Ch. 3 - Metabolism and Enzymes

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Life is built on chemical reactions that enable energy to flow through living systems.

- **sun** → organic molecules → ATP & organic molecules
- solar energy → ATP & organic molecules
- organic molecules → ATP & organic molecules

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AP Biology
Metabolism

Chemical reactions involve...

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

That’s why they’re called *anabolic* steroids!
Dehydration vs. Hydrolysis

- **dehydration** synthesis (synthesis)

- **hydrolysis** (digestion)
Laws of Thermodynamics

- **First Law** – Energy cannot be created or destroyed; only be transferred and transformed

*First law of thermodynamics:* Energy can be transferred or transformed but neither created nor destroyed. For example, the chemical (potential) energy in food will be converted to the kinetic energy of the cheetah’s movement in (b).

Figure 8.3
Laws of Thermodynamics

- **Second Law** – For a process to occur spontaneously, it must increase the entropy of the universe.

(b) Second law of thermodynamics: Every energy transfer or transformation increases the disorder (entropy) of the universe. For example, disorder is added to the cheetah’s surroundings in the form of heat and the small molecules that are the by-products of metabolism.

Figure 8.3
Living systems

1. increase the entropy of the universe

2. use energy to maintain order
Some chemical reactions release energy
- exergonic
- breaking down polymers
- hydrolysis = catabolism
Exergonic Reactions

- release energy
- often occur spontaneously

![Graph of exothermic reaction with potential energy and activation energy](image-url)
Some chemical reactions require input of energy
- endergonic
- building polymers
- dehydration synthesis = anabolism
Endergonic Reactions

- absorb energy
- will NOT occur without a source of energy
Endergonic vs. exergonic reactions

**exergonic**
- energy released
- digestion

**endergonic**
- energy invested
- synthesis

\[ \Delta G = \text{change in free energy} = \text{ability to do work} \]
Energy and life

- Organisms require energy to live.
- Where does that energy come from?
- coupling exergonic reactions (releasing energy) with endergonic reactions (needing energy)
What drives reactions?

- If reactions are “downhill”, why don’t they just happen spontaneously?
- Because covalent bonds are stable bonds.
**Activation energy**

- Breaking down large molecules requires an **initial** input of energy
- **activation energy**
- Large biomolecules are stable $\rightarrow$ must absorb energy for bonds to break

\[
\text{cellulose} \xrightarrow{\text{energy}} \text{CO}_2 + \text{H}_2\text{O} + \text{heat}
\]
Too much activation energy for life?

- **Activation energy** = (initial) amount of energy needed to **destabilize the bonds** of a molecule
- moves the reaction over an “energy hill”

![Diagram of energy levels and reaction]

Not a match! That’s too much energy to expose living cells to!
Reducing Activation energy

- **How?**
- **Catalysts!**
- Catalysts reduce the amount of energy to start a reaction.

![Diagram showing the reduction of activation energy in a reaction.](image)

Pheeew... that takes a lot less energy!
Biological catalysts

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

$\Delta G$
Enzymes

Biology Essentials - 048

Catalase

H₂O₂

Enzymes
Enzymes

- mostly **proteins** (and some RNA)
- function as biological **catalysts**
Enzymes Vocabs

- **Substrate**
  - reactant which binds to enzyme

- **Product**
  - end result of reaction

- **active site**
  - enzyme’s catalytic site
Properties of enzymes

- **Reaction-specific**
  - each enzyme works with a specific substrate

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

- **Affected by cellular conditions**
  - condition that affects protein structure (temperature, pH, salinity)
Naming conventions

- 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)
Lock-and-Key model

- Simplistic (outdated?) model
- substrate fits into 3-D structure of enzyme’s active site
- H bonds between substrate and enzyme like “key fits into lock”

Again, SHAPE matters!
**Induced Fit Model**

- a more accurate model
- substrate binding cause enzyme to **change shape** leading to a tighter fit – a **conformational change**
- bring chemical groups in position to catalyze reaction
How Enzymes Work

- lower activation energy needed to break old bonds and form new bonds

- Various approaches
  - straining substrate bonds
  - orienting substrates correctly
  - providing a favorable microenvironment
Activators

- **Cofactors**
  - non-protein, small **inorganic** ions (Mg, K, Ca, Zn, Fe, Cu)

- **Coenzymes**
  - non-protein, **organic** molecules
  - bind temporarily to enzyme
  - many **vitamins** (niacin or B3; riboflavin or B2; coenzyme A)
**Competitive Inhibitor**

- Inhibitor and substrate **compete for active site**
  - **Ex:** *Penicillin* blocks enzyme bacteria use to build cell walls
- Overcome by increasing substrate concentration so it out-competes inhibitor for active site on enzyme
Non-Competitive Inhibitor

- Inhibitor binds to site other than active site (allosteric)
- causes enzyme to change shape so that active site is no longer functional binding site
  → inactivates enzyme

**Ex:** cyanide poisoning irreversibly inhibits Cytochrome C
Cyanide and Cytochrome C

A Metabolic Poison: how cyanide disrupts ATP synthesis

by Blair Lyons
Irreversible Inhibition

- permanently binds to enzyme \( \rightarrow \) permanently changes shape of protein \( \rightarrow \) disable enzyme

**Ex:** nerve gas, sarin, many insecticides (malathion, parathion...)

- prevents the breakdown the neurotransmitter acetylcholine
Chemical reactions of life are organized in pathways
divide chemical reaction into many small steps
an artifact of evolution!
↑ efficiency
↑ control
Efficiency

- Enzymes embedded in membrane and arranged sequentially
- Link endergonic and exergonic reactions
Feedback Inhibition

- Regulation and coordination of production
- product is used by next step in pathway
- final product is inhibitor of earlier step
- **allosteric inhibitor** of earlier enzyme $\rightarrow$ no unnecessary accumulation of product

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A  B  C  D  E  F  G
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enzyme 1
enzyme 2
enzyme 3
enzyme 4
enzyme 5
enzyme 6

**allosteric inhibitor** of enzyme 1
Examples

- synthesis of the amino acid isoleucine from threonine
- isoleucine becomes the allosteric inhibitor of the first step in the pathway
- as product accumulates it collides with enzyme more often than substrate does
Cooperativity

- Substrate acts as an activator
  - substrate causes conformational change in enzyme (induced fit)
  - favors binding of substrate at 2\textsuperscript{nd} site
  - makes enzyme more active and effective

\textbf{Ex: hemoglobin}

\textbf{Hemoglobin}

- 4 polypeptide chains
- can bind 4 $\text{O}_2$;
- 1\textsuperscript{st} $\text{O}_2$ binds
- now easier for other 3 $\text{O}_2$ to bind
Factors that Affect Enzymes
Factors Affecting Enzyme Function

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

catalase
Enzyme Concentration

reaction rate

enzyme concentration
Factors affecting enzyme function

- Enzyme concentration
  - 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
Substrate Concentration

reaction rate

substrate concentration
**Substrate concentration**

- Substrate concentration
- as \( \uparrow \) substrate = \( \uparrow \) reaction rate
- more substrate = more frequently collide with enzyme
- reaction rate levels off
- all enzymes have active site engaged
- enzyme is **saturated**
- maximum rate of reaction
Temperature

Temperature vs. reaction rate graph with a peak at 37°.
Temperature

- **Optimum T°**
  - greatest number of molecular collisions
  - human enzymes = 35°- 40°C
  - body temp = 37°C

- **Heat: increase beyond optimum T°**
  - increased energy level of molecules disrupts bonds in enzyme and between enzyme and substrate
  - H, ionic = weak bonds
  - denaturation = lose 3D shape (3° structure)

- **Cold: decrease T°**
  - molecules move slower
  - decrease collisions between enzyme and substrate
Enzymes and Temperature

- Different enzymes function in different organisms in different environments.

The diagram shows the reaction rates of a human enzyme and a bacteria enzyme at different temperatures. The human enzyme peak is at 37°C (98.6°F), while the bacteria enzyme peak is at 70°C (158°F).
pH

- Changes in pH (add or remove H\(^+\))
  - disrupt bonds, disrupts 3D shape
  - disrupt attractions between charged amino acids (affecting 2° and 3° structures)
  - denatures protein

- Optimum pH?
  - most human enzymes = pH 6-8
  - depends on localized conditions (for ex: pepsin (stomach) = pH 2-3, trypsin (small intestines) = pH 8)
Salinity

reaction rate

salt concentration

AP Biology
Salinity

- changes in salinity
  - adds or removes cations (+) and anions (−)
  - disrupts bonds, disrupts 3-D shape
  - disrupts attractions between charged amino acids
  - affect 2° and 3° structure
  - denatures protein
  - enzymes intolerant of extreme salinity
  - Dead Sea is called dead for a reason!