

## Chapter 2

# Phosphorus in the Organic Life: Cells, Tissues, Organisms

As already mentioned (see Chap. 1), in the living cell phosphorus plays a decisive role in three different essential structures:

- In the cell membrane
- In the storage and retrieval system for genetic information, DNA and RNA
- In the energy system, ATP

Furthermore, in vertebrate animals it is an important component in sinew, cartilage, bone, and enamel.

## 2.1 The Cell Membrane

The fundamental building block of all living organisms is the cell. Some organisms consist of just one cell whereas others are built up by hundreds of millions of cells. All cells are separated from the surroundings by an envelope—the cell membrane. This membrane, a totally necessary structure, allows a much higher concentration of water-soluble compounds and water-suspended particles inside than outside the cell. The cell membrane consists of chains of fatty acids, the molecules of which contain 16 to 20 carbon atoms and a phosphate group at the end: the so-called phospholipids. In eukaryotic cells, there are also sugar molecules and membrane proteins attached to the phospholipids: these are arranged in double layers with the water-soluble phosphates pointing both inward and outward, with the tails of the fatty acids making up the middle (Singer and Nicolson 1972). The direct function of the phosphate group is to provide the essential orientation of the phospholipids, which in turn gives the cell membrane its fundamental characteristics.

## 2.2 DNA and RNA

Watson and Crick (see the reference list of Chap. 1) in 1953 presented the structure of DNA as a double helix (Fig. 2.1), and were awarded the Nobel Prize in medicine for this discovery 9 years later. However, DNA had been found much earlier, in 1868, when a Swiss medical doctor and biologist, Friedrich Miescher, found a phosphorus-containing compound in the nucleus of cells (Dahm 2005). The compound, he noted, was of a completely new type and very different from proteins, lipids, and carbohydrates. He called it “nuklein;” we call it “nucleic acid,” the NA in DNA and RNA.

The role of phosphate in DNA and RNA is to form, together with a pentose sugar, the “backbone” of the molecule (Fig. 2.1). It links the nucleotides, the nitrogen-based adenine (A), guanine (G), cytosine (C), and thymine (T), together to form DNA. [In RNA, uracil (U) replaces T.] These links in turn constitute the “letters” of the genetic information (Fig. 2.2).

## 2.3 ATP

A central molecule in the energy system of all living cells is adenosine triphosphate (ATP). It was discovered by Karl Lohmann in 1929, one of the fundamental discoveries in biochemistry that the Nobel committee mysteriously overlooked. Several other scientists, including Fritz Lipmann and Alexander Todd, later became Nobel Prize laureates for closer descriptions of its structure and functions. ATP is a coenzyme that carries out most of the intracellular energy transport. Energy is stored in

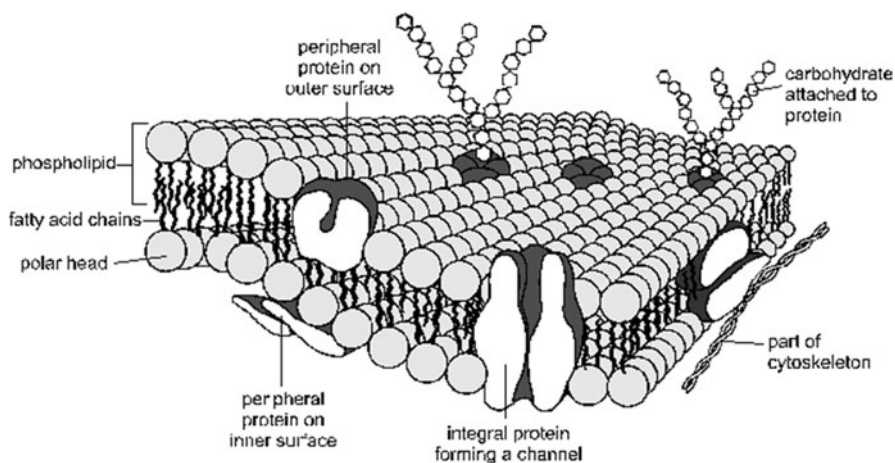
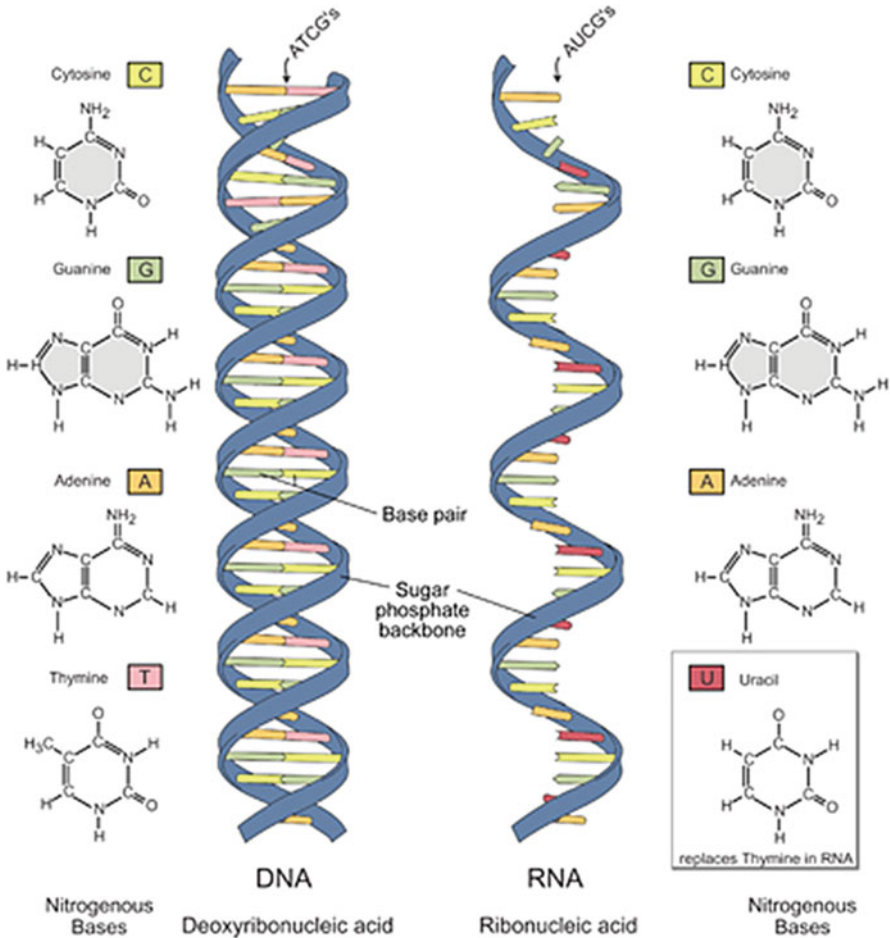


Fig. 2.1 Structure of the cell membrane (From [biologymad.com](http://biologymad.com))

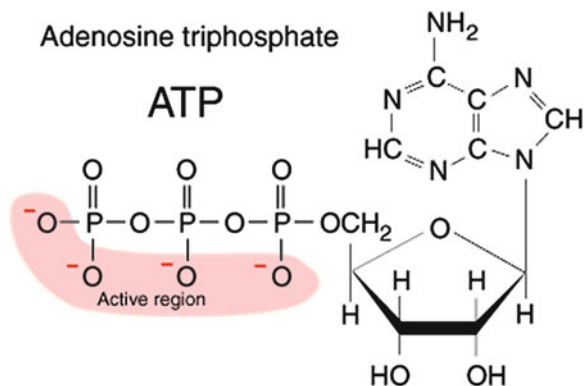


**Fig. 2.2** Structures of DNA and RNA [From the database of the National Human Genome Research Institute (NHGRI)]

cells in carbohydrates such as glycogen and in fat. When energy is needed, these compounds are oxidized and energy is moved from the storage molecules to adenosine phosphate. In the most common reaction, this energy capture occurs when adenosine diphosphate (ADP) adds another phosphate group to form ATP (Boyer 1997).

Cells require energy mainly for three types of tasks: (1) to drive metabolic reactions against energy gradients; (2) to do mechanical work such as moving a muscle (mostly the co-generated heat is a loss, but sometimes it can be the main goal of the process, as when bees in a hive in winter all flex their wings); and (3) to transport substances across cell membranes. When the bond is broken through hydrolysis

**Fig. 2.3** Structure of the adenosine triphosphate (ATP) molecule



(e.g., after addition of water), ATP loses one of the phosphate molecules and is degraded to ADP. As this is an exothermic reaction, about 7.3 kcal/mol or 30.6 kJ/mol is released, which is more or less equal to the energy contained in a peanut.

Thus, the role of phosphate in ATP is to transport energy to create energy-rich bindings (Lipmann 1945) (Fig. 2.3).

## 2.4 Sinew, Cartilage, Bone, and Enamel

Teeth and bones, as well as cartilage and sinew, obtain their hardness and strength from the minerals they contain, different forms of the so-called biological apatite, that is, calcium hydroxyapatite with the general formula  $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$ . Slight differences in composition render different forms of the biological apatite in different tissues with different physical and mechanical properties.

Enamel is the hardest, but also the most brittle, with the highest concentration of apatite and thereby of phosphorus. Bone, cartilage, and sinew follow in that order. Some 85 % of the phosphorus in the body of vertebrate organisms is in the form of these apatites, which is also why bone ashes can be used as a phosphate fertilizer. Phosphorus deficiency in the vertebrate body results in fragile bones and teeth, stiff joints, bone pain, loss of appetite, fatigue, irritability, numbness, weakness, and weight loss. For growing individuals, reduced size and poor bone and tooth development can also result from lack of phosphorus. Osteoporosis in the elderly, especially women, is thought to be associated not only with insufficient intake of calcium but also of phosphorus (Heaney 2004).

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