

**Chapter 8.**

**Metabolism & Enzymes**

MCC BP

---

---

---

---

---

---

---

---

**Flow of energy through life**

- Life is built on chemical reactions

MCC BP

---

---

---

---

---

---

---

---

**Chemical reactions of life**

- Metabolism**
  - forming bonds** between molecules
    - dehydration synthesis
    - anabolic reactions
  - breaking bonds** between molecules
    - hydrolysis
    - catabolic reactions

MCC BP

---

---

---

---

---

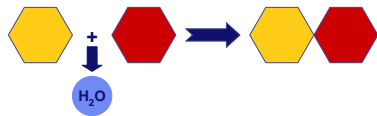
---

---

---

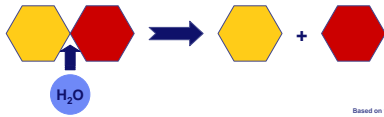
**Examples**

- **dehydration synthesis**




---

- **hydrolysis**



MCC BP Based on work by K. Foglia  
www.kimnky.com

---

---

---

---

---

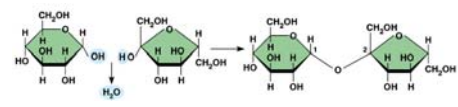
---

---

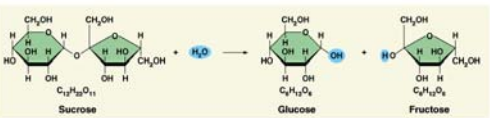
---

**Examples**

- **dehydration synthesis**



- **hydrolysis**



MCC BP Based on work by K. Foglia  
www.kimnky.com

---

---

---

---

---

---

---

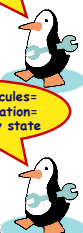
---

**Chemical reactions & energy**

- **Some chemical reactions release energy**
  - ◆ **exergonic**
  - ◆ digesting polymers
  - ◆ hydrolysis = catabolism
- **Some chemical reactions require input of energy**
  - ◆ **endergonic**
  - ◆ building polymers
  - ◆ dehydration synthesis = anabolism

digesting molecules=  
less organization=  
lower energy state

building molecules=  
more organization=  
higher energy state



MCC BP Based on work  
www.k

---

---

---

---

---

---

---

---

### Endergonic vs. exergonic reactions

**exergonic**  
energy released

**endergonic**  
energy invested

MCC BP  $\Delta G = \text{change in free energy} = \text{ability to do work}$

---

---

---

---

---

---

---

---

### Energy & life

- Organisms require energy to live
  - where does that energy come from?
    - coupling **exergonic reactions** (releasing energy) with **endergonic reactions** (needing energy)

MCC BP Based on work by K. Foglia www.kfoglia.com

---

---

---

---

---

---

---

---

### Spontaneous reactions?

- If reactions are “downhill”, why don’t they just happen spontaneously?
  - because covalent bonds are stable

MCC BP Based on

---

---

---

---

---

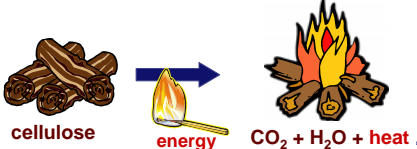
---

---

---

### Activation energy

- Breaking down large molecules requires an initial input of energy
  - ◆ activation energy
  - ◆ large biomolecules are stable
  - ◆ must absorb energy to break bonds



MCC BP

---

---

---

---

---


---

---

---

### Activation energy

- the amount of energy needed to destabilize the bonds of a molecule
  - ◆ moves the reaction over an “energy hill”



MCC BP

---

---

---

---

---

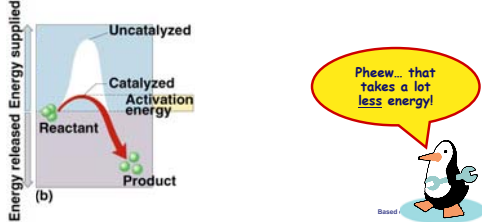
---

---

---

### Reducing Activation energy

- Catalysts
  - ◆ reducing the amount of energy to start a reaction



MCC BP

---

---

---

---

---

---

---

---

### Catalysts

- So what's a cell do to reduce activation energy?
  - get help! ... chemical help... **ENZYMES**

Based on work by www.kinr.com

---

---

---

---

---

---

---

---

### Enzymes

- Biological catalysts
  - proteins (& RNA)
  - facilitate chemical reactions
    - increase rate of reaction without being consumed
    - reduce activation energy
    - don't change free energy ( $\Delta G$ ) released or required
  - required for most biological reactions
  - highly specific
    - thousands of different enzymes in cells
  - control reactions

MCC BP

---

---

---

---

---

---

---

---

### Enzymes & substrates

**substrate**

- reactant which binds to enzyme
- enzyme-substrate complex: temporary association

**product**

- end result of reaction

MCC BP

led on work by K. Foglia www.kinr.com

---

---

---

---

---

---

---

---

### Enzymes & substrates

- Enzyme + substrates → products
  - sucrase**
    - enzyme breaks down sucrose
    - binds to sucrose & breaks disaccharide into fructose & glucose
  - DNA polymerase**
    - enzyme builds DNA
    - adds nucleotides to a growing DNA strand

MCC BP

---

---

---

---

---

---

---

---

### Lock and Key model

- Simplistic model of enzyme action
  - 3-D structure of enzyme fits substrate
- Active site
  - enzyme's catalytic center
  - pocket or groove on surface of globular protein
  - substrate fits into active site

MCC BP

---

---

---

---

---

---

---

---

### Induced fit model

- More accurate model of enzyme action
  - 3-D structure of enzyme fits substrate
  - as substrate binds, enzyme changes shape leading to a tighter fit
    - “conformational change”
    - bring chemical groups in position to catalyze reaction

MCC BP

---

---

---

---

---

---

---

---

### How does it work?

- **Variety of mechanisms to lower activation energy & speed up reaction**
  - ◆ active site orients substrates in correct position for reaction
    - enzyme brings substrate closer together
  - ◆ active site binds substrate & puts stress on bonds that must be broken, making it easier to separate molecules

MCC BP Based on work by K. Foglia  
www.kimshy.com

---

---

---

---


---

---

---

---

### Properties of Enzymes



MCC BP

---

---

---

---

---

---

---

---

### Specificity of enzymes

- **Reaction specific**
  - ◆ each enzyme is substrate-specific
    - due to fit between active site & substrate
      - ◆ substrates held in active site by weak interactions
        - H bonds
        - ionic bonds
  - ◆ enzymes named for reaction they catalyze
    - **sucrase** breaks down sucrose
    - **proteases** break down proteins
    - **lipases** break down lipids
    - **DNA polymerase** builds DNA
    - **pepsin** breaks down proteins (**polypeptides**)

MCC BP Based on work by K. Foglia  
www.kimshy.com

---

---

---

---

---

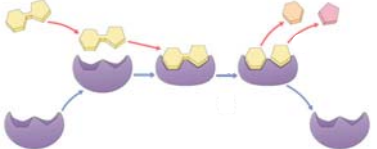
---

---

---

**Reusable**

- **Not consumed in reaction**
  - ◆ single enzyme molecule can catalyze thousands or more reactions per second
  - ◆ enzymes unaffected by the reaction



MCC BP based on work by K. Foglia  
www.kimshly.com

---

---

---

---

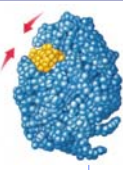
---

---

---

---

**Factors that Affect Enzymes**



MCC BP

---

---

---

---

---

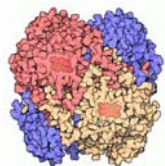
---

---

---

**Factors Affecting Enzymes**

- Enzyme concentration
- Substrate concentration
- Temperature
- pH
- Salinity
- Activators
- Inhibitors



MCC BP **catalase**

---

---

---

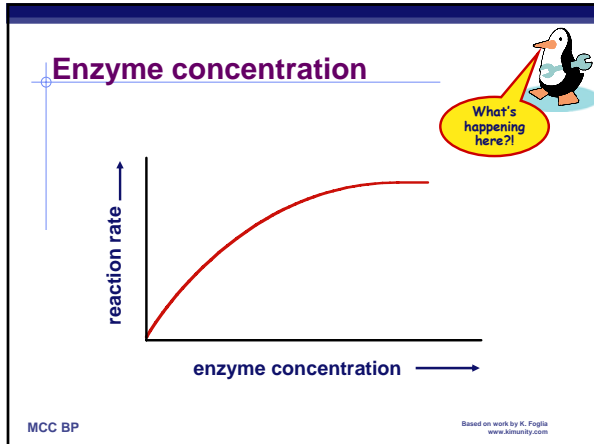
---

---

---

---

---



---

---

---

---

---

---

---

---

### Enzyme concentration

- **Effect on rates of enzyme activity**
  - ◆ as  $\uparrow$  enzyme =  $\uparrow$  reaction rate
    - more enzymes = more frequently collide with substrate
  - ◆ reaction rate levels off
    - substrate becomes limiting factor
    - not all enzyme molecules can find substrate

A diagram showing several red dots and a few yellow dots scattered across the space, representing molecules in a reaction mixture.

---

---

---

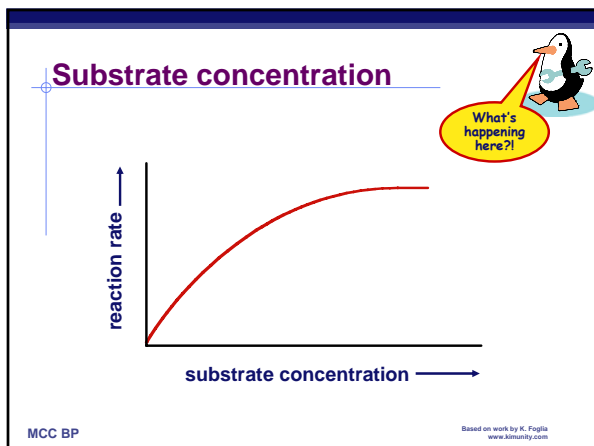
---

---

---

---

---



---

---

---

---

---

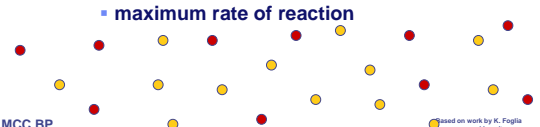
---

---

---

### Substrate concentration

- Effect on rates of enzyme activity
  - as  $\uparrow$  substrate =  $\uparrow$  reaction rate
    - more substrate = more frequently collide with enzymes
  - reaction rate levels off
    - all enzymes have active site engaged
    - enzyme is saturated
    - maximum rate of reaction



MCC BP Based on work by K. Foglia  
www.kimshy.com

---

---

---

---

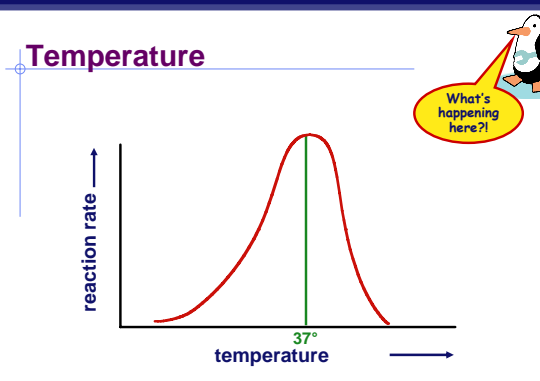
---

---

---

---

### Temperature



MCC BP Based on work by K. Foglia  
www.kimshy.com

---

---

---

---

---

---

---

---

### Temperature

- Effect on rates of enzyme activity
  - Optimum T°
    - greatest number of molecular collisions
    - human enzymes = 35°- 40°C (body temp = 37°C)
  - Increase beyond optimum T°
    - increased agitation of molecules disrupts bonds
      - H, ionic = weak bonds
      - denaturation = lose 3D shape (3° structure)
  - Decrease T°
    - molecules move slower
    - decrease collisions

MCC BP Based on work by K. Foglia  
www.kimshy.com

---

---

---

---

---

---

---

---

### Enzymes and temperature

- Different enzymes functional in different organisms

The graph plots 'Rate of reaction' on the y-axis against 'Temperature of reaction (°C)' on the x-axis. The x-axis has markers at 30, 40, 50, 60, 70, and 80. A brown bell-shaped curve represents the 'Optimum temperature for human enzyme', peaking at approximately 37°C. A red bell-shaped curve represents the 'Optimum temperature for enzyme from hot springs prokaryote', peaking at approximately 70°C.

MCC BP Based on work by K. Foglia www.kimnity.com

---

---

---

---

---

---

---

---

### How do ectotherms do it?

The graph plots 'Body temperature (°C)' on the y-axis against 'Ambient temperature (°C)' on the x-axis. Both axes range from 0 to 40 with markers every 10 units. A horizontal black line at 37°C is labeled 'Bobcat (endotherm)'. A blue line labeled 'Snake (ectotherm)' starts at (0, 0) and rises linearly to (40, 40). Illustrations of a bobcat and a snake are included.

MCC BP work by K. Foglia www.kimnity.com

---

---

---

---

---

---

---

---

### pH

The graph plots 'reaction rate' on the y-axis against 'pH' on the x-axis. The x-axis ranges from 0 to 10 with markers every 1 unit. A green bell-shaped curve labeled 'pepsin' peaks at pH 2. A red bell-shaped curve labeled 'trypsin' peaks at pH 8. A blue bell-shaped curve peaks at pH 9. A cartoon penguin with a speech bubble asks 'What's happening here?!'.

MCC BP Based on work by K. Foglia www.kimnity.com

---

---

---

---

---

---

---

---

### pH

- **Effect on rates of enzyme activity**
  - ◆ protein shape (conformation)
    - attraction of charged amino acids
  - ◆ pH changes
    - changes charges (add or remove H<sup>+</sup>)
    - disrupt bonds, disrupt 3D shape
      - ◆ affect 3<sup>o</sup> structure
  - ◆ most human enzymes = pH 6-8
    - depends on localized conditions
    - pepsin (stomach) = pH 3
    - trypsin (small intestines) = pH 8

MCC BP Based on work by K. Foglia  
www.kimshy.com

---

---

---

---

---

---

---

---

### Salinity

MCC BP Based on work by K. Foglia  
www.kimshy.com

---

---

---

---

---

---

---

---

### Salt concentration

- **Effect on rates of enzyme activity**
  - ◆ protein shape (conformation)
    - depends on attraction of charged amino acids
  - ◆ salinity changes
    - change [inorganic ions]
    - changes charges (add + or -)
    - disrupt bonds, disrupt 3D shape
      - ◆ affect 3<sup>o</sup> structure
  - ◆ enzymes intolerant of extreme salinity
    - Dead Sea is called dead for a reason!

MCC BP Based on work by K. Foglia  
www.kimshy.com

---

---

---

---

---

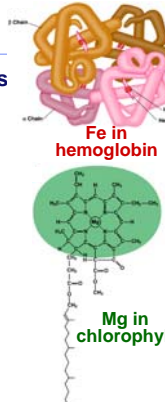
---

---

---

### Activators

- Compounds which help enzymes
- Cofactors
  - non-protein, small inorganic compounds & ions
    - Mg, K, Ca, Zn, Fe, Cu
    - bound in enzyme molecule
- Coenzymes
  - non-protein, organic molecules
    - bind temporarily or permanently to enzyme near active site
  - many vitamins
    - NAD (niacin; B3)
    - FAD (riboflavin; B2)
    - Coenzyme A



The diagram shows two examples of cofactors. The top part shows a pink and orange protein structure with a red dot representing an iron atom (Fe) in hemoglobin. The bottom part shows a green circular structure representing a chlorophyll molecule with a green dot representing a magnesium atom (Mg) in chlorophyll.

MCC BP

---

---

---

---

---

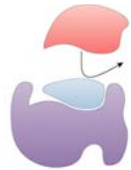
---

---

---

### Inhibitors

- Regulation of enzyme activity
  - other molecules that affect enzyme activity
- Selective inhibition & activation
  - competitive inhibition
  - noncompetitive inhibition
  - irreversible inhibition
  - feedback inhibition



The diagram shows a purple enzyme with a blue active site. A red, umbrella-shaped molecule is bound to the active site, representing an inhibitor.

MCC BP

---

---

---

---

---

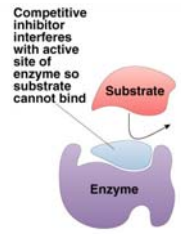
---

---

---

### Competitive Inhibitor

- Effect
  - inhibitor & substrate "compete" for active site
    - ex: penicillin blocks enzyme that bacteria use to build cell walls
    - ex: disulfiram (Antabuse) to overcome alcoholism
    - ex: methanol poisoning
  - overcome by increasing substrate concentration
    - saturate solution with substrate so it out-competes inhibitor for active site on enzyme



The diagram shows a purple enzyme with a blue active site. A red substrate molecule is being blocked by a red inhibitor molecule. Text next to the inhibitor says: "Competitive inhibitor interferes with active site of enzyme so substrate cannot bind".

(a) Competitive inhibition

MCC BP

---

---

---

---

---

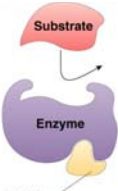
---

---

---

### Non-Competitive Inhibitor

- Effect
  - inhibitor binds to site other than active site
    - allosteric site
    - called **allosteric inhibitor**
      - ex: some anti-cancer drugs inhibit enzymes involved in synthesis of nucleotides & therefore in building of DNA = stop DNA production, stop division of more cancer cells
      - ex: heavy metal poisoning
      - ex: cyanide poisoning
    - causes enzyme to change shape
      - conformational change
    - renders active site unreceptive



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

MCC BP (b) Noncompetitive inhibition

---

---

---

---

---

---

---

---

### Irreversible inhibition

- Inhibitor permanently binds to enzyme
  - competitor
    - permanently binds to active site
  - allosteric
    - permanently changes shape of enzyme
    - ex: nerve gas, sarin, many insecticides (malathion, parathion...)
      - cholinesterase inhibitors doesn't breakdown the neurotransmitter, acetylcholine

MCC BP Based on work by K. Foglia www.kimunity.com

---

---

---

---

---

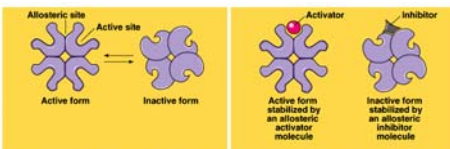
---

---

---

### Action of Allosteric control

- Inhibitors & activators
  - regulatory molecules attach to allosteric site causing conformational (shape) change
  - inhibitor keeps enzyme in inactive form
  - activator keeps enzyme in active form



MCC BP (a) Conformational changes in an allosteric enzyme (b) Allosteric regulation of the enzyme's activity

---

---

---

---

---

---

---

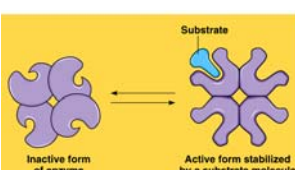
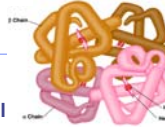
---

### Cooperativity

- Substrate acts as an activator
  - substrate causes conformational change in enzyme
    - induced fit
  - favors binding of substrate at 2<sup>nd</sup> site
  - makes enzyme more active & effective
    - ex: hemoglobin

4 polypeptide chains:

- bind 4 O<sub>2</sub>;
- 1<sup>st</sup> O<sub>2</sub> binds
- makes it easier for other 3 O<sub>2</sub> to bind



MCC

---

---

---

---

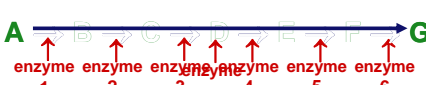
---

---

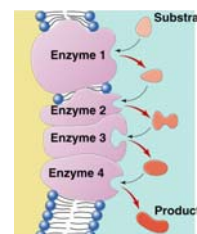
---

---

### Metabolic pathways



- Chemical reactions of life are organized in pathways
  - divide chemical reaction into many small steps
    - efficiency
    - control = regulation



MCC BP

---

---

---

---

---

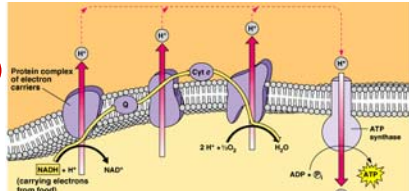
---

---

---

### Efficiency

- Groups of enzymes organized
  - if enzymes are embedded in membrane they are arranged sequentially
- Link endergonic & exergonic reactions



Whoa! all that going on in those little mitochondria!

MCC BP

---

---

---

---

---

---

---

---

### Feedback Inhibition

- Regulation & coordination of production
  - product is used by next step in pathway
  - final product is inhibitor of earlier step
    - allosteric inhibitor of earlier enzyme
    - feedback inhibition
  - no unnecessary accumulation of product

MCC BP allosteric inhibitor of enzyme 1 © by K. Foglia, kimmunity.com

---

---

---

---

---

---

---

---

### Feedback inhibition

- Example
  - synthesis of amino acid, isoleucine from amino acid, threonine

MCC BP

---

---

---

---

---

---

---

---

Any Questions??

MCC BP

---

---

---

---

---

---

---

---