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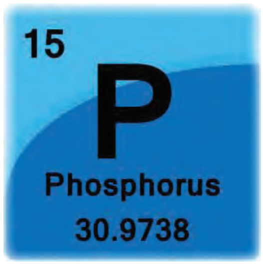
Special 3 Part Series: Part 3

LAKE WINNEBAGO
QUALITY IMPROVEMENT ASSOCIATION
of Fond du Lac County



This is the third and final article in a series examining phosphorus.

The first part looked at phosphorus as a pure element and its chemistry.

The second part described phosphorus in our environment and the phosphorus cycle.

This part investigates the role of phosphorus in living organisms.

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Understanding Phosphorus, Part 3

Phosphorus in Life

In the last part, we learned that phosphorus is present in rock and water in its most stable chemical form, the phosphate ion. That is true for living systems as well, all the phosphorus in living organisms is found as the phosphate ion or that ion chemically reacted with other biological molecules. Dissolved phosphate ion which is not incorporated into another biological molecule, it is still referred to as "inorganic" phosphate even though it is found in a living organism. It is called "organic" phosphorus only after it is incorporated into other biomolecules.

In the human body, there are 600 g (about 1.3 lbs) of phosphorus. It is the sixth most abundant element in the body. Most phosphorus, 85%, is found in the bone and teeth as the mineral hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$. This is similar to apatite rock ($Ca_3(PO_4)_2$) where most phosphorus is found in the earth's crust.

Phosphate ion undergoes two types of chemical reactions in cells, the formation of esters or diesters by reacting with an alcohol group (-OH), and anhydride formation when reacting with an acid group (-COOH) or another phosphate ion. All organic phosphate compounds are formed by one of these two reactions.

One of the main functions of phosphate ion in the cell is to act as a buffer, that is, to control acid levels. In the environment, the negatively charged phosphate ion interacted with positive metal ions, like calcium and aluminum. In the cell, the phosphate ion interacts with the hydrogen ion, H^+, to make $H_2PO_4^-$ and HPO_4^{2-}. These forms are still ions so they are still soluble and together they keep the pH, or acid level, of the cell constant. These also are a reservoir of inorganic phosphate that the cell can use for the other phosphate requiring functions and molecules.

All other functions of phosphate inside the cell are in combination with other biomolecules, making organic phosphate. The first of these functions is to temporarily capture energy from foods for later use. The energy is captured in high potential energy chemical bonds, the anhydride type connection mentioned above. The most common of these high energy molecules is adenosine triphosphate, ATP. In addition to temporary energy storage, this molecule is one of the precursor molecules of RNA. The energy of the anhydride links in ATP is used by the cell to drive reactions that otherwise would never happen. These reactions include building all the biomolecules needed for the cell to function, grow, and divide.

The next major biomolecule that incorporates phosphate is the nucleic acids, both DNA and RNA. DNA is often represented as a spiral ladder. The rungs of the ladder are the nitrogen containing bases that carry the genetic information. These rungs are held together by ester type links between phosphate and a sugar molecule, specifically for DNA, deoxyribose. Since each phosphate is able to make multiple ester links, it is the bridge between two deoxyribose sugar molecules to form the upright parts of the ladder, holding the bases in place. RNA is similar to DNA, it has the nitrogen containing base, a different but similar sugar ribose, and phosphate bridges. RNA is single stranded—only one side of the ladder and half of a rung.

The phospholipids are biomolecules that add a phosphate group to a molecule similar to fats and oils. Fats and oils do not mix with water and the portion of the phospholipid that resembles fat has that job, to not mix with water. However, after forming the ester type link to the lipid, the phosphate group is still ionized and readily mixes with water. This perfectly sets up the two almost independent parts of the phospholipid molecule for the job of creating the cell membrane, the barrier that keeps cell stuff inside and the rest of the world outside the cell. The cell membrane is made of two layers. The inner part of the cell is a water based fluid called the cytosol. The phosphate water-attracting part of the inner layer of the membrane faces the cytosol. The other lipid part of the molecule is held inside the membrane. This inner layer lipid interacts with the lipid portion of the outer layer of the membrane creating a water repelling double layer if oily fat. Finally, the phosphate portion of the outer membrane is exposed the exterior of the cell which is very often a watery environment. This dual-functioning phospholipid biomolecule can interact with the watery environment of the cell and outer cell fluid while preventing water, and other stuff, from crossing from one side to the other, effectively isolating the cell from the rest of the world.

Finally, phosphates are integral to internal chemistry regulation and relaying messages from outside to inside the cell. The biomolecule family responsible for chemical reactions and internal cell signaling is the protein family. Proteins run all the chemical reactions that keep the cell living. Some of these reactions need to be "on" some of the time and "off" at other times. Frequently, the on-off switch is adding or removing a phosphate group to or from the protein. This is the same idea for responding to external signals like hormones. Hormones tell the cell what conditions are like for the rest of the body. Once the hormone signal is received, a series of proteins can be turned on and others turned off by adding or removing phosphate so the cell properly responds to the rest of the body's needs.

Algae bloom on the surface of Lake Winnebago
Renee George

Phosphorus, then, has a tremendous impact on most cell functions, from energy and information storage and use, to keeping the cell intact and regulating the chemical reactions happening inside the cell. All in the form of the phosphate ion with its ability to form two types of structures, the anhydride and the ester groups. It is easy to see how limited amounts of phosphorus controls the rate of growth of pesky algae in our lakes and rivers.

Additional Sources:
http://lpi.oregonstate.edu/mic/minerals/phosphorus