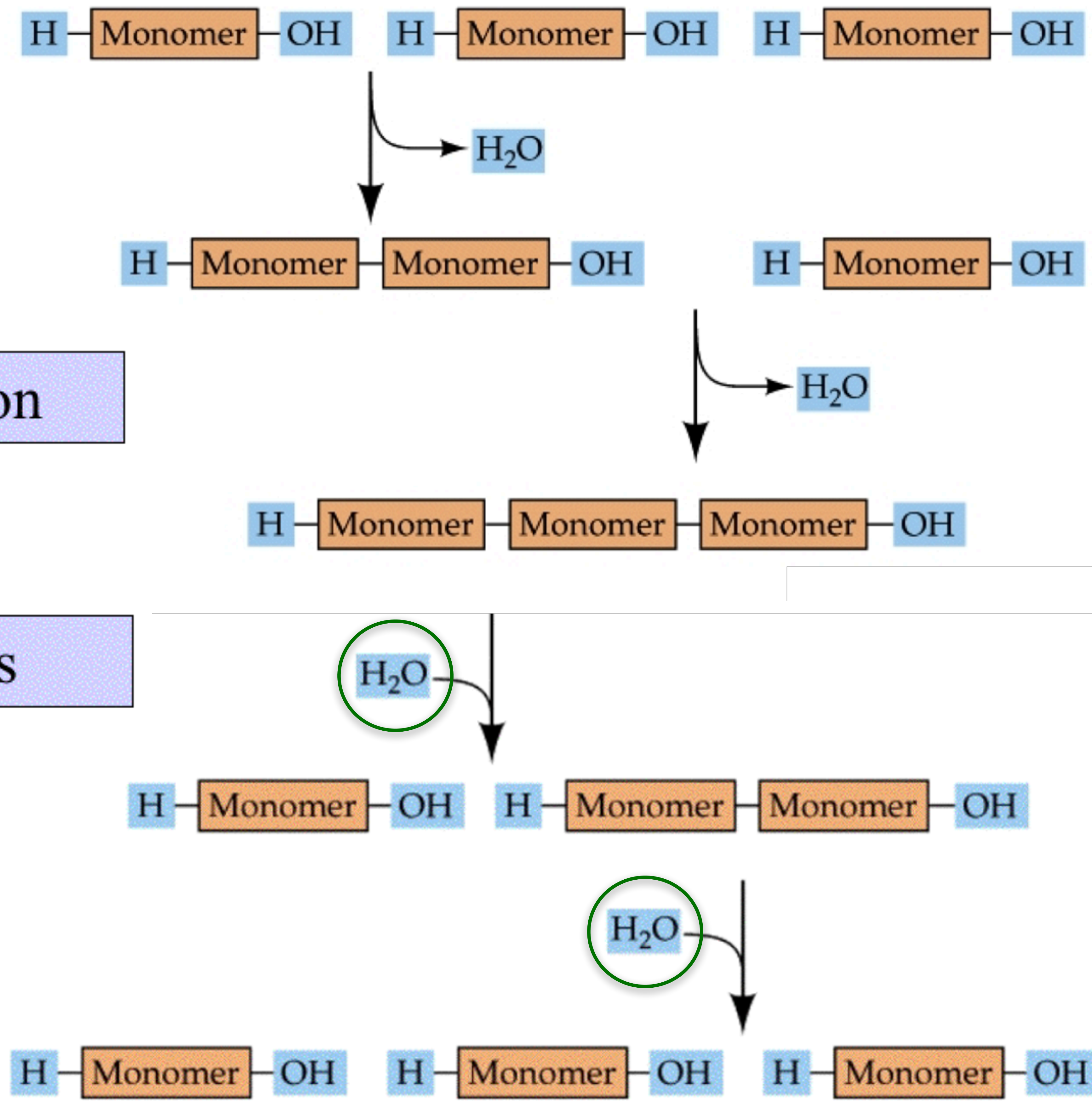
Lecture 18



Enzymes and Energetics…

Condensation

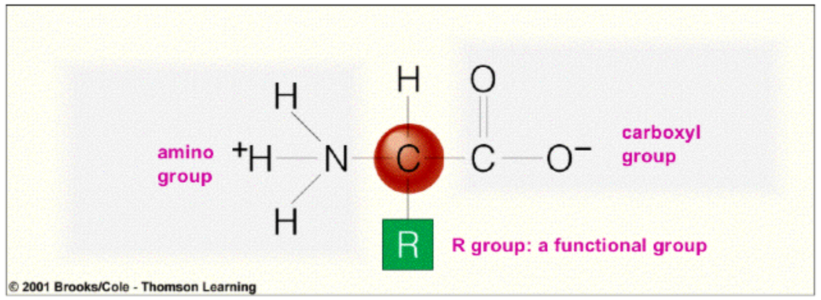


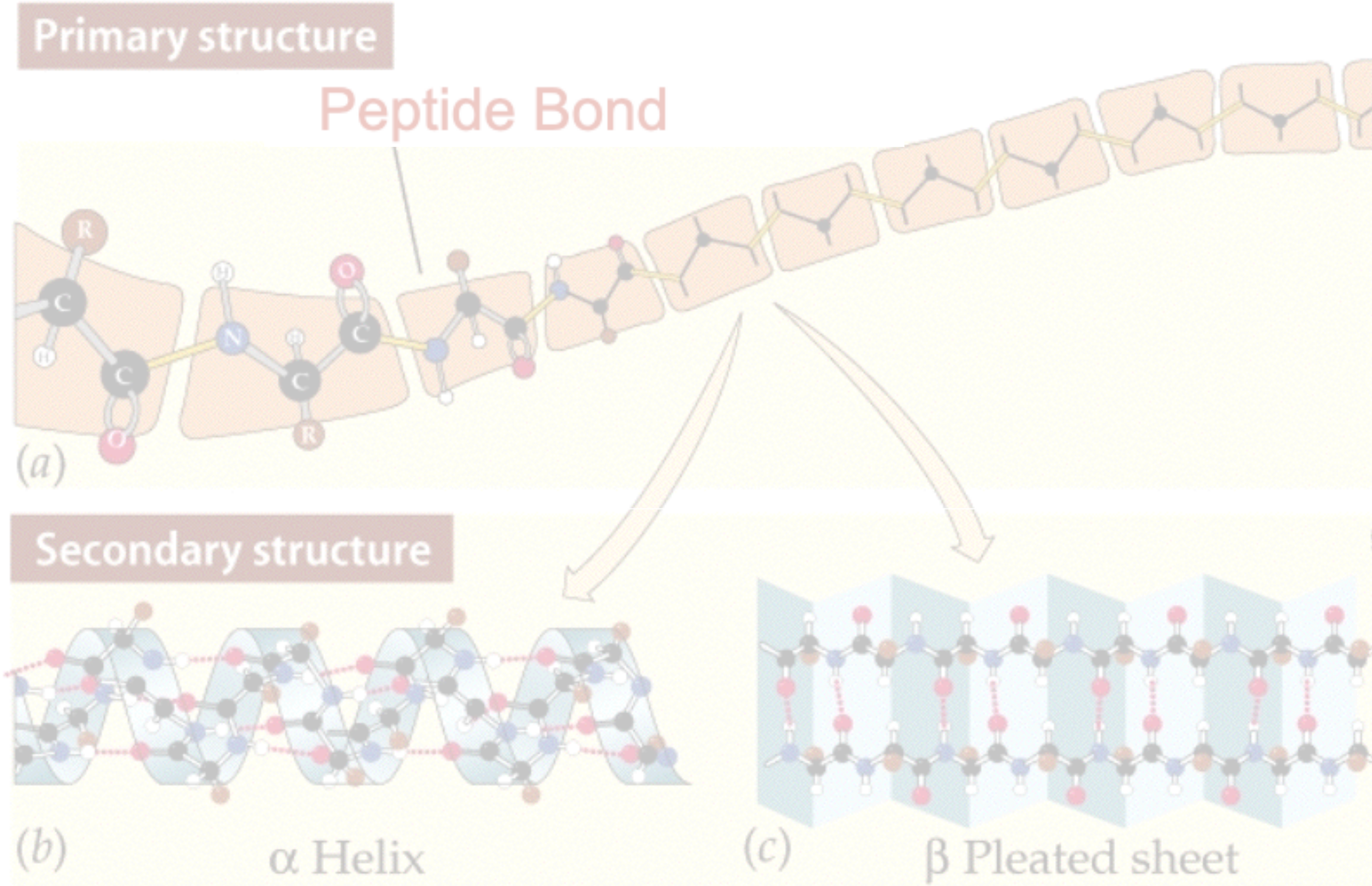


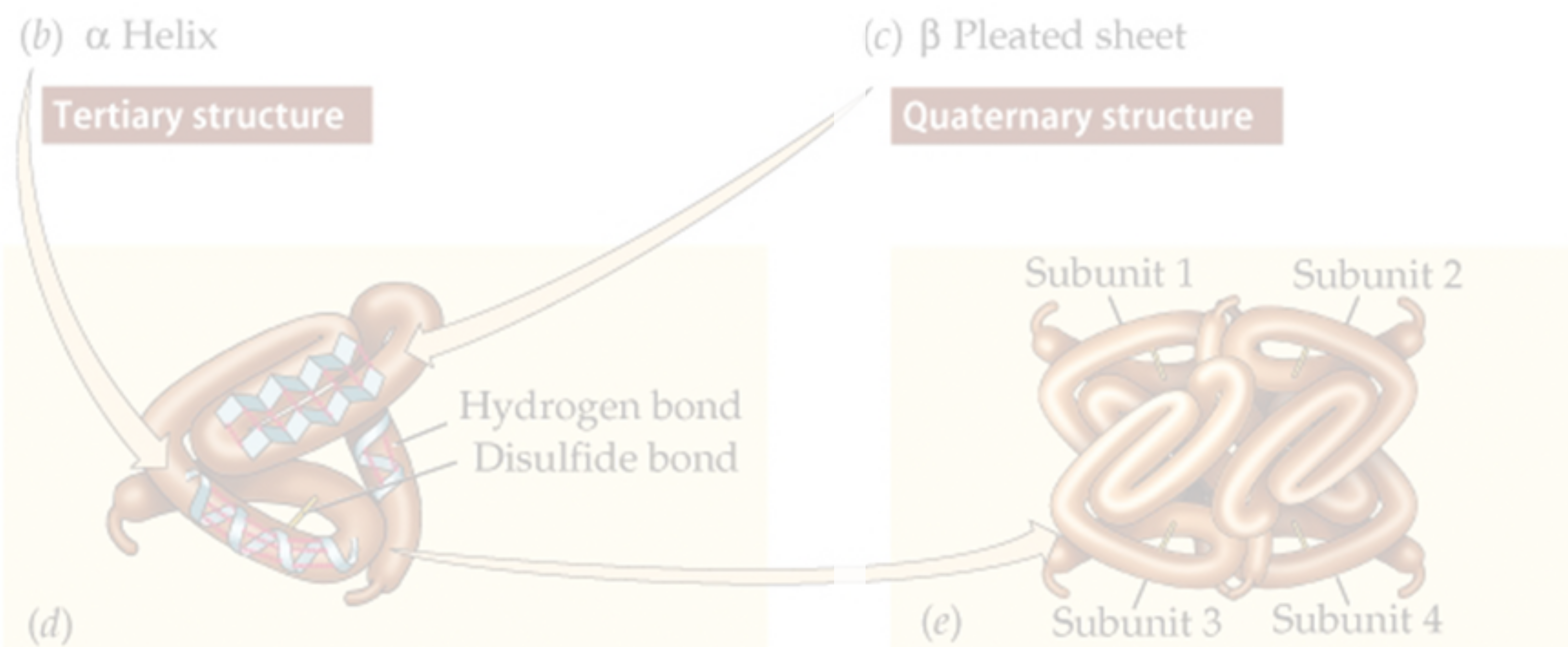
Condensation

Hydrolysis

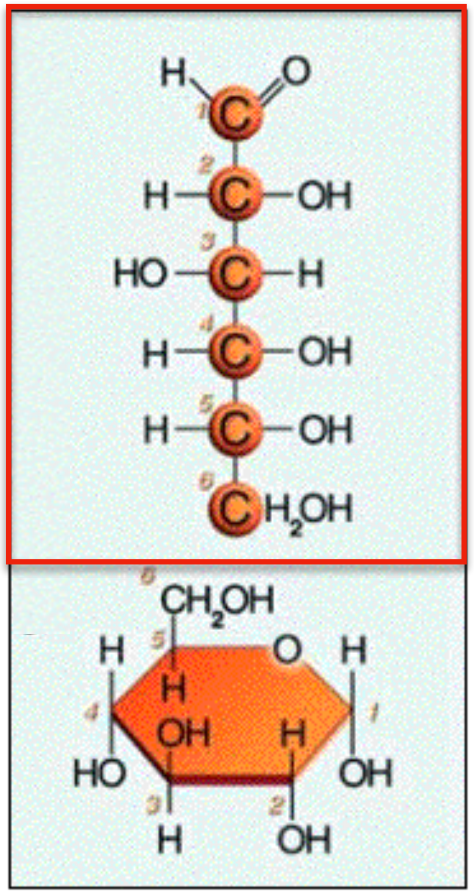
Amino acids


H
H
O
amino group
+H
N
C
C
O−
carboxyl group
H
R
R group: a functional group
© 2001 Brooks/Cole - Thomson Learning

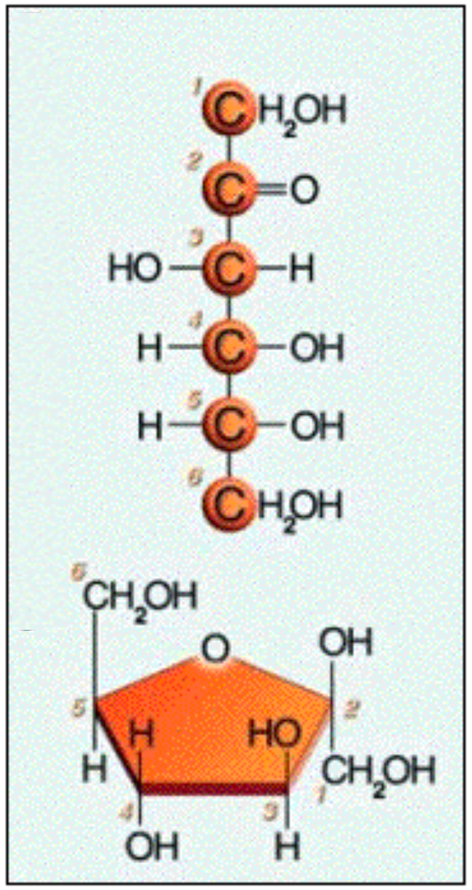

Primary structure
Peptide Bond
(a)
Secondary structure
(b)
α Helix
(c)
β Pleated sheet


(b) α Helix
(c) β Pleated sheet
Tertiary structure
Quaternary structure
Hydrogen bond
Disulfide bond
(d)
Subunit 1
Subunit 2
(e)
Subunit 3
Subunit 4

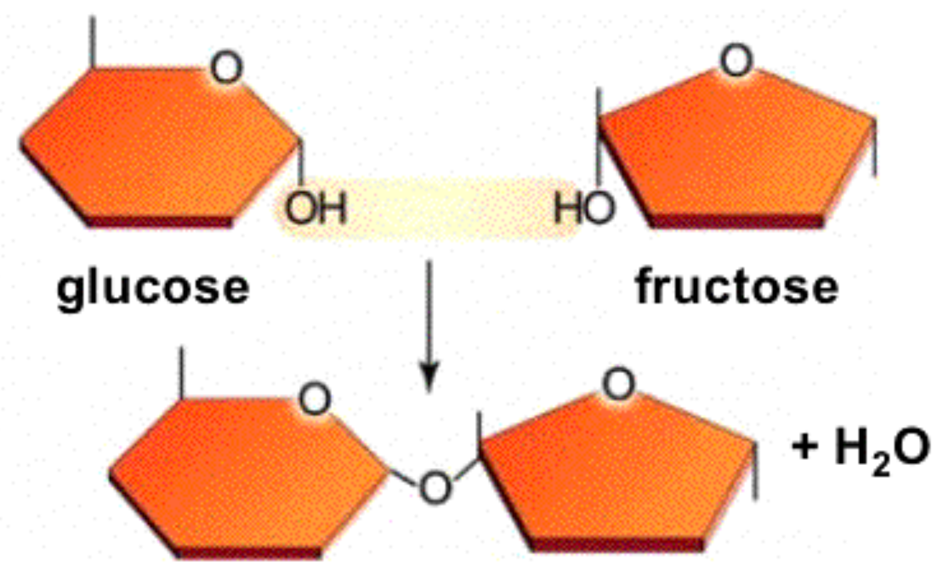
Carbohydrates: Sugars and Sugar Polymers



glucose

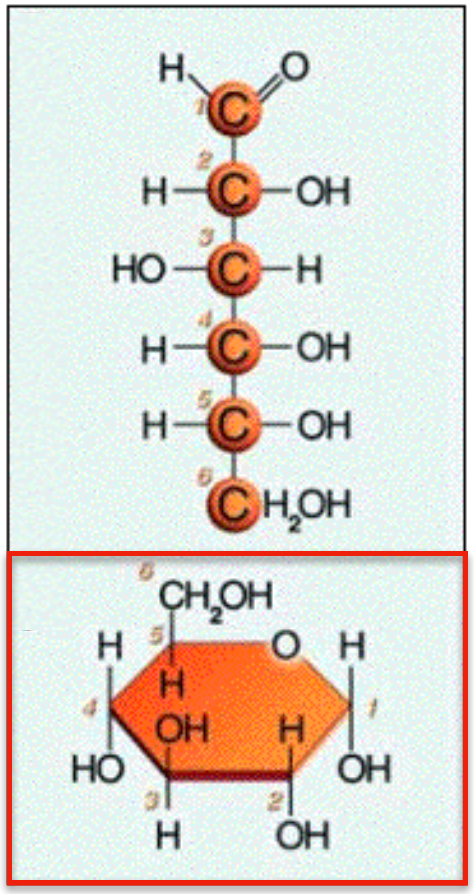


fructose

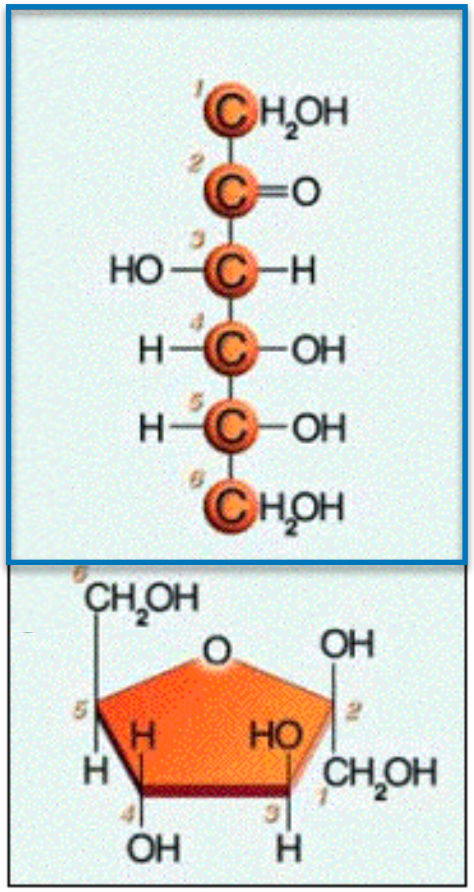


sucrose

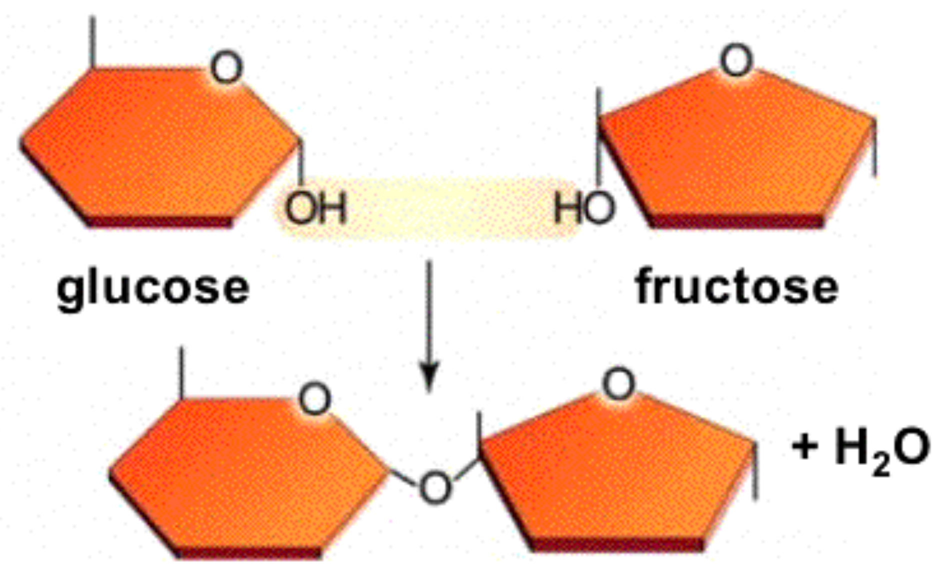
Carbohydrates: Sugars and Sugar Polymers



glucose

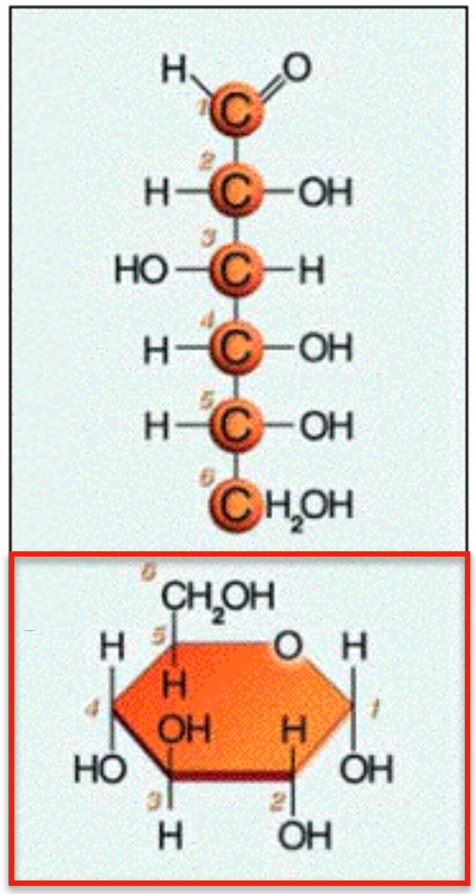


fructose

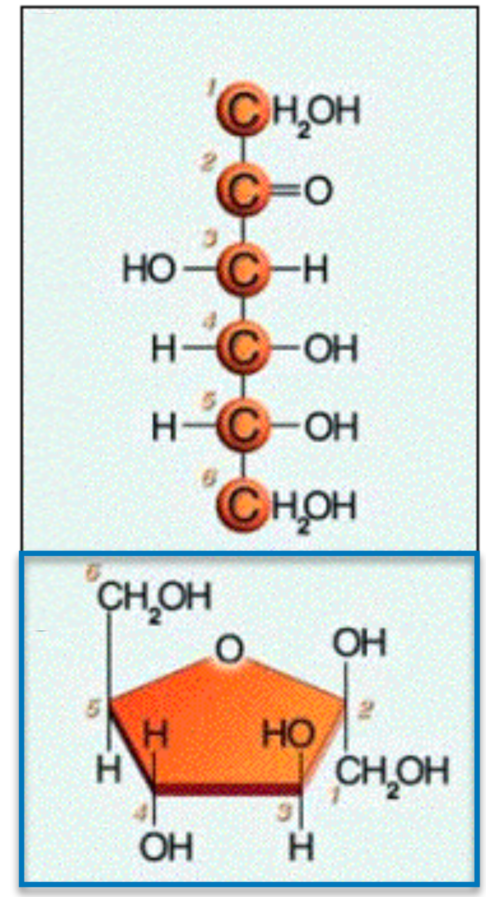


sucrose

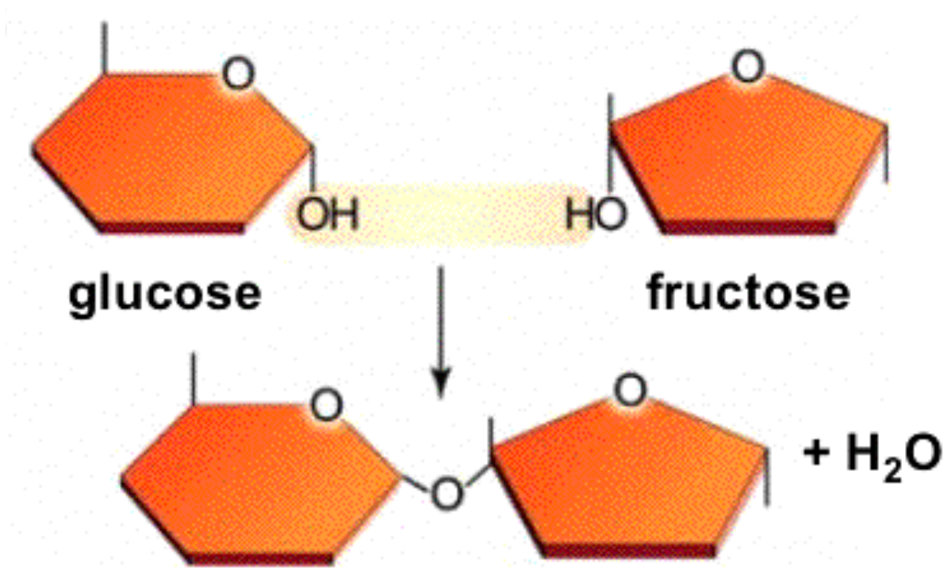
Carbohydrates: Sugars and Sugar Polymers



glucose

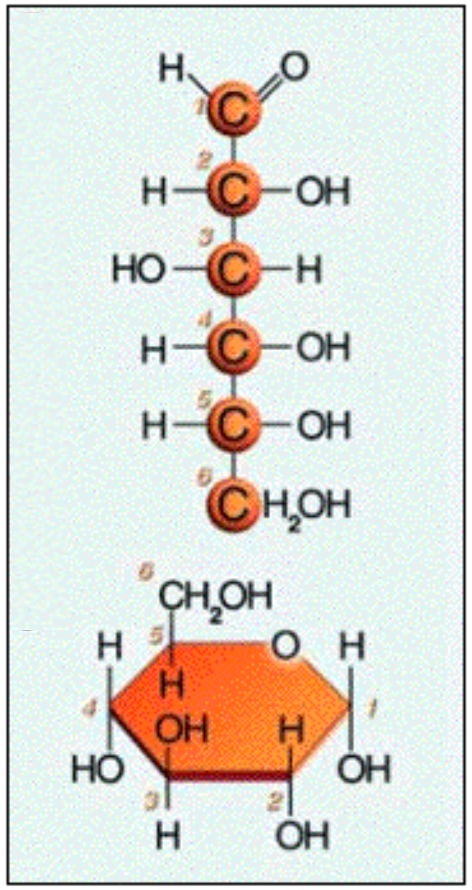


fructose

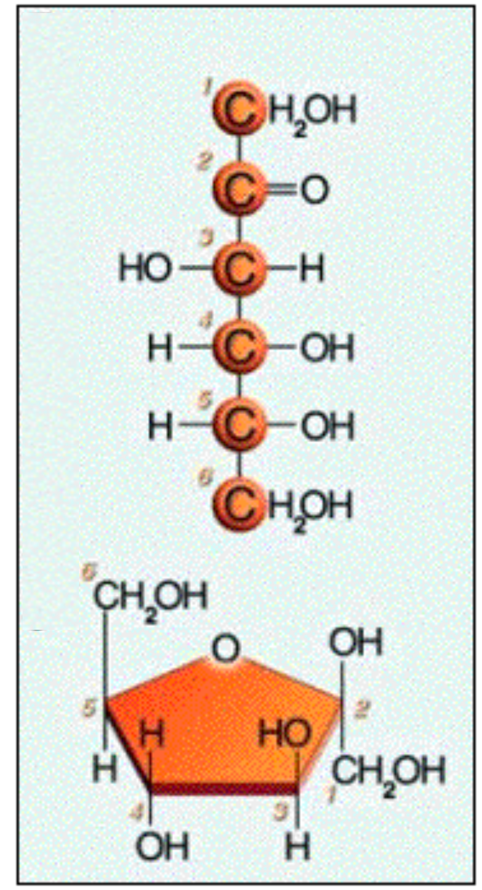


sucrose

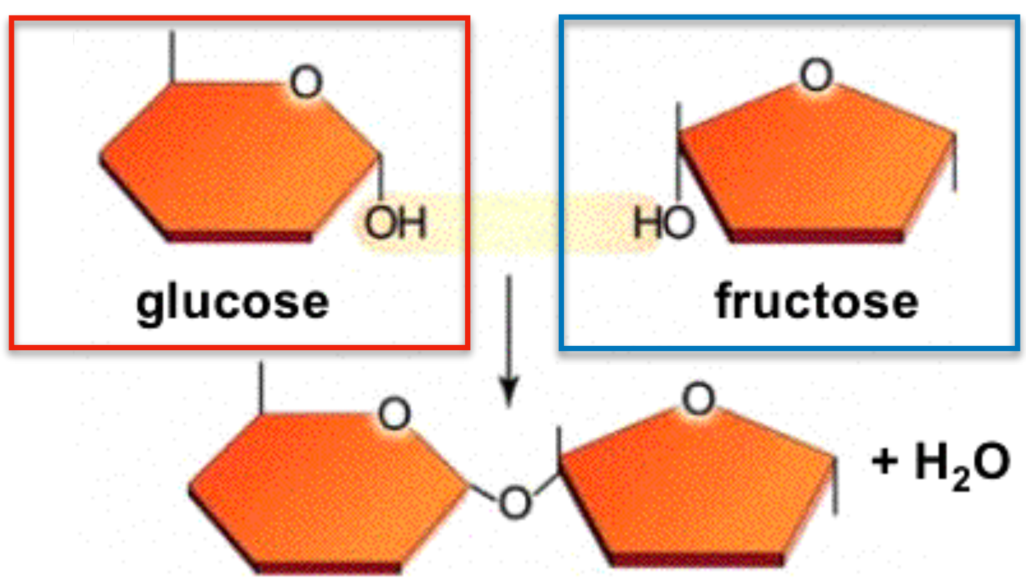
Carbohydrates: Sugars and Sugar Polymers



glucose

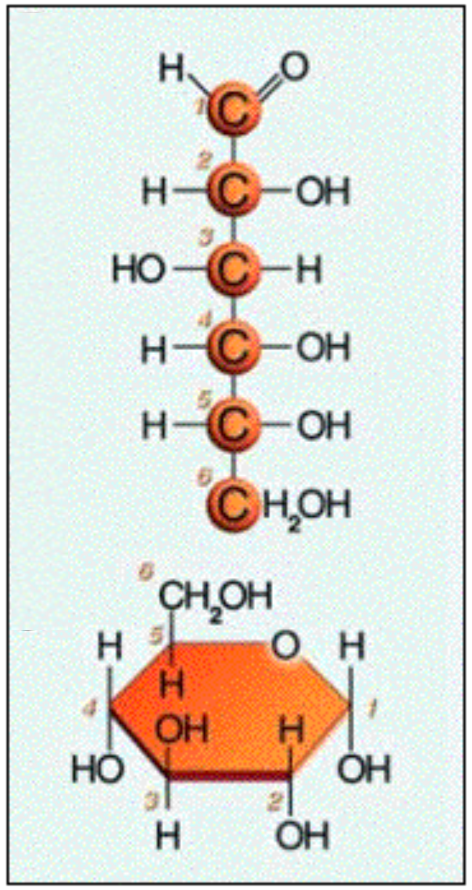


fructose

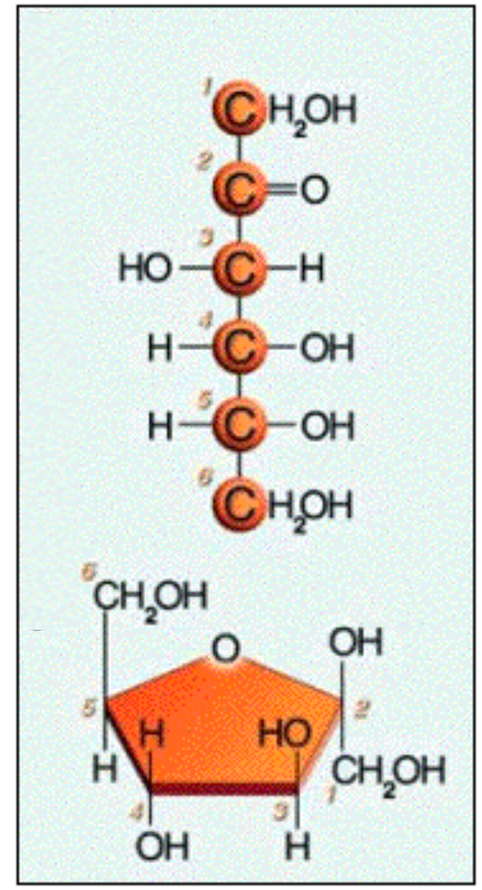


sucrose

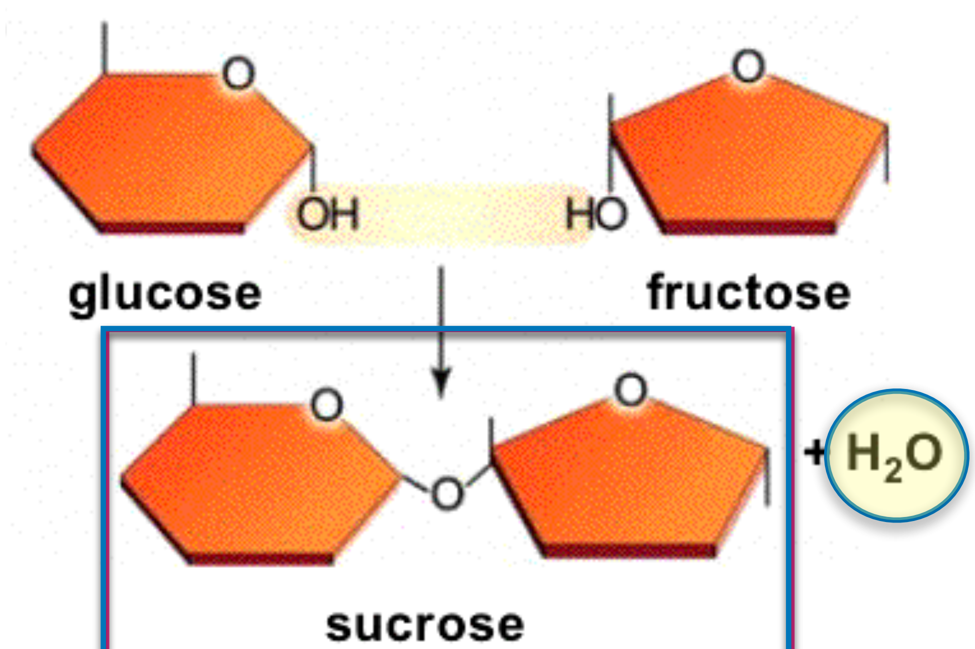
Carbohydrates: Sugars and Sugar Polymers



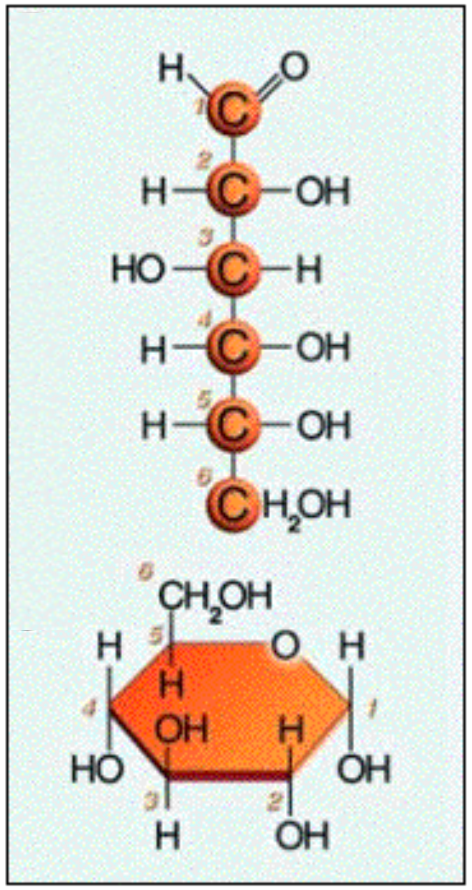
glucose



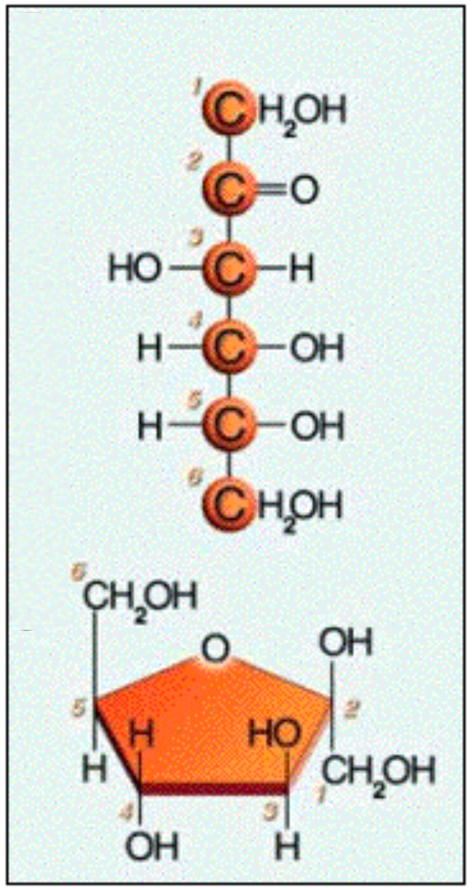
fructose



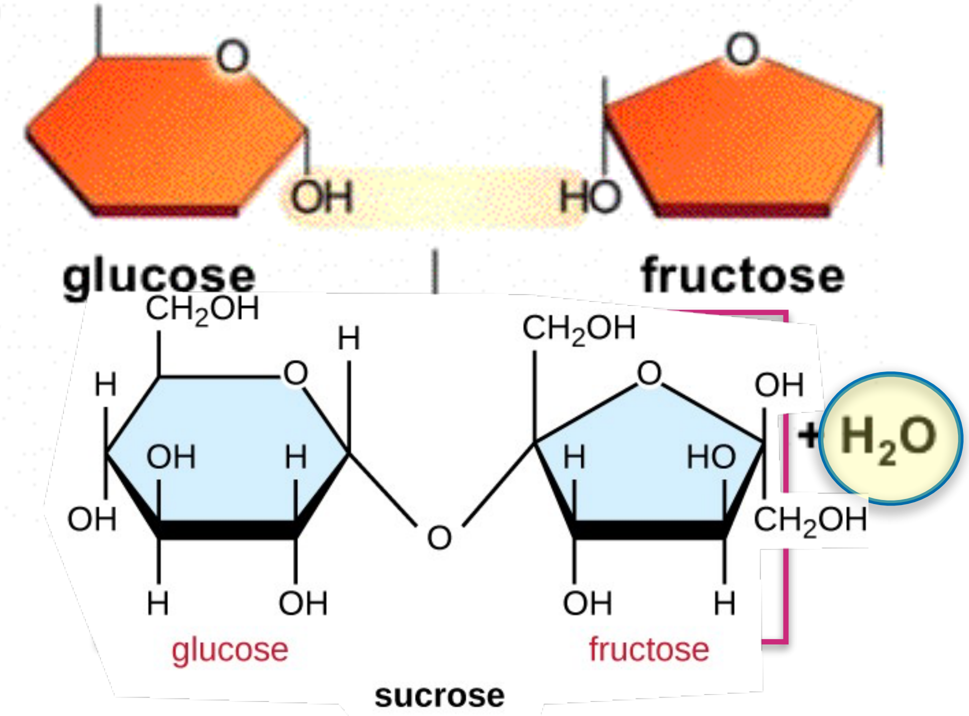
Carbohydrates: Sugars and Sugar Polymers

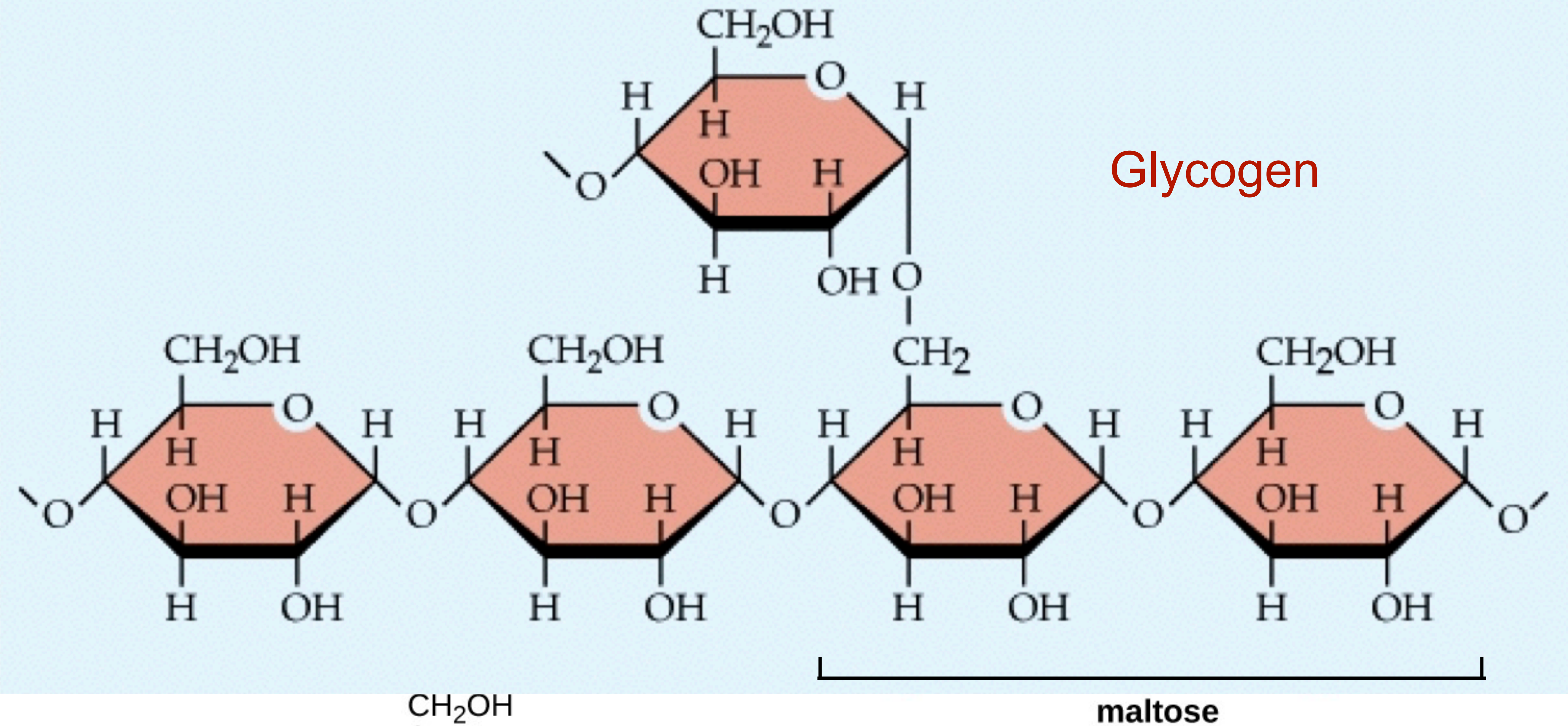


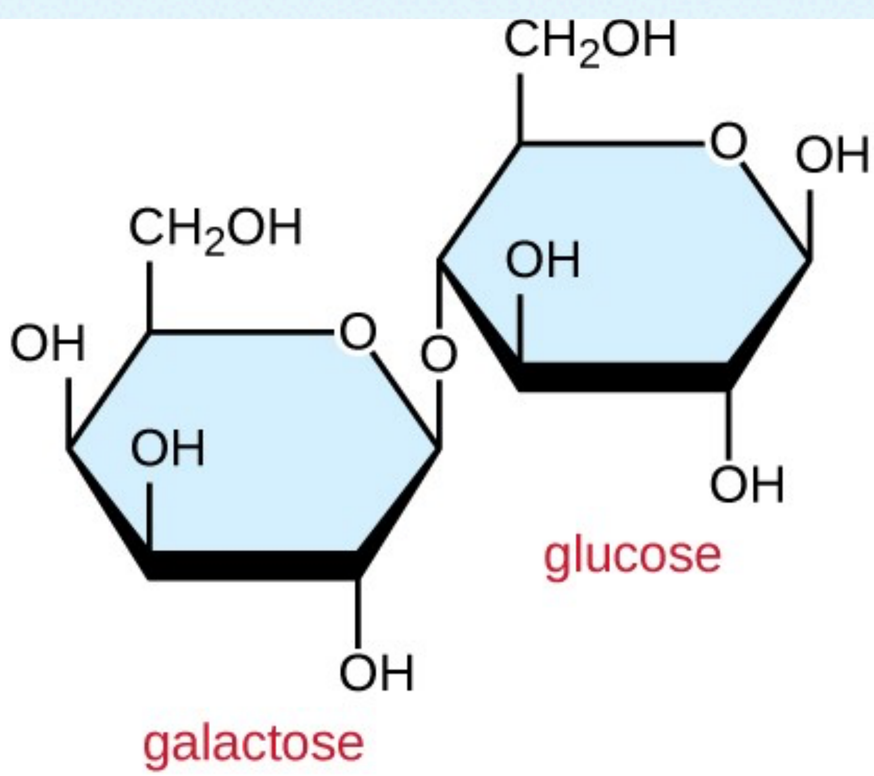
glucose



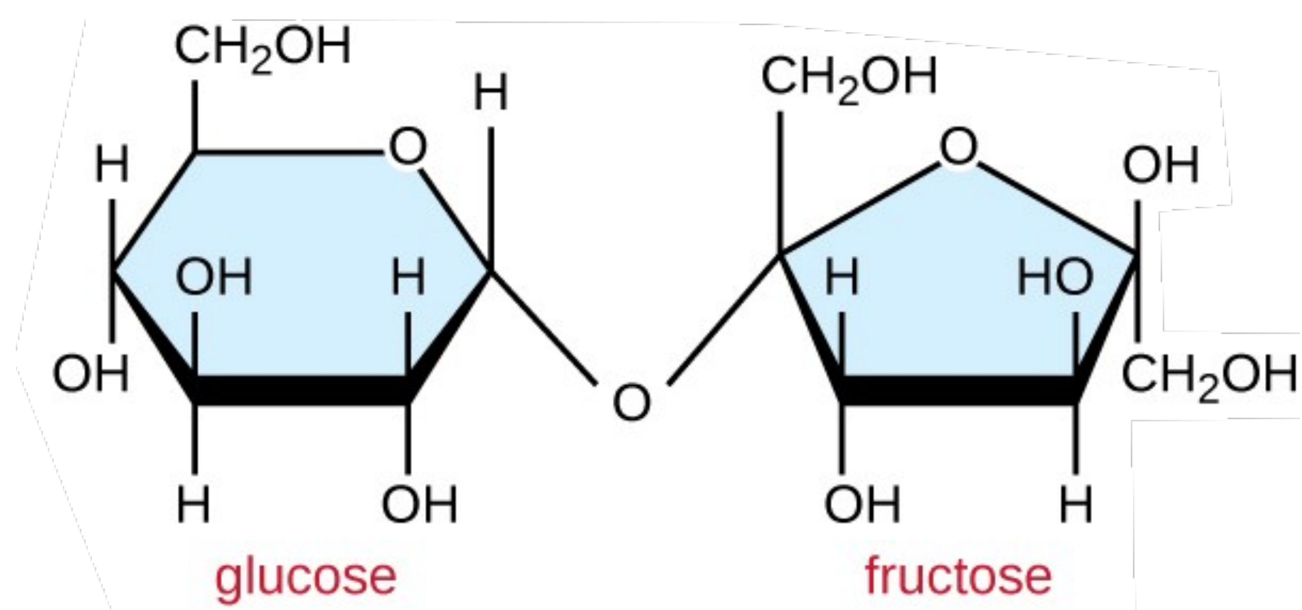
fructose





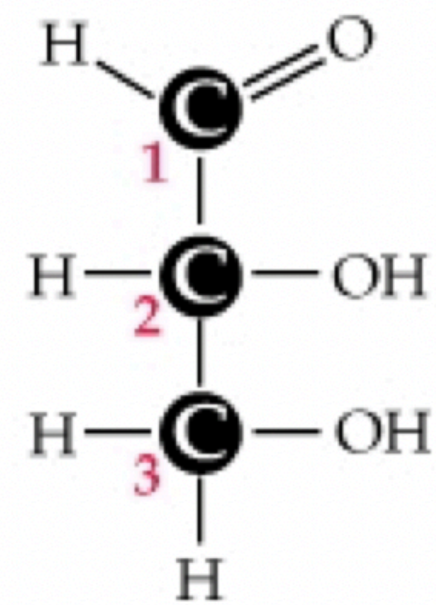


lactose

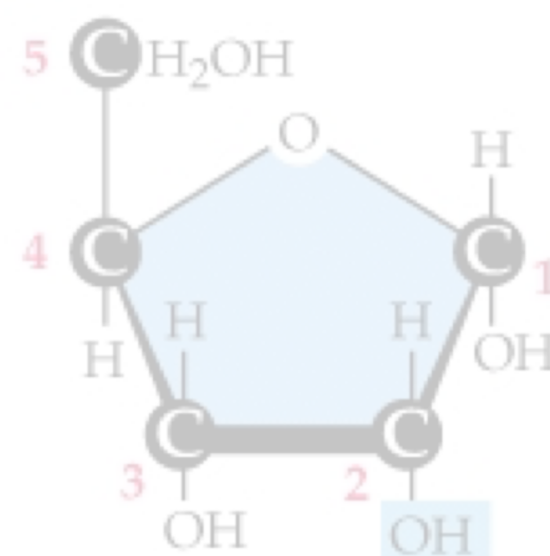


sucrose

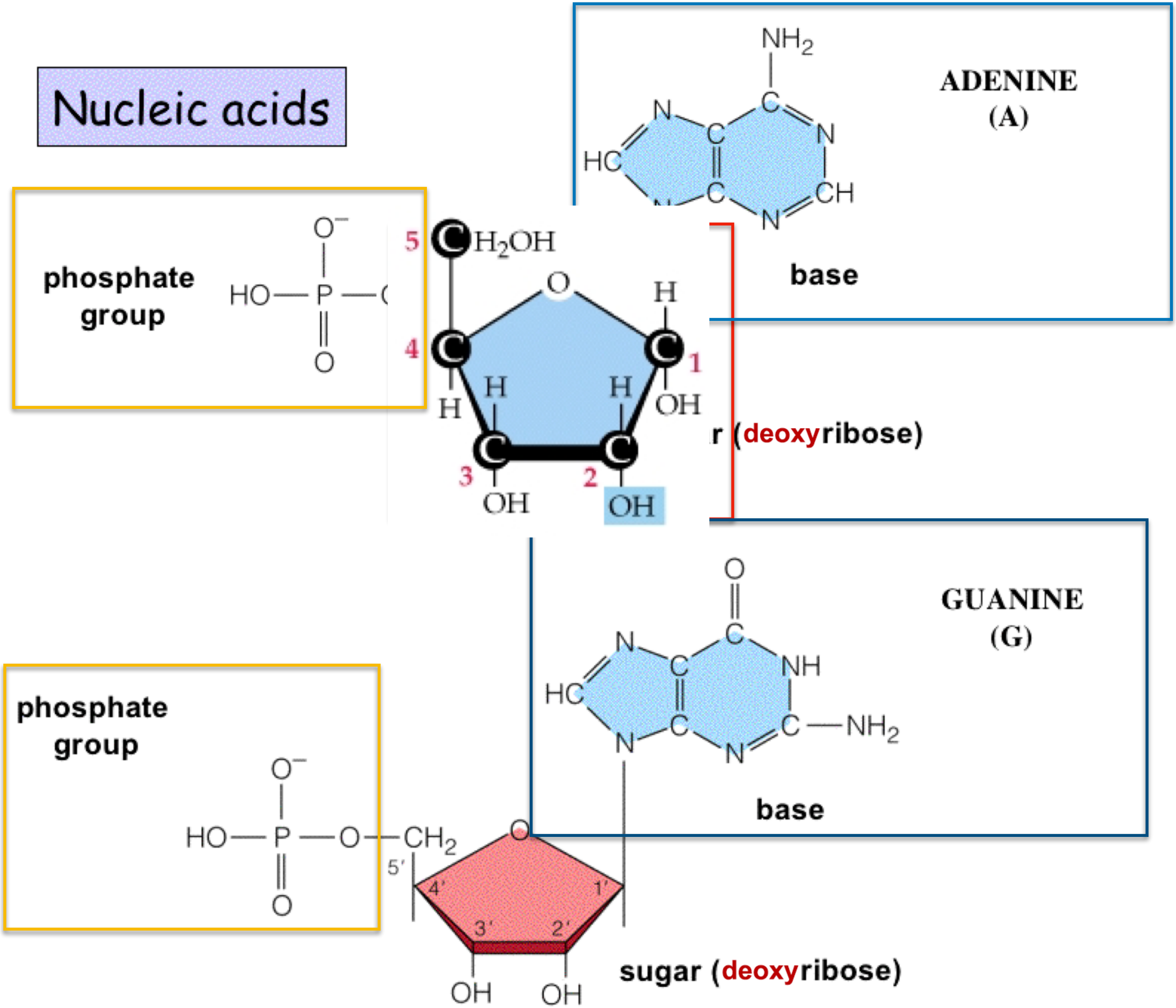
Three-carbon sugar

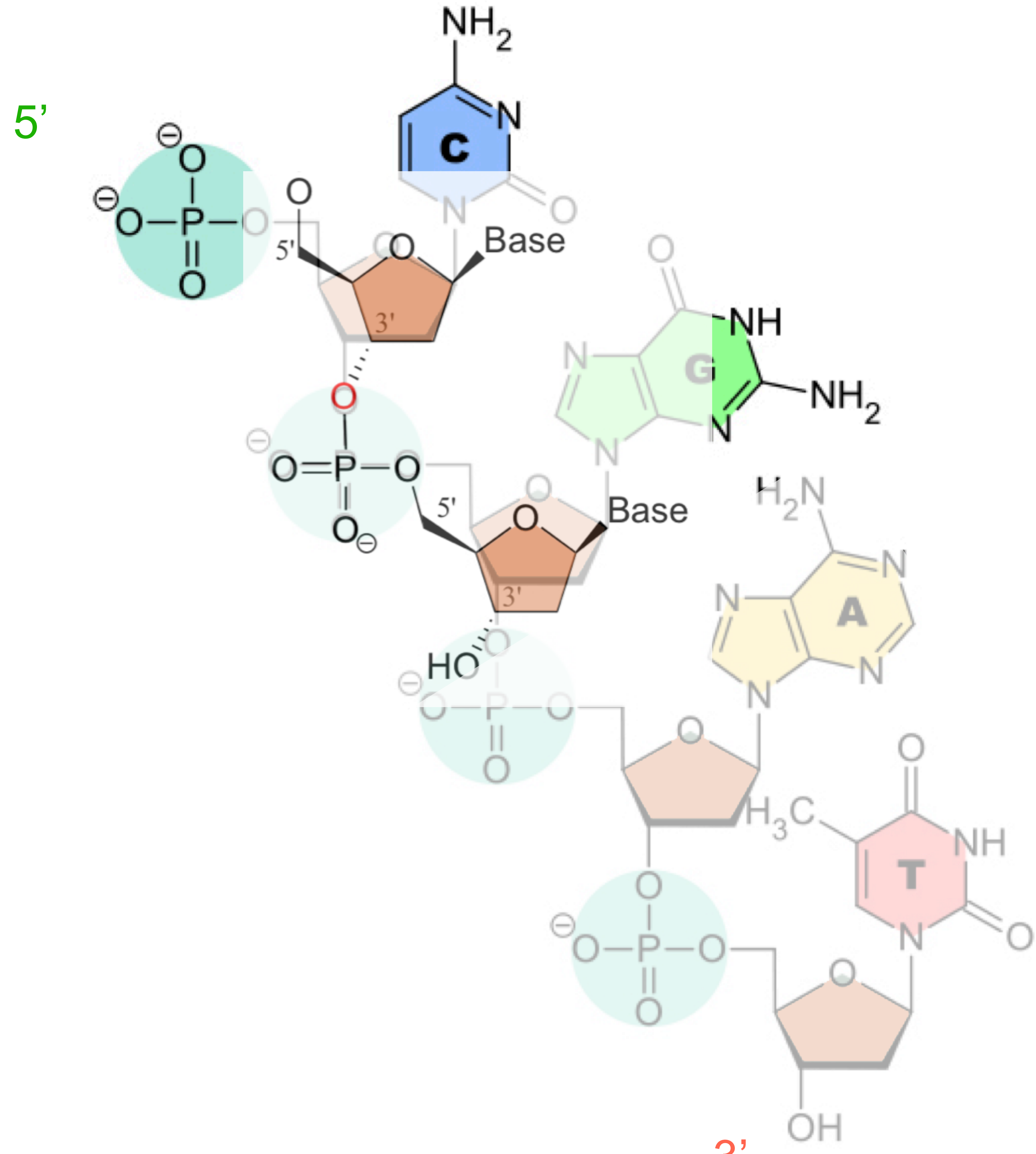


Five-carbon sugars

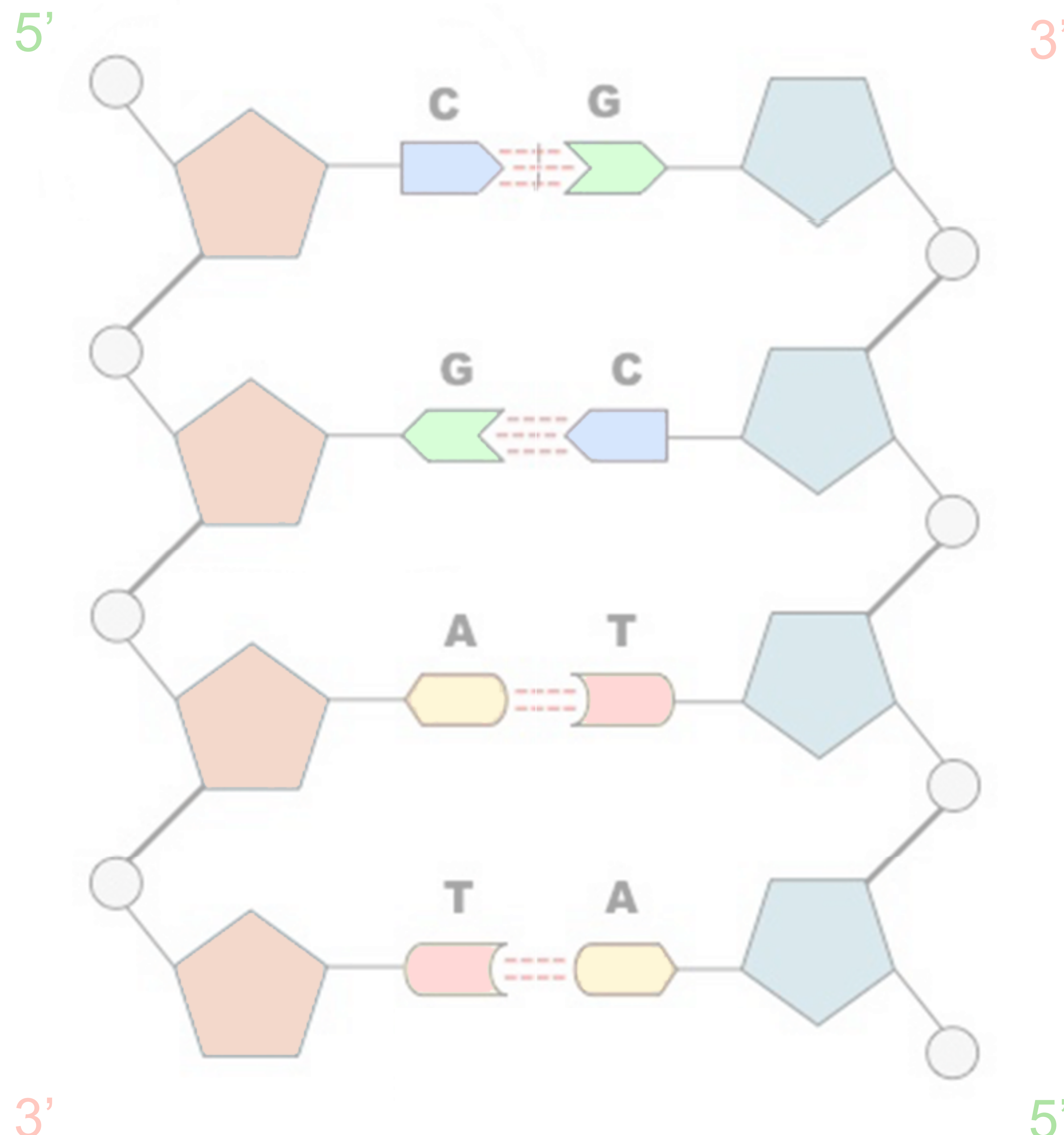


Nucleic acids

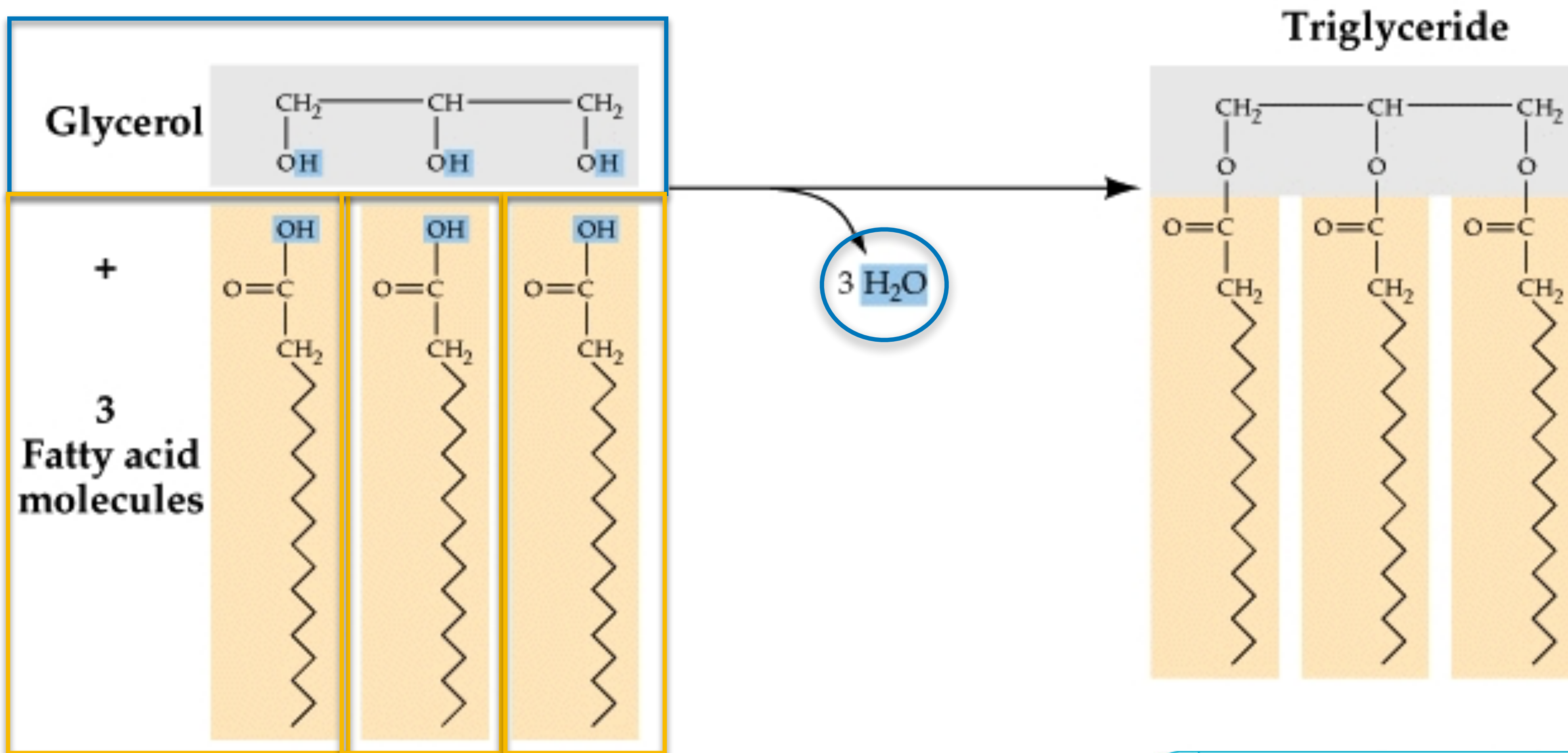


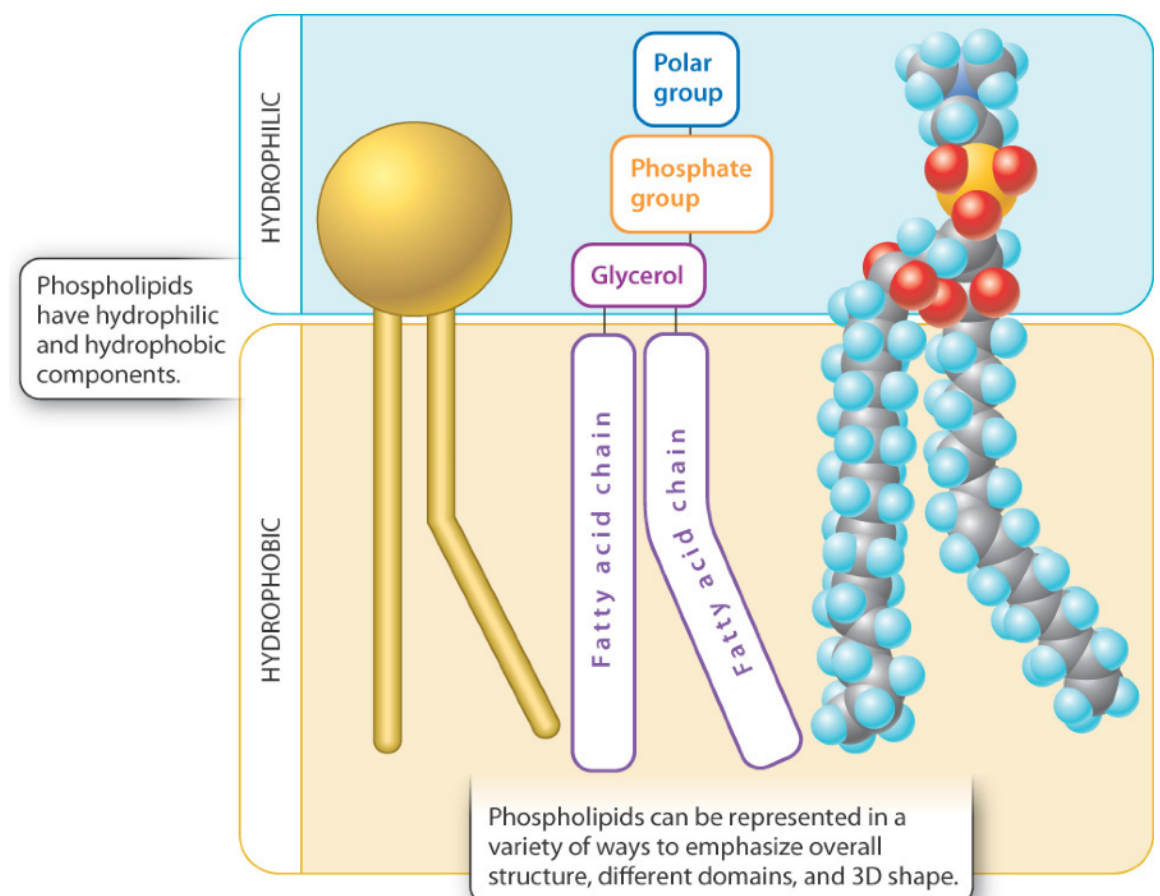


5’
3’
C
G
A
T
Base
Base
NH2
NH
H3C
OH
HO
5'
3'

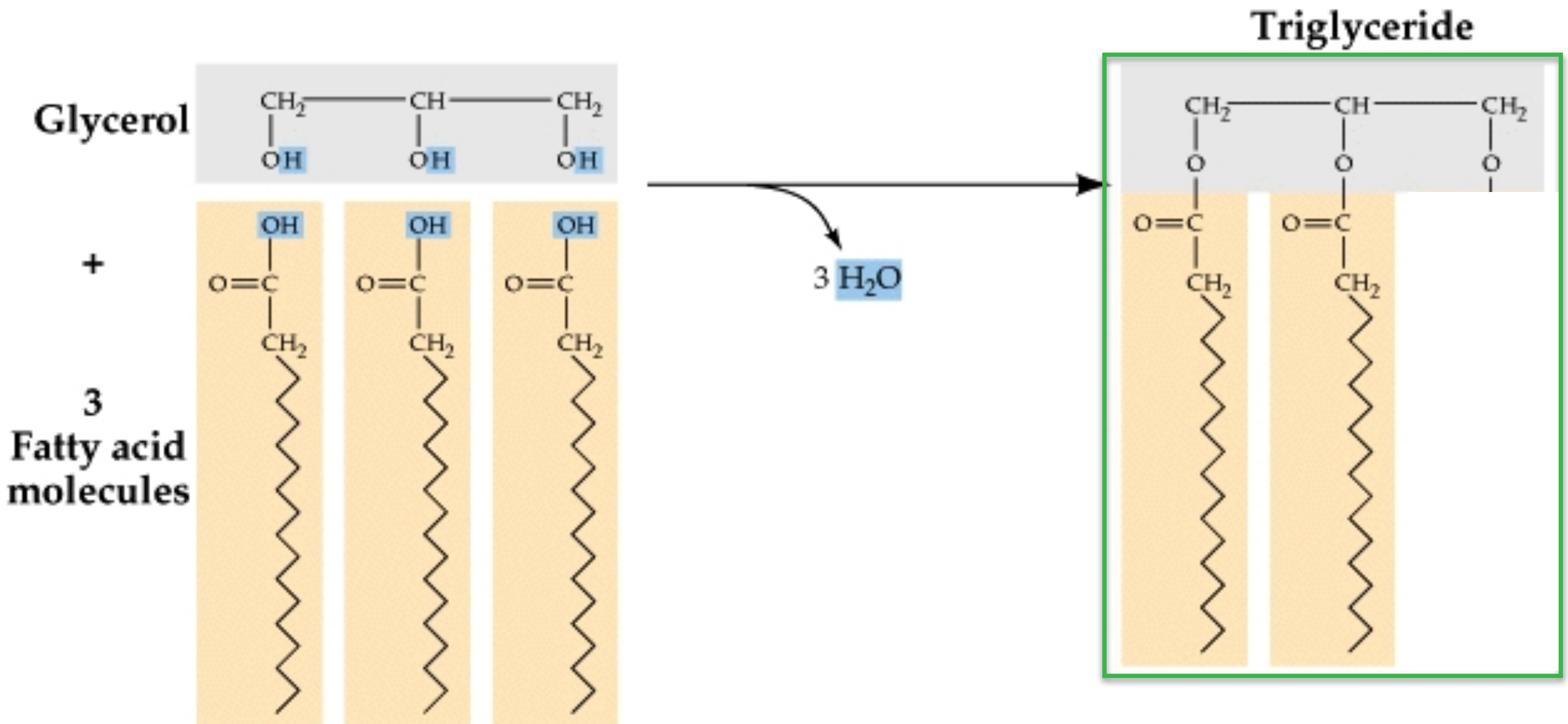

5'
3'
C
G
G
C
A
T
T
A
3'
5'

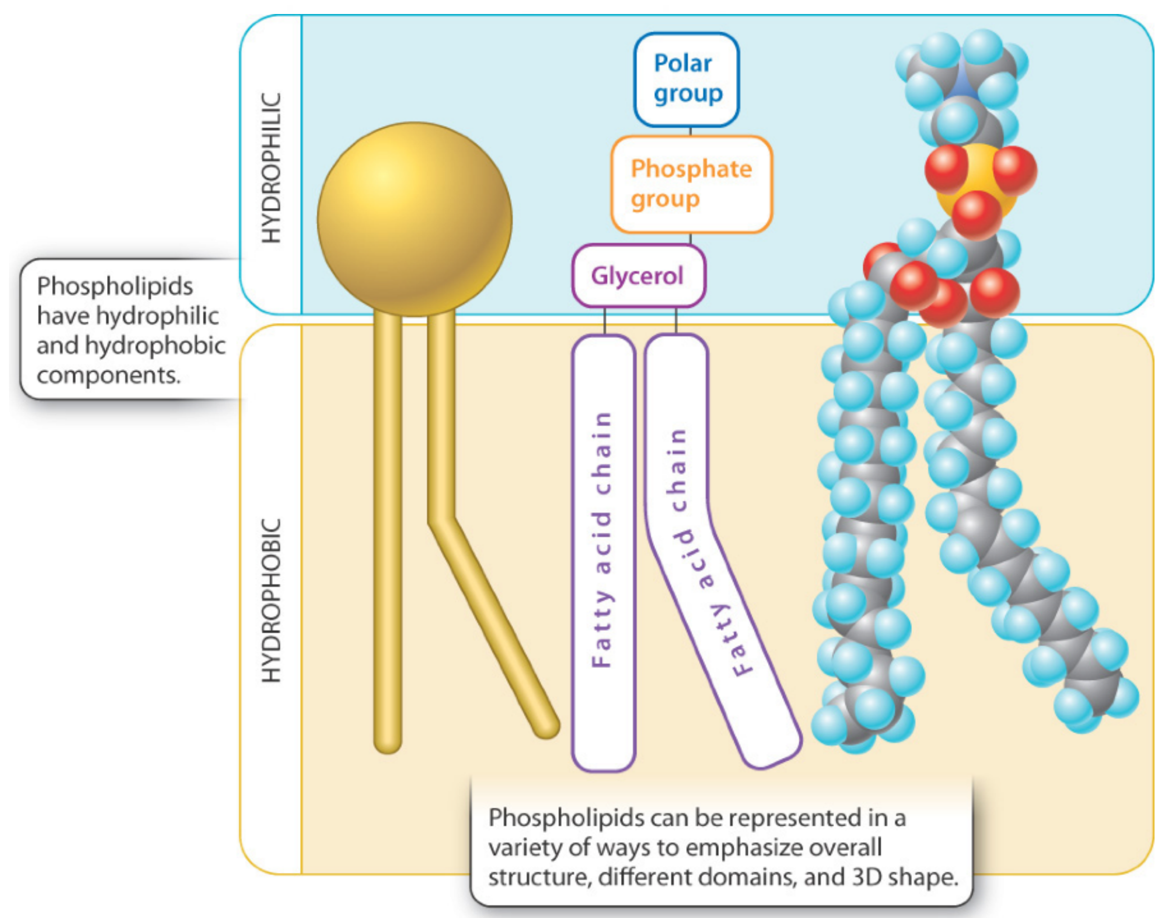
Lipids are in essence the "water-insoluble" molecules of life.



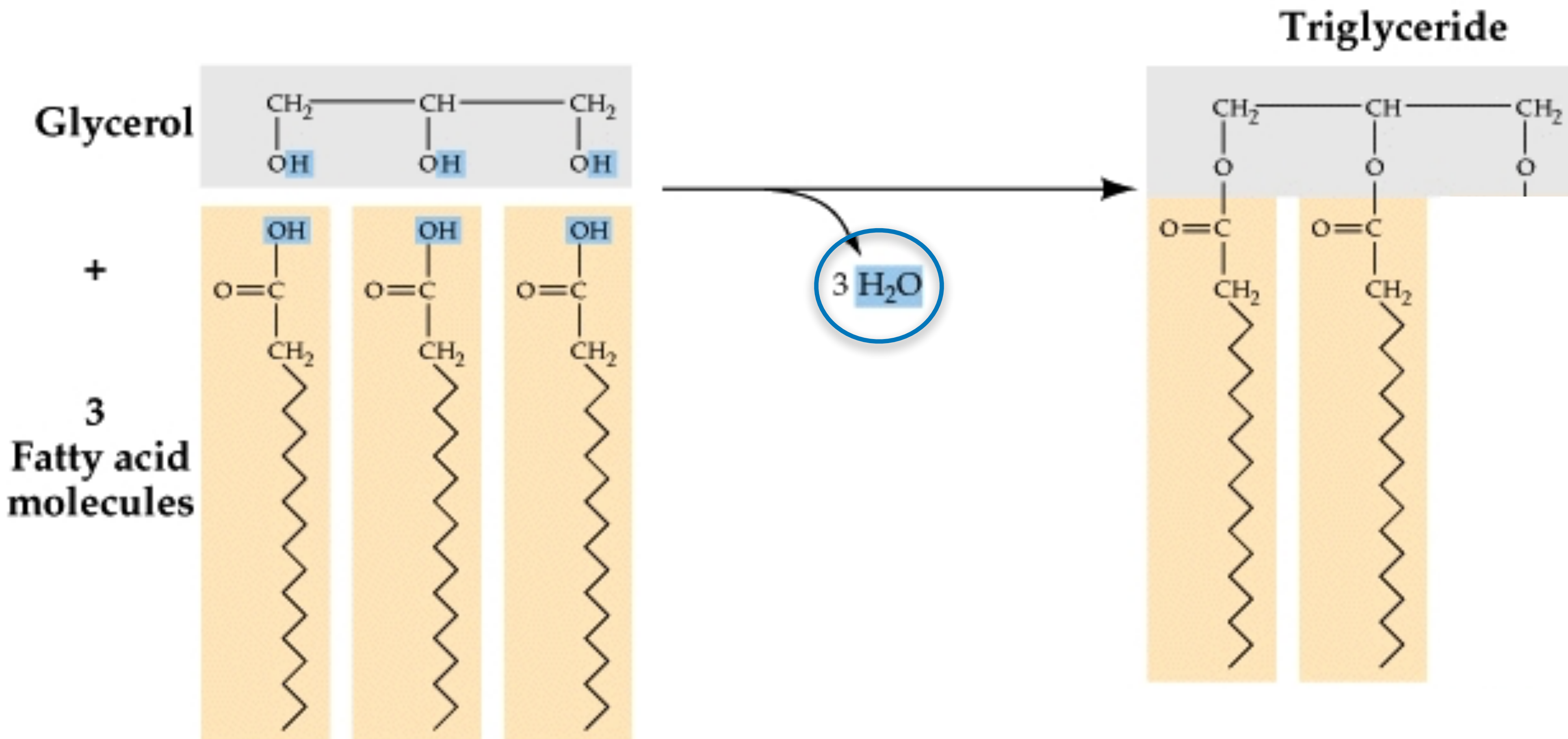


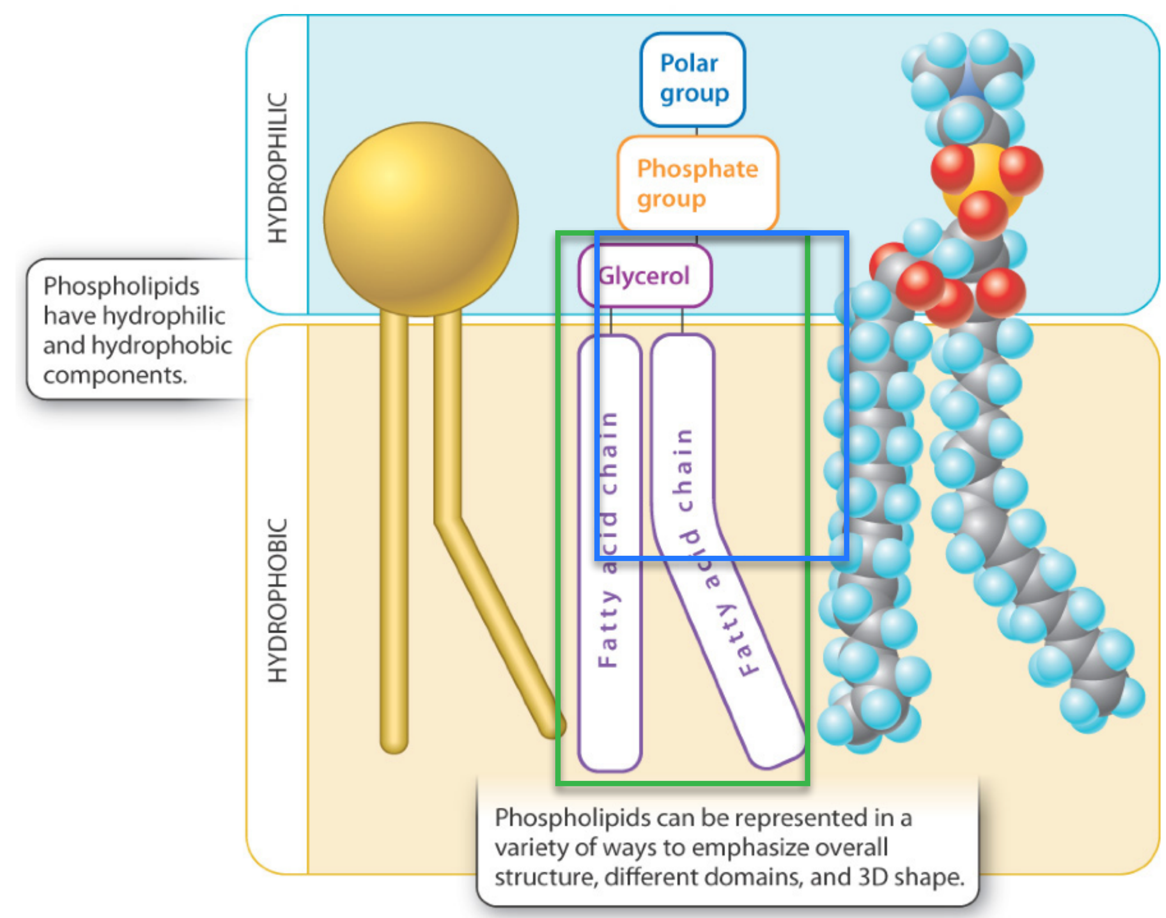
Lipids are in essence the "water-insoluble" molecules of life.



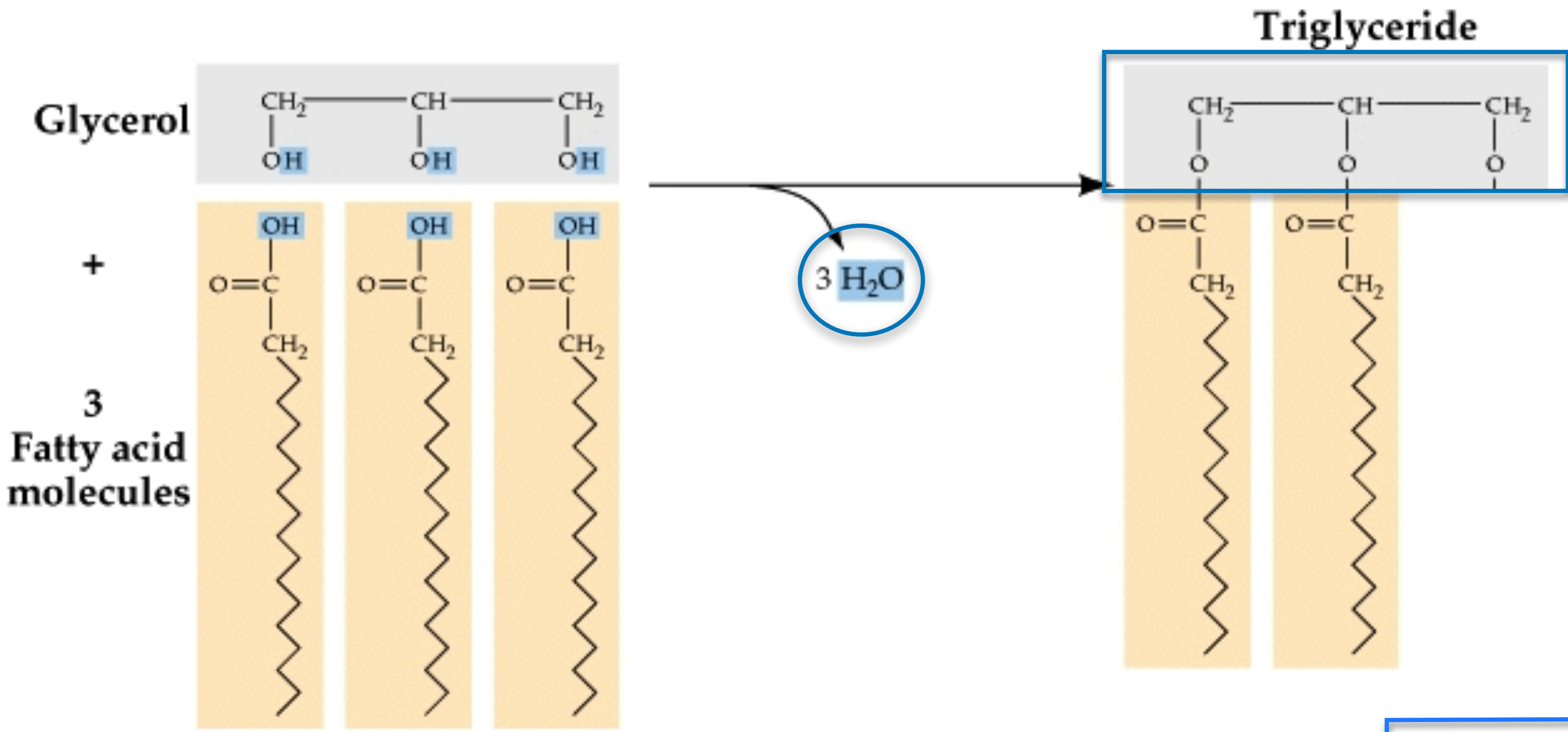


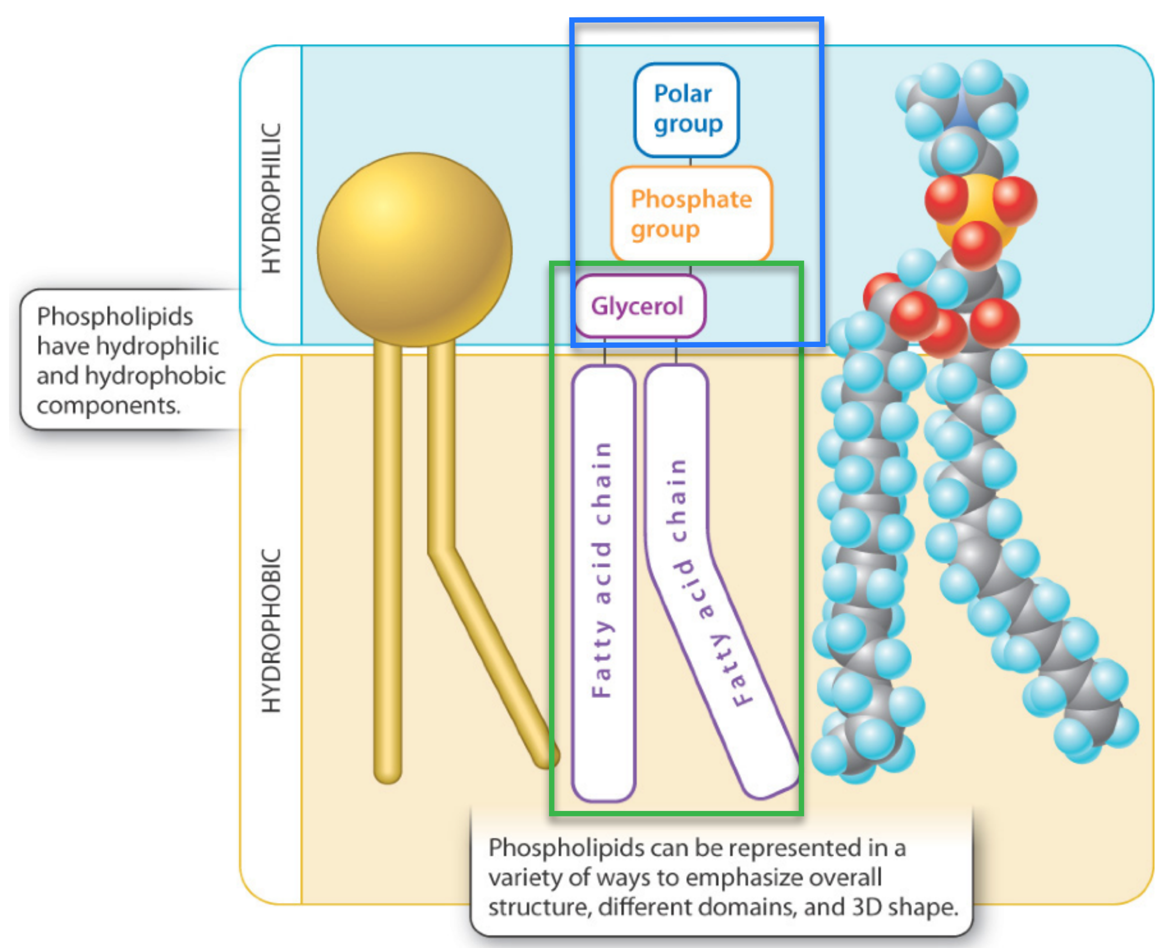
Lipids are in essence the "water-insoluble" molecules of life.

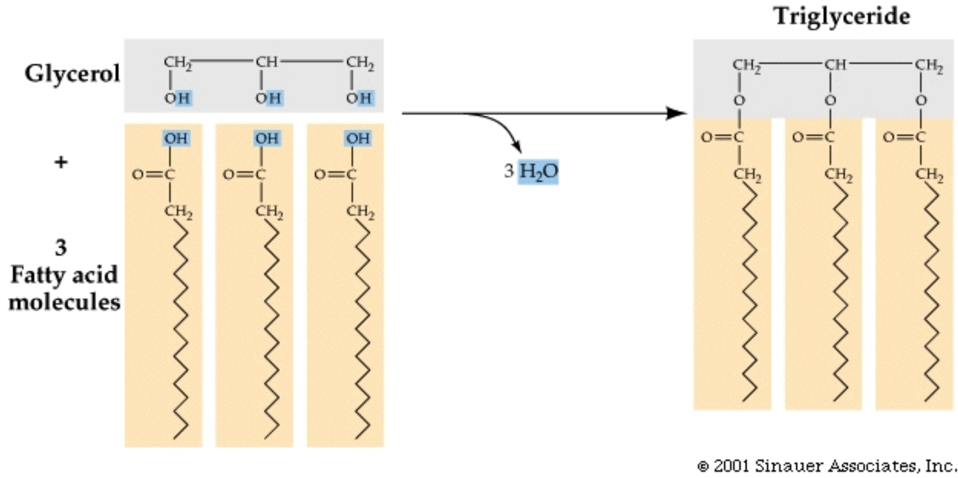


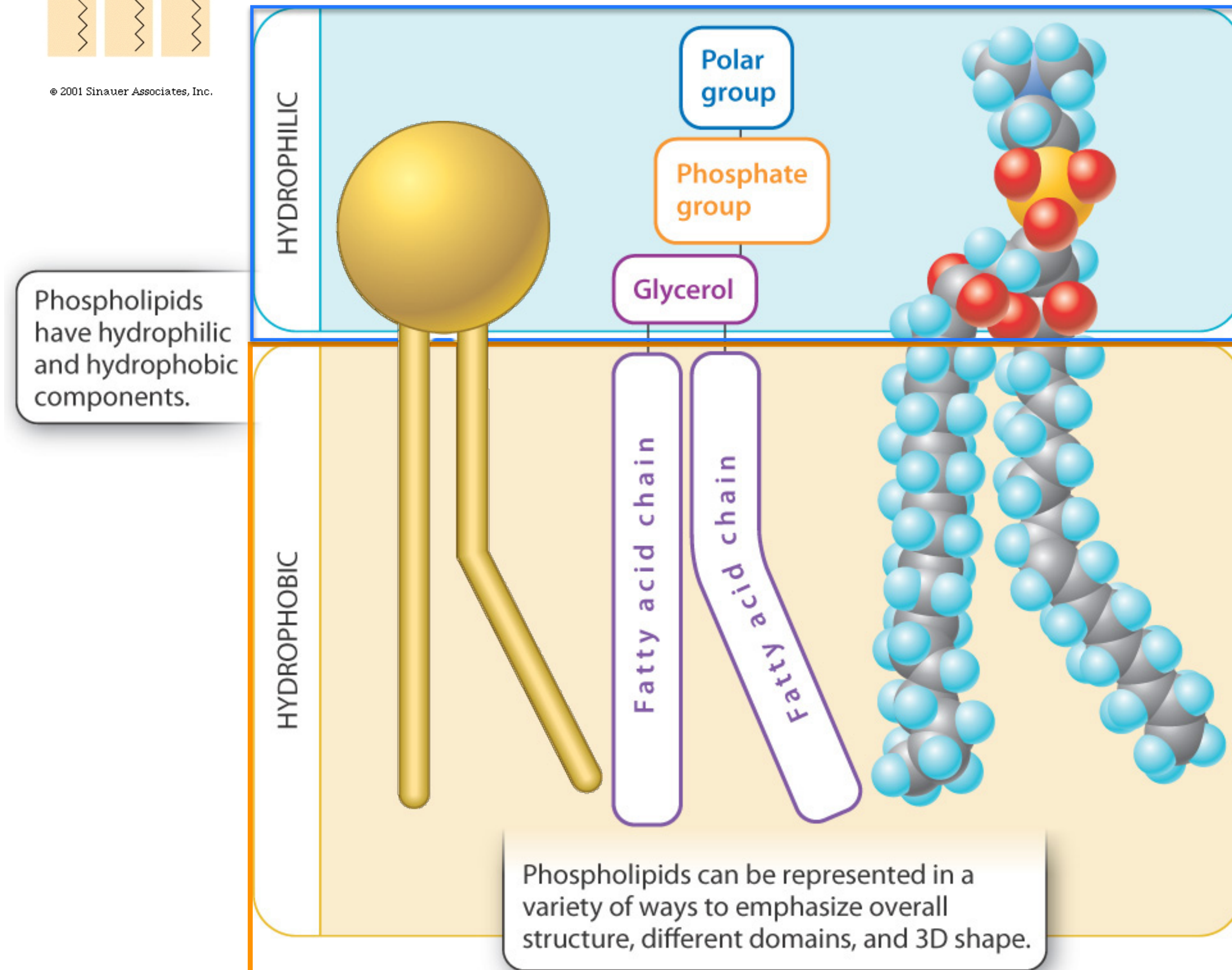


Lipids are in essence the "water-insoluble" molecules of life.



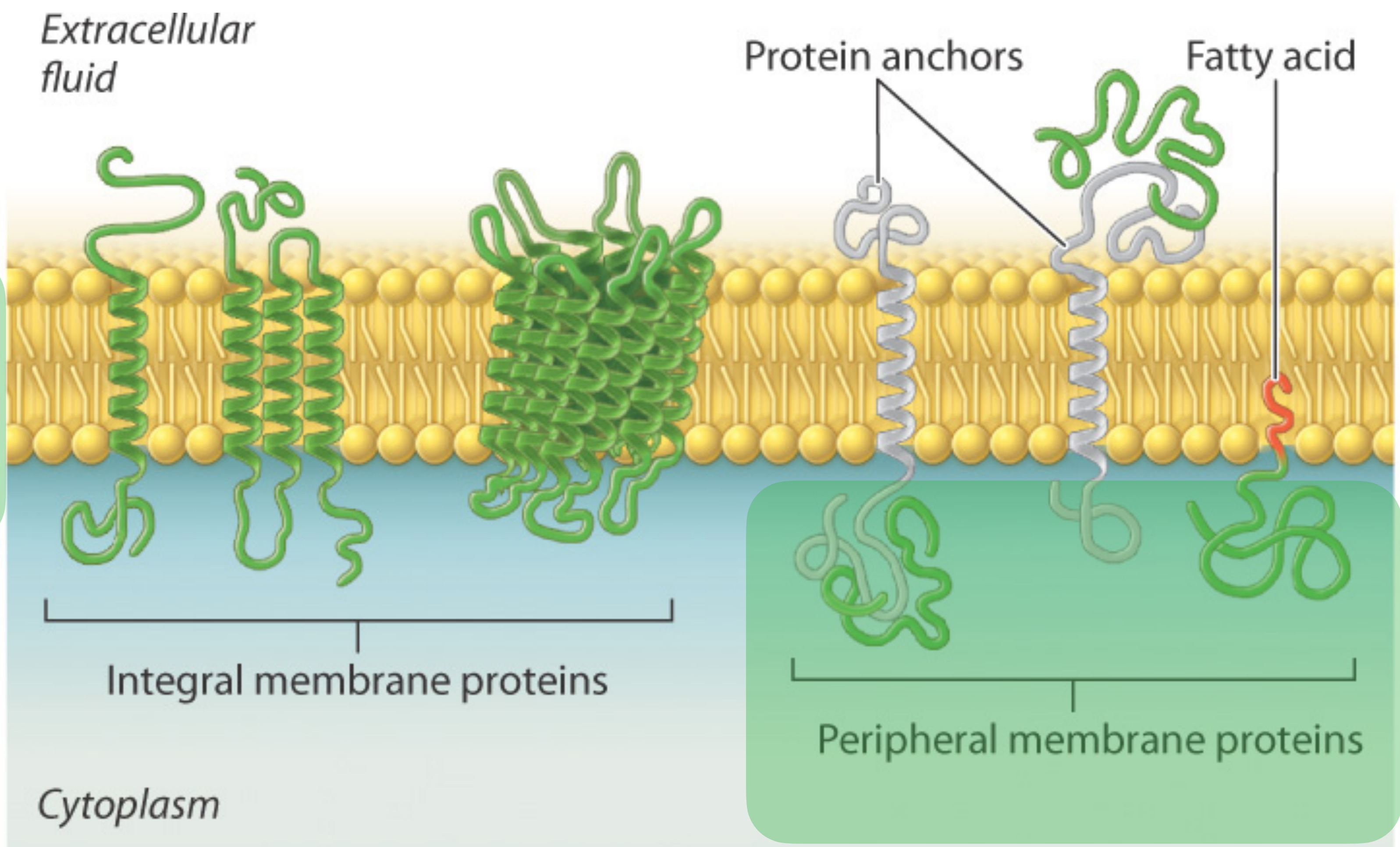



Triglyceride
Glycerol
+
3
Fatty acid
molecules
3 H2O
© 2001 Sinauer Associates, Inc.

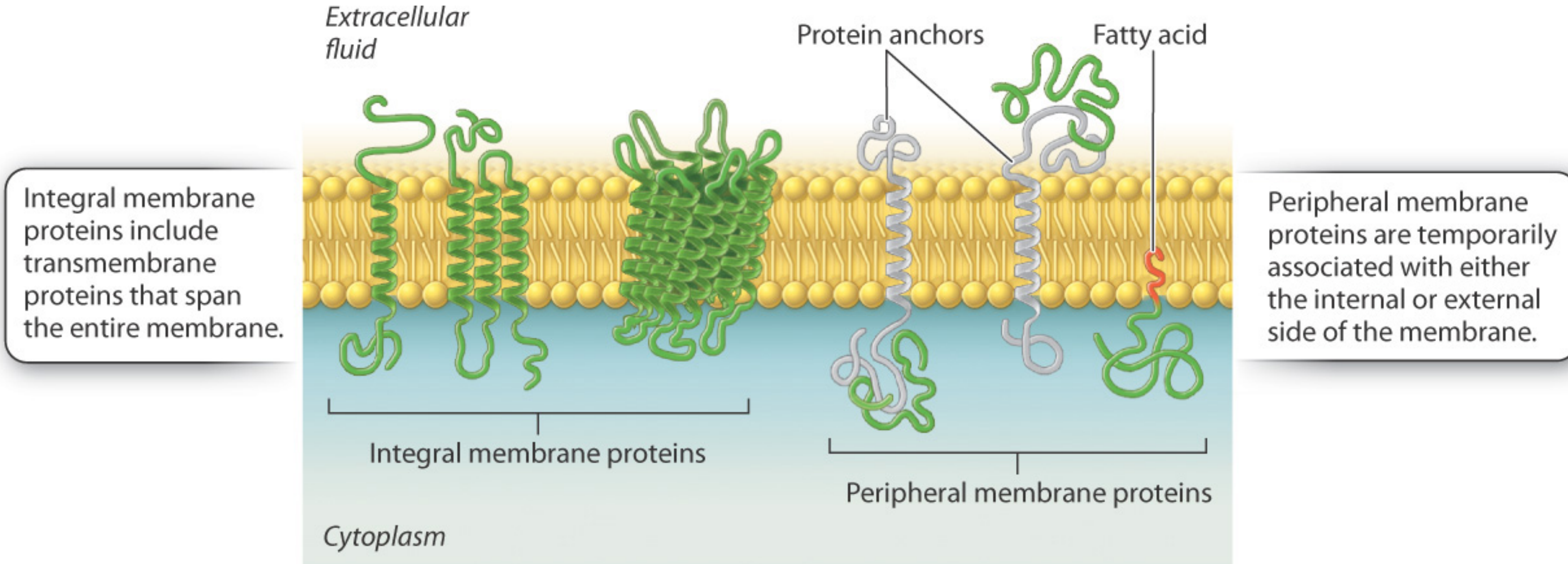

HYDROPHILIC
HYDROPHOBIC
Polar group
Phosphate group
Glycerol
Fatty acid chain
Fatty acid chain
Phospholipids have hydrophilic and hydrophobic components.
Phospholipids can be represented in a variety of ways to emphasize overall structure, different domains, and 3D shape.

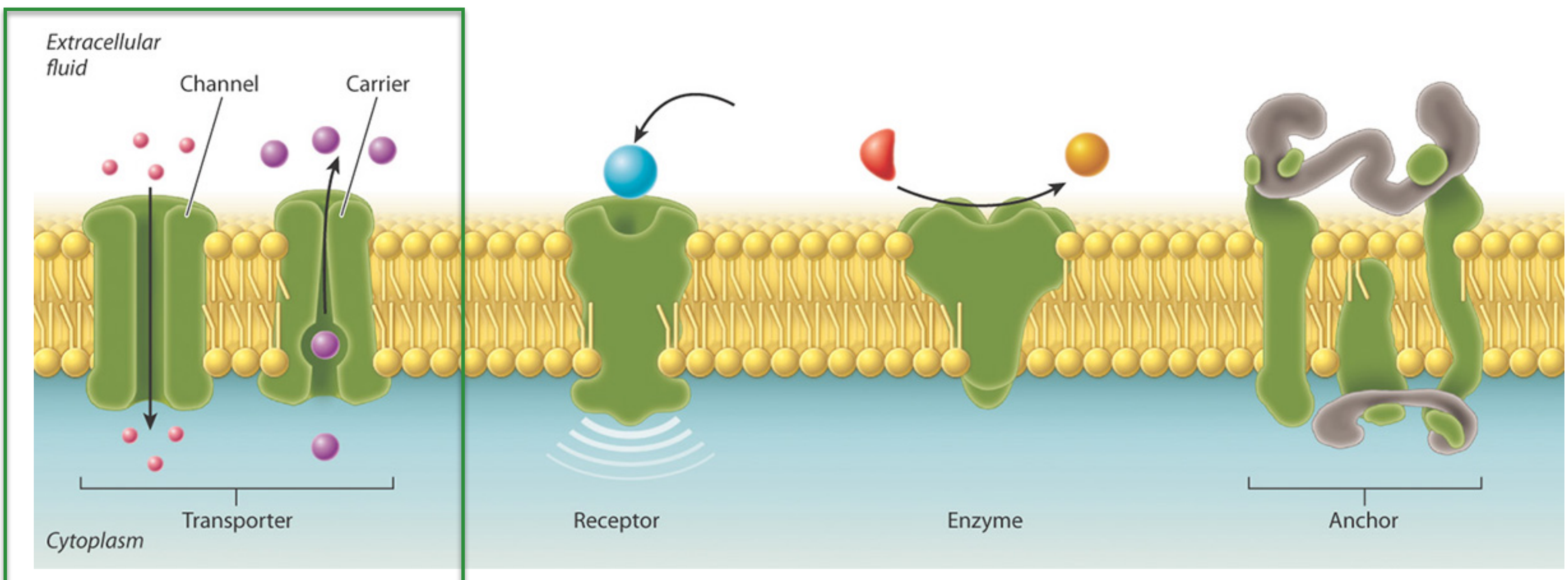
Lipids

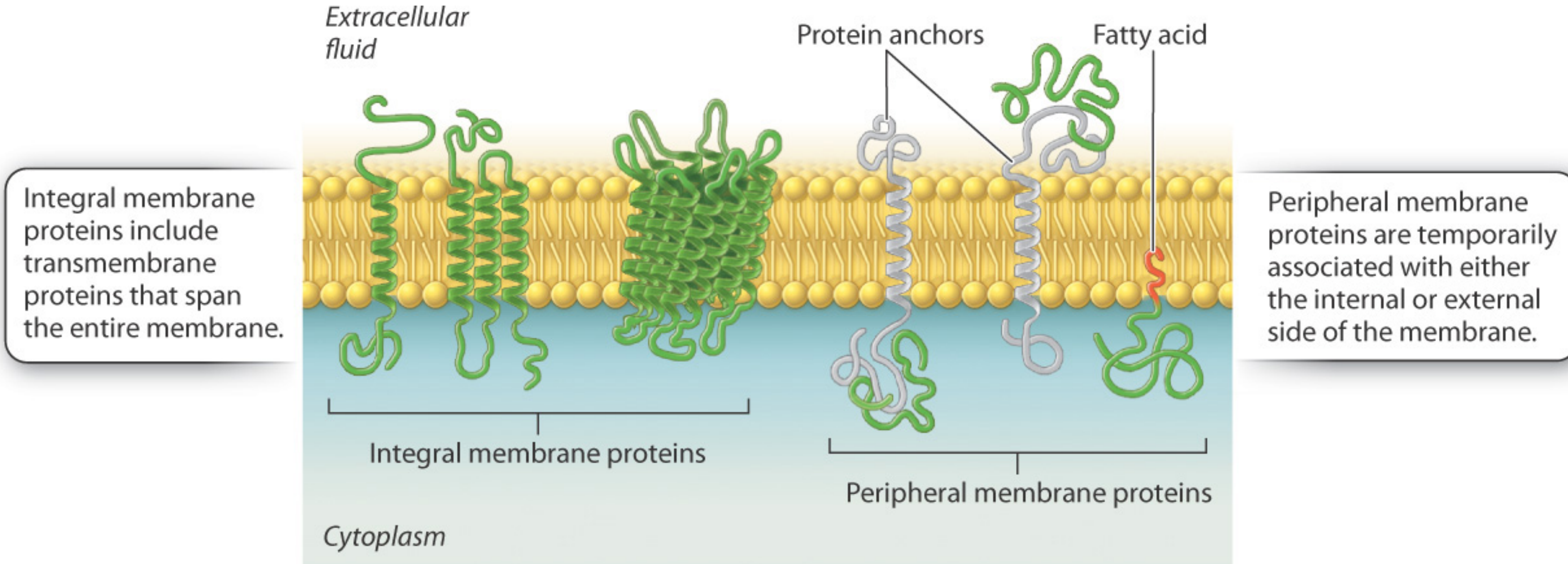
Integral membrane proteins include transmembrane proteins that span the entire membrane.

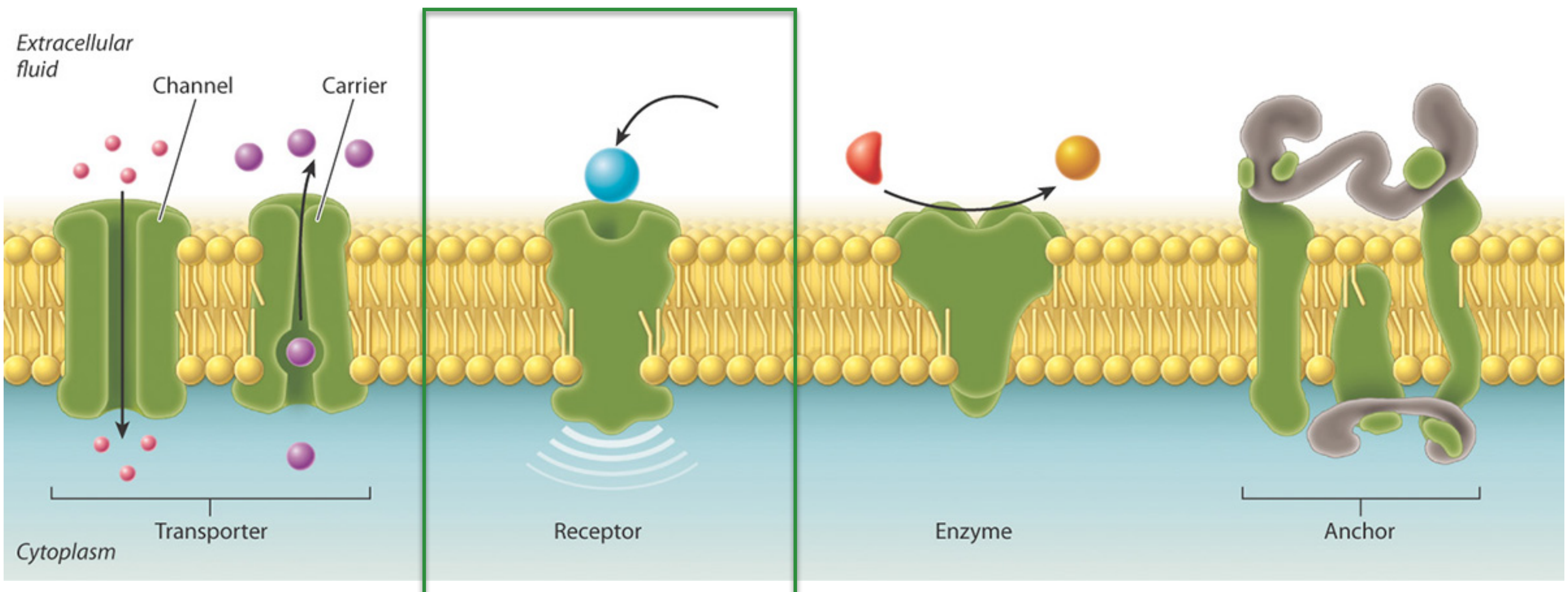


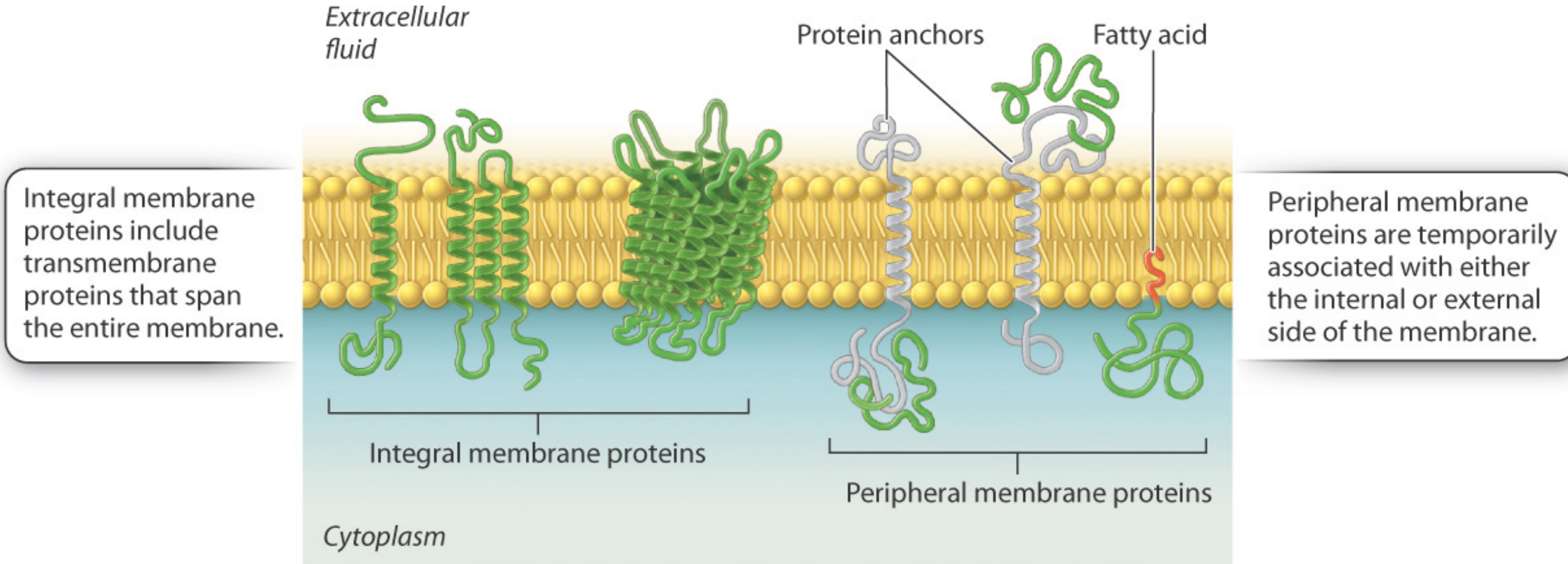
Peripheral membrane proteins are temporarily associated with either the internal or external side of the membrane.

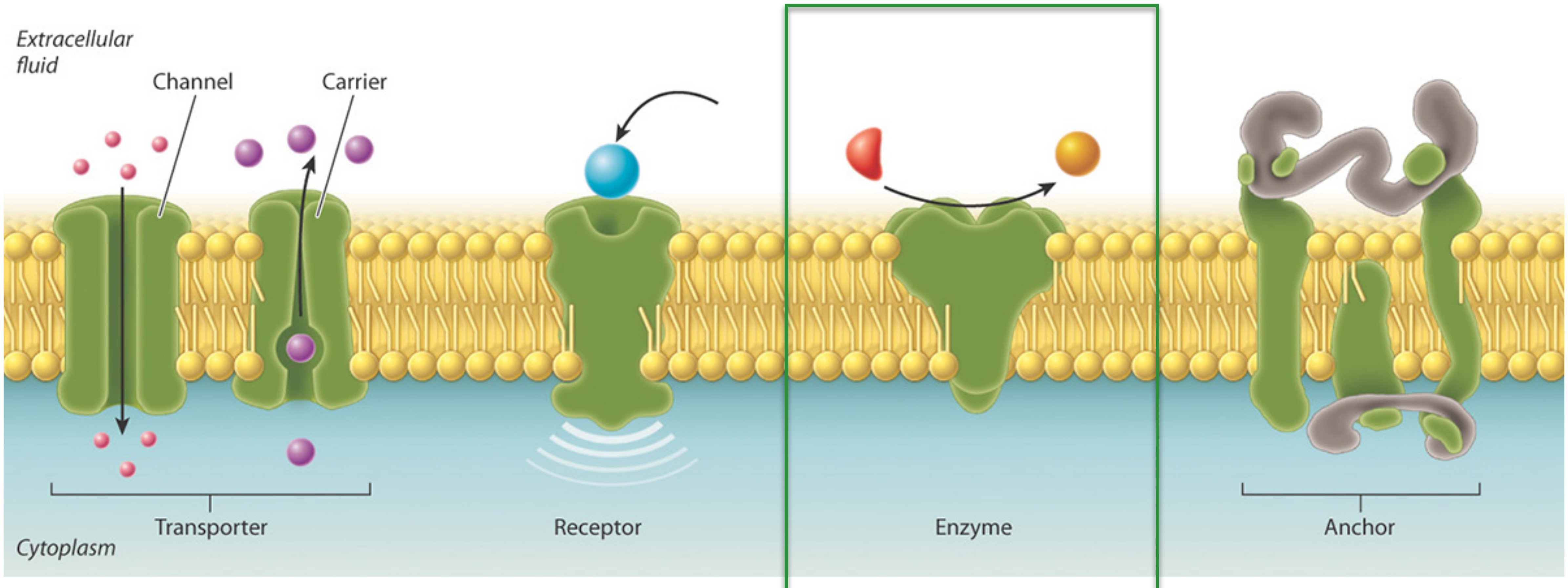

Extracellular fluid
Protein anchors
Fatty acid
Integral membrane proteins include transmembrane proteins that span the entire membrane.
Peripheral membrane proteins are temporarily associated with either the internal or external side of the membrane.
Integral membrane proteins
Peripheral membrane proteins
Cytoplasm

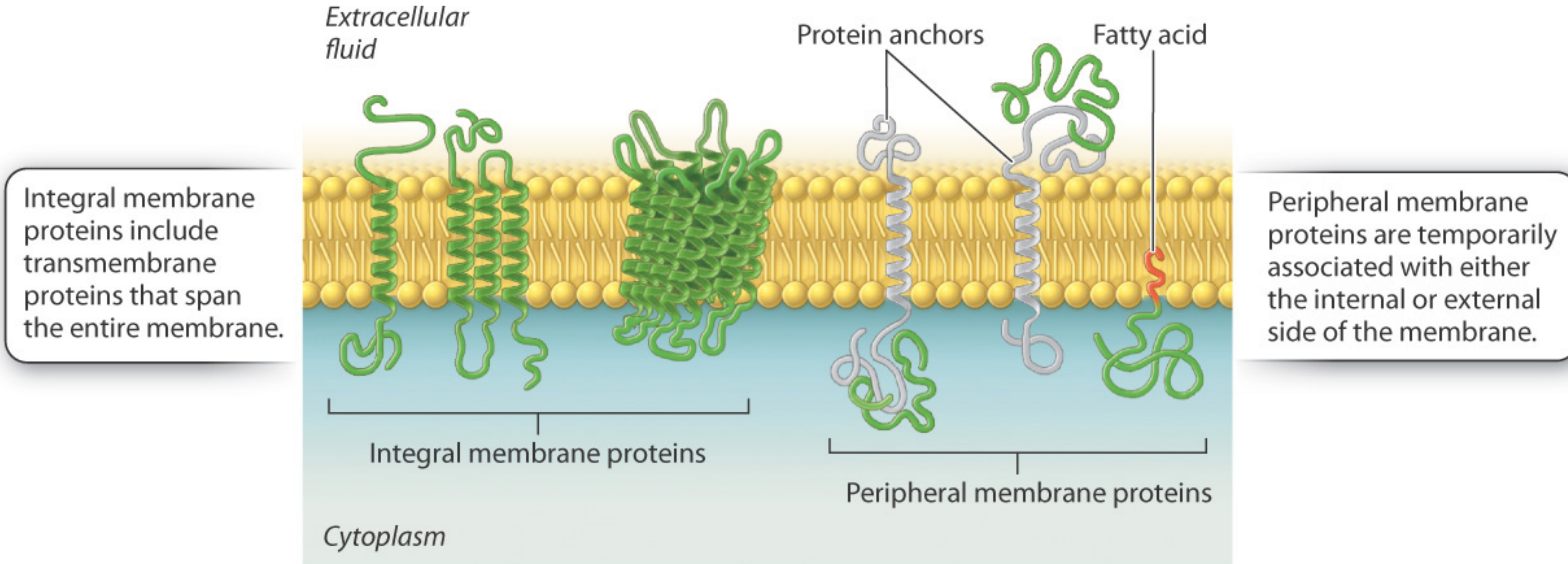

Extracellular fluid
Channel
Carrier
Transporter
Cytoplasm
Receptor
Enzyme
Anchor


Extracellular fluid
Protein anchors
Fatty acid
Integral membrane proteins include transmembrane proteins that span the entire membrane.
Peripheral membrane proteins are temporarily associated with either the internal or external side of the membrane.
Integral membrane proteins
Peripheral membrane proteins
Cytoplasm


Extracellular fluid
Channel
Carrier
Transporter
Receptor
Enzyme
Anchor
Cytoplasm


Extracellular fluid
Protein anchors
Fatty acid
Integral membrane proteins include transmembrane proteins that span the entire membrane.
Peripheral membrane proteins are temporarily associated with either the internal or external side of the membrane.
Integral membrane proteins
Peripheral membrane proteins
Cytoplasm


Extracellular fluid
Channel
Carrier
Transporter
Receptor
Enzyme
Anchor
Cytoplasm


Extracellular fluid
Protein anchors
Fatty acid
Integral membrane proteins include transmembrane proteins that span the entire membrane.
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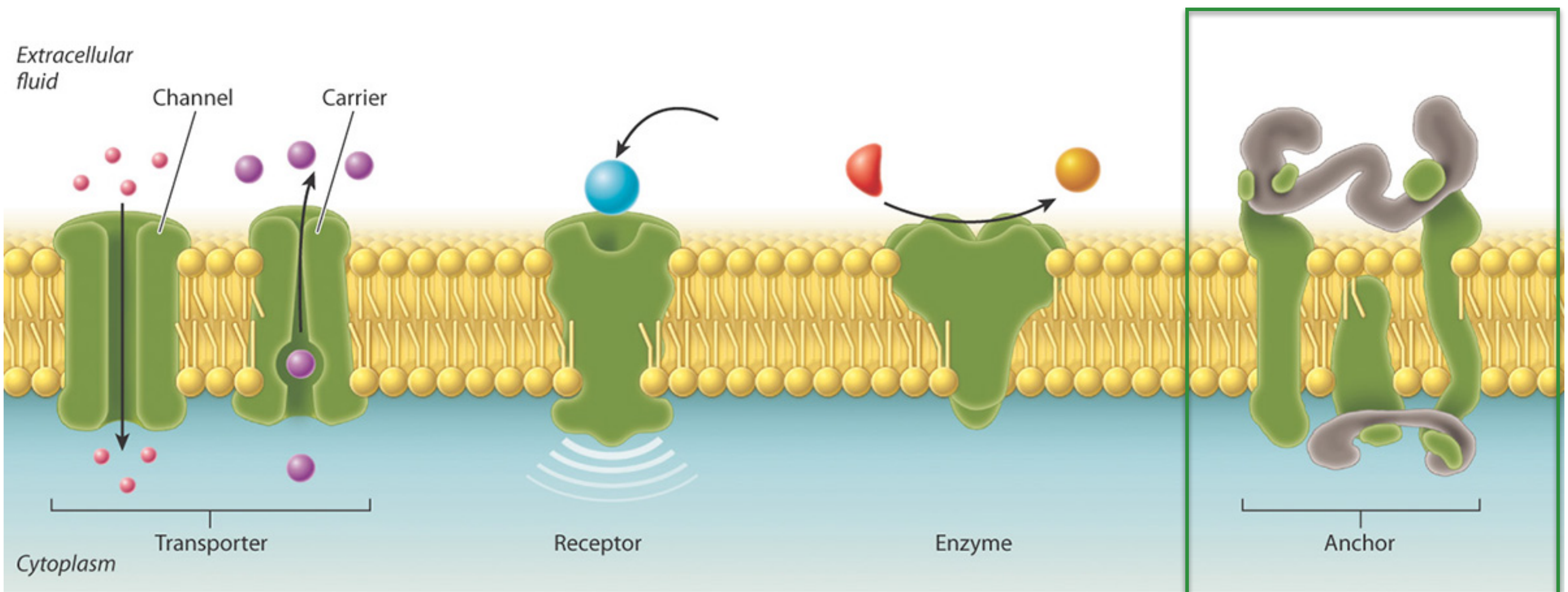
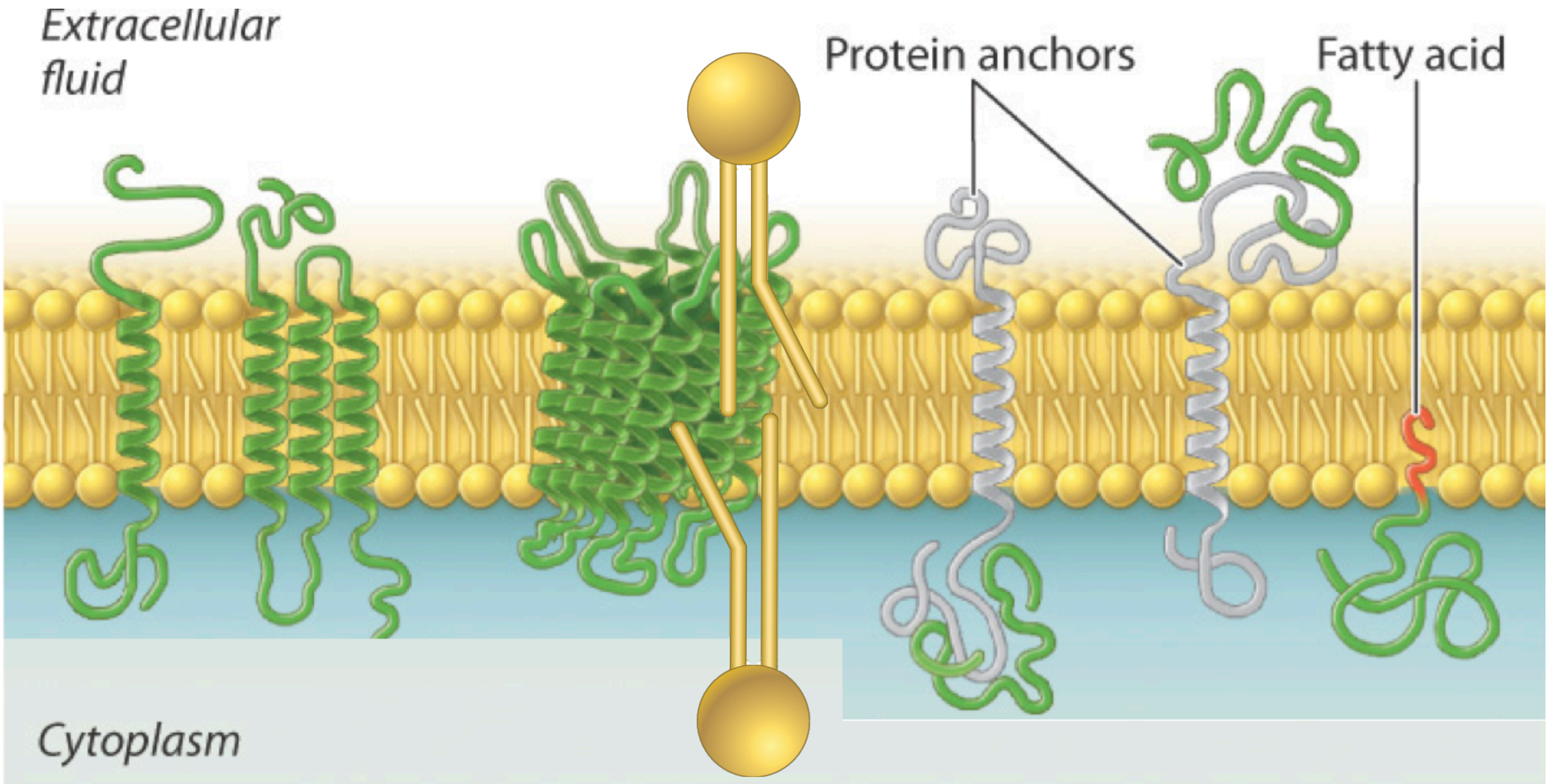
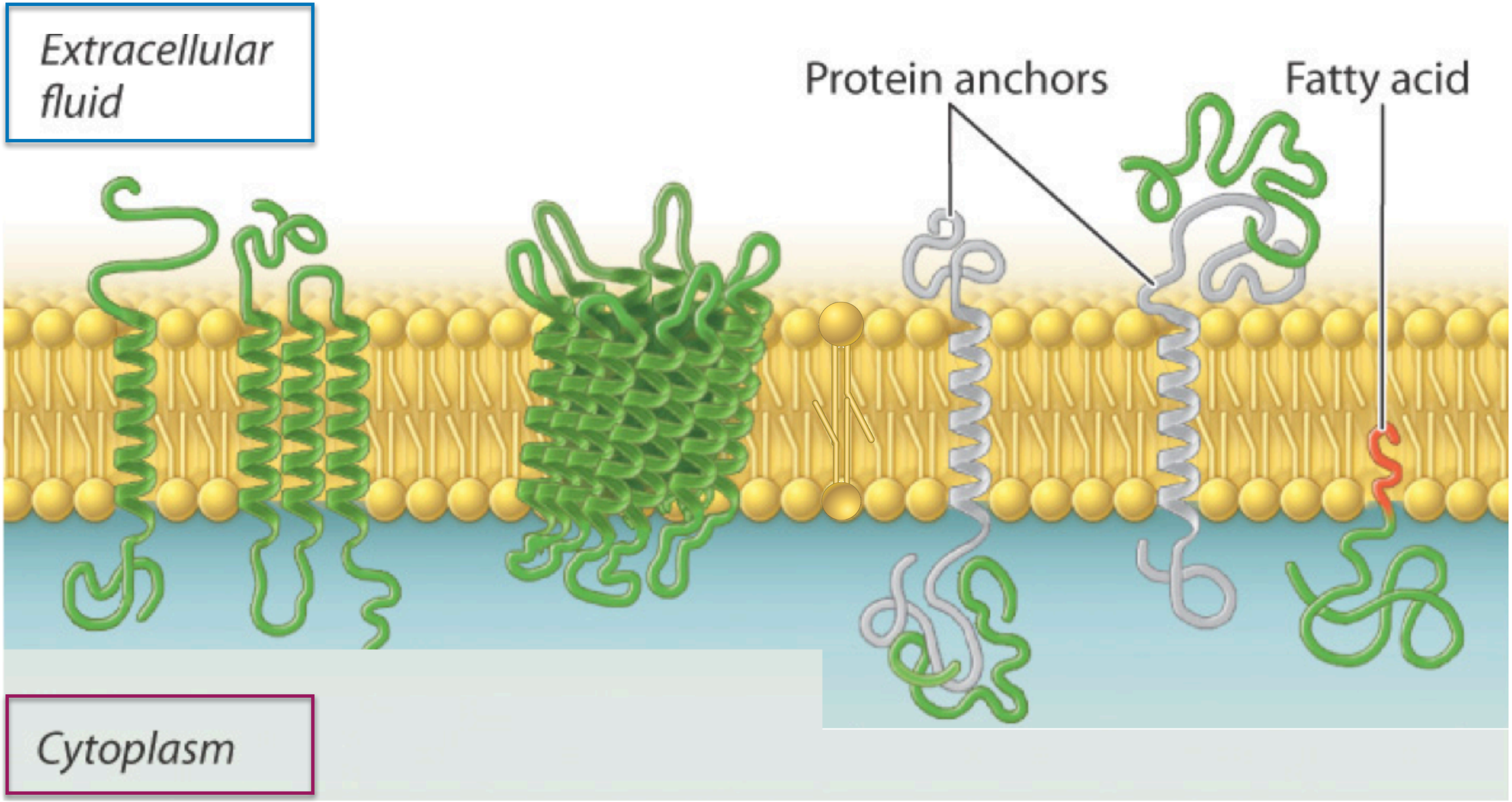
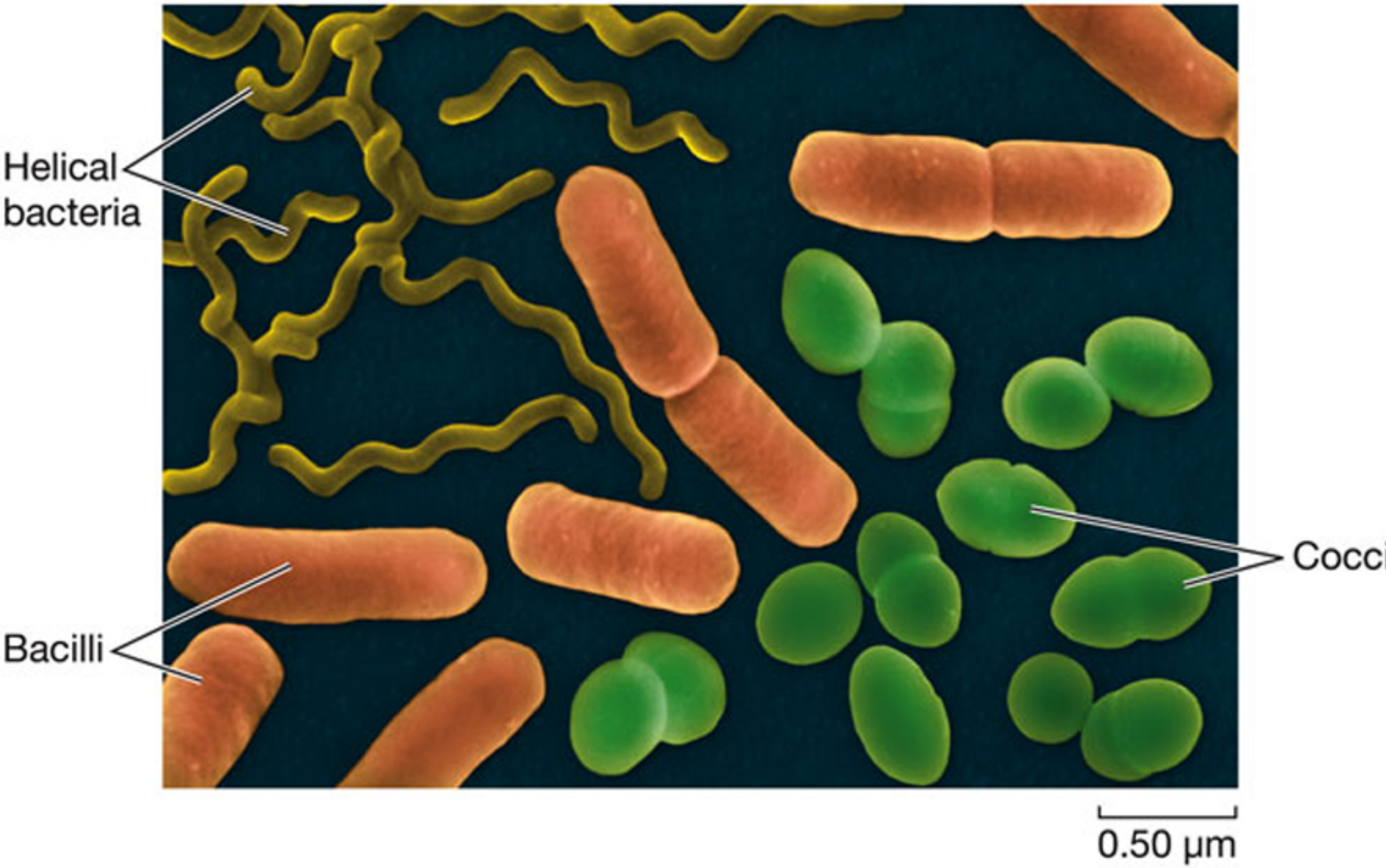
Integral membrane proteins
Peripheral membrane proteins
Cytoplasm


Extracellular fluid
Channel
Carrier
Transporter
Receptor
Enzyme
Anchor
Cytoplasm

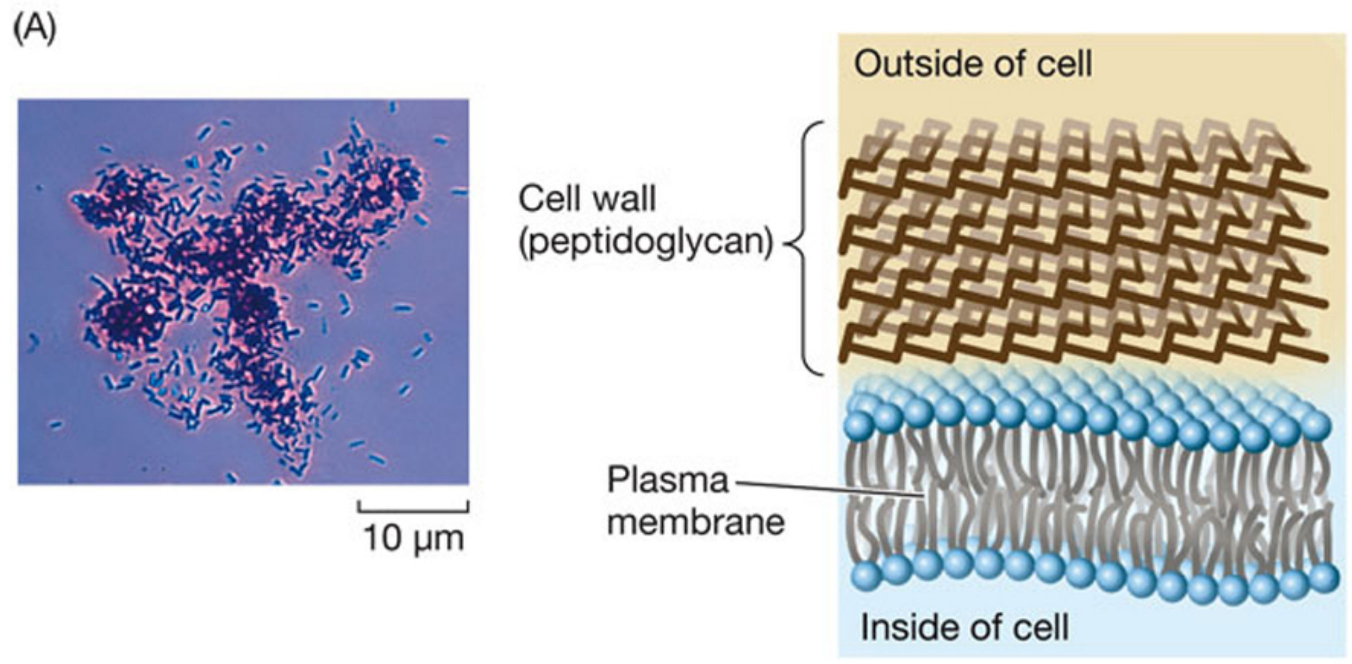

Extracellular fluid
Protein anchors
Fatty acid
Cytoplasm



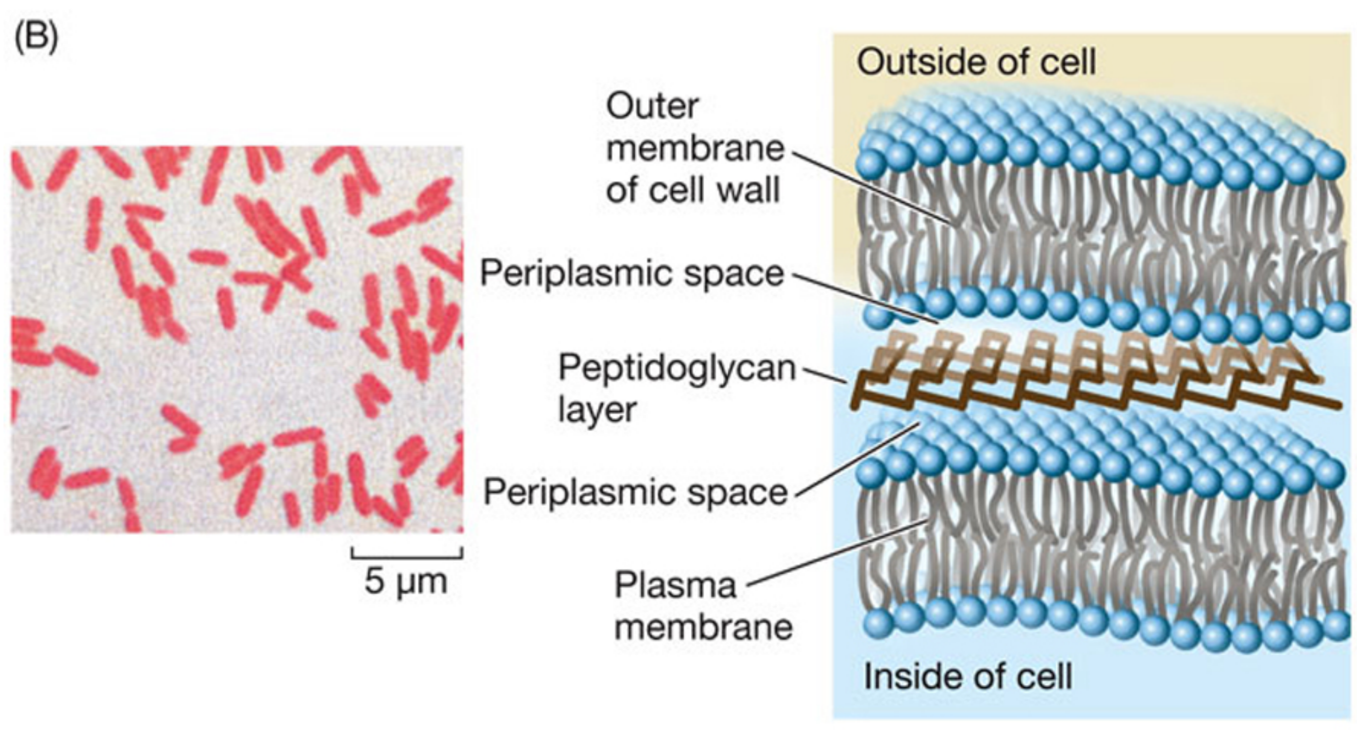
Extracellular fluid
Protein anchors
Fatty acid
Cytoplasm



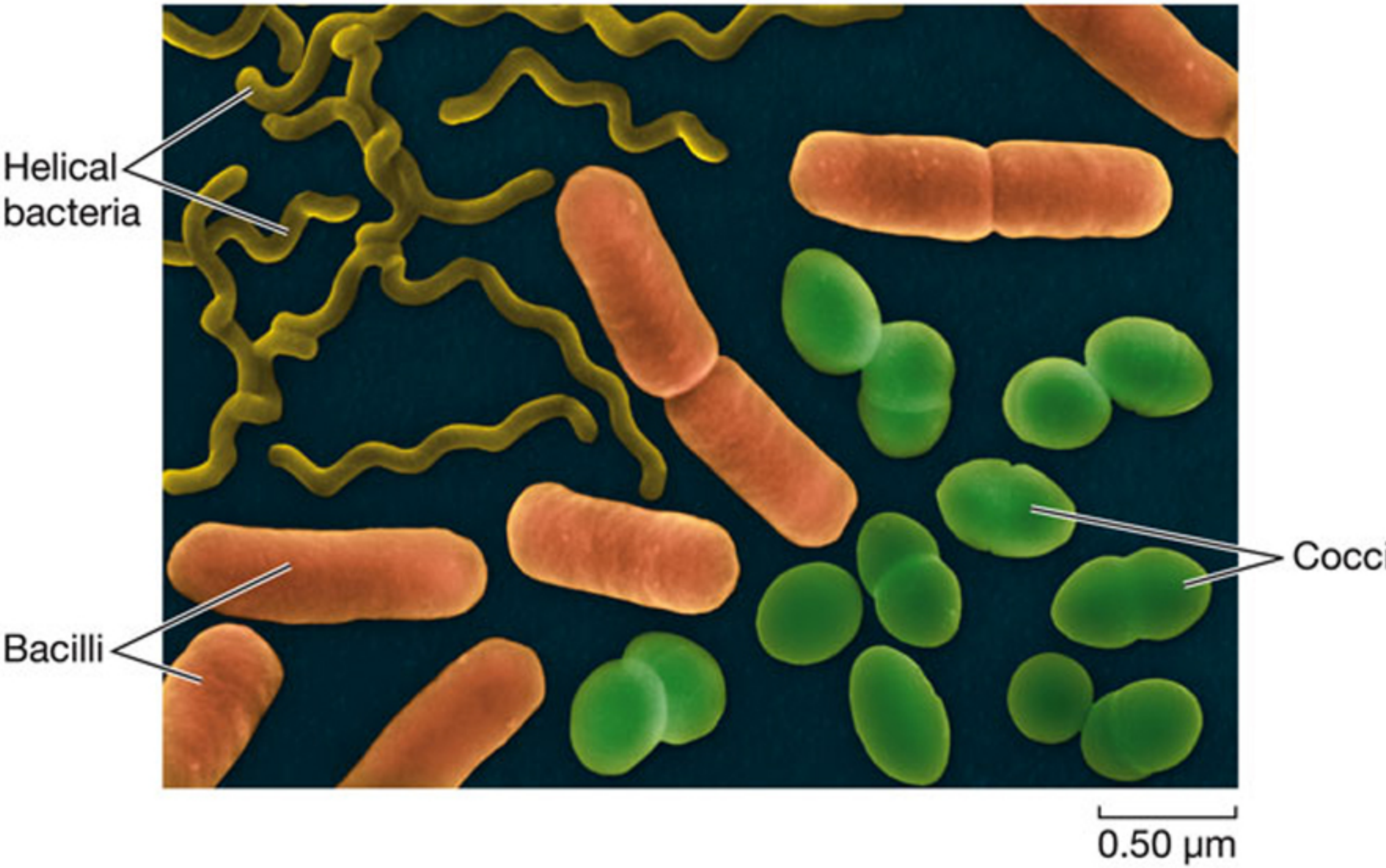
***LIFE 9e*, Figure 26.2**



Gram positive



Gram negative



LIFE 9e, **Figure 26.2**

(A) Cubes

	1-mm cube	2-mm cube	4-mm cube
Surface area	6 sides × 1^2 = 6 mm^2	6 sides × 2^2 = 24 mm^2	6 sides × 4^2 = 96 mm^2
Volume	1^3 = 1 mm^3	2^3 = 8 mm^3	4^3 = 64 mm^3
Surface area-to-volume ratio	6:1	3:1	1.5:1

(B) Spheres

Diameter	1 μm	2 μm	3 μm
Surface area $4 \pi r^2$	3.14 μm^2	12.56 μm^2	28.26 μm^2
Volume $4/3 \pi r^3$	0.52 μm^3	4.19 μm^3	14.18 μm^3
Surface area-to-volume ratio	6:1	3:1	2:1

(A) Cubes

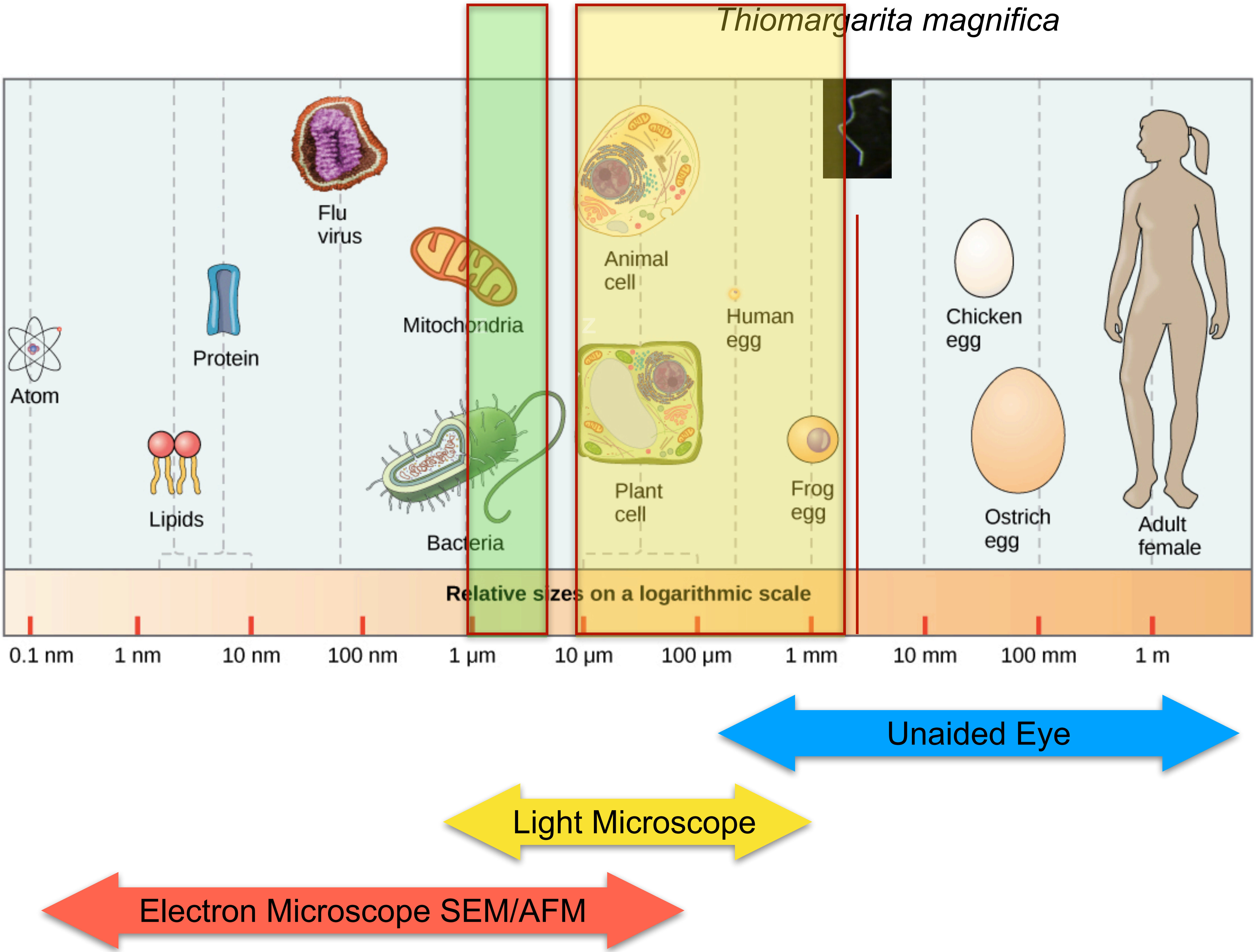
	1-mm cube	2-mm cube	4-mm cube
Surface area	6 sides × 1^2 = 6 mm^2	6 sides × 2^2 = 24 mm^2	6 sides × 4^2 = 96 mm^2
Volume	1^3 = 1 mm^3	2^3 = 8 mm^3	4^3 = 64 mm^3
Surface area-to-volume ratio	6:1	3:1	1.5:1

(B) Spheres

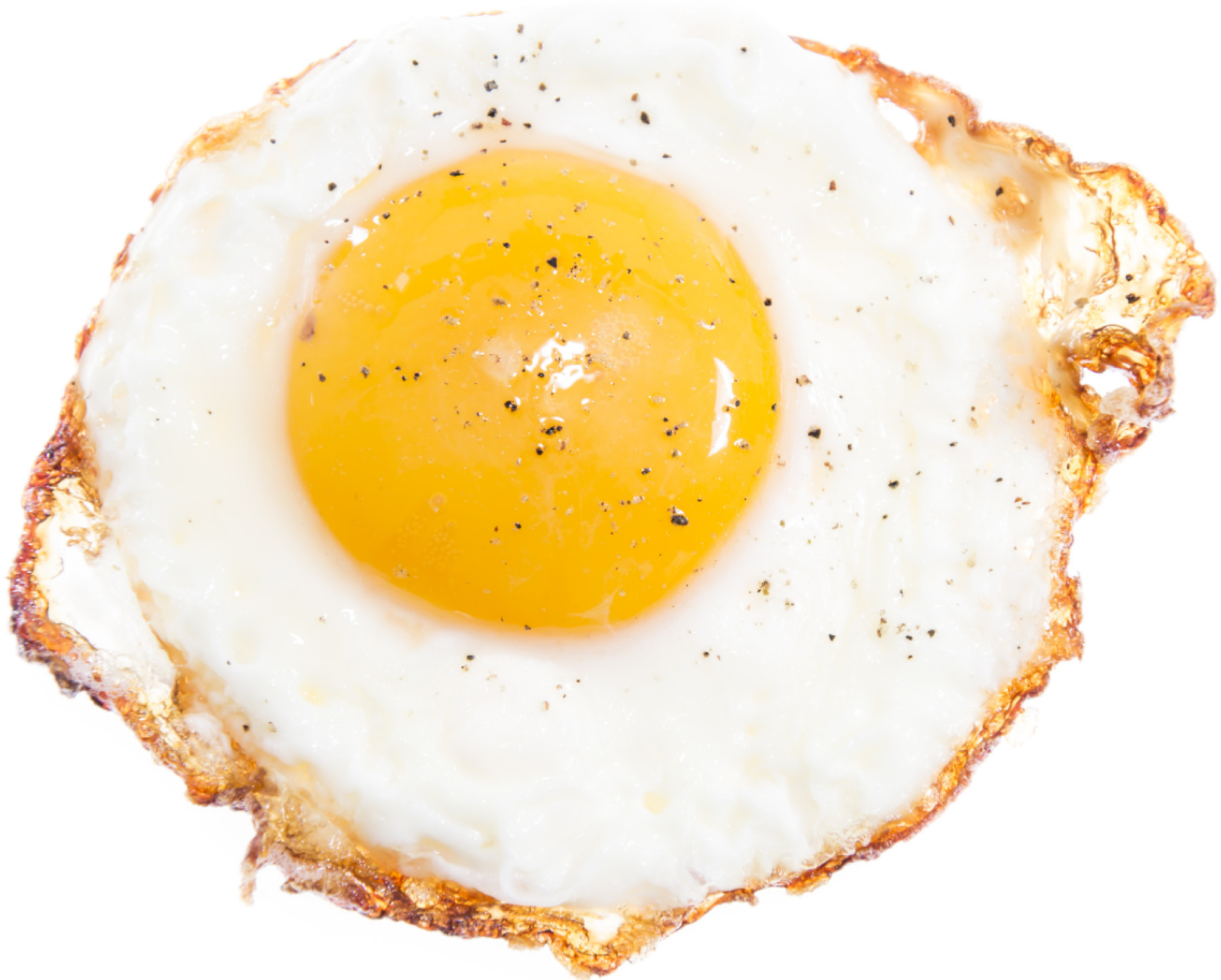
Diameter	1 μm	2 μm	3 μm
Surface area $4 \pi r^2$	3.14 μm^2	12.56 μm^2	28.26 μm^2
Volume $4/3 \pi r^3$	0.52 μm^3	4.19 μm^3	14.18 μm^3
Surface area-to-volume ratio	6:1	3:1	2:1

So, aside from anomalies like ***Thiomargarita sp.*** **Prokaryotes** stay small to allow for sufficient **SA / V** ratios to allow for diffusion in and out of the cell

How do **Eukaryotes** handle this problem of decreased SA / V ratios ?

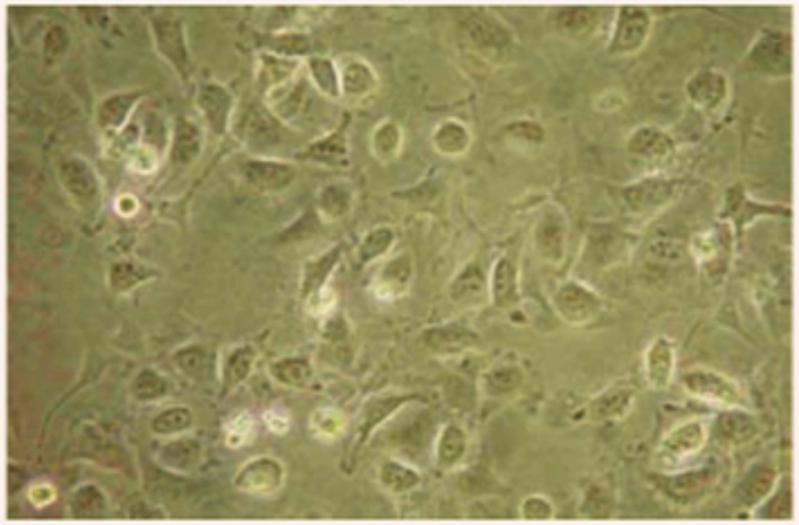


Thiomargarita magnifica
Atom
Lipids
Protein
Flu virus
Mitochondria
Bacteria
Animal cell
Plant cell
Human egg
Frog egg
Chicken egg
Ostrich egg
Adult female
Relative sizes on a logarithmic scale
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
10 mm
100 mm
1 m
Unaided Eye
Light Microscope
Electron Microscope SEM/AFM



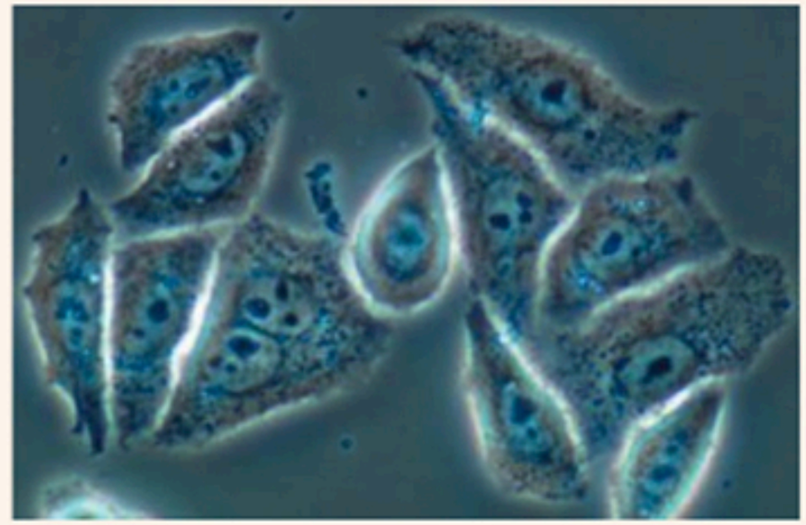
GREATER

Surface Area / Volume



140 μm

In **bright-field microscopy**, light passes directly through these human cells. Unless natural pigments are present, there is little contrast and details are not distinguished.

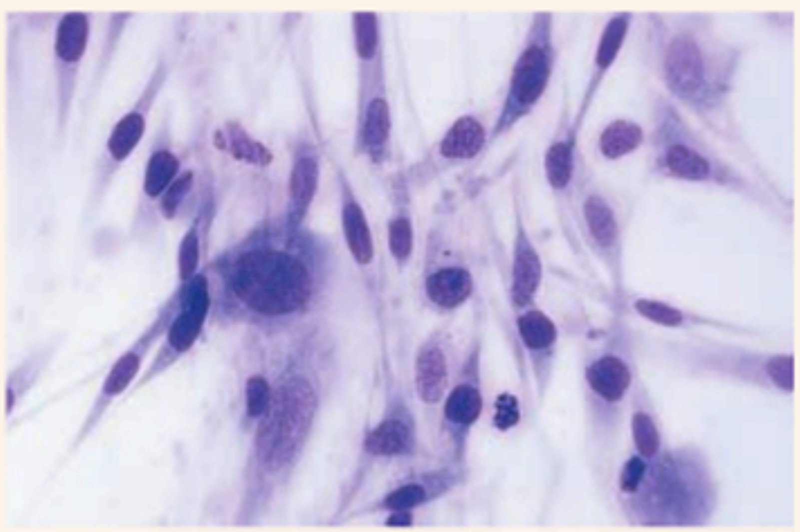


30 μm

In **phase-contrast microscopy**, contrast in the image is increased by emphasizing differences in refractive index (the capacity to bend light), thereby enhancing light and dark regions in the cell.

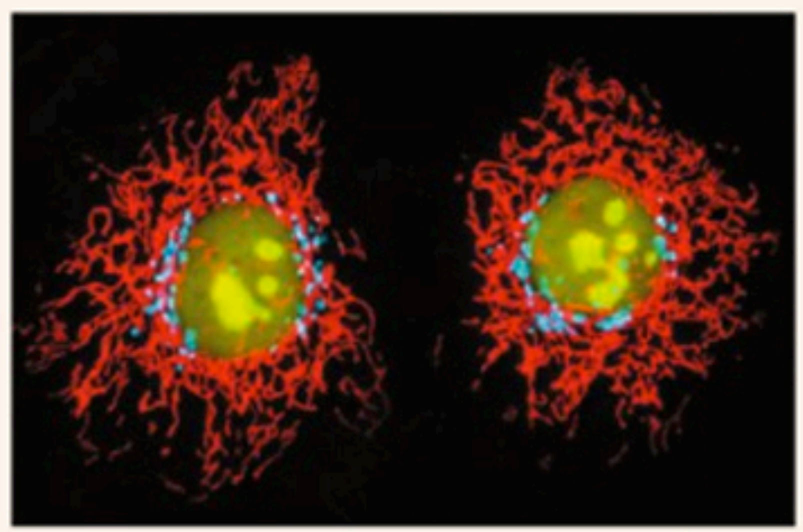
30 μm

Differential interference-contrast microscopy uses two beams of polarized light. The combined images look as if the cell is casting a shadow on one side.



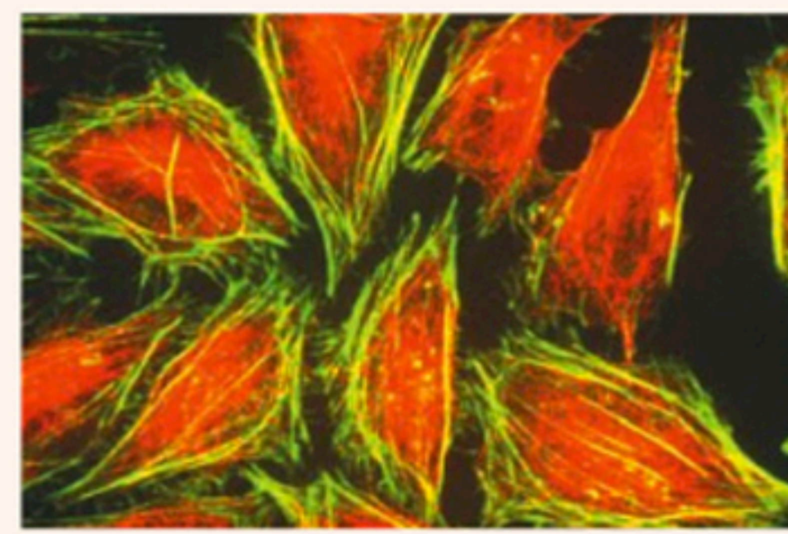
30 μm

In **stained bright-field microscopy**, a stain enhances contrast and reveals details not otherwise visible. Stains differ greatly in their chemistry and their capacity to bind to cell materials, so many choices are available.



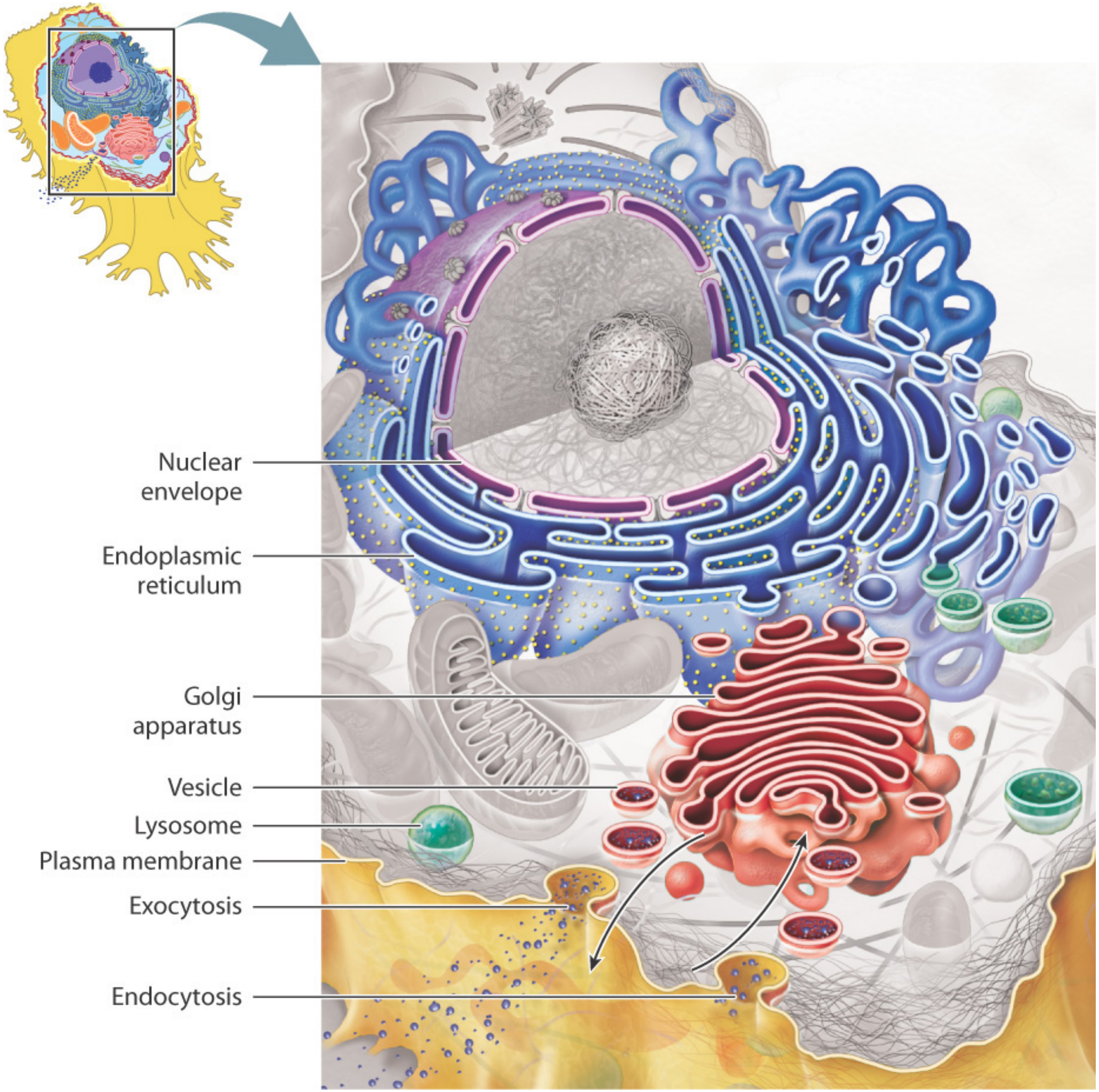
20 μm

In **fluorescence microscopy**, a natural substance in the cell or a fluorescent dye that binds to a specific cell material is stimulated by a beam of light, and the longer-wavelength fluorescent light is observed coming directly from the dye.



20 μm

Confocal microscopy uses fluorescent materials but adds a system of focusing both the stimulating and emitted light so that a single plane through the cell is seen. The result is a sharper two-dimensional image than with standard fluorescence microscopy.


Nuclear envelope
Endoplasmic reticulum
Golgi apparatus
Vesicle
Lysosome
Plasma membrane
Exocytosis
Endocytosis

The **nucleus** contains most of the cell's genetic material (DNA).

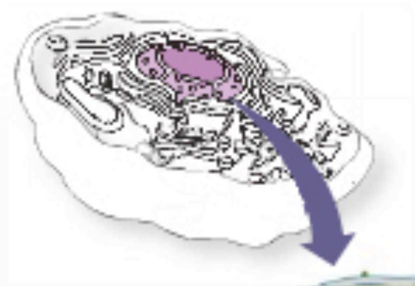
The **mitochondrion** is the power plant and industrial park of the cell in that it is the major source of for the storage and conversion of energy.

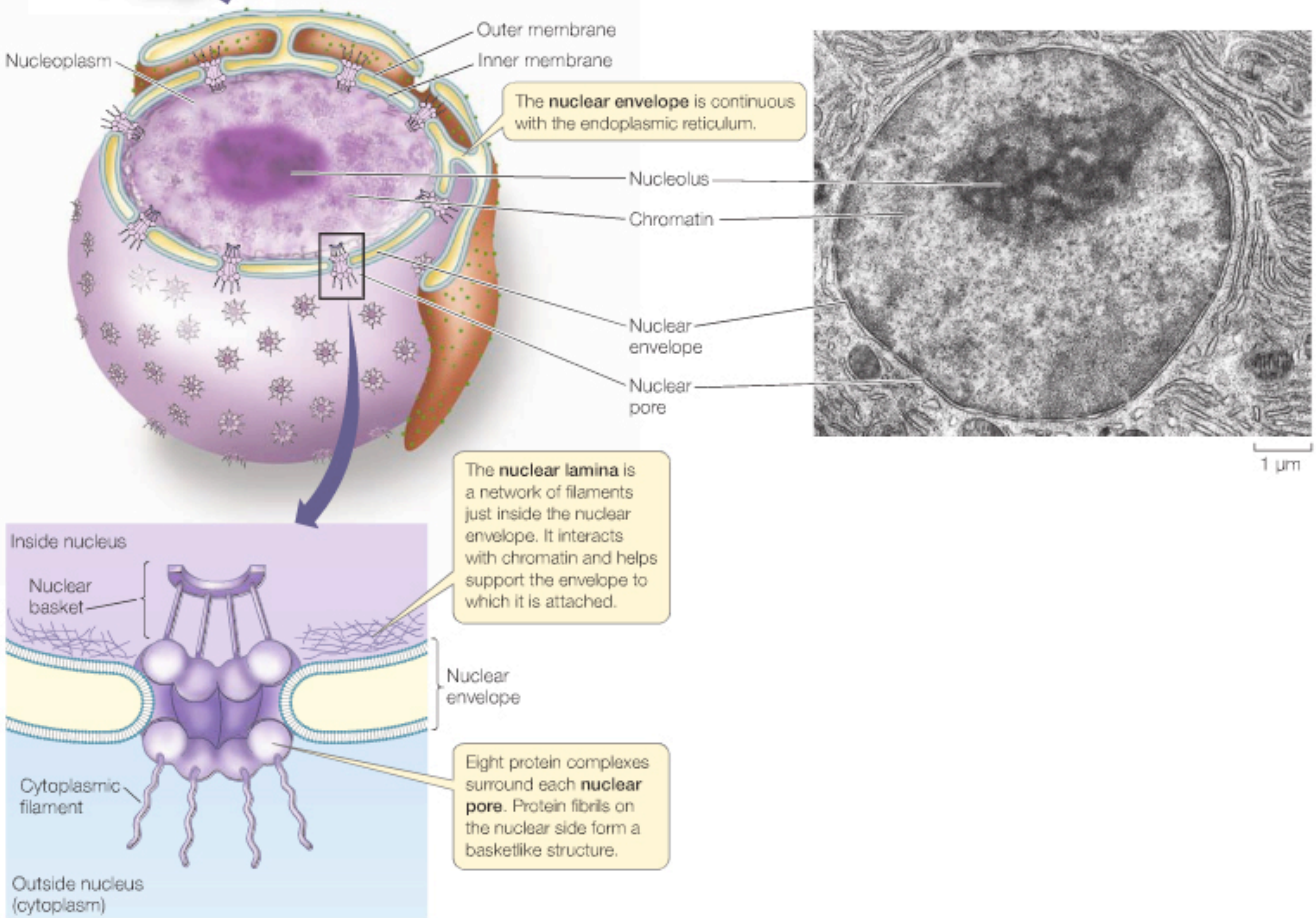
The **chloroplast** performs photosynthesis in bacterial and plant cells. As you know,

The **endoplasmic reticulum** and **Golgi apparatus** make up distinct compartments where proteins are packaged and sent to appropriate locations in the cell.

The **lysosome** and **vacuole** are cellular digestive systems, where large molecules are hydrolyzed into usable monomers.

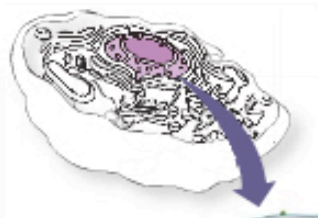
Eukaryotic cells tend to be larger than prokaryotic cells, and as such with all the volume changes and Volume/Surface Area ratio changes they have had to adapt a far more sophisticated network of **support structures** comprising the ***cytoskeleton***, that provides shape and structure to cells, among other functions.

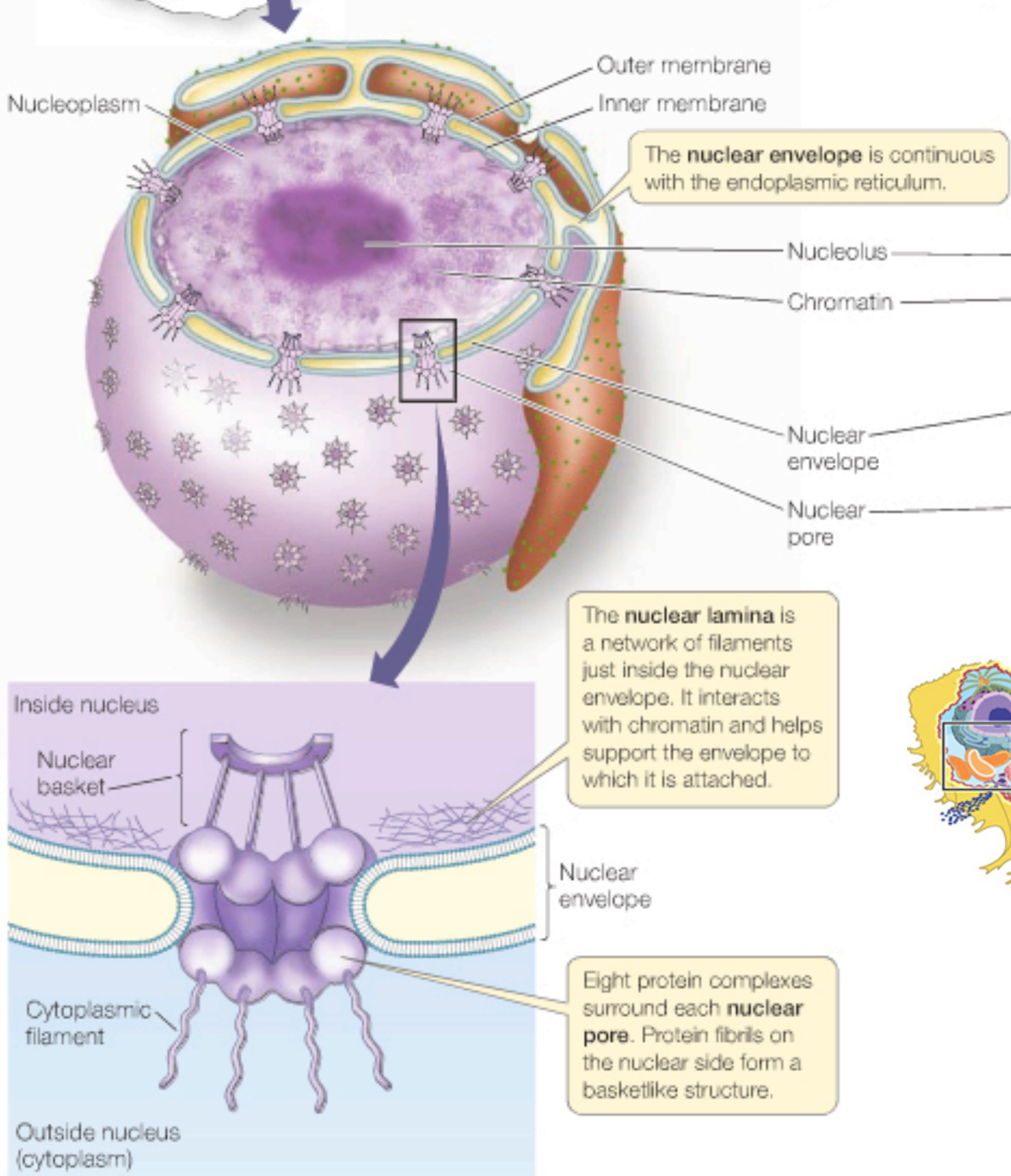


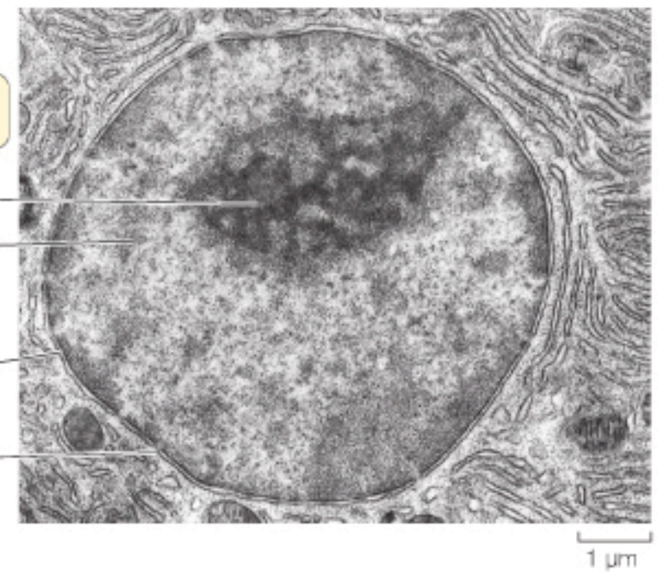


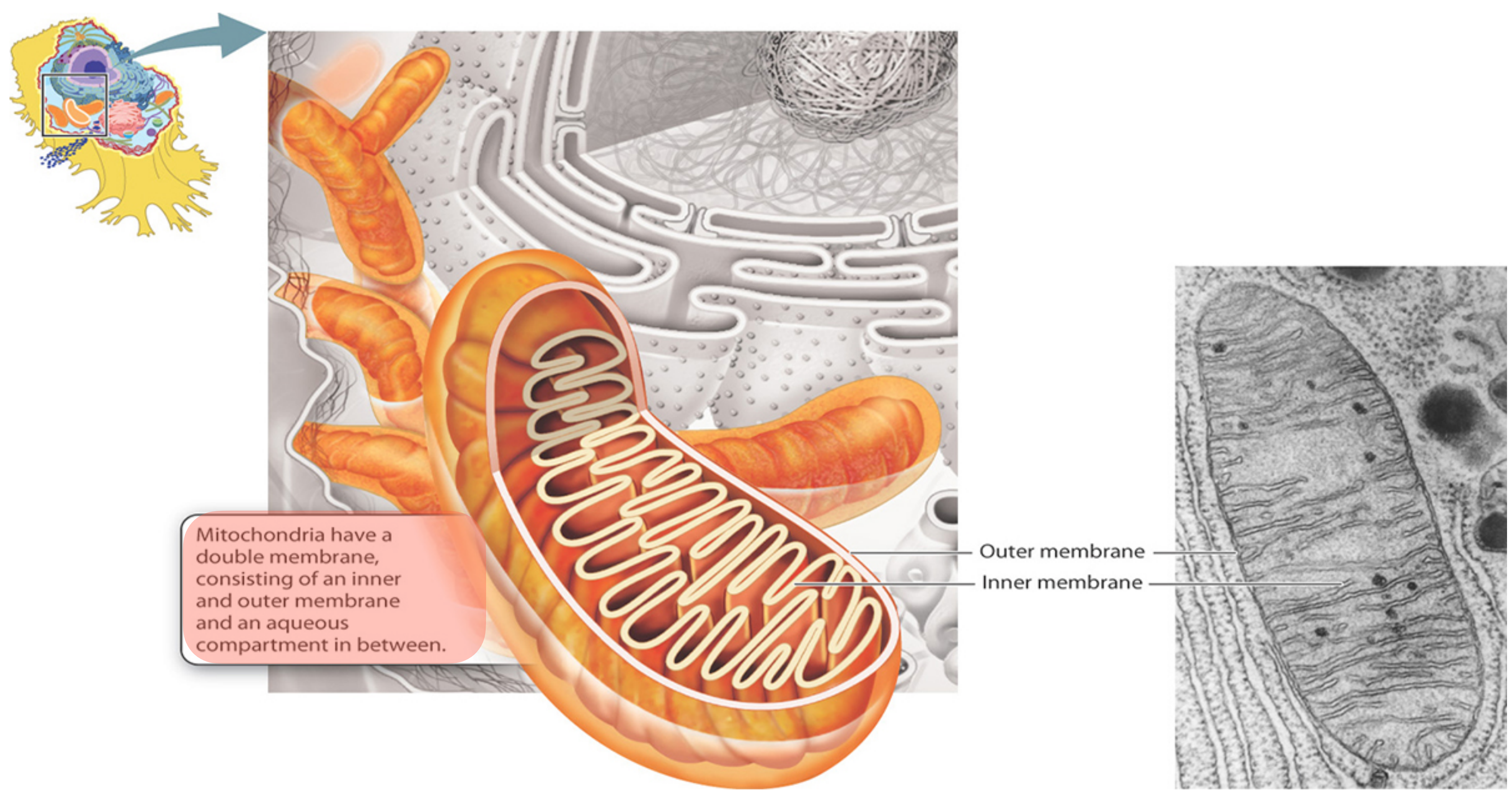
5.8 The Nucleus Is Enclosed by a Double Membrane The nuclear envelope (made up of two membranes), nucleolus, nuclear lamina, and nuclear pores are common features of all cell nuclei. The pores are the gateways through which proteins from the cytoplasm enter the nucleus, and genetic material (mRNA) exits the nucleus into the cytoplasm.

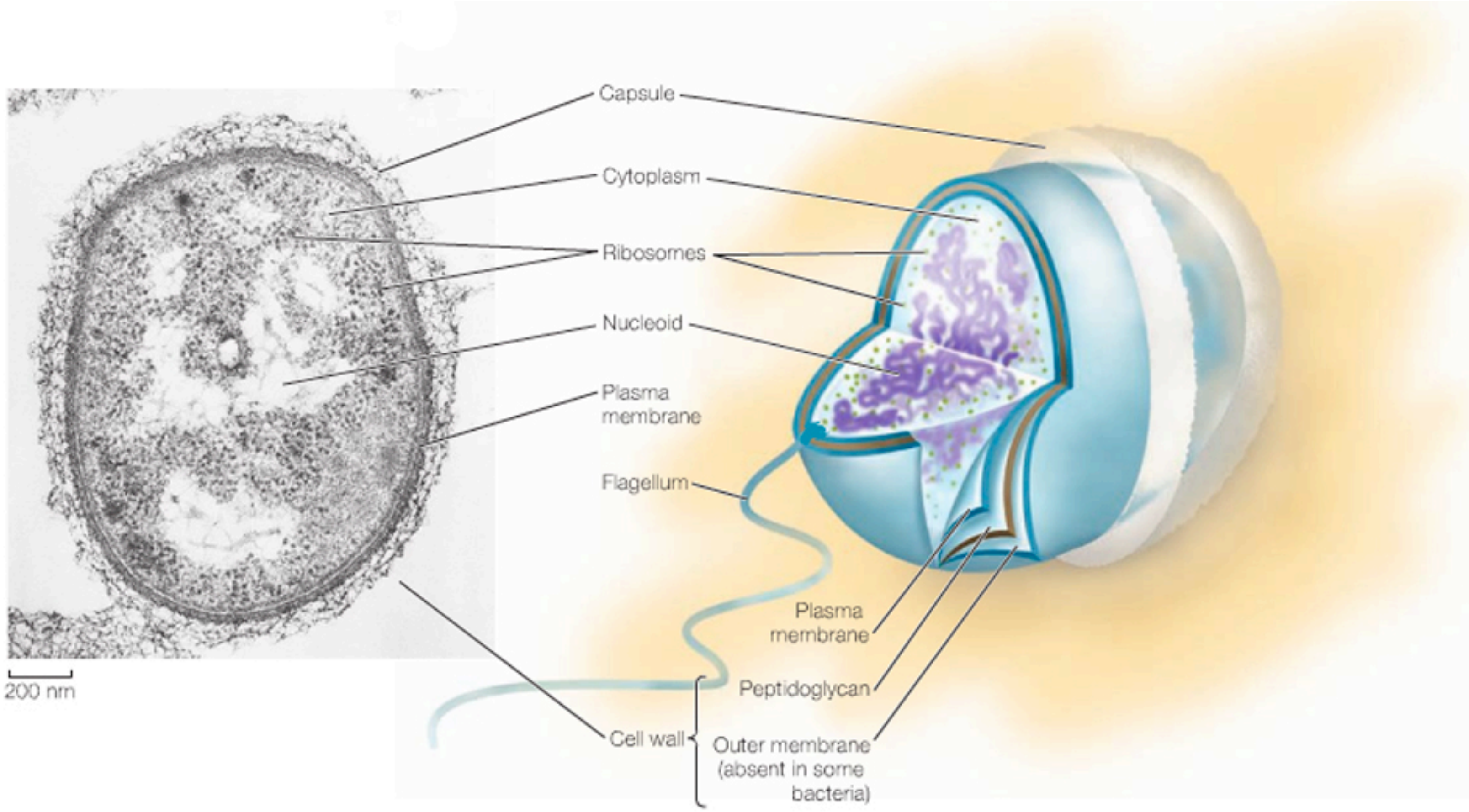
5.8 The Nucleus Is Enclosed by a Double Membrane The nuclear envelope (made up of two membranes), nucleolus, nuclear lamina, and nuclear pores are common features of all cell nuclei. The pores are the gateways through which proteins from the cytoplasm enter the nucleus, and genetic material (mRNA) exits the nucleus into the cytoplasm.



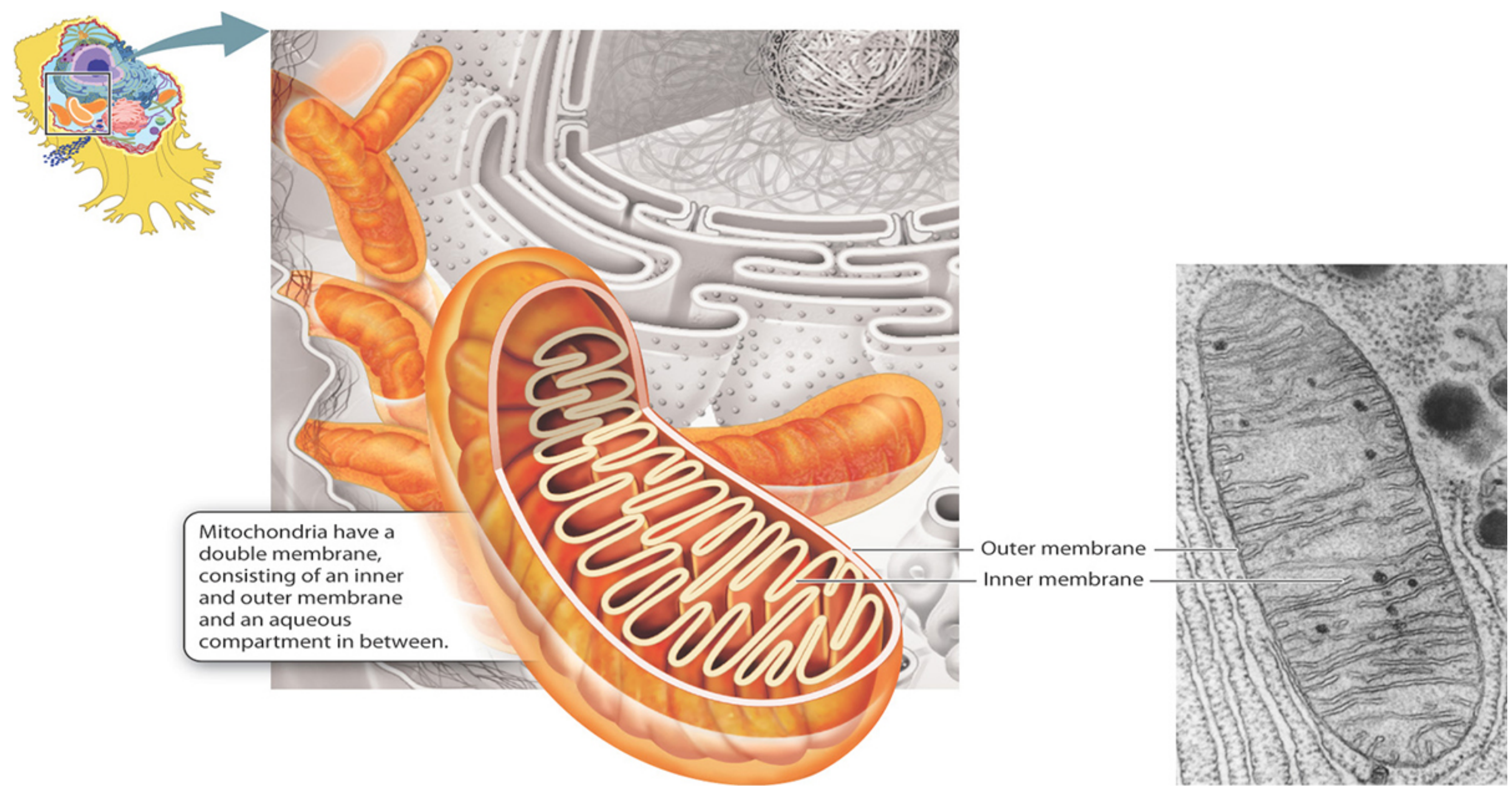








5.4 A Prokaryotic Cell The bacterium *Pseudomonas aeruginosa* illustrates the typical structures shared by all prokaryotic cells. This bacterium also has a protective outer membrane that not all prokaryotes have. The flagellum and capsule are also structures found in some, but not all, prokaryotic cells.



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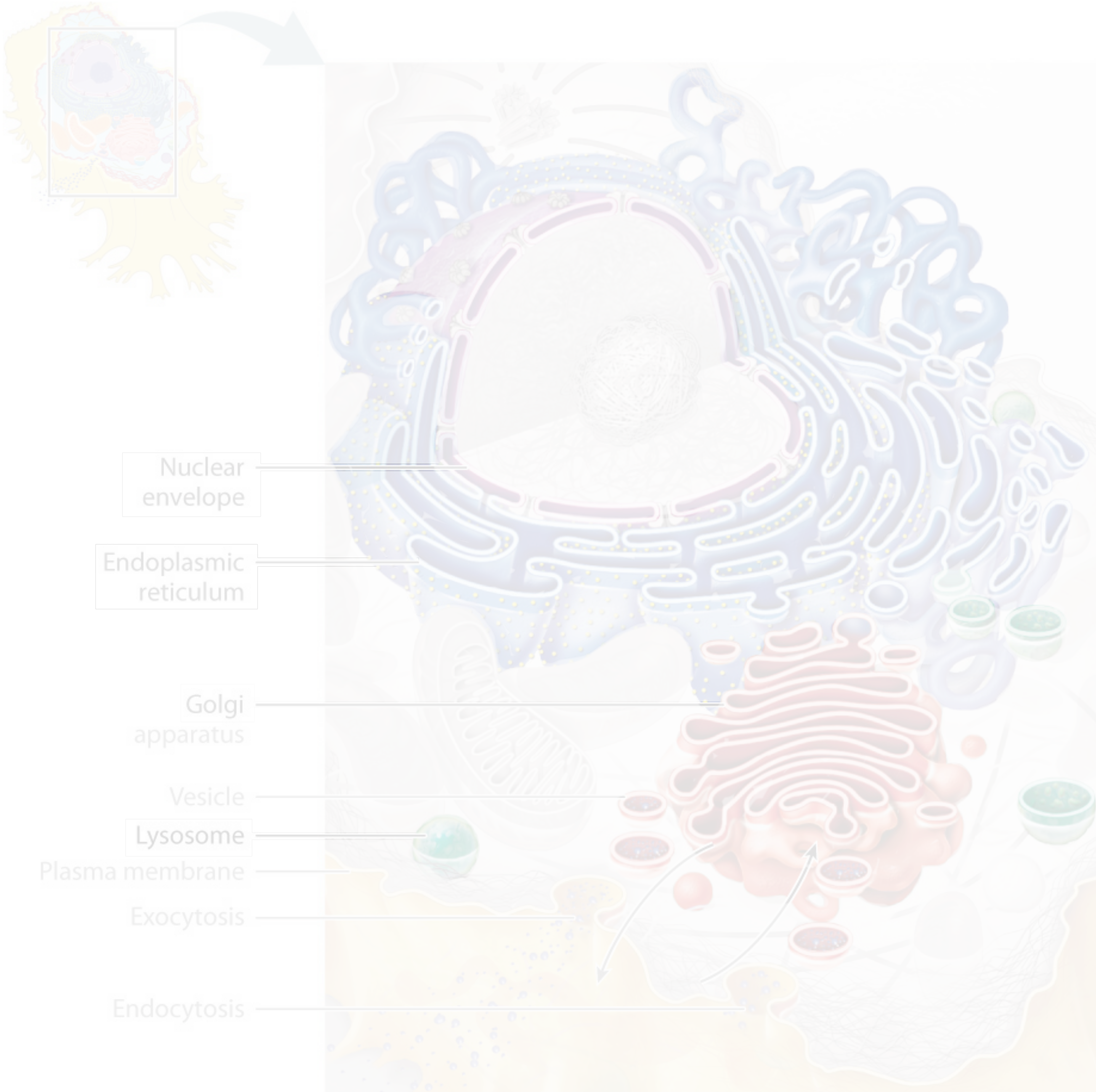
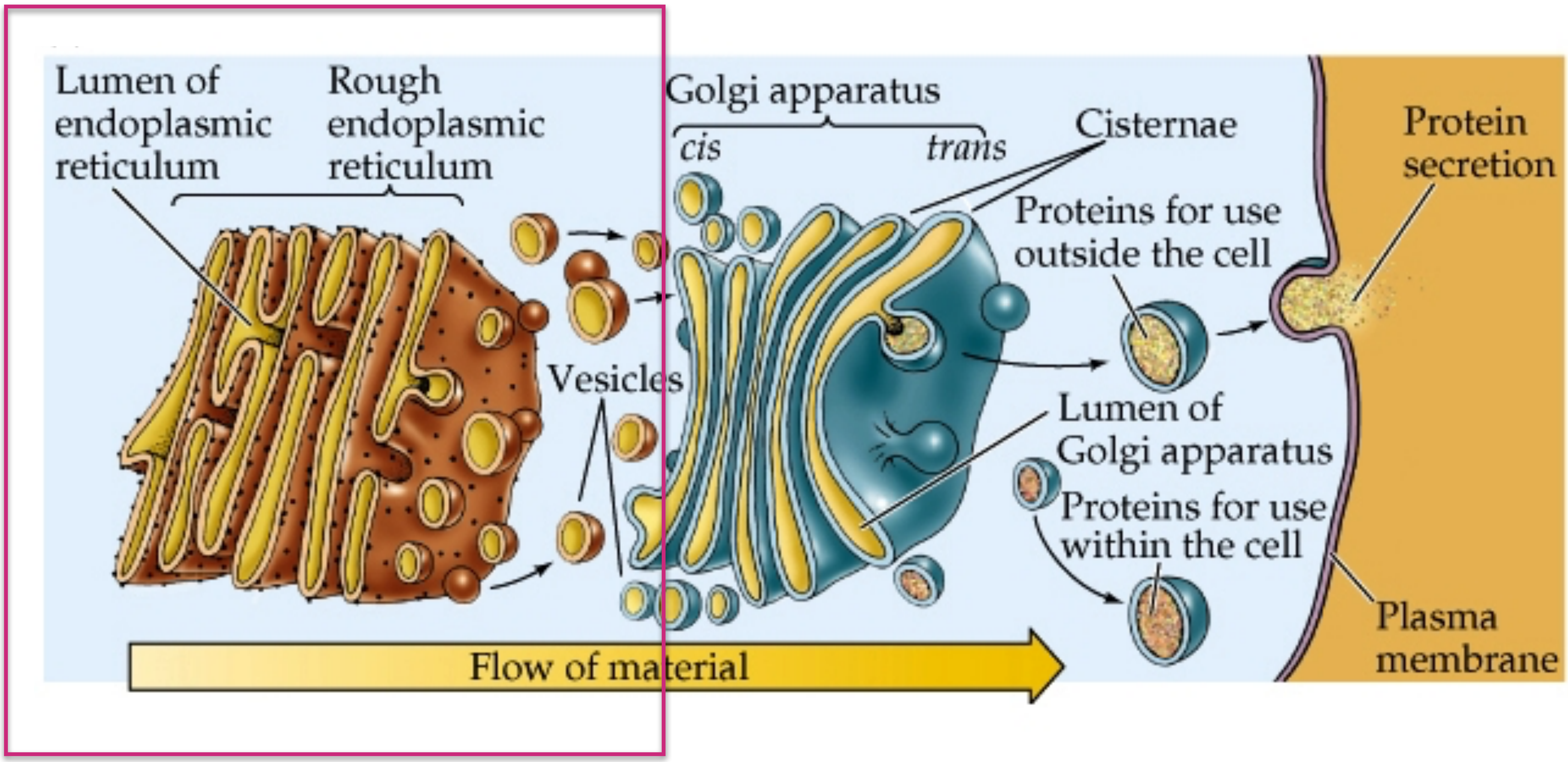
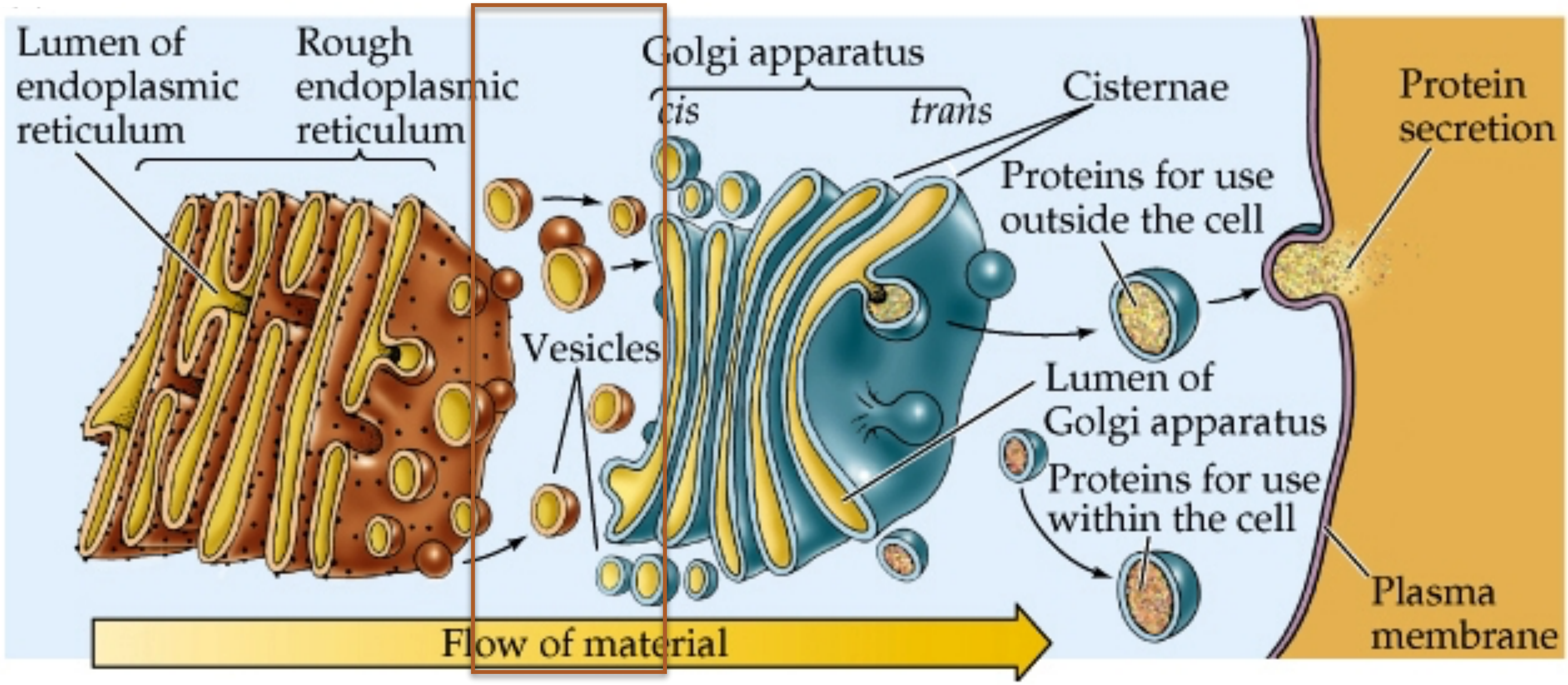

Nuclear envelope
Endoplasmic reticulum
Golgi apparatus
Vesicle
Lysosome
Plasma membrane
Exocytosis
Endocytosis


Lumen of endoplasmic reticulum
Rough endoplasmic reticulum
Golgi apparatus
cis
trans
Cisternae
Protein secretion
Proteins for use outside the cell
Vesicles
Lumen of Golgi apparatus
Proteins for use within the cell
Plasma membrane
Flow of material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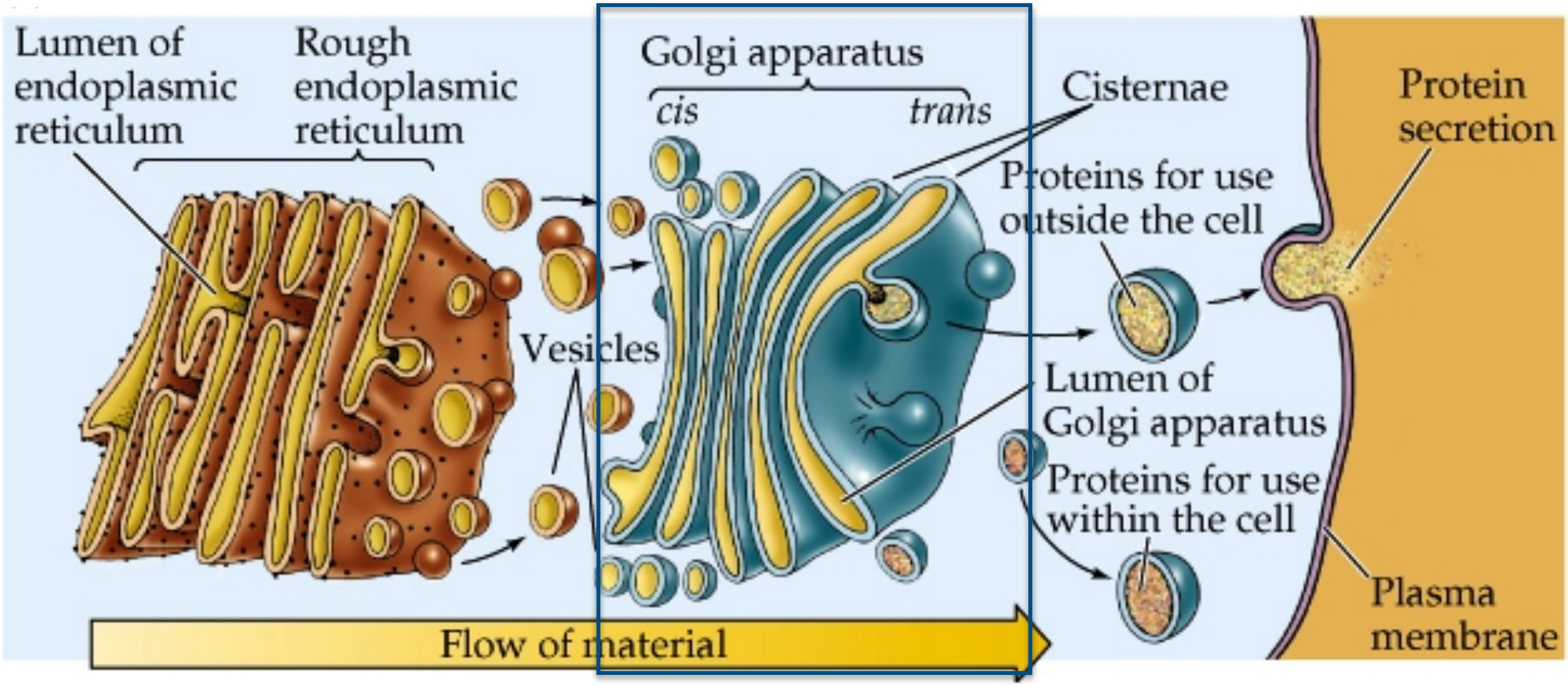
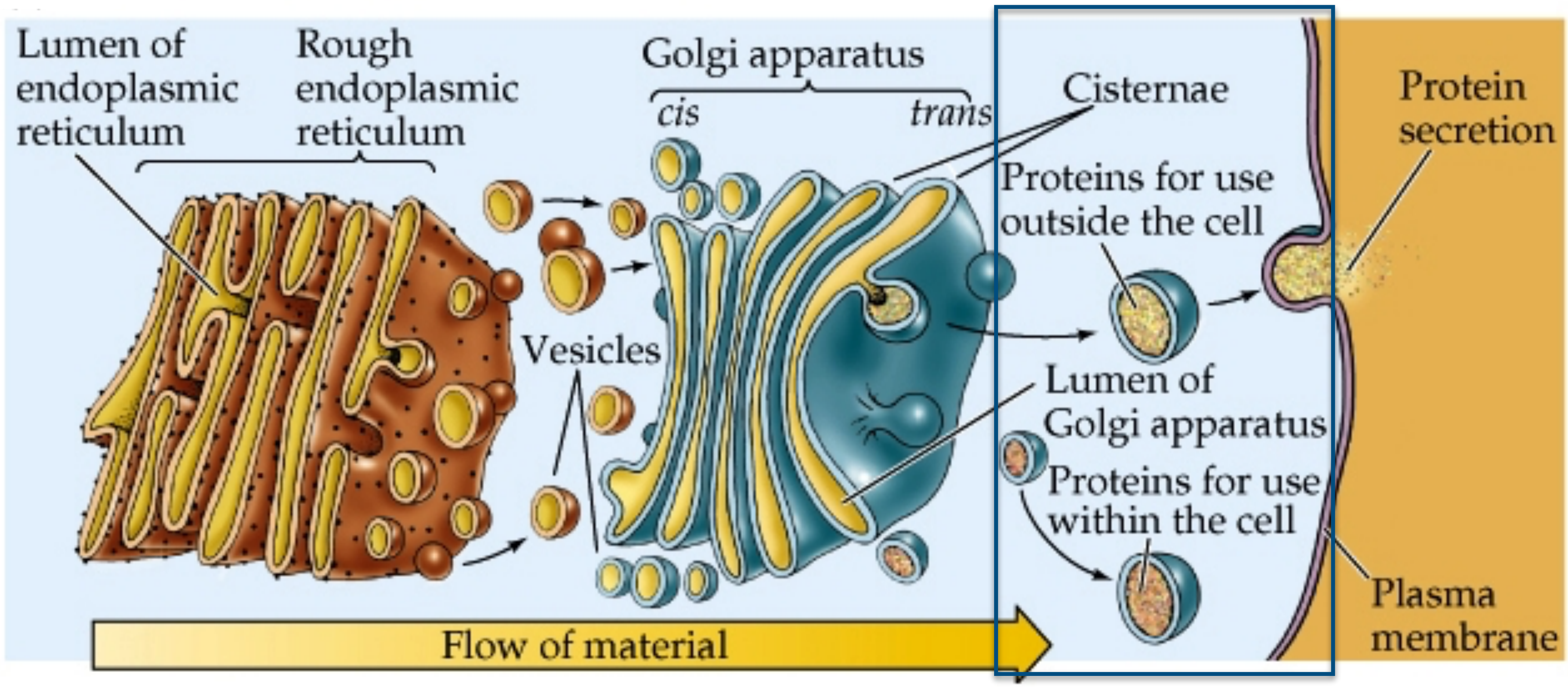
Plasma membrane
Flow of material


Lumen of
endoplasmic
reticulum
Rough
endoplasmic
reticulum
Golgi apparatus
cis
trans
Cisternae
Protein
secretion
Proteins for use
outside the cell
Vesicles
Lumen of
Golgi apparatus
Proteins for use
within the cell
Plasma
membrane
Flow of material


Lumen of endoplasmic reticulum
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Lumen of Golgi apparatus
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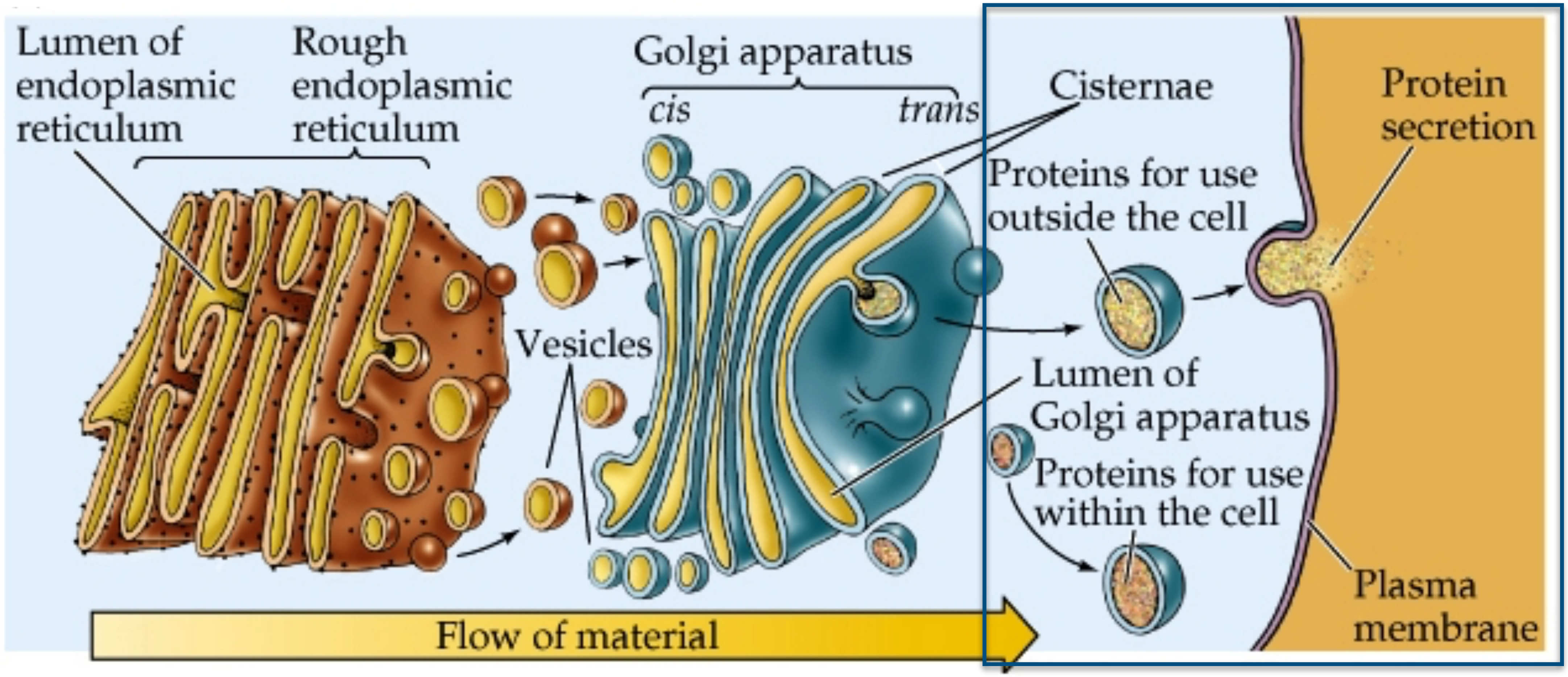
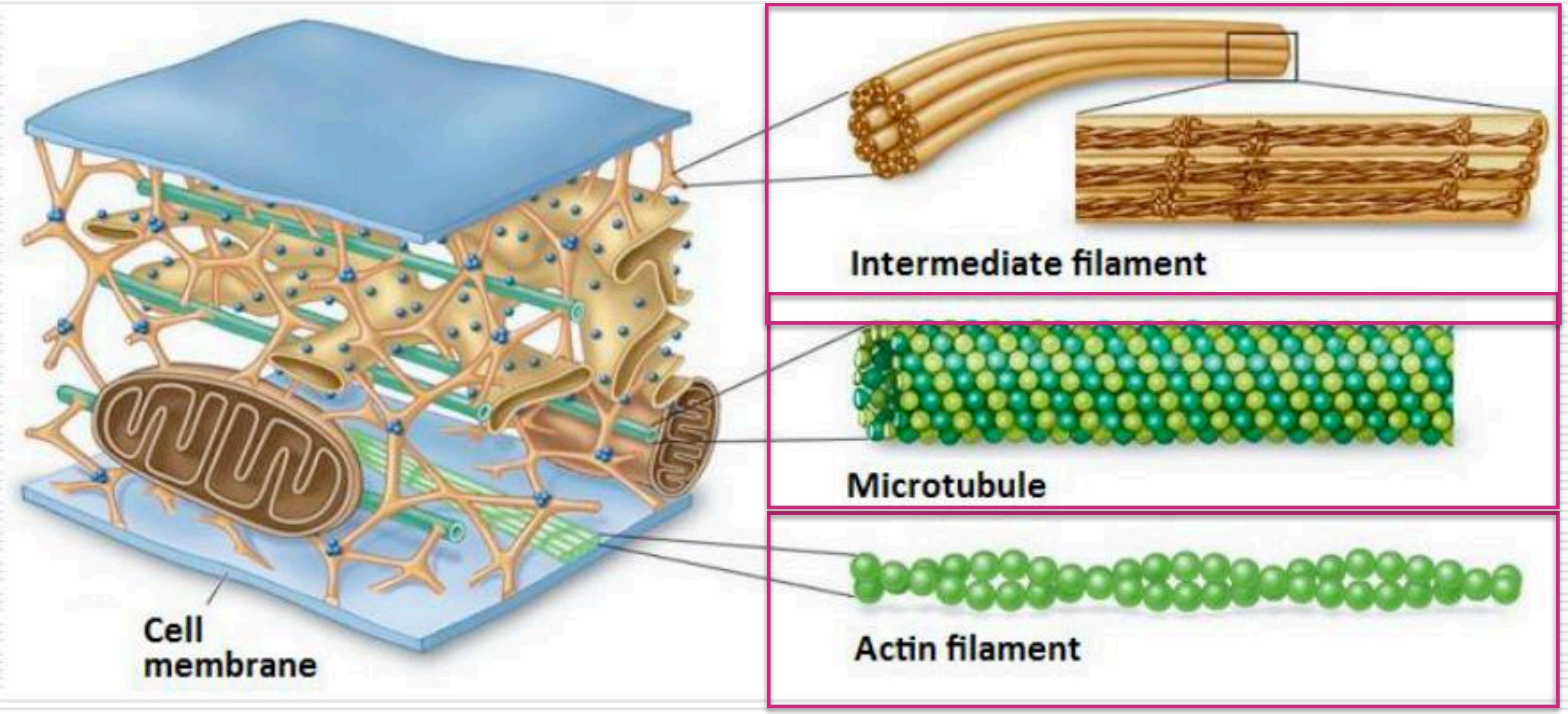
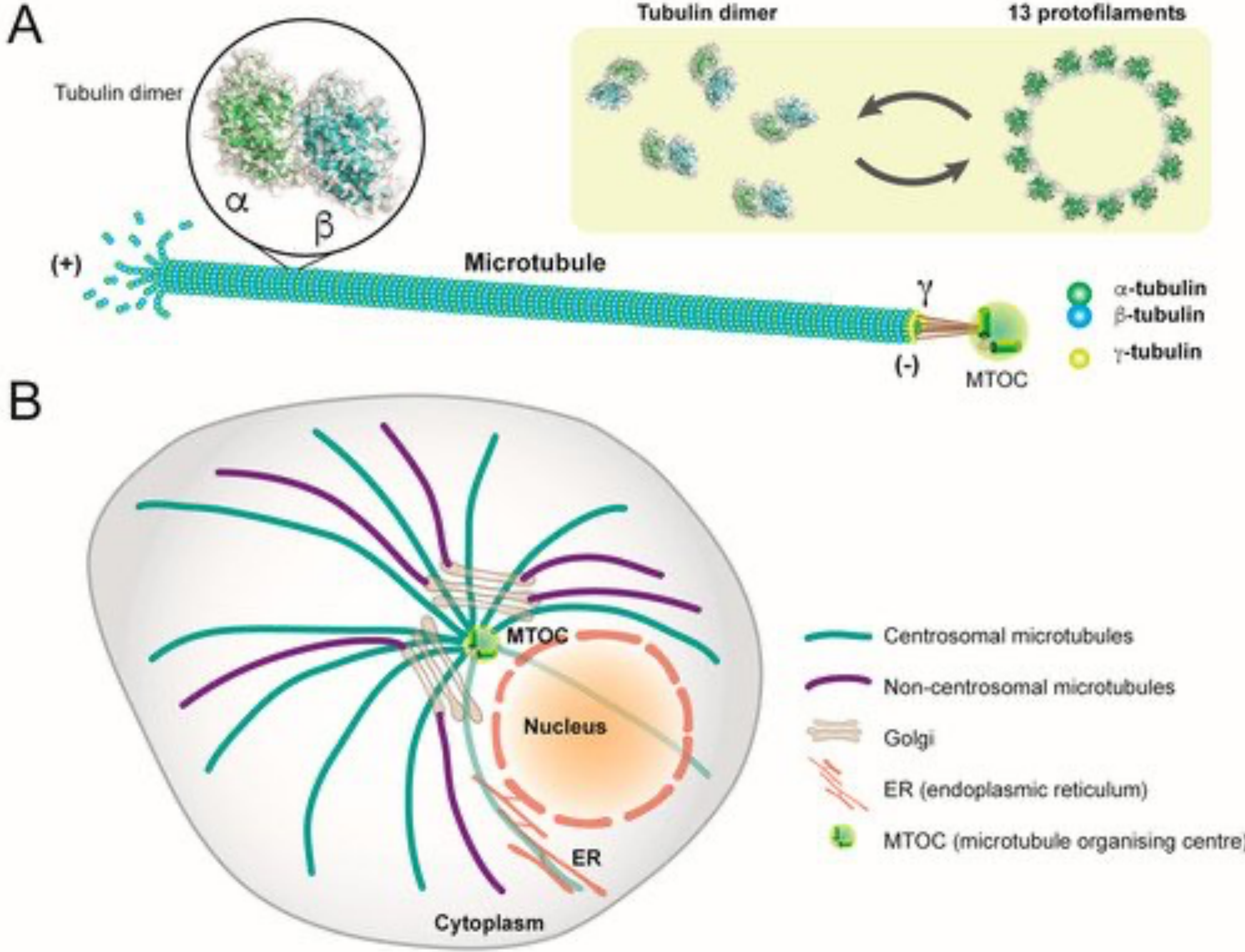
Flow of material

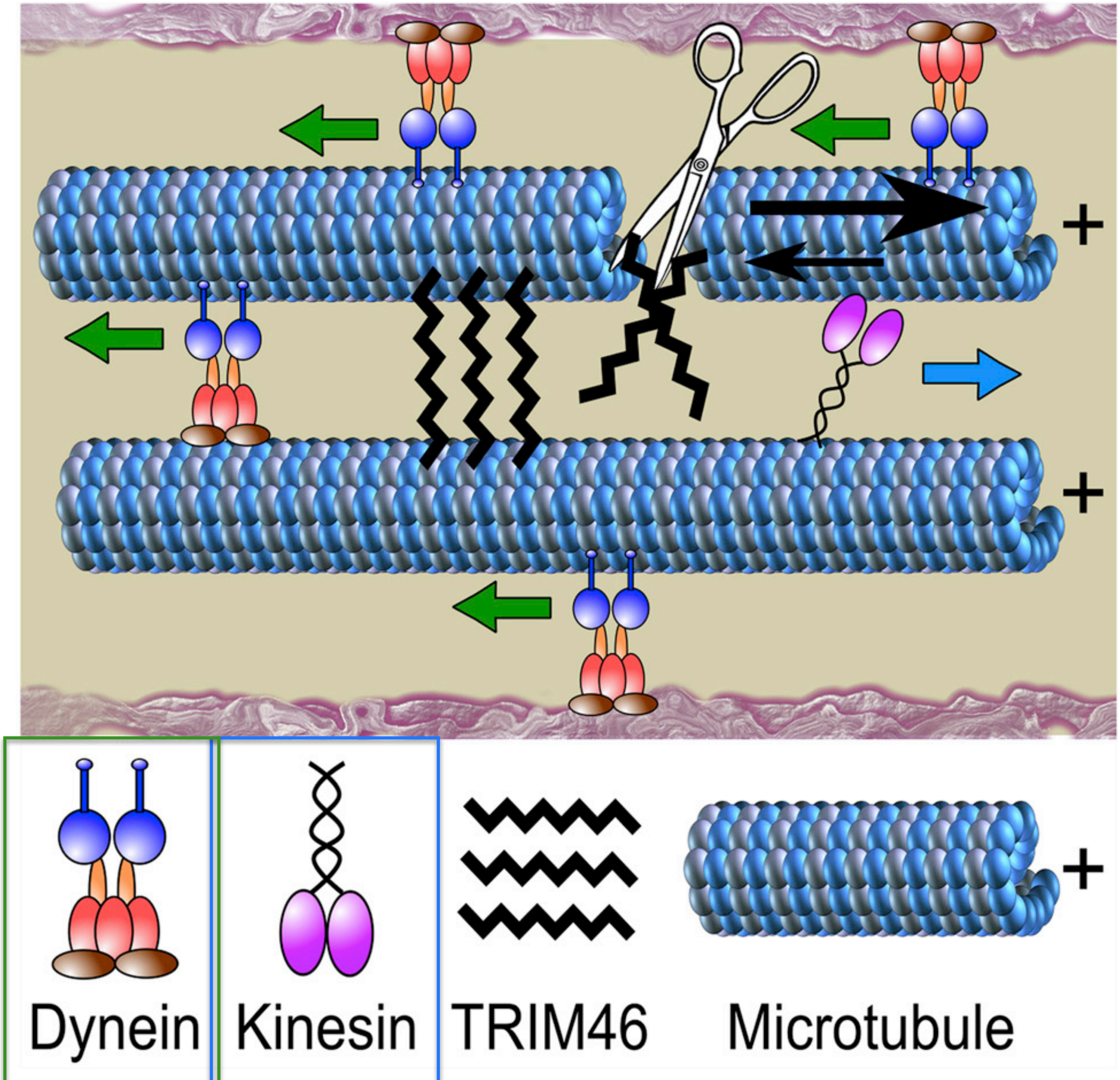


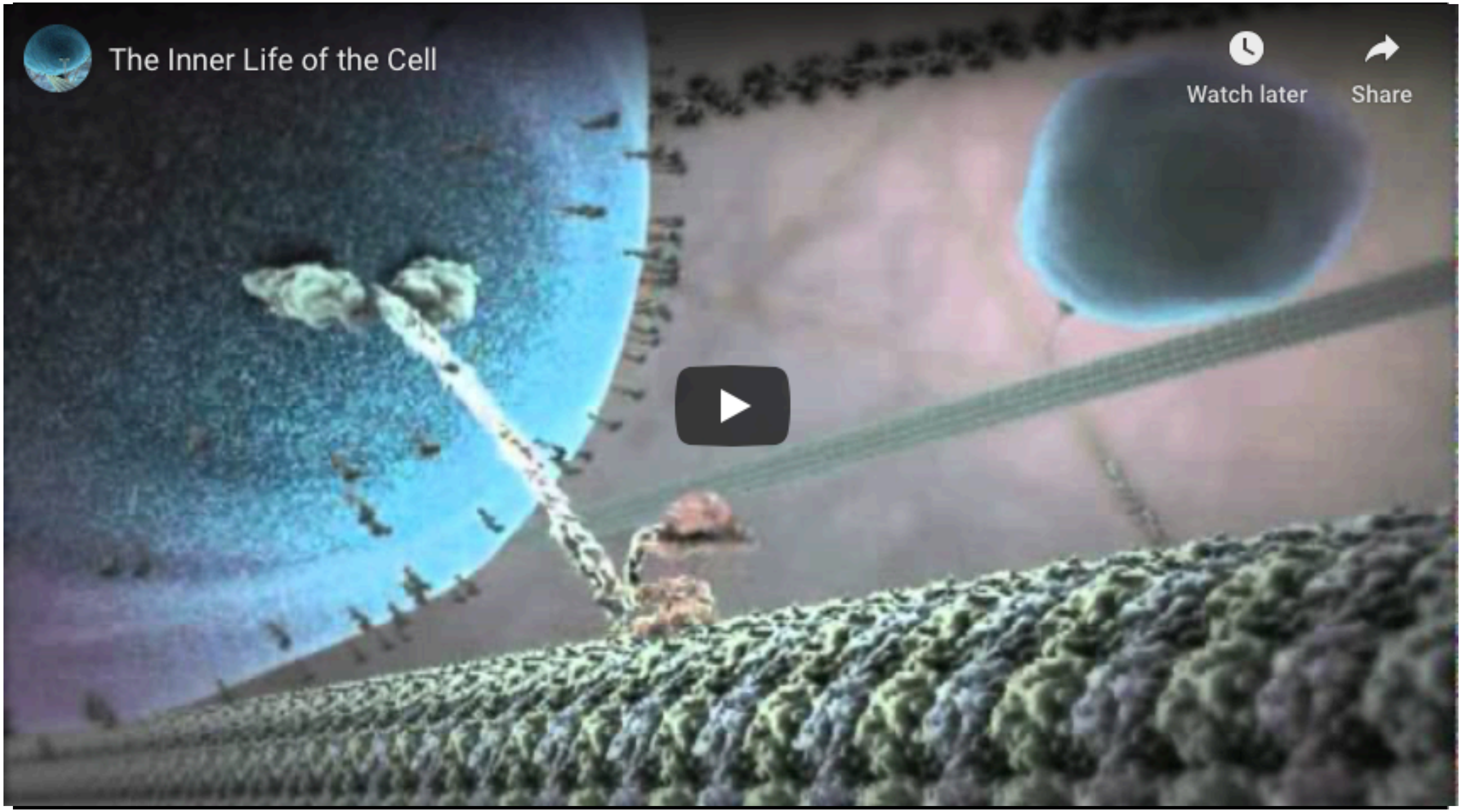
Lumen of endoplasmic reticulum
Rough endoplasmic reticulum
Golgi apparatus
cis
trans
Cisternae
Protein secretion
Proteins for use outside the cell
Vesicles
Lumen of Golgi apparatus
Proteins for use within the cell
Plasma membrane
Flow of material

Cytoskeleton Protein Fibers




A
Tubulin dimer
13 protofilaments
Tubulin dimer
α
β
(+)
Microtubule
γ
(-)
MTOC
α-tubulin
β-tubulin
γ-tubulin
B
MTOC
Nucleus
ER
Cytoplasm
Centrosomal microtubules
Non-centrosomal microtubules
Golgi
ER (endoplasmic reticulum)
MTOC (microtubule organising centre)


+
+
+
Dynein
Kinesin
TRIM46
Microtubule


The Inner Life of the Cell
Watch later
Share

Energy!

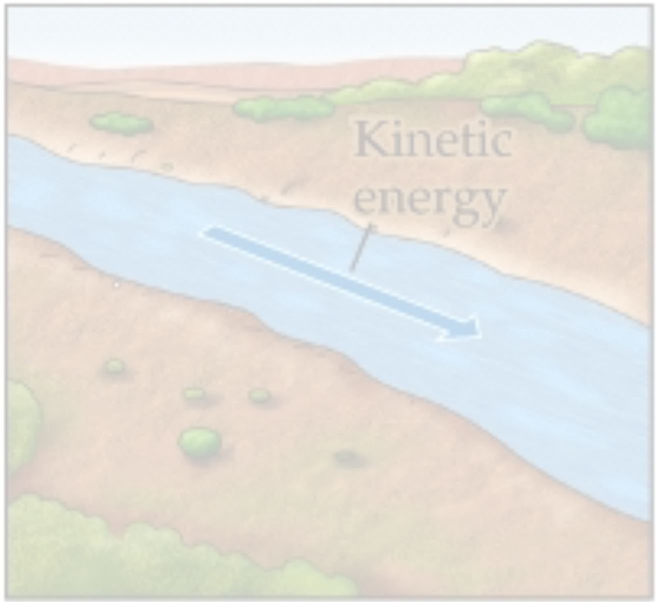
The law of conservation of energy states that -energy can neither be created nor destroyed it can only be converted from one form of energy to another.

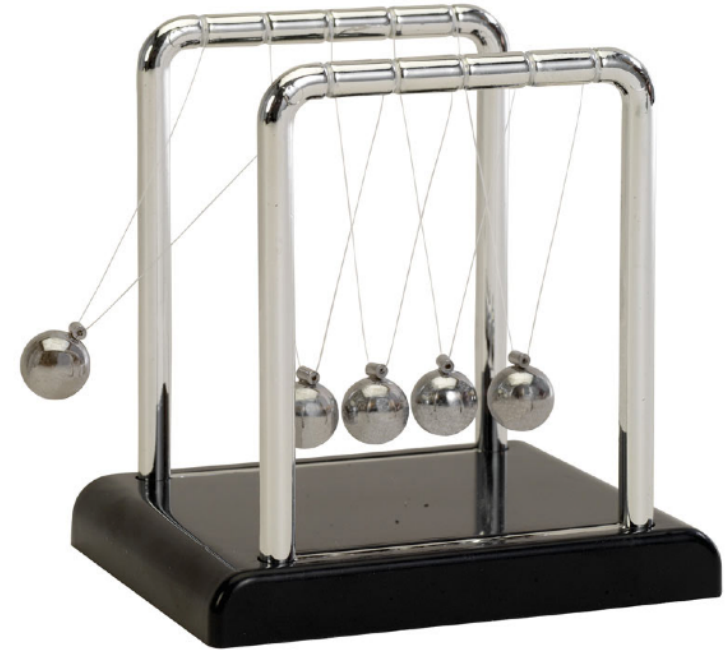
Albert Einstein

This means that a system always has the same amount of energy, unless it's added from the outside...

The only way to use energy, therefore, is to transform energy from one form to another.

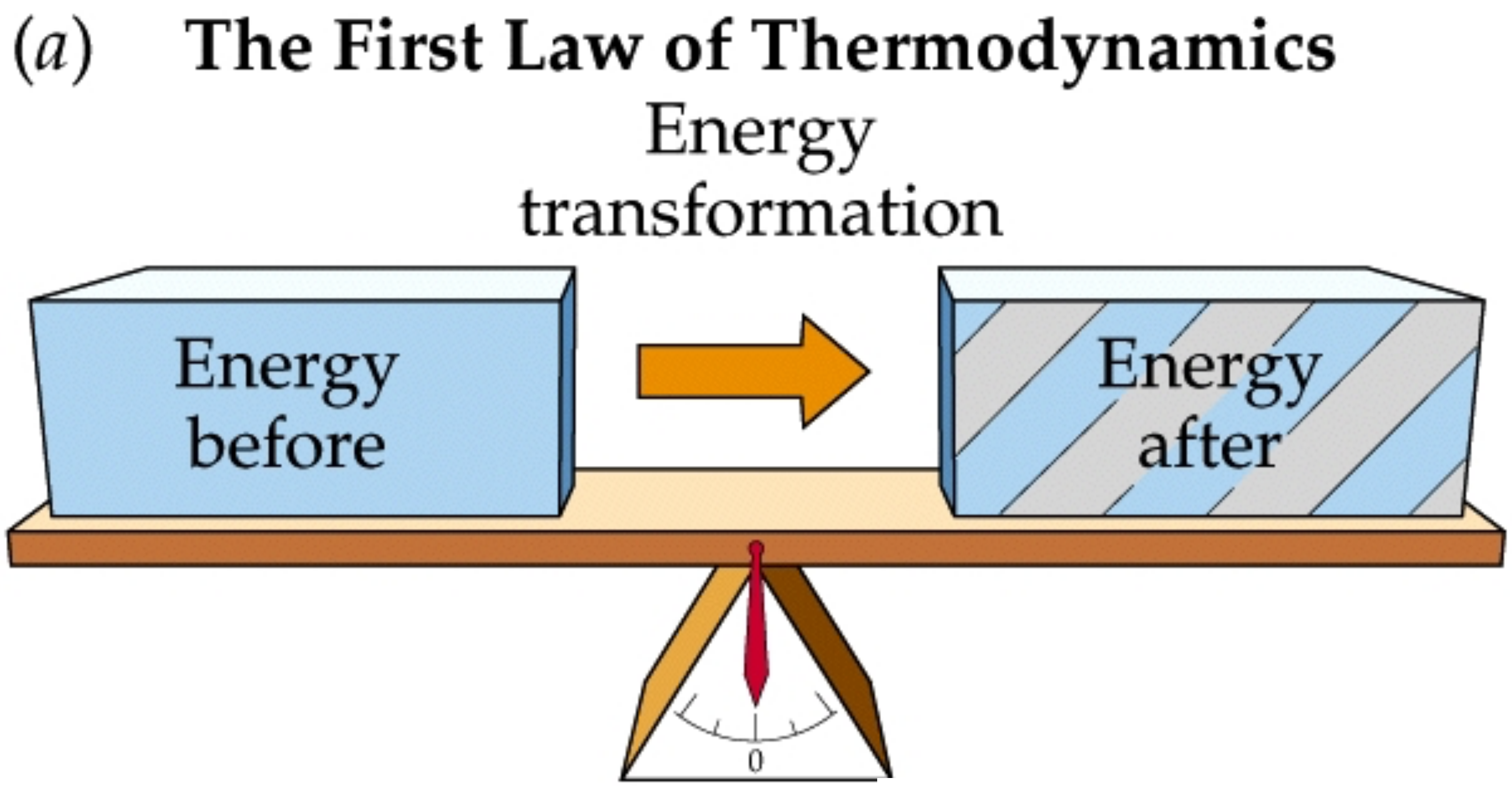
Potential vs. Kinetic energy



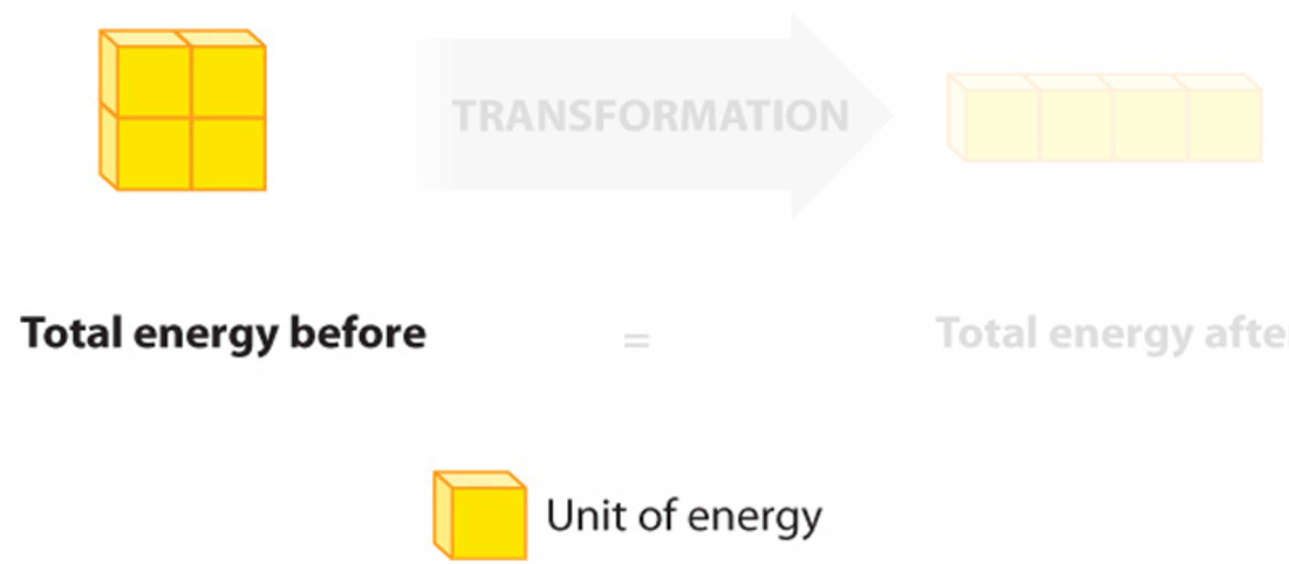


The FIRST law of thermodynamics: or the law of the conservation of energy, states: **the increase in the internal energy of a system is equal to the amount of energy added to the system by heat, plus the amount added in the form of work done on the system**.

1st Law

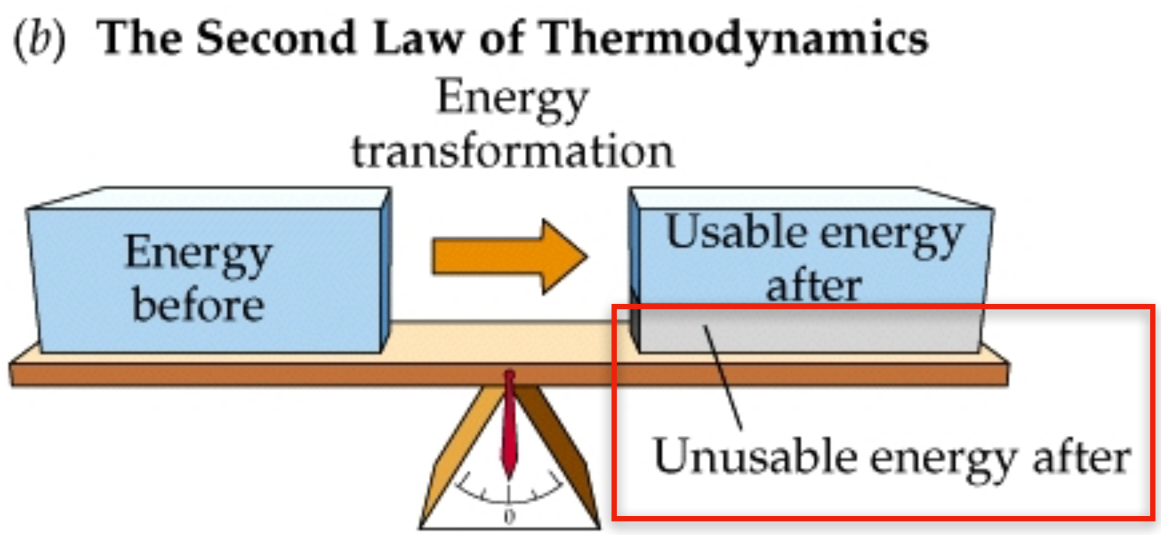

(a) The First Law of Thermodynamics
Energy
transformation
Energy
before
Energy
after
0

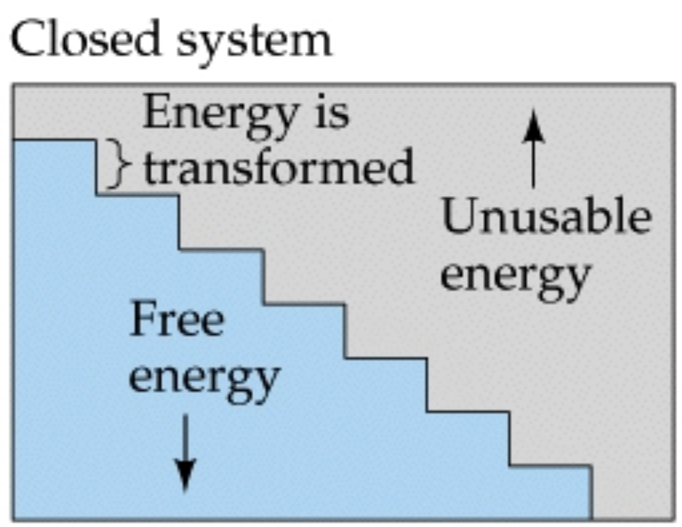
1st Law

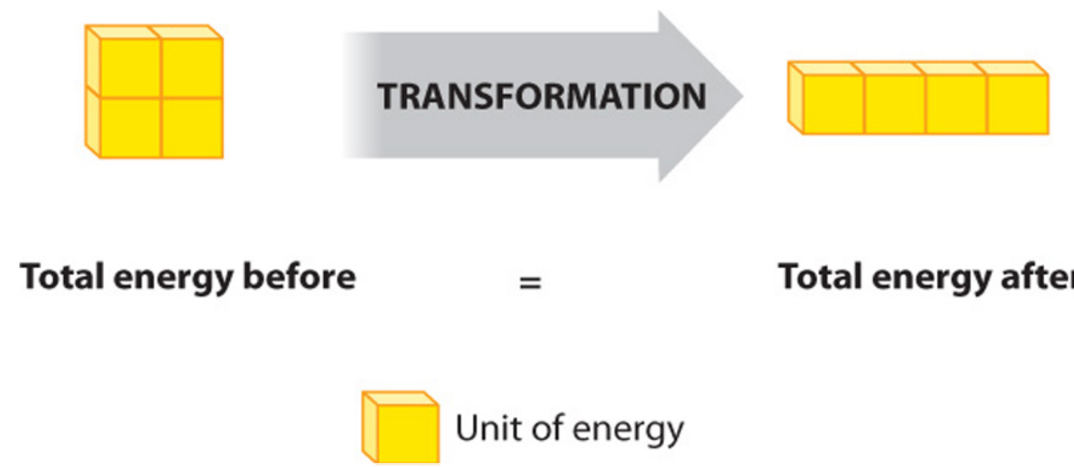

TRANSFORMATION
Total energy before
=
Total energy after
Unit of energy

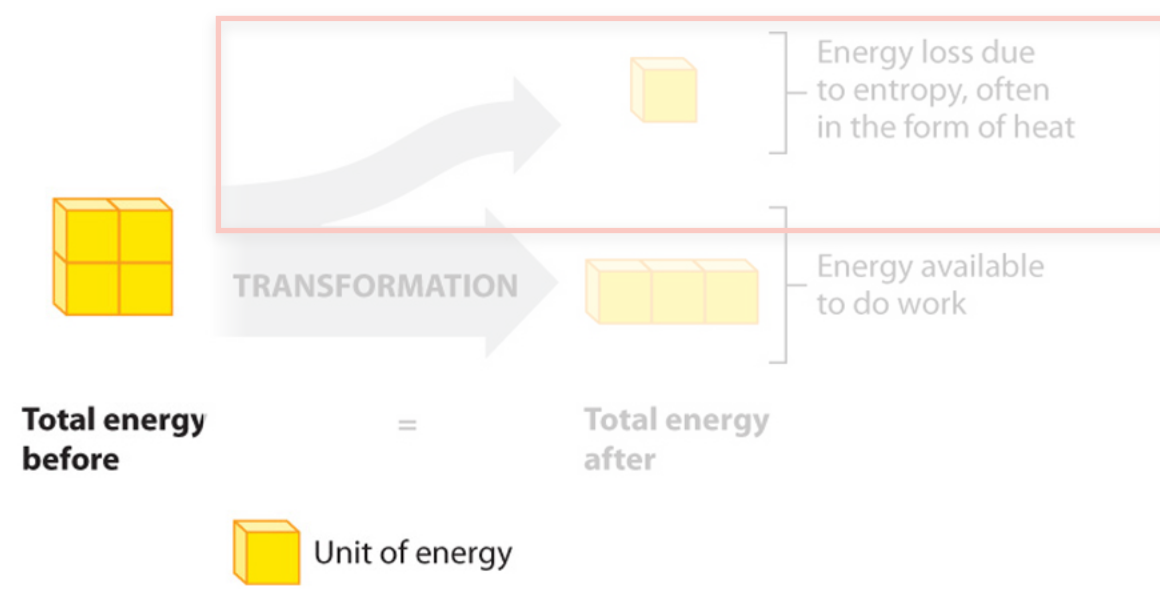
The **SECOND law: the total ENTROPY (S) of any thermodynamically isolated system tends to increase over time, approaching a maximum value.**

2nd Law


(b) The Second Law of Thermodynamics
Energy transformation
Energy before
Usable energy after
Unusable energy after
0


Closed system
Energy is transformed
Unusable energy
Free energy

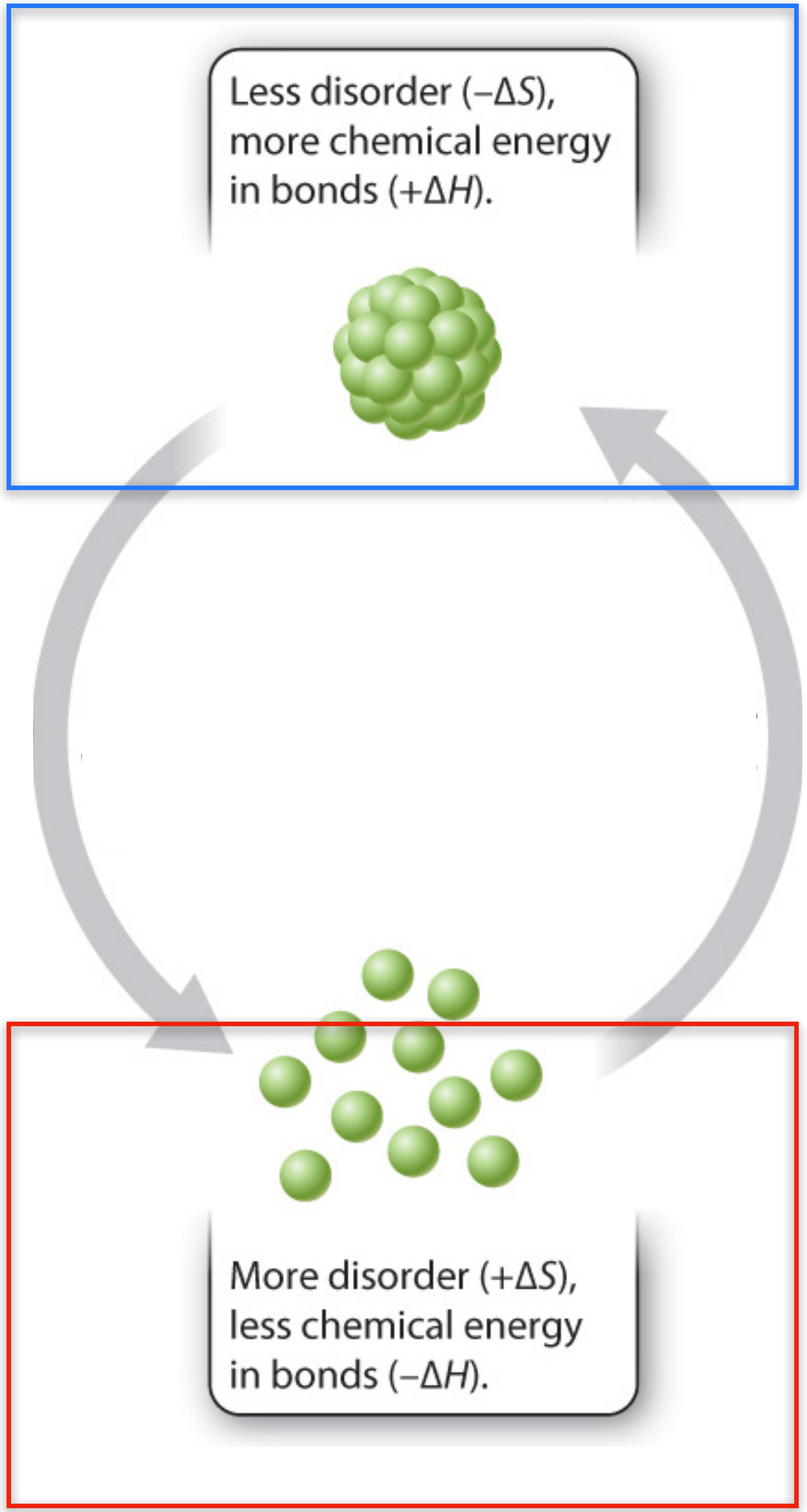

TRANSFORMATION
Total energy before
=
Total energy after
Unit of energy


Energy loss due to entropy, often in the form of heat
TRANSFORMATION
Energy available to do work
Total energy before
=
Total energy after
Unit of energy

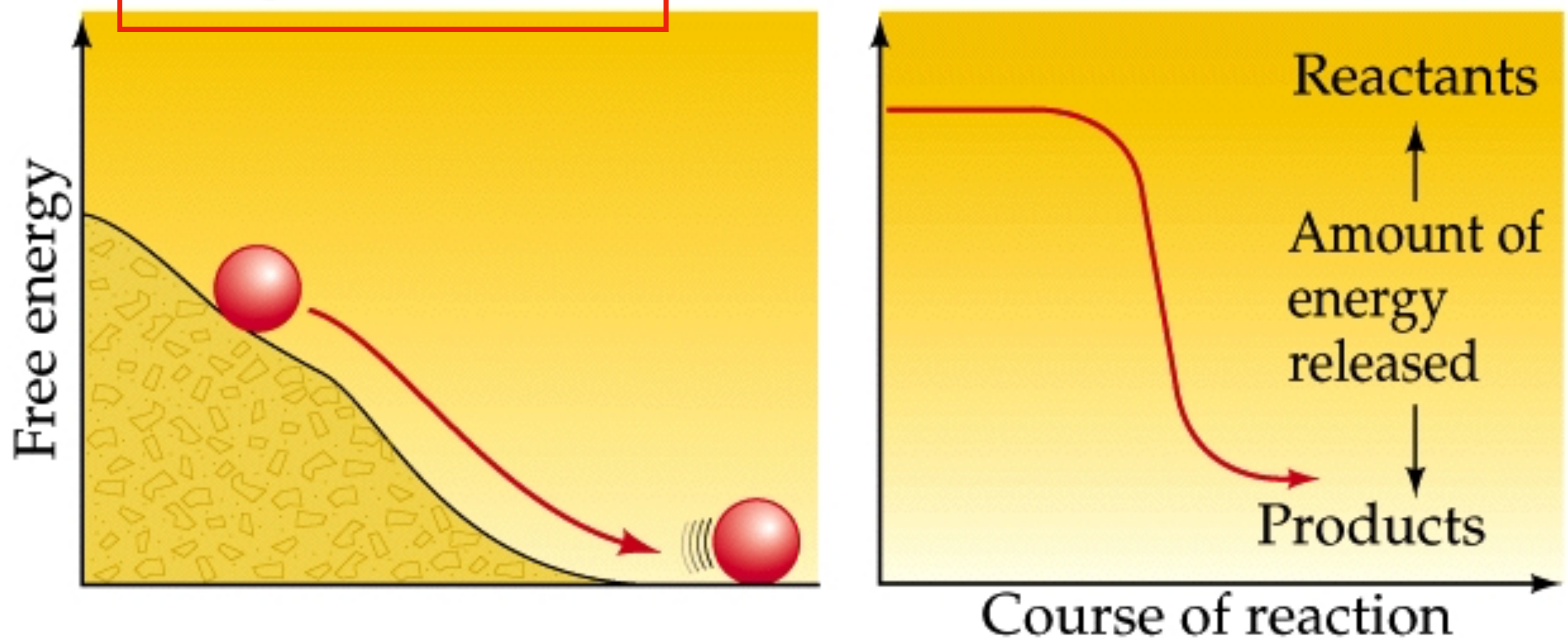
2nd Law

Entropy (S): a thermodynamic quantity representing the unavailability of a system's thermal energy for conversion into mechanical work, often interpreted as the degree of disorder or randomness in the system.

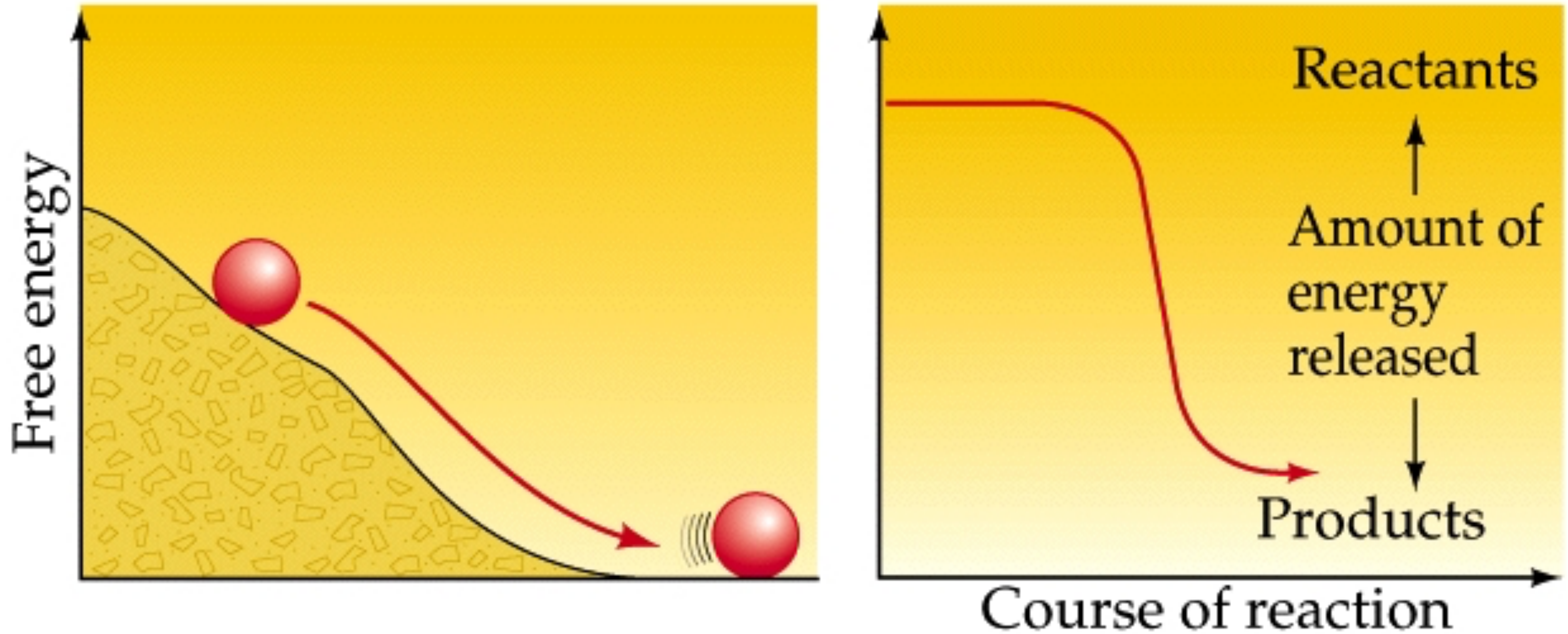
Enthalpy (H): a thermodynamic quantity equivalent to the total heat content of a system. It is equal to the internal energy of the system plus the product of pressure and volume.


Less disorder (−ΔS), more chemical energy in bonds (+ΔH).
More disorder (+ΔS), less chemical energy in bonds (−ΔH).

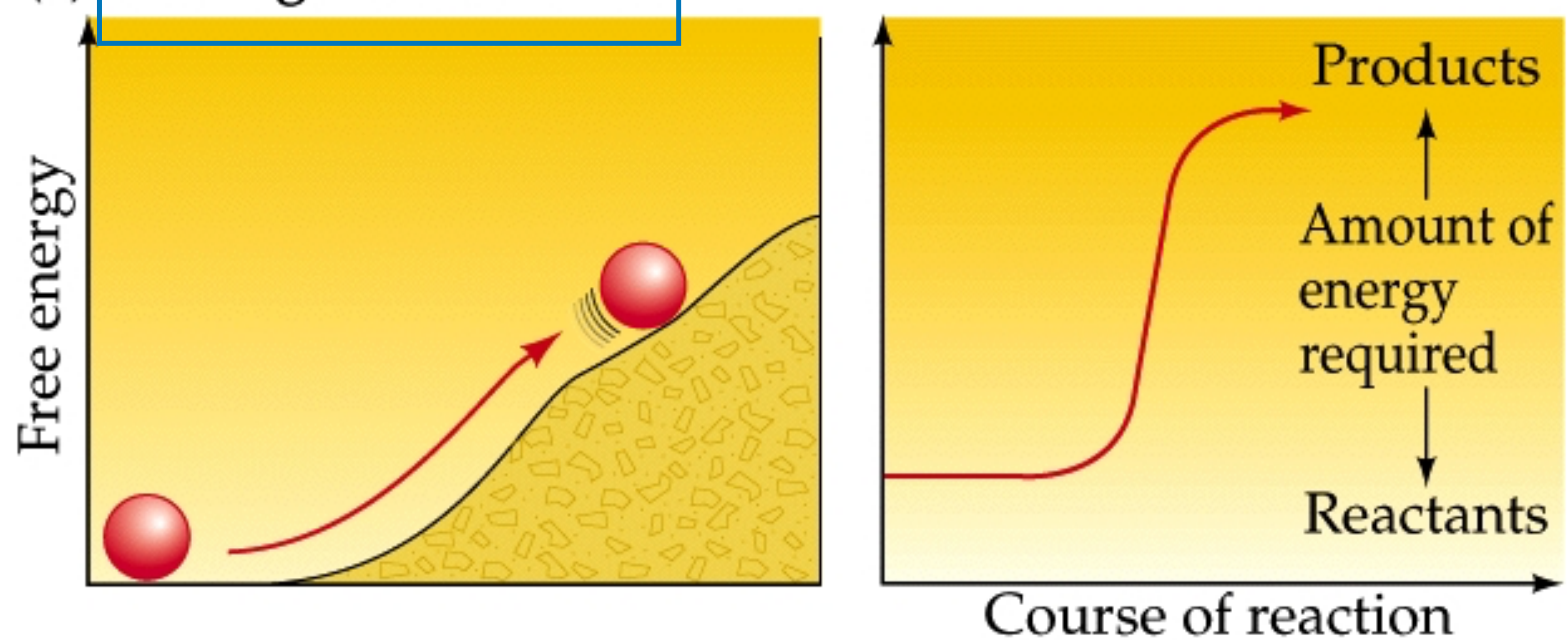
(*a*) **Exergonic reaction**



(*a*) **Exergonic reaction**



(*b*) **Endergonic reaction**



All reactions, however - at least in principle, are reversible. (A <---> B).

If (under certain, given conditions) **A ----> B** is spontaneous (and **exergonic**),

then **B ---->A** must be less than spontaneous (and **endergonic**).

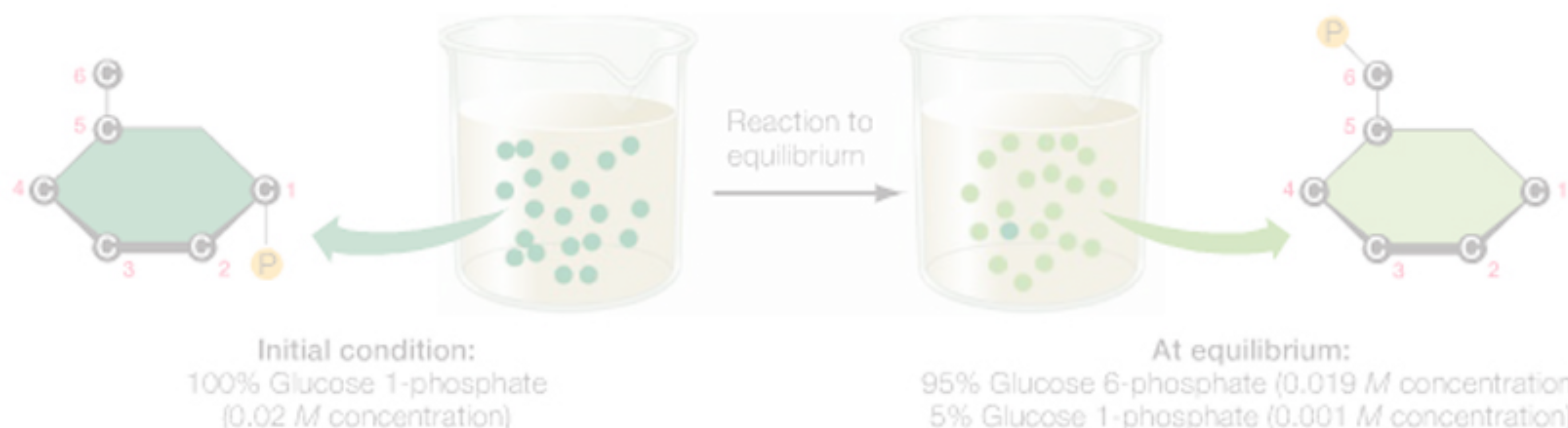
All other things being equal, adding more A generally speeds up the forward reaction…

A --------> **B**;

At some relative concentration of A and B, the net forward and reverse reactions taking place are in balance, and effectively cancel each other out.

That is not to say that, at equilibrium, there will always be equal amounts of **A** as there are of **B**

8.4 Chemical Reactions Run to Equilibrium No matter what quantities of glucose 1-phosphate and glucose 6-phosphate are dissolved in water, when equilibrium is attained, there will always be 95 percent glucose 6-phosphate and 5 percent glucose 1-phosphate.

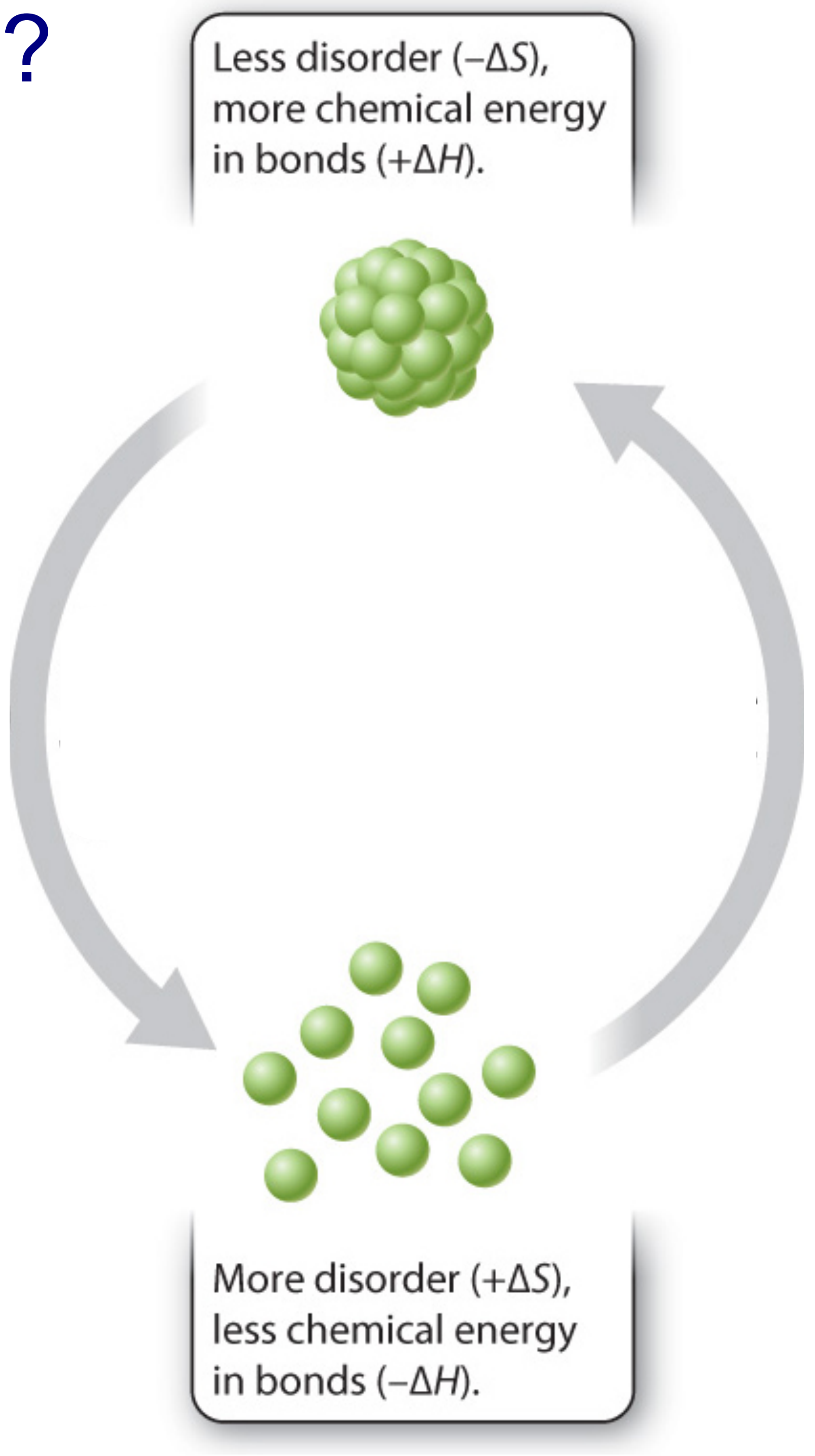


As a rule of thumb: the farther a reaction goes toward completion in order to reach equilibrium the greater the amount of **"free energy"** released.

What is **"free energy"** ??

"The **energy** associated with a chemical reaction that can be used to do work. "

often called "**Gibbs** free energy"



What is **“free energy”** ??

“The **energy** associated with a chemical reaction that can be used to do work. “

ENTROPY AND GIBBS FREE ENERGY

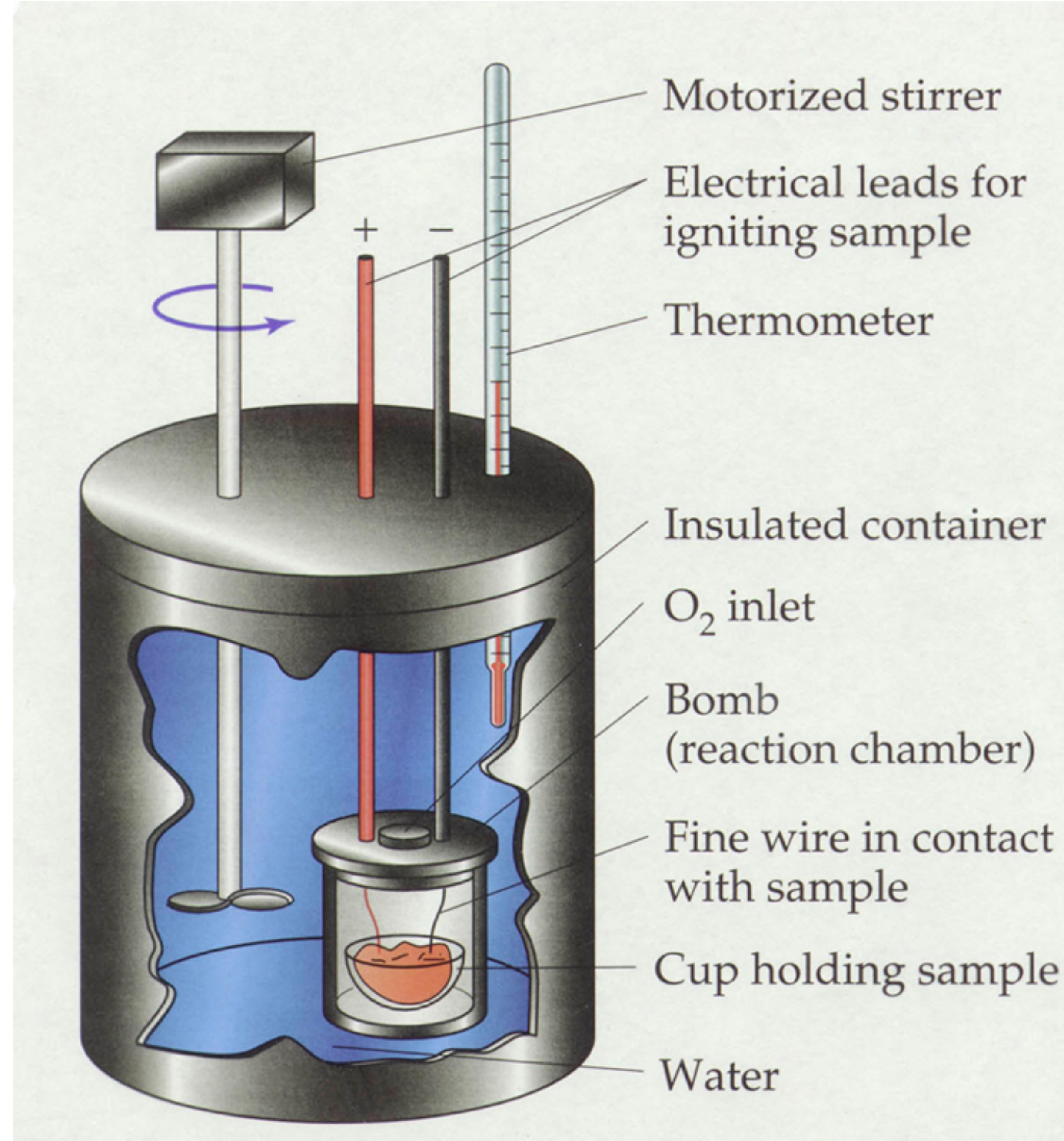
How are entropy and enthalpy related?

$$^{*}\ \Delta G^{o} = \Delta H^{o} - T\Delta S^{o}$$

Gibbs free energy is the energy that is available to do useful work.

A reaction will spontaneously occur if $\Delta G<0$ (exergonic reaction)

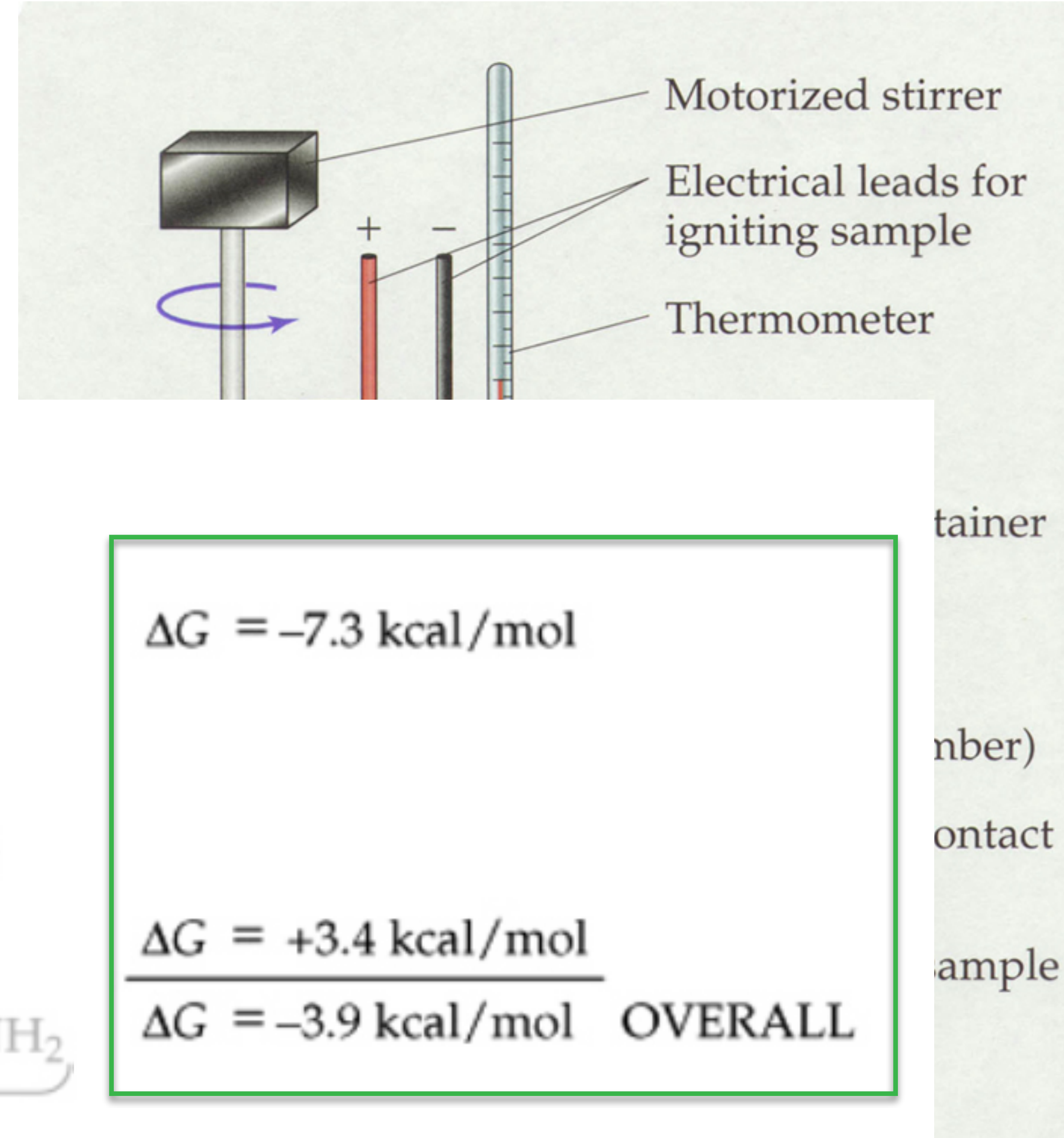
A reaction will NOT spontaneously occur if $\Delta G>0$ (endergonic reaction)

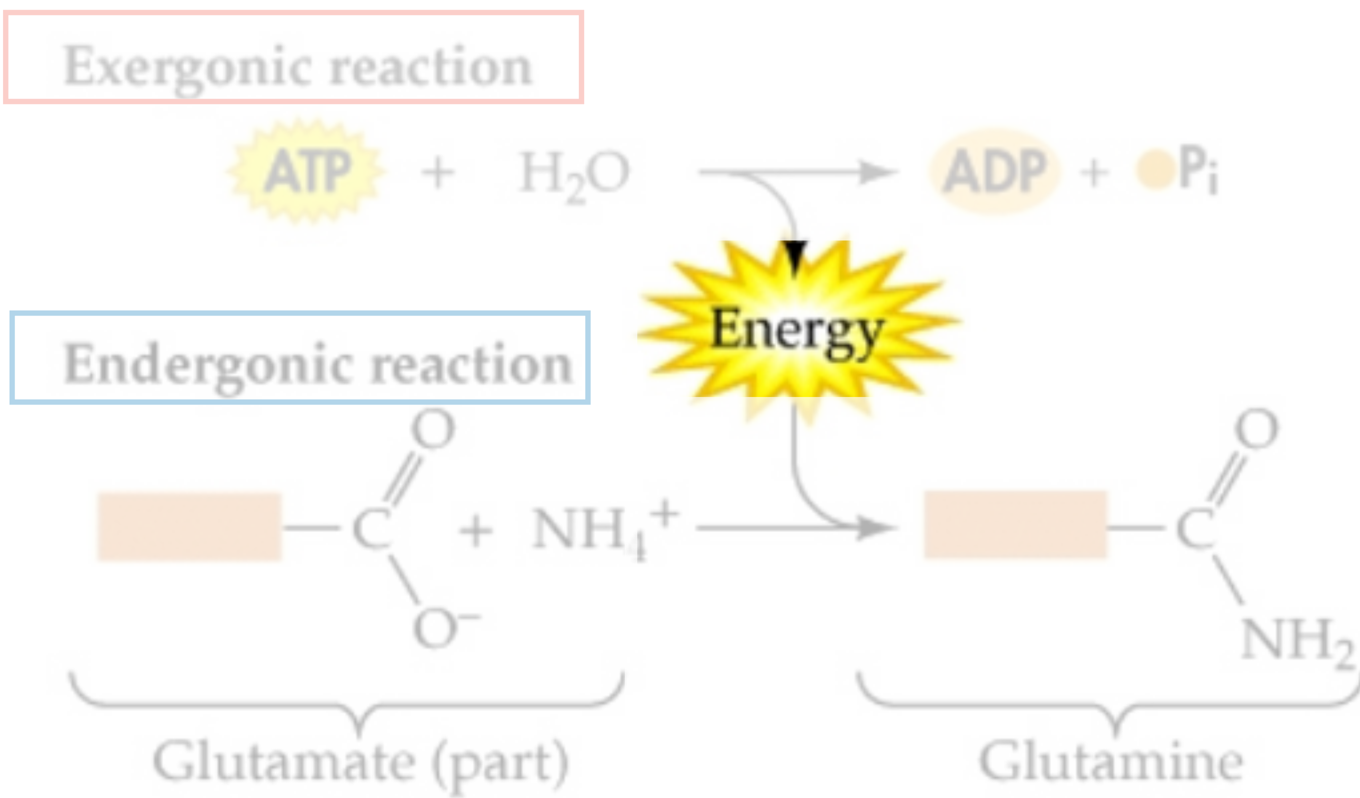


* at **STP** or standard temperature and pressure

What is **"free energy"** ??

"The **energy** associated with a chemical reaction that can be used to do work. "



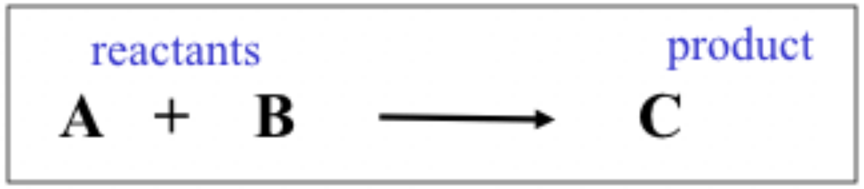


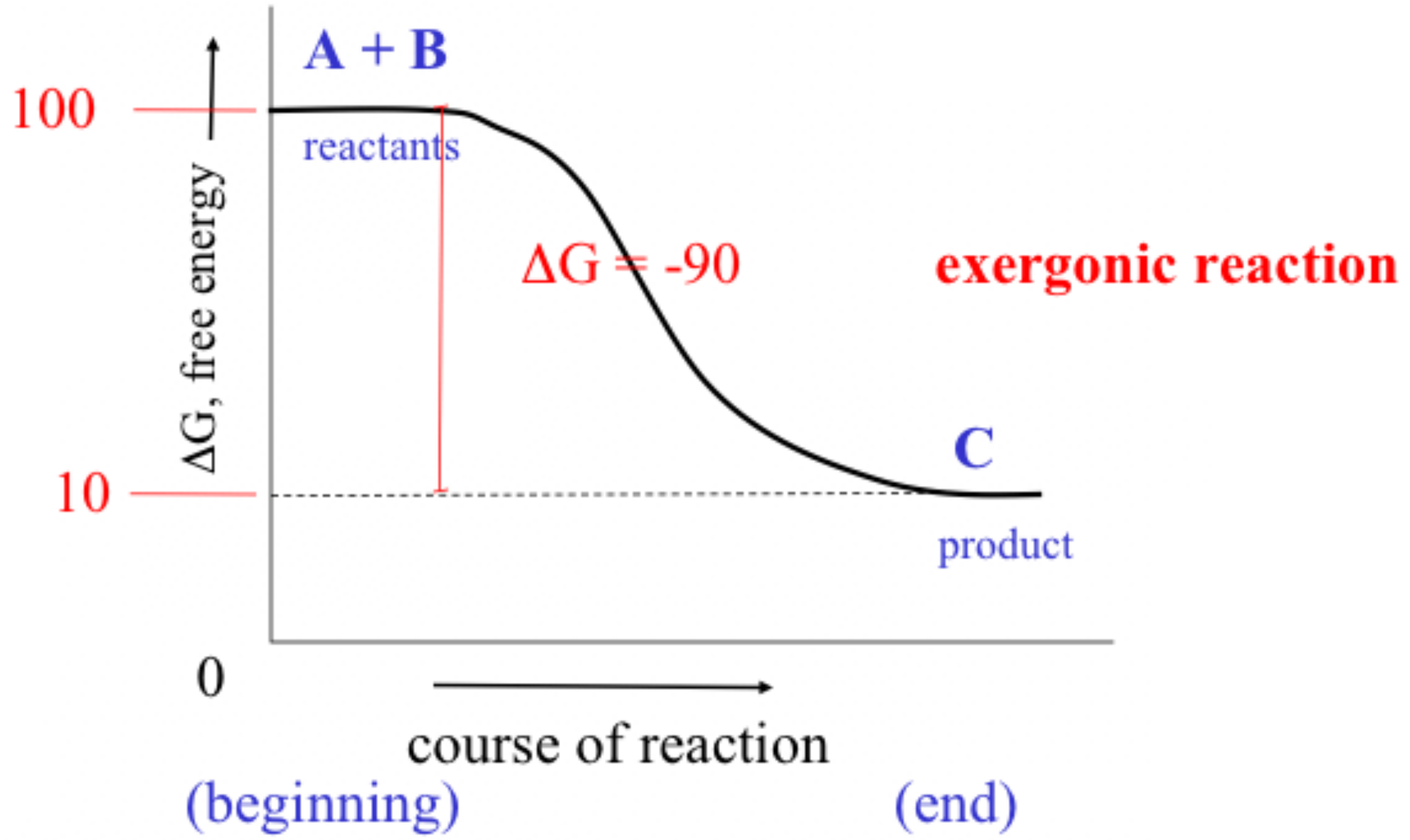
$$\Delta G = -7.3 \text{ kcal/mol}$$

$$\Delta G = +3.4 \text{ kcal/mol}$$

$$\Delta G = -3.9 \text{ kcal/mol} \quad \text{OVERALL}$$

- free energy example

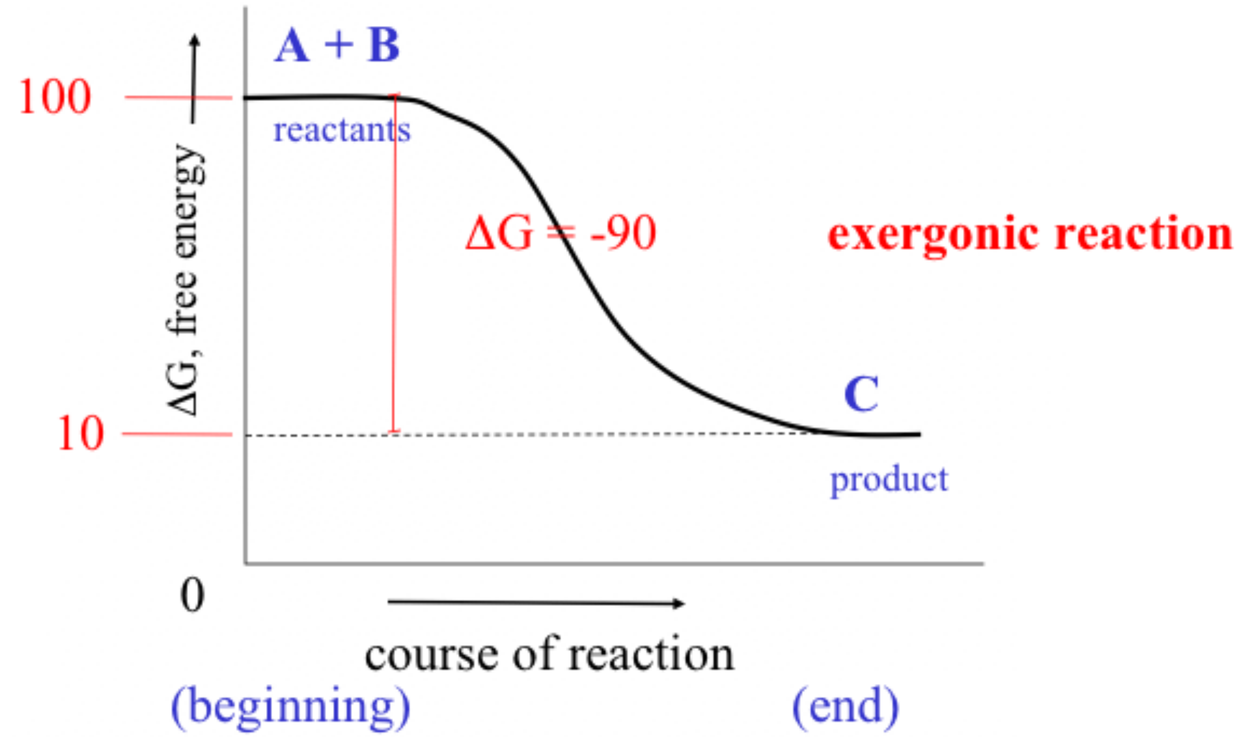




- free energy example

reactants → product

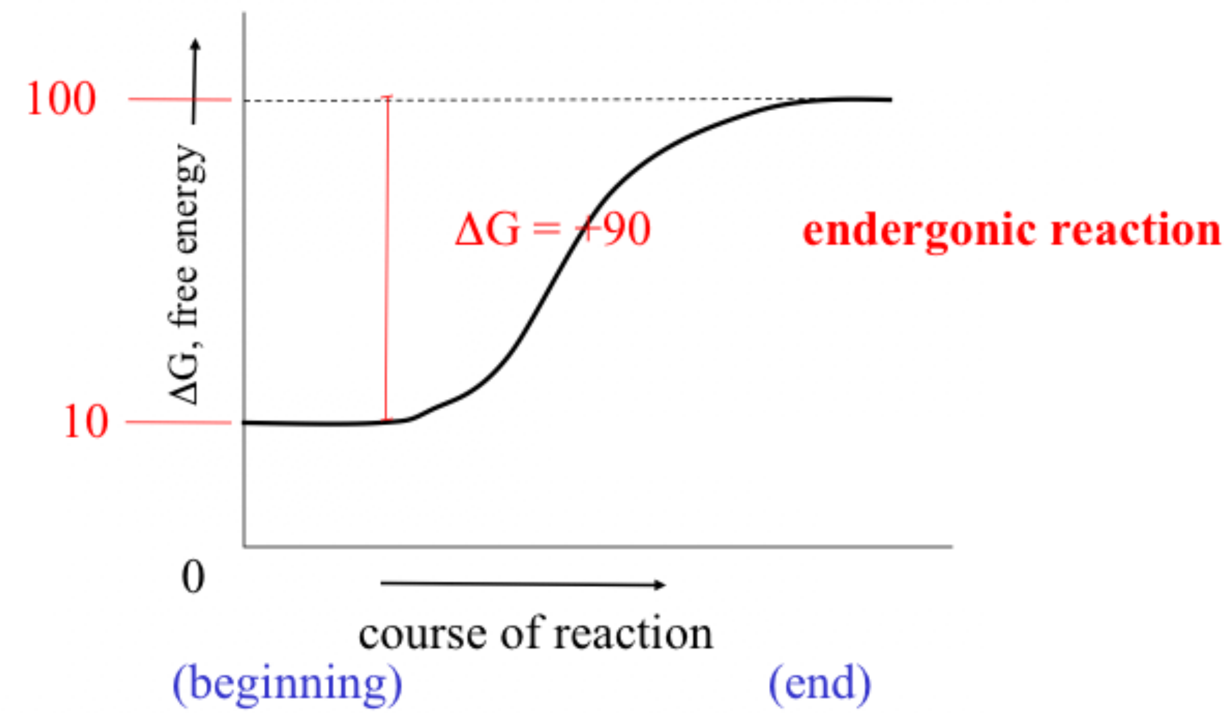
A + B ⟶ C



- free energy example

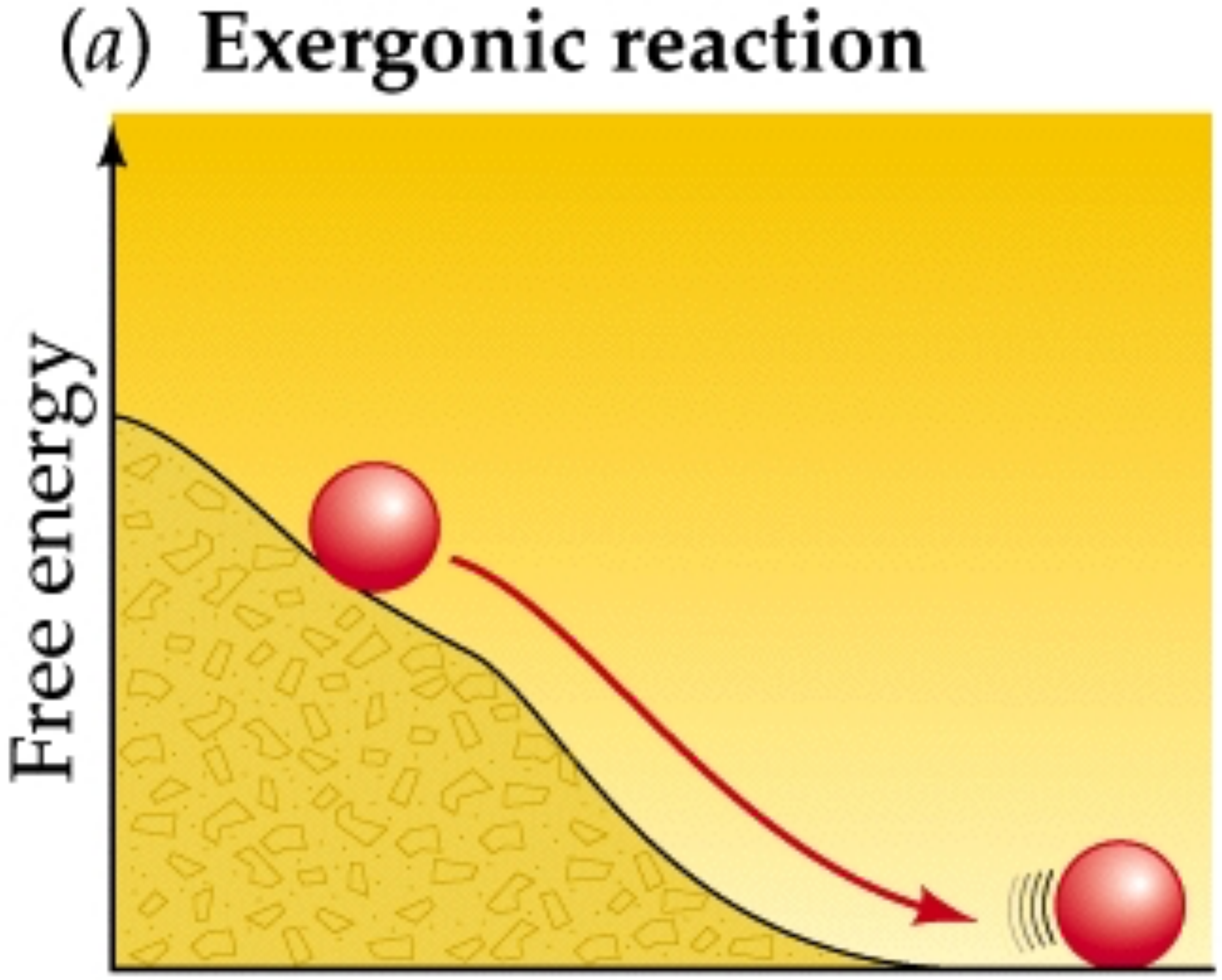
reactants → product

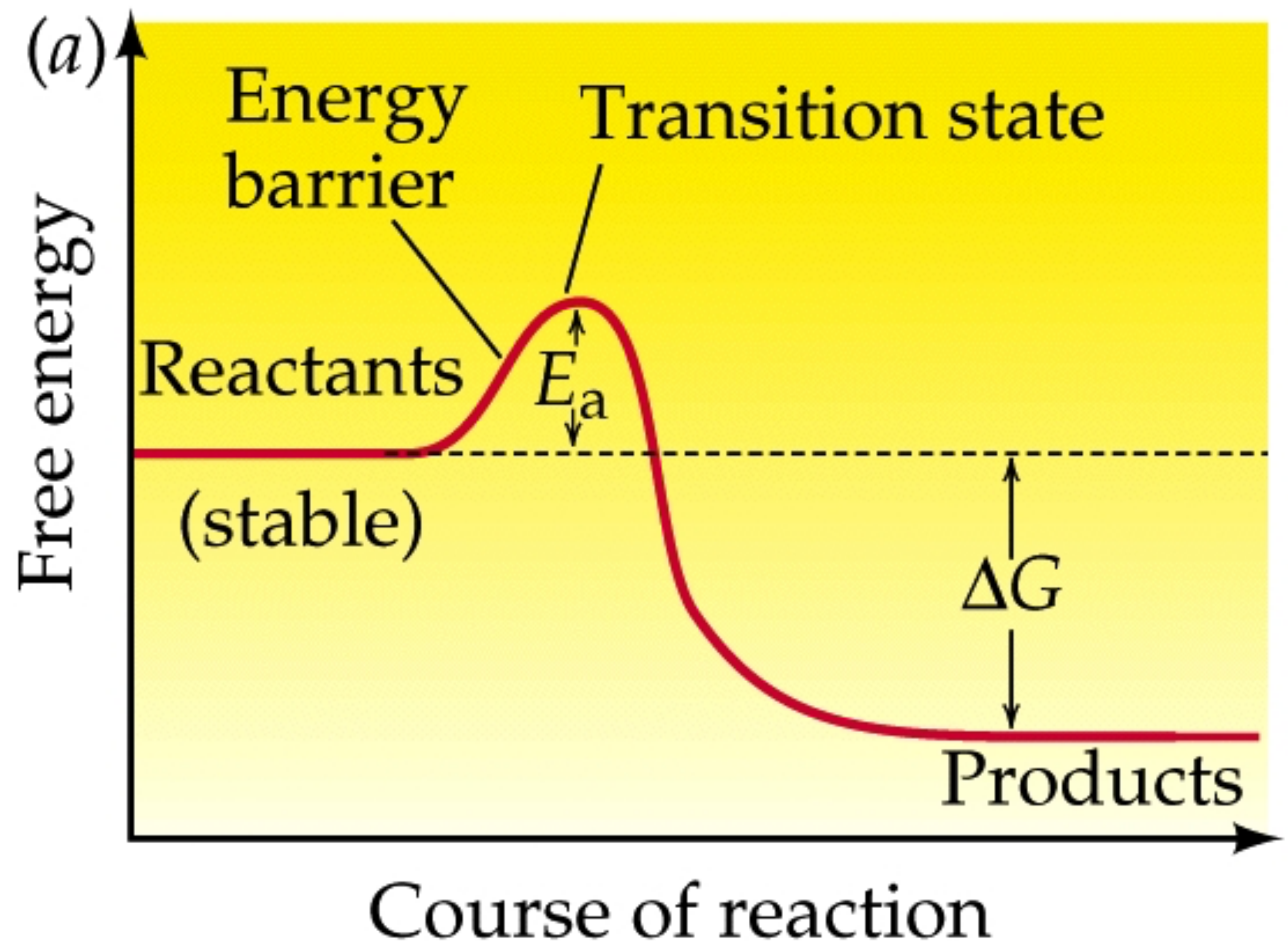
A + B ⟶ C

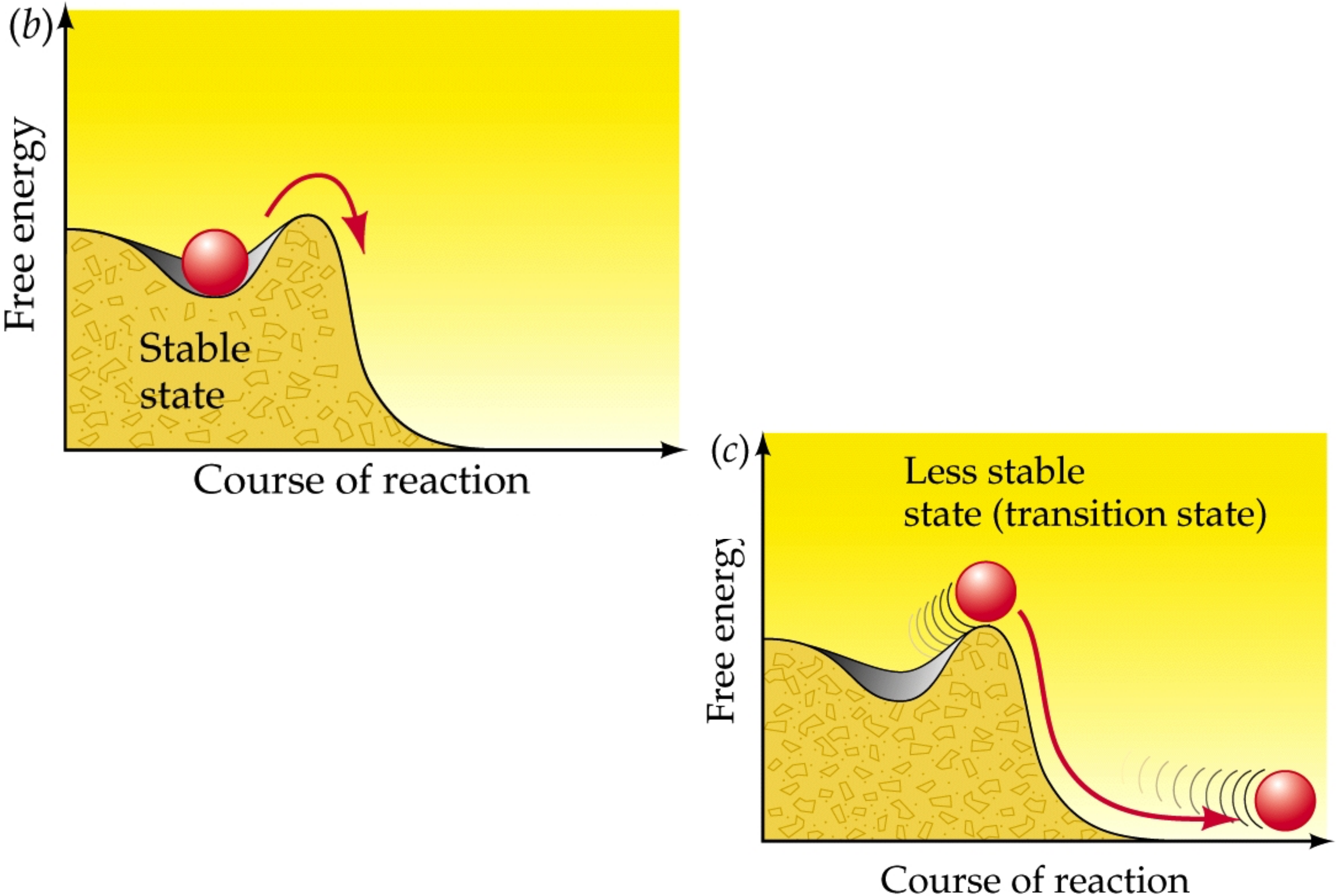


While it is easy to predict the direction that a spontaneous reaction will go, it is not so easy to predict the "likelihood" or rate of the reaction.

For a reaction to proceed, an **energy barrier** often must be overcome......




(a)
Energy
barrier
Transition state
Reactants
(stable)
E_a
ΔG
Products
Free energy
Course of reaction


(b)
Free energy
Stable
state
Course of reaction
(c)
Less stable
state (transition state)
Free energy
Course of reaction

Types of enzymes (Biological catalysts)

- "_______-ase" implies an enzyme

examples:

kinase adds phosphate (phosphorylates) another molecule

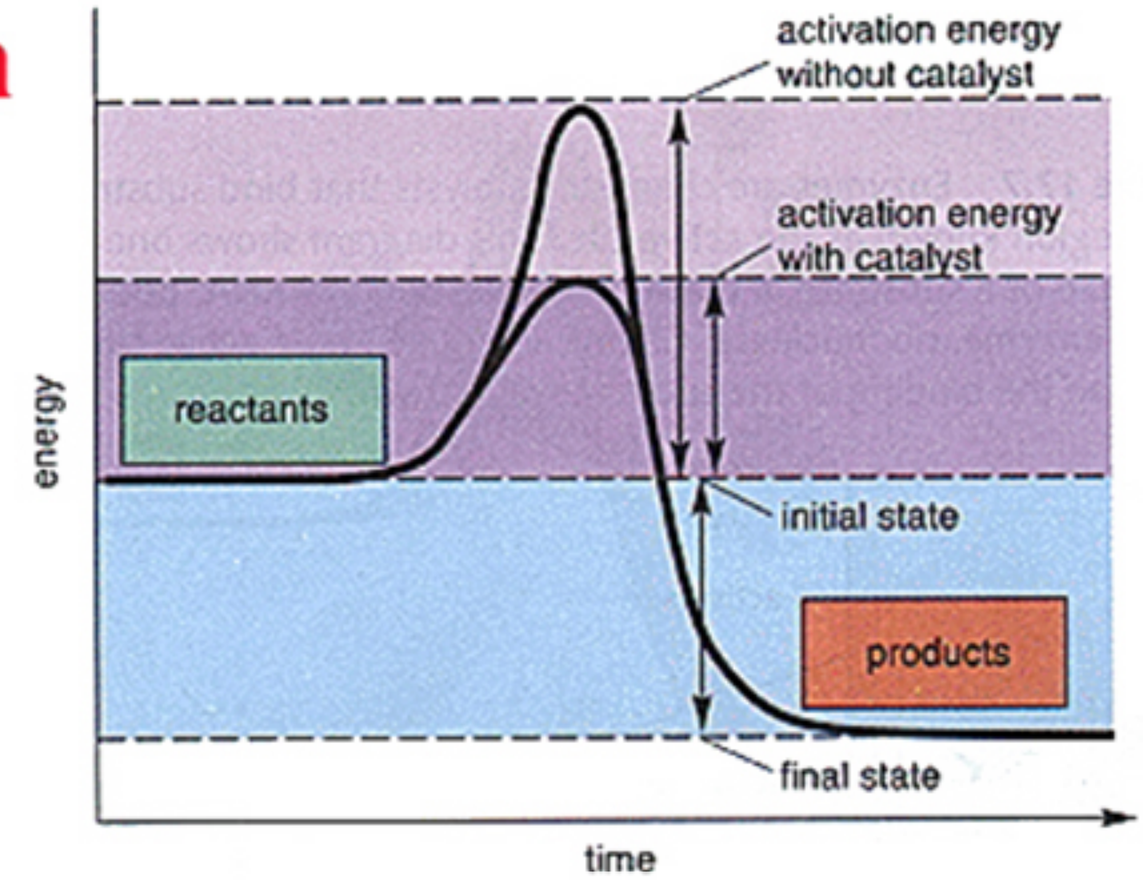
isomerase rearranges a molecule's structure

dehydrogenase oxidizes a compound (removes electrons)

reductase reduces a compound (adds electrons)

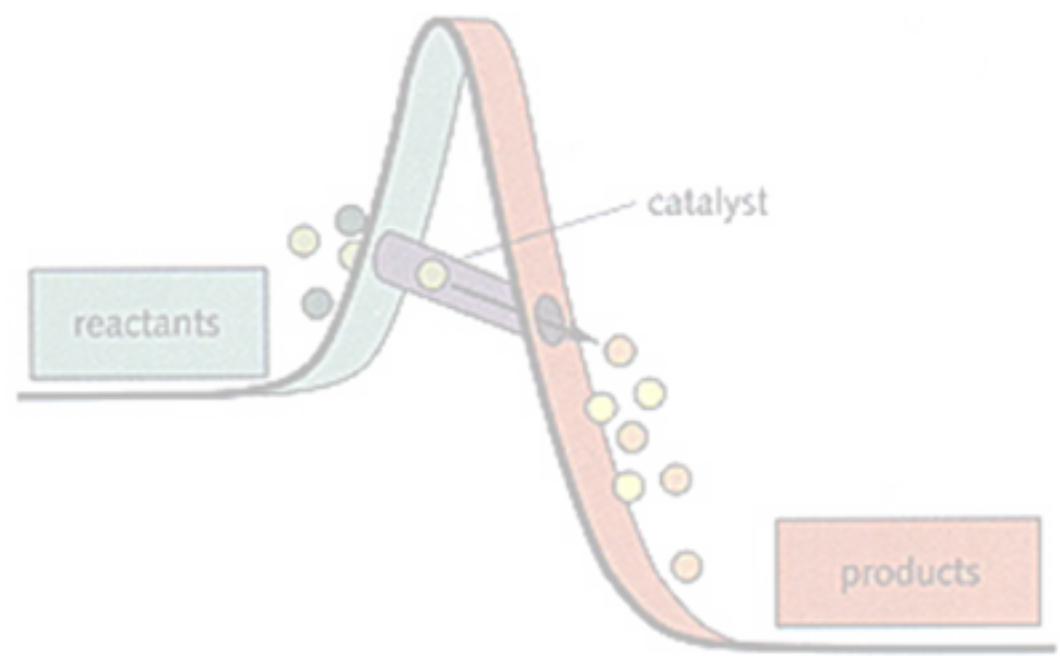
Energy of Activation

The energy required to start a chemical reaction.

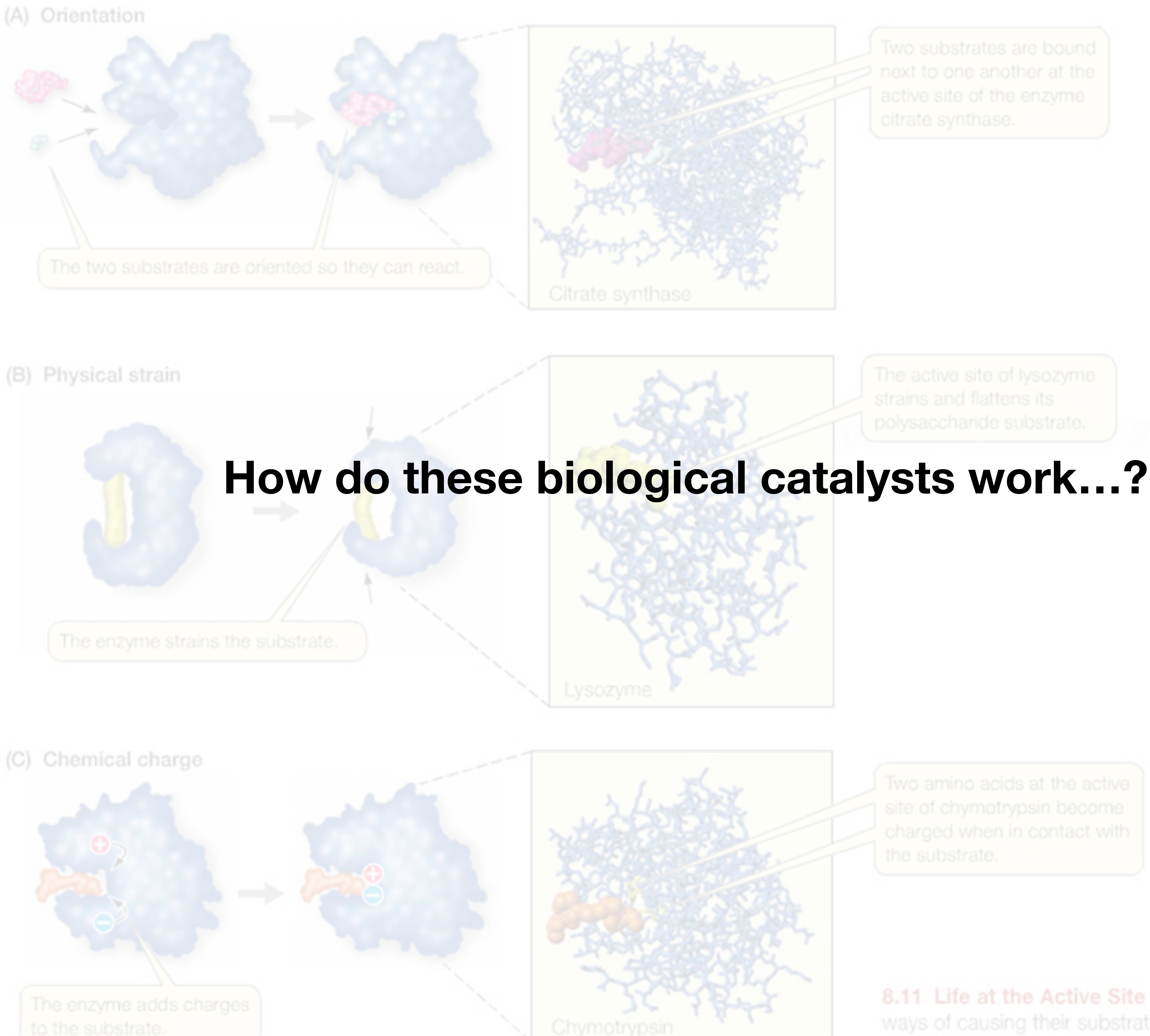


Lowering the Energy of Activation

This is the way in which chemical catalysts speed up chemical reactions.



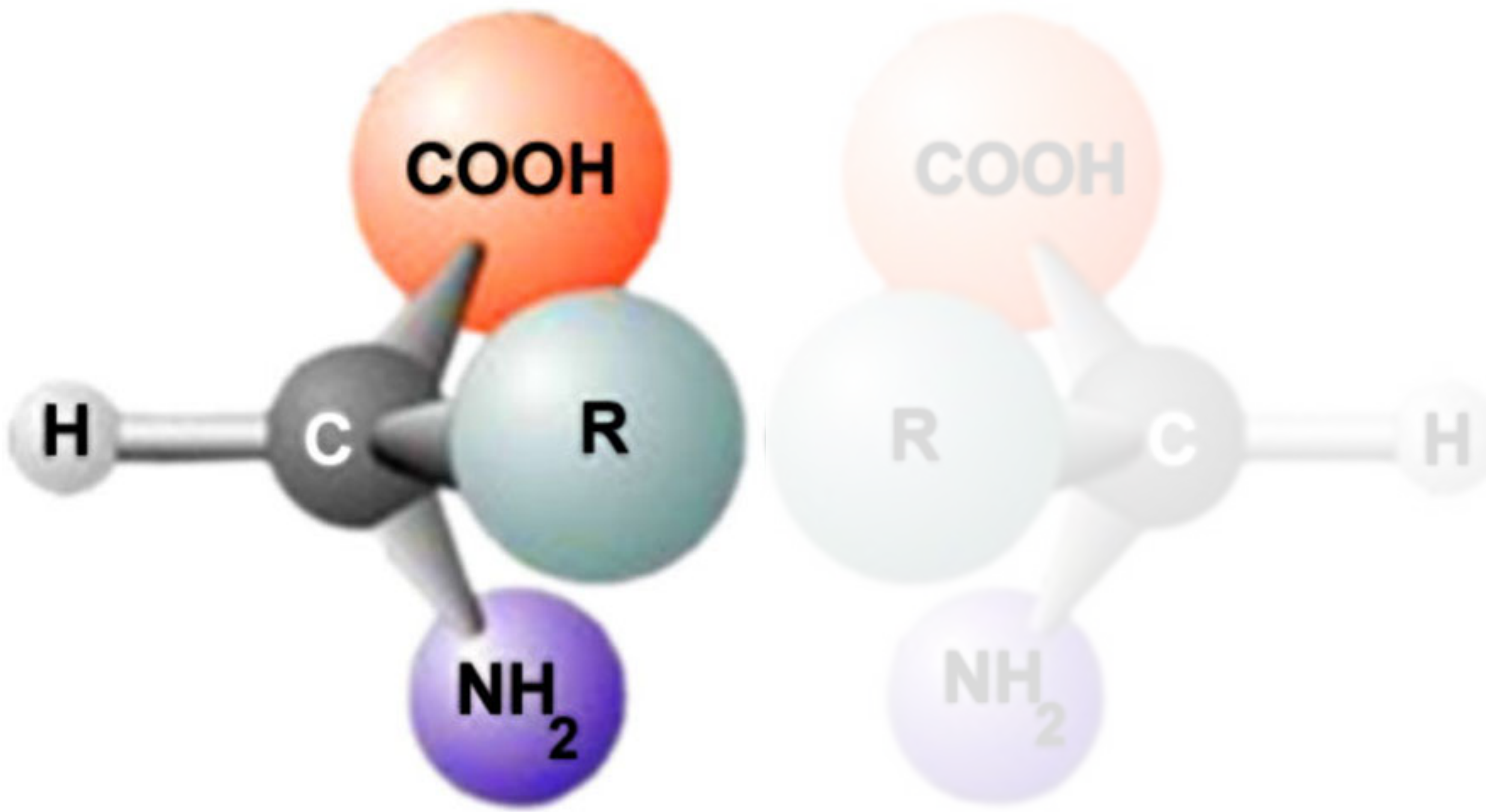
How do these biological catalysts work…?

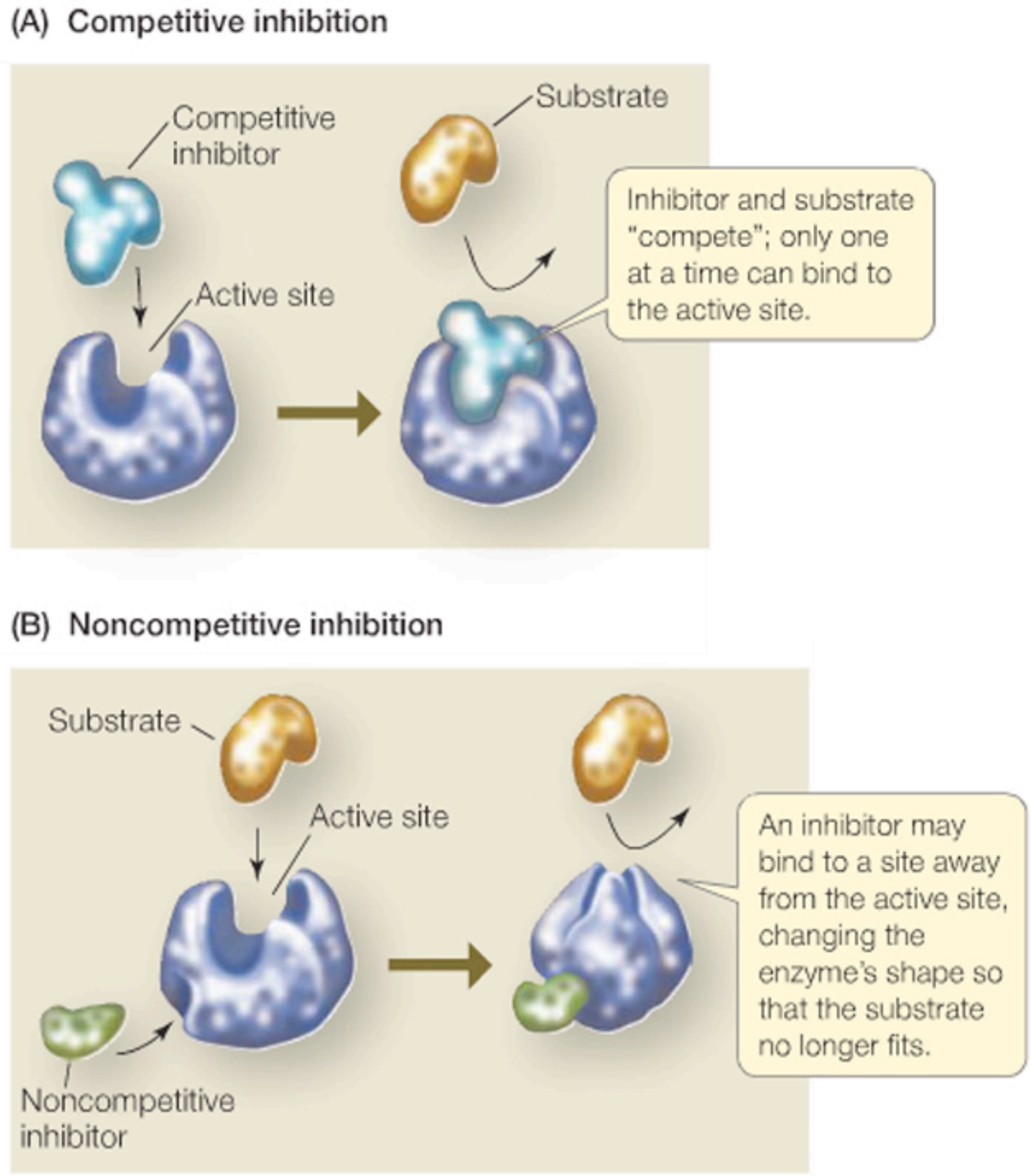


8.11 Life at the Active Site Enzymes have several ways of causing their substrates to enter the transition state: (A) orientation, (B) physical strain, and (C) chemical charge.

6.1 A Few Examples of Nonprotein Molecular "Partners" of Enzymes

TYPE OF MOLECULE	ROLE IN CATALYZED REACTIONS
Cofactors	
Iron	Oxidation/reduction
Copper	Oxidation/reduction
Zinc	Helps bind NAD
Coenzymes	
Biotin	Carries $—COO^-$
Coenzyme A	Carries $—CH_2—CH_3$
NAD	Carries electrons
FAD	Carries electrons
Prosthetic groups	
Heme	Binds ions, O_2, and electrons; contains iron cofactor
Flavin	Binds electrons
Retinal	Converts light energy


COOH
H
C
R
NH2
COOH
R
C
H
NH2



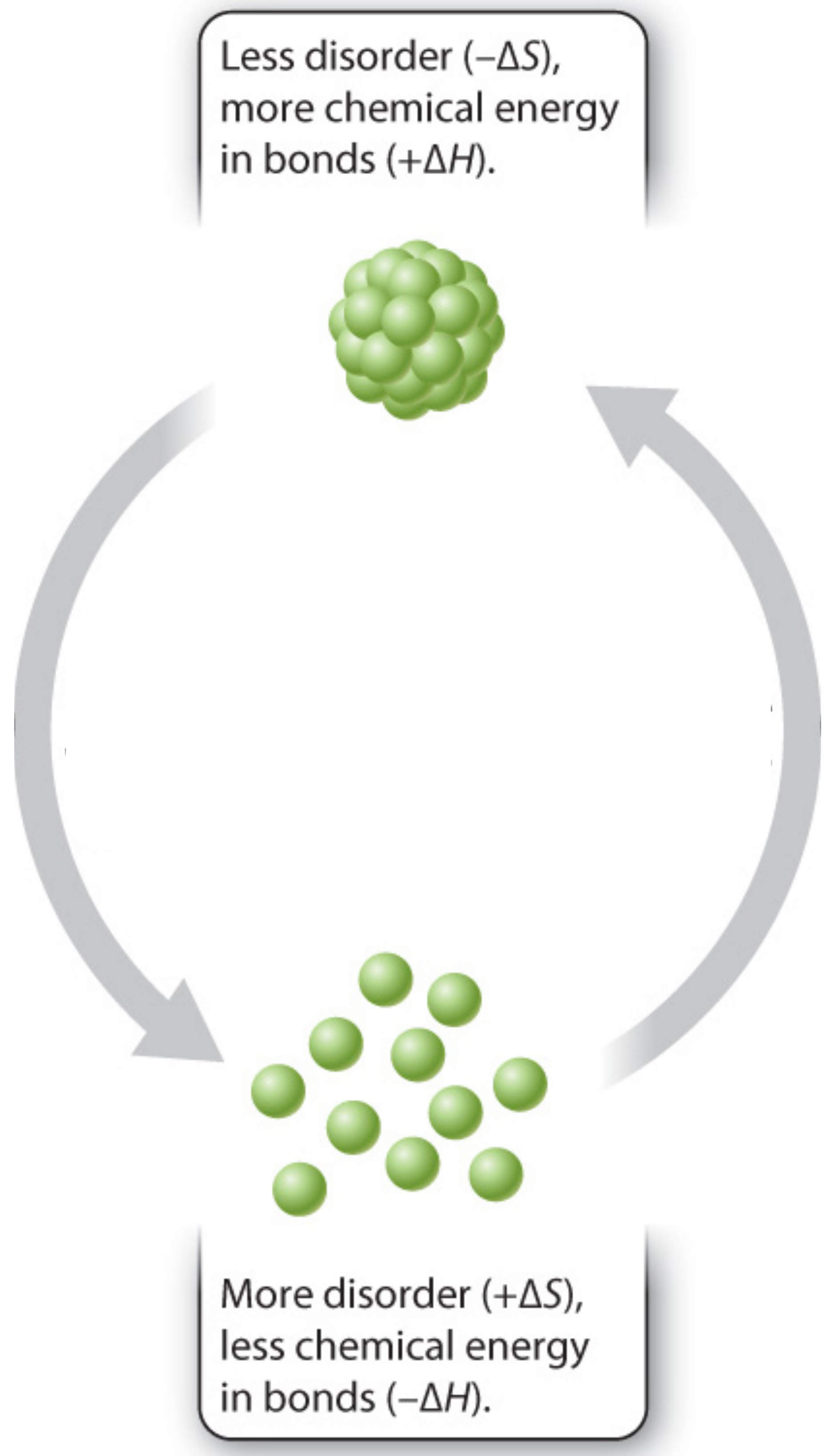
8.16 Reversible Inhibition (A) A competitive inhibitor binds temporarily to the active site of an enzyme. (B) A noncompetitive inhibitor binds temporarily to the enzyme at a site away from the active site. In both cases, the enzyme's function is disabled for only as long as the inhibitor remains bound.

Metabolism can be divided into two types of “collective” enzymatic activities: **anabolic** and **catabolic** reactions.

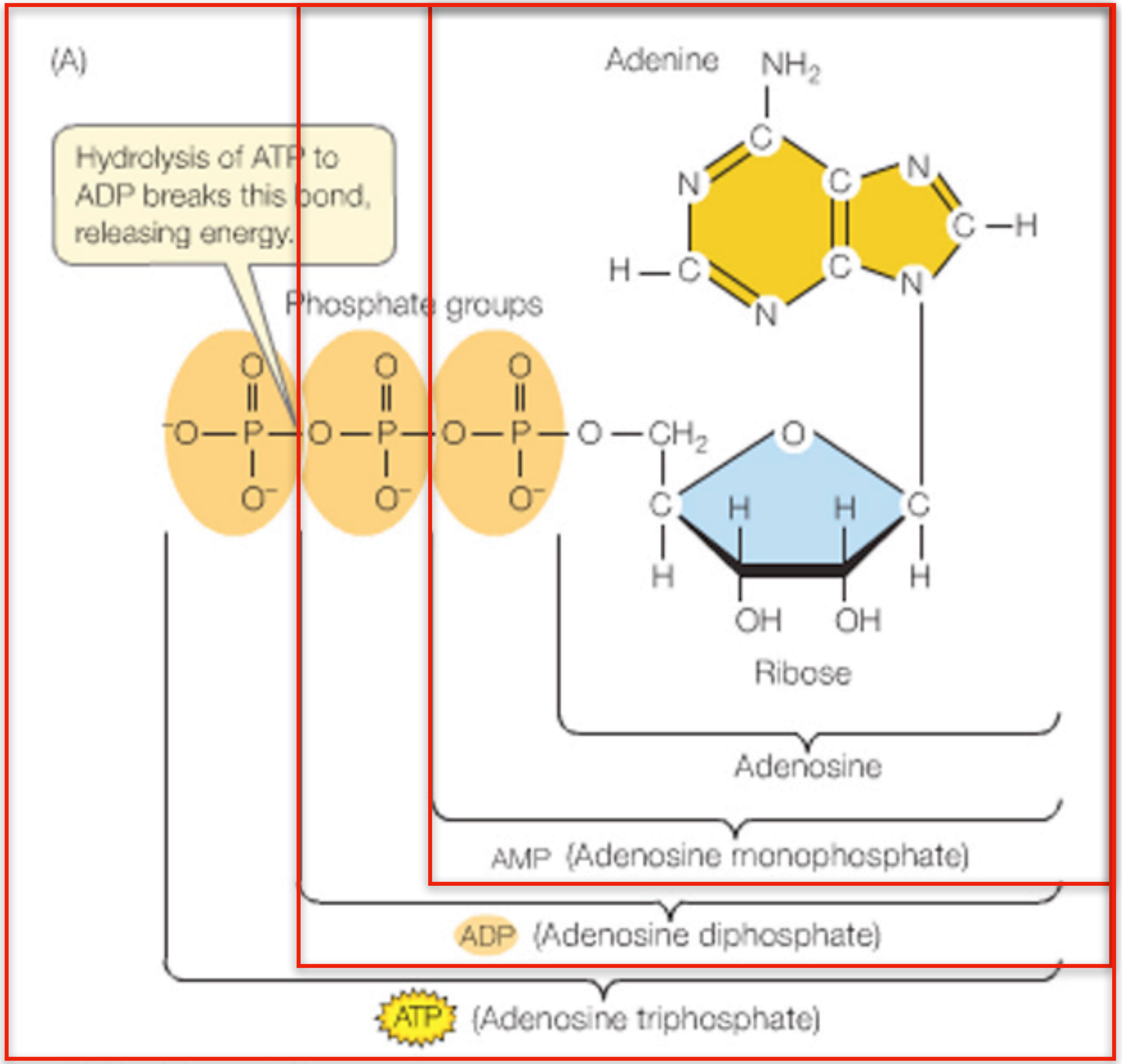
Anabolic reactions are those that link simple molecules together to make complex ones. These are energy-storing reactions......(e.g.condensation reactions?)

Anabolic reactions, which make single products from many smaller units; such reactions **"consume" the useable energy.**

Catabolic reactions may reduce an organized substance, such as a glucose molecule, into smaller more randomly distributed substances, such as carbon dioxide and water; such reactions generally **"release" useable energy.**


Less disorder (−ΔS), more chemical energy in bonds (+ΔH).
More disorder (+ΔS), less chemical energy in bonds (−ΔH).

ATP + H_2O ----> ADP + Pi + free energy.



(B) *Luciola cruciata*

ATP + H_2O ----> ADP + Pi + free energy

The change in standard free energy ($\triangle G^{o}$') ~ **7.3 kcal/mol** at a living cell's typical temperature and pH.

The equilibrium for this reaction is far to the right of the equation shown above, greatly favouring the **production of ADP**;

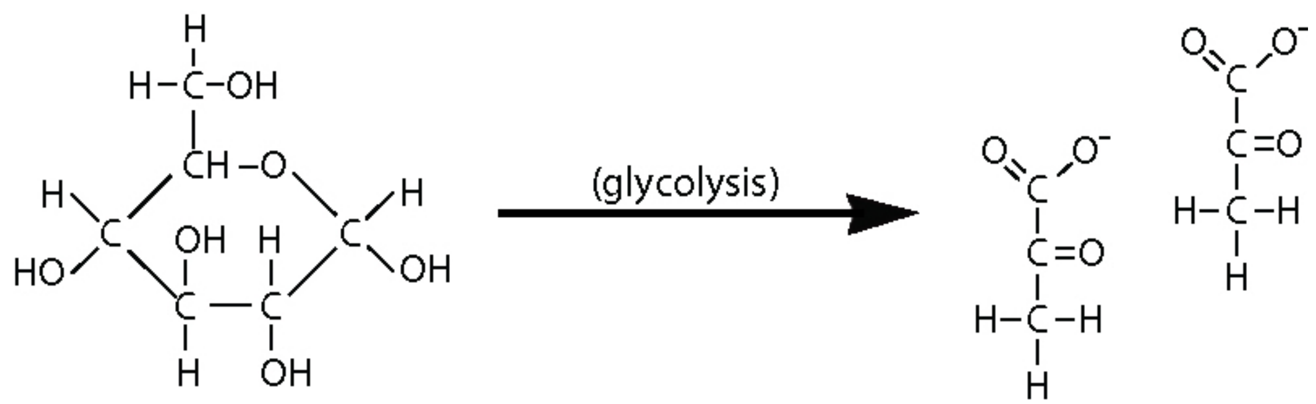
So much so that there are approximately 1 x 10^7 ADP molecules to each remaining ATP.

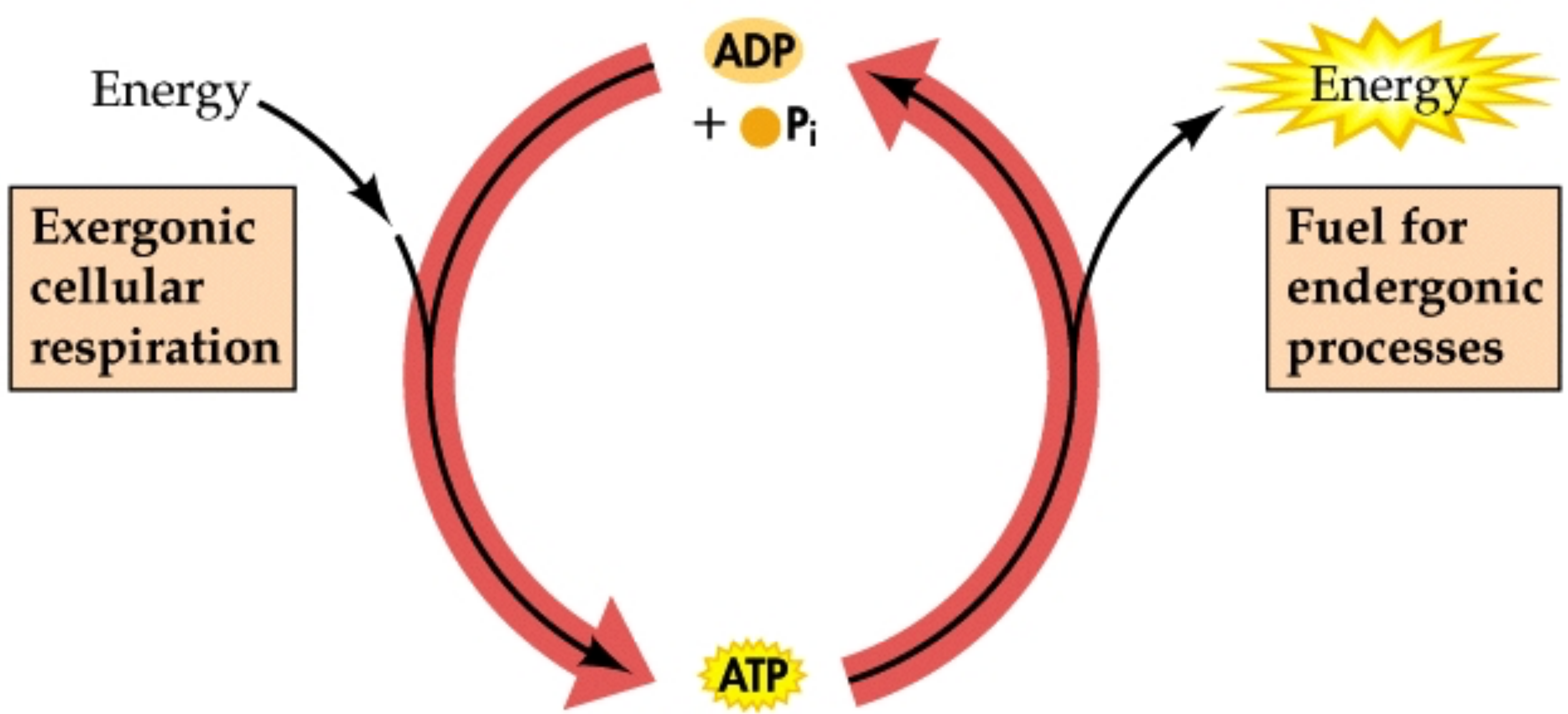
Making ATP from ADP (anabolic reaction) involves overcoming repulsive negative charges on the phosphates to be joined, the very same forces that provide the "free energy" released when ATP is broken apart to form ADP.

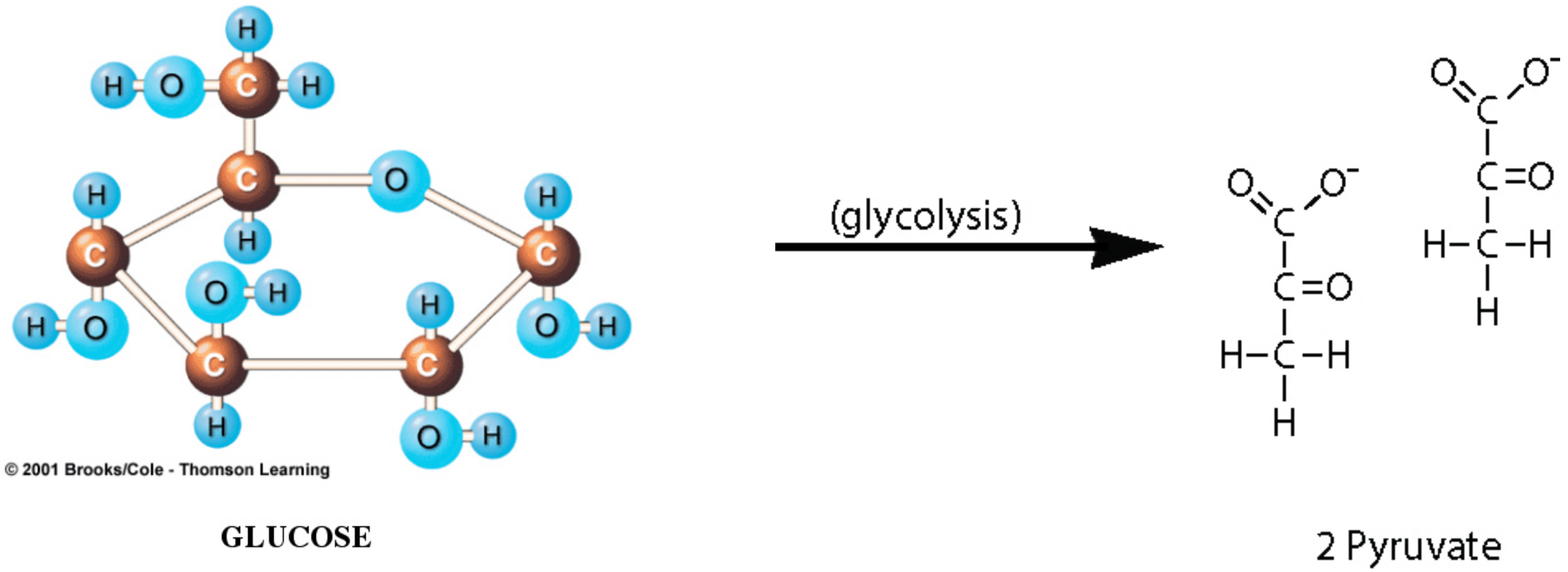
Making ATP from ADP involves overcoming repulsive negative charges on the phosphates to be joined.

The energy that is necessary to do this in humans and many other living cells is generally stored as **glucose** (or condensed derivatives thereof....) or other **fuel molecules**

and is released in the ensuing **exergonic process called Glycolysis**.





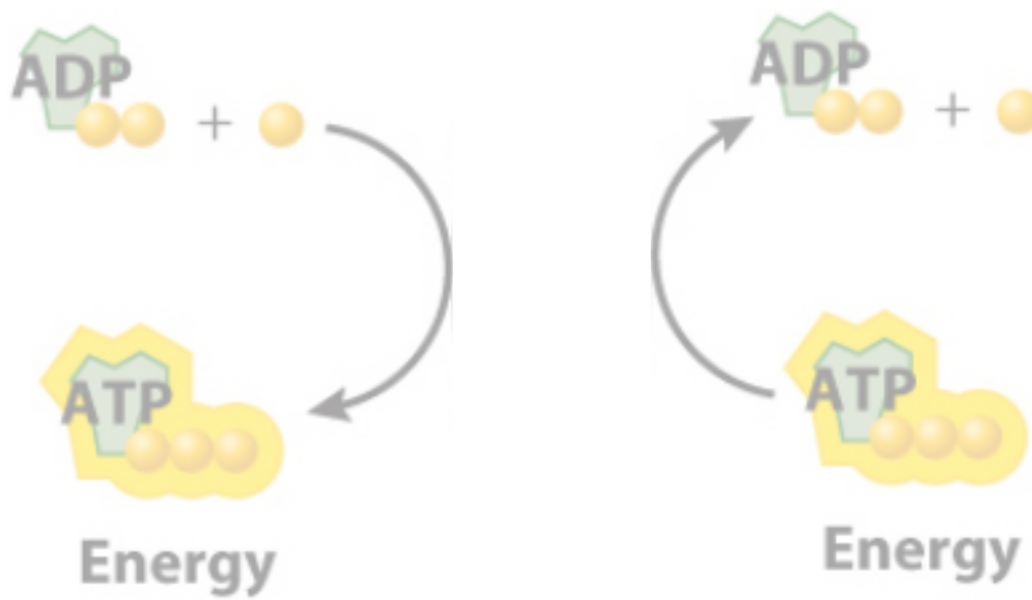


$C_6H_{12}O_6 + 6\ O_2 \text{ ---> } 6\ CO_2 + 6\ H_2O + \text{energy (heat)}$

Respiration

- 686 kcal/mol

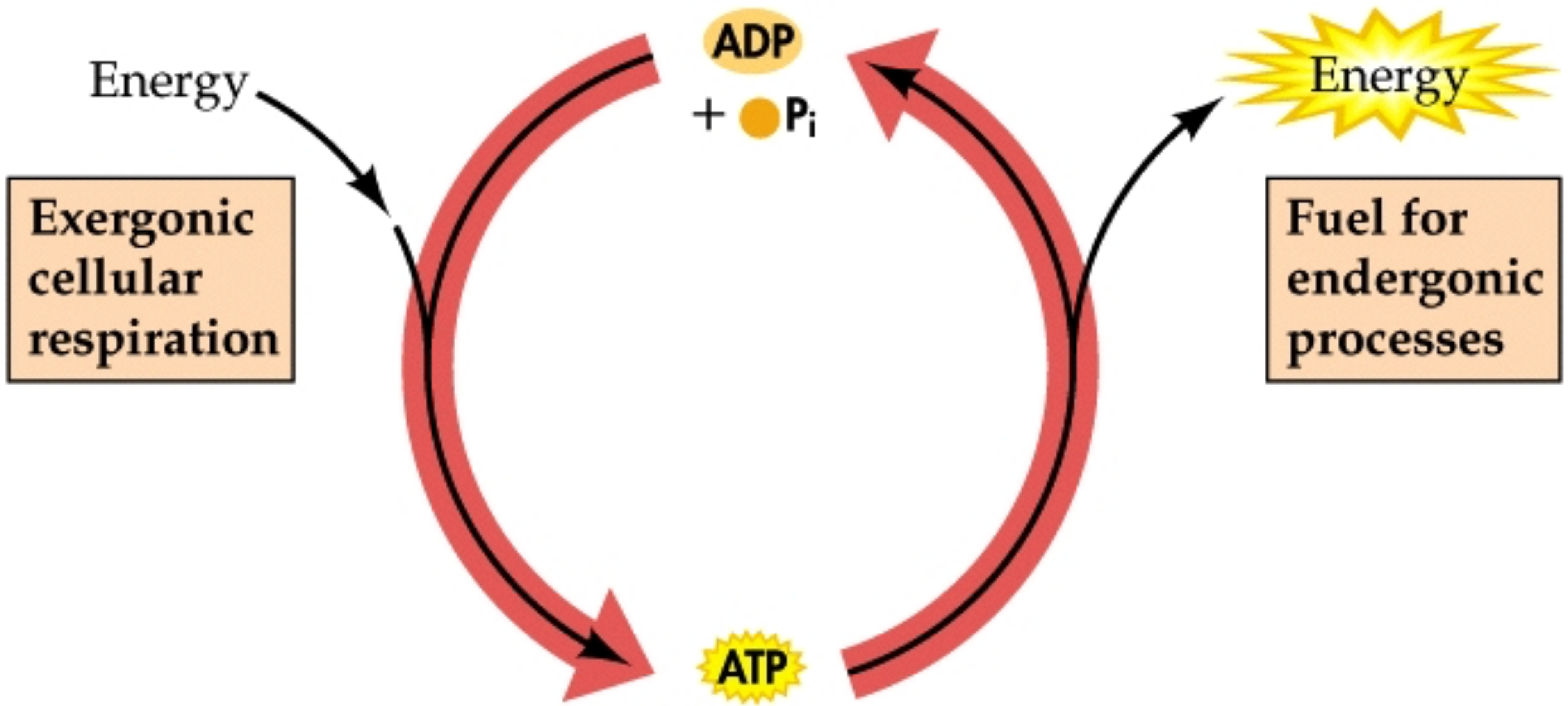
1 molecule of Glucose —> - 686 kcal/mol



- 7.3 kcal/mol

1 molecule of Glucose —> ~~~94~~ ATP's worth of energy

- 686 kcal/mol



Some kinds of cells metabolize glucose incompletely, and others do a much more efficient job and metabolize it completely.