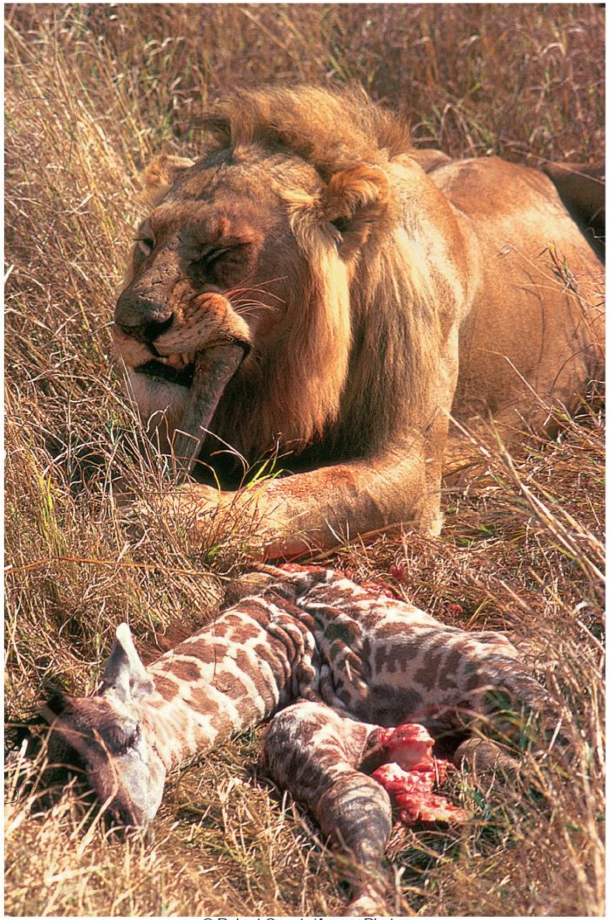
Energy and Metabolism

Chapter 6



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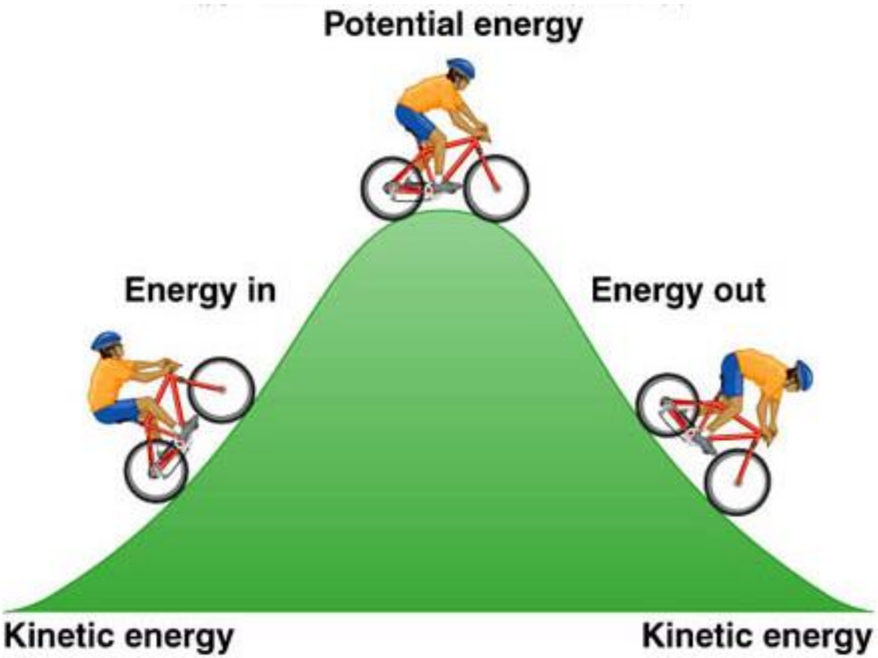
Flow of Energy

- **Thermodynamics**
  - Branch of chemistry concerned with energy changes
- Cells and biological processes are governed by the laws of physics and chemistry

"Now, in the *second* law of thermodynamics . . ."

http://vinodwadhawan.blogspot.com/2011/12/5-can-you-unscramble-egg.html

- Energy – capacity to do work
  - Two states
    1. **Kinetic** – energy of motion
    2. **Potential** – stored energy
  - Many forms – mechanical, heat, sound, electric current, light, or radioactivity

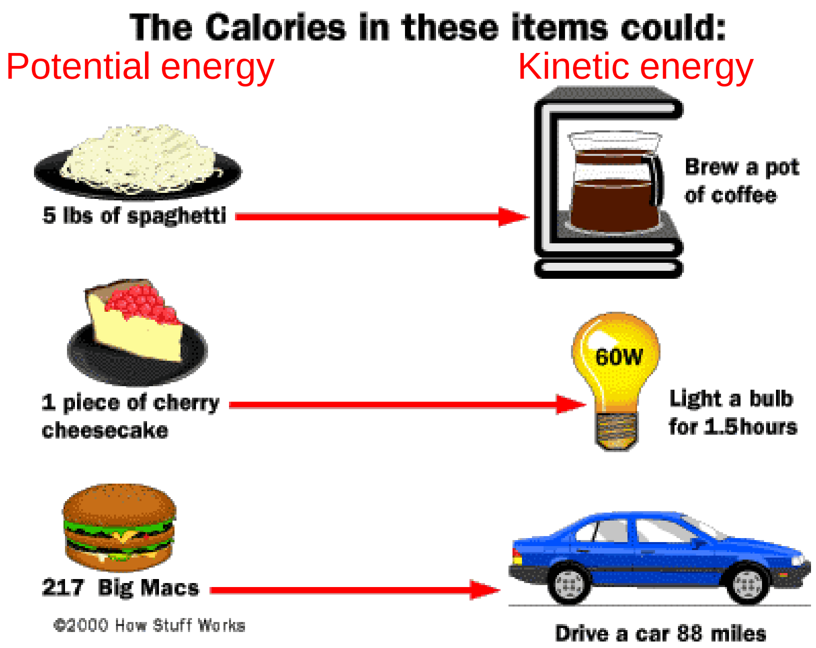


http://www.petervaldivia.com/technology/energy/

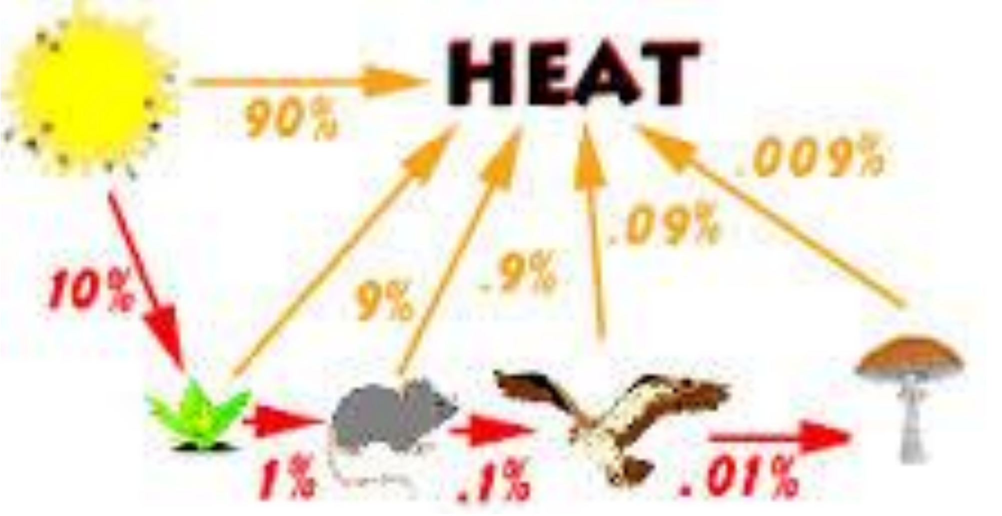
a. **Potential energy**

b. **Kinetic energy**

- Energy – capacity to do work
  - Heat is the most convenient way of measuring energy
    - 1 calorie = heat required to raise 1 gram of water 1ºC
    - calorie or Calorie (= 1000 calories)?



- Energy flows into the biological world from the sun
  - Photosynthetic organisms capture this energy
  - Stored as potential energy in chemical bonds

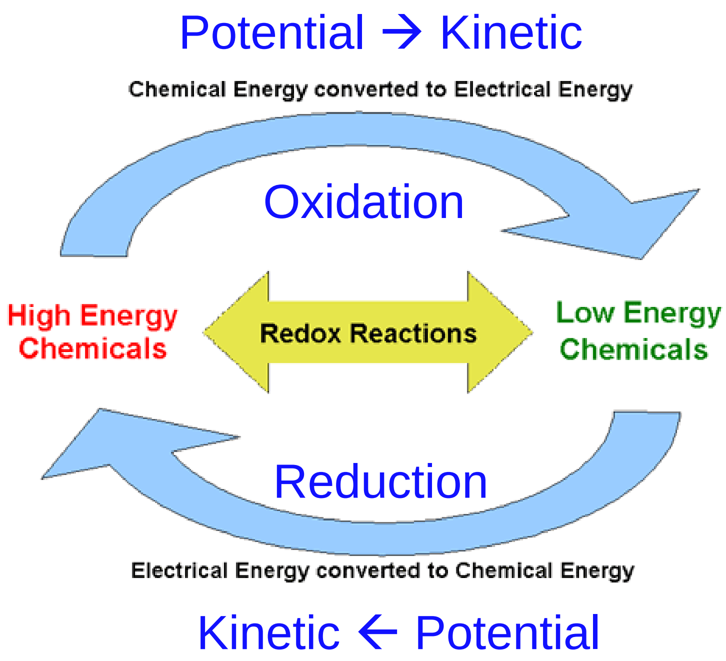


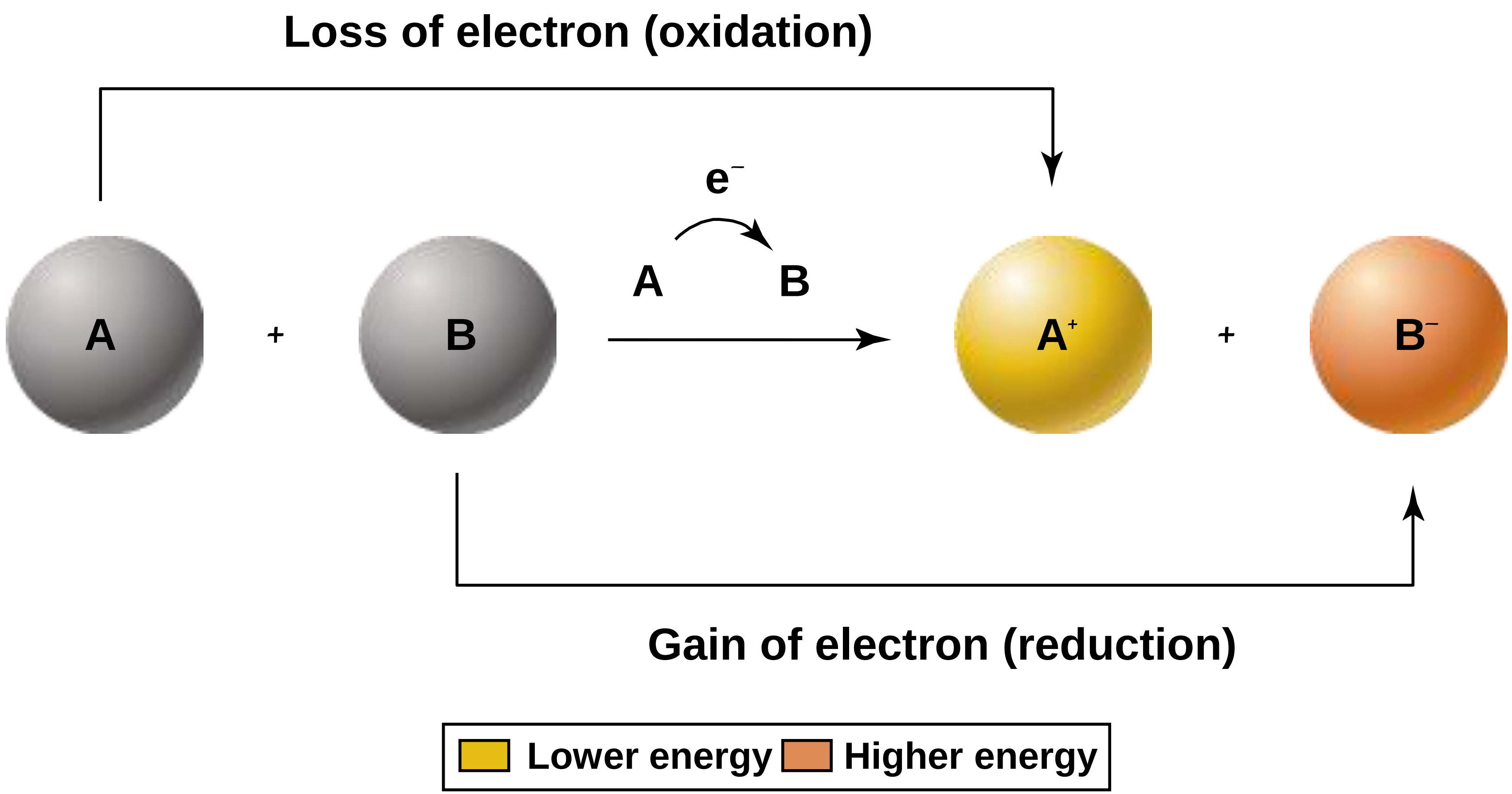
http://utahscience.oremjr.alpine.k12.ut.us/sciber99/8th/energy/sciber/ecosys.htm http://www.green-planet-solar-energy.com/oxidation-reduction-reactions.html

Redox reactions

- **Oxidation**
  - Atom or molecule loses an electron
- **Reduction**
  - Atom or molecule gains an electron
  - Higher level of energy than oxidized form
- **Oxidation-reduction reactions (redox)**
  - Reactions always paired

OILRIG

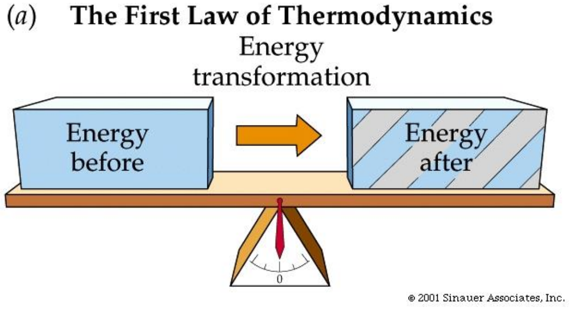



Loss of electron (oxidation)
e⁻
A
B
A
+
B
A⁺
+
B⁻
Gain of electron (reduction)
Lower energy
Higher energy

Laws of thermodynamics

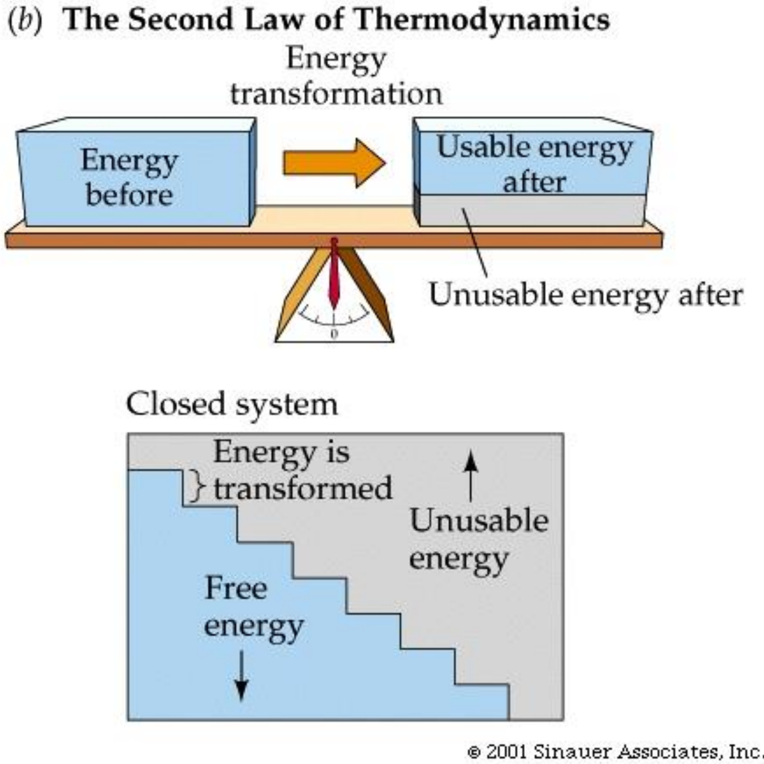
- **First law of thermodynamics**
  - <u>*Energy cannot be created nor destroyed*</u>
  - Energy can only change from one form to another
  - Total amount of energy in the universe remains constant
  - During each conversion, some energy is lost as heat

Conservation of Energy

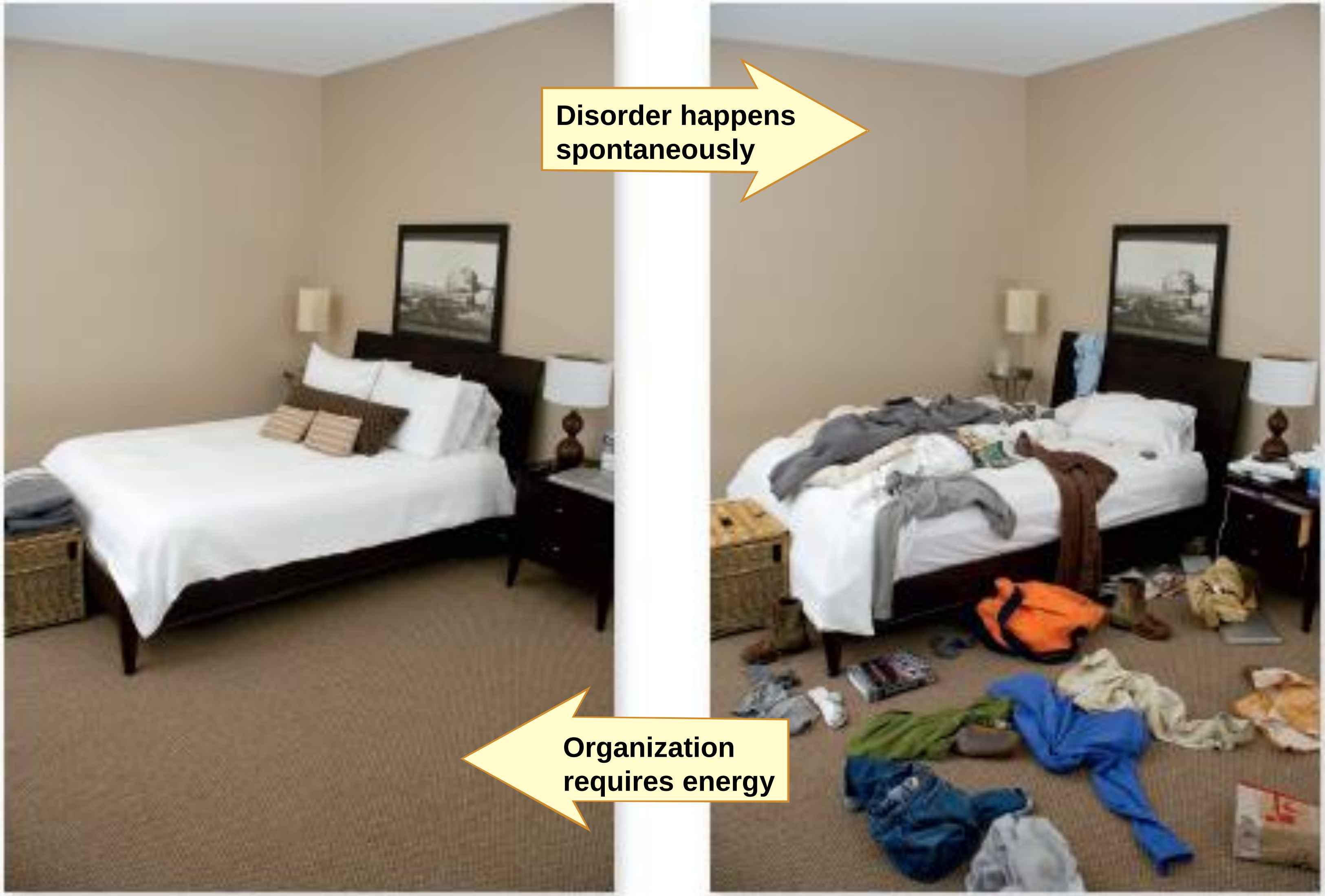


http://biology200.gsu.edu/houghton/2107%20%2713/lecture18.html

- **Second law of thermodynamics**
  - ***<u>Entropy (disorder</u>)*** *<u>is continuously increasing</u>*
  - Energy transformations proceed spontaneously to convert matter from a more ordered/less stable form to a less ordered/ more stable form
  - Heat is lost from all reactions



http://biology200.gsu.edu/houghton/2107%20%2713/lecture18.html



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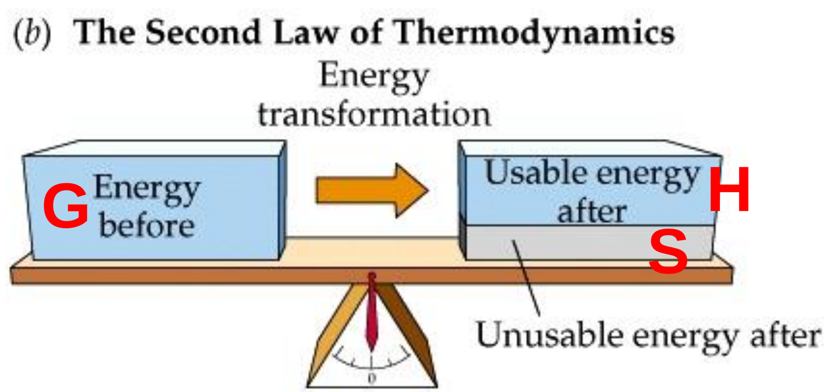
Free energy

- G = Energy available to do work (usable energy)
- **G = H – TS**
  - H = **enthalpy**, energy in a molecule’s chemical bonds
  - T = absolute temperature
  - S = **entropy**, unavailable energy (lost, unusable)



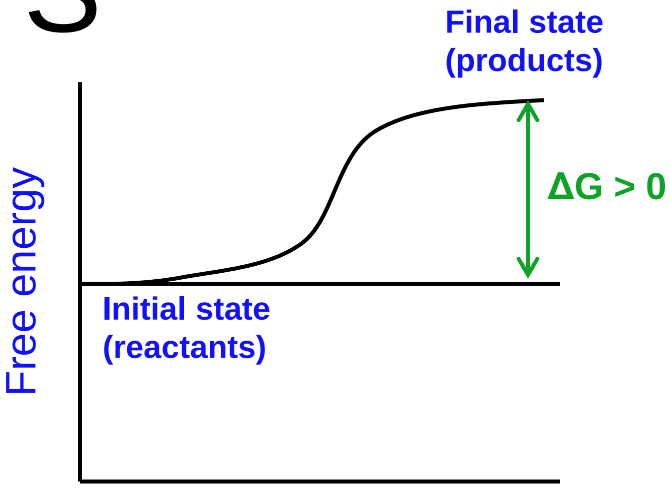
G = H – TS

http://biology200.gsu.edu/houghton/2107%20%2713/lecture18.html

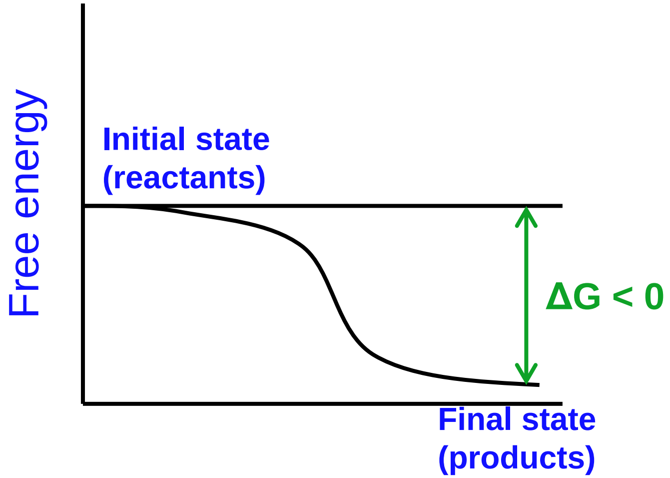
$\Delta G = \Delta H - TS$

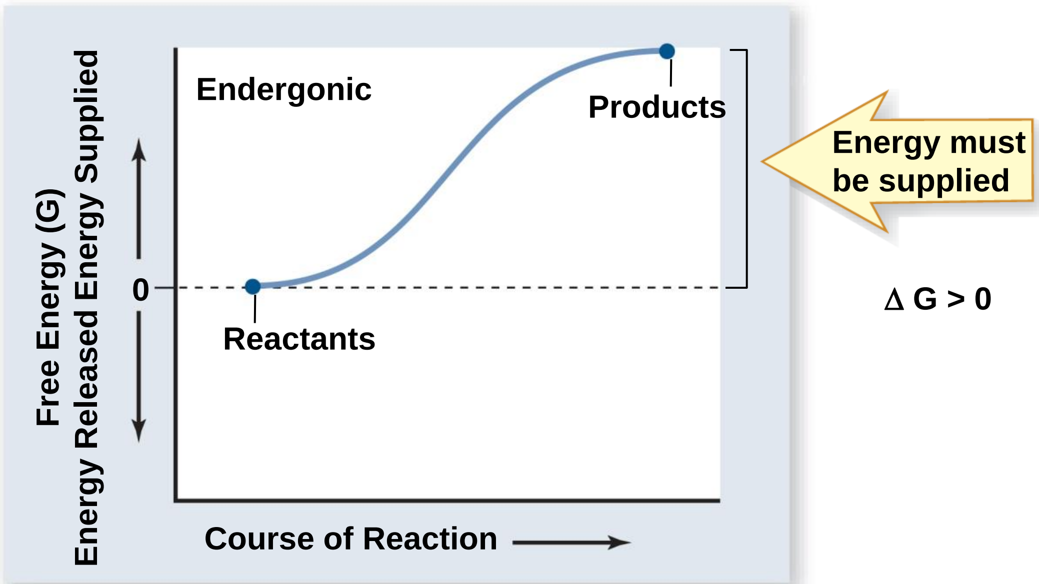
- ΔG = change in free energy

- Positive ΔG
  - Products have more free energy than reactants
  - H is higher or S is lower
  - **Endergonic**
  - Not spontaneous, *<u>requires input of energy</u>*

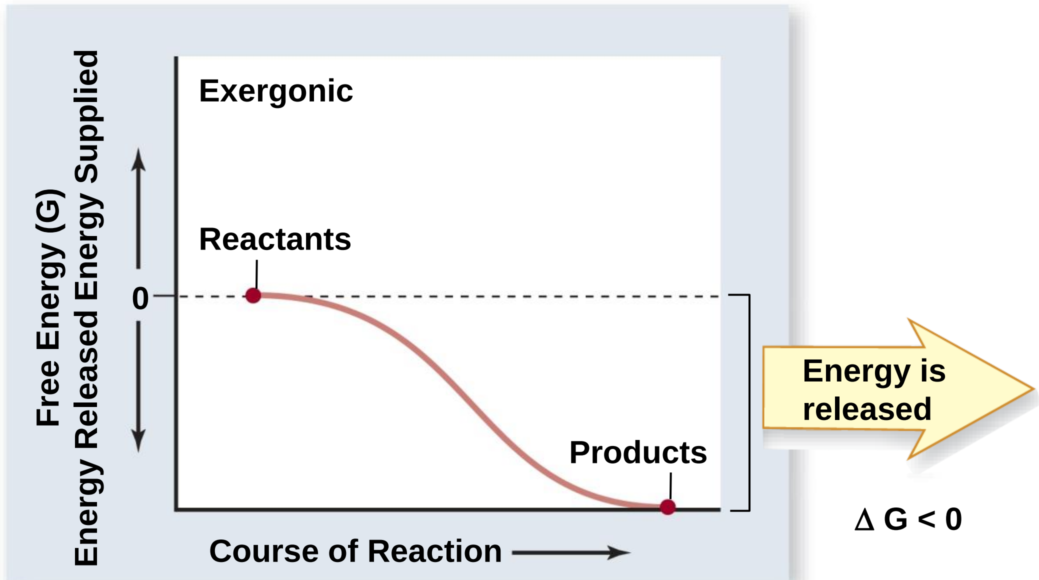


- Negative ΔG
  - Products have less free energy than reactants
  - H is lower or S is higher or both
  - **Exergonic**
  - Spontaneous (may not be instantaneous),
  - *<u>Releases energy</u>*




Endergonic
Products
Reactants
0
Free Energy (G)
Energy Released Energy Supplied
Course of Reaction
Energy must be supplied
Δ G > 0

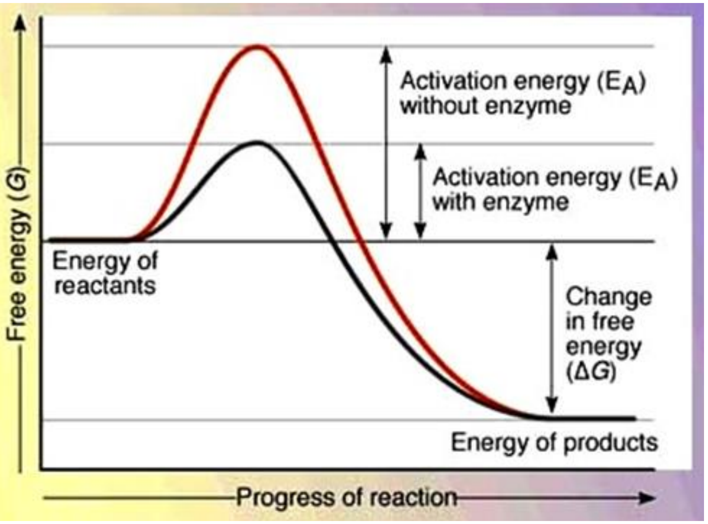
a.


Exergonic
Reactants
Products
0
Free Energy (G)
Energy Released Energy Supplied
Course of Reaction
Energy is released
Δ G < 0

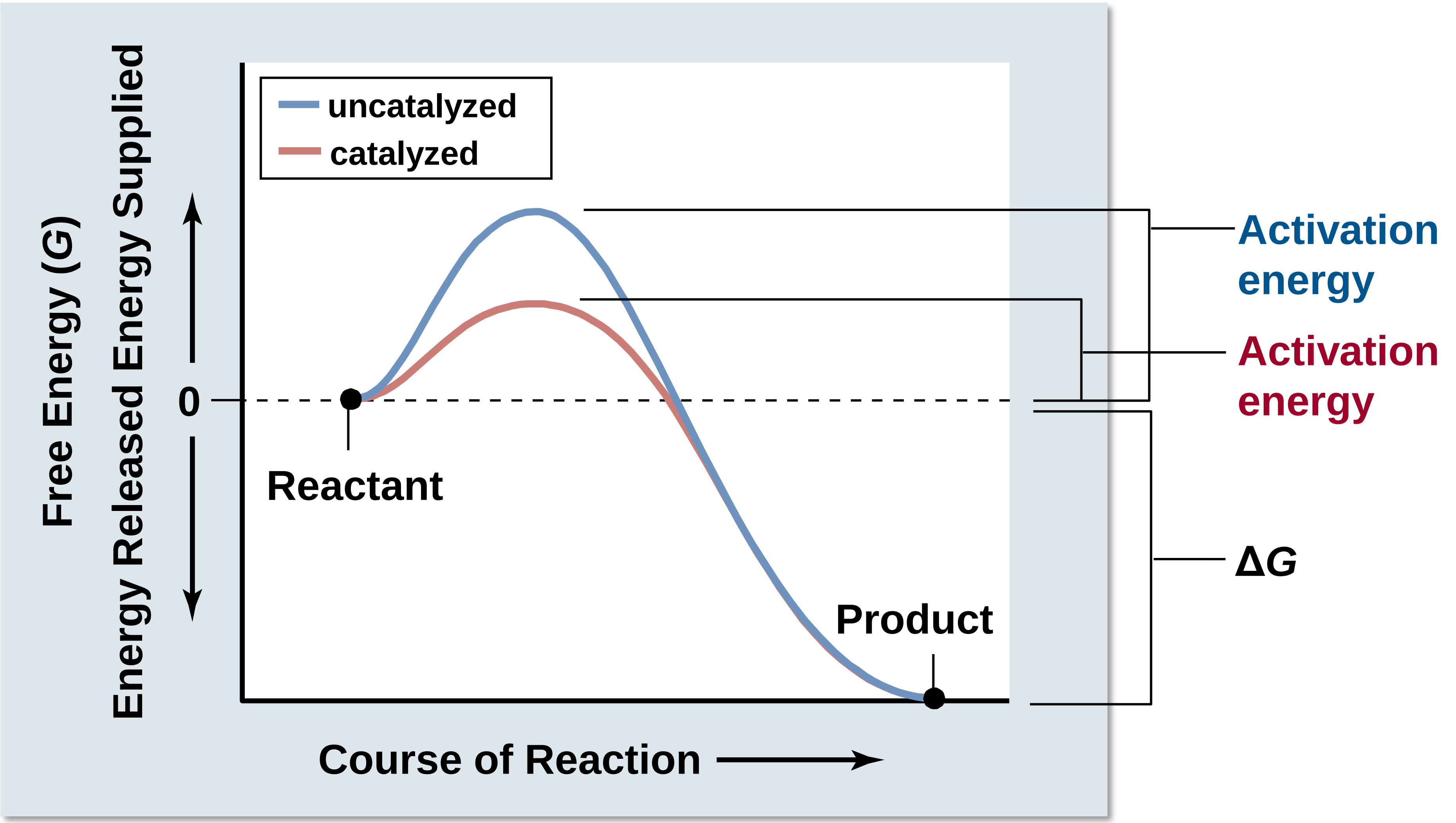
b.

Activation energy

- Extra energy (**E_A**) required to destabilize existing bonds and initiate a chemical reaction
- Exergonic reaction's rate depends on the activation energy required
  - Larger activation energy proceeds more slowly
- Rate can be increased 2 ways
  1. Increasing energy of reacting molecules (heating)
  2. Lowering activation energy



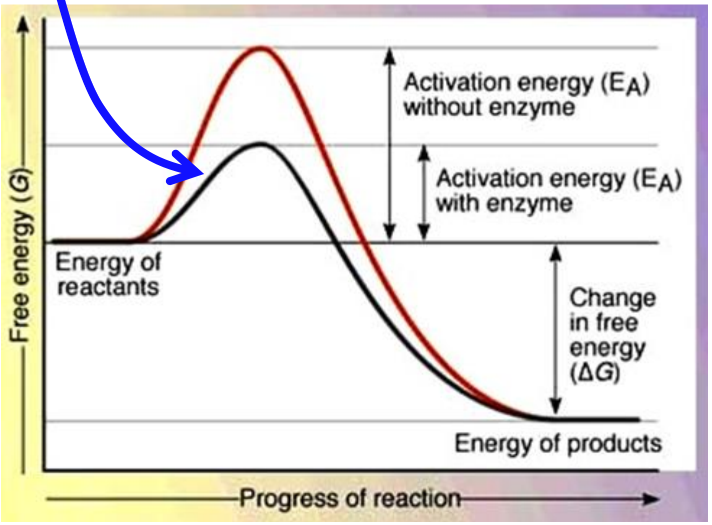
http://www4.nau.edu/meteorite/Meteorite/Book-GlossaryA.html



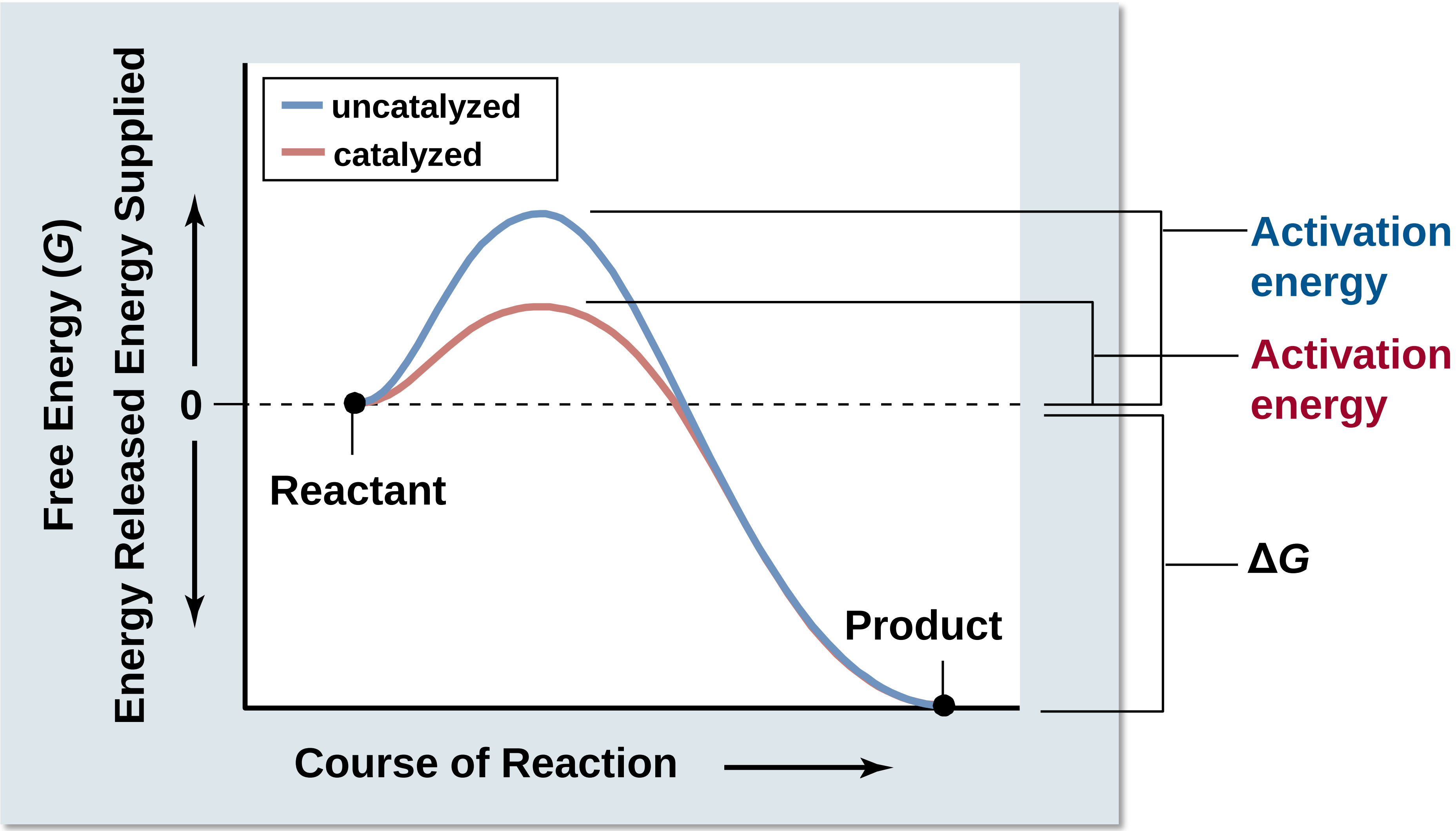
uncatalyzed
catalyzed
Free Energy (G)
Energy Released Energy Supplied
0
Reactant
Product
Course of Reaction
Activation energy
Activation energy
ΔG

Catalysts

- Substances that influence chemical bonds in a way that *lowers activation energy*
- Cannot violate laws of thermodynamics
  - Cannot make an endergonic reaction spontaneous
- Do not alter the proportion of reactant turned into product



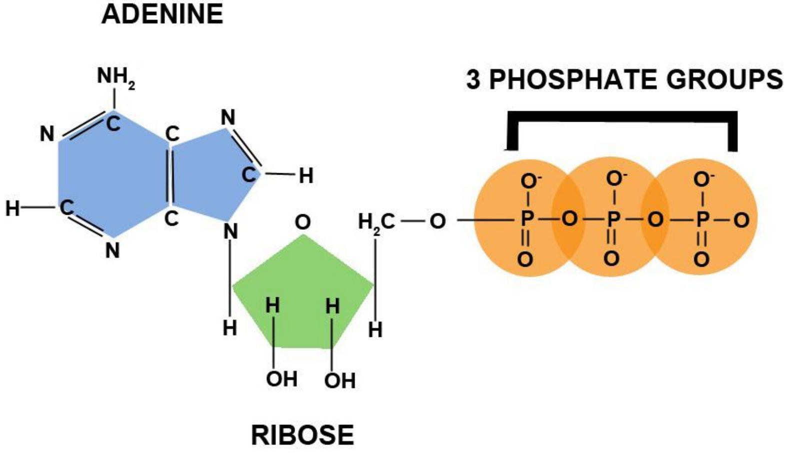
http://www4.nau.edu/meteorite/Meteorite/Book-GlossaryA.html



uncatalyzed
catalyzed
Free Energy (G)
Energy Released Energy Supplied
0
Reactant
Product
Course of Reaction
Activation energy
Activation energy
ΔG

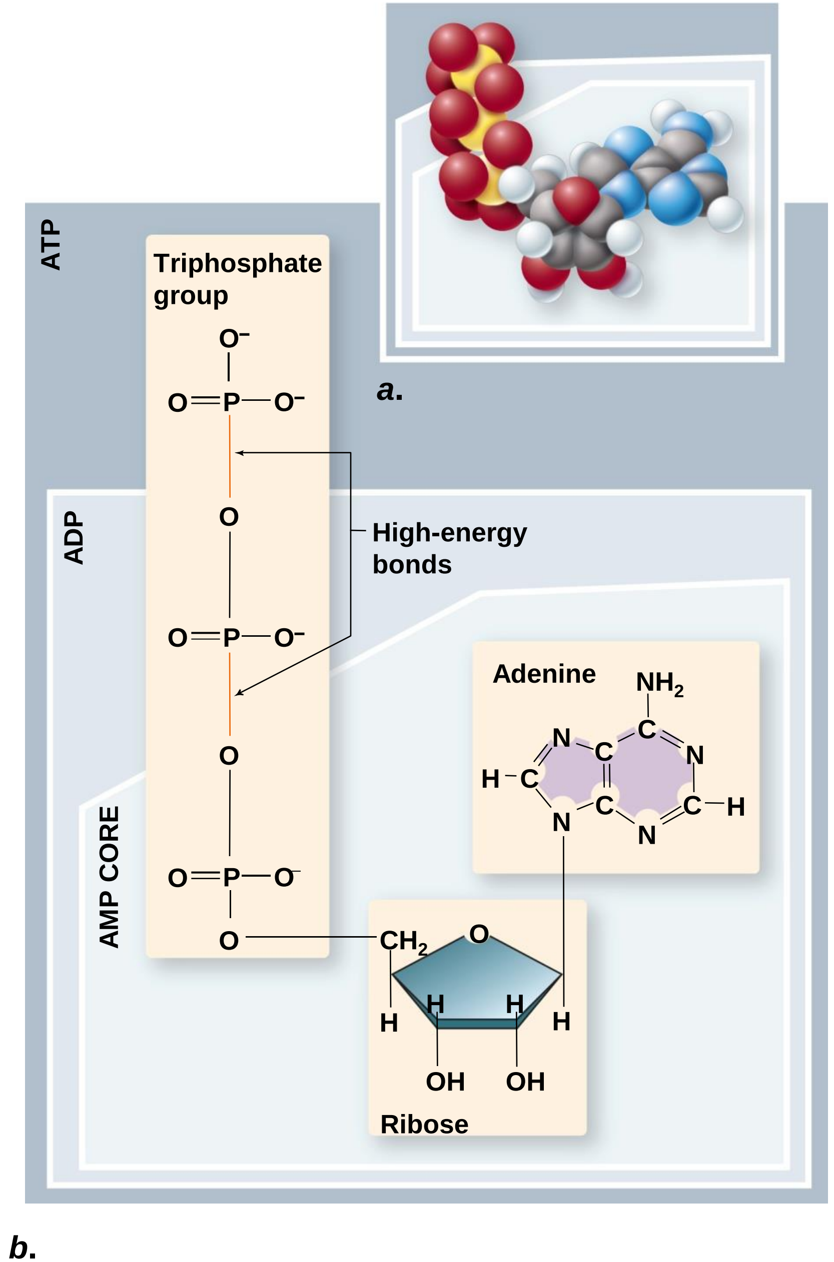
ATP

- **Adenosine triphosphate**
  - Chief "energy currency" all cells use
  - Composed of…
    - **Ribose** – 5 carbon sugar
    - **Adenine**
    - Chain of 3 phosphates
      - Key to energy storage
      - Bonds are unstable



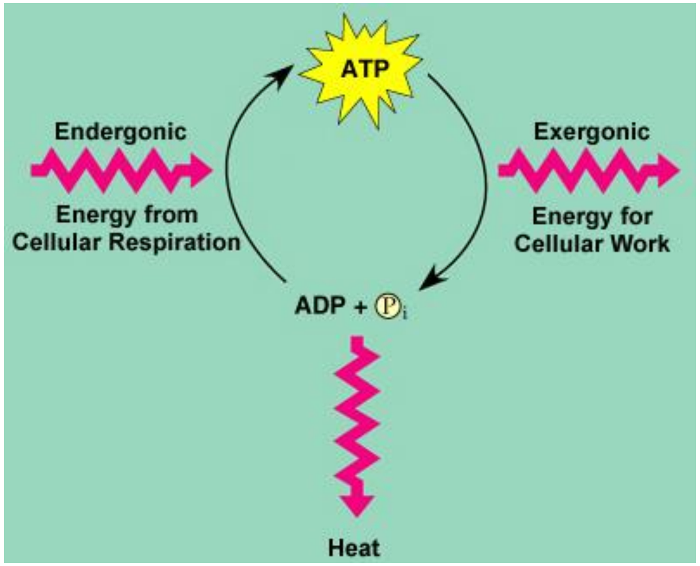
- **ADP** – 2 phosphates
- **AMP** – 1 phosphate – lowest energy form

http://chemwiki.ucdavis.edu/Physical_Chemistry/Thermodynamics/Case_Studies/Case_Study%3A_Thermodynamics_of_ATP

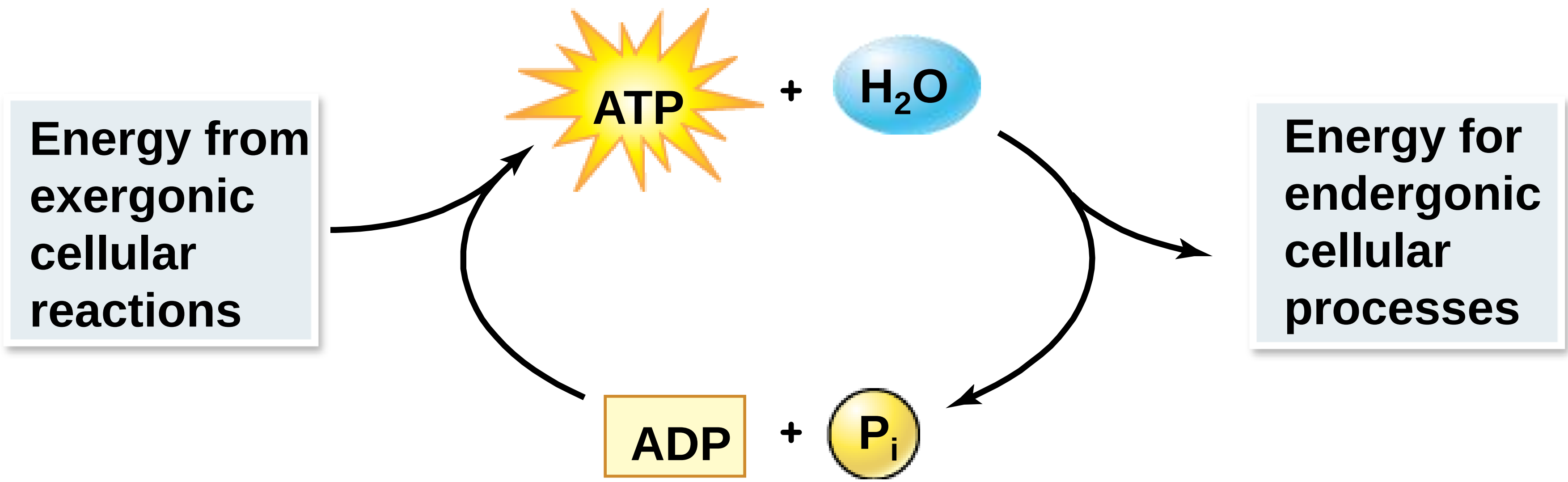

a.
ATP
ADP
AMP CORE
Triphosphate group
O⁻
O═P—O⁻
O
O═P—O⁻
O
O═P—O⁻
O
High-energy bonds
Adenine
NH2
N
C
N
H—C
C
C
N
N
C—H
CH2
O
H
H
H
H
OH
OH
Ribose
b.

ATP cycle

- Exergonic ATP hydrolysis drives coupled endergonic reactions
  - Coupled reaction results in net –ΔG (exergonic & spontaneous)

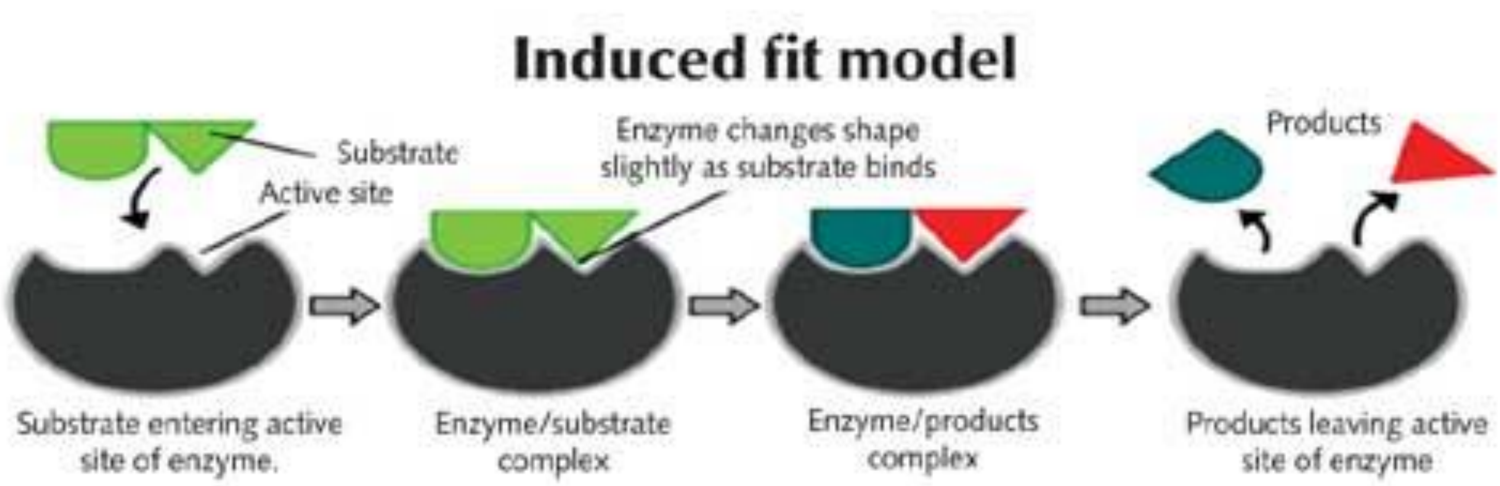


- ATP not suitable for long-term energy storage
  - Fats and carbohydrates better
  - Cells store only a few seconds worth of ATP


Energy from exergonic cellular reactions
ATP
+
H_2O
Energy for endergonic cellular processes
ADP
+
P_i

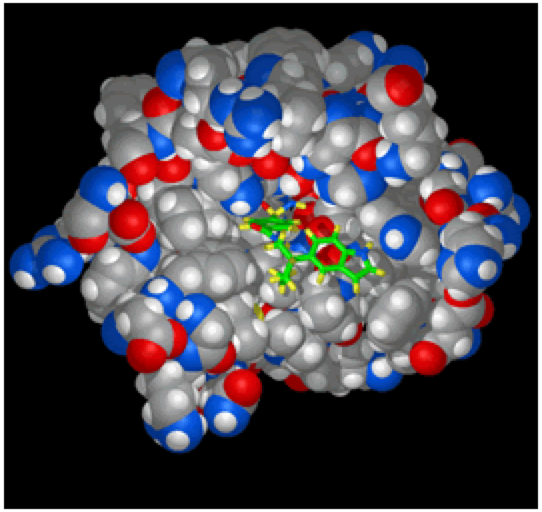
Enzymes: Biological Catalysts

- Most enzymes are protein
  - Some are RNA
- Shape of enzyme stabilizes a temporary association between substrates
- Enzyme not changed or consumed in reaction

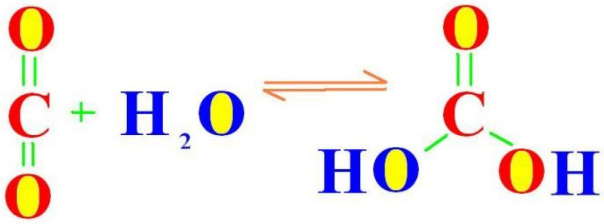


http://www.ptj.com.pk/Web-2010/04-10/Muhammad-Ayaz-Shaikh.htm

Enzymes: Biological Catalysts



- Example: Carbonic anhydrase (enzyme used to maintain blood pH)
  - 200 molecules of carbonic acid per hour made without enzyme
  - 600,000 molecules formed per second with enzyme

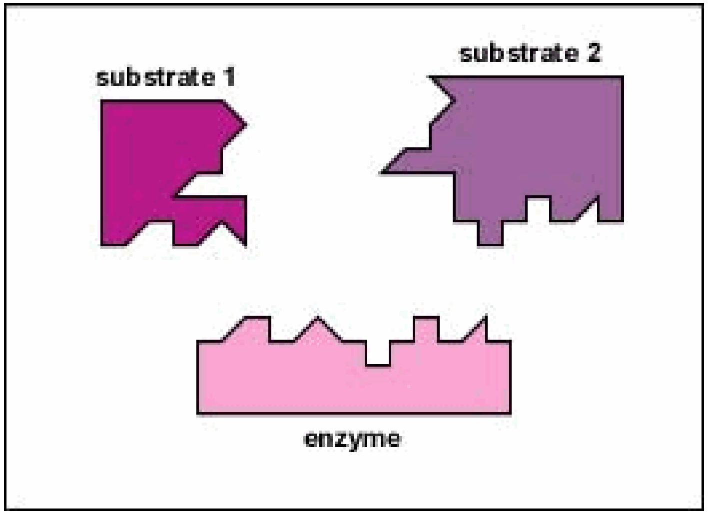


- Most enzymes end in *-ase*

http://faculty.ccbcmd.edu/courses/bio141/lecguide/unit6/genetics/proteins/enzymes/enzsub.html

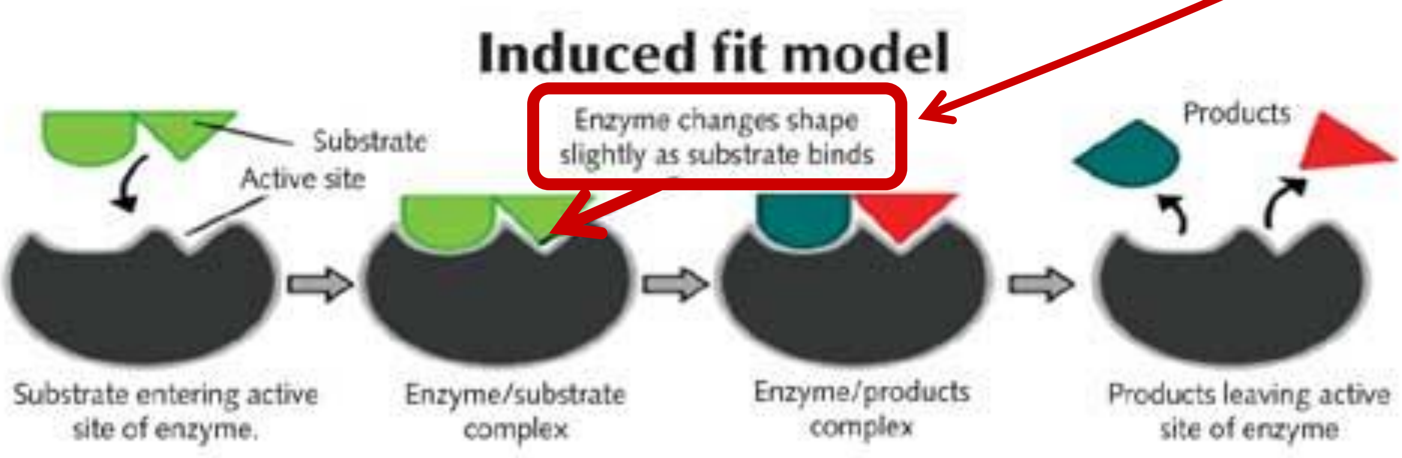
Active site

- Pockets or clefts for substrate binding
- Precise fit of substrate into active site
- Forms **enzyme–substrate complex**

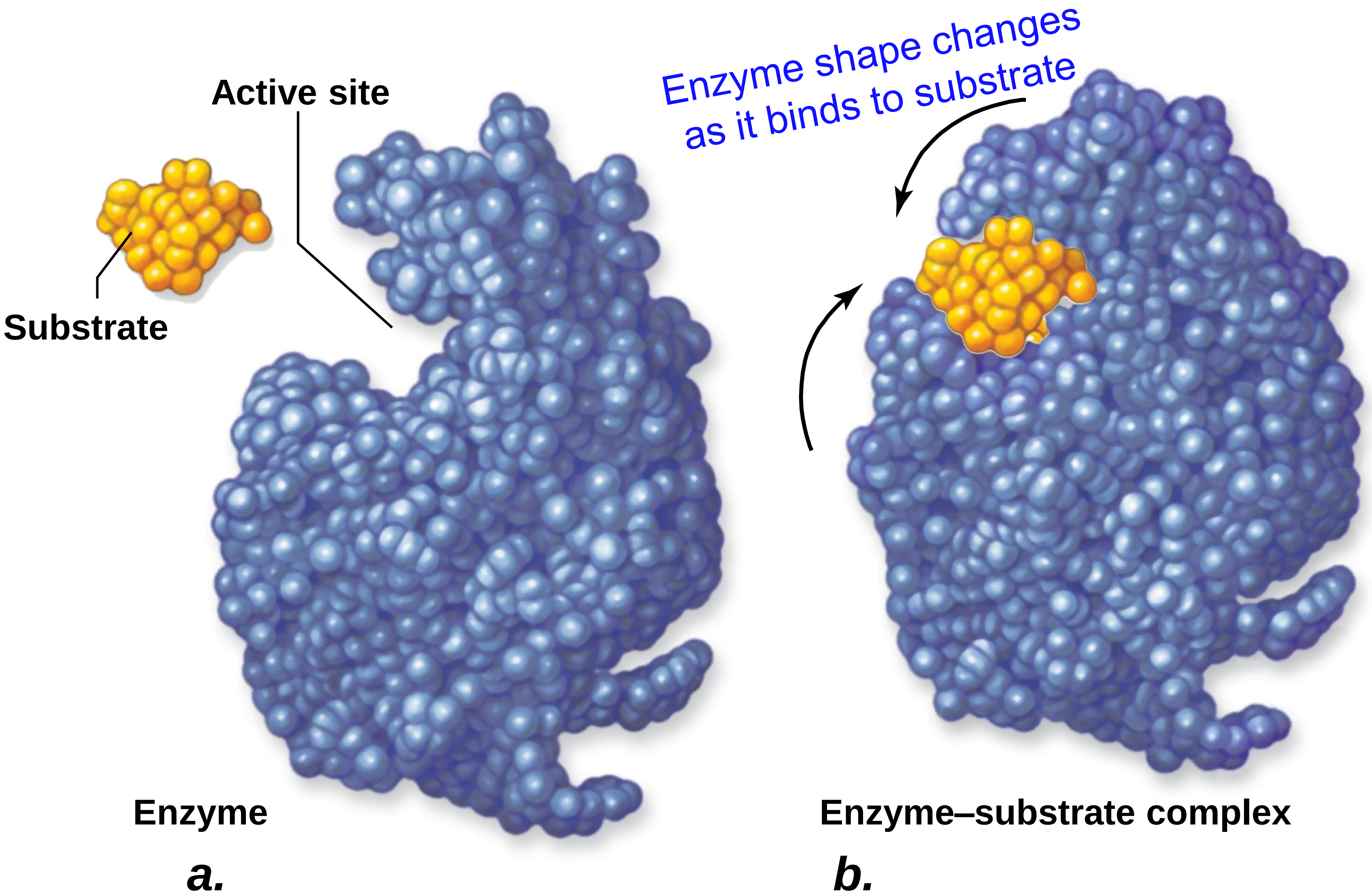


Active site

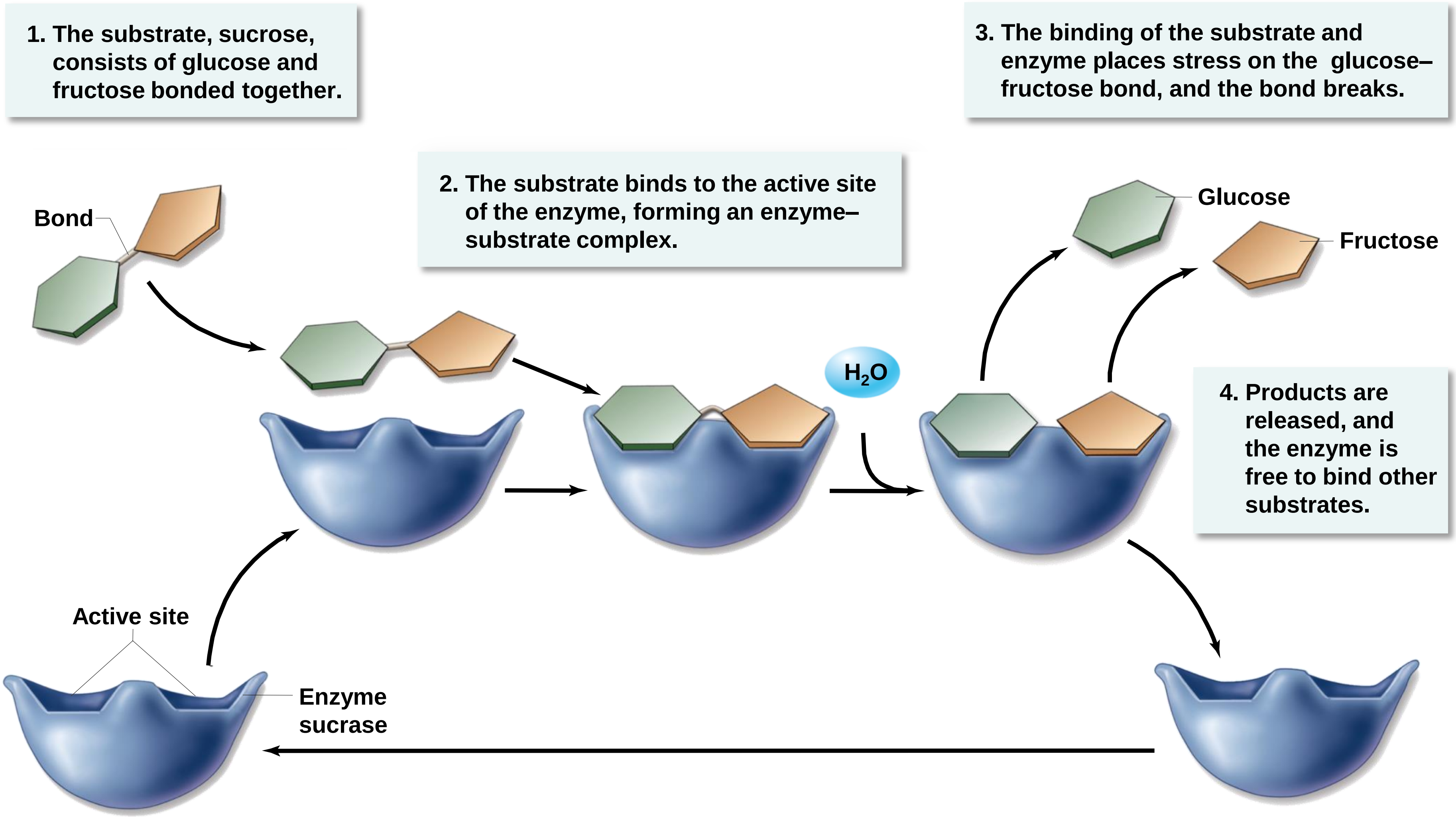
- As the **enzyme–substrate complex** forms…
  - The enzyme molecule changes shape slightly (**Induced fit**) → …
  - Applies stress to distort particular bond to lower activation energy to speed reaction



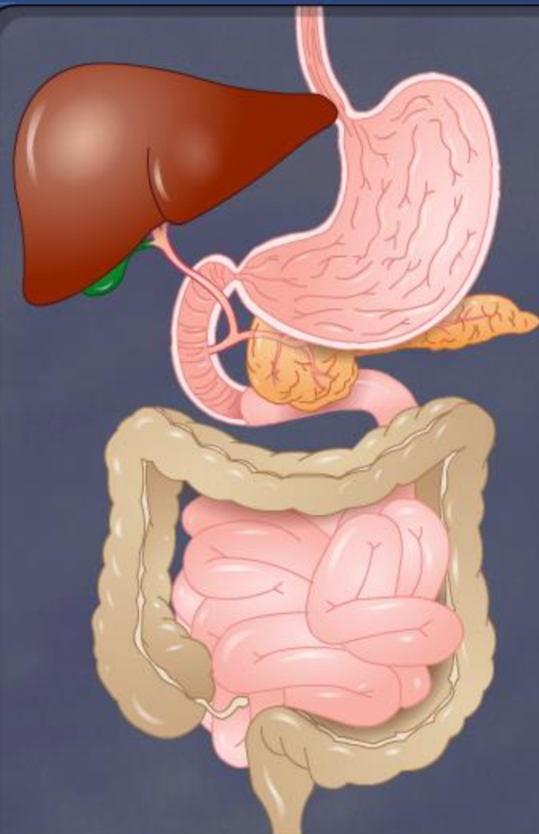
http://www.ptj.com.pk/Web-2010/04-10/Muhammad-Ayaz-Shaikh.htm


Active site
Substrate
Enzyme shape changes
as it binds to substrate
Enzyme
Enzyme–substrate complex
a.
b.

Enzyme shape changes as it binds to substrate



Enzyme Action and the Hydrolysis of Sucrose



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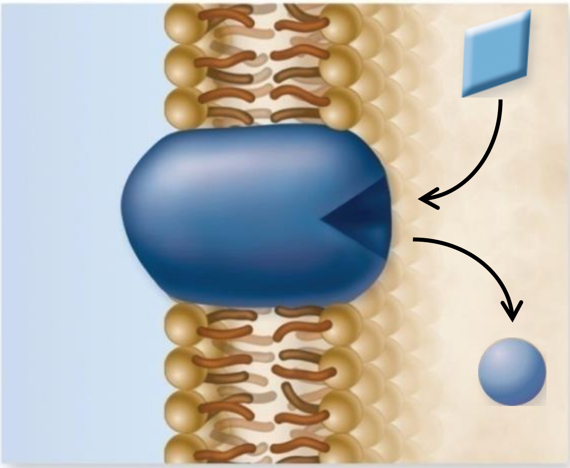
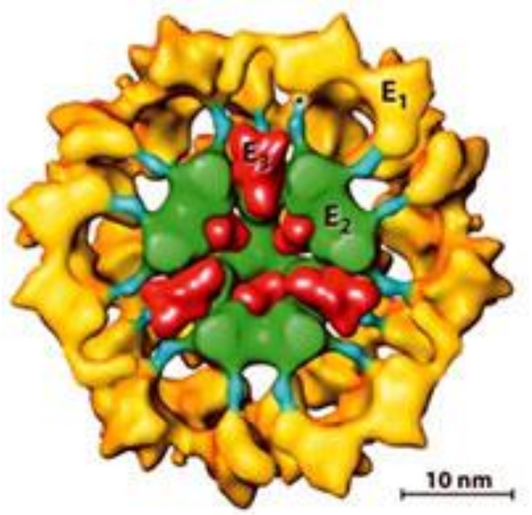
An example of how enzymes function in the body is from the enzyme sucrase. Sucrase resides on the surface of the microvilli on the intestinal epithelial (mucosal) cell surfaces.

- Enzymes may be suspended in the cytoplasm or attached to cell membranes and organelles



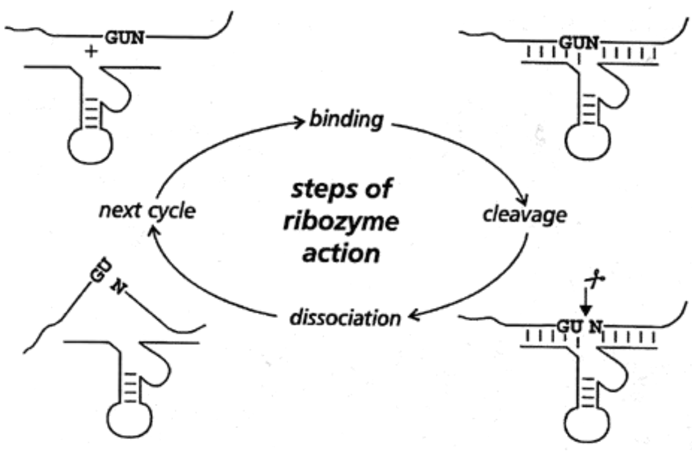
- **Multienzyme complexes** – subunits work together to form molecular machine
  - Product can be delivered easily to next enzyme
  - Unwanted side reactions prevented
  - All reactions can be controlled as a unit



http://msb.bio.uni-goettingen.de/SFB860/Projects_b.html

Nonprotein enzymes

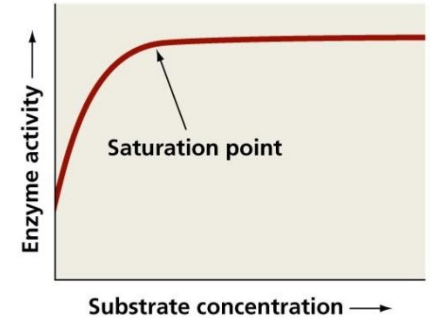
- **Ribozymes**
  - 1981 discovery that certain reactions catalyzed in cells by RNA molecule itself
  - Two kinds
    1. **Intramolecular catalysis** – catalyze reaction on RNA molecule itself
    2. **Intermolecular catalysis** – RNA acts on another molecule



http://chemistry.gsu.edu/faculty/Huang/ribozyme.htm

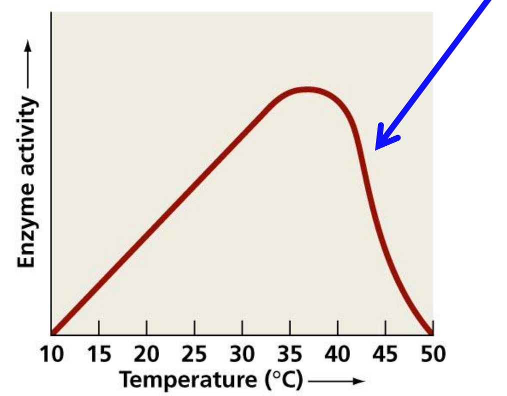
Enzyme function

- Rate of enzyme-catalyzed reaction *depends on concentrations of substrate and enzyme* (c)
- Any chemical or physical condition that affects the enzyme’s three-dimensional shape can change rate…
  – Optimum temperature (a)
  – Optimum pH (b)

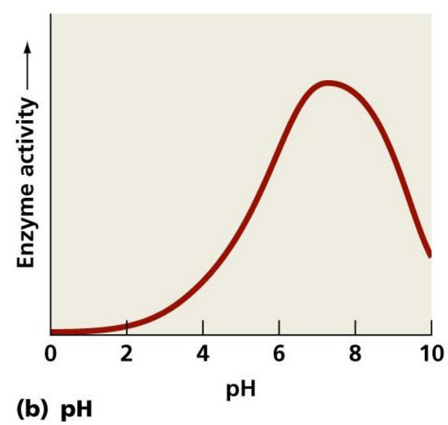


(c) Substrate concentration

What is happening here??



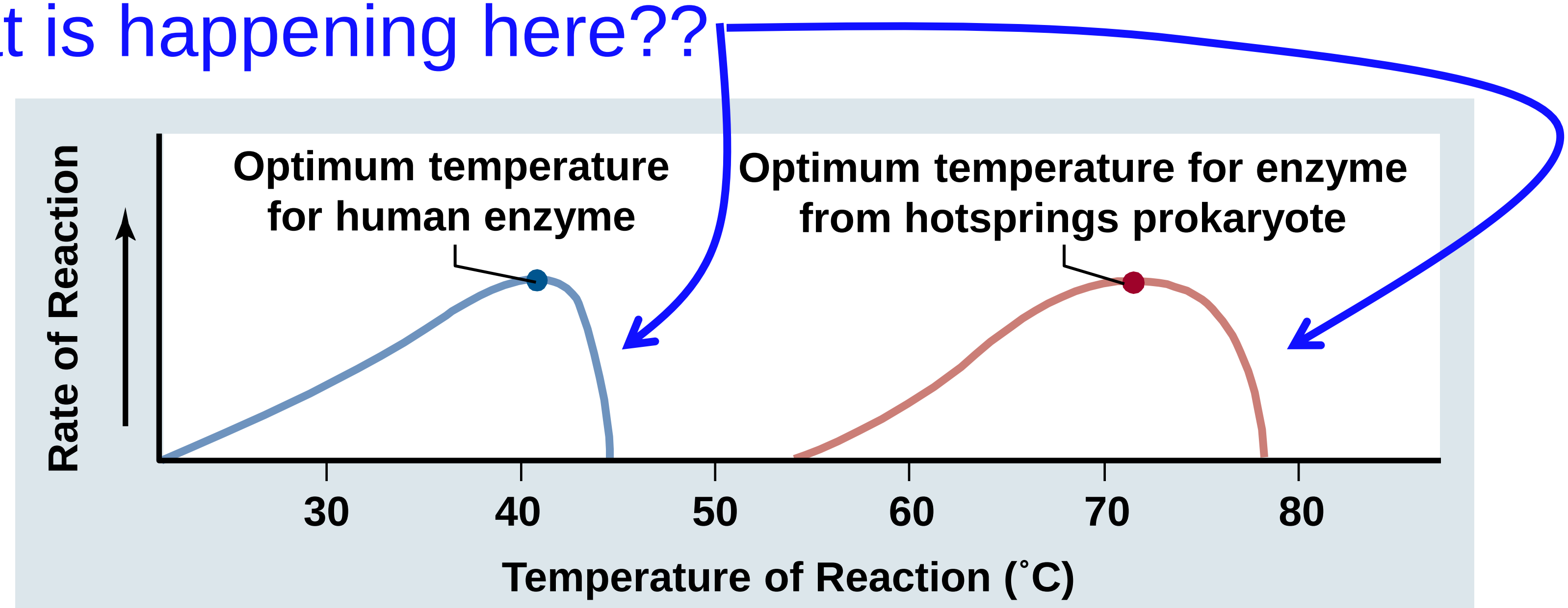
(a) Temperature



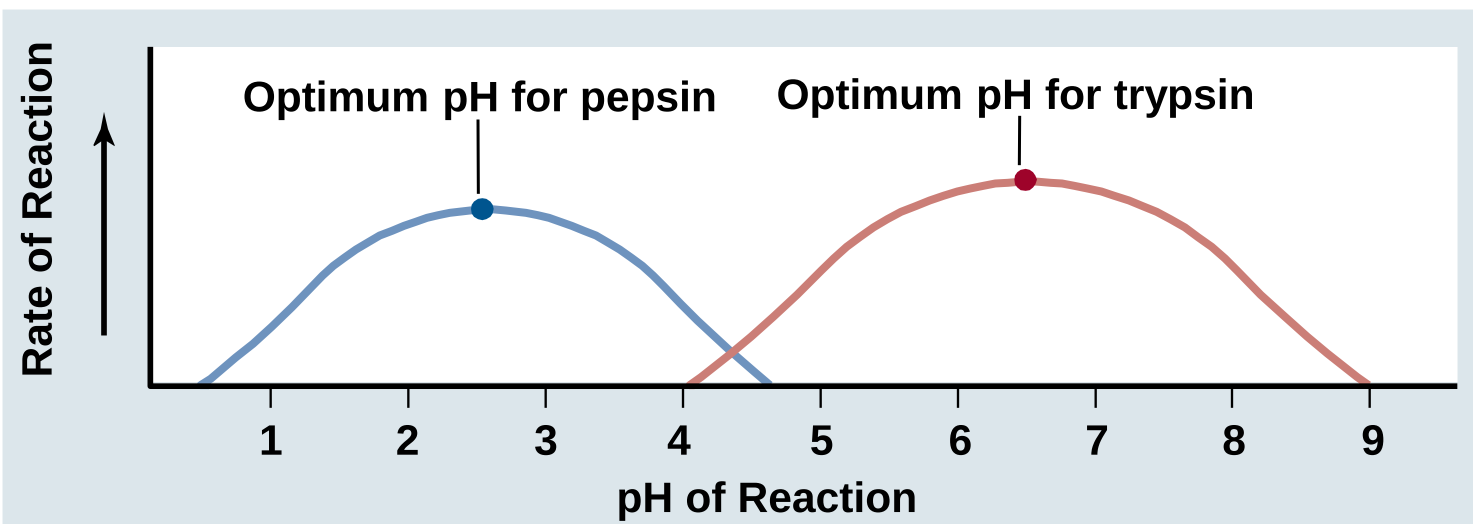
(b) pH

http://academic.pgcc.edu/~kroberts/Lecture/Chapter%205/enzymes.html

What is happening here??



a.

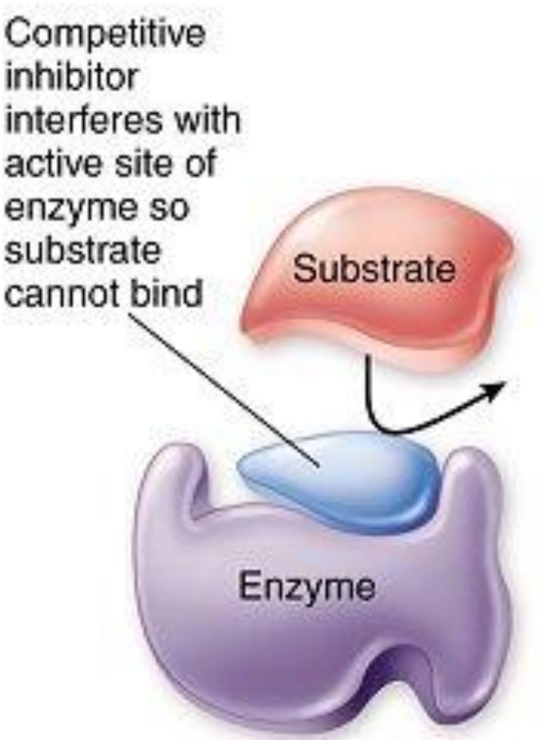


b.

Inhibitors

- **Inhibitor** – substance that binds to enzyme and decreases its activity

- **Competitive inhibitor**
  - Competes with substrate for active site
  - *<u>Physically blocks active site</u>*
  - Typically reversible

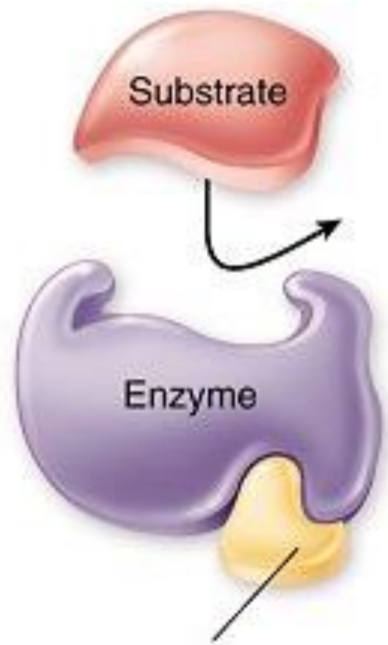


(a) Competitive inhibition

http://biochemanics.wordpress.com/tag/reversible-inhibitors/

Inhibitors

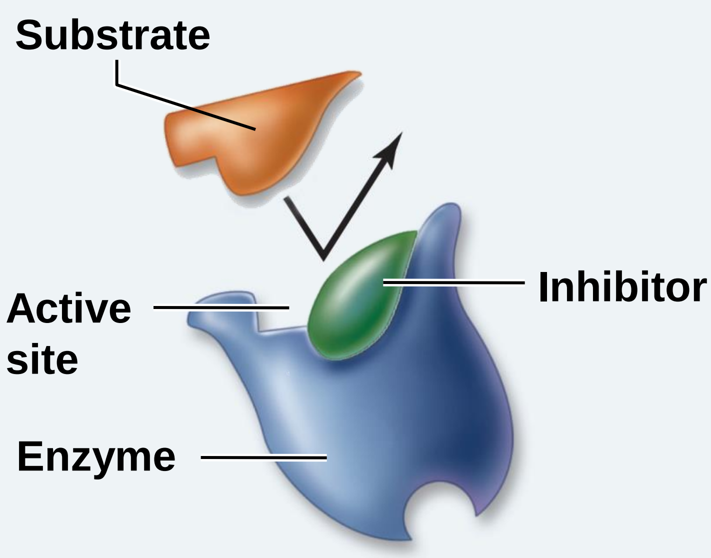
- **Noncompetitive inhibitor**
  - *<u>Binds to enzyme at a site other than active site</u>* (**allosteric site**)
  - Causes shape change that makes enzyme unable to bind substrate
  - Maybe irreversible (toxin) or reversible (allosteric regulation)



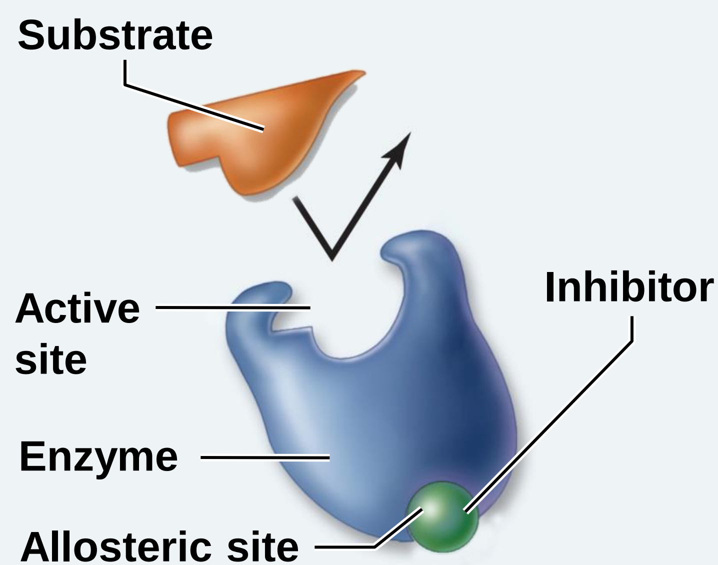
Noncompetitive inhibitor changes shape of enzyme so it cannot bind to substrate

(b) Noncompetitive inhibition

http://biochemanics.wordpress.com/tag/reversible-inhibitors/



Competitive inhibitor interferes with active site of enzyme so substrate cannot bind



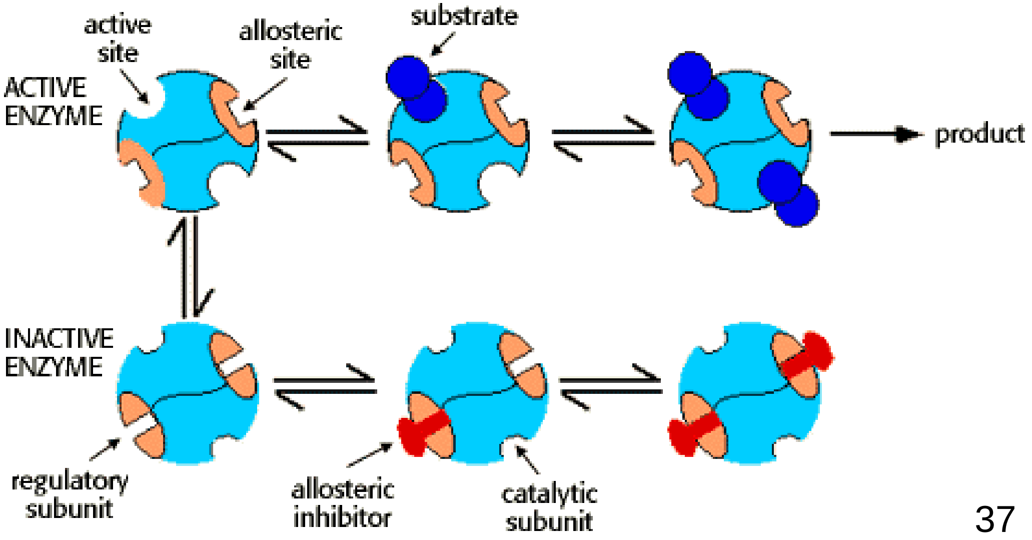
Noncompetitive inhibitor changes shape of enzyme so it cannot bind to substrate

***a*. Competitive inhibition**

***b*. Noncompetitive inhibition**

Allosteric Enzymes

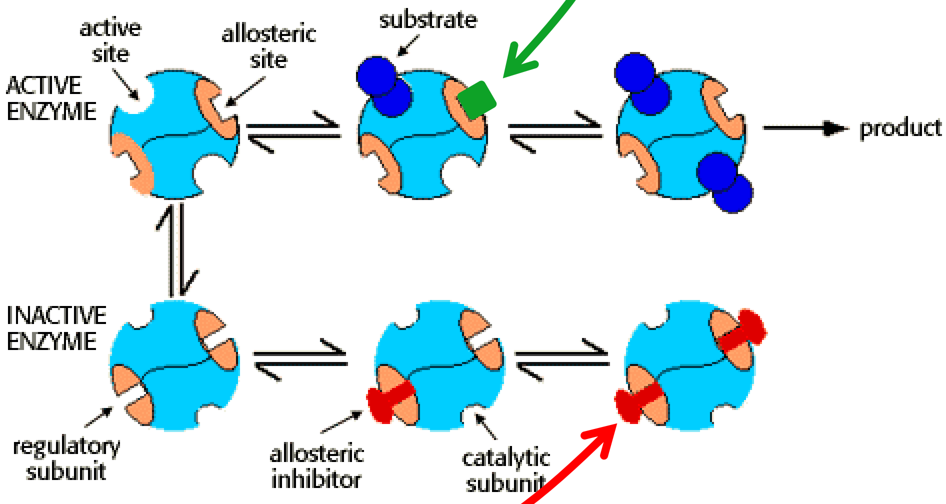
- **Allosteric enzymes** – enzymes exist in active and inactive forms
- Most *noncompetitive inhibitors* bind to allosteric site – chemical on/off switch



http://www.biology.arizona.edu/biochemistry/problem_sets/energy_enzymes_catalysis/03t.html

Allosteric Enzymes

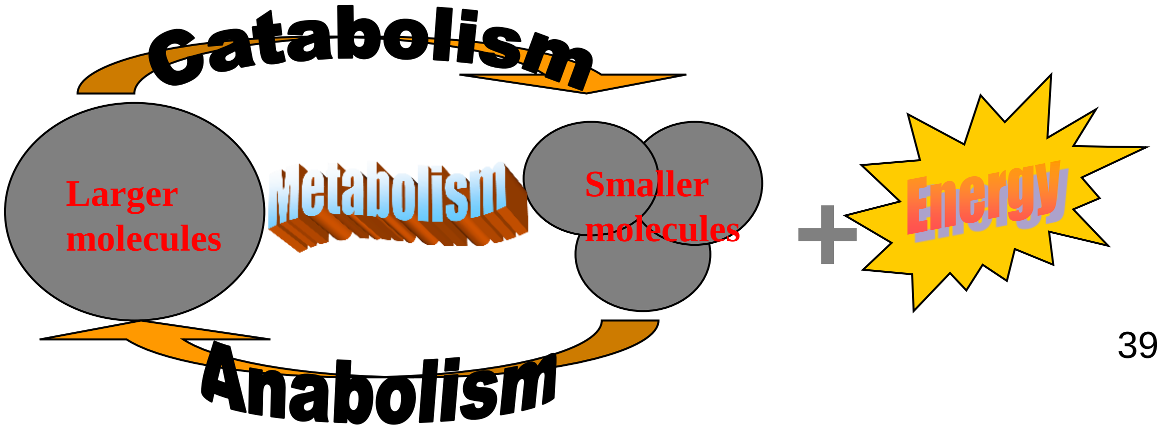
- **Allosteric inhibitor** – binds to allosteric site and reduces enzyme activity
- **Allosteric activator** – binds to allosteric site and increases enzyme activity



http://www.biology.arizona.edu/biochemistry/problem_sets/energy_enzymes_catalysis/03t.html

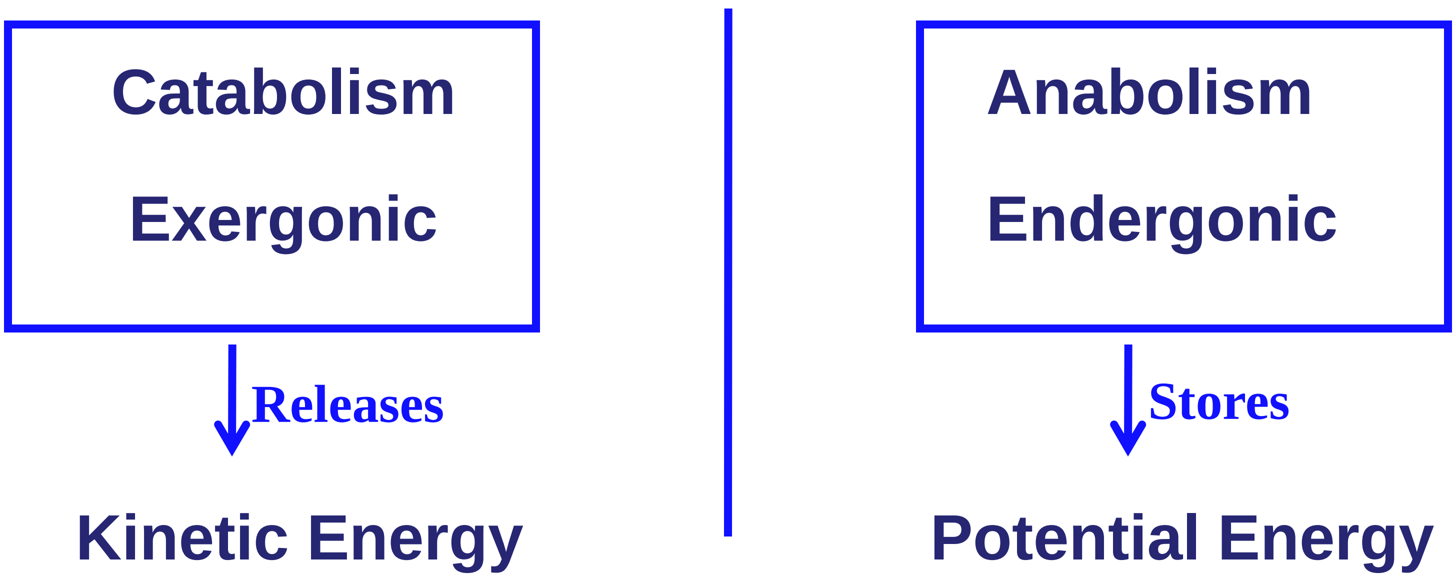
Metabolism

- Total of all chemical reactions carried out by an organism
  - **Anabolic reactions/anabolism**
    - Expend energy to build molecules
    - *Anabolic steroids = build muscle*
  - **Catabolic reactions/catabolism**
    - Harvest energy by breaking down molecules
    - *Starvation = breaks down muscle*



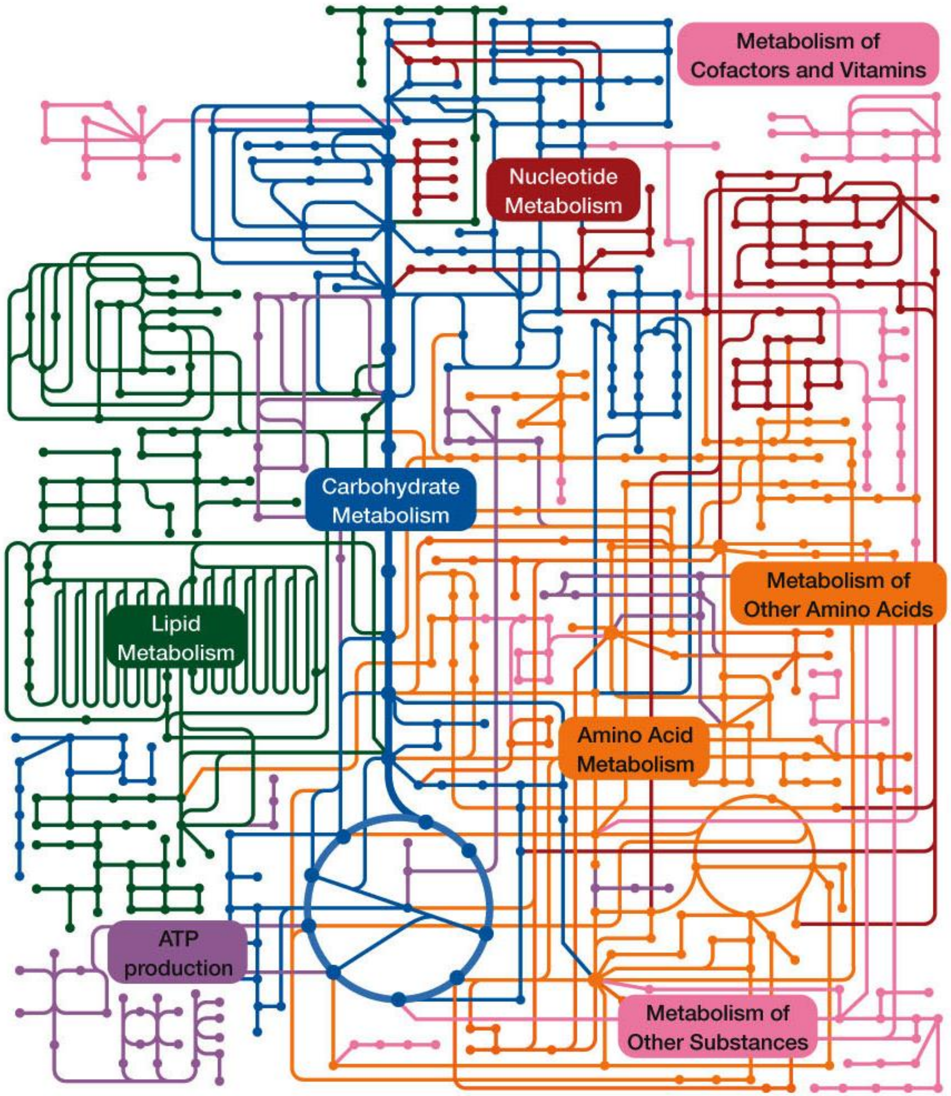
Energy and Energy Conversions

- Summary of terms:



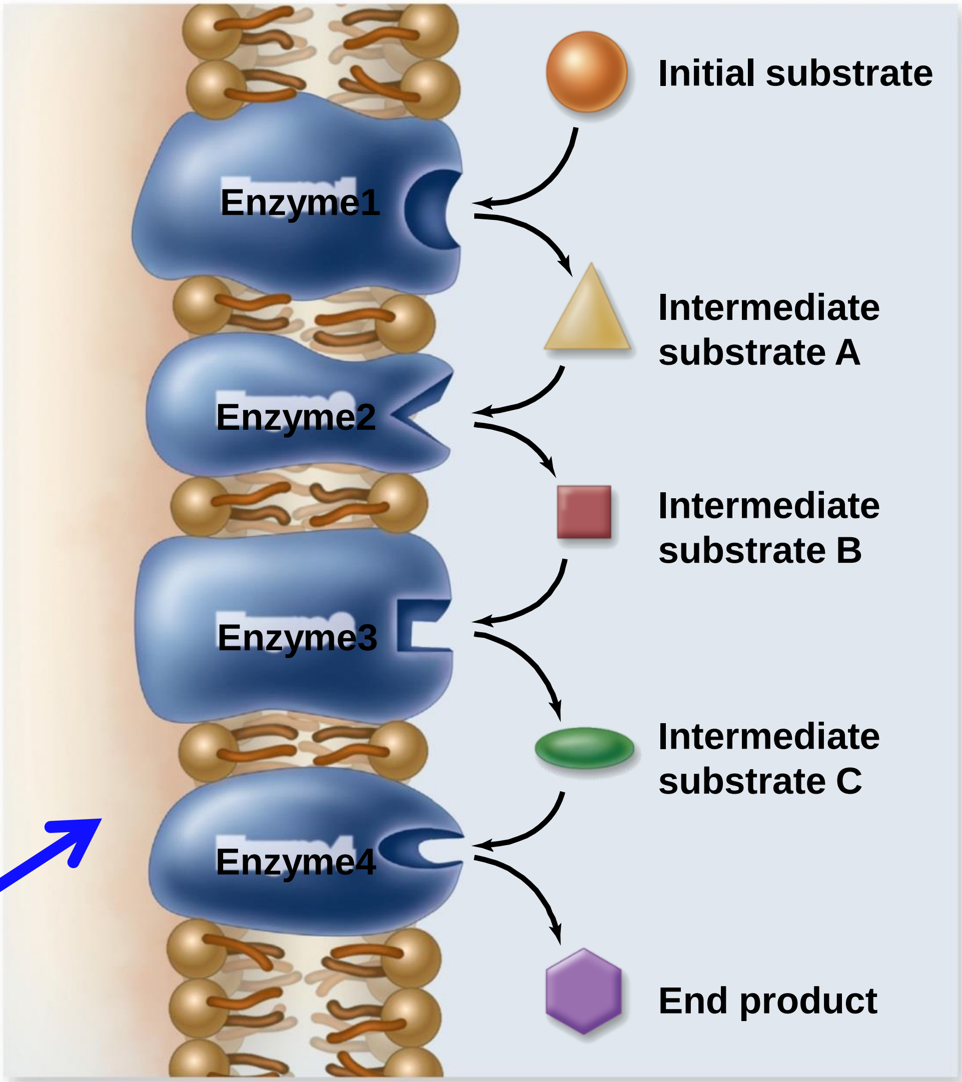
Biochemical pathways

- Chemical reactions that create/store or produce other chemical products for daily function
- Reactions occur in a sequence

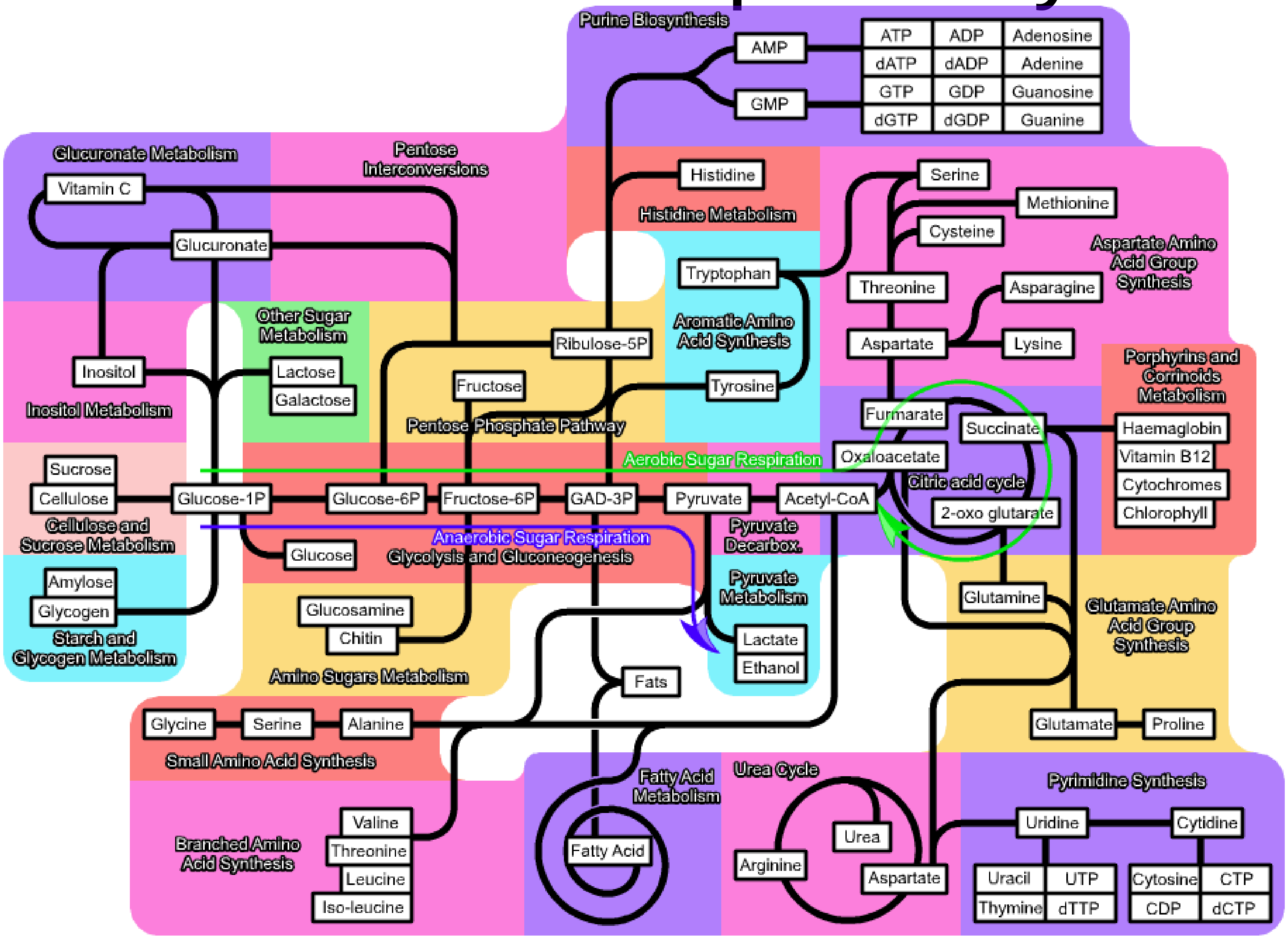


Biochemical pathways

- Product of one reaction is the substrate for the next reaction
- Some reactions such as glycolysis takes place in the cytoplasm; others such as the electron transport chain take place in organelles
- Enzymes in pathway maybe located within a single membrane



Basic metabolic pathway chart



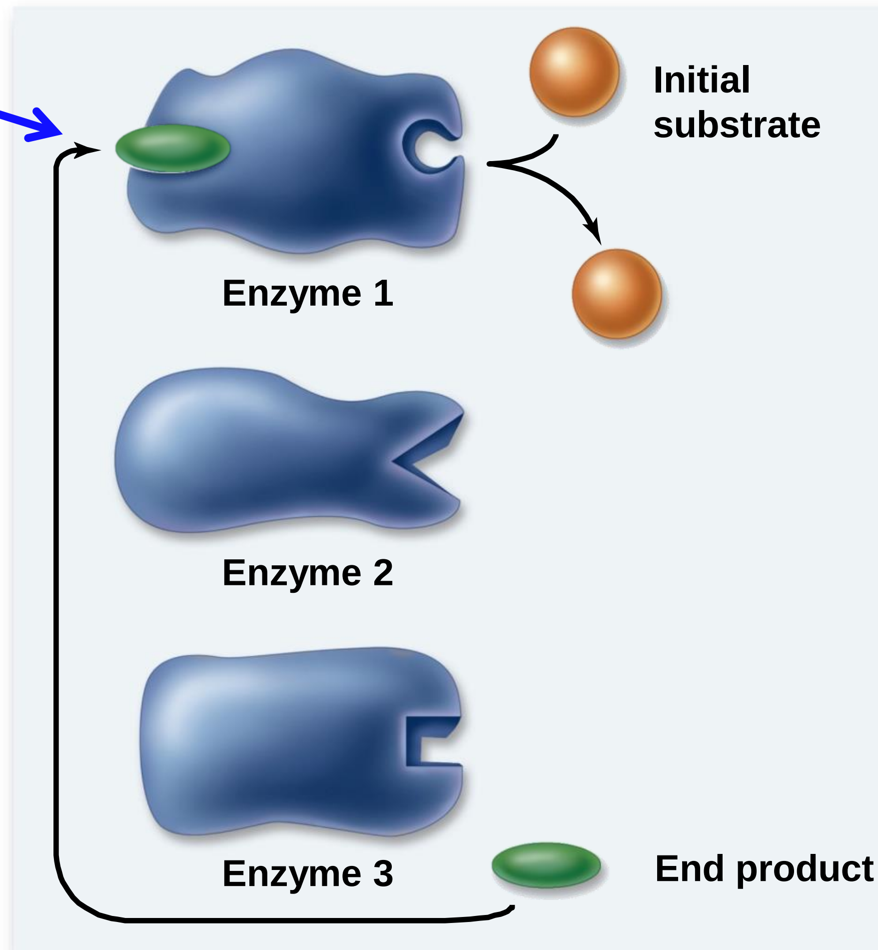
http://upload.wikimedia.org/wikipedia/commons/1/11/Metabolism_wip.png

Feedback inhibition

- End-product of pathway binds to an allosteric site on enzyme that catalyzes first reaction in pathway

- Shuts down pathway so raw materials and energy are not wasted

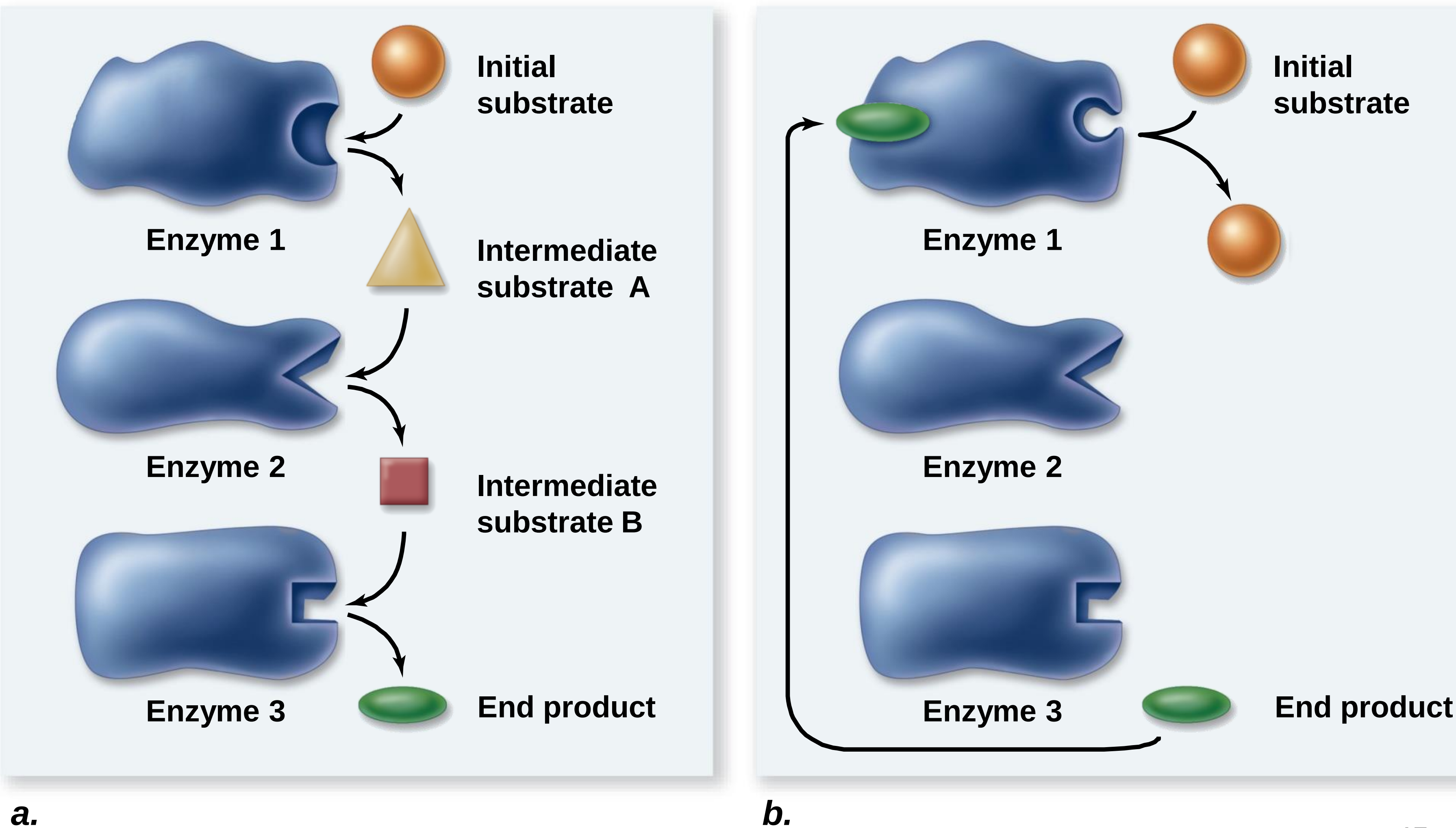
- Usually at or near first step in pathway



b.

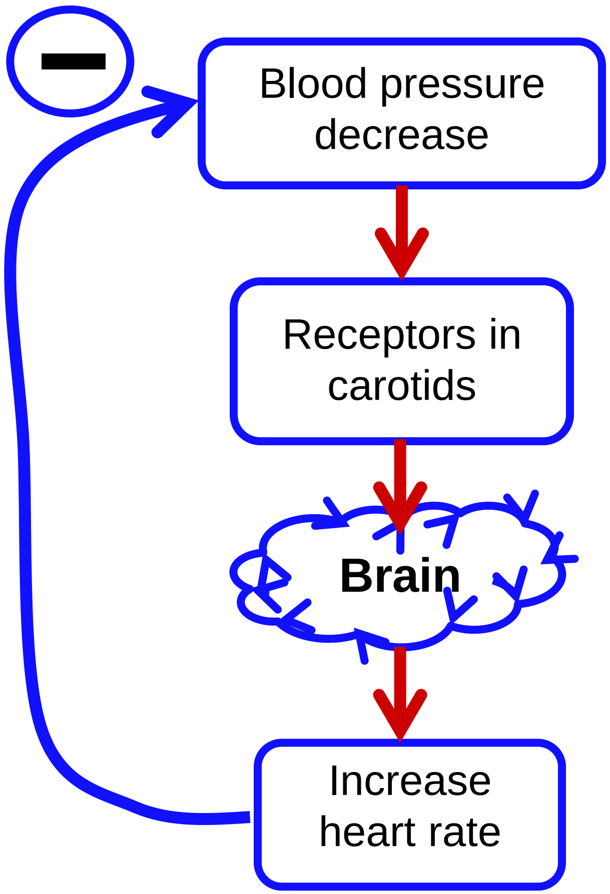
Biochemical pathway lacking feedback

Biochemical pathway with negative feedback



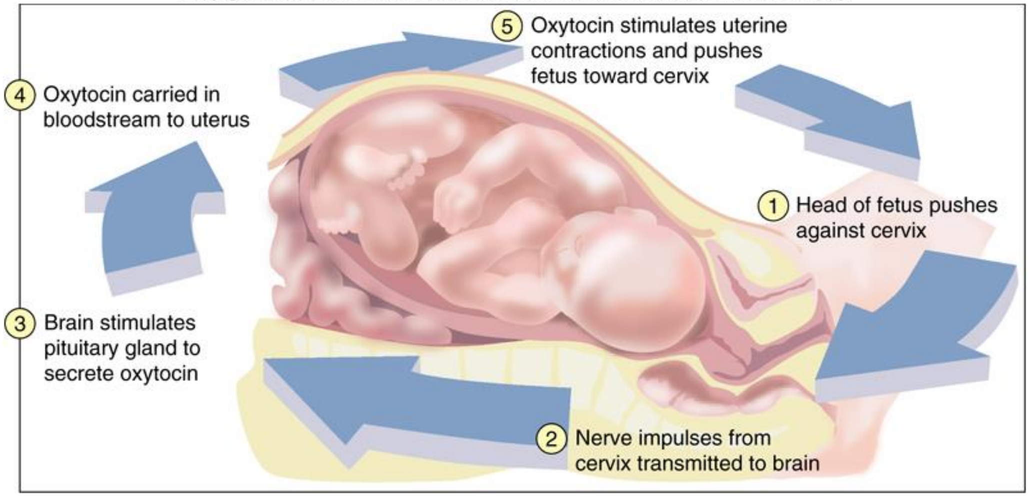
Negative vs. Positive Feedback

- **Negative feedback (inhibition)**
  - Most common control type
  - Downstream product increases, this increase level of product tells an upstream factor that there is enough and it slows or stops the reaction.
    - *Blood pressure: standup fast, HR increases to keep you from passing out, then HR returns to normal.*

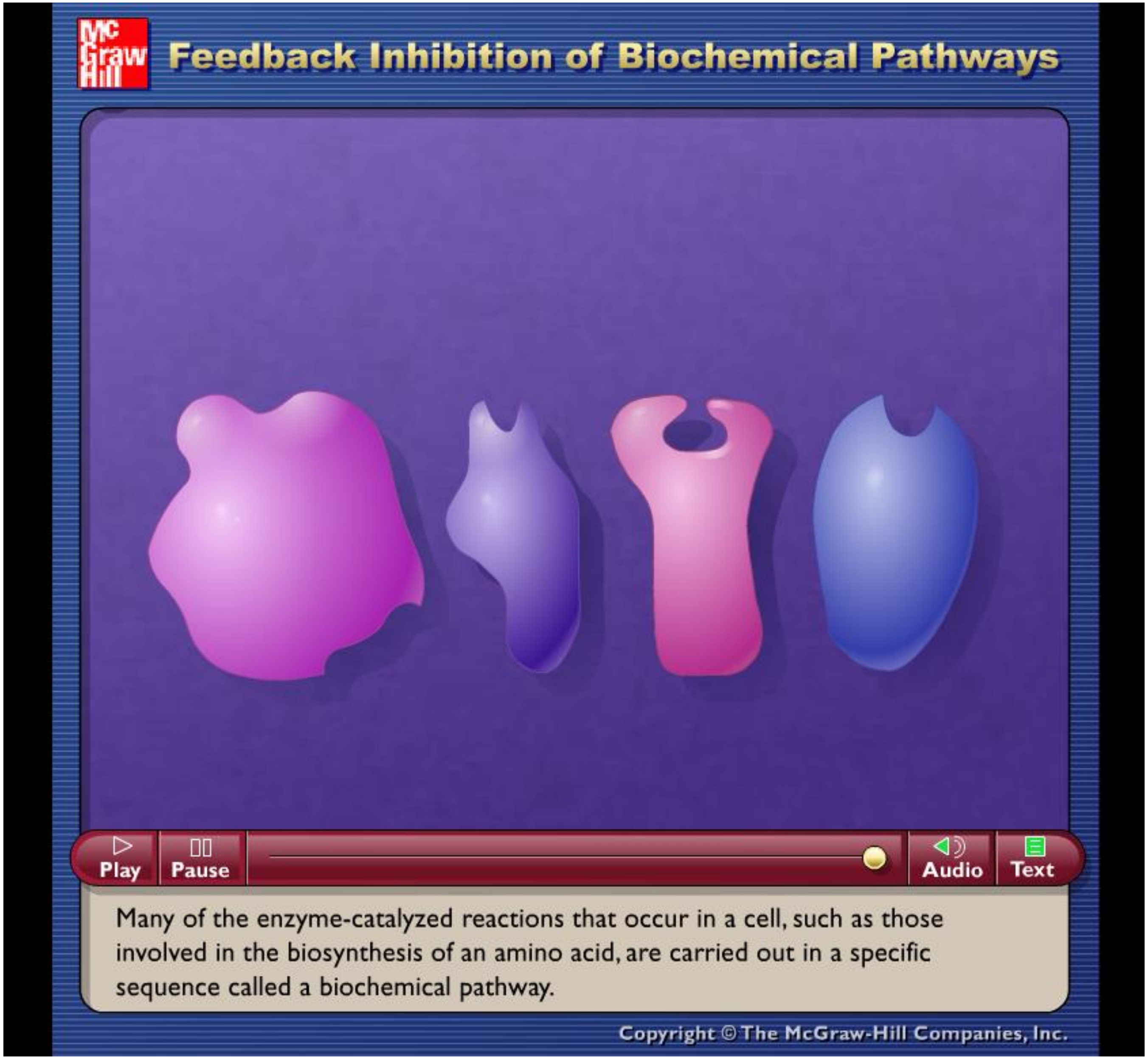


Negative vs. Positive Feedback

- **Positive feedback**
  - Very few examples in normal physiology that have a good outcome
  - Downstream product tells the upstream system that more needs to be produced
    - *Childbirth: control of the contractions, the harder the babies head pushes on the cervix causes hormones to be produced that increase the muscle contraction. This continues until baby and placenta are delivered.*



http://kageeamy2012.wikispaces.com/01+Homeostasis+%26+Chemical+Aspects


Feedback Inhibition of Biochemical Pathways
Play
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Audio
Text
Many of the enzyme-catalyzed reactions that occur in a cell, such as those involved in the biosynthesis of an amino acid, are carried out in a specific sequence called a biochemical pathway.
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