Visualizing Cell Processes

A Series of Five Programs
produced by BioMEDIA ASSOCIATES

Content Guide for Program 3

Photosynthesis and Cellular Respiration

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Each of the five programs in this series consists of a set of short, narrated, full-motion modules 1-3 minutes long. Each module conveys an essential process or concept of cellular biology. The modules are organized around national standards for teaching biology.

Photosynthesis uses light energy to make molecules that fuel the processes of life. During photosynthesis, raw materials—carbon dioxide and water—are converted into energy-rich fuel molecules such as sugars and fatty acids.

In order to harvest the energy stored in these fuel molecules, cells convert them back into carbon dioxide and water, the same raw materials that were used to begin the process. This enzymatic breakdown of fuel molecules is called cellular respiration.

A primitive way to extract energy from food molecules is by fermentation, a process carried out by yeasts and bacteria in which sugars are broken down into carbon dioxide and ethyl alcohol. A small amount of energy in the form of ATP is harvested for use by the cell. The alcohol waste product contains most of the chemical bond energy that held the sugar molecule together. (Ethyl alcohol is so high in stored energy it's used as fuel in race cars.)

1: Glycolysis

Glycolysis is the necessary first stage in aerobic respiration. In glycolysis, a molecule of glucose—a simple sugar—is broken down into two molecules of pyruvic acid. This process occurs in the cytosol, not in mitochondria where aerobic metabolism takes place.

Glycolysis involves a series of nine steps each mediated by an enzyme (depicted in the program as cylinders). In steps one through four, two ATPs are used to split a glucose molecule into two molecules of glyceraldehyde phosphate (P-GAL).

In the next steps, electrons from P-GAL are transferred to molecules of NAD+ converting them into molecules of NADH, an important energy carrier. In addition, two molecules of ATP are produced paying back the original investment of two ATPs. The end product of this reaction is two molecules of pyruvic acid— an important fuel molecule that can be further metabolized in mitochondria.

2: Aerobic Respiration

Most of a eukaryotic cell's ATP synthesis occurs in mitochondria, the sausage shaped organelles where aerobic respiration occurs. Mitochondria evolved from symbiotic bacteria that began living with nucleated cells somewhere between two and three billion years ago. They still retain enough of the original bacterial DNA to carry out their own reproduction.

A mitochondrion is a sack within a sack. The outer sac is thought to have originated as the engulfment membrane, belonging to that long ago host-cell. The inner membrane (the original symbiotic bacterium's plasma membrane) is folded, or contains finger-like projections providing increased surface area for the reactions involved in ATP synthesis.

Between the inner and outer membranes is the intermembrane space—a reservoir for hydrogen ions used for synthesizing ATP from ADP.

The inner chamber, known as the matrix, is a soup of enzymes that dismantle fuel molecules in cyclic reactions known as the Krebs cycle.

3: The Krebs Cycle and ATP Synthesis

When cyanobacteria began liberating oxygen into the atmosphere, around two billion years ago they drastically changed the evolutionary course of all life to follow. Oxygen's powerful attraction for electrons made it possible to break down the end product of glycolysis—pyruvic acid, into carbon dioxide and water with a tremendous harvest of energy.

In eukaryotic cells, pyruvic acid enters the mitochondrion where it falls into a series of reactions (the Krebs Cycle) in which the carbon backbones are broken down producing a cascade of energy-carrier molecules.

These energy carriers transfer energy to electron transport proteins embedded in the inner membrane of the mitochondrion. The energy is used to pull hydrogen ions out of the matrix, jamming them into the intermembrane space, setting up conditions for ATP synthesis.

The flood of hydrogen ions creates an imbalance in concentration and in electrical charge. This imbalance creates a back flow of hydrogen ions through the enzyme ATP synthase, the knobs on the mitochondrion's inner membrane. ATP synthase uses energy from the back flow of hydrogen ions to synthesize ATP. Aerobic respiration is vastly more efficient than glycolysis alone. One molecule of glucose broken down by glycolysis yields a net gain of two ATPs. The same glucose molecule, broken down in a mitochondrion, yields a gain of up to 38 ATPs.

As aerobic respiration became established in protist-like microbes, and oxygen became more abundant, the pace of evolution picked up leading to multicellular organisms and the evolutionary explosion of the major animal phyla around 550 million years ago.

PHOTOSYNTHESIS

Plant cells contain rounded green bodies called "chloroplasts." Just as mitochondria had their evolutionary beginnings as aerobic symbionts, chloroplasts evolved from photosynthetic symbionts. Chloroplasts retain some of their original DNA and carry out their own reproduction, independent of the plant cells in which they now live.

4: Chloroplasts, and The Light Dependent Reactions of Photosynthesis

Chloroplasts are composed of an outer membrane and an inner membrane containing stacks of hollow discs called “thylakoids.” The thylakoid membranes are embedded with chlorophyll molecules and proteins that make up a photo system for the conversion of light into chemical energy.

When light hits a chlorophyll molecule, its energy boosts one of the chlorophyll’s electrons to a higher energy level. Patches of chlorophyll molecules form light-trapping antennae that channel these excited electrons to a central chlorophyll called “the reaction center.” Reaction center chlorophylls pass the energized electrons to proteins embedded in the thylakoid membrane. These membrane proteins use the electron’s energy to synthesize NADPH and ATP, creating a supply of energy carriers that can be used in the synthesis of sugars and other biological compounds in the so called “light independent reactions of photosynthesis.”

In broad strokes, this is how the light dependent reactions work: Excited electrons from chlorophyll are captured by a protein complex called “Photosystem II” where they pass through a series of electron-carrier proteins embedded in the thylakoid membrane.

The electron carriers use the energy to pump hydrogen ions into the thylakoid space where they diffuse back through an enzyme—ATP synthase—that uses the flow of protons to generate ATP. (The same process found in mitochondria.)

The partially spent electron moves to a second reaction center called “Photosystem I” where another photon of light energy boosts the electron to an even higher energy level. It now has enough energy to make a second kind of energy carrier—NADPH.

The other process occurring on the thylakoid membrane is the splitting of water molecules. Water supplies hydrogen ions needed for ATP synthesis—and oxygen, which is given off as a waste product.

5: The Light Independent Reactions of Photosynthesis

Within a chloroplast the thylakoid discs float in a soup of enzymes— the stroma. This is where food molecules are manufactured. Diffusing into the stroma, ATP and NADPH supply energy for the synthesis of the universal building block of carbohydrates: glyceraldehyde phosphate—P-GAL, building up the three carbon compound from carbon dioxide taken in from the atmosphere.

The cycle of reaction, called the Calvin Cycle, is essentially the reverse of the Krebs Cycle found in mitochondria. The cyclic nature of these reactions are depicted by animation. Stop the program at various parts of the animated cycle and match the events with a text diagram of the Krebs cycle. The products are molecules of P-GAL that are exported into the cytosol and used in the synthesis of important biological molecules. For example, in the cytosol, two P-GALs bond together to form a familiar six-carbon sugar, glucose, a fuel for plant metabolism and for plant eaters, as well.

THE BIG PICTURE

Mitochondria and chloroplasts have similar biochemical machinery, (not so surprising when biologists finally realized that both energy transforming organelles originated as bacteria). Using light as an energy source, chloroplasts synthesize the molecules of life.

Mitochondria break down those very same molecules and extract their energy through the processes of aerobic respiration. The products of one are the reactants of the other, creating a great natural cycle the helps maintain life on earth.

Other video programs in the ***Visualizing Cell Processes Series***:

Cells and Molecules (15 minutes)
Modules: A Variety of Cells, Cell Organization, Overview of Organic Molecules, Prokaryotic Cells, The Evolution of Eukaryotic Cells.

Photosynthesis and Cellular Respiration (15 minutes)
Photosynthesis Modules: Chloroplast Structure, Light Trapping by Chlorophyll, Light–Dependent Reactions of Photosynthesis, The Light–Independent Reactions of Photosynthesis
Respiration Modules: Glycolysis and Fermentation, Mitochondrion Structure, Aerobic Respiration, Krebs Cycle, Electron Transport Chain, ATP synthesis

DNA and Cell Reproduction (15 minutes)
Modules: Mitosis: Chromosome Condensation, Mitosis: Stages, Cytokinesis, Meiosis, Nucleotide Structure and Bonding, Replication Enzymes, Replicating the Strands, The Twisting Problem, Proof Reading and Repair

The Genetic Code and Its Translation (15 minutes)
Modules: The Protein Nature of Life, Protein Structure, Transcription, Translation and Protein Synthesis, Gene Regulation in Prokaryotes, Classes of Eukaryote DNA, Exons and Introns, Mutations, Renegade DNA – The Viruses.