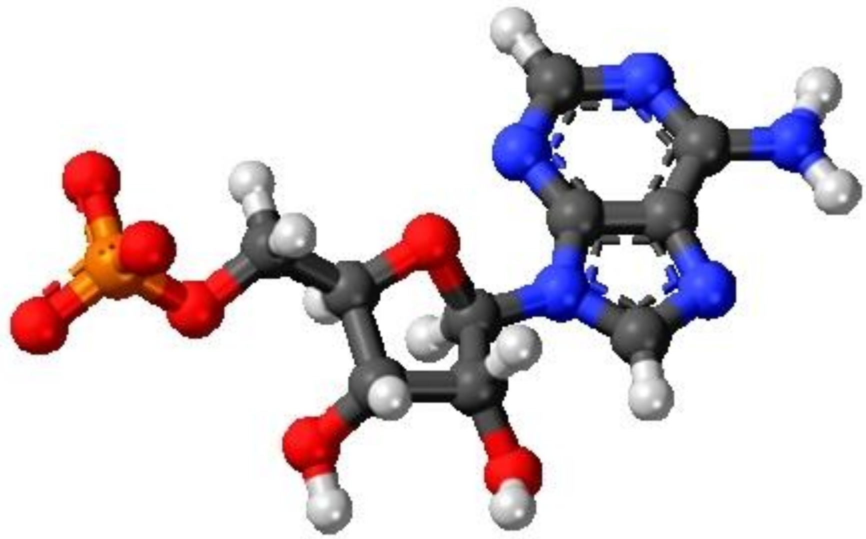
Phosphate



Adenosine monophosphate, nucleotide occurring in RNA. Creative Commons

Phosphate is an inorganic polyatomic ion whose molecular form is a negatively charged group of onephosphorus and four oxygen atoms. Phosphate comprises 99 percent of all naturally occurring phosphorus in the Earth crust and surface waters. Phosphate occurs naturally in the Earth crust in a variety of mineral formations in rock; it is also found in dissolved form in most water bodies, and is an essential part of livingorganisms, as a necessary part of all DNA, along with other cellular occurrences.

As phosphate rocks weather, considerable amounts of phosphate become dissolved in surface waters, and much of the phosphate becomes available to plants in the surface soils, thus being an important part of thephosphorus cycle. Due to the massive demand for agricultural output to feed the exploding human population, phosphate fertilizers have been produced in large amounts over the last half century, with unintended consequences of disruption of many aquatic ecosystems. The resulting surface runoff from agricultural areas has created many instances of large scale freshwater and marine algal blooms and concomitant threats to biodiversity in these surface waters.

Natural occurrence in the Earth crust

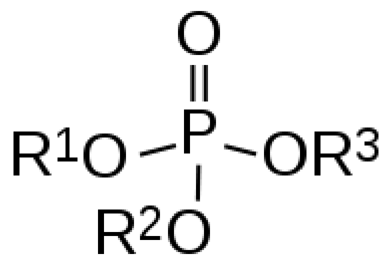
Hardrock phosphate, chiefly carbonate fluorapatite, Florida. Source: State of Florida

Phosphate rock is found in the seas of the world in the form of calcium phosphate, termed *phosphorite*.

It has been deposited in extensive layers that cover tens of thousands of square kilometers. Most phosphate rock beds have fewfossil occurrences, but the vast phosphate rock deposits on land in Florida and North Carolina are a notable exception, exhibiting plentiful fossil specimens. Major phosphate deposits in igneous rock are found in Canada, Russia, andSouth Africa. Sizable deposits of phosphate rock are found in some of the seamounts and small islands of Micronesia, such as Nauru and Banaba Island; however extraction from some of the other seamonts is economically infeasible with present technology and the availability of cheap, alternative sources.

Despite the fact that phosphorus is the eleventh most abundant element in the Earth's crust, typical concentrations in soils are in the range of 200 to 800 milligrams per kilogram. Many older soils as well as tropical soils are phosphate deficient; as a result, photosynthesis and carbon fixation is often limited by the low availability of phosphate.

Phosphate chemistry



Generalized structure of organophosphates, where each R is a different organic molecule.

Numerous phosphates are virtually insoluble in aqueous media at normaltemperatures in the Earth's crust. However, sodium, potassium, cesium and ammonium phosphates are all water soluble. Most ot the other phosphates are only slightly to moderately soluble, or are insoluble in water. Generally speaking, hydrogen and dihydrogen phosphates are slightly more soluble than their corresponding phosphates. Pyrophosphates exhibit the highest water solubility.

The phosphate ion is a hypervalent molecule, is classified as a polyatomic ion with a molar mass of 94.97 grams per mole. Its structure manifests a central phosphorus atom surrounded by four tetrahedral oxygen atoms. The phosphate ion carries a negative three electrical charge and is the conjugate base of the hydrogen phosphate ion, which in turn is the conjugate base of the dihydrogen phosphate ion, which correspondingly is the conjugate base of phosphoric acid.

Phosphate equilibrium between soil and aqueous systems

Considerable quantities of phosphate dissolve in surface waters; however, elevated pH levels severely impede the amounts of phosphate ions present in natural waters; much of this dissolved ionic form of phosphate actually occurs as HPO_4^{-2} or $H_2PO_4^{-1}$. The inverse process to phosphate dissolution occurs whenbiomass decays, becomes mineralized and precipitates from solution; in fact, the solution and precipitation processes are always occurring in dynamic equilibrium. These processes are also being carried out, not only in overt surface water bodies, but continually in soil interstices where there are minute quantities of water.

Because phosphate ions carry a high effective negative charge density, they are easily attracted and bound to positive ions in the natural environment. Correspondingly, organic phosphates somewhat shield this high charge density and actually make these sometimes large organic phosphate molecules more mobile in the environment than their inorganic counterparts. In the majority of soils organic phosphates account for thirty to sixty percent of the phosphate content

Biological uptake of phosphate

In aqueous systems there are fewer absorbing surfaces, so that the rate of organism uptake of phosphate is much higher than in soils. Thus small increases in aqueous phosphate can generate rapid and overt enhancement of biological productivity; algal blooms are one common phenomenon arising from this phenomenology.

Both phosphate and nitrogen compounds are theoretically limiting to plant productivity; however, threshold phosphate concentrations are in fact required for the very fixation of nitrogen. Therefore, in practice, phosphate is typically the limiting factor in terrestrial plant productivity. Nature has adapted to this critical role of phosphate, by allowing many plants to recycle phosphate, without using soil as an intermediary. For example, in some dystrophic forests a large amount of phosphate is taken up by mycorrhizal hyphae acting directly on leaf litter, bypassing the need for soil uptake.

Agricultural role of phosphate

Satellite view of 2011 massive Lake Erie algal bloom, caused chiefly by phosphate runoff from agricultural fertilizer. Source: NASA

Soil phosphate levels are critical to sustain agricultural productivity of crops. Since harvested biomass permanently removes phosphate from the land, ongoing supplementation of chemical phosphate fertilizers are generally required. After cropping systems begin in a given area, the original soil phosphate is sufficient to sustain cropping agriculture for only about six decades. Presently, the greatest phosphate deficiency is in tropical and subtropical soil regimes where soil phosphates are naturally low, and where the indigenous populations can least afford the luxury of chemical phosphate addtions.

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