Chapter 5:
Microbial Metabolism

1. Enzymes

2. ATP Production

3. Autotrophic Processes

1. Enzymes

Biochemical Reactions

All living cells depend on biochemical reactions to maintain homeostasis.

All of the biochemical reactions in an organism are collectively referred to as metabolism, which is of 2 basic types:

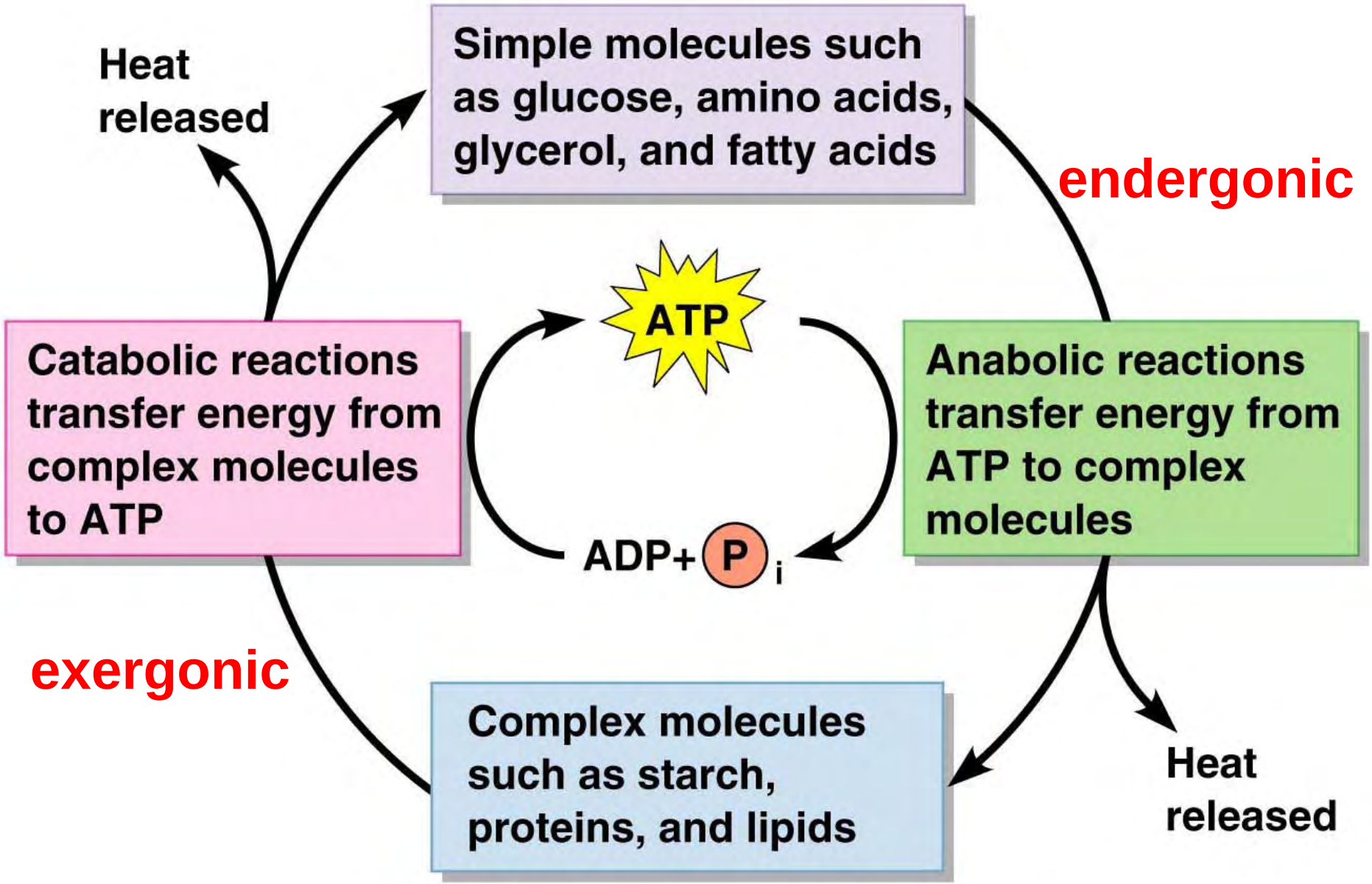
catabolic: reactions that "break down" molecules

- **generally energy *releasing* or exergonic**

anabolic: reactions that build new molecules

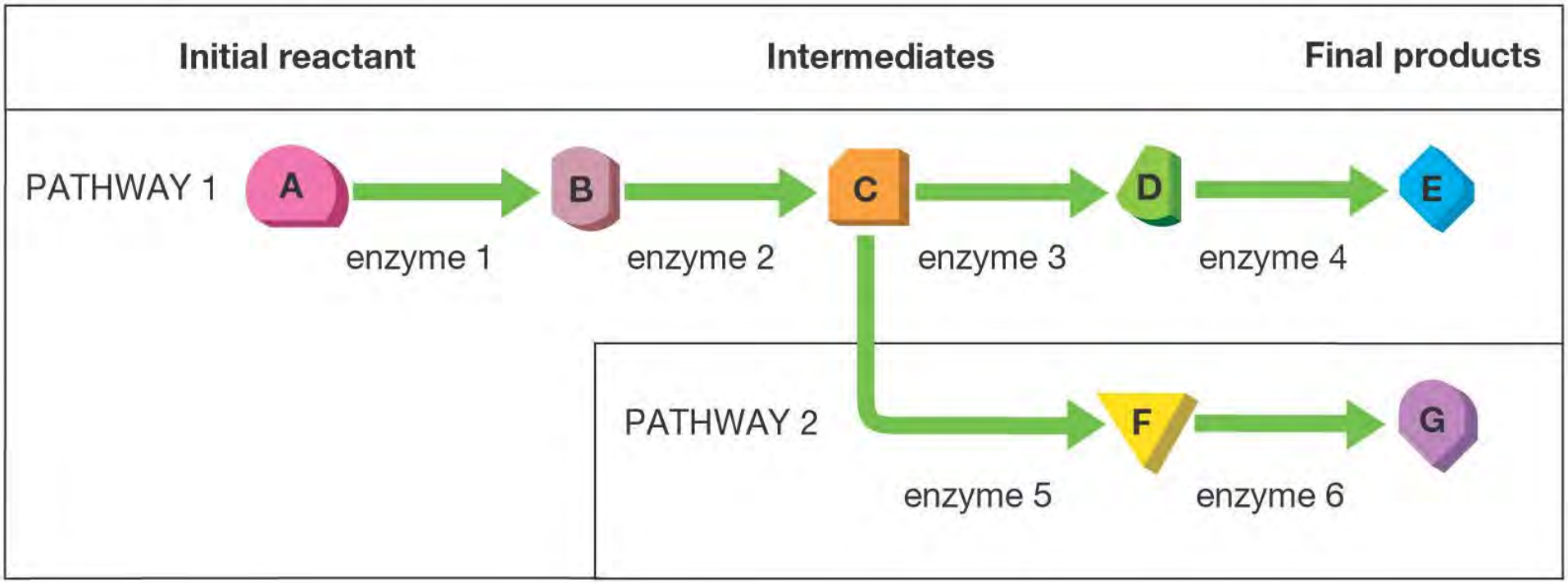
- **generally energy *requiring* or endergonic**

****exergonic* reactions provide energy for *endergonic* ones!****



All organisms, prokaryotic or eukaryotic, need to build the molecules they need, and find the energy to do so!

Metabolic Pathways



Most biochemical reactions are part of a series of reactions referred to as a <u>metabolic</u> <u>pathway</u>:

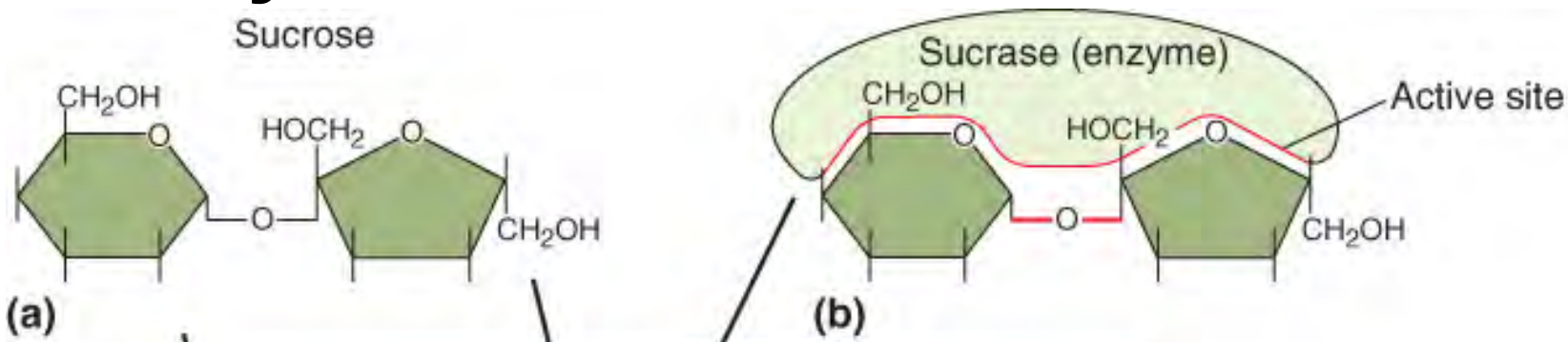
- **it usu. takes multiple reactions to make "end-product"**
- **pathways can be <u>catabolic</u> or <u>anabolic</u>**
- **each reaction is catalyzed by its own enzyme**

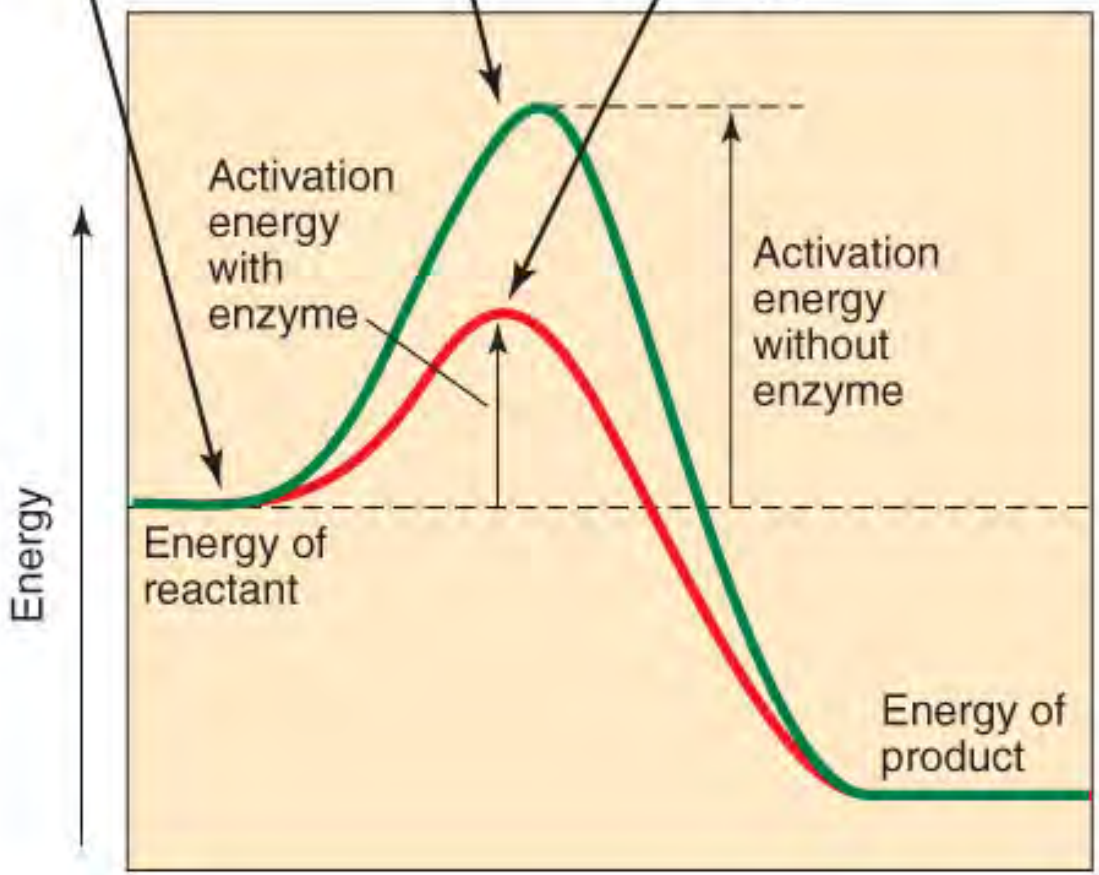
Enzyme Basics

Almost all biochemical reactions are *catalyzed* by a specific <u>enzyme</u>:

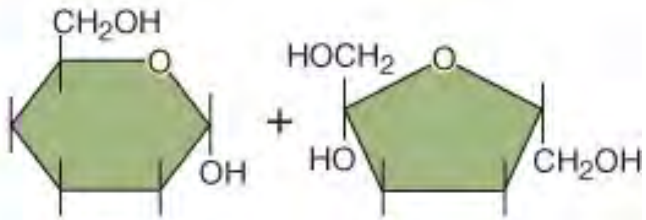
- **proteins that accelerate the rate of a reaction without being changed themselves**
  - **lower the activation energy (E_a)**
- **the need for enzymes provides a way to control or regulate biochemical reactions**
  - **reactions won't occur unless the enzyme that catalyzes the reaction is present <u>*& active*</u>**

Enzymes lower the Activation Energy

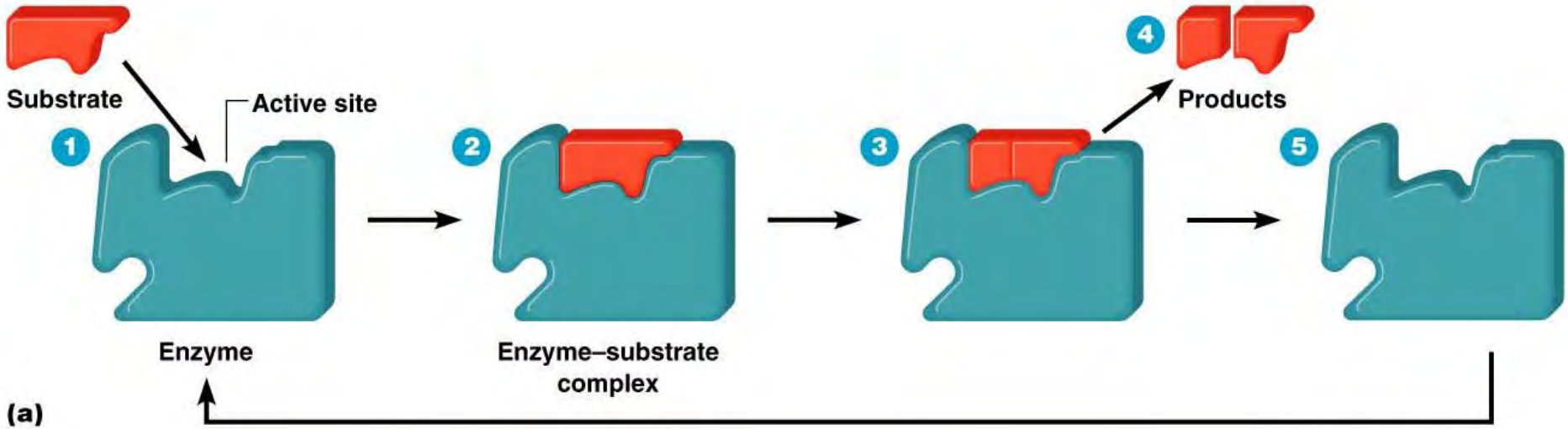


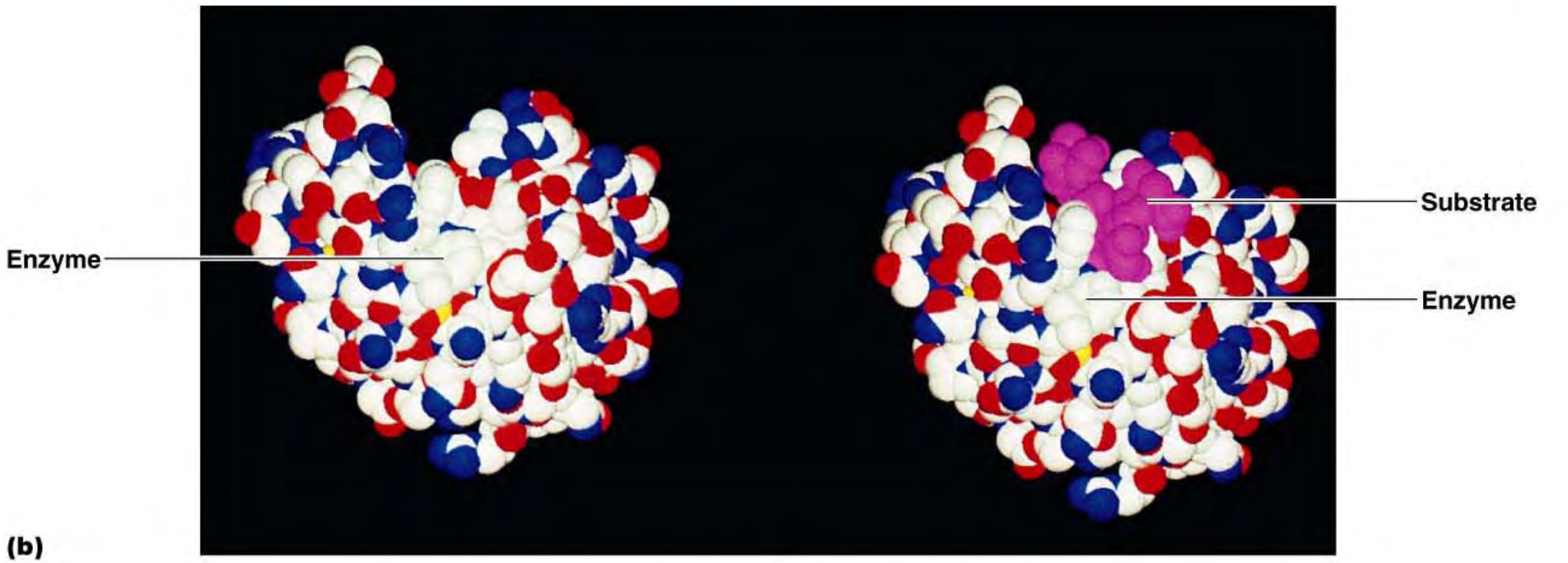


****reactions won't occur unless the E_a requirement is met****



Enzymes physically bind Substrates





Control of Enzyme Activity

Biochemical reactions can be controlled by changes in enzyme activity, which can be influenced in several ways:

1) Changes in the amount of enzyme or substrate

- **more enzyme &/or more substrate = more product!**

2) Changes in temperature, pH or [salt]

- **can effect enzyme structure, hence its activity**

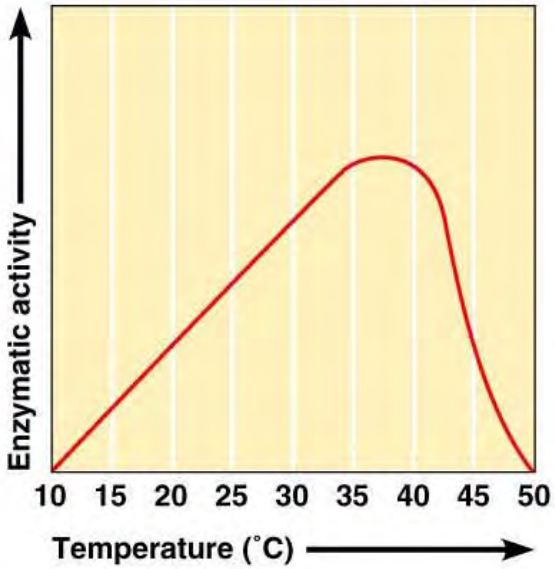
3) Availability of any necessary cofactors

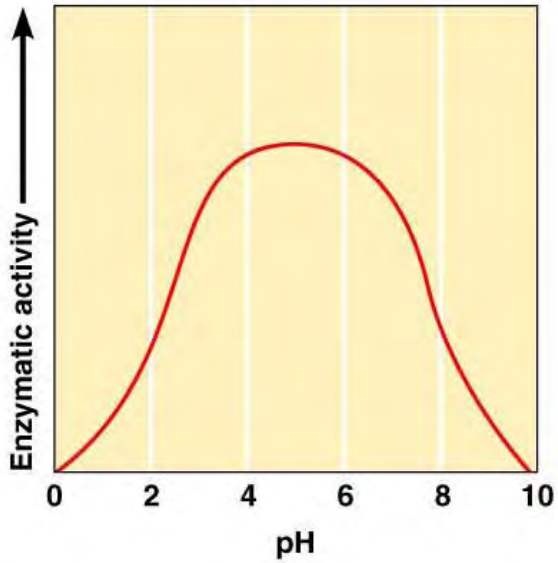
- **some enzymes don't work w/o a *non-protein* cofactor**

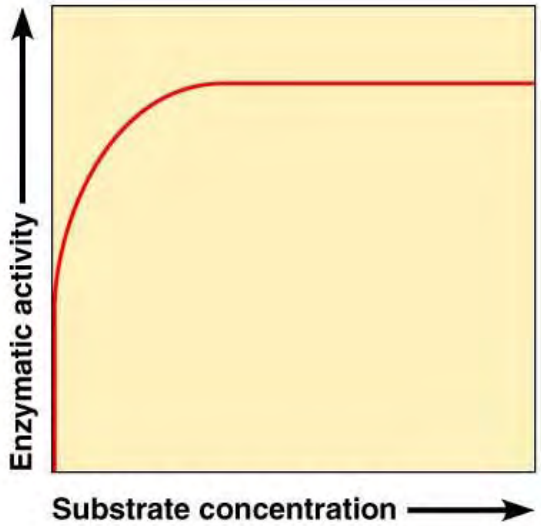
4) Effect of inhibitors

- **molecules that bind to enzymes & reduce their activity**

Factors effecting Enzyme Activity







Temperature

- reactions occur more rapidly as temperature rises

**as long as enzyme is active (heat can <u>denature</u> enzymes)

pH

- enzyme structure depends on pH

**pH affects charge of “R groups”, protein structure

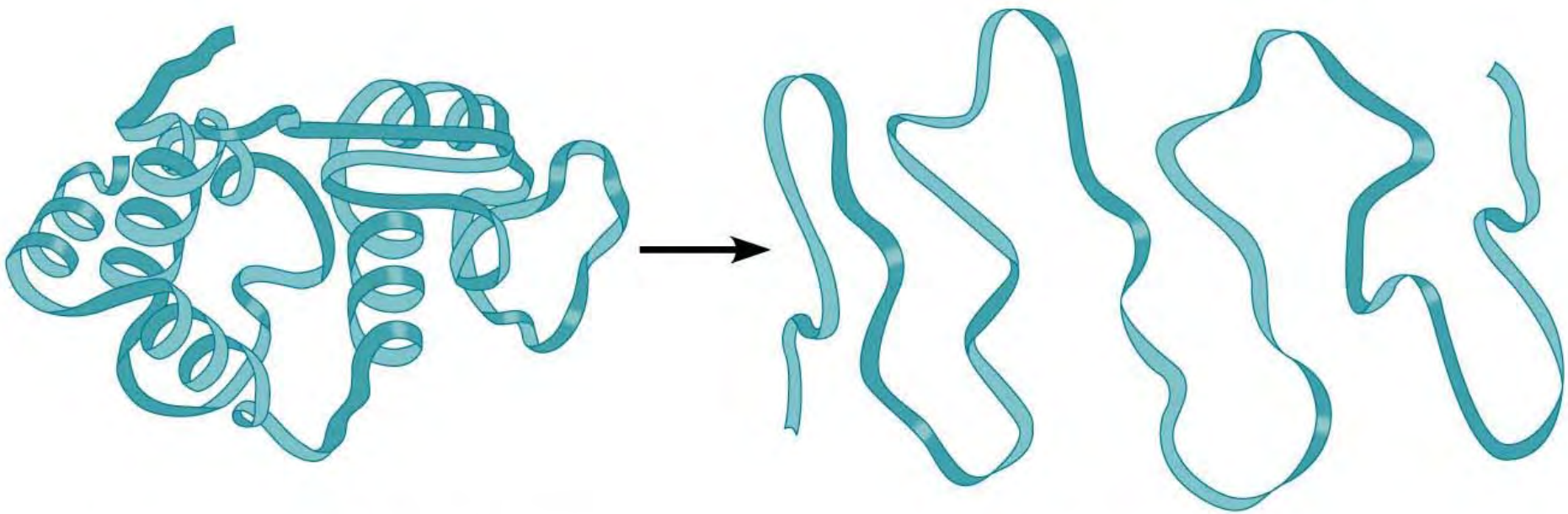
[Substrate]

- reactions occur more rapidly as [substrate] rises

**<u>saturation</u> occurs when [substrate] is high enough

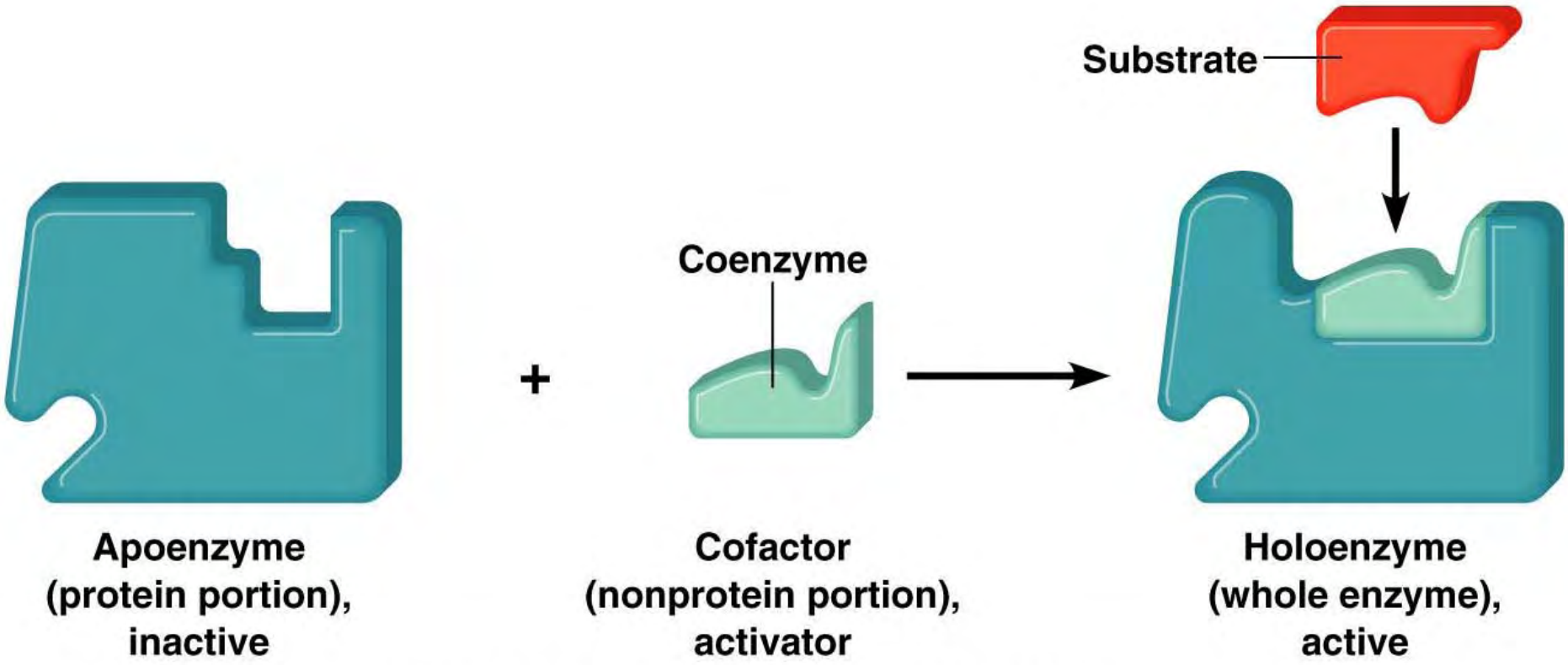
Enzyme Denaturation

- **enzymes are polypeptides that retain their ability to function only when folded properly**
- **changes in temperature, pH or [salt] can disrupt amino acid "R group" interactions causing the protein to unfold, i.e. become <u>denatured</u>**



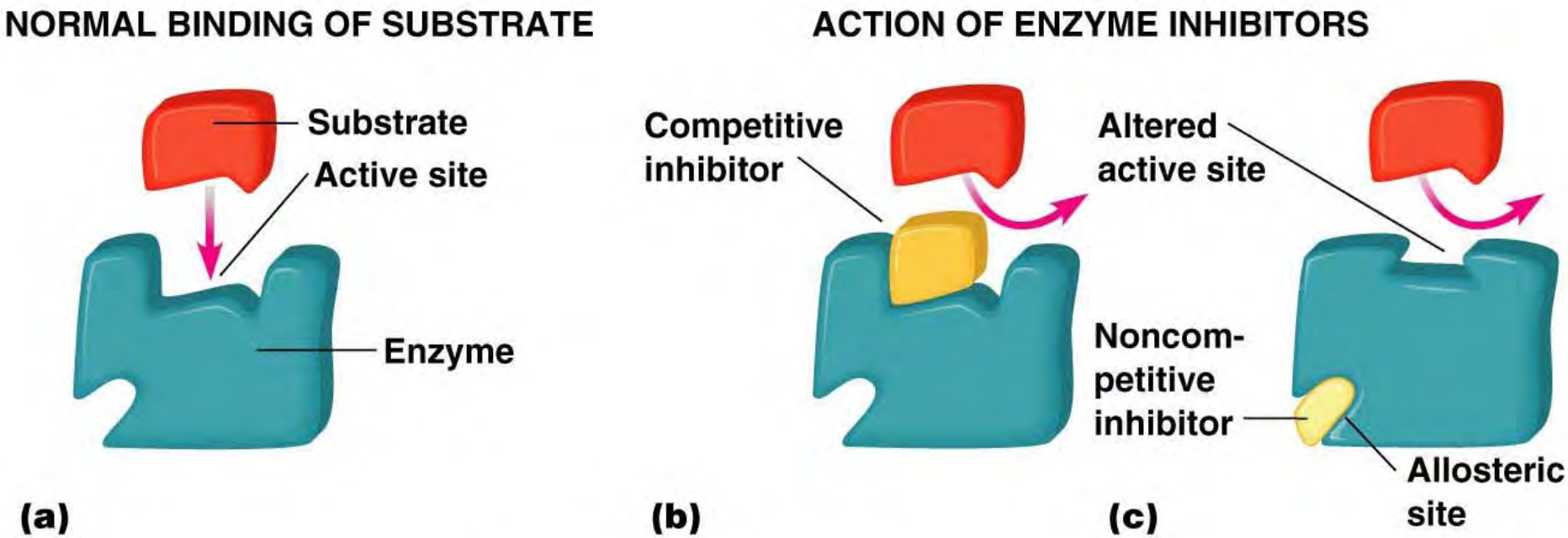
****mutations can also lead to misfolded, non-functional enzymes****

Some Enzymes Require Cofactors



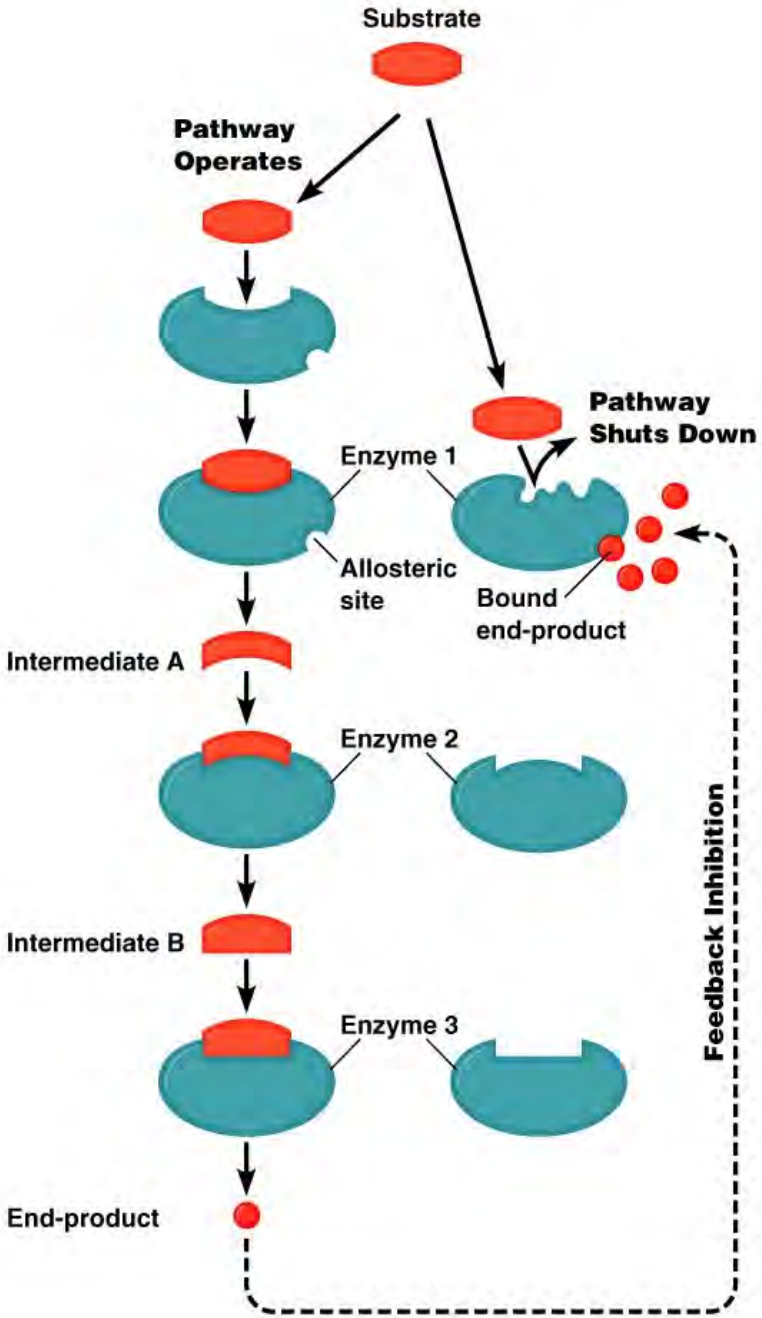
- **can be a metal ion, vitamin, or other "non-protein"**
  - **if the cofactor is organic, it is called a <u>coenzyme</u>**
- **enzyme is inactive w/o cofactor**

Enzyme Inhibition



- **inhibitors bind enzymes in 1 of 2 ways:**
  - **<u>competitive</u> inhibition (binding to active site)**
  - **<u>allosteric</u> inhibition (binding elsewhere, changing shape)**
- **inhibitors can bind <u>reversibly</u> (can "come off") or <u>irreversibly</u> (don't come off, e.g. "poisons")**

Feedback Inhibition



The end-products of metabolic pathways are important *reversible* enzyme inhibitors

- **inhibit 1st enzyme in pathway, turning the pathway "off"**

  low [inhibitor] = pathway ON

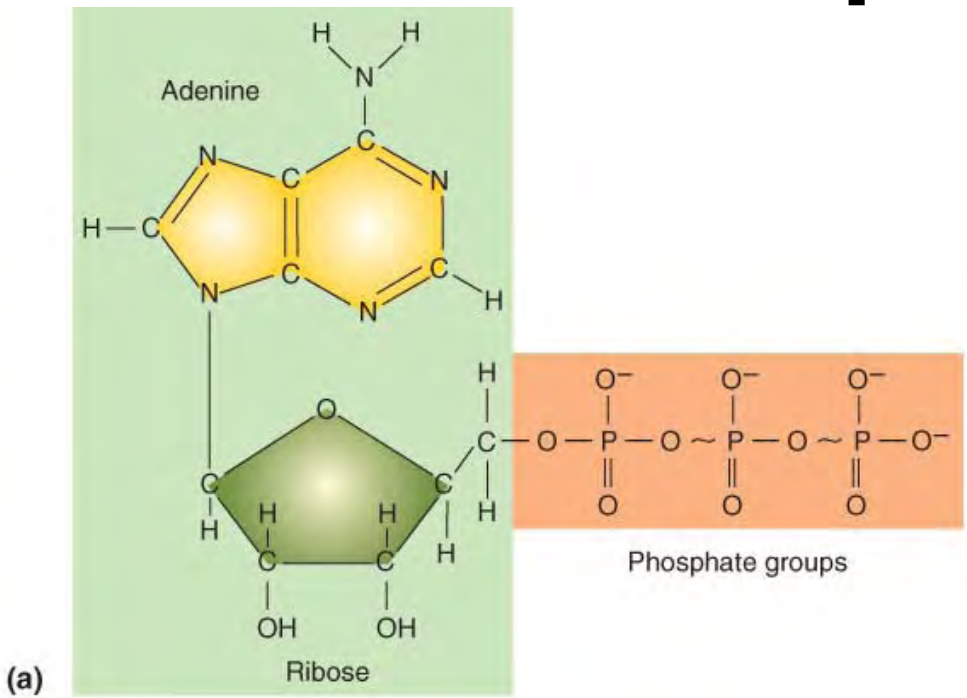
  high [inhibitor] = pathway OFF

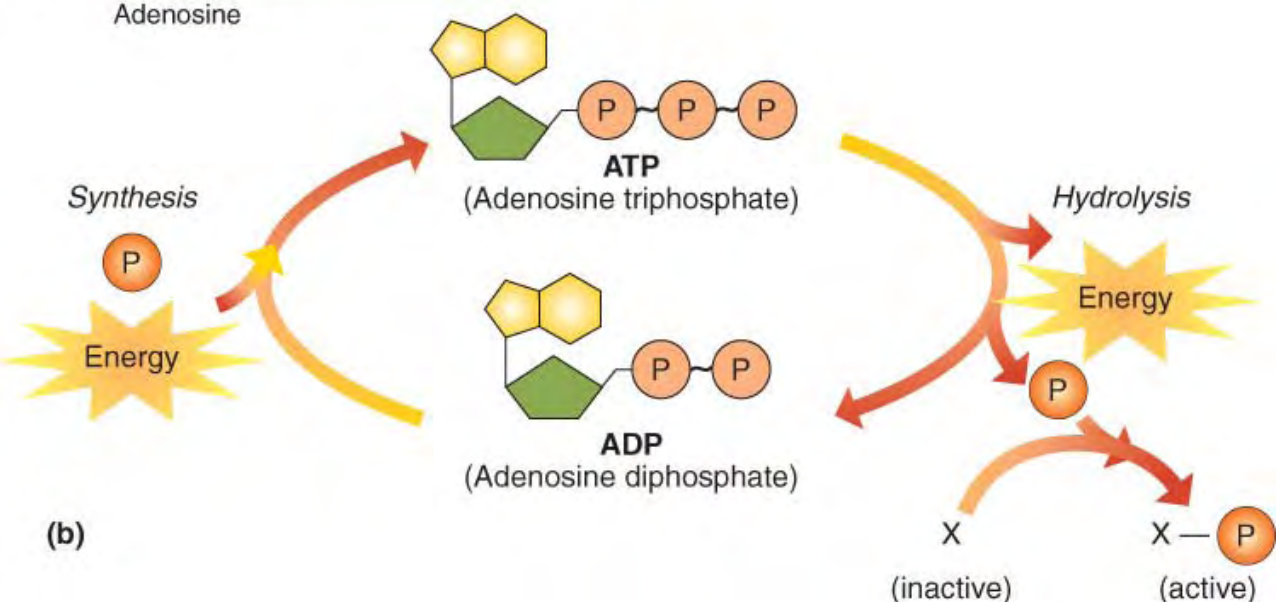
- **can be competitive or allosteric inhibition**

- **provide an important way of regulating end-product levels**

2. ATP Production

Adenosine Triphosphate (ATP)



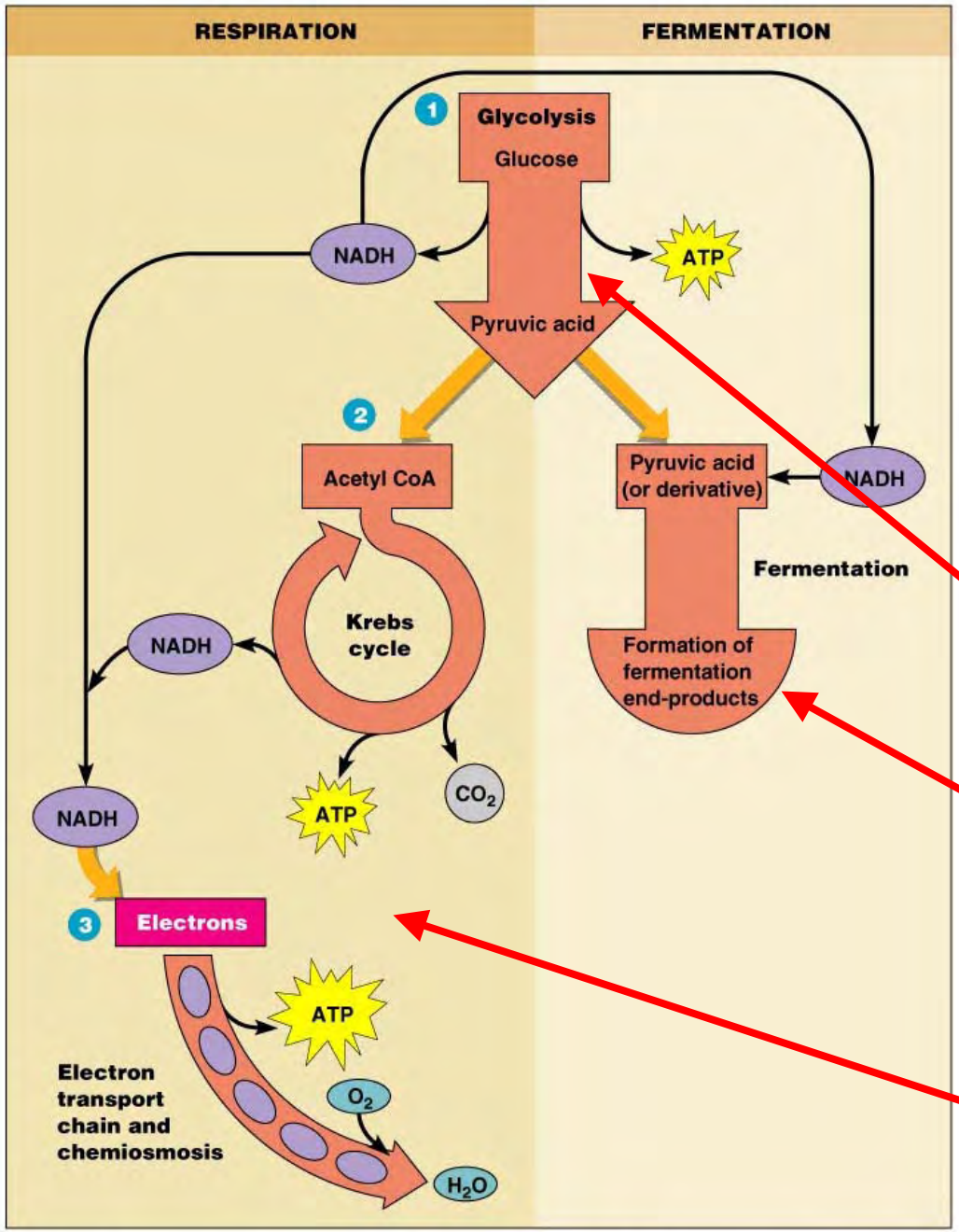


Preferred source of <u>useable</u> energy for ALL cells:

- **breaking bond of 3rd phosphate releases ideal amt of energy**
- **bond is easily broken (low E_a)**

****This is why organisms convert "food" energy to "ATP" energy****

How is ATP produced?



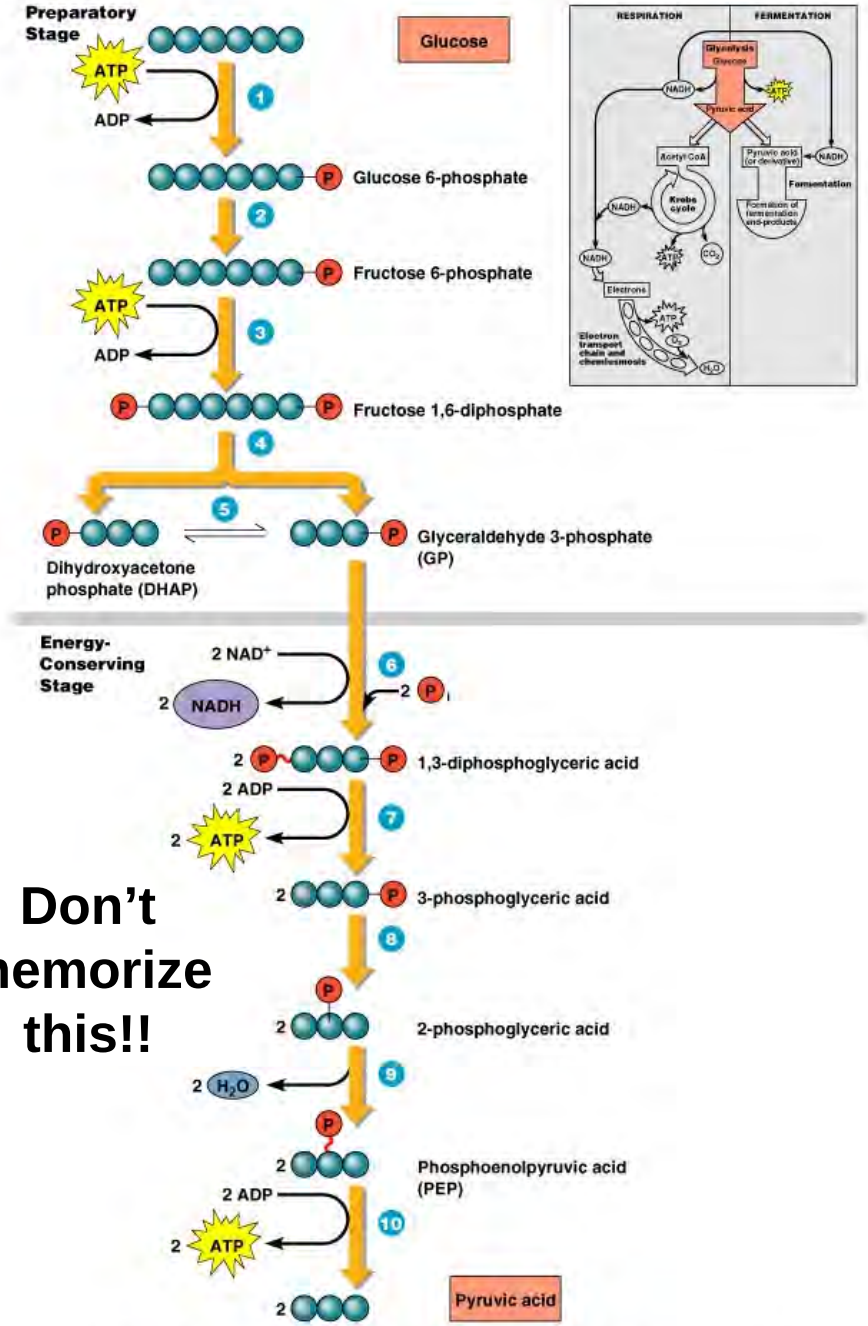
In most organisms, energy from a "food source" is converted to energy in ATP by <u>glycolysis</u> followed by 1 of 2 processes:

FERMENTATION
(low ATP yield)

or

RESPIRATION
(high ATP yield)

Glycolysis



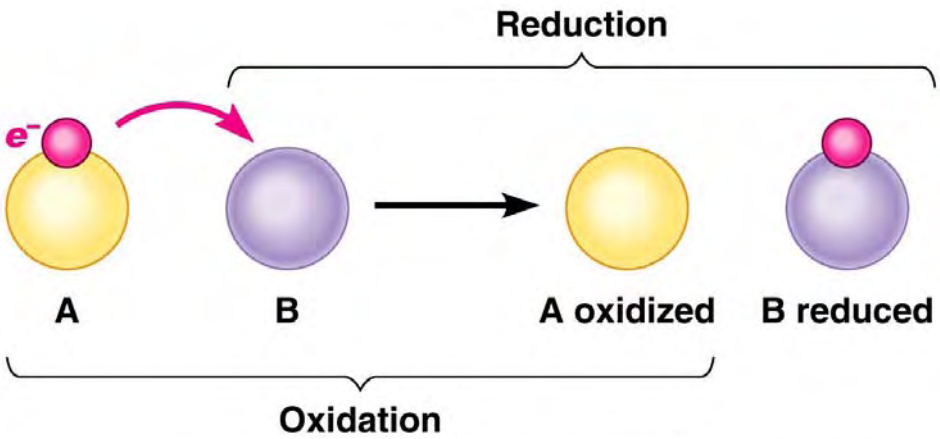
Don't memorize this!!

Glycolysis is a catabolic pathway by which sugars such as glucose (& several other "food" sources) are broken down to two 3-Carbon molecules of pyruvic acid (or pyruvate):

- **releases energy to yield 2 ATP per glucose**
- **also transfers high energy electrons (+ H) to NAD^+ to yield 2 NADH**

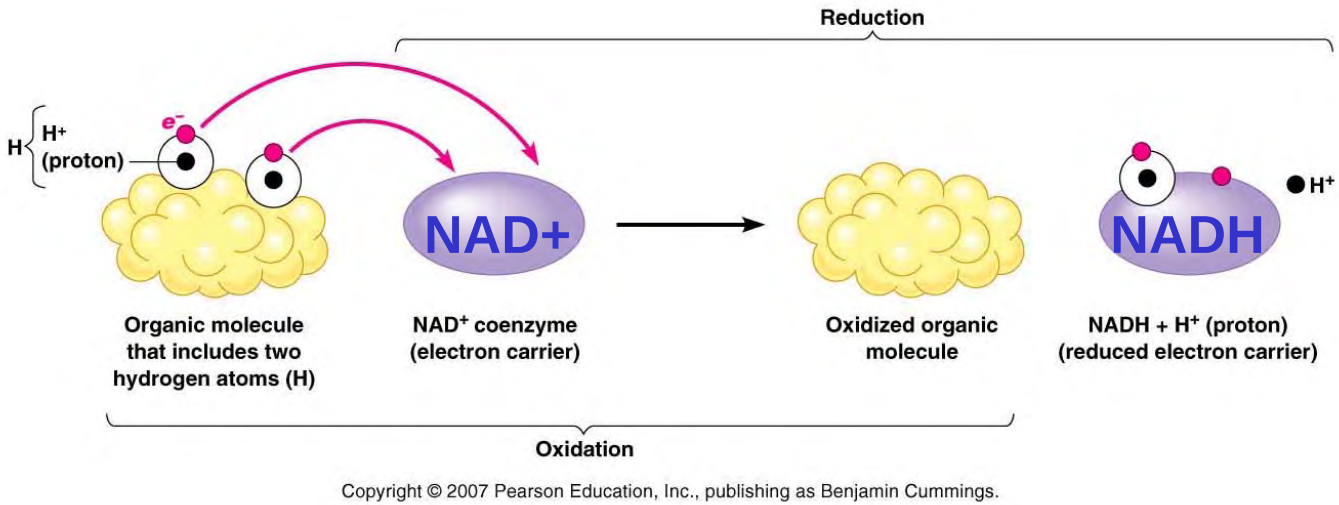
Oxidation/Reduction

Much of the energy in "food" molecules such as glucose is captured as high energy electrons (e^-) by electron carriers such as NADH & $FADH_2$



- **when a molecule receives or gains electrons it is said to be <u>reduced</u>**

****e^- are typically transferred as part of a Hydrogen atom****



- **a molecule that gives up electrons (i.e., loses H) is said to be <u>oxidized</u>**

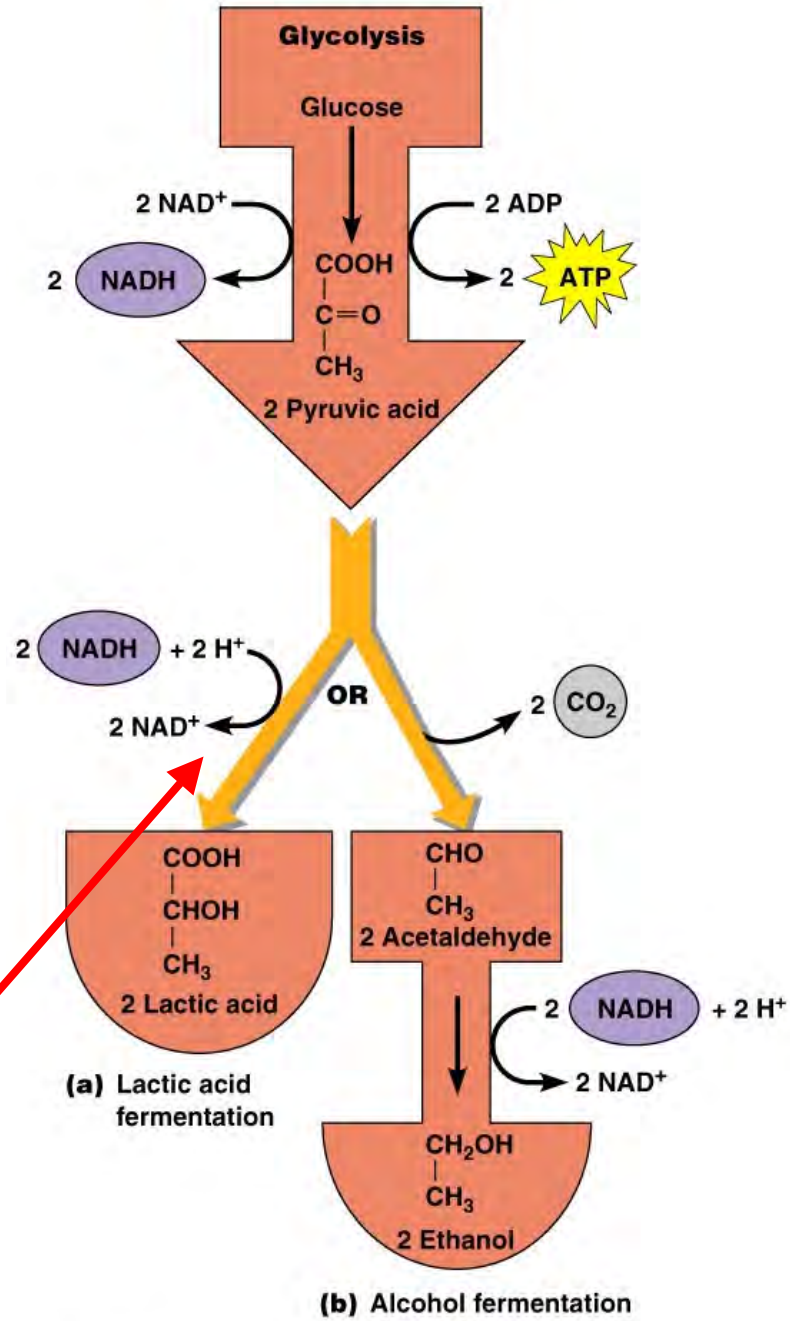
Fermentation

ATP production begins & ends with glycolysis in organisms that ferment.

Fermentation is all about recycling NAD^+ so that glycolysis can continue:

glycolysis ⇄ **NAD^+** / **NADH** ⇄ **fermentation**

- **NADH is oxidized to NAD^+ by reducing pyruvate to lactic acid for example**



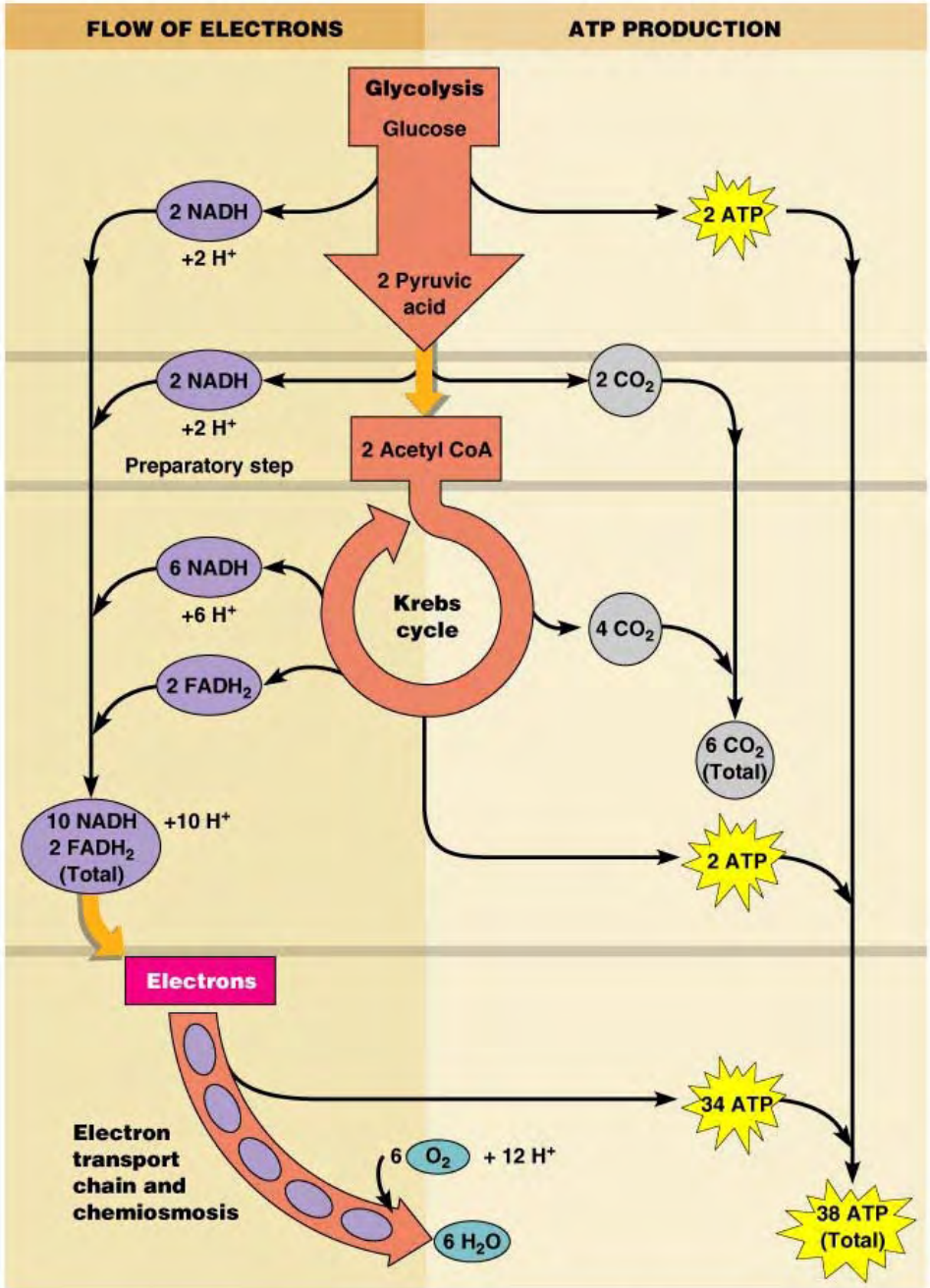
Different Fermentation Products

TABLE 5.4 Some Industrial Uses for Different Types Of Fermentations

* Fermentation End-Product(s)	Industrial or Commercial Use	Starting Material	Microorganism
Ethanol	Beer	Malt extract	*Saccharomyces cerevisiae* (yeast, a fungus)
	Wine	Grape or other fruit juices	*Saccharomyces cerevisiae* var. *ellipsoideus*
	Fuel	Agricultural wastes	*Saccharomyces cerevisiae*
Acetic Acid	Vinegar	Ethanol	*Acetobacter* (bacterium)
Lactic Acid	Cheese, yogurt	Milk	*Lactobacillus, Streptococcus* (bacteria)
	Rye bread	Grain, sugar	*Lactobacillus delbruckii* (bacterium)
	Sauerkraut	Cabbage	*Lactobacillus plantarum* (bacterium)
	Summer sausage	Meat	*Pediococcus* (bacterium)
Propionic Acid and Carbon Dioxide	Swiss cheese	Lactic acid	*Propionibacterium freudenreichii* (bacterium)
Acetone and Butanol	Pharmaceutical, industrial uses	Molasses	*Clostridium acetobutylicum* (bacterium)
Glycerol	Pharmaceutical, industrial uses	Molasses	*Saccharomyces cerevisiae*
Citric Acid	Flavoring	Molasses	*Aspergillus* (fungus)
Methane	Fuel	Acetic acid	*Methanosarcina* (bacterium)
Sorbose	Vitamin C (ascorbic acid)	Sorbitol	*Gluconobacter*

Different organisms recycle NAD^+ in different ways, resulting in a variety of fermentation end-products.

Respiration



After glycolysis, energy in pyruvate & NADH is used to produce much more ATP by respiration:

KREBS CYCLE

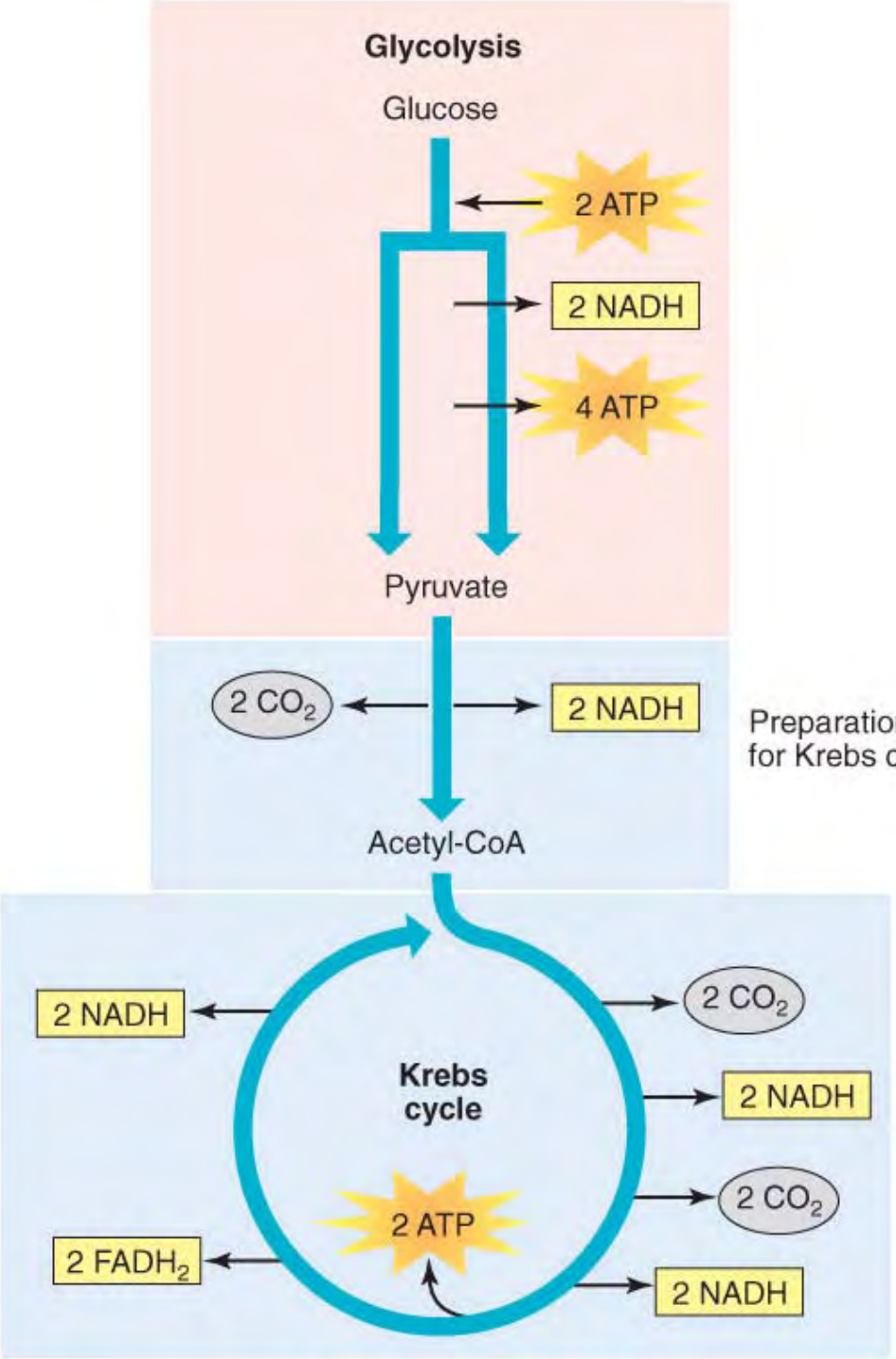
- breaks down pyruvate to 3 CO_2, energy captured as e^- by NADH & $FADH_2$

ELECTRON TRANSPORT

- e^- from NADH, $FADH_2$ used to produce H^+ gradient

CHEMIOSMOSIS

- H^+ gradient used to make ATP



The Krebs cycle

- **a cyclical metabolic pathway catalyzed by enzymes in the matrix of mitochondria**
- **requires 2-C <u>acetyl</u> groups connected to coenzyme A (acetyl-CoA)**

(3-C) pyruvate + CoA

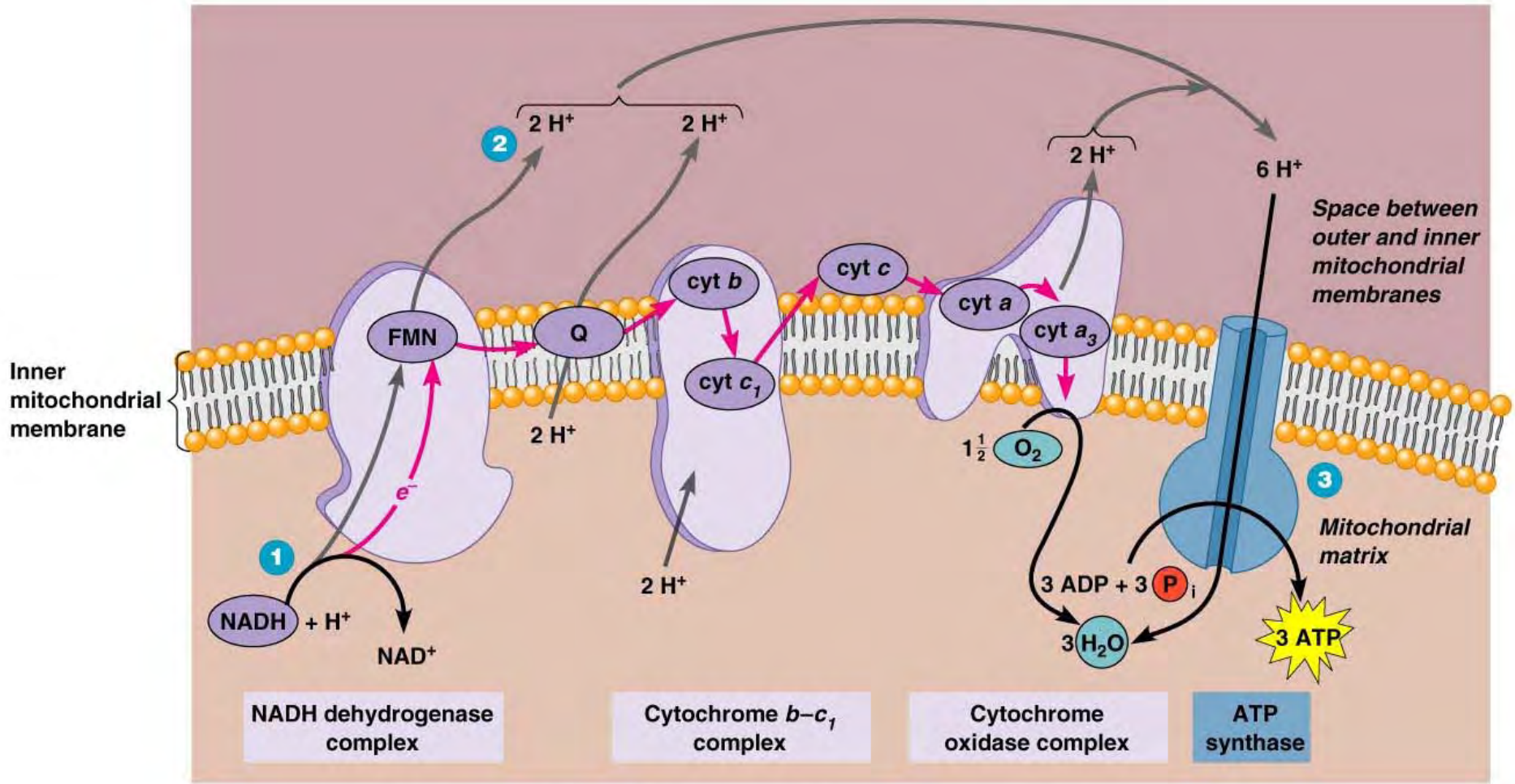
↓

(2-C) acetyl-CoA + CO_2

⇣

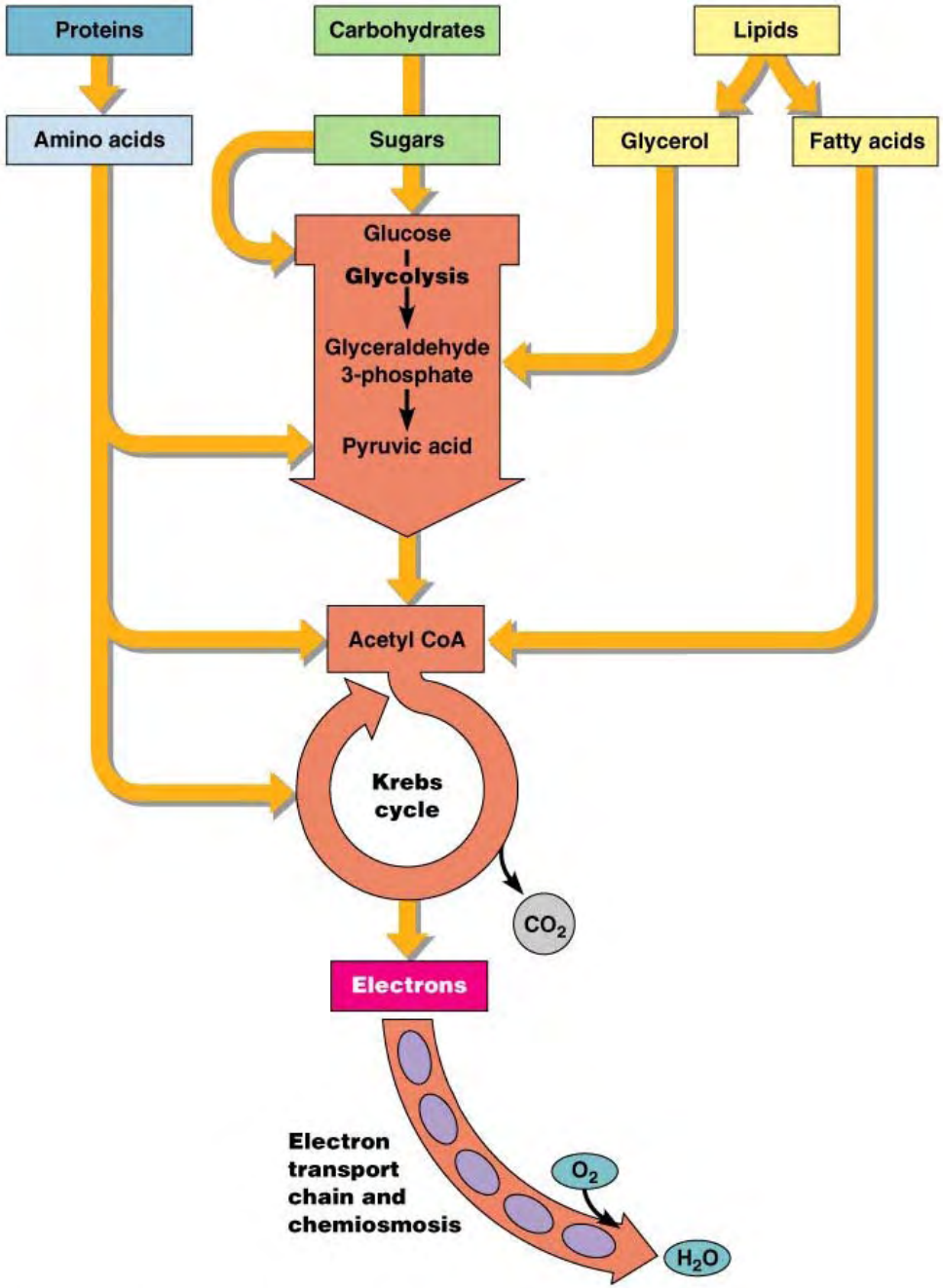
(Krebs cycle)

Electron Transport & Chemiosmosis



Occurs in the mitochondria of eukaryotes and at the plasma membrane of prokaryotes.

- **oxygen (O_2) is usually the <u>final electron acceptor</u>, but other molecules can play this role in *anaerobic* respiration**



Lipid & Protein Catabolism

Lipids and proteins can also be used as sources of energy to produce ATP

- **different amino acids enter glycolysis or the Krebs cycle at various stages**

- **fatty acids are broken down to acetyl groups & fed into the Krebs cycle**

Summary of ATP Production

TABLE 5.5	Aerobic Respiration, Anaerobic Respiration, and Fermentation Compared			
Energy-Producing Process	Growth Conditions	Final Hydrogen (Electron) Acceptor	Type of Phosphorylation Used to Generate ATP	ATP Molecules Produced per Glucose Molecule
Aerobic Respiration	Aerobic	Molecular oxygen (O_2)	Substrate-level and oxidative	36(eukaryotes) 38 (prokaryotes)
Anaerobic Respiration	Anaerobic	Usually an inorganic substance (such as NO_3^-, SO_4^{2-}, or CO_3^{2-}) but not molecular oxygen (O_2)	Substrate-level and oxidative	Variable (fewer than 38 but more than 2)
Fermentation	Aerobic or anaerobic	An organic molecule	Substrate-level	2

Obligate <u>anaerobes</u>:

- **fermentation or anaerobic respiration**

Obligate <u>aerobes</u>:

- **aerobic respiration (& brief periods of fermentation)**

<u>Facultative</u> anaerobes:

- **can survive via aerobic respiration OR fermentation**

3. Autotrophic Processes

All organisms depend on Autotrophs

Autotrophs can produce organic molecules from CO_2, an inorganic carbon source.

- **all heterotrophs require an organic source of carbon**
- **organic molecules, directly or indirectly, come from autotrophs**

The source of energy for autotrophic processes can be:

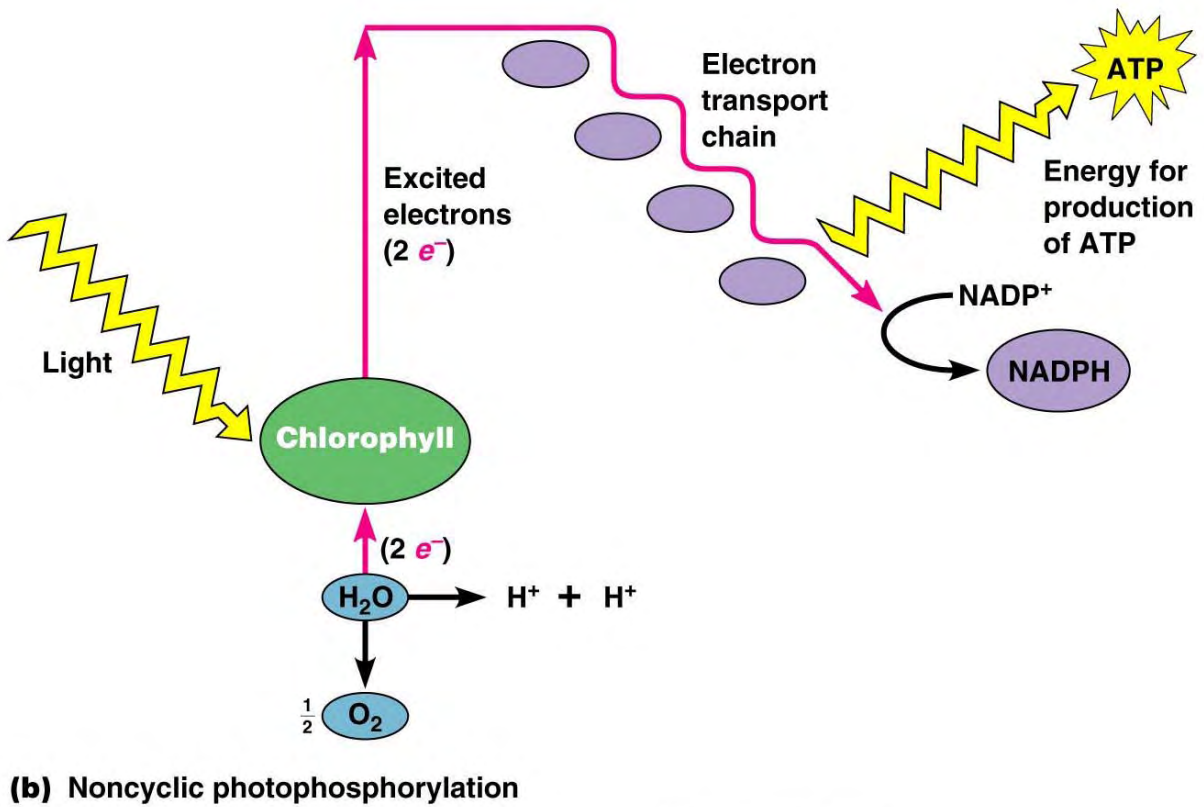
LIGHT: photoautotrophs that carry out photosynthesis

CHEMICAL: chemoautotrophs that use various molecules as a source of high energy e^-

Light Reactions of Photosynthesis

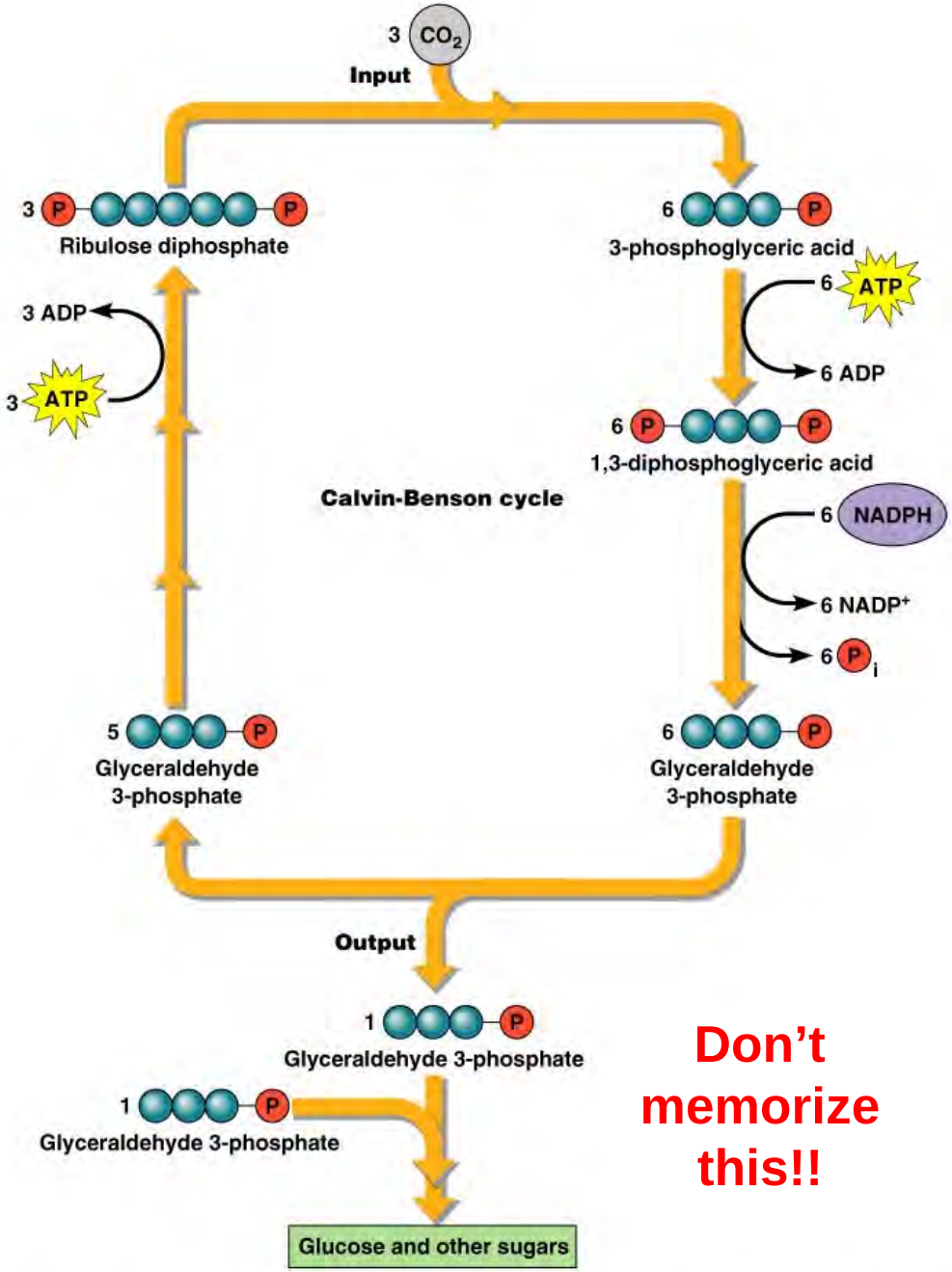
Electrons (from H_2O) energized by sunlight:

- fuel the synthesis of ATP through electron transport & chemiosmosis (much like respiration)
- ultimately reduce $NADP^+$ to NADPH
- ATP & NADPH provide energy to fuel production of sugars in the "dark" reactions



(b) Noncyclic photophosphorylation

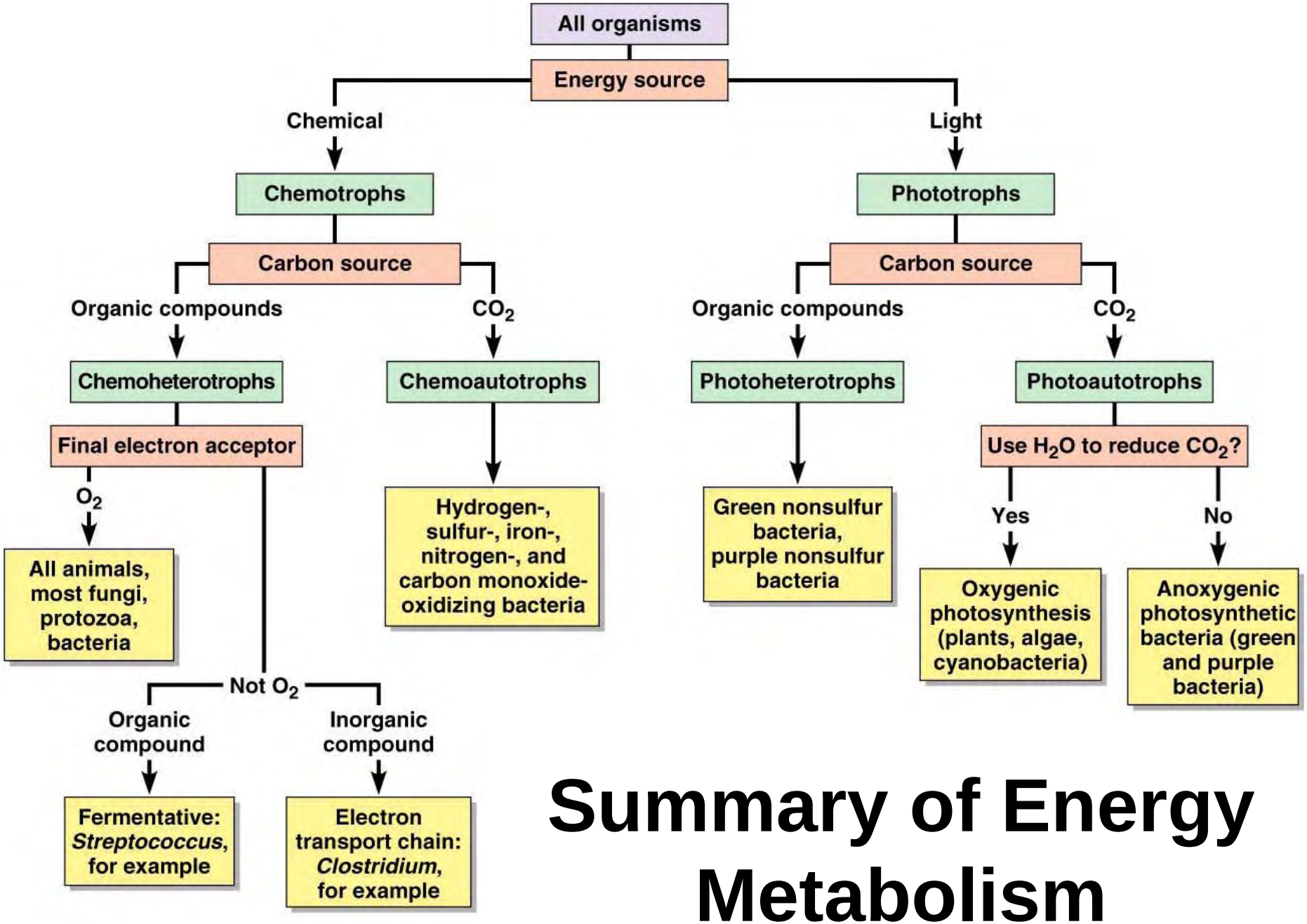
"Dark" Reactions



Involves an anabolic pathway known as the Calvin-Benson cycle:

- **endergonic reactions of this pathway are fueled by ATP & NADPH from the "light" reactions**
- **resulting sugars can be used as a source of energy or to build other organic molecules**

Don't memorize this!!



Summary of Energy Metabolism

Key Terms for Chapter 5

- catabolic, anabolic; exergonic, endergonic
- activation energy, substrate, active site
- cofactor vs coenzyme, denatured
- feedback inhibition: competitive vs allosteric
- glycolysis, fermentation, respiration
- Krebs cycle, electron transport, chemiosmosis
- oxidation vs reduction
- Calvin-Benson cycle

Relevant Chapter Questions

rvw: 1-7, 18, 20-22 MC: 1, 4-10