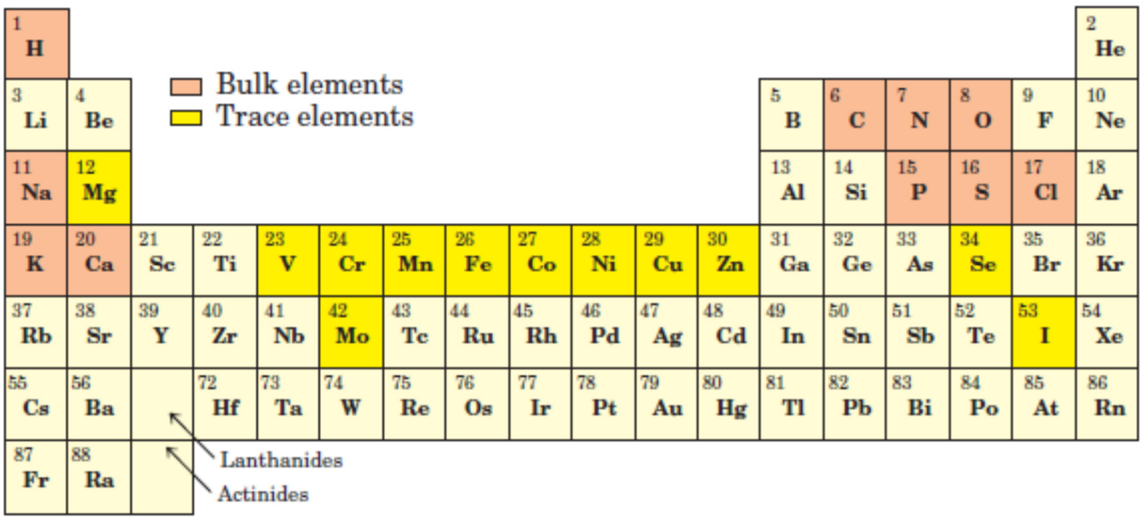
Chemistry of life

Major elements present in any living systems are hydrogen, oxygen, carbon, nitrogen, phosphorus & sulphur.

The atomic composition of the cell: H = 63%, O = 24% C = 10%, N = 1.4 %, P = 0.2 % & S = < 0.1%

Trace amount: Ca, Cl, K, Na, Mg, Mn, Fe, Se, I etc

Let us see the periodic table and see where all these elements are present.



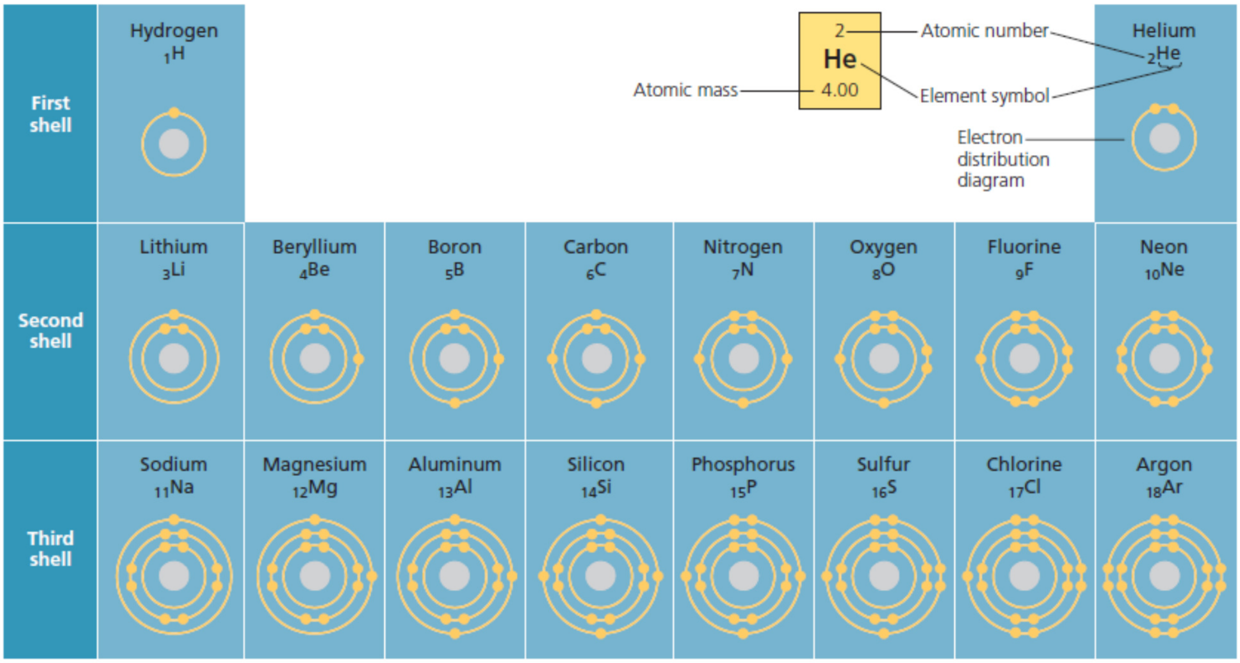
When we look at the composition of elements, C, N, O & H constitutes more than 95%. They are also lightest elements in the periodic table (As we go down in the periodic table, atomic number is going to increase so as atomic mass)

Suppose we want to design a moving machine like car what are the critical things we look for before selecting material to construct a body of the car?

Important properties of these elements are their ability to form bond with other elements to form compounds/molecules.

Let us see the molecular composition of the life. 80% is water & the dry weight of remaining 20% contains 50% protein, 15% carbohydrates, 10% lipids & fats & 15% nucleic acids.

Formation of these molecules and the interaction between these molecules depends on the chemical properties of the important six elements we mentioned it before. In this course, we just learn Chemistry to logically understand the structure and functions of Biomolecules and their interaction. Two important properties are valency and electronegativity of particular atom. The Valency of an atom is unpaired electron in the outer orbital of the shell. This gives an opportunity for the element to combine with other element.



▲ **Figure 2.9 Electron distribution diagrams for the first 18 elements in the periodic table.** In a standard periodic table (see Appendix B), information for each element is presented as shown for helium in the inset. In the diagrams in this table, electrons are represented as yellow dots and electron shells as concentric circles. These diagrams are a convenient way to picture the distribution of an atom's electrons among its electron shells, but these simplified models do not accurately represent the shape of the atom or the location of its electrons. The elements are arranged in rows, each representing the filling of an electron shell. As electrons are added, they occupy the lowest available shell.

? *What is the atomic number of magnesium? How many protons and electrons does it have? How many electron shells? How many valence electrons?*

Valency of H = 1, C=4, 0 = 2, N = 3 or 4, P = 3 or 5 and S = 2 (As shown in the figure), 4, 6

Covalent Bond: sharing of a pair of valence electrons by two atoms.

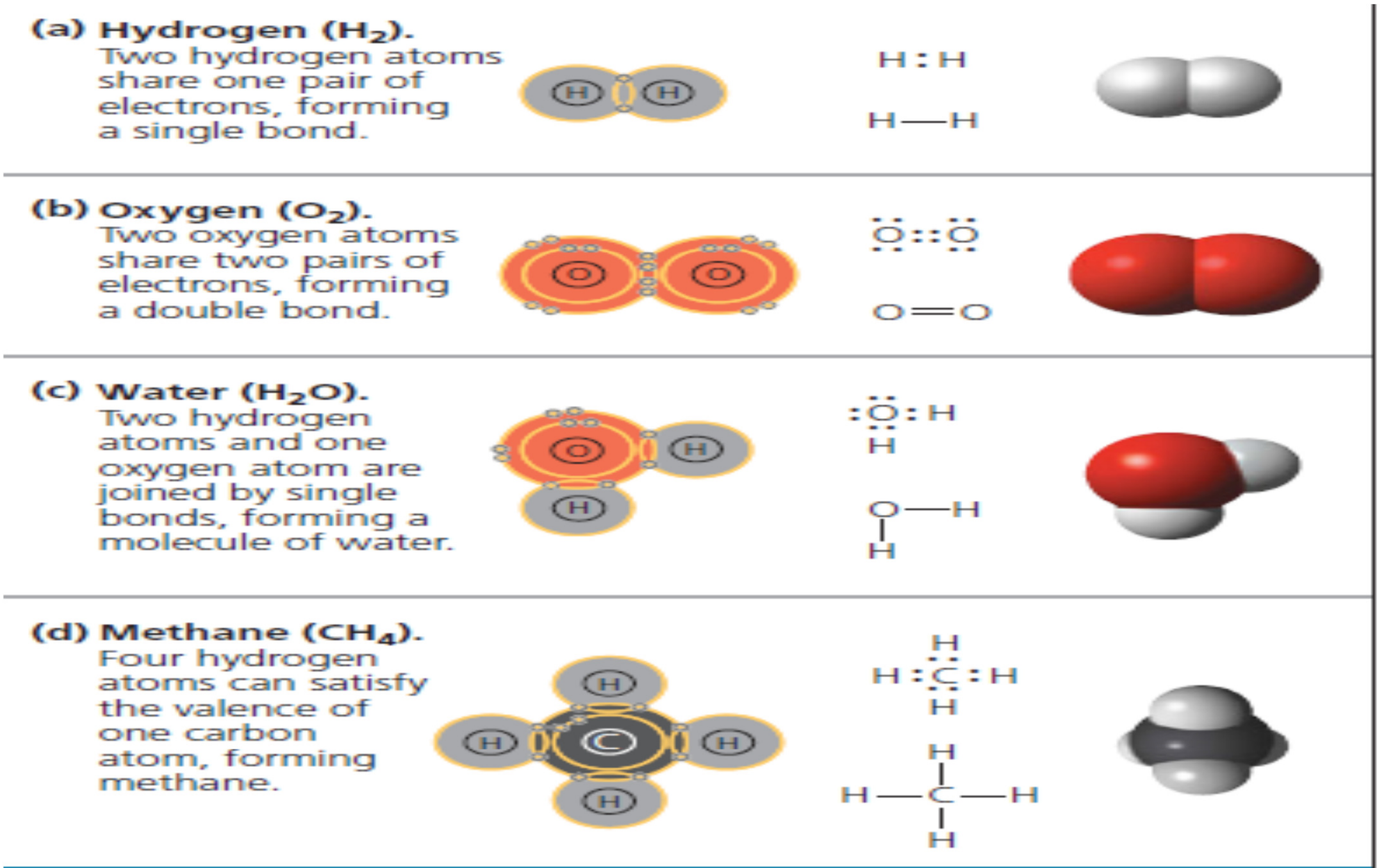
C−C single bond. Energy required to break them is equal to 80 Kcal/mol

C=C double bond (more energy is required to break them compared to single bond between them)

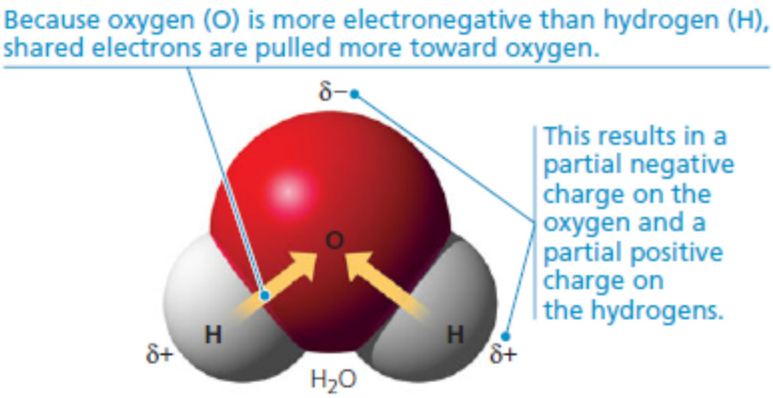
C≡C triple bond (more energy is required to break them compared to double bond)

Covalent bonds are very strong. Suppose if we compare covalent bond strength to say random energy fluctuation in daily life- random thermal fluctuations at room temperature are on the order of 0.6 kilocalories per mole. Covalent bonds are extremely stable, usually, unless something is attacking them and breaking them.

Atoms in a molecule attract shared electrons in varying degrees, depending on the element. The attraction of a particular atom for the electrons of a covalent bond is called its electronegativity. The more electronegative this atom is, the more strongly it pulls shared electrons towards itself. When one atom is bonded with more electronegative atom the electrons of the bond are not shared equally. There exists a polarity between the atoms. This type of bond is called polar covalent bond. Such bonds vary in their polarity depending on the relative electronegativity of the two atoms. For example the bond between the hydrogen atom and oxygen atom in water molecule is quite polar.



▲ **Figure 2.12 Covalent bonding in four molecules.** The number of electrons required to complete an atom's valence shell generally determines how many covalent bonds that atom will form. This figure shows several ways of indicating covalent bonds.



▲ **Figure 2.13 Polar covalent bonds in a water molecule.**

How do we know that polarity exist between two atoms of elements? What is the measuring way?

TABLE 1.3 The Electronegativities of Selected Elements[a]

IA	IIA	IB	IIB	IIIA	IVA	VA	VIA	VIIA
H 2.1								
Li 1.0	Be 1.5			B 2.0	C 2.5	N 3.0	O 3.5	F 4.0
Na 0.9	Mg 1.2			Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0
K 0.8	Ca 1.0							Br 2.8
								I 2.5

increasing electronegativity →

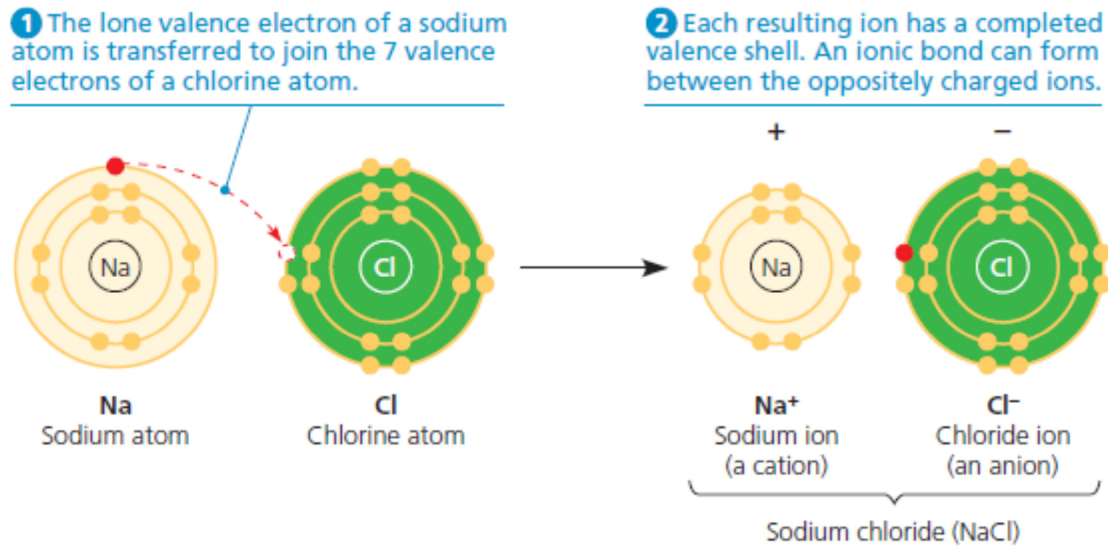
increasing electronegativity ↑

[a]Electronegativity values are relative, not absolute. As a result, there are several scales of electronegativities. The electronegativities listed here are from the scale devised by Linus Pauling.

Please refer the figure above. Suppose if the difference in electronegativity between the two atoms is 0.5 and more, there exist polarity.

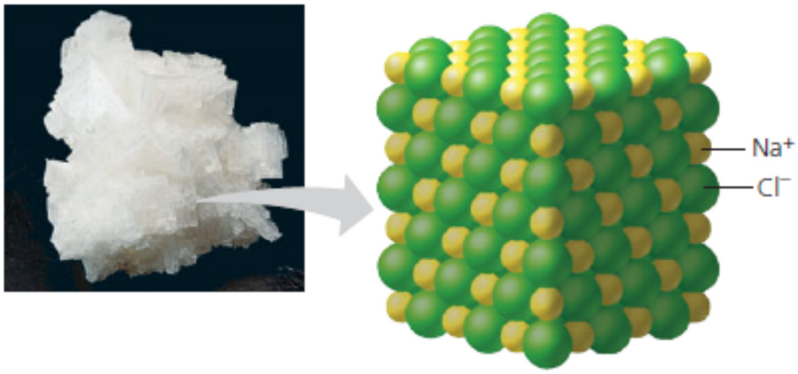
Example: carbon and hydrogen C-H the difference in electronegativity is 0.4 so it is non-polar. Carbon and oxygen C-O The difference is 1.0 therefore polarity exist.

Ionic Bond: transfer of electrons from one atom to another atom to form bond. The atom should form ions i.e. it should be in ionic state (positively charged or negatively charged) before it forms bond with another oppositely charged ion.



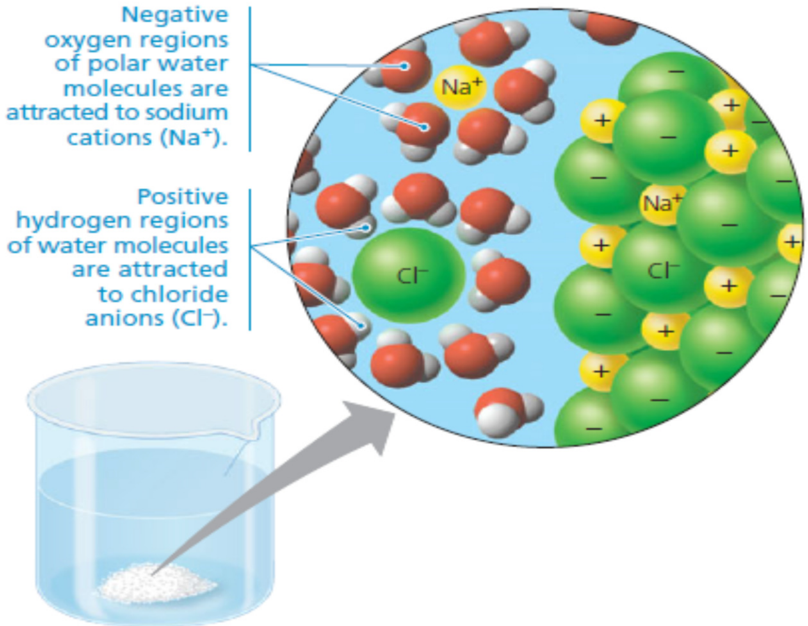
▲ **Figure 2.14 Electron transfer and ionic bonding.** The attraction between oppositely charged atoms, or ions, is an ionic bond. An ionic bond can form between any two oppositely charged ions, even if they have not been formed by transfer of an electron from one to the other.

The bonds are strong as long as it is not disturbed. If it is disturbed it becomes fragile.



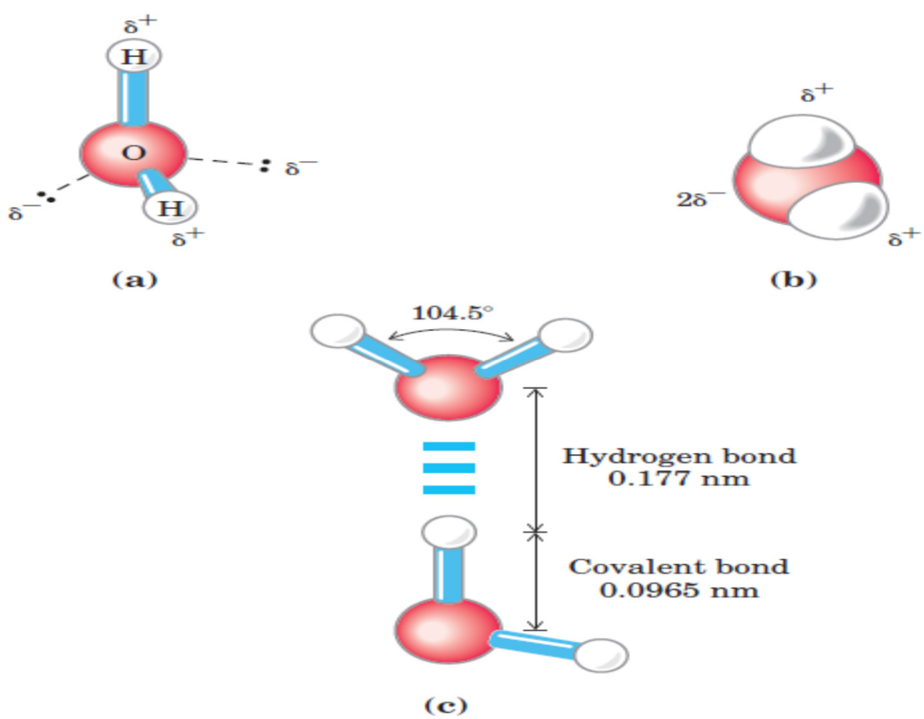
▲ **Figure 2.15 A sodium chloride (NaCl) crystal.** The sodium ions (Na^+) and chloride ions (Cl^-) are held together by ionic bonds. The formula NaCl tells us that the ratio of Na^+ to Cl^- is 1:1.

Ex: Once the water is added to NaCl, the ionic bond breaks.



▲ **Figure 3.7 Table salt dissolving in water.** A sphere of water molecules, called a hydration shell, surrounds each solute ion.

Hydrogen bonds: In Polar compounds or molecules there exist +∂ & -∂ charge due to difference in electronegativity of covalent bonded atoms. This helps in making bonds with other nearby polar compounds due to charge difference. The bond strength is ≈ 5 Kcal/mol.



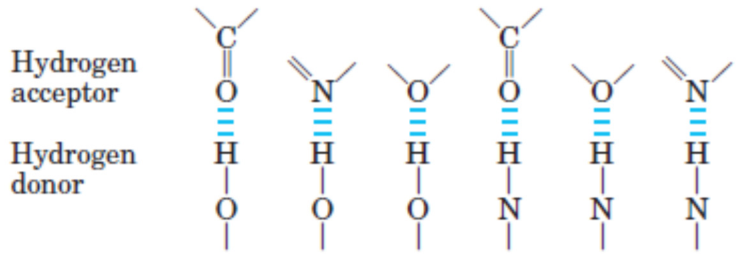


FIGURE 2–3 Common hydrogen bonds in biological systems. The hydrogen acceptor is usually oxygen or nitrogen; the hydrogen donor is another electronegative atom.

Vanderwaal's interaction: Even a molecule with nonpolar covalent bonds may have positively and negatively charged regions. Electrons are not always symmetrically distributed in such a molecule; at any instant, they may accumulate by chance in one part of the molecule or another. The results are ever-changing regions of positive and negative charge that enable all atoms and molecules to stick to one another. These **van der Waals interactions** are individually weak and occur only when atoms and molecules are very close together. When many such interactions occur simultaneously, however, they can be powerful: Van der Waals interactions are the reason a gecko lizard can walk straight up a wall! Each gecko toe has hundreds of thousands of tiny hairs, with multiple projections at each hair's tip that increase surface area. Apparently, the van der Waals interactions between the hair tip molecules and the molecules of the wall's surface are so numerous that despite their individual weakness, together they can support the gecko's body weight. The bond strength is approximately 1 Kcal/mol.

Hydrophobic 'Forces': Suppose if the oil is mixed in water what will be the result?

One of the important things we notice is both of them separates each other. Oil is a hydrocarbon (carbon & hydrogen) & it is nonpolar. It cannot make hydrogen bonds with water. It develops phobia towards water (hydrophobic) and wants to move away from water. This makes oil molecules interact with each other with weak forces. This phenomenon is called hydrophobic interaction forces.

The formations of all biological molecules backbone are by covalent bonds. But the shape they take up depends much less on their covalent bonds than all of these non-covalent interactions that are taking place-- the hydrogen bonds, the ionic bonds, hydrophobic forces, the van der Waals interactions-- that determine whether some long molecule folds up this way or folds up the other way etc.

Substitution of elements and toxicity:

There is a periodicity of properties of elements and these properties are related to number of electrons and their energy states in elemental atoms. Biological substitution of one element for another is thus possible when the preferred element is scarce. Ex: strontium can sometimes be found to substitute for calcium in the bones when strontium is more available than calcium. Radioactive strontium isotopes are sometimes released in nuclear accidents, so the incorporation of strontium into the bones is a cause for concern (Please see the periodic table & analyze).

Another example is incorporation of lead into the body (substituted for carbon). Lead affects Kidney and nervous system therefore it is highly toxic after certain concentration in the body. Similarly, arsenic can substitute for phosphorus- Arsenic is highly toxic. Selenium instead of Sulfur may get into the biological systems. Though Selenium is used by certain organisms in parts per million levels, after certain concentration it becomes toxic to the organisms.

Importance of carbon

Of all chemical elements, carbon is unparalleled in its ability to form molecules that are large, complex, and varied, making possible the diversity of organisms that have evolved on Earth. Proteins, DNA, carbohydrates, and other molecules that distinguish living matter from inanimate material are all composed of carbon atoms bonded to one another and to atoms of other elements. Hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), and phosphorus (P) are other common ingredients of these compounds, but it is the element carbon (C) that accounts for the enormous variety of biological molecules.

Carbon chains form the skeletons of most organic molecules. The skeletons vary in length and may be straight, branched, or arranged in closed rings. Some carbon skeletons have double bonds, which vary in number and location. Such variation in carbon skeletons is one important source of the molecular complexity and diversity that characterize living matter. In addition, atoms of other elements can be bonded to the skeletons at available sites.