Cellular Respiration and Photosynthesis
ENVS 10
Lecture 5

Energy Flow and Chemical Cycling in the Biosphere

- Fuel molecules in food represent solar energy.
  - Energy stored in food can be traced back to the sun.
- Animals depend on plants to convert solar energy to chemical energy.
  - This chemical energy is in the form of sugars and other organic molecules.

- Photosynthesis
  - Uses light energy from the sun to power a chemical process that makes organic molecules.
  - Occurs in the chloroplasts of the leaves of terrestrial plants.
- Cellular Respiration
  - Harvests energy stored in sugar and other organic molecules to make a different form of energy.
  - Occurs mostly in the mitochondria of plant and animal cells.

Producers and Consumers

- Autotrophs
  - Are “self-feeders.”
  - Include plants and other organisms that make all their own organic matter from inorganic nutrients.
  - Biologists call them Producers in ecosystems
- Heterotrophs
  - Are “other-feeders.”
  - Include humans and other animals that cannot make organic molecules from inorganic ones.
  - Biologists call them Consumers because eat plants or other animals

Figure 6.2

Chemical Cycling between Photosynthesis and Cellular Respiration

- The ingredients for photosynthesis are carbon dioxide and water.
  - CO_2 is obtained from the air by a plant’s leaves.
  - H_2O is obtained from the damp soil by a plant’s roots.
- Chloroplasts rearrange the atoms of these ingredients to produce sugars (glucose) and other organic molecules.
  - Oxygen gas is a by-product of photosynthesis.

- Both plants and animals perform cellular respiration.
  - Cellular respiration is a chemical process that harvests energy stored in sugars and other organic molecules.
  - Cellular respiration occurs in mitochondria.
  - Uses O_2 to convert food energy to ATP (energy).
- The waste products of cellular respiration, CO_2 and H_2O, are used in photosynthesis.

Chemical elements essential for life recycle between cellular respiration and photosynthesis

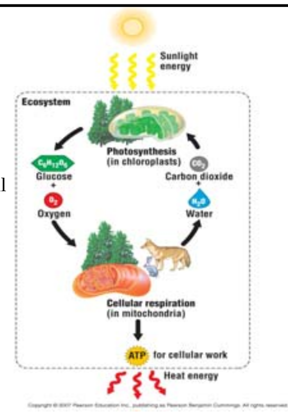
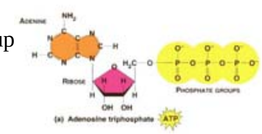


Figure 6.3

ATP

- Adenosine triphosphate
- Product of Cellular Respiration
- Main energy source for cells - stores and releases energy to power cellular work!
- Organic molecule called adenosine and a tail with three phosphate groups.
- Made when phosphate group added to ADP - Adenosine diphosphate



The ATP Cycle - Energy Coupling

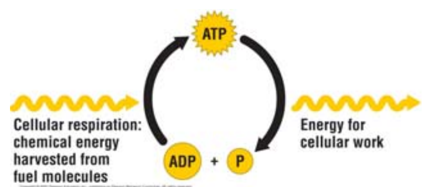


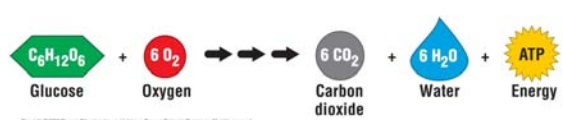
Figure 5.7

Cellular Respiration: Aerobic Harvest of Food Energy

- Cellular respiration
  - Is the main way that chemical energy is harvested from organic fuel molecules and converted to ATP (energy).
  - Is an *aerobic* process—it requires oxygen.

The Overall Equation for Cellular Respiration

- A common fuel molecule for cellular respiration is glucose.
  - The overall equation for what happens to glucose during cellular respiration is below:



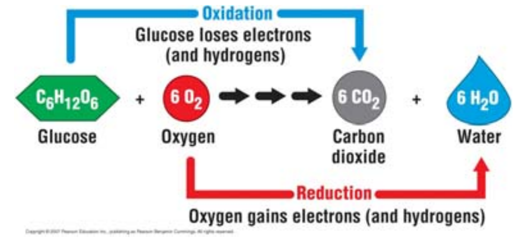
Unnumbered Figure 6.1

The Role of Oxygen in Cellular Respiration

- During cellular respiration, hydrogen (in glucose) and its bonding electrons change partners.
  - Hydrogen and its electrons go from sugar to oxygen, forming water.

- Redox Reaction
  - Chemical reaction that transfer electrons from one substance to another are called oxidation-reduction reactions, "redox reactions" for short.

- The loss of electrons during a redox reaction is called oxidation.
- The acceptance of electrons during a redox reaction is called reduction.



Unnumbered Figure 6.2

- When hydrogen and its bonding electrons change partners from sugar to oxygen in cellular respiration, energy is released. Why does the electron transfer to oxygen release energy?
  - When electrons move from glucose to oxygen, it is as though they were falling; oxygen is an "electron grabber".
  - Like an apple falling from a tree
  - This "fall" of electrons releases energy in a stepwise cascade during cellular respiration.

NADH and Electron Transport Chains

- The path that electrons take on their way down from glucose to oxygen involves many steps.

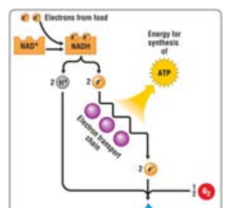


Figure 6.6

- The first step is an electron acceptor called NAD^+
- The transfer of electrons from organic fuel (food) to NAD^+ reduces it to NADH.
- The rest of the path consists of an electron transport chain.
- These lead ultimately to the production of large amounts of ATP.

The Metabolic Pathway of Cellular Respiration

- Cellular respiration is an example of a metabolic pathway
  - A series of chemical reactions in cells.
- All of the reactions involved in cellular respiration can be grouped into three main stages:
  - Glycolysis
  - The citric acid cycle
  - Electron transport

A Road Map for Cellular Respiration

- The path of glucose through cellular respiration

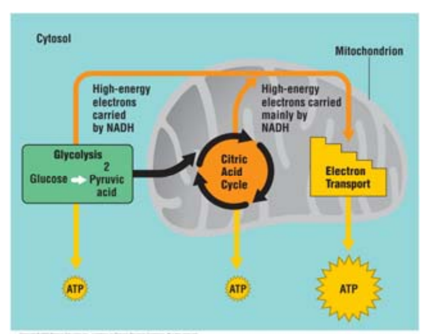


Figure 6.7

Stage 1: Glycolysis

- Glycolysis breaks a six-carbon molecule of glucose into two molecules of <u>pyruvic acid</u> (3-carbon molecules)
  - These molecules then donate high energy electrons to NAD^+, forming NADH.
- Glycolysis makes some ATP directly when enzymes transfer phosphate groups from fuel molecules to ADP.
- Review: Glycolysis breaks sugar into pyruvic acid and creates and stores some energy as NADH and ATP; occurs in cytolosol

Stage 1: Glycolysis

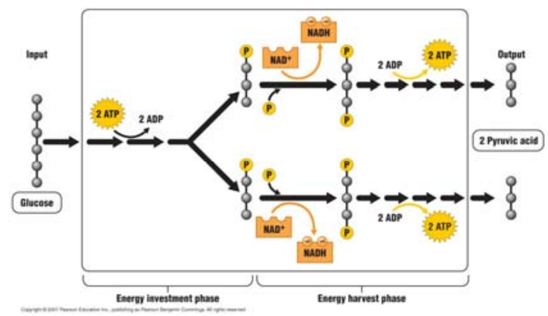


Figure 6.8

Stage 2: The Citric Acid Cycle

- The citric acid cycle completes the breakdown of sugar (glucose).
- In the citric acid cycle, pyruvic acid from glycolysis is first "prepped" into a usable form, Acetyl CoA.

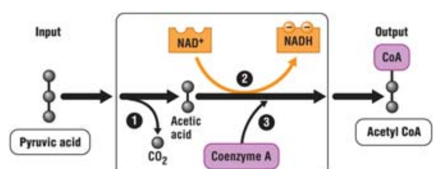


Figure 6.10

- The citric acid cycle finishes extracting the energy of sugar by breaking the acetic acid molecules all the way down to CO_2.
  - The cycle uses some of this energy to make ATP.
  - The cycle captures more energy in the form of NADH and $FADH_2$.
    - Electron acceptors/carriers
  - Occurs in Mitochondria

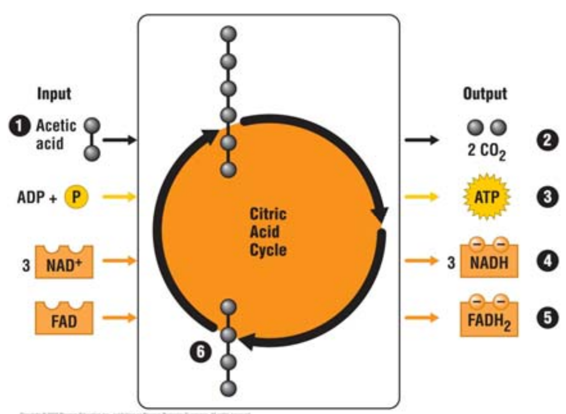


Figure 6.11

Stage 3: Electron Transport

- Electron transport releases the energy your cells need to <u>make most of their ATP</u>.
- The molecules of electron transport chains are built into the inner membranes of mitochondria.
  - The chain functions as a chemical machine that uses energy released by the "fall" of electrons to pump hydrogen ions across the inner mitochondrial membrane.
  - These ions store energy because they become more concentrated on one side of the memrbane.

- When the hydrogen ions rush back through the membrane, they release energy.
  - The ions flow through ATP synthase.
  - ATP synthase takes the energy from this flow, and synthesizes ATP by attaching phosphate groups to ADP.
- Occurs in Mitochondrial membrane

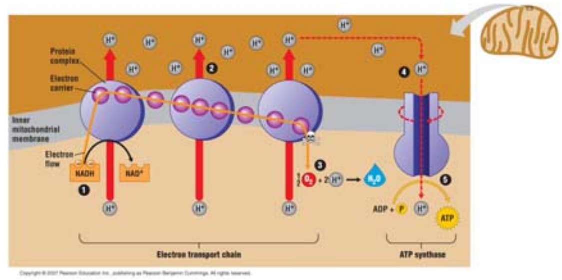


Figure 6.12

Adding Up the ATP from Cellular Respiration

- A summary of ATP yield during cellular respiration

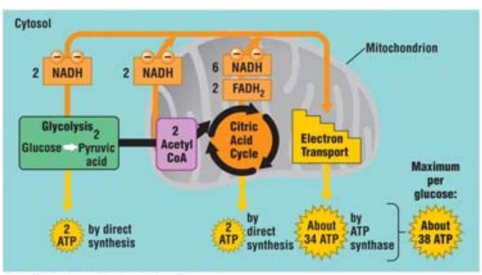


Figure 6.14

The Basics of Photosynthesis

- Almost all plants are photosynthetic autotrophs, as are some bacteria and protists.
  - They generate their own organic matter through photosynthesis.

Figure 7.2

Photosynthesis Occurs in Chloroplasts

- Chloroplasts
  - Are found in the interior cells of leaves.
  - Contain stroma, a thick fluid.
  - Contain thylakoids, membranous sacs.

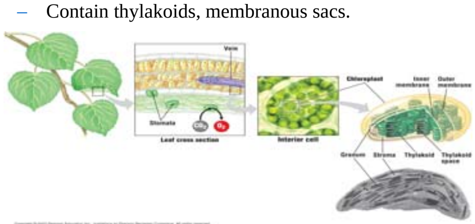
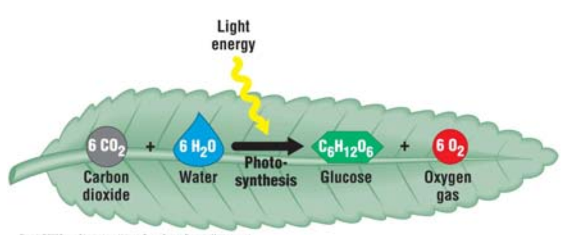


Figure 7.3

The Overall Equation for Photosynthesis

- The reactants and products of the reaction



Unnumbered Figure 7.1

- In photosynthesis,
  - Energized electrons are “boosted uphill” and added to carbon dioxide to make sugar.
  - Hydrogen moved with electrons so redox reaction is hydrogen transfered from water to carbon dioxide to make sugar.
  - Requires chloroplasts to split water molecules.
  - Requires energy - Sunlight provides the energy.

A Photosynthesis Road Map

- Photosynthesis is composed of two processes:
  - The light reactions convert solar energy to chemical energy.
  - The Calvin cycle makes sugar from carbon dioxide.

Photosynthesis: Summary of two processes

Light Reactions: convert solar energy to chemical energy

- In Thylakoids of chloroplasts
- Chlorophyll absorb light energy
- Energy converted to ATP and NADPH

Calvin Cycle: sugar production

- Uses ATP and NADPH from light reactions to power sugar production from CO_2

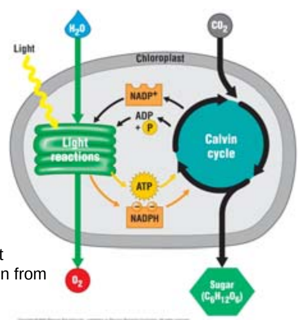


Figure 7.4

The Light Reactions: Converting Solar Energy to Chemical Energy

- Chloroplasts are chemical factories powered by the sun that convert solar energy into chemical energy.
- Sunlight is a type of energy called radiation or electromagnetic energy that travels through space as waves.
- Chloroplasts absorb select wavelengths of light that drive photosynthesis.

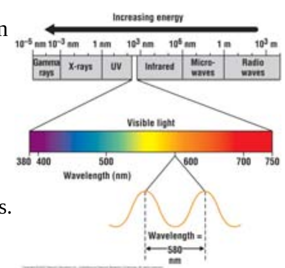


Figure 7.5

Chloroplast Pigments

- Chloroplasts contain several pigments:
  - Chlorophyll a: absorbs blue-violet and red light; participates directly in light reactions
  - Chlorophyll b: absorbs blue and orange light; broadens the range of light that a plant can use by conveying absorbed energy to *chlorophyll a*
  - Carotenoids: absorbs blue-green light; some pass energy to *chlorophyll a*, others absorb and dissipate excessive light energy that would otherwise damage chlorophyll

How Photosystems Harvest Light Energy

- Theory of light as waves explains most of light’s properties.
- Light also behaves as photons, discrete packets of energy.
- Chlorophyll pigment molecules absorb photons.
  - Electrons in the pigment molecule gain energy.
  - The energy is released and used.

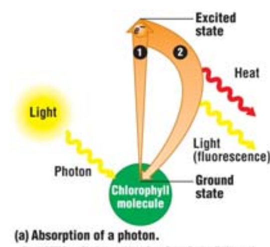


Figure 7.9

- A photosystem
  - Is an organized group of chlorophyll and other molecules.
    - Cluster of a few hundred pigment molecules, including chlorophyll *a* and *b* and carotenoids
  - Is a light-gathering antenna that focuses energy onto a reaction center.

Photosystems

Reaction Center: chlorophyll *a* transfers light excited electron to a primary electron acceptor.

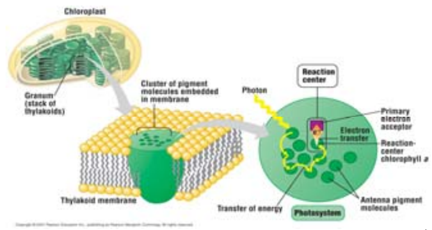


Figure 7.10

A different photosystem then uses the trapped energy from the electron acceptor to make ATP and NADPH.

How the Light Reactions Generate ATP and NADPH

Photosynthesis Stage 1: Two types of photosystems cooperate in the light reactions - Water-splitting and NADPH-producing

1. Photons excite electrons in chlorophyll of water-splitting photosystem and are then trapped by acceptor
2. Energized electrons then pass *down* transport chain to NADPH-producing photosystem
3. NADPH-producing photosystem transfers electrons to $NADP^+$ reducing it to NADPH

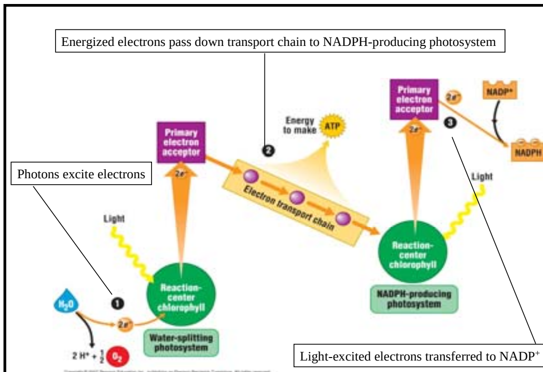


Figure 7.11

Figure 7.12

- An electron transport chain
  - Connects the two photosystems.
  - Releases energy that the chloroplast uses to make ATP.
  - Hydrogen ions pumped across thylakoid membrane, when the hydrogen ions rush back through the membrane, they flow through ATP synthase.
  - ATP synthase takes the energy from this flow, and synthesizes ATP by attaching phosphate groups to ADP.

The two photosystems and the electron transport chain that connects them transfer electrons from H_2O to $NADP^+$, reducing it to NADPH. The electron transport chain also functions as a H^+ pump. ATP synthase uses energy of H^+ gradient to make ATP.

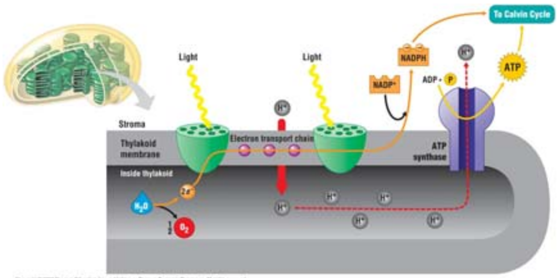


Figure 7.13

The Calvin Cycle: Making Sugar from Carbon Dioxide

- The Calvin cycle
  - Functions like a sugar factory within a chloroplast.
  - Called a cycle because regenerates the starting material with each turn.
  - Inputs are CO_2 from the air and ATP and NADPH produced by light reactions.
  - Constructs an energy-rich sugar molecule called glyceraldehyde 3-phosphate (G3P).
  - Plant call then uses G3P to make glucose and other organic molecules it needs.

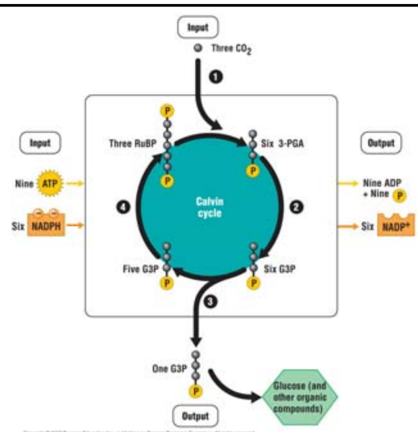


Figure 7.14

The Environmental Impact of Photosynthesis

- Photosynthesis has an enormous impact on the atmosphere.
  - It swaps O_2 for CO_2.
    - The O_2 sustains cellular respiration in many organisms.
    - Helps moderate temperatures on Earth.

How Photosynthesis Moderates Global Warming

- Greenhouses used to grow plant indoors
  - Trap sunlight that warms the air inside.

Figure 7.17

- A similar process, the greenhouse effect,
  - Warms the atmosphere.
  - Is caused by atmospheric CO_2.
  - Operates on a global scale.

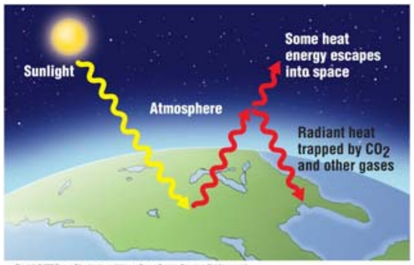


Figure 7.18

- Greenhouse gases are the most likely cause of global warming, a slow but steady rise in the Earth's surface temperature.
  - Gases in atmosphere that absorb heat radiation
  - Natural: water vapor, CO_2, CH_4
  - Synthetic: chlorofluorocarbons (e.g., aerosol sprays)
  - Destruction of forests may be increasing this effect.

Carbon Dioxide: CO_2

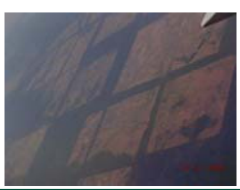
- One of the most important greenhouse gases
- Photosynthesis absorbs billions of tons of CO_2 each year
- Carbon returns to atmosphere by cellular respiration, action of decomposers, fires
- Large amount trapped in forests, undecomposed organisms, fossil fuels buried deep under the Earth's surface

Global Warming

- Since the industrial revolution, the atmospheric concentration of CO_2 has increased over 35% - burning carbon-based fossil fuels (coal, oil, gasoline)
- Increasing concentrations of greenhouse gases have been linked to *global warming* - slow but steady rise in Earth's surface temperature

Global Warming

- Rise in CO_2 coincided with widespread deforestation
- Reduces removal of CO_2 from atmosphere by forests
- Compounds the problem!



Energy Plantation and Carbon Sequestration

- Energy Plantations
- Carbon Sequestration

Figure 7.1