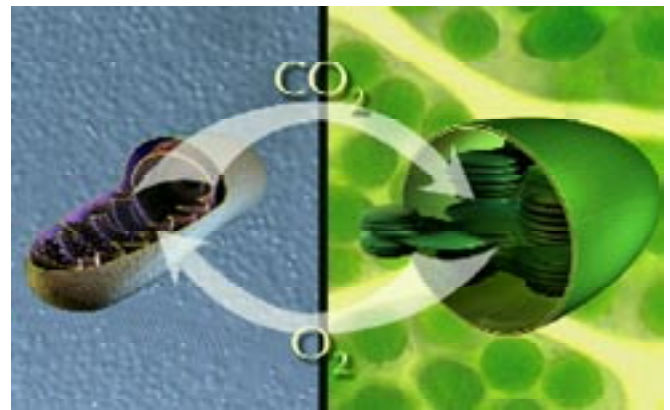


Inside the Living Cell

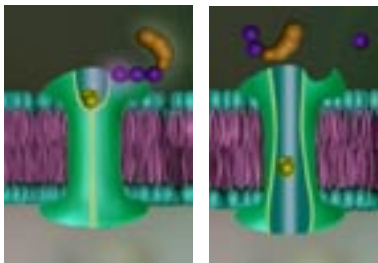
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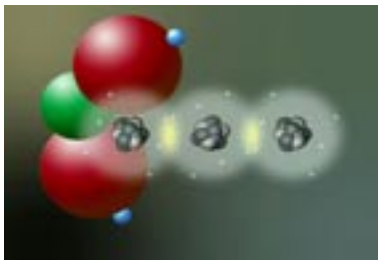
How Cells Obtain Energy

CELLS USE A LOT OF ENERGY

Life is an energy intensive process. It takes energy to operate muscles, extract wastes, make new cells, heal wounds, even to think. It's in an organism's cells where all this energy is spent.



In some cells, as much as half of a cell's energy output is used to transfer molecules across the cell membrane, a process called "active transport."

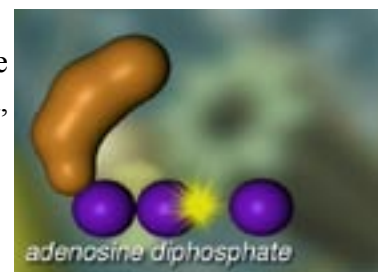
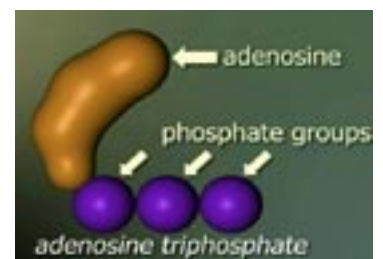


Cell movements require energy and thousands of energy-hungry chemical reactions go on in every living cell, every second, every day. The kind of energy cells use is chemical bond energy, the shared electrons that holds atoms together in molecules.

ATP THE UNIVERSAL ENERGY CARRIER

Most cell processes use the same energy source, the rechargeable energy carrier, adenosine tri phosphate -- ATP.

ATP has this arrangement: a molecular unit of adenosine coupled to a chain of three phosphate groups, thus the name, adenosine tri phosphate. The phosphate groups are held to each other by very high energy chemical bonds. But under certain conditions, the end phosphate can break away and the energy released to the energy-hungry reactions that keep a cell alive. When the end phosphate is released, what is left is ADP, adenosine diphosphate. This change from tri to di is taking place constantly as ATPs circulate through cells.



The recharging of ADP to ATP requires a huge energy investment, and that energy comes from the food we eat. How energy is extracted from food molecules and used to synthesize ATP is one of the great discoveries of modern biology.

MITOCHONDRIA, THE CELL'S POWERHOUSES

All nucleated cells contain mitochondria, the tiny bodies where ATP is produced. The best way to see mitochondria clearly is to squeeze the cell under a cover-glass until it ruptures, forming a thin membrane bubble, a little aquarium in which float a few of its mitochondria.

A mitochondrion consists of two sacs made of membrane. Folds in the inner sac increase the surface area for chemical reactions that produce ATP. By breaking up mitochondria and separating out the membranes, biochemists have discovered exactly where the chemical reactions involved in synthesizing ATP actually occur.

First, mitochondria take in molecules derived from food, molecules with lots of chemical-bond energy. These molecules are the break-down products of sugars and fats.

Sugar contains enough chemical bond energy to burn with a hot blue flame, but fat contains even more. Fat has about twice the energy content of sugar. If you can boil one test tube of water on a spoon full of sugar, a spoon full of fat will boil two.

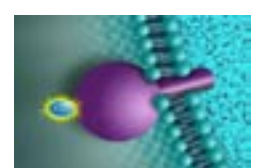
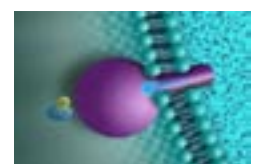
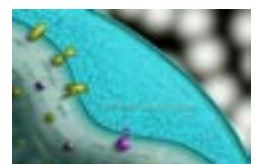
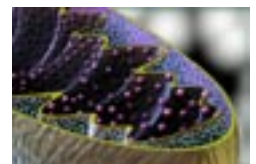
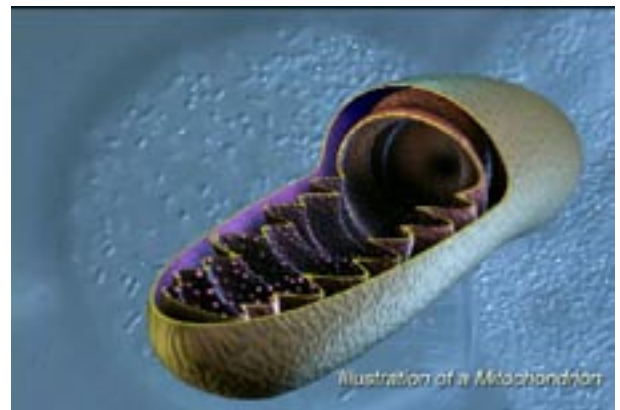
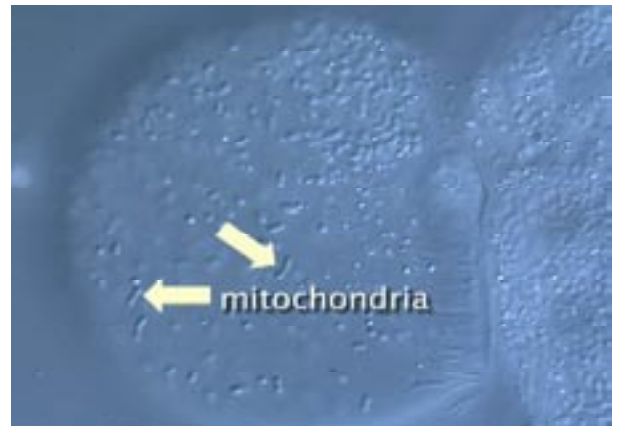
To understand how energy is extracted from these fuel molecules we need to climb right inside of a mitochondrion. In the space between the two sacs fuel molecules are disassembled in a way that releases their chemical bond energy. This energy, in the form of electrons, drives molecular pumps embedded in the inner membrane. The pumps push hydrogen ions, obtained from the fuel molecules, into the inner membrane sac. It's like blowing up a balloon.

It's during this process that oxygen plays its role. Oxygen has a powerful attraction for electrons. Think of the electrons released from fuel molecules as a stream of water. What oxygen does is lower the streambed dramatically, so that the water can do a lot more work.

Some bacteria can live in oxygen-free environments, but also have the ability to use oxygen if it is available. Without oxygen one of these cells can make two ATP molecules for every sugar molecule metabolized. With oxygen, the same cell can make 36 ATPs from each sugar molecule. Oxygen's powerful pull on electrons allows most of the energy in fuel molecules to be used to pump in hydrogen ions, increasing pressure in the outer sac.



The folded inner membrane is studded with enzymes. These enzymes, ATP synthase, offer an opening through which the built-up hydrogen ions can escape. As they exit through ATP synthase, they generate the energy required to bond the terminal phosphate on to ADP, converting it to ATP. That's how the ATP battery is recharged.

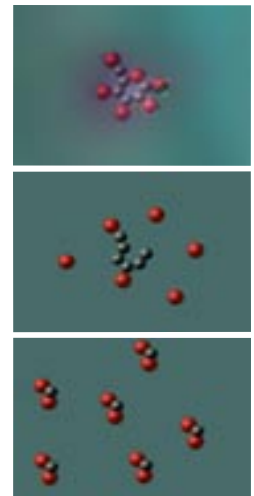


MITOCHONDRIA - continued

But what happens to all those carbon atoms that originally made up the fuel molecules? In the process, they combine with oxygen to form CO₂, carbon dioxide.

Carbon dioxide leaves the mitochondrion and escapes through the cell membrane where it's picked up by the blood stream and transferred to your lungs and exhaled when you breathe.

That's animal respiration: Oxygen in -- burn fuel molecules -- make ATP -- carbon dioxide out.

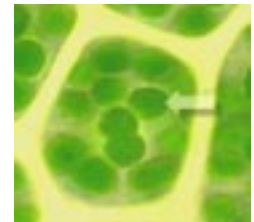


PHOTOSYNTHESIS



Photosynthesis is the way plants make fuel molecules to feed their mitochondria. In terms of getting energy, the only real difference between plants and animals is that plants make their own fuel molecules, where as we animals, in order to get fuel for our mitochondria, must eat plants, or eat something that has.

Under the microscope, a leaf cell looks like a box full of green jellybeans. These are chloroplasts, organelles containing chlorophyll molecules. There are several kinds of chlorophyll. The green chlorophyll found in plants absorbs the energetic blue and red wavelengths of light, while reflecting away green.



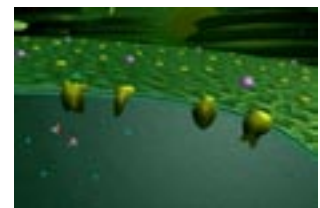
The first electron micrographs of sections through chloroplasts stunned biologists. These were definitely something more than little green jellybeans. They were bodies with an elaborate internal structure. They found that chloroplasts contain stacks of hollow discs called thylakoids. The thylakoid discs are covered by a carpet of chlorophyll molecules.



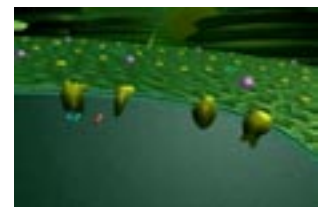
In these green carpets, light energy is converted into chemical energy -- a process that drives the living world.

THE LIGHT REACTIONS OF PHOTOSYNTHESIS

When light hits a plant some of the light energy absorbed by its chloroplasts is used to split water molecules into hydrogen ions and oxygen. The oxygen, a waste product, enters the atmosphere. The hydrogen ions are used in making ATP, the same energy carrier produced by mitochondria.



When a chlorophyll molecule absorbs a photon of light energy, it transfers the energy to an electron. So the arrays of chlorophyll act like solar panels, producing electron energy. But instead of flowing down a wire, the electrons flow through molecular pumps that pump hydrogen ions into the thylakoid space. Just as in mitochondria, these pressurized ions pass out through enzymes that create ATP and other energy carriers. These molecules supply the energy for the food-making reactions of photosynthesis.

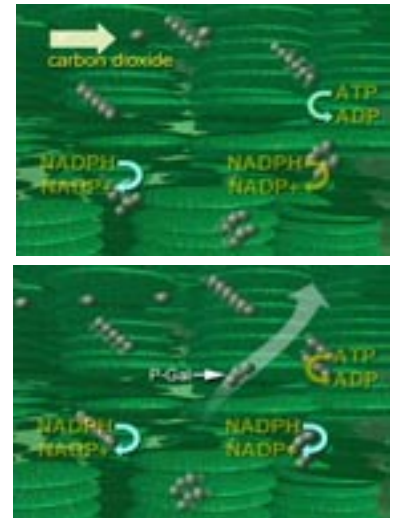


THE LIGHT INDEPENDENT REACTIONS

Food-making chemistry occurs in the soupy fluid that surrounds the thylakoid discs. Here, in a complex series of reactions known as the Calvin Cycle, carbon dioxide is coupled with longer carbon chains, using energy supplied by ATP and other energy carriers acquired from “the light reactions.” This cycle produces a kind of molecule with the rather intimidating name of Phosphogyceraldehyde, pGAL for short.

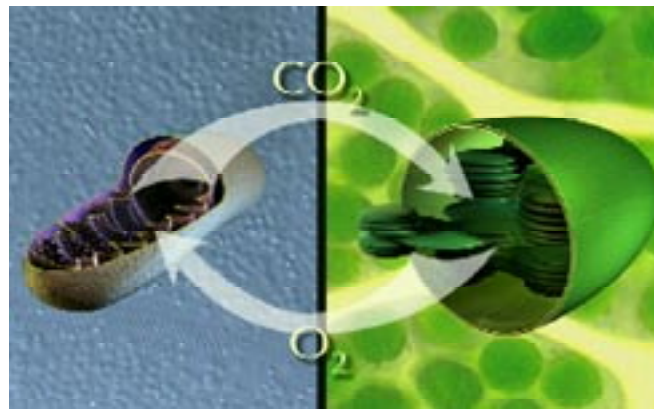
Some of the pGAL molecules keep the cycle rolling, and some of the three carbon pGALS enter an enzyme that unites them to form the six carbon sugar glucose.

So the essence of photosynthesis is: carbon dioxide in, light on, out comes oxygen, and glucose sugar.



SUMMARY AND REVIEW

So the cell’s two energy transforming organelles, mitochondria and chloroplasts, feed on the waste products of each other. CO₂ given off by mitochondria is exactly what chloroplasts need to make pGAL the building block of sugars and other carbohydrates. The oxygen released by chloroplasts during the light reactions is exactly what mitochondria need to drive the electrons -- that pump in the hydrogen ions -- making it possible for ATP synthase to add that terminal phosphate to ADP, creating ATP, the universal energy carrier.



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