## The Elements and Life

We know what the elements are. But what is life? From the point of view of natural science, living systems must fulfill three criteria:

1. **Metabolism (maintains the viability of the individual)**
2. **Reaction to foreign stimuli**
3. **Reproduction (survival of the species)**

These criteria are plausible and can be investigated by scientific methods. Nevertheless, a phenomenon is missing that is intrinsic to all life forms:

4. **All life wants to live!**

Why this is so cannot be explained. Equally inexplicable is the trend towards the more-complex structures and systems observed in evolution. Even if we conclude from this that life in its beginning had to be relatively simple, it was still not primitive. Manfred Eigen (Nobel Prize 1967) in particular pointed out that one property of matter must have played a decisive role: the ability to self-assemble. From there he postulated that “Life comes into existence when the conditions for it are suitable”. Could a different life have come into existence had the conditions been different? We don’t know. Instead, we know a lot about life that we can observe and investigate.

Let us begin with the simple question as to how many elements were involved in the adventure of life. The central position is occupied by carbon with its versatile reactivity profile. In terms of amount, it is exceeded by hydrogen and oxygen. This is because life most probably began in water and all life forms contain a lot of water, for example, humans with about 60 %. The record at 99 % is held by the jellyfish. Nitrogen is the key element of proteins. From here, the amounts clearly decrease. In total, the function of 17 main-group elements (old nomenclature) and 10 transition-metal ions (i.e. 27 elements) has been elucidated. Tungsten occurs very rarely, yet has been found in some organisms.

The so-called trace elements in general have a catalytic function or are involved in regulatory processes. Some elements exhibit contradicting properties. For example, selenium in large amounts is highly toxic, but a deficiency can have serious health repercussions. It all comes down to the dosage, but this we have known, at the latest, since Parcelsus.

Which elements do life forms require to code their genetic inheritance? First, it is surprising that all life forms use the same alphabet at the genetic level. The barcode of life consists of four letters:

**A** (for adenine)
**T** (for thymine)
**G** (for guanine)
**C** (for cytosine)


*Evolution only considered 27 elements for the process of life:*

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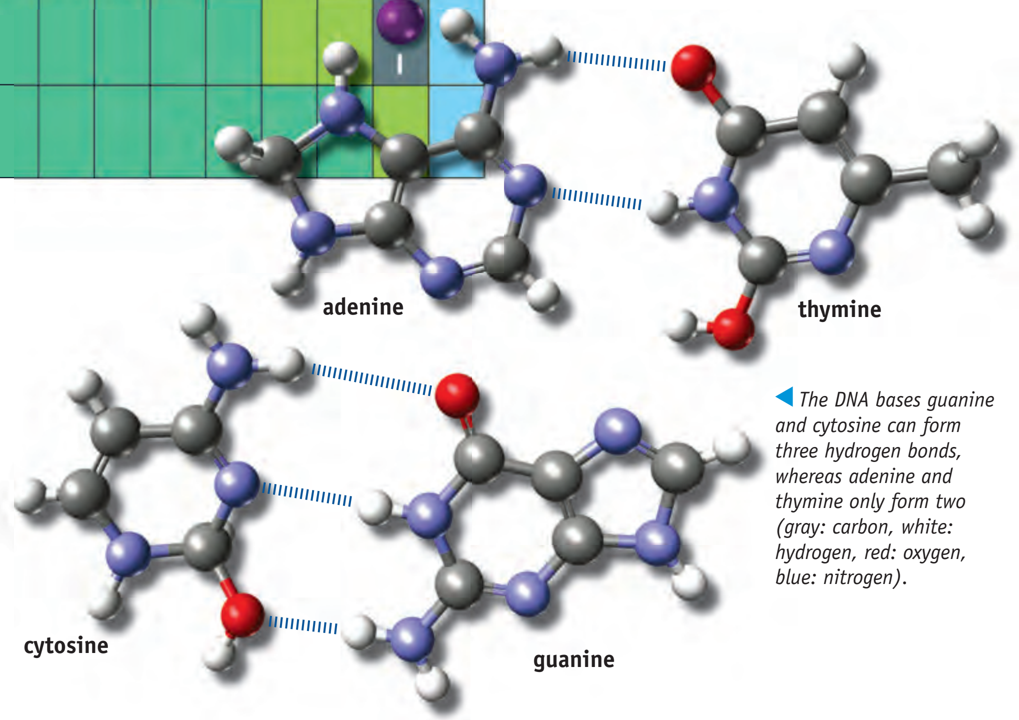
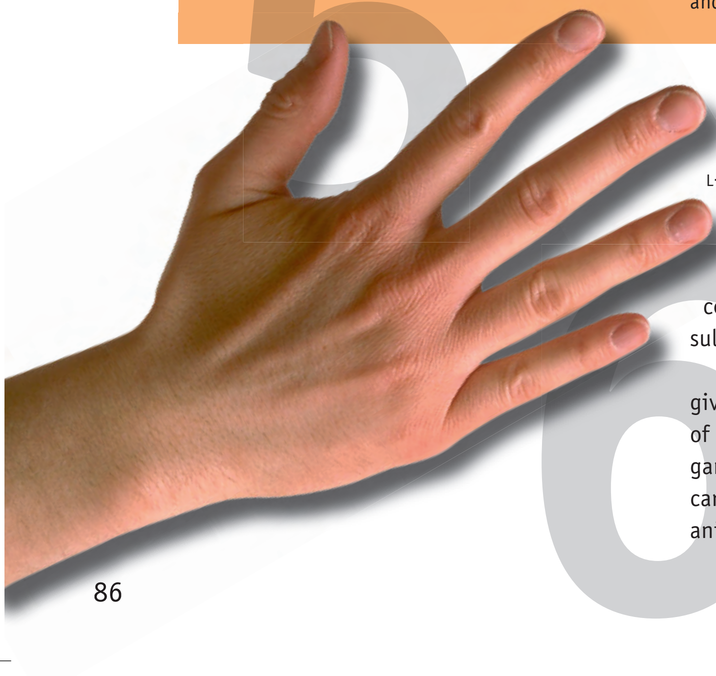
|---|---|---|---|---|---|---|---|---|
| *H* | = | *hydrogen* | *B* | = | *boron* | *C* | = | *carbon* |
| *N* | = | *nitrogen* | *O* | = | *oxygen* | *F* | = | *fluorine* |
| *Na* | = | *sodium* | *Mg* | = | *magnesium* | *Si* | = | *silicon* |
| *P* | = | *phosphorus* | *S* | = | *sulfur* | *Cl* | = | *chlorine* |
| *K* | = | *potassium* | *Ca* | = | *calcium* | *V* | = | *vanadium* |
| *Cr* | = | *chromium* | *Mn* | = | *manganese* | *Fe* | = | *iron* |
| *Co* | = | *cobalt* | *Ni* | = | *nickel* | *Cu* | = | *copper* |
| *Zn* | = | *zinc* | *Se* | = | *selenium* | *Br* | = | *bromine* |
| *Mo* | = | *molybdenum* | *I* | = | *iodine* | *W* | = | *tungsten* |

Two pairs, namely A+T and G+C form the so-called base pairs that are kept together by two or three hydrogen-bond bridges, respectively. Hydrogen bonds are about 0.28 nm long, and despite their relatively low bond energy of only about 25 kJ, the sum is a relatively stable bonding between the two DNA strands of the double helix. Three such bases code for a particular amino acid in proteins. Turning our attention back to the elements, it is remarkable that the four bases (A, T, G, and C) are only made up of four elements:



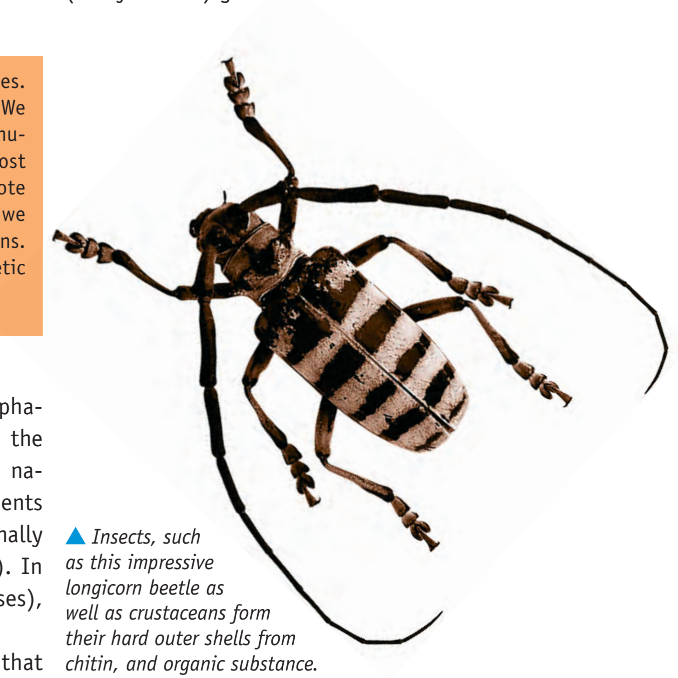

*The DNA bases guanine and cytosine can form three hydrogen bonds, whereas adenine and thymine only form two (gray: carbon, white: hydrogen, red: oxygen, blue: nitrogen).*

carbon, hydrogen, nitrogen, and oxygen (C, H, N, and O). To form the stable double helix, nature still required phosphoric acid as a connecting link between the special sugar molecules of the molecular strand, hence the element phosphorus was also enlisted.[1]



The building blocks of proteins are the alpha-amino acids, and exclusively those with the L-configuration. There are 20 that occur in nature. They too all consist of the four elements C, H, N, and O; two amino acids additionally contain sulfur (cysteine and methionine). In certain, but vital, enzymes (the peroxidases), sulfur is replaced by selenium.

The formation of hard skeletal structures that give some life forms their shape is a consequence of calcium. Simply said, the shells of lower organisms are generally made up of brittle calcium carbonate and the interior skeletons of higher animals are made up of tough calcium phosphate. The mechanistic properties are clearly improved by the incorporation of proteins. Insects and crustaceans have a shell made of chitin, a chain molecule (polymer) based on chemically modified (acetylamino-) glucose.



▲ *Insects, such as this impressive longicorn beetle as well as crustaceans form their hard outer shells from chitin, and organic substance.*

Sodium and potassium are used for the electrochemical transfer of signals in the nervous system. The contraction and relaxation of muscles are regulated by an interplay of calcium and

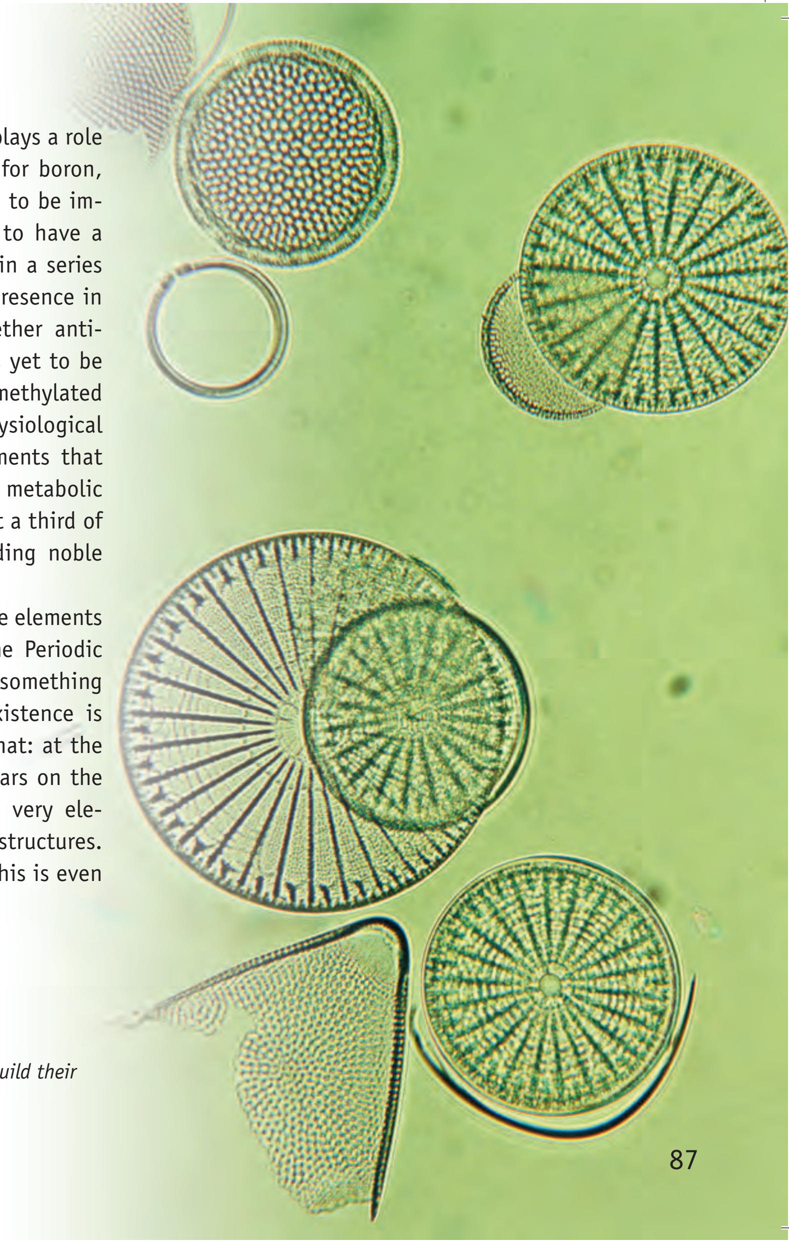
[1] The number 4 recurs remarkably often: carbon, the central element of life, is tetravalent. Life has four criteria. The genetic code is written with four "letters", which in turn are made up of four elements. (The elements themselves occur in four states of matter: solid, liquid, gas, and plasma.) It could, of course, just be a coincidental frequency, as the number 5 is also conspicuously often encountered in life. We have five sense, five fingers and toes. Starfish have five arms. Apples have five carpels. We encounter the number 6 in honeycombs and in numerous examples in the world of crystals, the most prominent being snowflakes. We can only take note of these facts, and even partly explain them. But we must be careful not to draw any deeper conclusions. Or did someone have an idea to combine arithmetic and life?

magnesium ions. The counterion is generally the chloride ion.

What is the purpose of the many trace elements? Nature placed tight constraints on life. It takes place in a temperature range between 0 °C and about 40 °C (although there are exceptions of up to 100 °C). The pressure is constant at about 1 atmosphere, and the pH value deviates very little from neutral (about pH 7). Nevertheless, an incredible variety of molecules are formed in cells. The secret lies in the fact that during the process of evolution an unimaginable number of biological catalysts came into being; these enzymes allow the production of all these substances. The entire genome of an organism is essentially a huge library of production codes for these catalysts. As enzymes are proteins, they are also only made up of the five elements C, H, N, O, and S. Special tasks require the additional assistance of the complex-forming properties of metals, for example, iron in hemoglobin for oxygen transport, magnesium in chlorophyll as part of the photosynthetic apparatus, cobalt in vitamin B12 for methylation reactions, and molybdenum for nitrogen fixation in the root nodules of legumes such as beans and peas.

There are some exceptions. The diatoms are unicellular microorganisms that protect themselves with a filigree skeleton of silicon dioxide (silicic acid). The sometimes major fossil deposits of kieselguhr (diatomaceous earth or diatomite) are quite well-known. Silicic acid also plays a role in higher life forms. This is also true for boron, which previously had only been known to be important for plants. But it also seems to have a function in animals. Nickel is present in a series of anaerobic microorganisms, but its presence in higher life forms is not certain. Whether antimony belongs to the trace elements is yet to be determined. Mercury is known to be methylated in organisms, but seems to be of no physiological importance. The total number of elements that are known for certain to be involved in metabolic pathways amounts to 27, that is, about a third of the elements in consideration (excluding noble gases and radioactive elements).

Why evolution only made use of these elements cannot be answered. The fact that the Periodic Table holds the possibility of allowing something as wonderful as life to come into existence is and remains a mystery. But not only that: at the end of the development, a being appears on the screen that is able to discover these very elements and to find out about their substructures. And the fact that we can ponder over this is even more mysterious.



▶ *Diatoms (unicellular organisms in water) build their highly symmetrical skeletons out of silica.*