Energy and Chemical Reactions

All living organisms require energy for survival. In this topic we will examine some general principles about energy usage and chemical reactions within cells.

Objective # 1

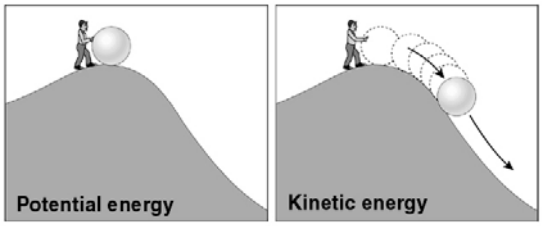
Define the term "energy" and distinguish between potential and kinetic energy.

Objective 1

- Energy is the ability to cause change. Any change in the universe requires energy. Energy comes in 2 forms:
  - Potential energy is stored energy. No change is currently taking place
  - Kinetic energy is currently causing change. This always involves some type of motion.

Objective 1

Potential and Kinetic Energy



Objective # 2

State the first and second laws of thermodynamics and explain how they apply to living organisms.

Objective 2

- Thermodynamics is the study of energy changes.
- Two fundamental laws govern all energy changes in the universe. These 2 laws are called the first and second laws of thermodynamics:

Objective 2

- First Law:
  - Energy can be converted from one form to another, but it cannot be created or destroyed.
  - This means the total amount of energy in a closed system remains constant.

Objective 2

- Second Law:
  - Whenever an energy conversion takes place, some of the energy gets converted into a more dispersed and less useful form (usually random molecular motion = heat).
- In other words, the more dispersed the energy is, the less useful it is.

Objective 2

- Free energy (G) is a measure of the amount of energy available to do useful work.
- Whenever an energy change takes place, the total amount of energy stays the same, but the Free Energy decreases as disorganization (entropy) increases and the energy becomes more dispersed.

Objective 2

- The 2 laws of thermodynamics tell us that all living organisms require a continual input of energy in order to counteract the inevitable tendency for any system to become more disorganized as energy changes take place.

Objective # 3

Explain what a chemical reaction is and discuss how chemical equations are used to describe the changes that take place during a chemical reaction.

Objective 3

- Most of the changes that take place in living organisms are the result of chemical reactions.
- What is a chemical reaction?
  - As atoms and molecules move around, they collide with each other. If they collide with enough force, existing chemical bonds can break and new bonds can form.

Objective 3

- Chemical equations can be used to describe the changes that take place during a chemical reaction:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Reactants Products

- During a chemical reaction no atoms are created or destroyed.

13

Objective 3

- Most reactions are reversible:
  - reading from left to right is called the forward reaction
  - reading from right to left is called the reverse reaction
- At equilibrium, the rate of the forward reaction equals the rate of the reverse reaction.

14

Objective # 4

Distinguish between endergonic and exergonic reactions and explain how they are coupled in living organisms. Describe the role of ATP in the coupling of chemical reactions.

15

Objective 4

- Chemical reactions involve a change in free energy as well as a change in the types of molecules present.

16

Objective 4

- All atoms and molecules have a certain amount of free energy:
  - potential energy stored in the chemical bonds that hold them together.
  - kinetic energy due to their constant random motion.
- Large, complex molecules have more free energy than small molecules.

17

Objective 4

- Exergonic reactions:
  - the reactants have more free energy than the products:
    $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
    more free energy less free energy
  - involve a net release of energy and/or an increase in entropy
  - occur spontaneously (without a net input of energy)

18

Objective 4

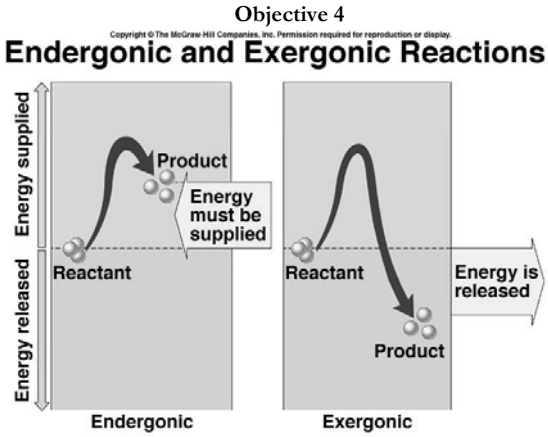
- Endergonic reactions:
- the reactants have less free energy than the products:

  $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

  less free energy more free energy
- involve a net input of energy and/or a decrease in entropy
- do not occur spontaneously

19

Objective 4



20

Objective 4

- Living organisms have the ability to couple exergonic and endergonic reactions:
  - energy released by exergonic reactions is captured and used to make ATP
  - ATP provides the energy needed to power the cell's endergonic reactions.

21

Objective # 5

Explain the concepts of transition state and activation energy.

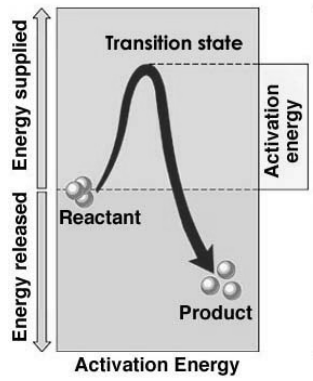
22

Objective 5

- All reactions, both endergonic and exergonic, require an input of energy to get started. This energy is called activation energy.
- Activation energy is needed to bring the reactants close together and weaken existing bonds. This produces an unstable state of maximum potential energy called the transition state.

23

Objective 5



24

Objective # 6

Describe some methods that can be used to speed up chemical reactions.

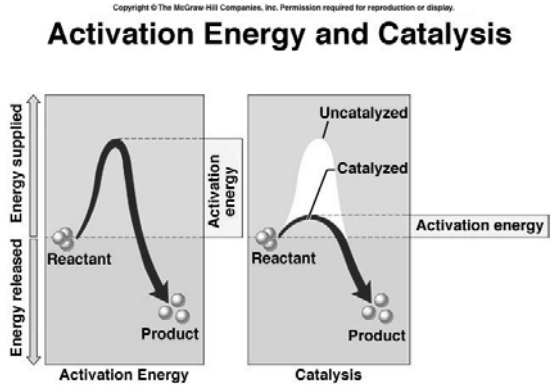
Objective 6

- In most cases, molecules do not have enough kinetic energy to reach the transition state when they collide.
- Therefore, most collisions are non-productive, and the reaction proceeds very slowly if at all.
- What can be done to speed up these reactions?

Objective 6

1) Add Heat – molecules move faster so they collide more frequently and with greater force.
2) Add a catalyst – a catalyst reduces the energy needed to reach the activation state, without being changed itself. Proteins that function as catalysts are called enzymes.

Objective 6



Objective 6

- Unlike heat, which speeds up all reactions indiscriminately, enzymes are highly specific. Each enzyme typically speeds up only one or a few similar chemical reactions.
- Therefore, by controlling which enzymes are made, a cell can control which reactions take place in the cell.

Objective # 7

Describe the structure, function, and characteristics of enzymes.

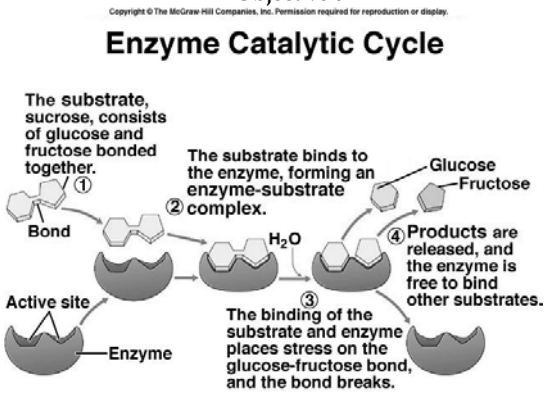
Objective 7

- Almost all enzymes are globular proteins with one or more pockets on their surface called active sites.
- Reactants bind to the active site to form an enzyme-substrate complex.
- The 3-D shape of the active site and the substrates must match, like a lock and key.

Objective 7

- Binding of the substrates causes the enzyme to adjust its shape slightly, leading to a better induced fit.
- When this happens, the substrates are brought close together and existing bonds are stressed. This reduces the amount of energy needed to reach the transition state.

Objective 7



Objective 7

To learn more about enzymes, complete the exercise "Enzymes" in unit 1 of the *Process of Science* CD-ROM.

Objective # 8

Explain how the following factors can affect enzyme activity:

a) temperature
b) pH
c) inhibitors and activators
d) cofactors

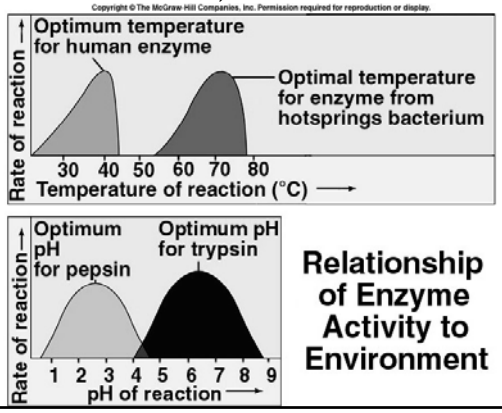
Objective 8

- The rate of an enzyme-catalyzed reaction is affected by the concentration of both the enzyme and its substrates.
- In addition, any physical or chemical factors that affect the enzyme's 3-D shape can affect the enzyme's ability to catalyze the reaction

Objective 8a & b

- Temperature and pH:
  - Most enzymes have an optimum temperature and an optimum pH. These are related to the environment where the enzyme normally functions.
  - Enzyme activity decreases above or below the optimum.

Objective 8a & b



Objective 8c

- Inhibitors and activators are substances that bind to an enzyme and affect its ability to catalyze a reaction.
- Activators increase enzyme activity and inhibitors decrease enzyme activity.

Objective 8d

- Cofactors are nonprotein substances required by enzymes in order to function. For example, the active site of many enzymes contain metal ions that help draw electrons away from the substrates.
- Organic molecules that function as cofactors are called coenzymes.

Objective # 9

Define the terms "metabolism" and "metabolic pathway" (or "biochemical pathway") and explain how metabolic pathways are regulated.

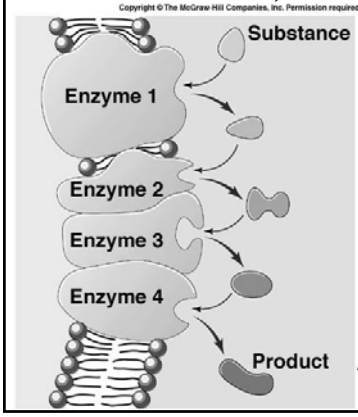
Objective 9

- Metabolism refers to the sum of all chemical reactions carried out by an organism:
  - reactions that join small molecules together to form larger, more complex molecules are called anabolic.
  - reactions that break large molecules down into smaller subunits are called catabolic.

Objective 9

- A sequence of chemical reactions, where the product of one reaction serves as a substrate for the next, is called a metabolic pathway (or biochemical pathway).
- Most metabolic pathways take place in specific regions of the cell.

Objective 9



A Biochemical Pathway