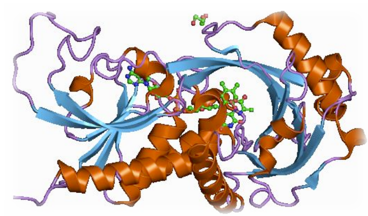
The Building Blocks of Life

Module 4 • i2P • La Ruta de Sal

"Few scientists acquainted with the chemistry of biological systems at the molecular level can avoid being inspired."

- Donald Cram



BITS OF LIFE

Chemistry is the study of matter. Matter is defined as "anything that has a mass and occupies space". A tree occupies space, and it is matter. A marshmallow occupies space, and it is matter. You occupy space, and you are matter. Virtually everything we can see is matter, and yet not all matter is equal.

There is a fundamental difference between you and a marshmallow. One of the two can move around a room, express opinions, adapt, play chess, and consume food (have you ever lost a chess-match to a marshmallow?). The difference is that one form of matter - you - are alive, and the marshmallow is not.

According to molecular biologist Daniel E. Koshland Jr., life should be defined according to the following seven conditions (see: definition of life):

1. it can reproduce;
2. it has the ability to adapt;
3. it is organized into at least one specialized compartment called a cell;
4. it can take energy from the environment and change it from one form to another;
5. it will ultimately degrade into a state known as death;
6. it responds to the surrounding environment through sensory stimuli;
7. it is able to maintain numerous metabolic reactions simultaneously.

A marshmallow fulfills none of these criteria; you fulfill them all. Yet curiously both you and a marshmallow are composed of very similar atoms. The human body is made of four principle elements: oxygen, carbon, hydrogen and

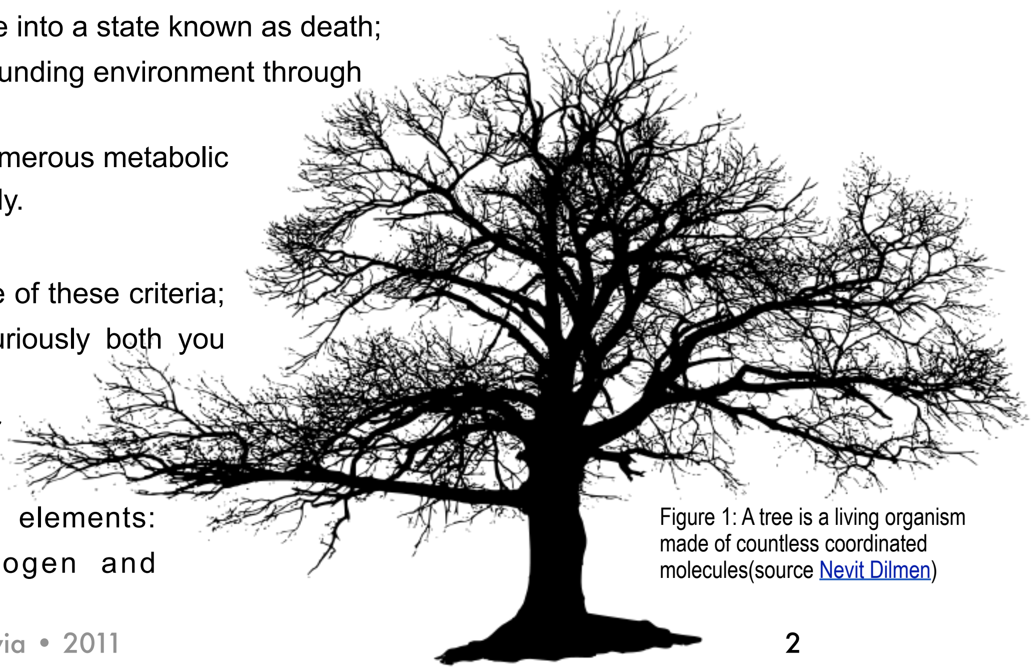


Figure 1: A tree is a living organism made of countless coordinated molecules(source Nevit Dilmen)

nitrogen. A marshmallow is also composed of oxygen, carbon, and hydrogen, but not nitrogen. This implies that the element nitrogen may confer life. Yet evidence is to the contrary: nitrogen is distributed widely through our solar system in matter that is inert and lifeless.

What is the chemical explanation for life?

Organic Chemistry

The answer to this question has been a matter of preoccupation for philosophers and scientists for centuries - but without resolution. The study of the compounds associated with life is called organic chemistry.

Definition: Organic

Of or relating to an organism; a living entity.

Figure 2: Friedrich Wohler, the first person to synthesize an organic compound in a laboratory.

It was once believed that only living things contained organic compounds, and that organic molecules contained an ill-defined 'vital force' that conferred life (analogous to the 'force' in the Stars Wars movie saga). However in 1928 when Friedrich Wohler (see: Wohler) accidentally created the organic compound urea from inorganic chemicals he had on his laboratory shelf, the scientific world was shocked. How could 'molecules of life' be created from lifeless substances off a shelf?

Since then it has been demonstrated that many lifeless materials are composed of organic compounds. The fuel that powers planes and cars is an organic compound. The list of organic materials also includes plastics, foods, drugs, explosives, paints, composite hockey sticks and perfumes.

Bonding

An organic molecule is composed of a series of atoms that are held together by bonds. A chemical bond is the relationship between two atoms in a molecule. All bonds store energy. Without the ability to bond, atoms could not form molecules and the world as we know it would not exist.

Definition: Organic Chemistry

The chemistry of compounds containing carbon (originally defined as the chemistry of substances produced by living organisms but now extended to substances synthesized artificially)

see: organic chemistry

All bonds are the result of interactions between electrons donated to the bond by participating atoms. In chemistry there are two principal kinds of bonds: *covalent* bonds and *ionic* bonds. An example of an ionic bond is found in table salt. It is an ionic bond that holds the sodium atom and chlorine atom together to form the salt crystals on the Salar de Uyuni, and the strength of the ionic bond will help support the weight of the i2P runners as they cross the salt flats.

In an ionic bond electrons are held tightly by the participating atoms and not shared, a covalent bond is formed when electrons from the participating atoms are shared. The bond that forms between a carbon and a nitrogen atom is an example of covalent bond. Both ionic and covalent bonds are present in the molecules associated with life.

Figure : A color representation of the emission line spectrum of neutral and ionized Carbon excited in a electrical discharge.

Carbon

Definition: Organic Chemistry

The chemistry of the carbon atom.

Organic molecules always contain at least one carbon atom. In this sense, carbon forms the backbone of all organic compounds. The ability of carbon to form covalent bonds is central to organic chemistry. To understand the bonding of carbon in organic compounds one must look at the structure of the carbon atom. Carbon has atomic number six in the periodic table which means that in its native form the carbon atom has six protons, six neutrons and six electrons. A covalent bond occurs when two adjoining atoms share a pair of electrons. The structure of the carbon atom is such that it has four available electrons to share. This means that it can form four covalent bonds with other atoms. No other element can form four reliable bonds like carbon (silicon can form four bonds, but those bonds have different properties).

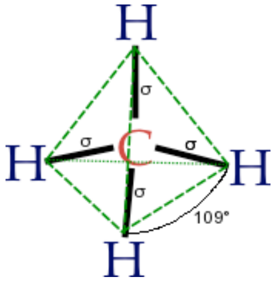


Figure 4: Each Carbon atom has the ability to form 4 bonds, each in a different direction, as illustrated in this illustration of a methane molecule (source: wmcommons)

The ability to form so many bonds makes carbon a very good atom with which to build complex molecules. Moreover, when carbon forms 4 covalent bonds, each bond is in a different direction from the carbon atom (visualize each of the four bonds extending from the carbon atom an ‘arm with a hand’ where each arm is equally distributed around the surface of a sphere). Thus, carbon based molecules can take many shapes: long chains as are found in hydrocarbons (oil), branching molecules like natural rubber, and ring structures like menthol from peppermint. Carbon

Did You Know?

The most poisonous molecule known to man is the botulism toxin. Botulism is a complex molecule made up of the four principal elements found in humans, oxygen, hydrogen, carbon and nitrogen, plus sulfur.

see: Botulism

can bond in so many different combinations that there are now over four million individual organic compounds that have been identified (see: organic).

Molecules of Life

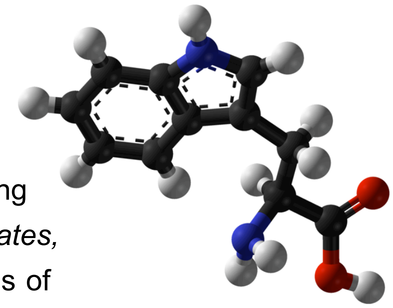


Figure 5: Tryptophan is a a protein essential to human health

There are four classes of carbon-based molecules that make up all living cells and tissue: *proteins, carbohydrates, lipids* and *nucleic acids*. Although all classes of molecules are made of similar atoms (Carbon, oxygen, hydrogen and nitrogen), they are assembled differently and perform different functions in living systems.

Proteins are composed of chains of molecules called amino acids. All amino acids contain the four major 'elements of life'; carbon, oxygen, hydrogen and nitrogen. Proteins have three main functions in biological systems.

- They serve as enzymes that catalyze chemical reactions
- They serve a signaling function, either as receivers of or as messengers of information.
- They have a structural function (found in muscle, cartilage, nails, hooves, and hair)

Figure 6: Eggshells are principally made of protein and tree trunks of carbohydrate (sources: Lokilech, dxlinh).

Carbohydrates are molecules that are composed of carbon and at least one water molecule (hence the term *carbo* (carbon) and *hydrate* (water)). Carbohydrates are a source of energy and form structural components of plants and some animals (stems of plants, trunks of trees, shells), and are important mediators of energy metabolism. They also make up part of the molecules that contain the 'code of life' (DNA and RNA) (see: carbohydrates). DNA and RNA are principally composed of nucleic acids. Lastly Lipids are a group of molecules that form fats and waxes. Their principle functions are to store energy, serve as structural function in cell walls, and serve as messengers. The i2P team will be eating mostly carbohydrates and lipids to fuel the run on the Salar.

Coordination of Molecules

Protein, carbohydrate, lipid and nucleic acid molecules must do the following to form and sustain life:

- Be arranged and coordinated in a very specific order
- Have a steady source of energy
- Have a steady supply of water

In tiny organisms like bacteria, the structure and coordination of molecules is relatively straightforward. Nonetheless, within a single celled organism, there is complex organization that compartmentalizes different cell functions. Large life forms like redwood trees, blue whales and human beings require a complex arrangement of molecules to allow for sustainable and reproducible life. This is accomplished by grouping molecules to form cell and tissue types like a heart, stomach, or brain in animals, or a trunk, branch, or leaf in plants.

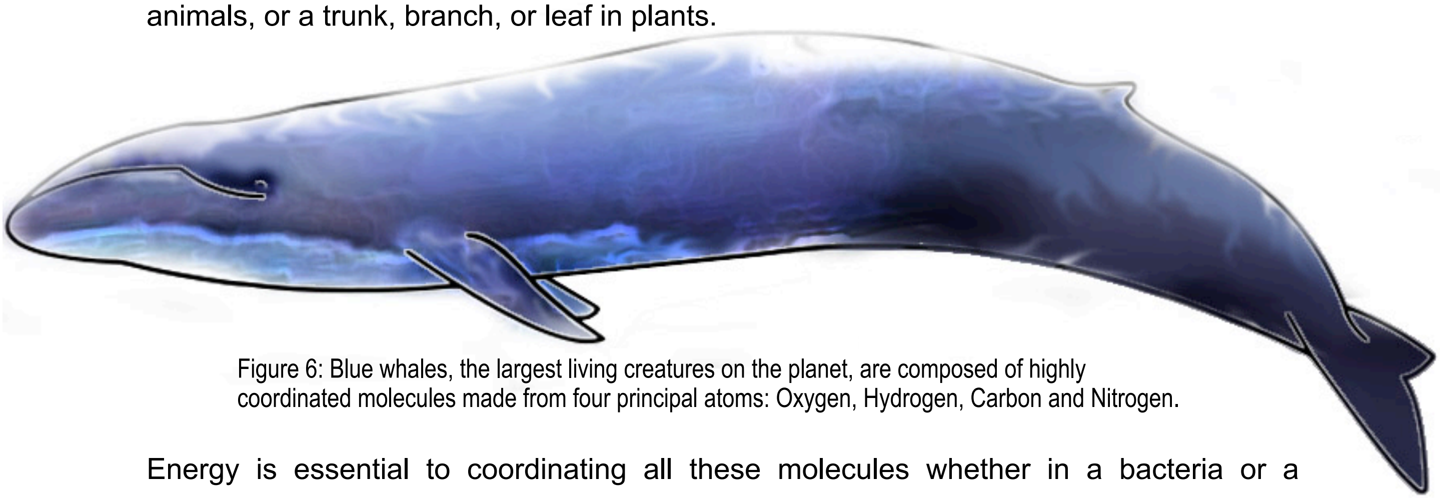


Figure 6: Blue whales, the largest living creatures on the planet, are composed of highly coordinated molecules made from four principal atoms: Oxygen, Hydrogen, Carbon and Nitrogen.

Energy is essential to coordinating all these molecules whether in a bacteria or a redwood tree. Without the ability to capture food a human will perish. Without the ability to capture sunlight a tree will die. Yet sound molecular structure, coordination and sources of energy alone are not enough to guarantee life. A stable and hospitable environment is essential.

Let us do a little imaginary experiment. If a healthy human being (excellent structure and coordination of molecules) with endless food supplies (energy) is made to stand naked outside in freezing temperatures, what will occur? Heat will gradually be lost from the body. As the core body temperature falls, chemical reactions that provide energy to body systems will begin to slow down. As chemical reactions slow down, organs like the heart, brain, and liver will fail, and death will follow.

Recall that atoms and molecules behave differently at different temperatures. So if the temperature of the human body is not stable the organic molecules that we are composed of will not react properly. Death from hypothermia is really a chemical death; the failure of chemical reactions in the body.

Life in Salt

The Salar de Uyuni is a vast area that is almost devoid of life, other than a scattering of animals that cross on foot. Why is the Salar so inhospitable to life? Is this because there are no organic molecules around from which to build life, or a lack of usable energy? Or is the environment chemically harsh?

> Did You Know?
>
> The ancient Sumerian civilization of Mesopotamia declined largely due to salt which gradually built up in the soil over hundreds of years of irrigation, making the fields infertile.
>
> see: salt

For life to survive on the Salar a few needs must be met. The Salar is bathed in sunlight daily so there is energy to support plants and other photosynthesizing life forms. There are certainly plants on the land encircling the Salar, like giant cacti, that could migrate onto the flats if they were able to. Seeds driven by the wind or rainwater do fall on the Salar but fail to germinate. It follows that the failure of plant life on the Salar indicates that it is a chemically inhospitable environment that does not support plant life. It has been demonstrated that high salt concentrations in soil obstructs seed germination and impedes the absorption of water and nutrients by plants. Thus it appears that the Salar de Uyuni is toxic to plant life.

Figure 7: Salt crystals which are composed of sodium and chloride (source: Mark Schellhase)

Or is it? This is one of the questions the i2P team will ask on the expedition to Bolivia. With the assistance of Dr. George Agnes from Simon Fraser University the i2P Youth Ambassadors will conduct an analysis of the Salar to establish if there are any organisms living on or in the flats.

Vital Force

We have successfully defined the atoms and molecules that make up life forms. We understand that to sustain life these atoms and molecules must be carefully arranged, coordinated, and supported by a steady supply of energy. We also understand that the atoms and molecules will not react properly if they are not in a stable environment.

> Did You Know?
>
> **Vitalism** is a school of scientific thought that attempts to explain the nature of life as resulting from a vital force peculiar to living organisms and different from all other forces found outside living things.

Has this knowledge brought us any closer to resolving the question we posed at the outset of the module about the difference between a marshmallow and a human being? Why is a marshmallow not alive and what vital force enlivens the organic molecules of life forms? Is it a magical force, or a gift decreed by a greater being? Or is life strictly a chemical process whose formula continues to elude scientists?

Figure 8: source: Lmbuga Galipedia