Energy Transformations

H.B.2: The student will demonstrate the understanding that the essential functions of life take place within cells or systems of cells.

H.B.2A.1 Construct explanations of how the structures of carbohydrates, lipids, proteins, and nucleic acids (including DNA and RNA) are related to their functions in organisms.

H.B.3: The student will demonstrate the understanding that all essential processes within organisms require energy which in most ecosystems is ultimately derived from the Sun and transferred into chemical energy by the photosynthetic organisms of that ecosystem.

H.B.3A.2 Develop and revise models to describe how photosynthesis transforms light energy into stored chemical energy.

H.B.3A.3 Construct scientific arguments to support claims that chemical elements in the sugar molecules produced by photosynthesis may interact with other elements to form amino acids, lipids, nucleic acids or other large organic molecules.

H.B.3A.4 Develop models of the major inputs and outputs of cellular respiration (aerobic and anaerobic) to exemplify the chemical process in which the bonds of molecules are broken, the bonds of new compounds are formed and a net transfer of energy results.

H.B.3A.5 Plan and conduct scientific investigations or computer simulations to determine the relationship between variables that affect the processes of fermentation and/or cellular respiration in living organisms and interpret the data in terms of real-world phenomena.
Photosynthesis, Cellular Respiration and ATP

- Life processes require a constant supply of energy.
- Cells use energy that is stored in the bonds of certain organic molecules.
  - *Adenosine triphosphate (ATP)* is a molecule that transfers energy from the breakdown of food molecules to cell processes.
ATP: Energy Molecule

- Adenosine triphosphate (ATP) is the most important biological molecule that supplies energy to the cell.
- A molecule of ATP is composed of three parts:
  - A *nitrogenous base* (adenine)
  - A *sugar* (ribose)
  - Three *phosphate groups* (therefore the name triphosphate) bonded together by “high energy” bonds
The ATP-ADP Cycle

- The energy stored in ATP is released when a phosphate group is removed from the molecule.
- ATP has three phosphate groups, but the bond holding the third phosphate groups is very easily broken.
  - When the phosphate is removed, ATP becomes ADP—adenosine diphosphate, a phosphate is released into the cytoplasm and energy is released.
    - Exergonic reaction
- ADP is a lower energy molecule than ATP, but can be converted to ATP by the addition of a phosphate group.

\[ \text{ATP} \rightarrow \text{ADP} + \text{phosphate} + \text{energy available for cell processes} \]
ATP → ADP + P + Energy
The ATP-ADP Cycle

• To supply the cell with energy, ADP is continually converted to ATP by the addition of a phosphate during the process of cellular respiration.

• ATP carries much more energy than ADP.
  • As the cell requires more energy, it uses energy from the breakdown of food molecules to attach a free phosphate group to an ADP molecule in order to make ATP.
    • Endergonic reaction
  • ADP + phosphate + energy from breakdown of food molecules $\rightarrow$ ATP
ADP + P + Energy → ATP

The energy to make ATP comes from catabolic reactions that are exergonic.

Energy input

ADP + Pi

Energy release

ATP hydrolysis provides the energy for cellular processes that are endergonic.
In a Nutshell, ATP

• ATP is consumed in the cell by energy-requiring processes and can be generated by energy-releasing processes.
  • In this way ATP transfers energy between separate biochemical reactions in the cell.

• ATP is the main energy source for the majority of cellular functions.
  • This includes the synthesis of organic molecules, including DNA and proteins. ATP also plays a critical role in the transport of organic molecules across cell membranes, for example during exocytosis and endocytosis.
ATP-ADP Cycle

• http://www.dnatube.com/video/3421/ATP-cycle
Check for Understanding # 1

1. What other two molecules have a similar structure to ATP?
2. Energy is released when which molecule is formed (ATP or ADP)?
3. Which Biomolecule serves as the main energy source for life?
4. What molecule serves as the energy source for cellular processes?
5. What common household item could be used to model the ATP/ADP cycle?
Energy Transformations

• All organisms need a constant source of energy to survive.
• The ultimate source of energy for most life on Earth is the Sun.
• Photosynthesis, which occurs in the chloroplast of plant cells, is the overall process by which solar energy (sunlight) is used to chemically convert water and carbon dioxide into chemical energy stored in simple sugars (such as glucose).
Photosynthesis

• This process occurs in two stages:
  • Light-Dependent Cycle
  • Light-Independent Cycle (a.k.a. Calvin Cycle)
Photosynthesis: Light-Dependent Cycle

• Requires solar energy
  • Relies on solar energy

• Solar energy is absorbed by chloroplasts and two energy-storing molecules (ATP and NADPH) are produced.

• Solar energy is used to split water molecules that results in the release of oxygen as a waste product.
  • The splitting of water molecules allows for the temporary transfer of the solar energy to electrons released by the broken bonds. This energy is used to make ATP and NADPH.
In a Nut Shell
Photosynthesis: Light-Dependent Cycle

- Requires solar energy from the sun
- Occurs in chloroplast of plant cells
  - Thylakoids
- Makes ATP, NADPH, and Oxygen
Check for Understanding #2

1. Where do the light dependent reactions occur?
2. What is produced in the light reactions?
3. What is NADP+? NADPH?
4. What is released into the atmosphere as a waste product during the light reactions?
5. What replaces electrons lost by photosystem II?
6. What process makes ATP?
7. What happens to the ATP and NADPH made?
Photosynthesis: Light-Independent Cycle

• Does not require solar energy.
• Carbon dioxide from the atmosphere and energy carried by ATP and NADPH is used to make simple sugars (such as glucose).
  • These simple sugars store chemical energy.
In a Nut Shell
Photosynthesis: Light-Independent Cycle

• Does NOT require solar energy from the sun
• Occurs in chloroplast of plant cells
  • Stroma
• Makes glucose sugar
Check for Understanding #3

1. What are the “other names” for the Light independent reactions?
2. What are all the products from that part of photosynthesis?
3. How are the ATP/ADP cycle and photosynthesis related? Explain.
4. What is the purpose NADPH in photosynthesis? (2 part answer)
Photosynthesis

• The process photosynthesis is generally represented using a balanced chemical equation. However, this equation does not represent all of the steps that occur during the process of photosynthesis.

\[
\text{Solar energy} \quad 6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2
\]

• In general, six carbon dioxide molecules and six water molecules are needed to produce one glucose molecule and six oxygen molecules.
Photosynthesis

• The reactants, water and carbon dioxide are input during different stages of the process.
  • water is used during the light-dependent reactions
  • carbon dioxide is used during the Calvin cycle
• Each of the products (oxygen and glucose) is an output of different stages of the process.
  • Oxygen is released during the light-dependent reactions
  • Glucose is formed during the Calvin cycle.
• Solar energy is needed to split the water molecules.
Photosynthesis

• *Photosynthesis* is the overall process by which solar energy (sunlight) is used to chemically convert water and carbon dioxide into chemical energy stored in simple sugars (such as glucose).

• The simple sugars produced by the fixation of atmospheric carbon (from carbon dioxide) are mostly recycled to keep the Calvin cycle (light-independent reactions) going.

  • Some of these sugars, however, are converted to form other carbohydrates such as glucose, starch and cellulose.
Photosynthesis

• Glucose can be used by the cell for energy to make ATP during cellular respiration or it can be converted into starch or cellulose.

• The sugars produced by photosynthesis also provide carbon skeletons that can interact with elements such as nitrogen, sulfur, and phosphorus to make other organic molecules such as amino acids, lipids or nucleic acids.

• ***Light Absorbing pigments such as Chlorophyll, Lycopene, Carotene and Xanthophyll are found in Chloroplasts.***
Factors Affecting Photosynthesis

• Many factors affect the rate of photosynthesis, including:
  • Water
  • Temperature
  • Intensity of light

• Water- a shortage can slow or stop photosynthesis
• Temperature- photosynthesis depends on enzymes that work best between 0 and 35 C. Temps above or below will slow photosynthesis.
• Intensity of light- increasing light intensity increases the rate of photosynthesis. The rate will level off.
Check for Understanding # 4

1. What type of organism makes their own food?
2. What is the main source of Energy on earth?
3. What are the two stages of photosynthesis?
4. Where does photosynthesis occur?
5. What are the overall reactants of photosynthesis?
6. What are the overall products of photosynthesis?
7. What pigments are found in a chloroplast?
Cellular Respiration

- Objectives:
  - Understand the processes of Aerobic and Anaerobic respiration
  - The amounts of ATP generated by both types of cell respiration
  - The location of each part of the Aerobic and Anaerobic Respiration processes
  - Make a model to represent cellular respiration
In a Nutshell
Cellular Respiration

• The ultimate goal of *cellular respiration* is to convert the chemical energy in food to chemical energy stored in *adenosine triphosphate (ATP)*.
  • ATP can then release the energy for cellular metabolic processes, such as active transport across cell membranes, protein synthesis, and muscle contraction.

• Any food (organic) molecule, including carbohydrates, fats/lipids, and proteins can be broken down into smaller molecules and then used as a source of energy to produce ATP molecules occurs via Cellular Respiration.
Cellular Respiration

- To transfer the energy stored in glucose to the ATP molecule, a cell must break down glucose slowly in a series of steps and capture the energy in stages.
  - Glycolysis
  - Electron Transport Chain
Cellular Respiration: Glycolysis

• The first stage
• A glucose molecule is broken down into pyruvic acid molecules with a net gain of two ATP molecules.
• A series of reactions using enzymes that takes place in the cytoplasm
• Occurs in the cytoplasm of the cell
  • Plant and animal cells
• Does not require Oxygen = Anaerobic
Check for Understanding #5

1. Where does glycolysis occur?
2. What is produced during glycolysis?
3. Is glycolysis aerobic or anaerobic?
4. Describe the energy input and net gain.
5. What is the starting molecule?
6. What is the goal of glycolysis?
Cellular Respiration

• If oxygen is available, the two-stage process of \textit{aerobic respiration} occurs, primarily in the mitochondria of the cell.
Cellular Respiration: Aerobic

- The first stage of aerobic respiration is called the *Krebs cycle*.
- The pyruvic acid, produced by glycolysis, travels to the mitochondria where it is broken down in a cycle of chemical reactions, from which carbon dioxide and energy (used to form a small number of ATP molecules – 2 ATP) are released.
- The main product of the Kreb’s cycle are energy carrying molecules that get sent on to the next stage.
- Takes place in the Mitochondria
Check for Understanding # 6

1. Where does the Kreb’s cycle occur?
2. What is the first reactant of the Kreb’s cycle?
3. How many total ATP are produced in the Kreb’s cycle?
4. Why is the Kreb’s cycle an aerobic process?
5. What is produced in the Kreb’s cycle?
6. What are the carriers for the Kreb’s cycle?
Cellular Respiration: Aerobic

- The second stage of aerobic respiration is the *electron transport chain*.
- The electron transport chain is a series of chemical reactions in which energy is transferred to form a large number of ATP molecules (up to 34 ATP).
- At the end of the chain oxygen enters the process and is combined with hydrogen to form water.
- Takes place in the Mitochondria
Check for Understanding # 7

1. Where does the ETC take place?
2. How many ATP molecules are made in the ETC?
3. What has to be present for the ETC to take place?
4. What is the purpose of oxygen in the ETC?
In a Nut Shell
Aerobic Respiration

• the process of aerobic respiration is generally represented using a balanced chemical equation. However, this equation does not represent all of the steps that occur during the process of aerobic respiration.

• \( C_6H_{12}O_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{energy (ATP)} \)

• In general, one glucose molecule and six oxygen molecules are needed to produce six carbon dioxide molecules and six water molecules.
In a Nut Shell
Aerobic Respiration

- Each of the reactants (glucose and oxygen) is used during different stages of cellular respiration. Glucose is an input of glycolysis and oxygen is an input of the electron transport chain of aerobic respiration.
- Each of the products (carbon dioxide and water) is formed during different stages of the process. Carbon dioxide is released from the Krebs cycle and water is released at the end of the electron transport chain.
- Up to 38 molecules of ATP are made from the breakdown of one glucose molecule: 2 from glycolysis and up to 36 from aerobic respiration.
- Most of the energy released by cellular respiration, that is not used to make ATP, is released in the form of heat.
Check for Understanding # 8

1. How many ATP come from Glycolysis?
2. What is the MAIN goal of glycolysis?
3. How many ATP come from the Kreb’s cycle?
4. How many ATP come from the ETC?
5. Which of the three parts of cellular respiration are aerobic, and which are anaerobic?
Cellular Respiration: Anaerobic

• If no oxygen is available, cells can obtain energy through the process of *anaerobic respiration*.

• *Fermentation* is an anaerobic process that allows glycolysis (which is also anaerobic) to continue making ATP in the absence of oxygen.
  • Fermentation is not an efficient process and results in the formation of far fewer ATP molecules than aerobic respiration. (only 2 ATP compared to up to 36 ATP)
Fermentation

• Two fermentation processes that occur in many organisms are:
  • Lactic Acid
  • Alcoholic

• No matter which path is taken, which is dependent upon what type of organism/cell, glycolysis occurs first
Fermentation: Lactic Acid

• Occurs, for example, in muscle tissues during rapid and vigorous exercise when muscle cells may be depleted of oxygen.

• Also used by bacteria in the production of food products such as yogurt and sauerkraut.

• The pyruvic acid formed during glycolysis is broken down to lactic acid, and in the process energy is released, which can be used in glycolysis to make ATP.

  • Glucose → Pyruvic acid → Lactic acid + energy

• Once oxygen becomes available again, muscle cells return to using aerobic respiration.
Fermentation: Alcoholic

- Occurs in many yeast species
- Pyruvic acid formed during glycolysis is broken down to produce alcohol and carbon dioxide, and in the process energy is released can be used by glycolysis to make ATP.
  - Glucose $\rightarrow$ Pyruvic acid $\rightarrow$ alcohol + carbon dioxide + energy
Check for Understanding # 9

• 1. When does fermentation occur?
• 2. Where does fermentation occur?
• 3. What is the purpose of fermentation?
• 4. Why is it important that glycolysis continues?
• 5. What are the 2 types of fermentation? Give an example of each.
• The products of photosynthesis become the reactants used in cellular respiration

• The products of cellular respiration become the reactants used in photosynthesis
• Aerobic respiration creates more ATP energy molecules than fermentation
Check for Understanding # 10

1. When there is no oxygen available to an animal cell what type of cell respiration occurs?
2. What are the two types of Fermentation?
3. When muscle cells undergo fermentation, what is the waste product produced?
4. When yeast cells undergo fermentation, what is the waste product produced?