Cycles

The second law of thermodynamics states that systems have a tendency towards disorder - that is, that over time, they should become less complex (or more random). Given enough time, the entire universe will gradually 'run down'.

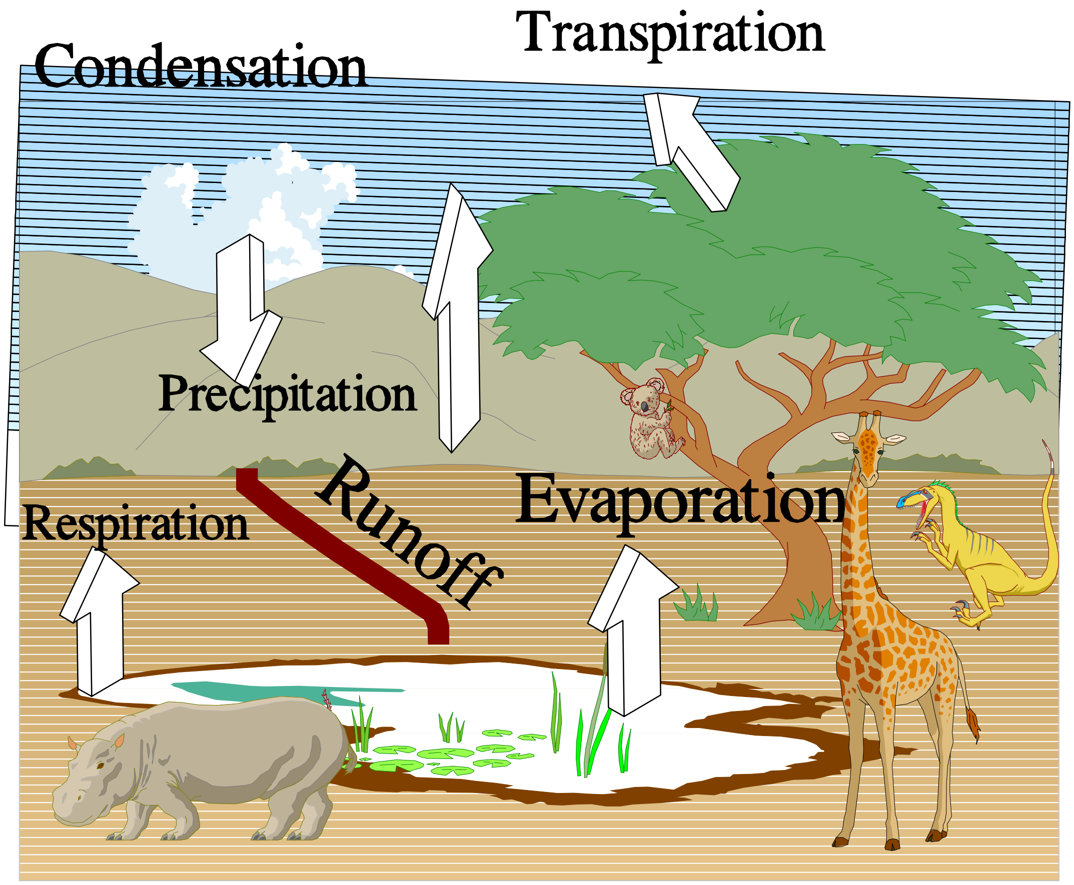
How then can we explain living systems, with their incredible complexity, apparently thriving despite the second law and its implications? Fortunately, the universe is not a uniform place, and universal concepts of time dwarf our own perspectives. In the process of running down, our sun will convert trillions and trillions of tons of energetic material into less energetic material, and in the process radiate energy out into space. The Earth lies in the path of this extravagance of energy, and thus is in the enviable position of gaining more energy than it loses to the surrounding state.

This energy can be utilized by living (**biotic**) and non-living (**abiotic**) systems alike. We will first examine two cycles that are driven by energy from the sun. These are the **water cycle** and the **carbon cycle**. These two cycles are critical to life on Earth. The water cycle is abiotic in nature, while the carbon cycle exists largely through the actions of living organisms.

The Water Cycle

Water, in its liquid form, is a collection of molecules loosely held together by weak electrical attraction between the molecules. All molecules, except those at the absolute zero of interstellar space, tend to vibrate in place. This vibration is called kinetic energy, and is measured as temperature. Molecules in a **solid** are close together and bound tightly. **Liquids** have their molecules bound more loosely and spaced further apart, and **gases** have the molecules spaced the greatest distance apart. If you add energy to a solid, the molecules vibrate more vigorously; with enough energy, the solid structure dissolves into a liquid. Continue to add energy (heat) and the liquid will evaporate into a gas.

The sun's rays strike water and add enough energy to the molecules at the surface that they break free of the water - they evaporate into the air to form **water vapor**. Warm liquids and gases (both liquids and gases can be called **fluids**) are less dense than cold fluids because in the warm fluids the molecules have more energy and are bouncing further apart, so that in any given volume there is are fewer molecules. The less dense fluids rise over the denser ones, so the evaporated water rises into the **atmosphere**. As the water vapor rises, it cools and **condenses**. **Clouds** are regions of tiny condensed water droplets. These coalesce and the heavier water drops fall to the ground as **rain** or **snow**, depending on the temperature. There, the water either runs over the surface, or percolates through the ground, as gravity pulls it to the lowest possible point. At any place along this route, the water may be evaporated again. Plants take up a lot of water which simply passes through their bodies and evaporates at the leaves (this process, **transpiration,** seems wasteful, but the flow of water brings in minerals and carries them to the tops of the plant, and the evaporating water cools the plant). Animals also evaporate a lot of water through their breathing.

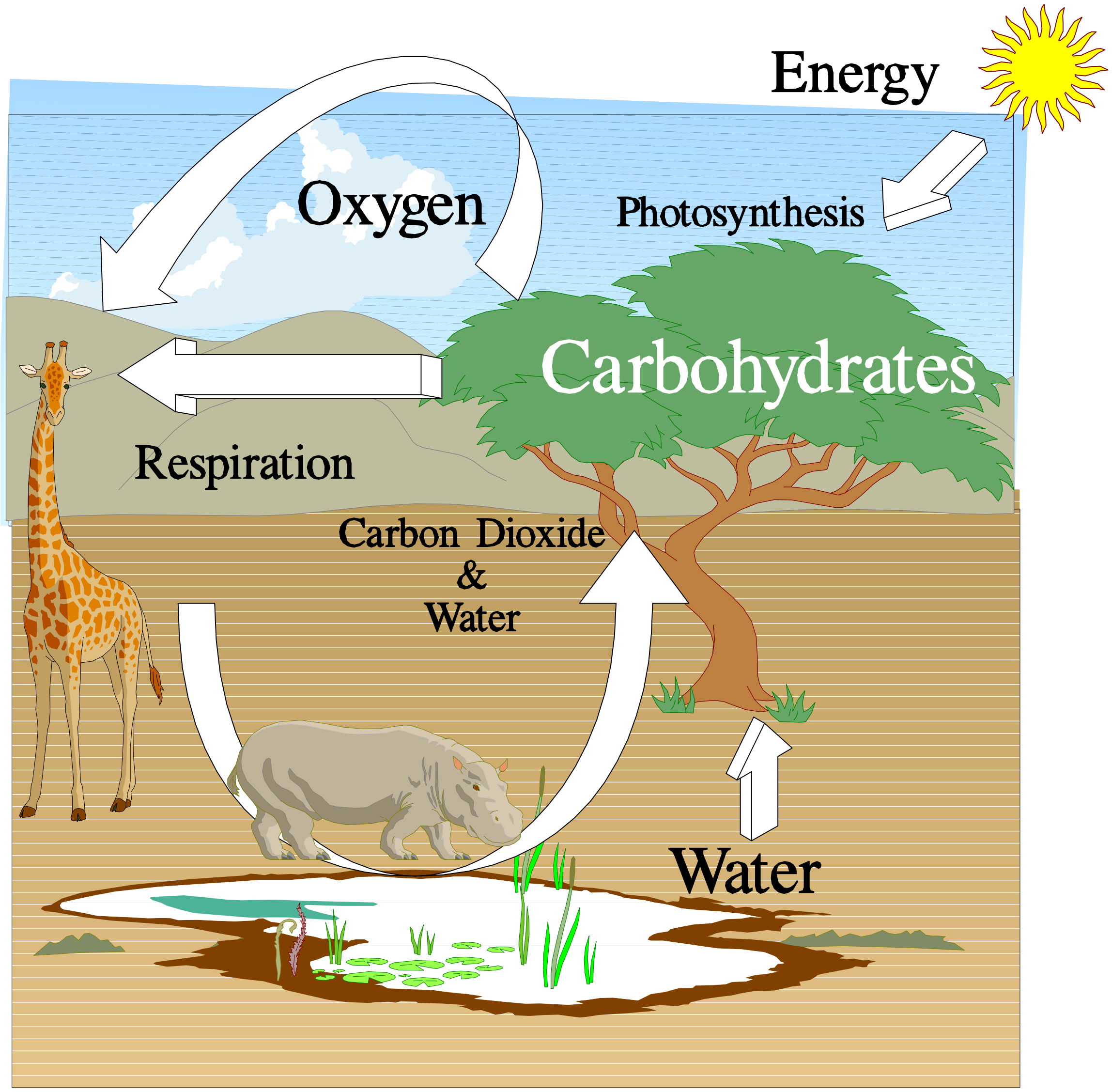


The Water Cycle

The Carbon Cycle

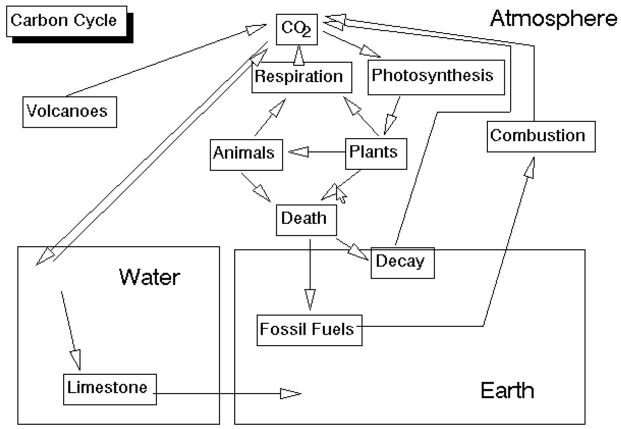
The other cycle crucial to life is the **carbon cycle**. Plants take in energy from the sun and use it to split water molecules (H_2O), which are composed of hydrogen and oxygen. They also take in **carbon dioxide** (CO_2). They combine hydrogen, carbon, and oxygen into **carbohydrates**, chemicals with the general formula CH_20. A carbohydrate may have thousands of atoms, but they will always be in the ratio of one carbon to two hydrogens to one oxygen. The process by which plants convert carbon dioxide and water to carbohydrates is known as **photosynthesis**. Since the plants take up more oxygen (in the CO_2 and H_2O) than they need for the carbohydrates, they end up ridding themselves of the excess oxygen to the atmosphere. This is the oxygen we breath. In fact, the early Earth had no oxygen in the atmosphere until early photosynthetic organisms (types of bacteria, in this case) produced it. The action of plants and other photosynthetic organisms over the last 2 or 3 billion years has raised the percentage of O_2 in the atmosphere to about 21%. Much more and forests would spontaneously ignite! In addition, oxygen is toxic to many organisms.

When plants need energy, they 'burn' some of the carbohydrates they have formed (usually stored in the form of starch); this releases energy they can use to grow, obtain minerals, etc. In the process, they combine the carbohydrates with oxygen to form carbon dioxide and water — the exact materials they started out with. This process is called **respiration**. Most plants photosynthesize much more than they respire; the net result is an accumulation of carbon in the carbohydrates of the plants' bodies and of oxygen in the atmosphere. Animals which eat the plants use the carbohydrates for respiration, returning carbon dioxide into the atmosphere and removing oxygen from the atmosphere. All in all, respiration and photosynthesis are in balance over the planet.



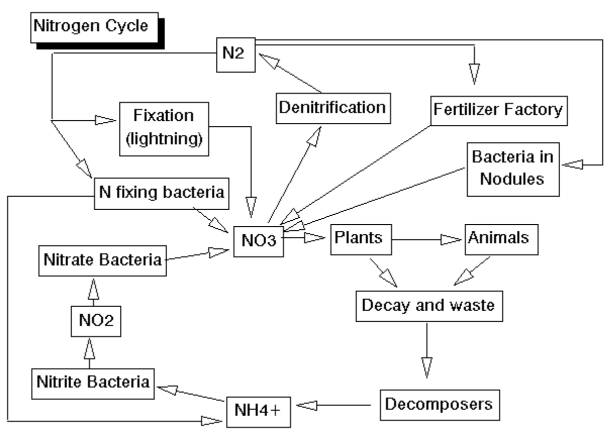
The Carbon Cycle

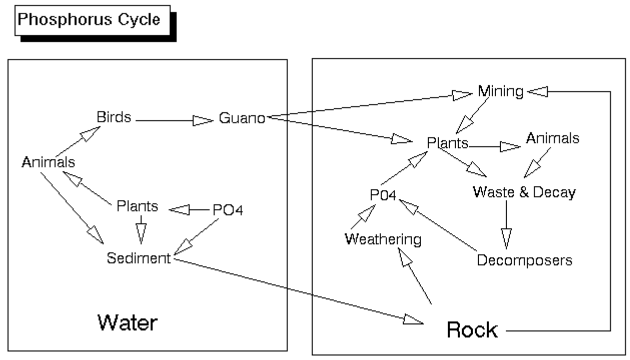
The material above describes much of the biotic part of the carbon cycle. There are also immense abiotic processes involved. Volcanoes bring up CO_2 from deep in the Earth's crust. Water in the oceans absorbs CO_2 from the atmosphere; it may eventually be turned into rock (limestone). Animals and plants die; when they die they may be **decomposed** by other organisms; this respiration returns their CO_2 to the atmosphere. If they are buried before they can decompose, however, they may form **fossil fuels**. When we burn coal or oil or gas we are returning that CO_2 to the atmosphere. A more detailed view of the carbon cycle is found below:



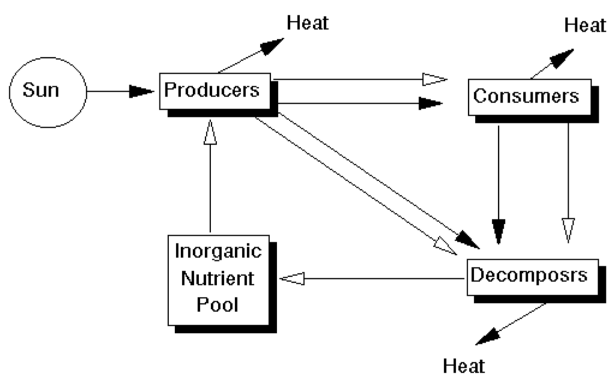
Other Cycles:

There are other cycles besides the carbon cycle and the water cycle. Two of particular importance are the **nitrogen cycle** and the **phosphorous cycle**. Both of these are important plant nutrients. Nitrogen is used in **proteins**; phosphorous is used to make cell membranes and ATP. As in the carbon cycle, the material moves from plants to animals and back. The abiotic part of the environment also plays a major role.





Finally, there is the cycling of energy through the ecosystem. Energy from the sun is absorbed by plants and incorporated into the carbohydrates. As the plants are eaten by animals (consumers), the energy is transferred as well. Likewise, when plants and animals die and decompose, the energy in their carbohydrates is used by the decomposers. At all levels, the organisms use some of the energy for their own activities; once used, this energy is lost from the system as heat. At the same time the energy is moving through the system as carbohydrates, other nutrients and minerals such as nitrogen and phosphorous are also passed along. The crucial difference is that these nutrients are never lost from the system; instead, they are able to be used by the plants and reincorporated into living tissue:



This crucial difference will become the basis for our discussion of trophic levels.

Some questions you should be able to answer:

How much water is there on Earth?
How much is in the oceans? Freshwater lakes and rivers? Ice? Groundwater?
What is a simple chemical formula for photosynthesis? Respiration?
What are the inputs for photosynthesis? The outputs?
What are the inputs for respiration? The outputs?
How does energy move through an ecosystem? In what forms?
How have humans affected the carbon cycle?
How have humans affected the nitrogen and phosphorous cycles?
What environmental problems have arisen from human alteration of basic biogeochemical cycles?