Matter: Elements and Compounds

**Matter** is defined as anything that takes up space and has mass. Matter exists in many diverse forms, each with its own characteristics. Rock, metals, and glass are just few examples of what seems an endless assortment of matter.

**Element** is a substance that cannot be broken down by other substances by chemical reactions. Today chemists recognize 92 elements occurring in nature e.g. gold, copper, carbon, and oxygen. Two or more elements may be combined in a fixed ratio to produce a compound. Table salt, for example, is actually sodium chloride (NaCl), a compound that is composed of elements sodium (Na) and chlorine (Cl).
Elements Essential to Life

About 25 of the 92 natural elements are known to be essential to life, but four of these—carbon (C), oxygen (O), hydrogen (H), and nitrogen (N)—make up 90% of living matter. Phosphorus (P), sulfur (S), calcium (Ca), potassium (K) and a few other elements account for most of the remaining 4% of an organism’s weight.

Trace elements are those required by organisms in minute quantities. However, because they are mandatory for good health, trace elements are not nutrient of marginal importance to the organisms.
The Structure and Behavior of Atoms

- The units of matter are called atoms.
- An atom is the smallest possible amount of element that retains that element’s properties.
- Each atom has at its center a dense positively charged nucleus, which is surrounded at some distance by a cloud of negatively charged electrons.
- Electrons held in orbit by electrostatic attraction to the nucleus.
Although the atom is the smallest unit having the physical and chemical properties of its element, these tiny bits of matter are composed of even smaller parts, called subatomic particles.

Stable subatomic particles are: **neutron, protons, and electrons**.

Neutrons and protons are densely packed together tightly to form a dense core, or nucleus at the center of the atom.

Electrons and protons are electrically charged.

The number of protons present in atomic nucleus determines its **atomic number**.

The electric charge carried by each proton is exactly equal and opposite to charge carried by a single electron.
carbon atom
atomic number = 6

hydrogen atom
atomic number = 1
The neutron and proton are almost identical in mass, each about $1.7 \times 10^{-24}$ grams and other conventional units are not very useful for describing the mass of the objects. Thus, for atoms and subatomic particle, scientists use a unit of measurement called dalton.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Weight (Daltons)</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Proton</td>
<td>1</td>
<td>+1</td>
</tr>
<tr>
<td>Electron</td>
<td>$1/2000$</td>
<td>-1</td>
</tr>
</tbody>
</table>

The atomic weight or mass number is the sum of protons and neutrons located in the nucleus of the atom.
The Outermost Electrons Determine How Atoms Interact
Protons and neutrons are welded tightly to one another in the nucleus and change partners only under extreme conditions.

On the other hand, electrons are in continuous motion around the nucleus, but motions on this submicroscopic scale obey different laws from those we are familiar with in everyday life.

These laws dictate electrons in an atom can exist only in certain discrete regions (or orbit) of movement and that there is strict limit to the number of electrons that can be accommodated in an orbit of a given type, so-called electron shell.

First electron shell can hold maximum 2 electrons.

Second and third shell can hold up to 8 electrons.
<table>
<thead>
<tr>
<th>element</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Hydrogen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2  Helium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6  Carbon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7  Nitrogen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8  Oxygen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Neon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Sodium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Magnesium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 Phosphorus</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>16 Sulfur</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 Chlorine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 Argon</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>19 Potassium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 Calcium</td>
<td></td>
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</tbody>
</table>
Atoms that have unfilled electron shell are less stable and have tendency to interact with other atoms to complete their unfilled electrons.

This electron exchange can be achieved either by transferring electrons from one atom to another or by sharing electrons between two atoms.

These two strategies generate the two types of chemical bonds: **ionic bond and covalent bond**.
Atoms

Sharing of electrons

Covalent bond

Transfer of electron

Positive ion

Negative ion

Ionic bond
Ionic Bonds Form by the Gain and Loss of Electrons

Ionic bonds are most likely to be formed by atoms that have just one or two electrons in their unfilled outer shell or just one or two electrons short of acquiring a filled outer shell. For example, Na with atomic number 11 can donate one electron from its 3th shell to chlorine with atomic number 17. This event leads formation of compound called NaCl or table salt. When electrons jump from Na to Cl, both atoms become electrically charged.

Na lost electron and has one less electron than it has proton in its nucleus Na⁺
Cl gain electron and has one more electron than it has protons Cl⁻
Figure 2.8 Essential Cell Biology, 2/e. (© 2004 Garland Science)
A covalent bond is the sharing of pair of electrons by two atoms. For example, when two hydrogen atoms approach each other, they share their electrons and thus filling their outermost shells. In the simplest possible molecule - a molecule of hydrogen-two H atoms, each with a single electron, share their two electrons, filling their outermost electrons.
two hydrogen atoms

- TOO CLOSE (nuclei repel each other)
- TOO FAR (no attraction)
- JUST RIGHT (covalent bond)

0.074 nm

hydrogen molecule
There Are Different types of covalent Bonds

With six electrons in its second electron shell, oxygen needs two more electrons to complete its outermost shell.

Two oxygen atoms form a molecule by sharing two pairs of outermost electrons.

The atoms are joined by what is called a **double covalent bond**.

Nitrogen has five electrons in outermost shell, three less than it needs for complete outermost shell. Two nitrogen atoms will join together by a **triple covalent bond** and share pairs of outermost electrons. The molecules we have looked at so far are H₂, O₂, and N₂.

Water is a compound whose molecular formula is H₂O; it takes two atoms of hydrogen to satisfy outermost electron shell of one oxygen. Another molecule that is also compound is methane, a component of natural gas with a molecular formula CH₄. Carbon has four unshared electrons, so its bonding capacity is 4.
CARBON SKELETONS

Carbon has a unique role in the cell because of its ability to form strong covalent bonds with other carbon atoms. Thus carbon atoms can join to form chains or branched trees or rings.

![Carbon skeleton diagrams]

Also written as

also written as

also written as
ALTERNATING DOUBLE BONDS

The carbon chain can include double bonds. If these are on alternate carbon atoms, the bonding electrons move within the molecule, stabilizing the structure by a phenomenon called resonance.

Alternating double bonds in a ring can generate a very stable structure.

the truth is somewhere between these two structures

often written as benzene
When two atoms joined by a single covalent bond belong to different elements, the two atoms usually attract the shared electrons to different degrees. Compared with C atom, for example, O and N atoms attracts electrons relatively more strongly, whereas an H atom attracts electrons relatively weakly.

By definition, a polar structure is one in which the positive charge is concentrated toward one end of the molecule (the positive pole) and negative charge is concentrated toward other end (negative pole).
Polar covalent bonds are extremely important in biology because they allow molecules to interact through electrical forces. Any large molecule with many polar groups will have a pattern of partial positives and negative charges on its surface.
A third type of chemical bond important in life is the hydrogen bond. Hydrogen bond occurs when a hydrogen atom covalently bonded to one electronegative atom is also attracted to another electronegative atom. In living cells, the electronegative partners involved are usually oxygen and nitrogen.
Water Is Held by Hydrogen Bonds

Water accounts 70% of a cell weight, and most intracellular reactions occur in an aqueous environment. Life on earth is thought to have begun in the ocean and the conditions in the primeval environment and put a permanent stamp on the chemistry of living things. Life is therefore hinges on the properties of water. Hydrogen bond is much weaker than the covalent bond. Thermal motions of electron can even break hydrogen bonds. But the combined effect of many of many weak bonds is far from trivial.

Each water molecule can form hydrogen bonds through its two hydrogen atoms to two other water molecules, producing a network in which hydrogen bonds are being continually broken and formed.

It is because of these interlocking hydrogen bonds that water at room temperature is liquid.
WATER STRUCTURE

Molecules of water join together transiently in a hydrogen-bonded lattice.

The cohesive nature of water is responsible for many of its unusual properties, such as high surface tension, specific heat, and heat of vaporization.
**Hydrophilic molecules:** molecules, like alcohols that contain polar bond and can form hydrogen bonds with water. DNA, RNA, and majority of proteins are hydrophilic molecules.

**Ionic substances** such as sodium chloride dissolve because water molecules are attracted to the positive (Na\(^+\)) or negative (Cl\(^-\)) charge of each ion.

**Polar substances** such as urea dissolve because their molecules form hydrogen bonds with the surrounding water molecules.
**Hydrophobic molecules**: molecules are uncharged and can not form hydrogen bonds. Therefore, hydrophobic molecules are not soluble in water. Hydrocarbons are the examples for hydrophobic cellular constituents. Tails of fatty acids are the example for hydrocarbon.
Molecules in Cells

A Cell Is Formed from Carbon Compounds

Carbon is outstanding among all the elements in its ability to form large molecules. Since carbon has 4 electron vacancies in its outermost shell, it can form 4 covalent bonds with other molecules.

The small and large carbon compounds made by cells are called organic molecules. All other molecules, including water, are said to be inorganic.

Certain combinations of atoms, such as the methyl (-CH3), hydroxyl (-OH), carboxyl (-COOH), carbonyl (-C=O), phosphoryl (-PO32-), and amino (-NH2) groups occur repeatedly in organic molecules.
C-O COMPOUNDS

Many biological compounds contain a carbon bonded to an oxygen. For example,

**alcohol**

\[ \text{H} \quad -\text{C} = \text{OH} \quad \text{H} \]

The \(-\text{OH}\) is called a **hydroxyl** group.

**aldehyde**

\[ -\text{C} = \text{O} \quad \text{H} \]

The \(\text{C} = \text{O}\) is called a **carbonyl** group.

**ketone**

\[ \text{C} \quad \text{C} \quad \text{C} = \text{O} \]

**carboxylic acid**

\[ -\text{C} = \text{O} \quad \text{H} \quad \text{O} \]

The \(-\text{COOH}\) is called a **carboxyl** group. In water this loses an \(\text{H}^+\) ion to become \(-\text{COO}^-\).

**esters**

Esters are formed by combining an acid and an alcohol.

\[ \text{acid} \quad \text{alcohol} \rightarrow \text{ester} \quad \text{H}_2\text{O} \]
C–N COMPOUNDS

Amines and amides are two important examples of compounds containing a carbon linked to a nitrogen.

Amines in water combine with an $\text{H}^+$ ion to become positively charged.

\[
\begin{align*}
\text{amine} & \quad + \quad \text{H}^+ \\
\text{C–N} & \quad \leftrightarrow \quad \text{C}^+\text{N}^- \\
\end{align*}
\]

Amides are formed by combining an acid and an amine. Unlike amines, amides are uncharged in water. An example is the peptide bond that joins amino acids in a protein.

\[
\begin{align*}
\text{acid} & \quad + \quad \text{amine} \\
\text{C}–\text{O} & \quad \longrightarrow \quad \text{C}–\text{N} \\
\text{H}_2\text{N}–\text{C} & \quad \longrightarrow \quad \text{C}–\text{O} & \quad + \quad \text{H}_2\text{O} \\
\text{amine} & \quad \longrightarrow \quad \text{amide} \\
\end{align*}
\]

Nitrogen also occurs in several ring compounds, including important constituents of nucleic acids: purines and pyrimidines.

\[
\text{cytosine (pyrimidine)}
\]
methane  methyl group
PHOSPHATES

Inorganic phosphate is a stable ion formed from phosphoric acid, $\text{H}_3\text{PO}_4$. It is often written as $\text{P}_i$.

Phosphate esters can form between a phosphate and a free hydroxyl group. Phosphoryl groups are often attached to proteins in this way.

The combination of a phosphate and a carboxyl group, or two or more phosphate groups, gives an acid anhydride.

High-energy acyl phosphate bond (carboxylic-phosphoric acid anhydride) found in some metabolites.

Phosphoanhydride—a high-energy bond found in molecules such as ATP.
Cell Contain Four Major Families of Small Organic Molecules

The small organic molecules of the cell are carbon compounds with molecular weights in the range 100 to 1000 that contain up to 30 or so carbon atoms.

- They are usually found in free cytoplasm
- Can be used as monomer
- Can form giant polymeric macromolecules
- Have diverse roles in cell

Generally, cell contains four major molecules, the sugars, the fatty acids, the amino acids, and nucleotides
Sugars Are Energy Source for Cells and Subunits of Polysaccharides

The monosaccharide are the simple sugar with formula of \((\text{CH}_2\text{O})_n\), where \(n\) can be 3, 4, 5, or 6. For example, glucose has the formula \((\text{C}_6\text{H}_{12}\text{O}_6)\) and can be shown in a variety of ways.

![Image of glucose molecule](image)
Glucose can be converted to other sugar molecules simply changing the orientation of some of the hydroxyl groups.

**ISOMERS**

Many monosaccharides differ only in the spatial arrangement of atoms—that is, they are isomers. For example, glucose, galactose, and mannose have the same formula \((C_6H_{12}O_6)\) but differ in the arrangement of groups around one or two carbon atoms.

These small differences make only minor changes in the chemical properties of the sugars. But they are recognized by enzymes and other proteins and therefore can have important biological effects.
Monosaccharides can be linked by covalent bonds to form larger carbohydrates.

Monosaccharide + Monosaccharide = disaccharide

Such as sucrose, which is composed of a glucose and a fructose unit

Monosaccharide + Monosaccharide + Monosaccharide = trisaccharide

If the monomer number is between 3 and 50, it is called *oligosaccharide*

If the monomer number is more than 50, it is called *polysaccharide*