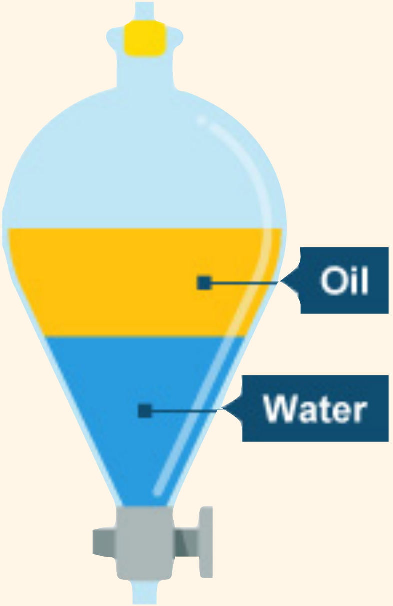
Chem 150, Spring 2015

Unit 12 - Lipids

Introduction

- Biomolecules include
  - Proteins
  - Nucleic acids
  - Carbohydrates
  - **Lipids**



- Lipids are not defined by the chemical structures, like the other classes of biomolecules, but instead by their physical properties.
  - They are the components of cells that dissolve in non-polar (oily) solvents, and include fats, steroids, isoprenoids, phospholipids, glycolipids…

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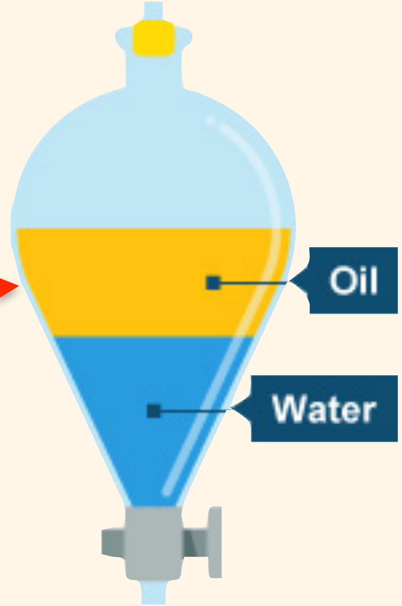

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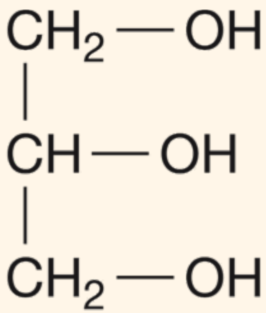
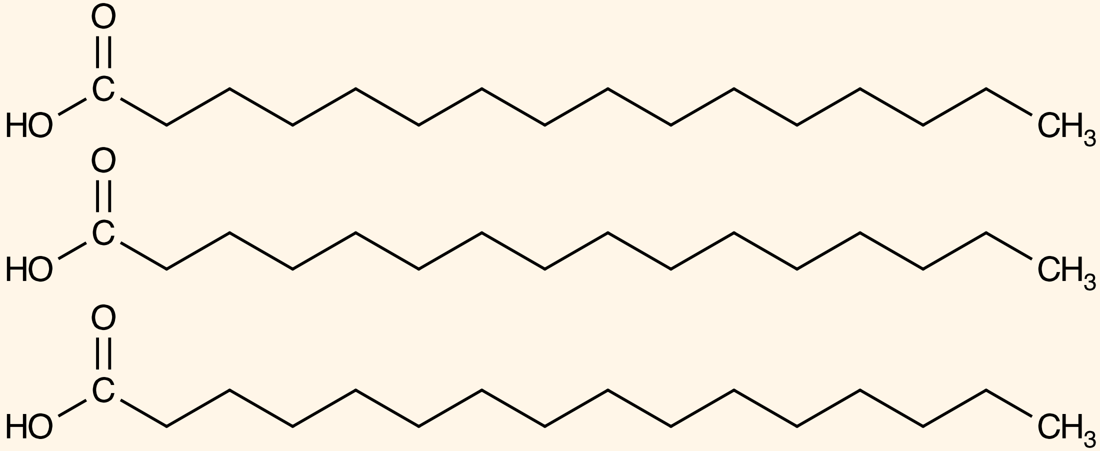
16.1 Fatty Acids and Triglycerides

- Animal fats and vegetable oils are triglycerides (triacylglycerols).
- Triglycerides are an important energy source tissues such as muscle, liver and kidneys.
- Triglycerides are made from one glycerol molecule plus three fatty acids (long chain carboxylic acid).

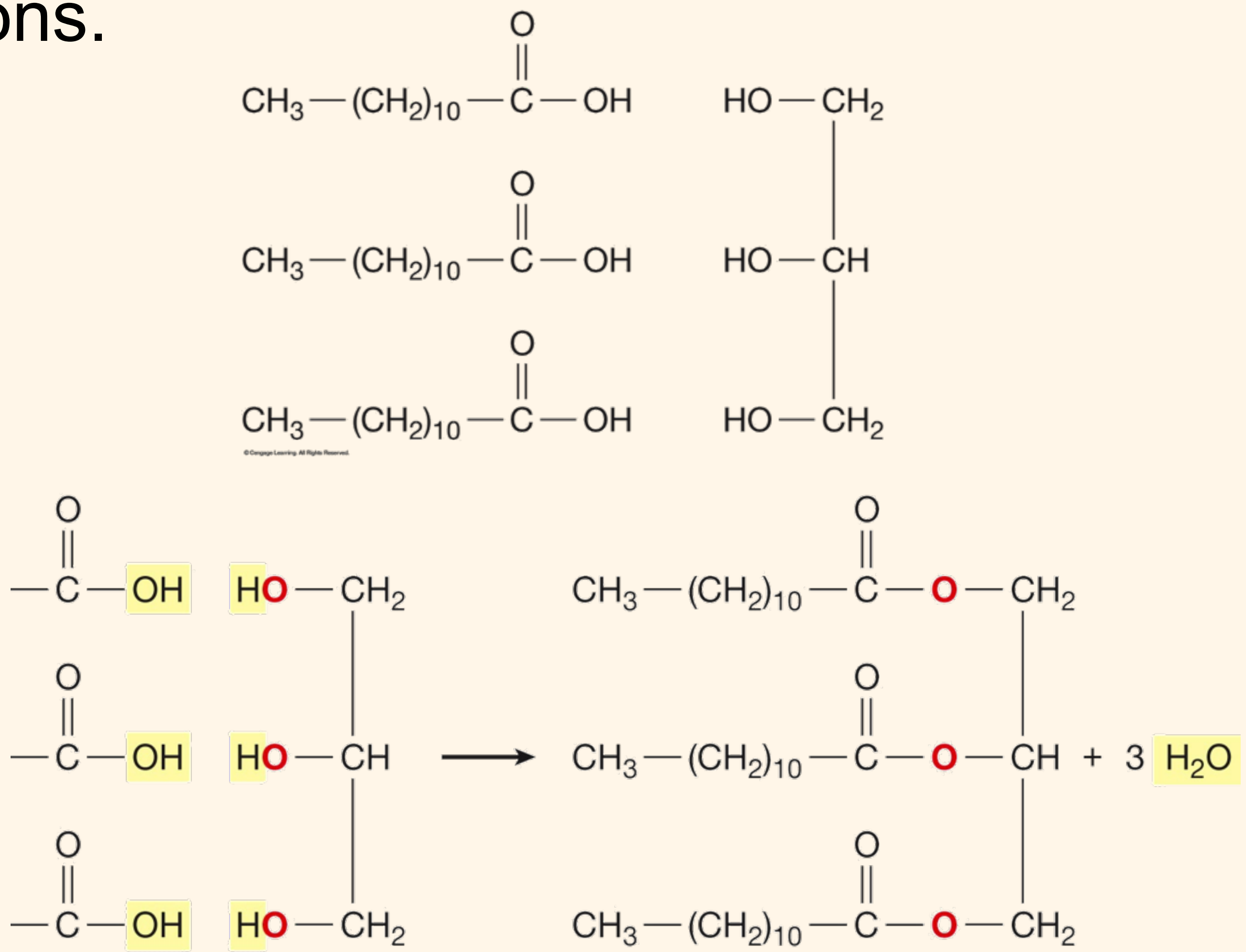


Glycerol
(glycerin)



3 Fatty acids

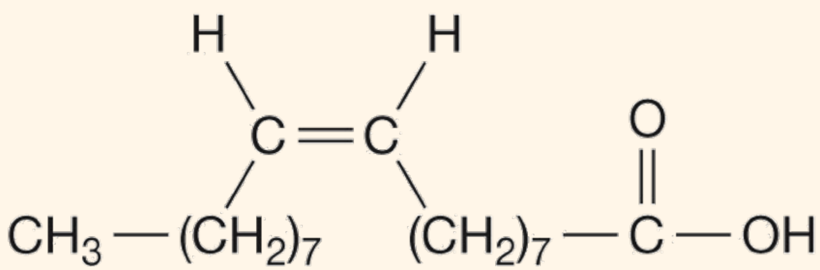
- Triglycerides are formed by three condensation reactions.



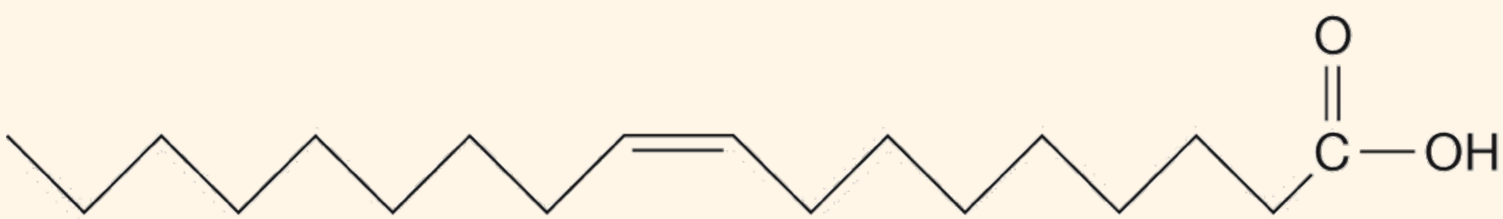
The triglyceride

Saturated and Unsaturated Fatty Acids

- **Saturated fatty acids** do not contain any alkene groups.
- **Unsaturated fatty acids** contain at least one alkene group. Naturally occurring fatty acids contain *cis* alkene(s).



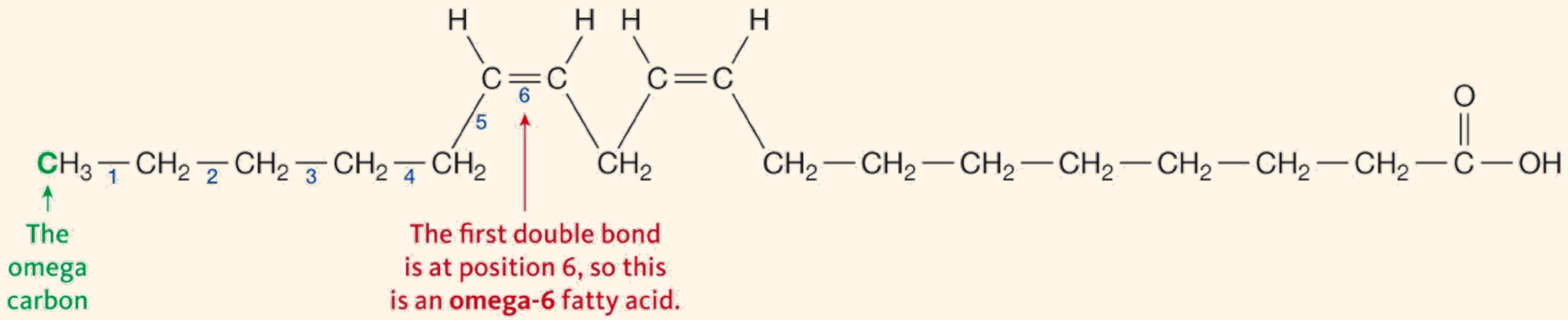
Abbreviated structure of oleic acid, showing the *cis* geometry



Line structure of oleic acid

Classification

- Monounsaturated fatty acid: contain only one alkene group
- Polyunsaturated fatty acid: contains more than one alkene group.
- Unsaturated fatty acids are classified by the number and position of first alkene group from the final carbon of the chain (omega carbon).



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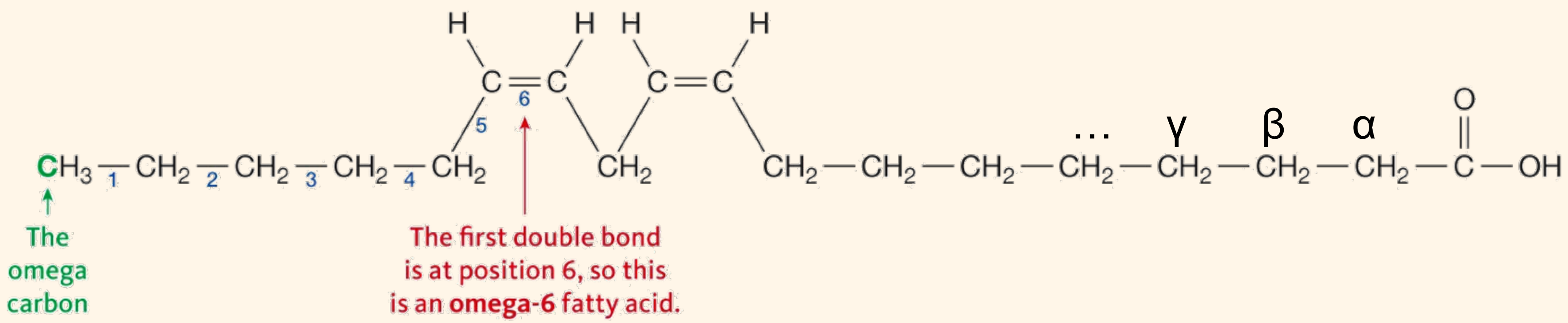

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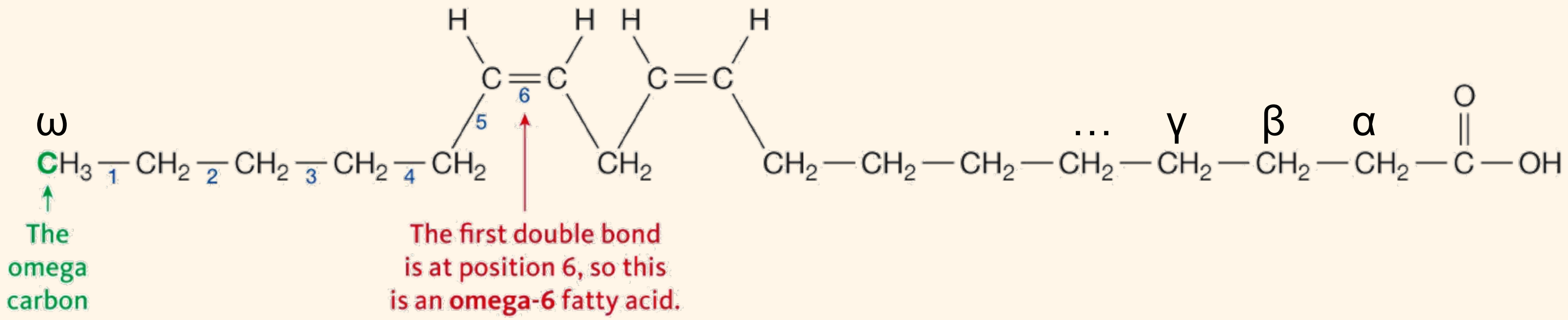

Fatty Acids in Triglycerides

- Triglycerides often contain three different fatty acids, with any combination of saturated or unsaturated.
- Because fatty acids are a major component in triglycerides, fatty acids and triglycerides have similar physical properties. For example, they are both insoluble in water but soluble in organic solvents.

Physical Properties

- Saturated fats are able to align themselves and tend to form solids at room temperature, therefore they have higher melting points.
- The cis alkene bonds of unsaturated fats create "kinks" in the structure that prevent close packing.
  - These "kinks" lower the melting points of fatty acids and the fats or oils that contain them.

Melting point =

Physical Properties

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- The ci … eate "kinks … cking.
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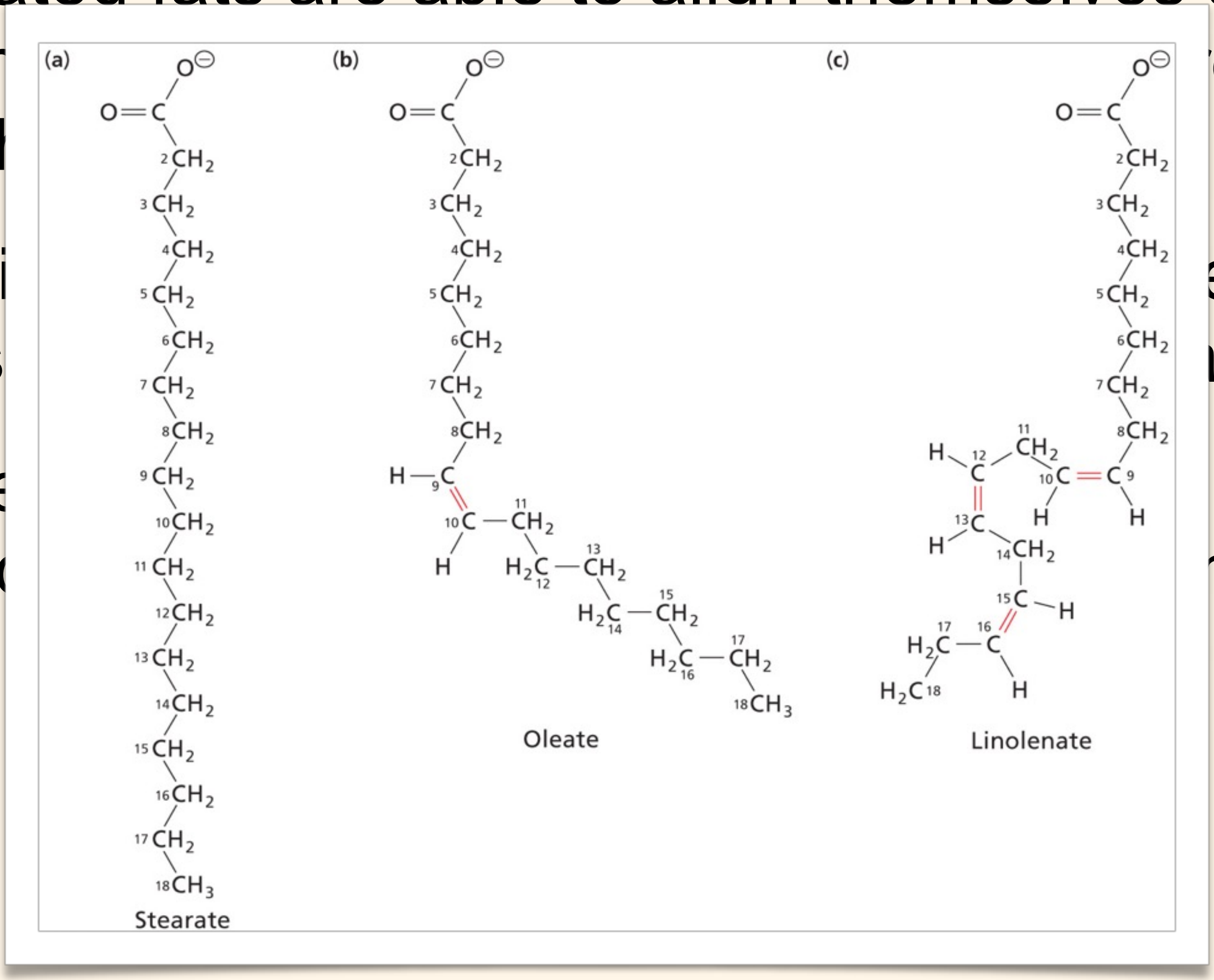

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Melting point = 69°C 14°C -5°C

Melting Points

- Percentage of saturated and unsaturated fats in common fats and oils effect the melting points.

TABLE 16.2 The Physical Properties and Fatty Acid Composition of Some Fats and Oils

Fat or Oil	Melting Point	State at Room Temperature	Saturated Fatty Acids	Monounsaturated Fatty Acids	Polyunsaturated Fatty Acids
Lard (pork fat)	34°C	Solid	41%	47%	12%
Butterfat	32°C	Solid	68%	28%	4%
Coconut oil	25°C	Solid	92%	8%	0%
Cod liver oil	−5°C	Liquid	20%	62%	18%
Olive oil	−6°C	Liquid	15%	75%	10%
Corn oil	−20°C	Liquid	13%	29%	58%

Melting Points

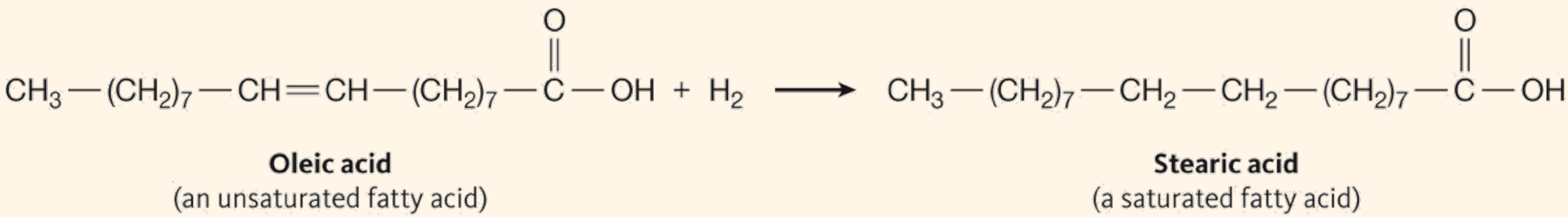
- Humans cannot synthesize polyunsaturated fatty acids, so these are **essential fatty acids** in our diet.

TABLE 16.1 The Structures of Common Fatty Acids

Name and Melting Point	Structure
Lauric acid (44°C)	$CH_3—(CH_2)_{10}—COOH$
Myristic acid (55°C)	$CH_3—(CH_2)_{12}—COOH$
Palmitic acid (63°C)	$CH_3—(CH_2)_{14}—COOH$
Stearic acid (69°C)	$CH_3—(CH_2)_{16}—COOH$
Palmitoleic acid (0°C)	$CH_3—(CH_2)_5—CH{=}CH—(CH_2)_7—COOH$
Oleic acid (14°C)	$CH_3—(CH_2)_7—CH{=}CH—(CH_2)_7—COOH$
Linoleic acid (−5°C)	$CH_3—(CH_2)_4—CH{=}CH—CH_2—CH{=}CH—(CH_2)_7—COOH$
Linolenic acid (−11°C)	$CH_3—CH_2—CH{=}CH—CH_2—CH{=}CH—CH_2—CH{=}CH—(CH_2)_7—COOH$

16.2 Chemical Reactions of Triglycerides

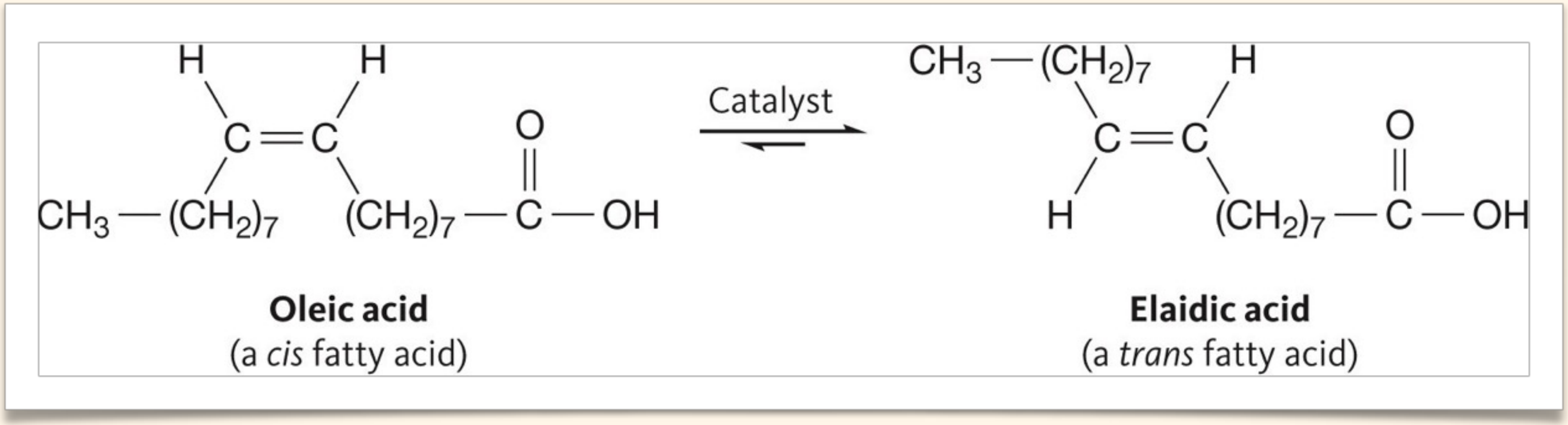
- Unsaturated fatty acids can be hydrogenated to produce saturated fatty acids.



- A firm solid is produced when unsaturated triglycerides are hydrogenated.
- Saturated fats are more desirable in baking because they are more stable in the presence of oxygen and do not become rancid as rapidly.

16.2 Chemical Reactions of Triglycerides

- Often oils are only partially hydrogenated, and some of the *cis* fats are converted into *trans* fats in the process.



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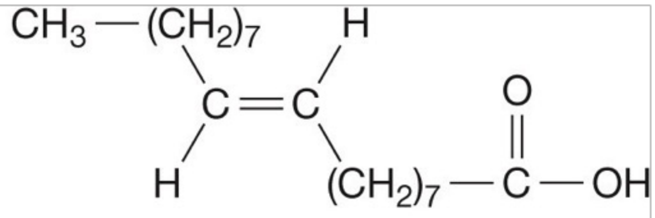

Elaidic acid
(a *trans* fatty acid)

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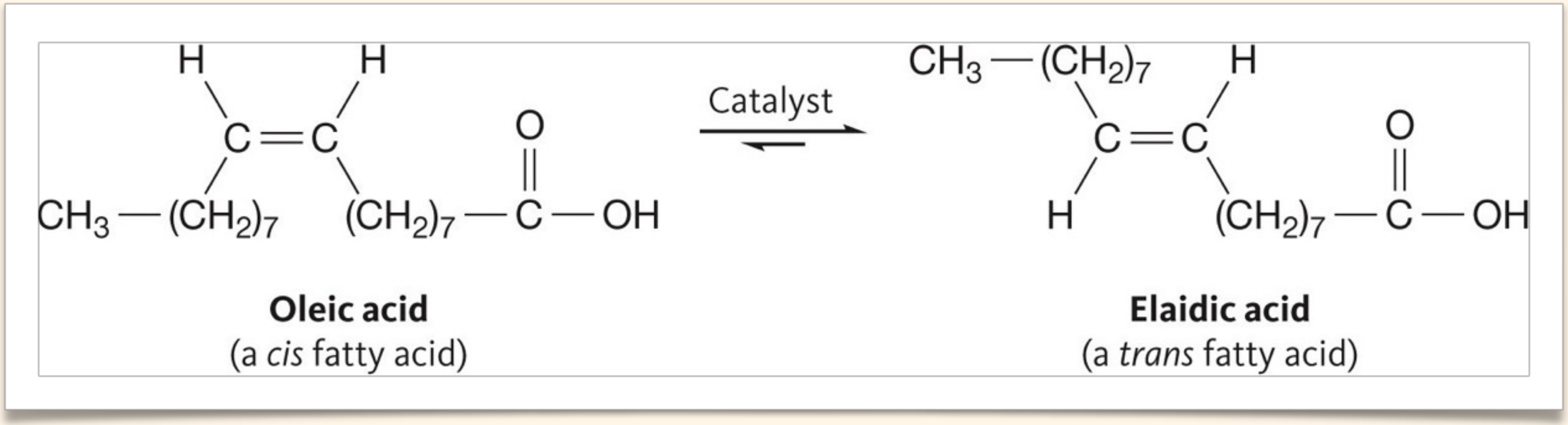
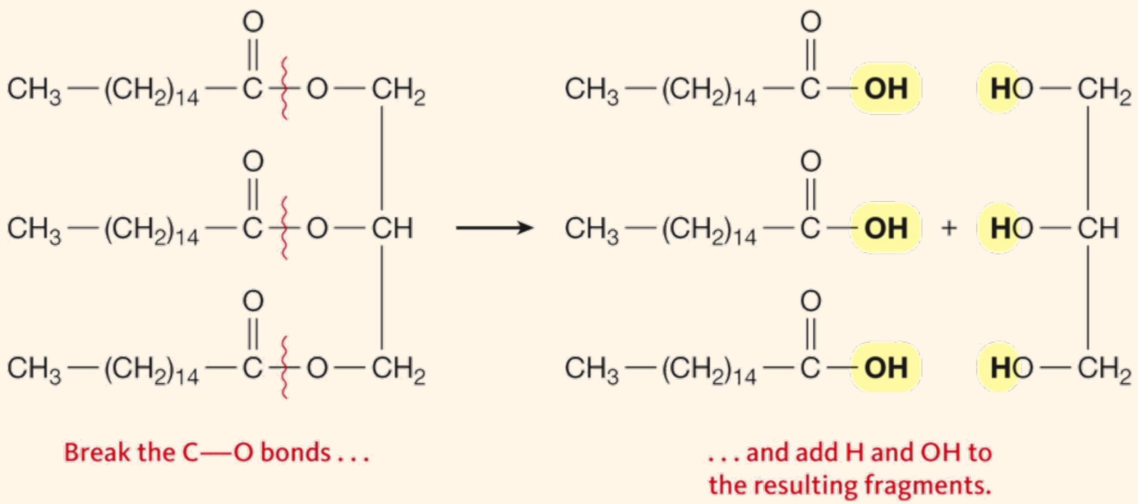


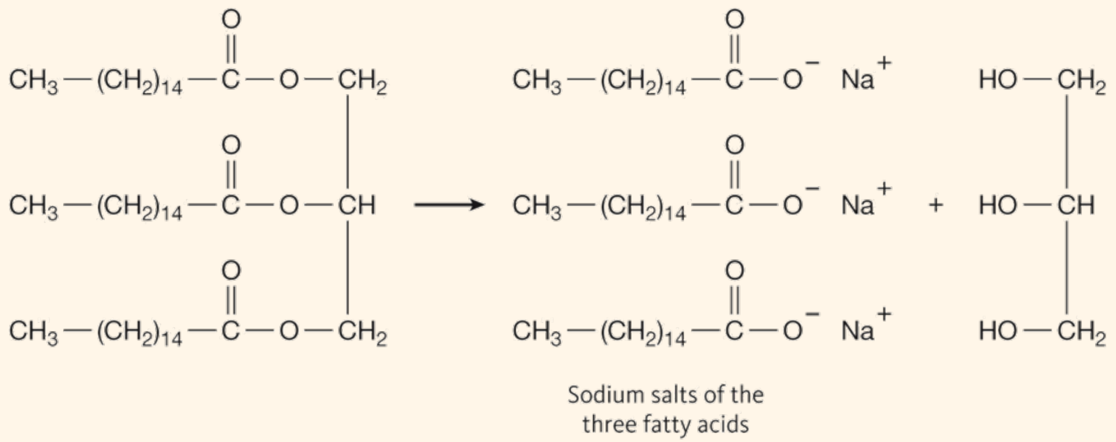
Hydrolysis of Triglycerides

- Triglycerides are esters and can be hydrolyzed.

Hydrolysis by aqueous H_2SO_4:

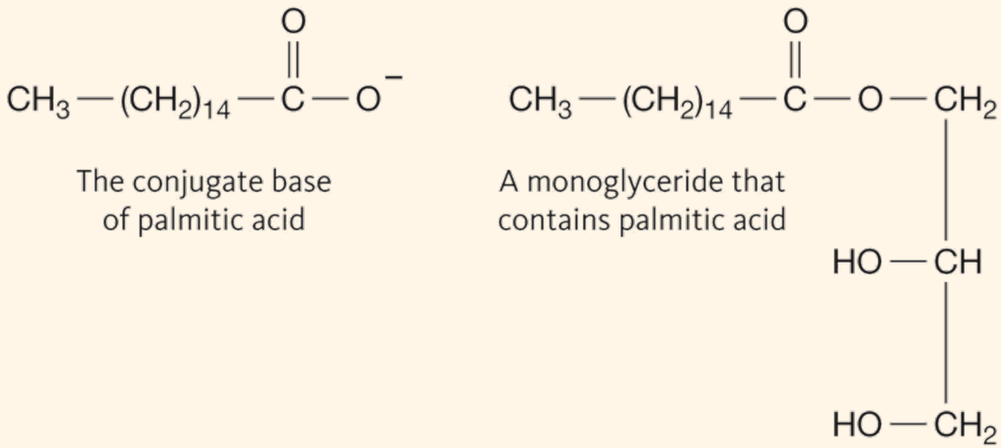


Hydrolysis by aqueous NaOH:



Fat Digestion

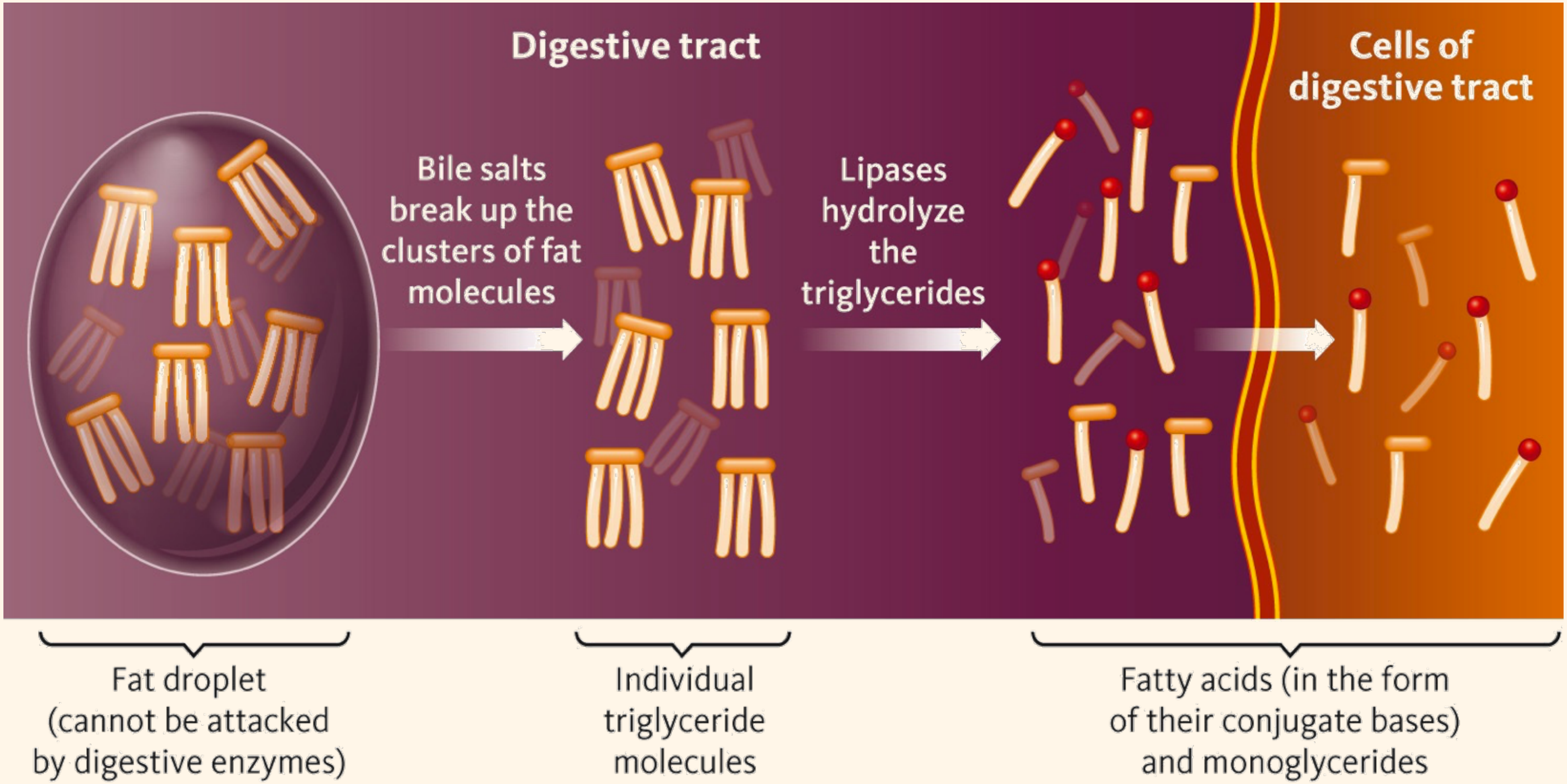
- Bile salts, which are like detergents, and enzymes are necessary to digest triglycerides.
- Bile salts break up (emulsify) clusters of fat molecules.
- **Lipases**, which are enzymes, break the triglycerides into a monoglyceride (glycerol with a single fatty acid attached) and the conjugate bases of two fatty acids.



The conjugate base of palmitic acid

A monoglyceride that contains palmitic acid

Digestion of a Triglyceride



16.3 Catabolism of fatty acids

- Triglycerides are the most efficient energy sources: burning one gram of fat gives 9 kcal, carbohydrates or proteins give 4 kcal.
- Breakdown of fatty acids starts with an activation reaction (fatty acid → fatty acyl-CoA) and then the four steps of beta oxidation.
- The addition of Coenzyme A allows for enzymes to recognize and bind to the fatty acid

Beta Oxidation- Obtaining Energy from Fatty Acids

- Beta oxidation shortens the fatty acyl-CoA by two carbons, producing acetyl-CoA. The shortened fatty acyl-CoA then undergoes beta oxidation until all of the carbons have been used to produce acetyl-CoA in a series of 4 reactions

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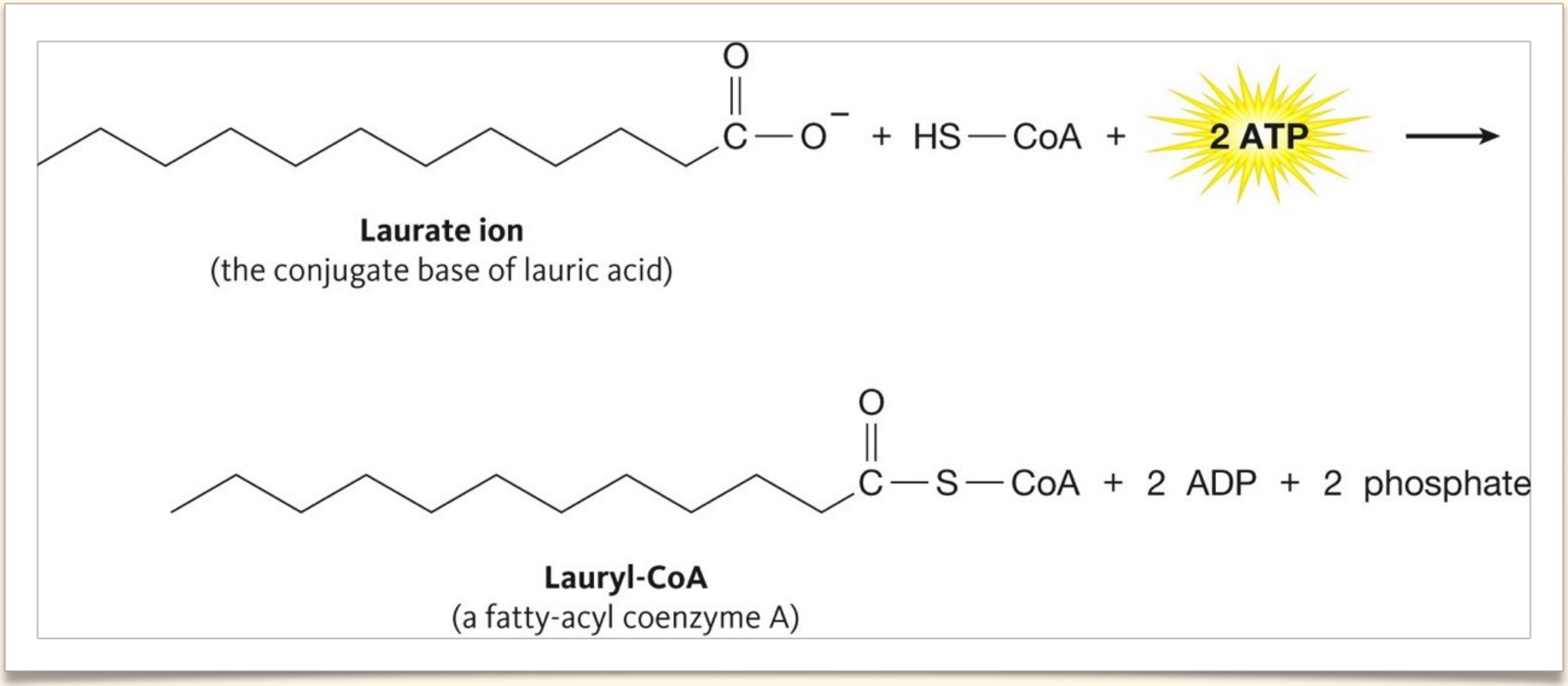

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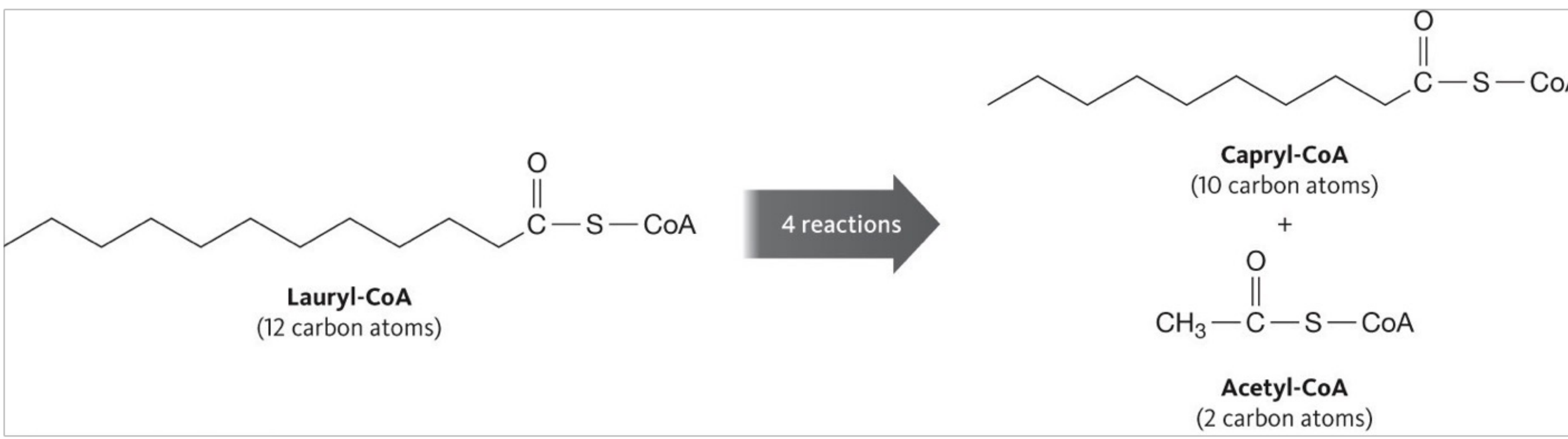

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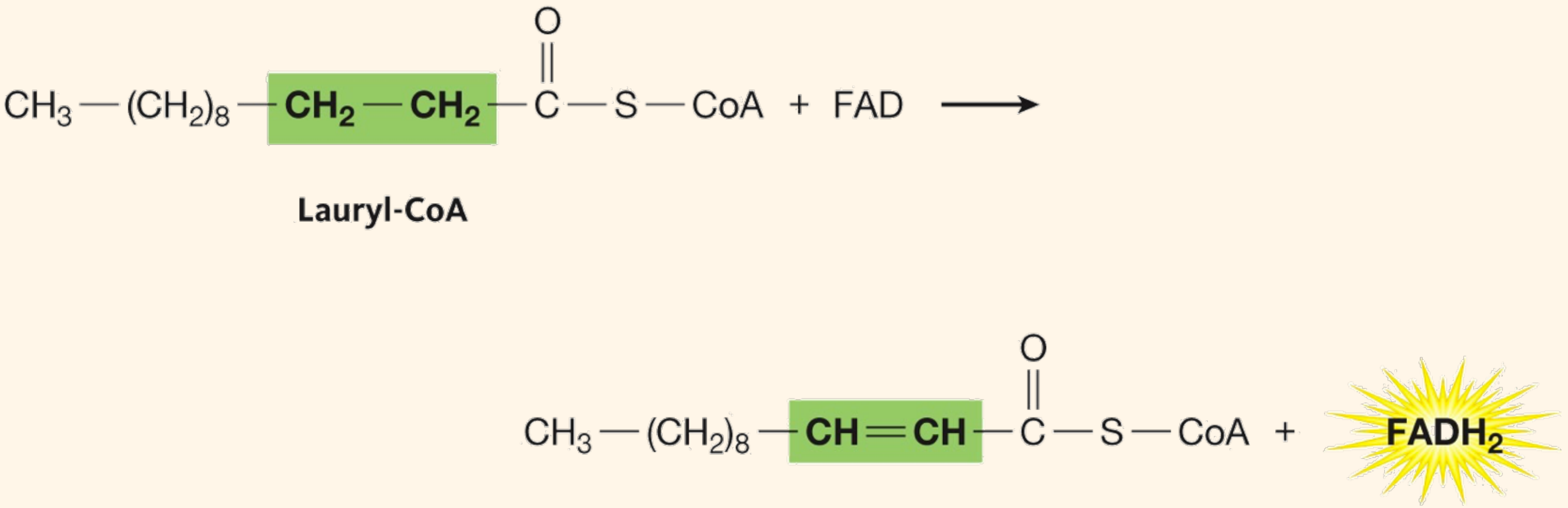
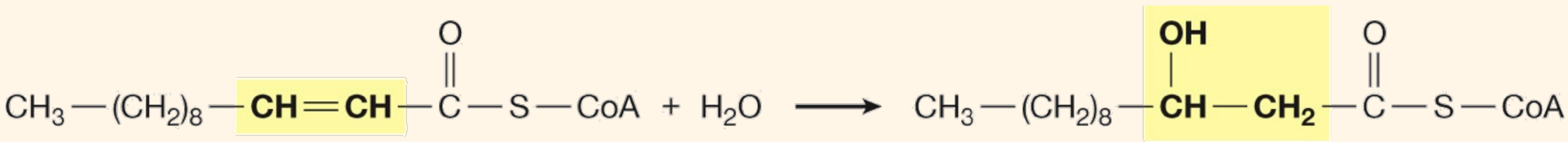
Reaction 1

- Dehydrogenation of the two carbons closest to the carbonyl group



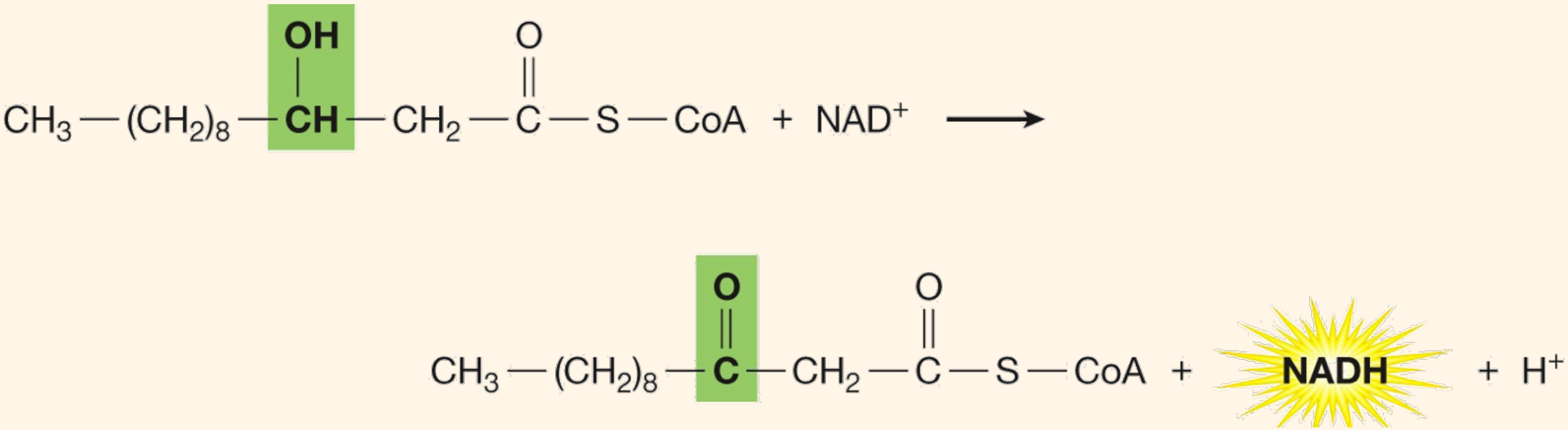
Reaction 2

- Hydration of the β-carbon



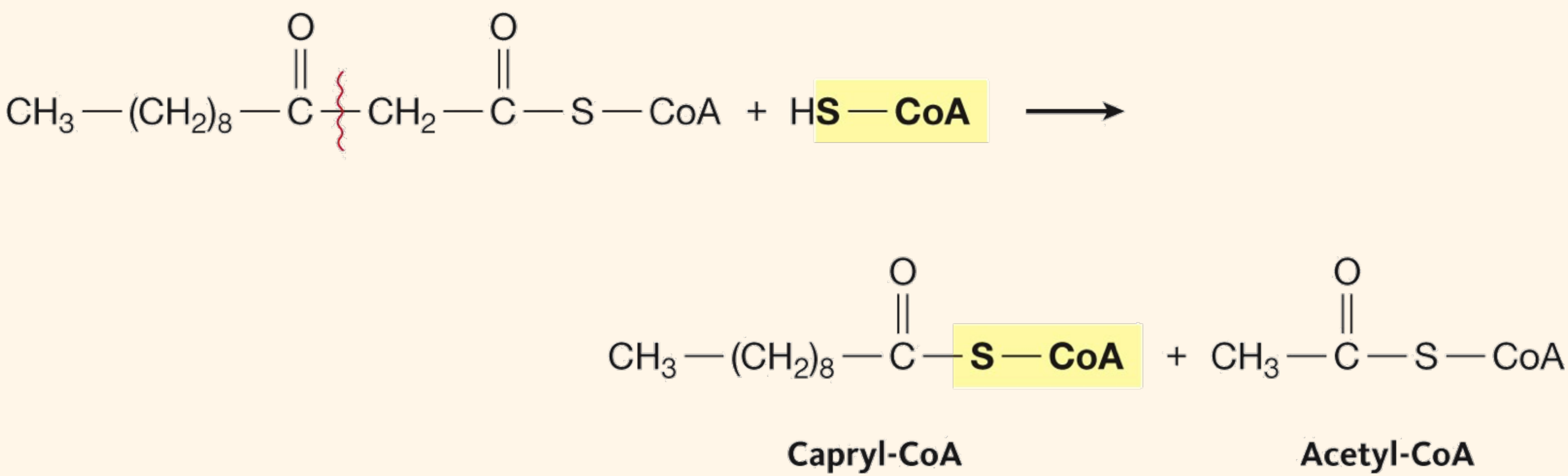
Reaction 3

- Oxidation of the alcohol group

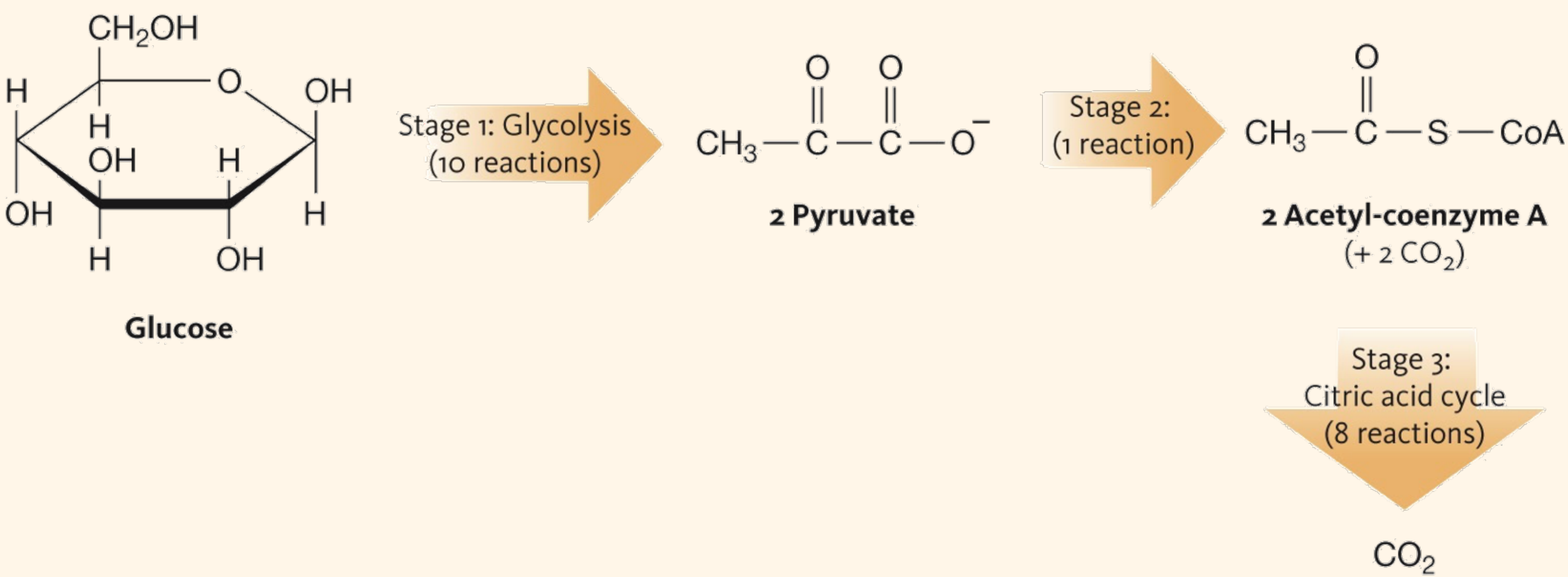


Reaction 4

- Carbon-carbon bond to the right of the ketone group is broken to produce acetyl-CoA and a new fatty acyl-CoA



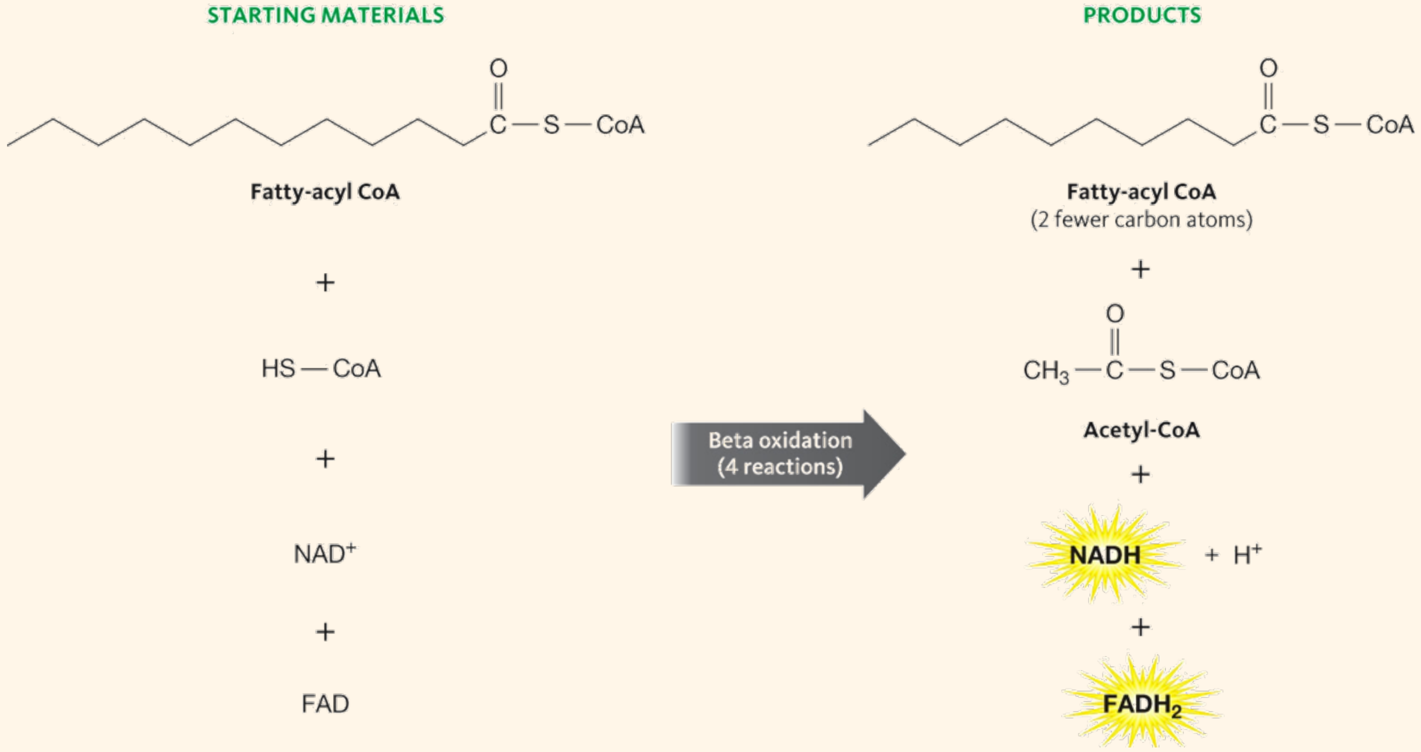
Catabolism of Glucose

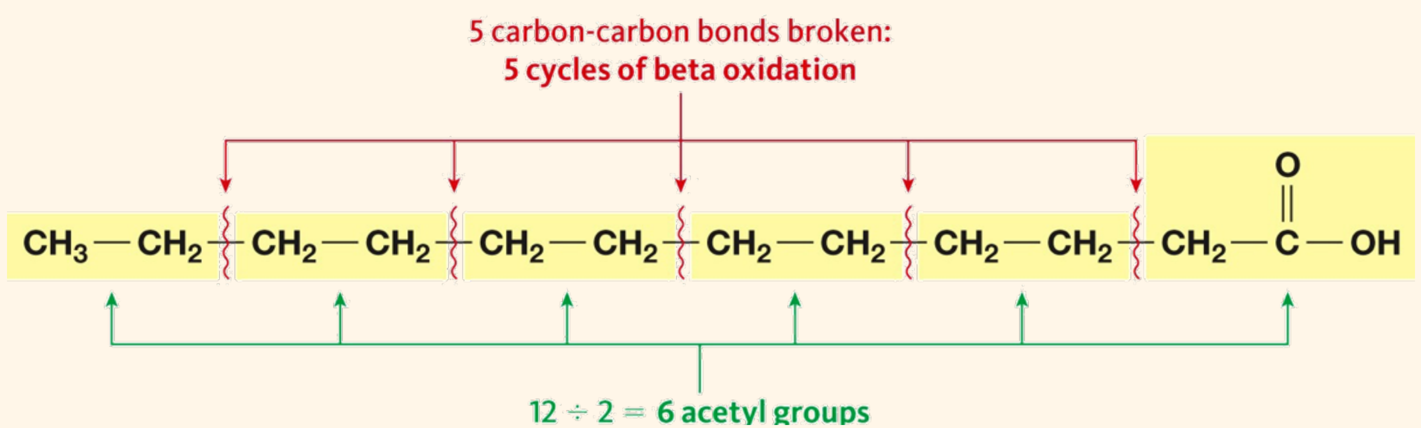


Three key features of beta oxidation

- It produces 1 each of NADH and $FADH_2$
- It forms a molecule of acetyl-CoA what can enter the citric acid cycle to form other high energy molecules
- It forms a new fatty acyl-CoA that can be used in another beta oxidation.

Beta Oxidation





Example: Lauric Acid Oxidation

TABLE 16.3 The Complete Oxidation of Lauric Acid, a Saturated Fatty Acid

Pathway	Function	High-Energy Molecules Formed or Consumed*	Number of Occurrences When Lauric Acid Is Oxidized	Total High-Energy Molecules Formed or Consumed*
Activation	Converts lauric acid into lauryl-CoA	2 ATP broken down	1	2 ATP broken down
Beta oxidation	Breaks down lauryl-CoA into 6 molecules of acetyl-CoA	1 NADH 1 $FADH_2$	5	5 NADH 5 $FADH_2$
Citric acid cycle	Oxidizes the acetyl group of acetyl-CoA into CO_2	1 ATP 3 NADH 1 $FADH_2$	6	6 ATP 18 NADH 6 $FADH_2$
Overall oxidation of lauric acid	**Oxidizes lauric acid into CO_2**			**2 ATP broken down** **6 ATP formed** **23 NADH** **11 $FADH_2$**

*Consumed molecules are in red.

We have seen that the NADH + H^+ and $FADH_2$ can go on to produce additional ATP's by coupling the electron transport chain, where these reduced nucleotides are deoxidized with O_2, with ATP synthase.

NADH + H^+ will produce 2.5 ATP's and $FADH_2$ will produce 1.5 ATP's

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Unsaturated Fatty Acids

- Unsaturated fatty acids undergo a similar process, but produce one $FADH_2$ fewer than a saturated fatty acid for every double bond in the chain.

Try It!

Question:

How many cycles of beta oxidation are required to break down one molecule of palmitic acid, a saturated fatty acid that has the molecular formula $C_{16}H_{32}O_2$? How many molecules of acetyl-CoA will be formed? What will the ATP yield be?

Fatty Acids produce similar amounts of ATP on a Mass Basis

- 1 mole Lauric acid (200.3 g/mol) produces 78 molecules of ATP and 1 mole palmitic acid (256.4 g/mol) produces 106 molecules of ATP.
- When comparing the breakdown of 100 g each by mass, you see they make very similar amounts of ATP:

$$100\text{ g lauric acid}\left(\frac{78\text{ mol ATP}}{1\text{ mol lauric acid}}\right)\left(\frac{1\text{ mol lauric acid}}{200.3\text{ g lauric acid}}\right) = 38.9\text{ mol ATP}$$

$$100\text{ g palmitic acid}\left(\frac{106\text{ mol ATP}}{1\text{ mol palmitic acid}}\right)\left(\frac{1\text{ mol palmitic acid}}{256.4\text{ g palmitic acid}}\right) = 41.3\text{ mol ATP}$$

Fats vs Carbohydrates

- Comparing this to carbohydrates

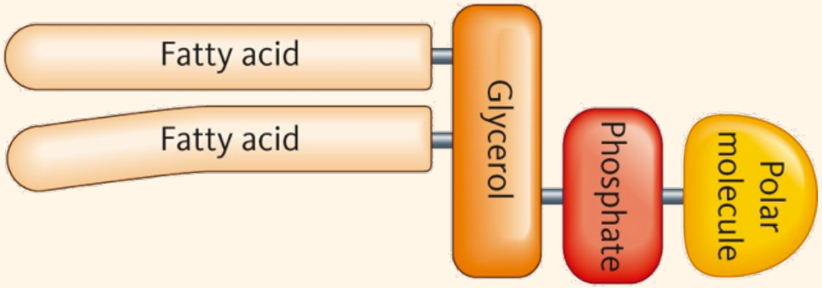
$$100\text{ g glucose}\left(\frac{32\text{ mol ATP}}{1\text{ mol glucose}}\right)\left(\frac{1\text{ mol glucose}}{180.2\text{ g glucose}}\right)=17.8\text{ mol ATP}$$

$$\approx\frac{40\text{ mol ATP from fat}}{18\text{ mol ATP from carbohydrates}}=2.2\text{ times more energy from fat}$$

16.4 Glycerophospholipids and Cell Membranes

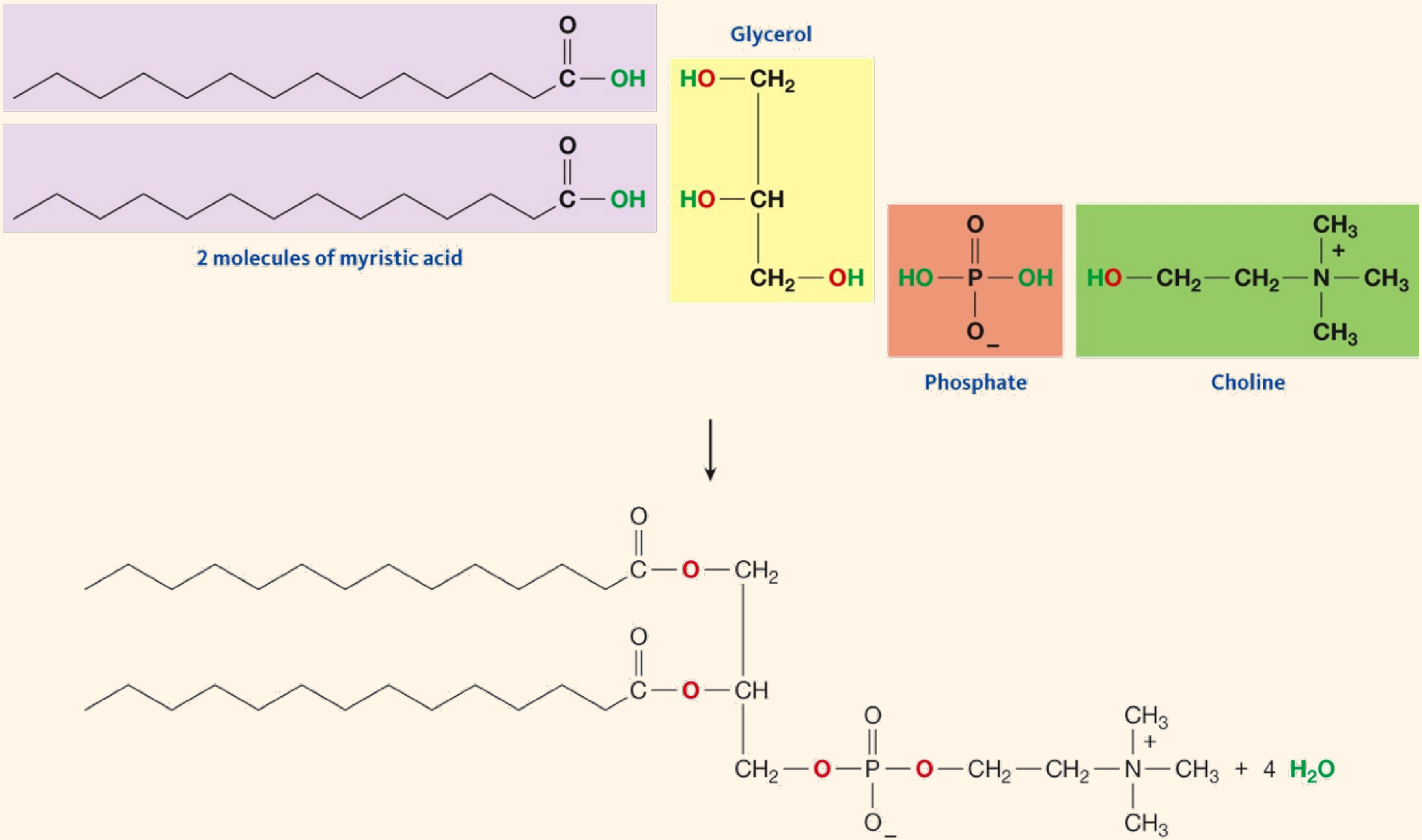
- Cell membranes are made of phospholipids, which contain one or more long hydrocarbon chain attached to a phosphate group.
- Example: Glycerophospholipids are composed of two fatty acids, glycerol, a phosphate group, and a polar molecule (typically choline, serine or ethanolamine).

General structure of a triglyceride



General structure of a glycerophospholipid

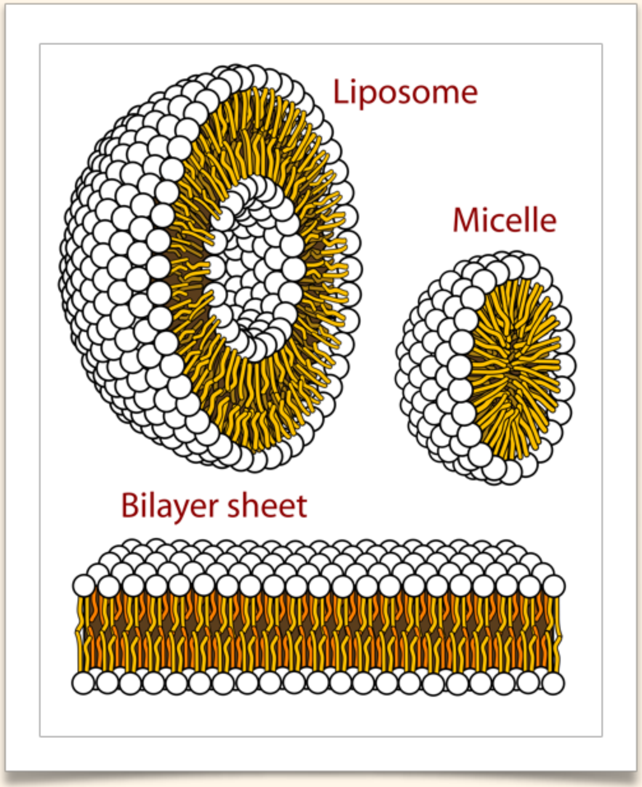
Formation of a Glycerophospholipid



Lecithin
(a glycerophospholipid)

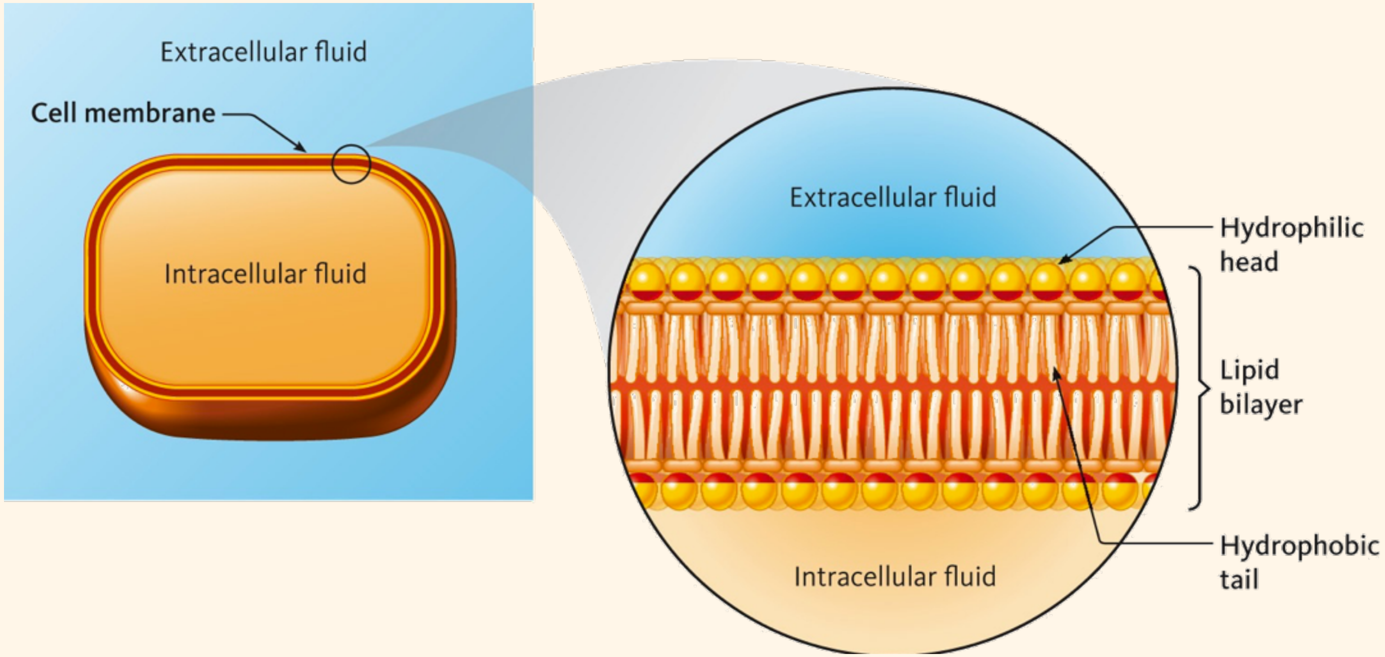
Lipid Bilayer

- Earlier we discussed how soaps aggregate to form micelles when mixed with water.
- Glycerophospholipids aggregate to form lipid bilayers when mixed with water



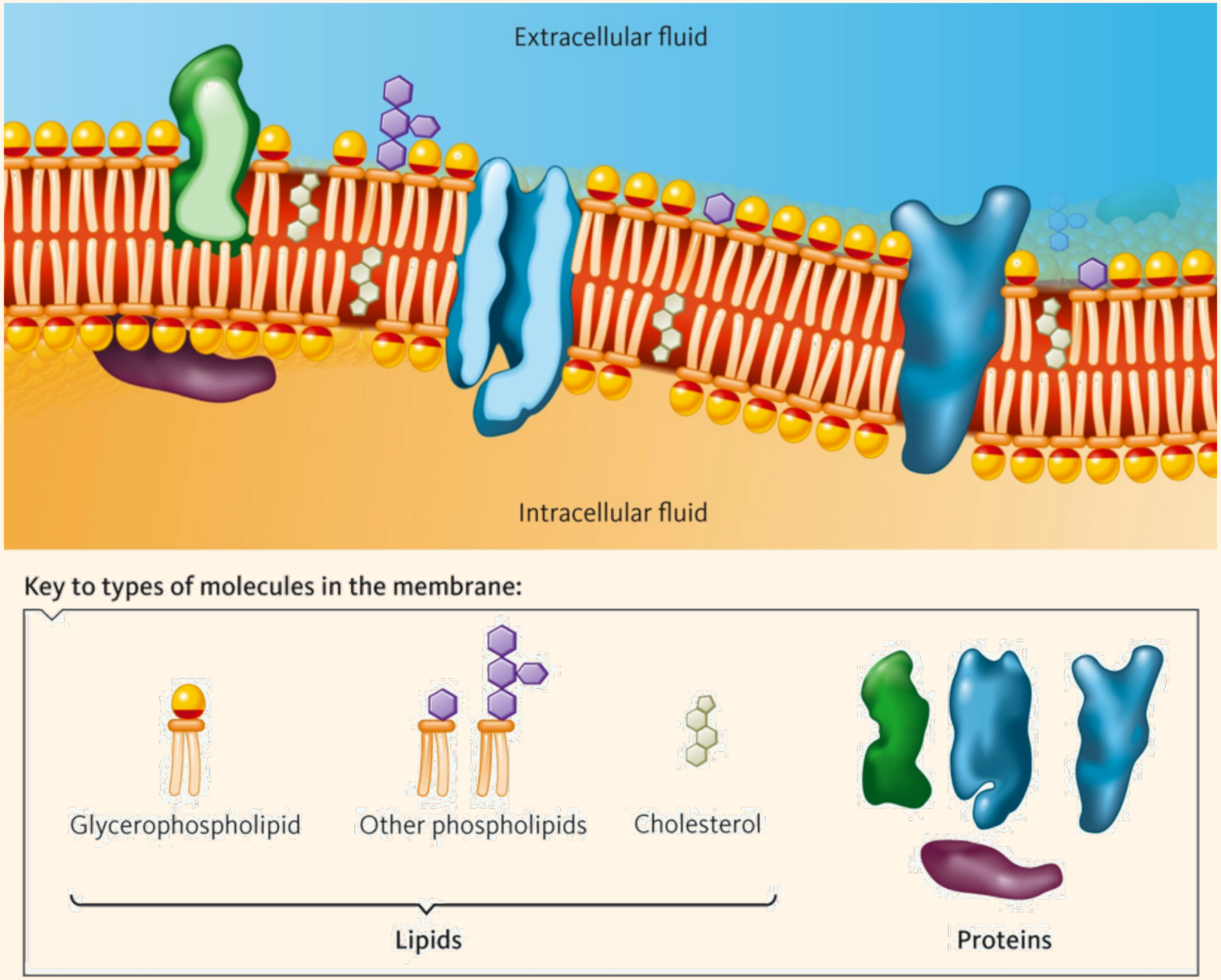
Lipid Bilayer

- A lipid bilayer is the basic component of cell membranes.
- Hydrophilic groups of the glycerophospholipids face out to the aqueous intra- and extracellular environment. Hydrophobic tails face each other.
- This creates a strong flexible coating for a cell that prevents free exchange of molecules and ions between the inside and outside of a cell.



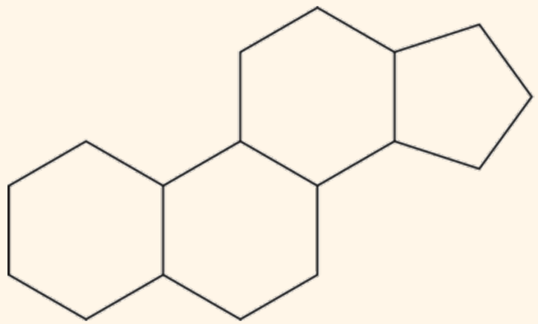
Other Components in the Lipid Bilayer

- Membranes contain many other molecules, including proteins and steroids.



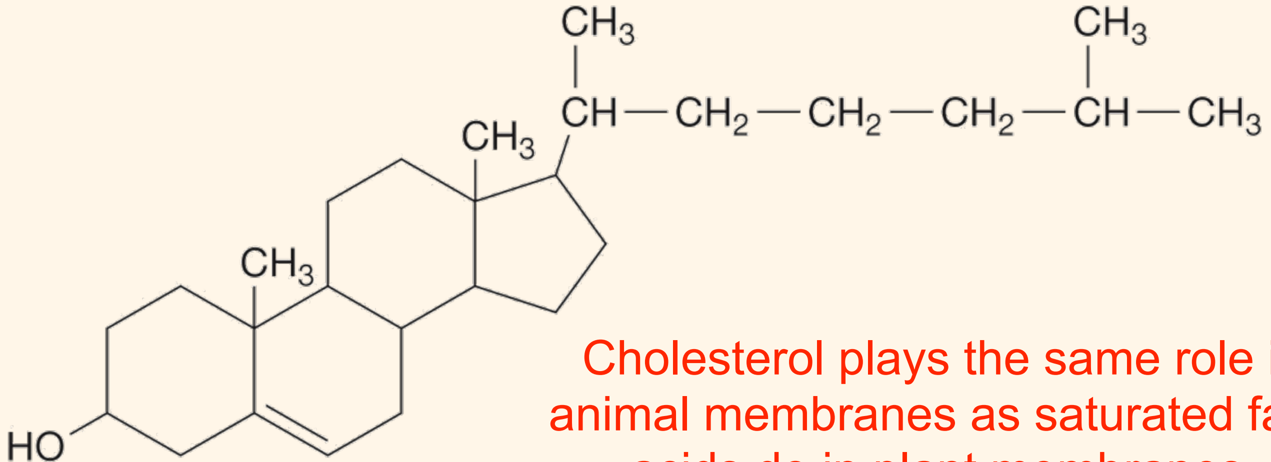
Steroids and Cholesterol

- Steroids are a class of lipids that contain a fused ring nucleus.



The steroid nucleus

- Cholesterol is a common steroid.



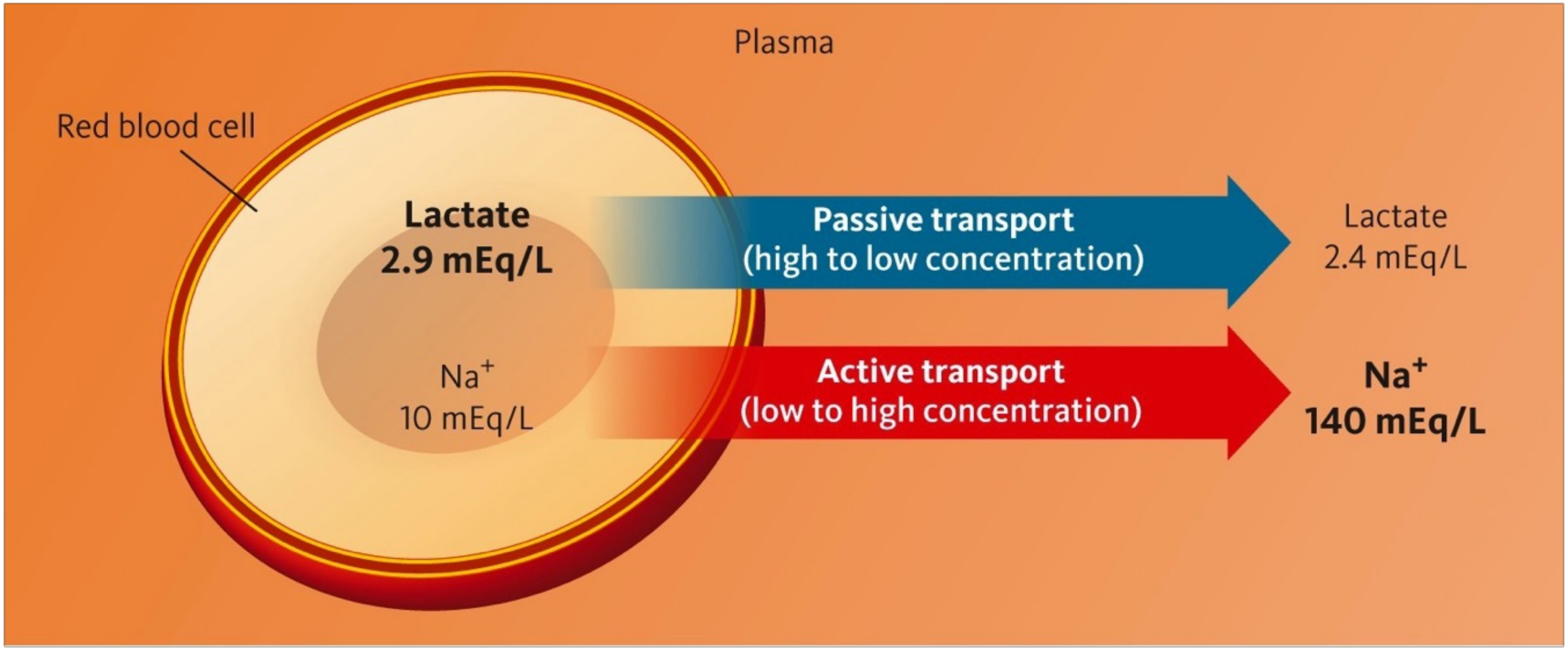
Cholesterol

Cholesterol plays the same role in animal membranes as saturated fatty acids do in plant membranes.

Proteins in the Cell Membrane

- Many of the proteins in membranes are transport proteins
  - These proteins provide passageways for ions and molecules to cross the lipid bilayer.
- Passive transport occurs when a molecule or ion diffuses from higher concentration to lower concentration (down a **concentration gradient**).
- Active transport occurs when a molecule or ion moves from lower concentration to higher concentration (up a **concentration gradient**).
  - Active transport requires a source of energy.

Active and Passive Transport



16.5 Concentration gradients and ATP formation

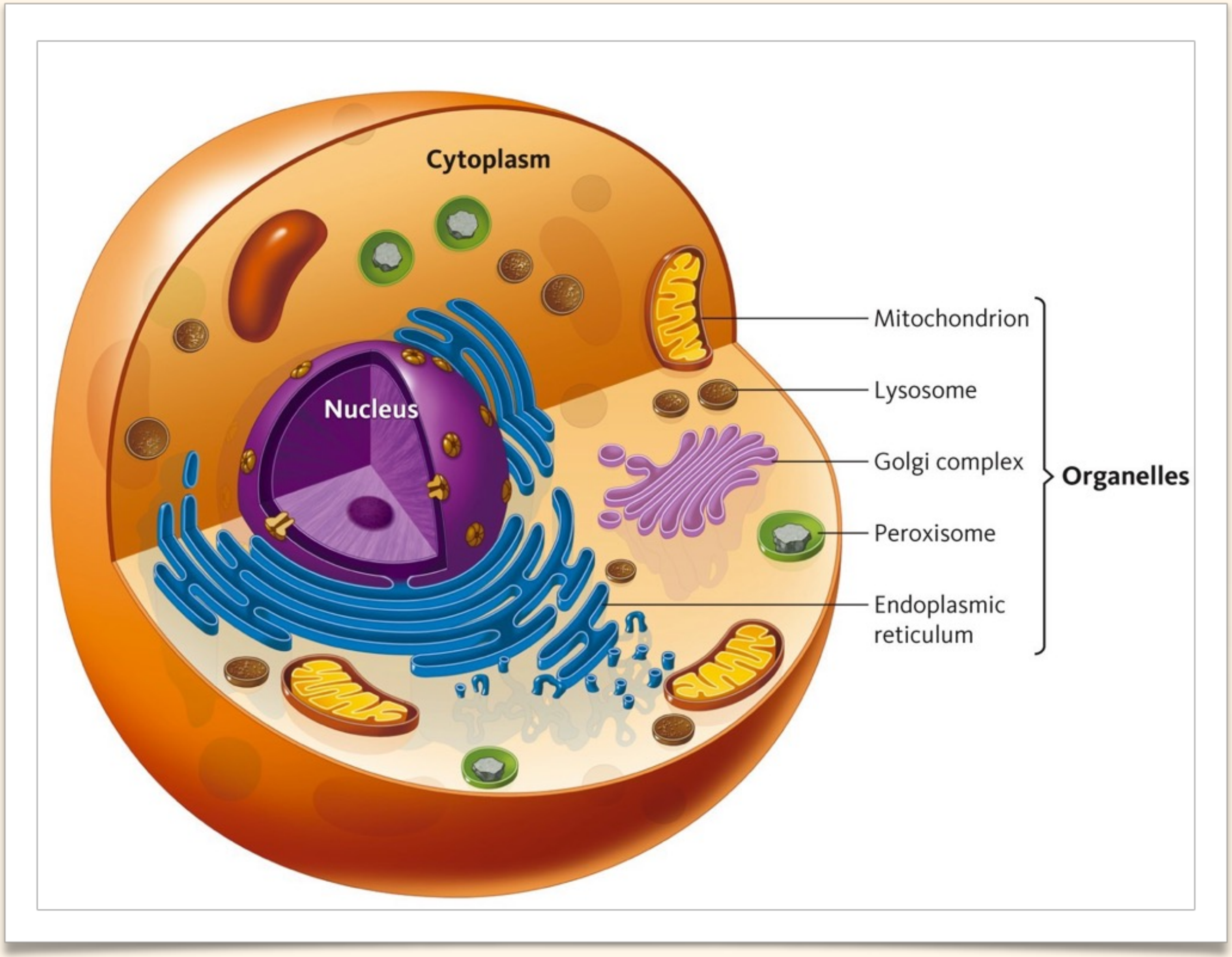
- Prokaryotes (bacteria) have a less complex internal structure than eukaryotes.
  - Eukaryotic cells contain membrane bound organelles.

TABLE 16.7 Organelles in Eukaryotic Cells

Structure	Function
Endoplasmic reticulum	Builds proteins and lipids
Golgi complex	Processes and sorts proteins after they are synthesized
Lysosome	Hydrolyzes worn-out and damaged cell components
Peroxisome	Oxidizes waste products and foreign material
Mitochondrion	Carries out most catabolic pathways, and produces ATP for the cell
Chloroplast (plants only)	Carries out photosynthesis

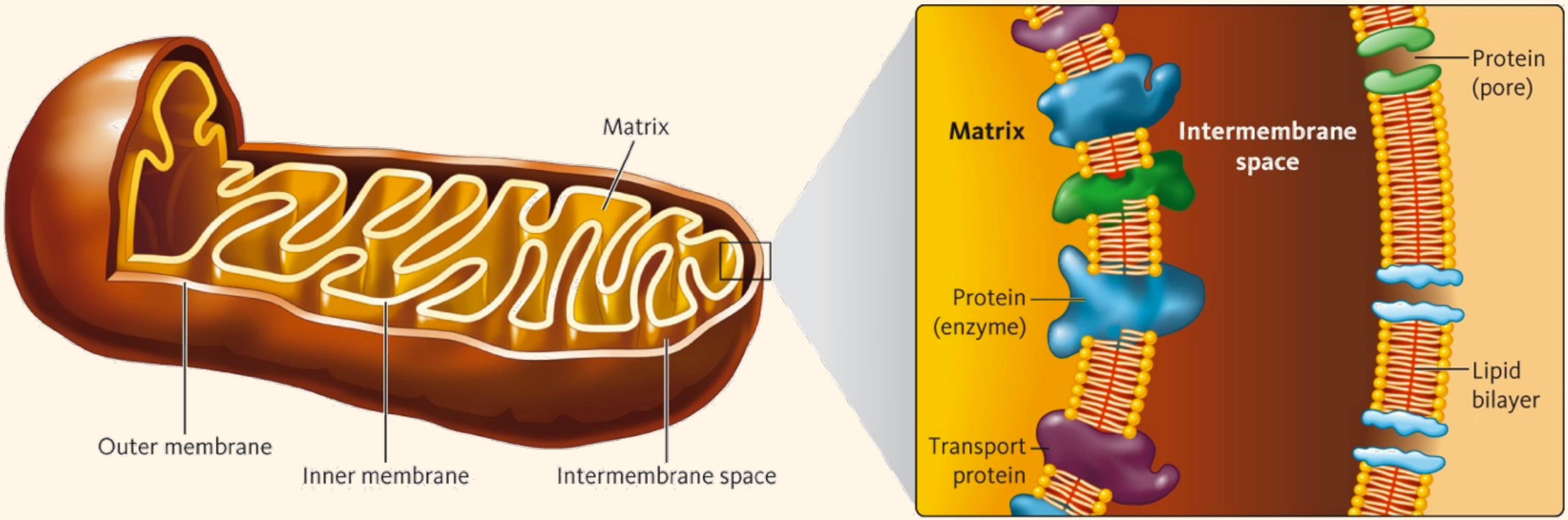
Mitochondria

- Eukaryotic cell.



Mitochondria

- One of these, the mitochondria, is the primary location for ATP production in eukaryotic cells .



Mitochondria

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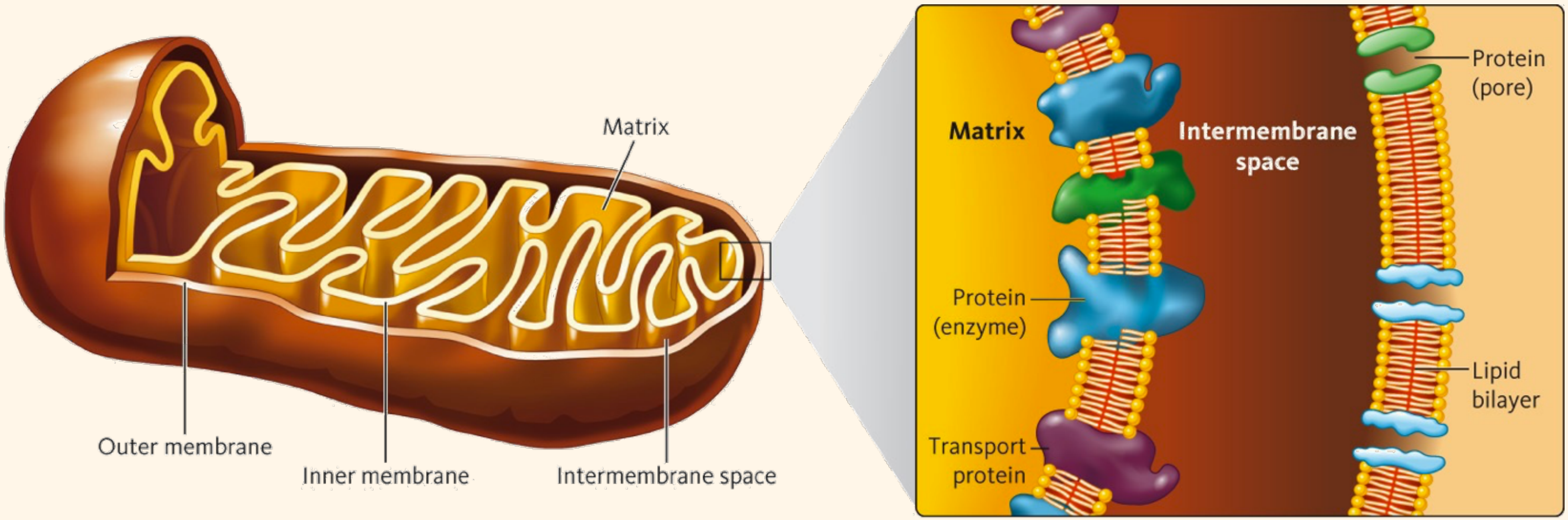


Mitochondria are believe to have evolved from a free-living bacterium

Electron Transport Chain

- A set of enzymes in the mitochondria carry out the electron transport chain. These enzymes use O_2 to convert $FADH_2$ and NADH back to their oxidized forms and release energy:

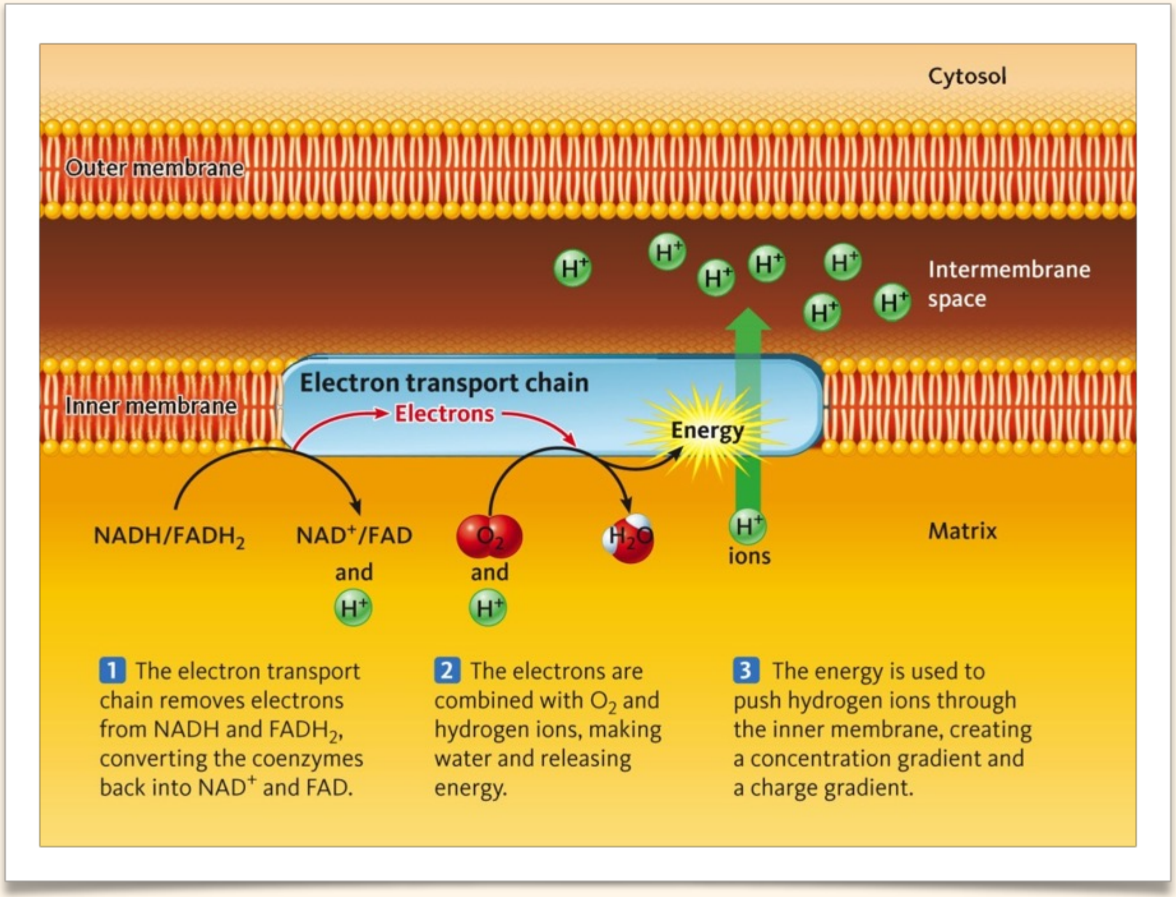
$$2\ FADH_2 + O_2 \rightarrow 2\ FAD + 2\ H_2O + \text{Energy}$$

$$2\ NADH + 2H^+ + O_2 \rightarrow 2\ NAD^+ + 2\ H_2O + \text{Energy}$$

- The energy is used to produce a concentration gradient of H^+ ion across the mitochondrial membrane, which is then used to produce ATP.

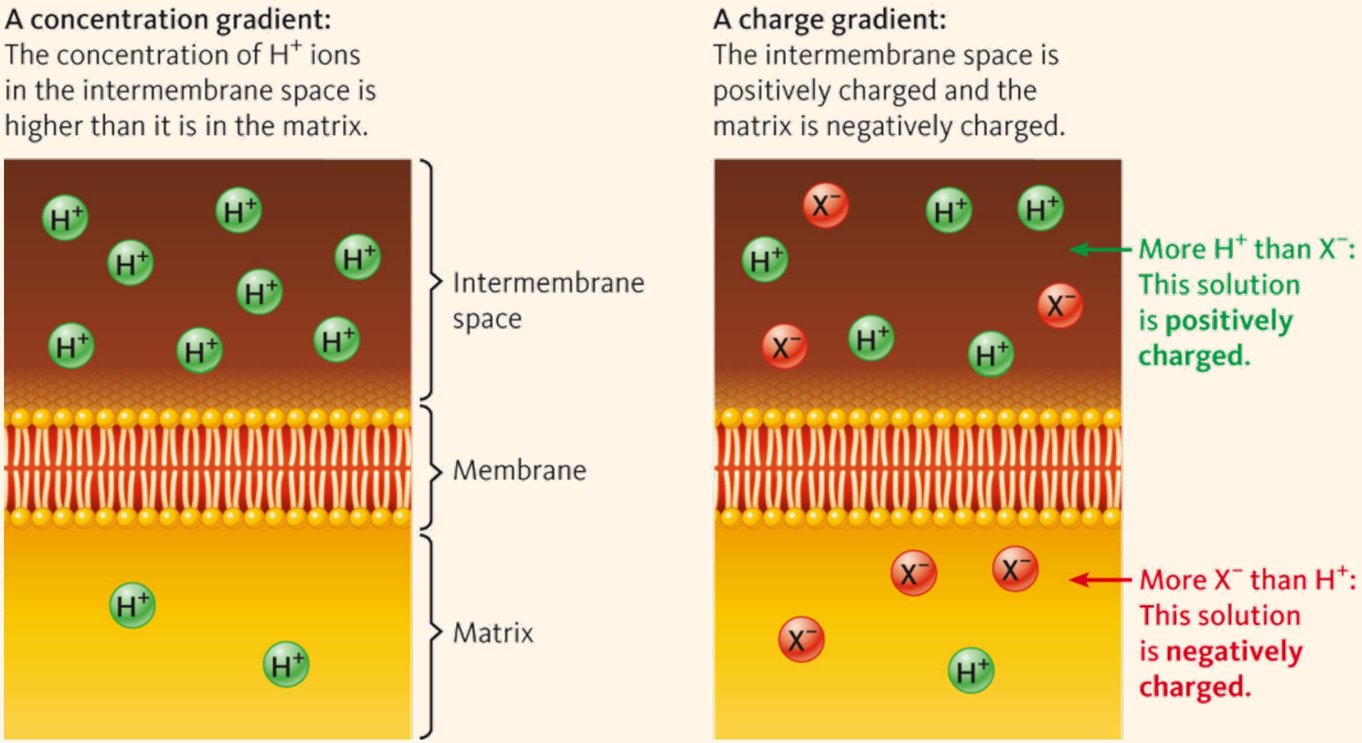
Electron Transport Chain

- Energy is used by the electron transport chain to actively transport H^+ into the intermembrane space, creating a concentration gradient.



Charge and Concentration Gradient

- In addition to a concentration gradient, a charge gradient is also produced because there is now a high concentration of positive ions in the intermembrane space.

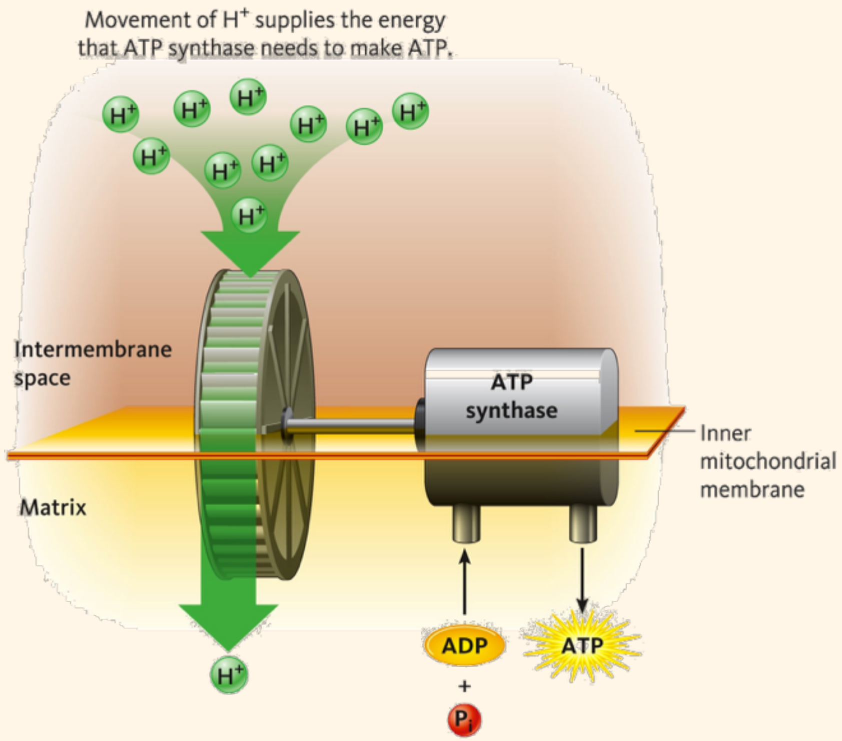


$FADH_2$ vs NADH

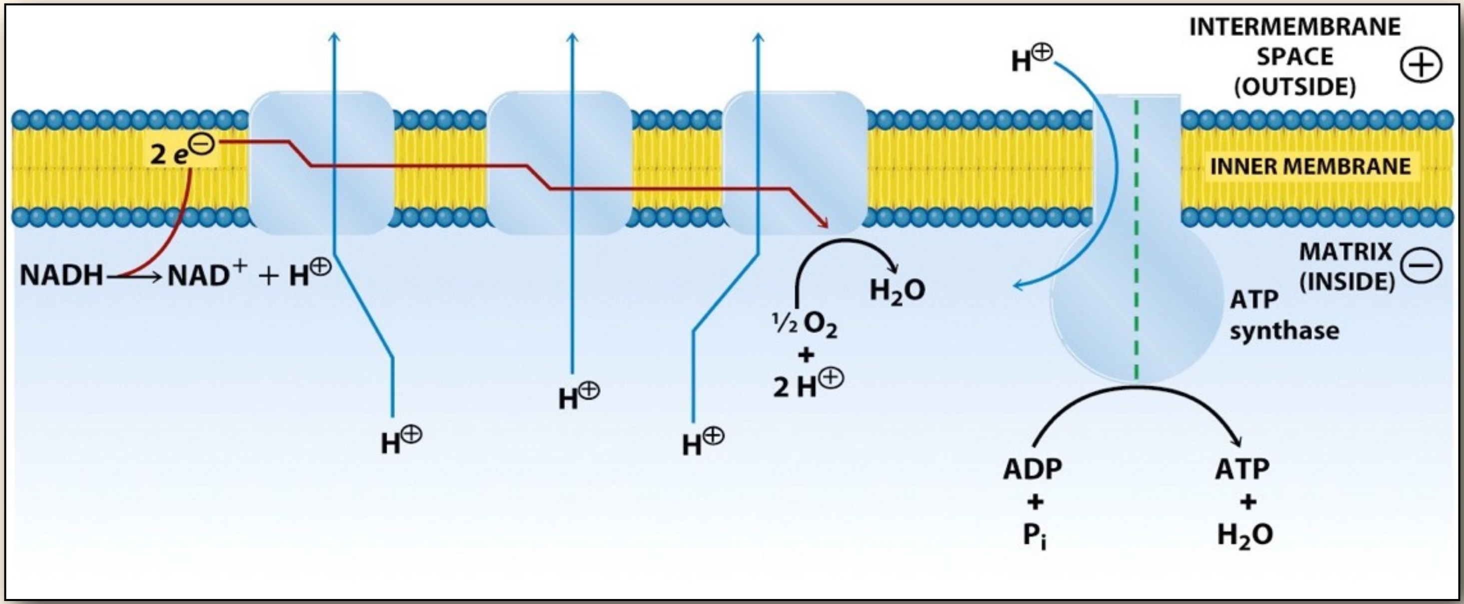
- More energy is released reoxidizing NADH + H^+ than reoxidizing $FADH_2$
  - Therefore, fewer H^+ are transported across the membrane when oxidizing $FADH_2$.
- The electron transport chain is able to push 10 H^+ through the membrane for every NADH+H^+ oxidized, but only 6 H^+ for every $FADH_2$ oxidized.

ATP Synthase

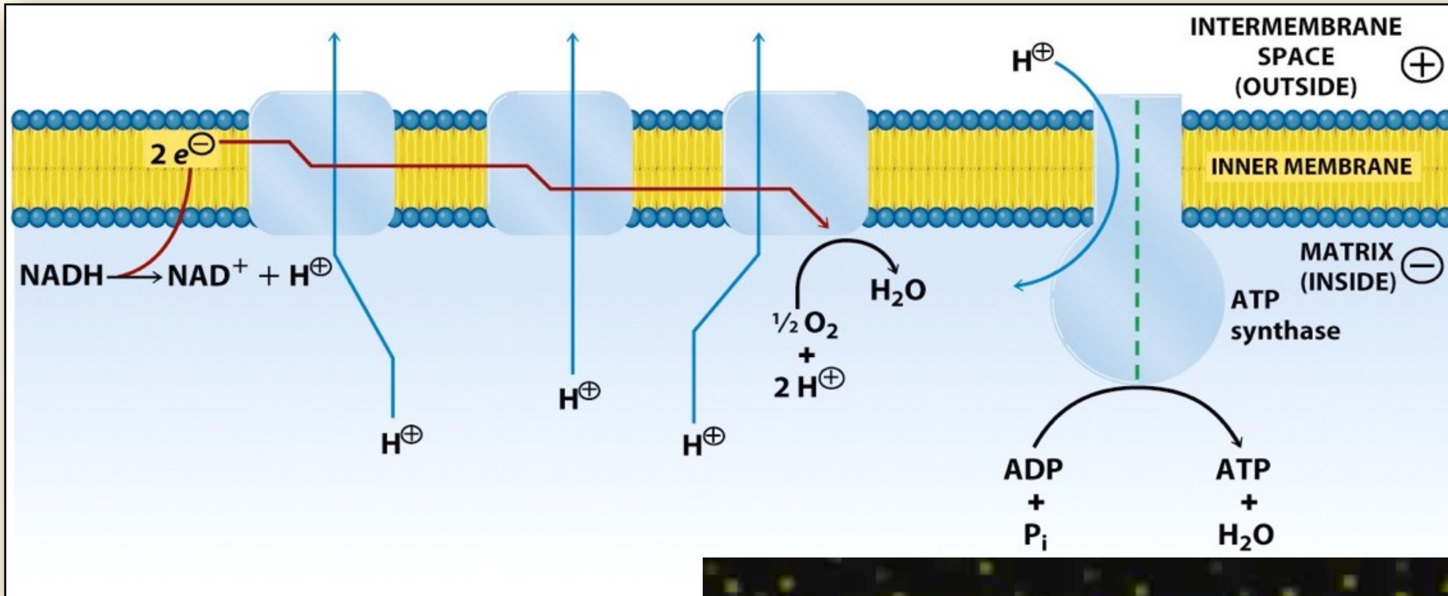
- Next, hydrogen ions move through ATP synthase back into the matrix.
- This movement releases the energy from the gradient and allows ATP synthase to produce ATP from ADP and P_i. Movement of 3 H^+ are required to make one molecule ATP.

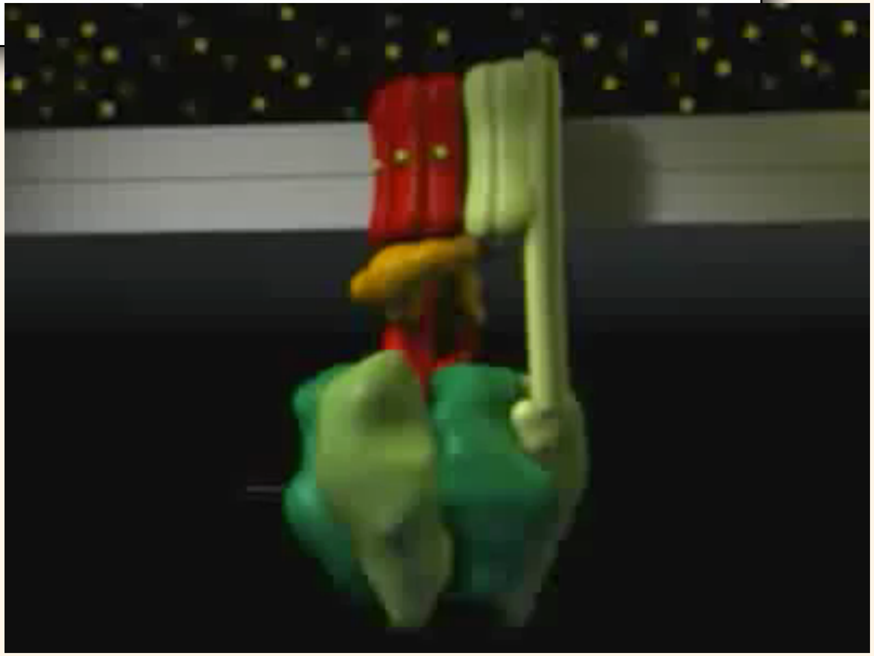


Electron Transport Chain and ATP Synthase

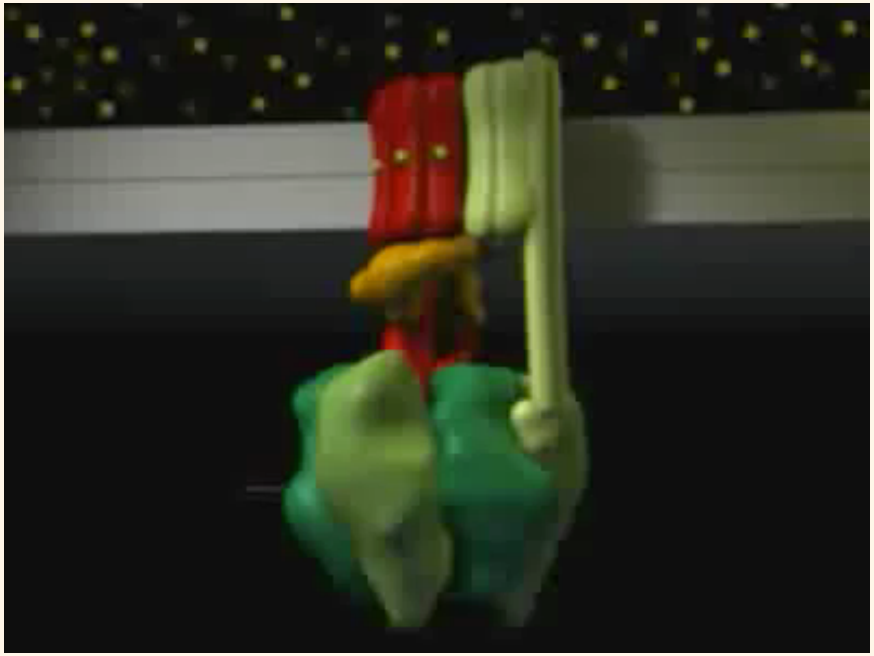


Electron Transport Chain and ATP Synthase





Electron Transport Chain and ATP Synthase



Transport Proteins

- A transport protein then moves ATP into the intermembrane and one H^+, ADP, P_i into the matrix.

- Movement of 4 H^+ **total** are required to make one molecule ATP

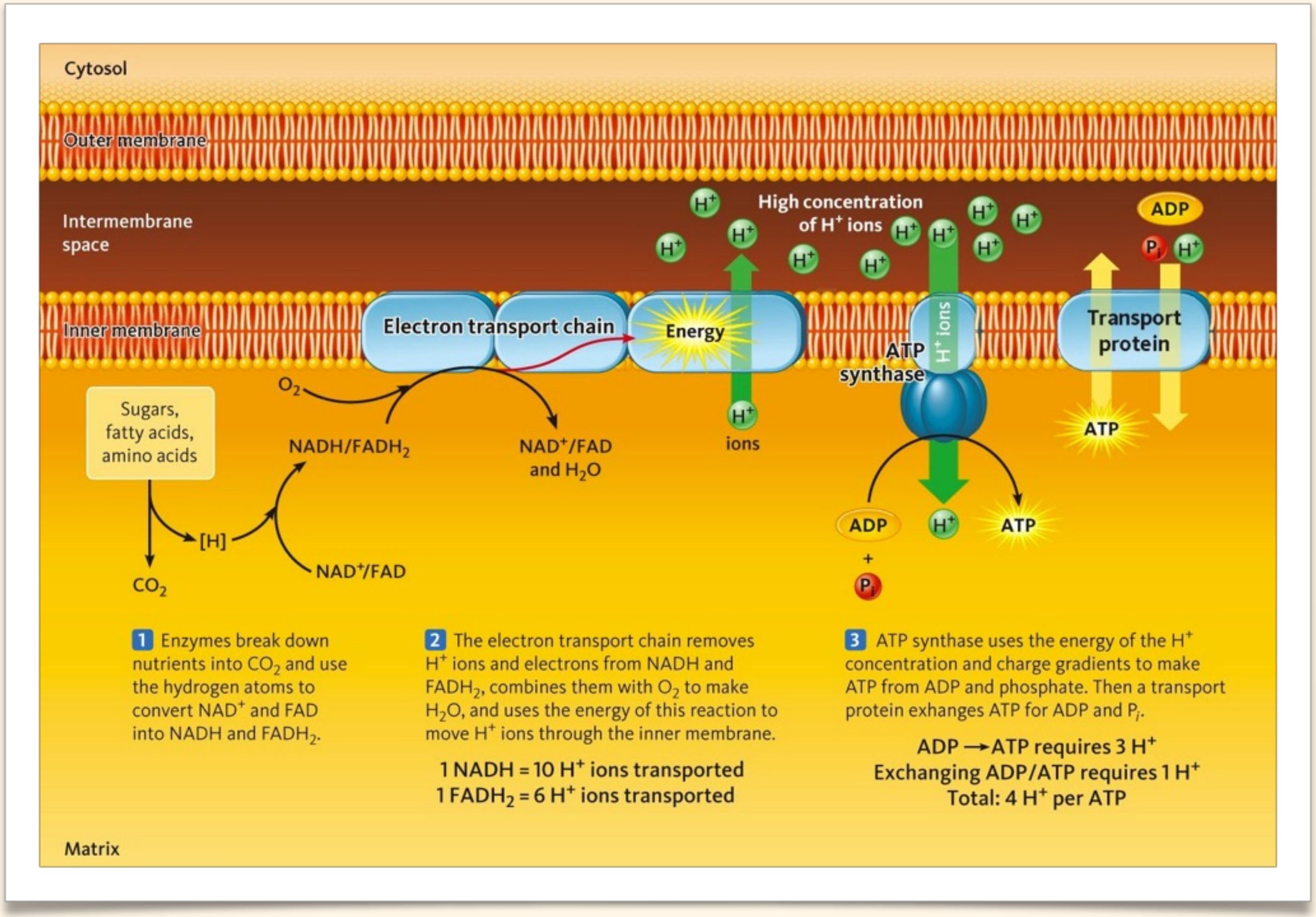
- In terms of coenzymes:

  One mole of NADH produces 2.5 moles ATP

  One mole of $FADH_2$ produces 1.5 moles ATP

Oxidative Phosphorylation

- The process that begins with oxidation of NADH and $FADH_2$ and ends with ATP production and transport is known as oxidative phosphorylation.



Other Uses for Concentration Gradients

- Concentration gradients supply energy for other purposes.
- Cells use ATP hydrolysis to create gradients with sodium and potassium ions, which in turn can be used for other cellular processes like nerve impulse transmission

Other Uses for Concentration Gradients

- Unit 13: Nucleic Acids and Protein Synthesis
  - Chapter 17 in Armstrong