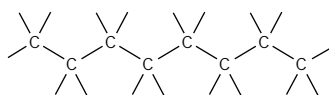


Chemical Bonds and Groups - Part 1

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CARBON SKELETONS

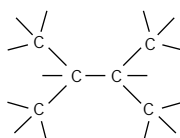
Carbon has a unique role in the cell because of its ability to form strong covalent bonds with other carbon atoms. Thus carbon atoms can join to form chains.



also written as



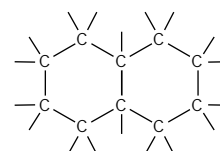
or branched trees



also written as



or rings



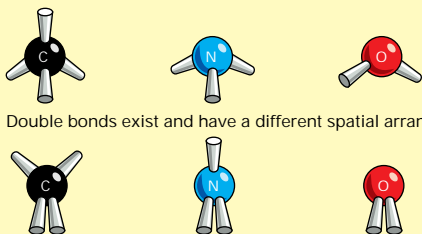
also written as



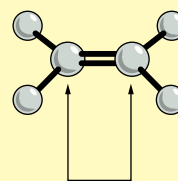
COVALENT BONDS

A covalent bond forms when two atoms come very close together and share one or more of their electrons. In a single bond one electron from each of the two atoms is shared; in a double bond a total of four electrons are shared.

Each atom forms a fixed number of covalent bonds in a defined spatial arrangement. For example, carbon forms four single bonds arranged tetrahedrally, whereas nitrogen forms three single bonds and oxygen forms two single bonds arranged as shown below.



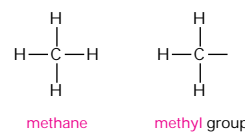
Double bonds exist and have a different spatial arrangement.



Atoms joined by two or more covalent bonds cannot rotate freely around the bond axis. This restriction is a major influence on the three-dimensional shape of many macromolecules.

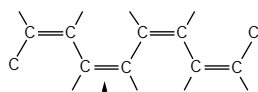
C-H COMPOUNDS

Carbon and hydrogen together make stable compounds (or groups) called hydrocarbons. These are nonpolar, do not form hydrogen bonds, and are generally insoluble in water.

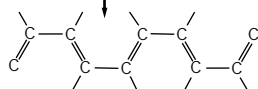


ALTERNATING DOUBLE BONDS

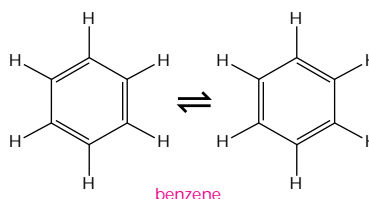
The carbon chain can include double bonds. If these are on alternate carbon atoms, the bonding electrons move within the molecule, stabilizing the structure by a phenomenon called resonance.



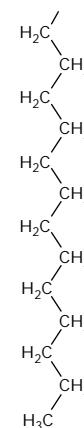
the truth is somewhere between these two structures



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



often written as



part of the hydrocarbon "tail" of a fatty acid molecule

Chemical Bonds and Groups - Part 2

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C-O COMPOUNDS

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

alcohol



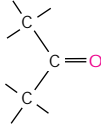
The -OH is called a **hydroxyl** group.

aldehyde



The C=O is called a **carbonyl** group.

ketone



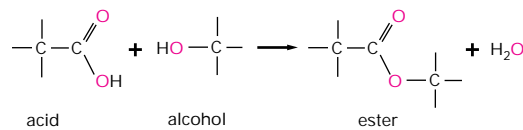
carboxylic acid



The -COOH is called a **carboxyl** group. In water this loses an H⁺ ion to become -COO⁻.

esters

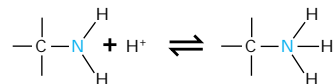
Esters are formed by combining an acid and an alcohol.



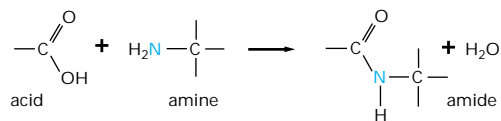
C-N COMPOUNDS

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

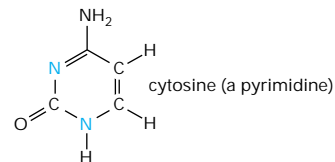
Amines in water combine with an H⁺ ion to become positively charged.



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.



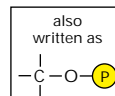
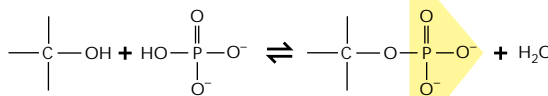
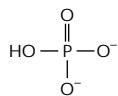
Nitrogen also occurs in several ring compounds, including important constituents of nucleic acids: purines and pyrimidines.



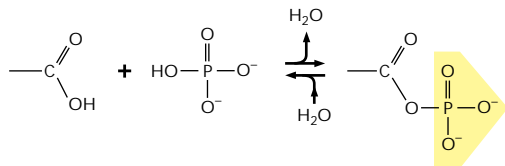
PHOSPHATES

Inorganic phosphate is a stable ion formed from phosphoric acid, H₃PO₄. It is often written as P_i.

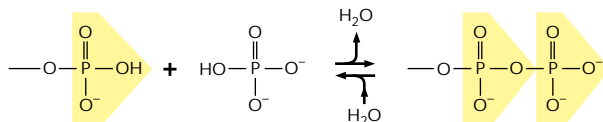
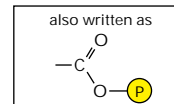
Phosphate esters can form between a phosphate and a free hydroxyl group. Phosphate groups are often attached to proteins in this way.



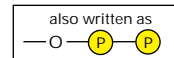
The combination of a phosphate and a carboxyl group, or two or more phosphate groups, gives an acid anhydride.



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



phosphoanhydride—a high-energy bond found in molecules such as ATP

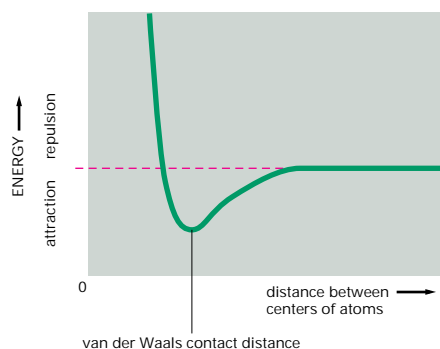


Types of Weak Non-covalent Bonds - Part 1

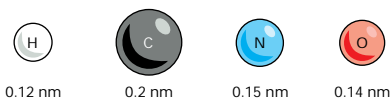
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VAN DER WAALS FORCES

At very short distances any two atoms show a weak bonding interaction due to their fluctuating electrical charges. If the two atoms are too close together, however, they repel each other very strongly.



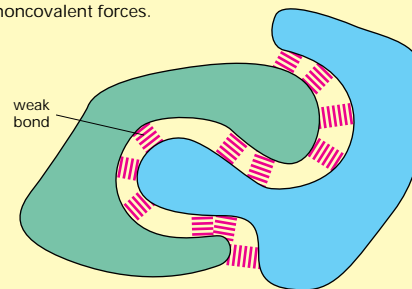
Each atom has a characteristic "size," or **van der Waals radius**: the contact distance between any two atoms is the sum of their van der Waals radii.



Two atoms will be attracted to each other by van der Waals forces until the distance between them equals the sum of their van der Waals radii. Although they are individually very weak, **van der Waals attractions** can become important when two macromolecular surfaces fit very close together.

WEAK CHEMICAL BONDS

Organic molecules can interact with other molecules through short-range noncovalent forces.



Weak chemical bonds have less than 1/20 the strength of a strong covalent bond. They are strong enough to provide tight binding only when many of them are formed simultaneously.

HYDROGEN BONDS

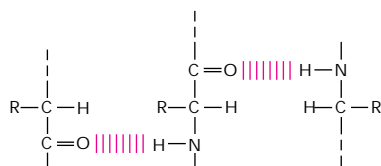
As already described for water (see Panel 2-2, pp. 50-51) **hydrogen bonds** form when a hydrogen atom is "sandwiched" between two electron-attracting atoms (usually oxygen or nitrogen).

Hydrogen bonds are strongest when the three atoms are in a straight line:

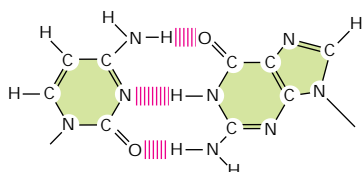


Examples in macromolecules:

Amino acids in polypeptide chains hydrogen-bonded together.

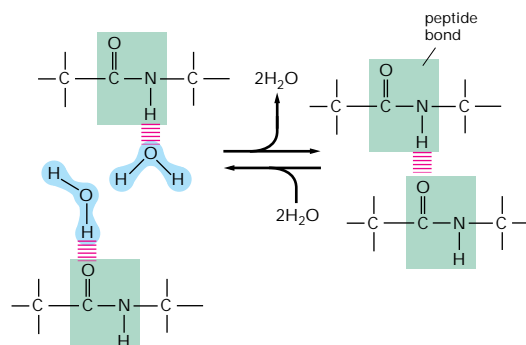


Two bases, G and C, hydrogen-bonded in DNA or RNA.



HYDROGEN BONDS IN WATER

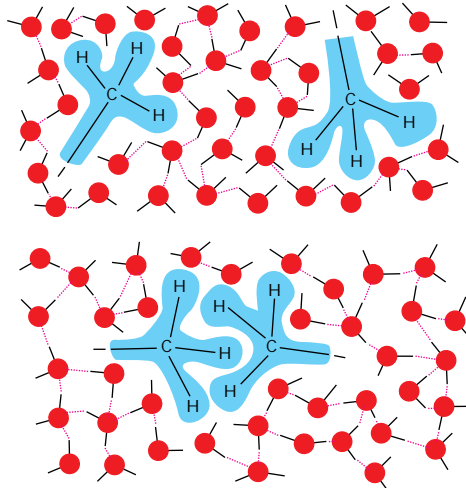
Any molecules that can form hydrogen bonds to each other can alternatively form hydrogen bonds to water molecules. Because of this competition with water molecules, the hydrogen bonds formed between two molecules dissolved in water are relatively weak.



Types of Weak Non-covalent Bonds - Part 2

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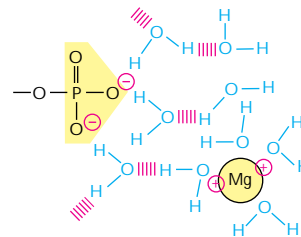
HYDROPHOBIC FORCES



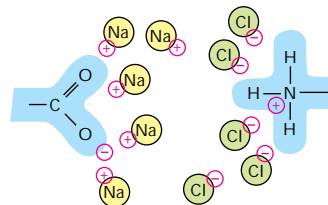
Water forces hydrophobic groups together in order to minimize their disruptive effects on the hydrogen-bonded water network. Hydrophobic groups held together in this way are sometimes said to be held together by "hydrophobic bonds," even though the attraction is actually caused by a repulsion from the water.

IONIC BONDS IN AQUEOUS SOLUTIONS

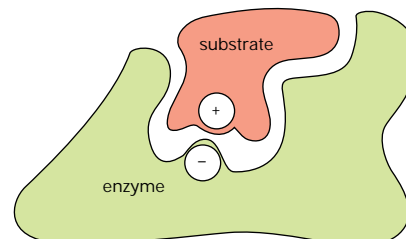
Charged groups are shielded by their interactions with water molecules. Ionic bonds are therefore quite weak in water.



Similarly, other ions in solution can cluster around charged groups and further weaken ionic bonds.



Despite being weakened by water and salt, ionic bonds are very important in biological systems; an enzyme that binds a positively charged substrate will often have a negatively charged amino acid side chain at the appropriate place.



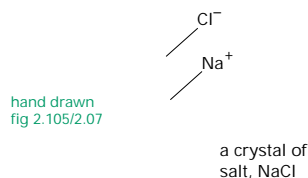
IONIC BONDS

Ionic interactions occur either between fully charged groups (ionic bond) or between partially charged groups.



The force of attraction between the two charges, δ^+ and δ^- , falls off rapidly as the distance between the charges increases.

In the absence of water, ionic forces are very strong. They are responsible for the strength of such minerals as marble and agate.



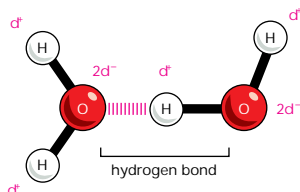
Chemical Properties of Water - Part 1

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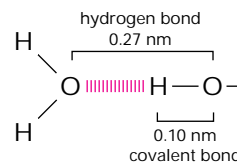
HYDROGEN BONDS

Because they are polarized, two adjacent H₂O molecules can form a linkage known as a **hydrogen bond**. Hydrogen bonds have only about 1/20 the strength of a covalent bond.

Hydrogen bonds are strongest when the three atoms lie in a straight line.

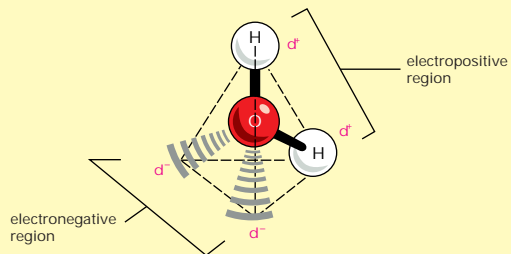


bond lengths



WATER

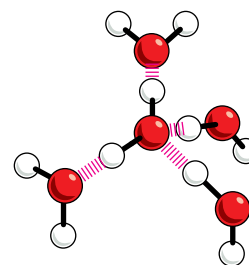
Two atoms, connected by a covalent bond, may exert different attractions for the electrons of the bond. In such cases the bond is **polar**, with one end slightly negatively charged (δ^-) and the other slightly positively charged (δ^+).



Although a water molecule has an overall neutral charge (having the same number of electrons and protons), the electrons are asymmetrically distributed, which makes the molecule polar. The oxygen nucleus draws electrons away from the hydrogen nuclei, leaving these nuclei with a small net positive charge. The excess of electron density on the oxygen atom creates weakly negative regions at the other two corners of an imaginary tetrahedron.

WATER STRUCTURE

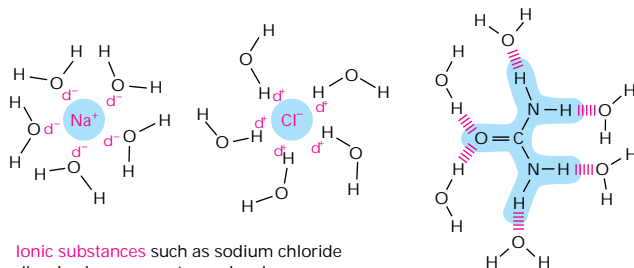
Molecules of water join together transiently in a hydrogen-bonded lattice. Even at 37°C, 15% of the water molecules are joined to four others in a short-lived assembly known as a "flickering cluster."



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

Substances that dissolve readily in water are termed **hydrophilic**. They are composed of ions or polar molecules that attract water molecules through electrical charge effects. Water molecules surround each ion or polar molecule on the surface of a solid substance and carry it into solution.

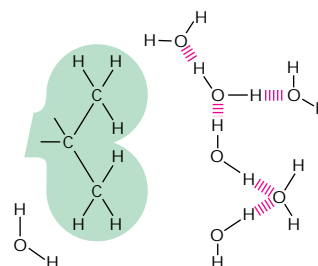


Ionic substances such as sodium chloride dissolve because water molecules are attracted to the positive (Na^+) or negative (Cl^-) charge of each ion.

Polar substances such as urea dissolve because their molecules form hydrogen bonds with the surrounding water molecules

HYDROPHOBIC MOLECULES

Molecules that contain a preponderance of non-polar bonds are usually insoluble in water and are termed **hydrophobic**. This is true, especially, of hydrocarbons, which contain many C-H bonds. Water molecules are not attracted to such molecules and so have little tendency to surround them and carry them into solution.

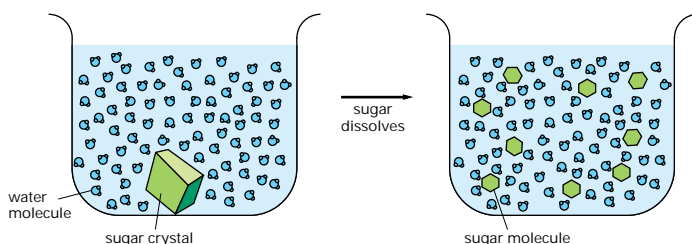


Chemical Properties of Water - Part 2

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WATER AS A SOLVENT

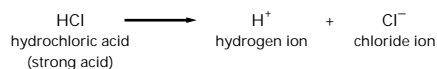
Many substances, such as household sugar, **dissolve** in water. That is, their molecules separate from each other, each becoming surrounded by water molecules.



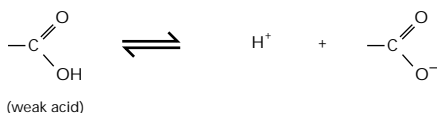
When a substance dissolves in a liquid, the mixture is termed a **solution**. The dissolved substance (in this case sugar) is the **solute**, and the liquid that does the dissolving (in this case water) is the **solvent**. Water is an excellent solvent for many substances because of its polar bonds.

ACIDS

Substances that release hydrogen ions into solution are called **acids**.



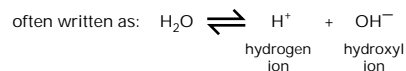
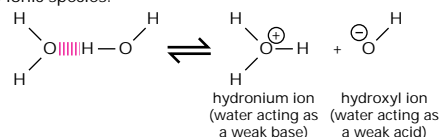
Many of the acids important in the cell are only partially dissociated, and they are therefore **weak acids**—for example, the carboxyl group (–COOH), which dissociates to give a hydrogen ion in solution



Note that this is a reversible reaction.

HYDROGEN ION EXCHANGE

Positively charged hydrogen ions (H⁺) can spontaneously move from one water molecule to another, thereby creating two ionic species.



Since the process is rapidly reversible, hydrogen ions are continually shuttling between water molecules. Pure water contains a steady state concentration of hydrogen ions and hydroxyl ions (both 10⁻⁷ M).

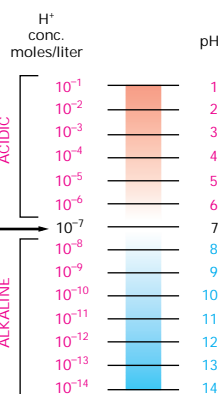
pH

The acidity of a solution is defined by the concentration of H⁺ ions it possesses. For convenience we use the pH scale, where

$$\text{pH} = -\log_{10}[\text{H}^+]$$

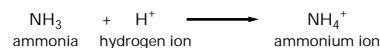
For pure water

$$[\text{H}^+] = 10^{-7} \text{ moles/liter}$$

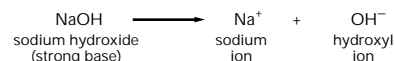


BASES

Substances that reduce the number of hydrogen ions in solution are called **bases**. Some bases, such as ammonia, combine directly with hydrogen ions.



Other bases, such as sodium hydroxide, reduce the number of H⁺ ions indirectly, by making OH⁻ ions that then combine directly with H⁺ ions to make H₂O.



Many bases found in cells are partially dissociated and are termed **weak bases**. This is true of compounds that contain an amino group (–NH₂), which has a weak tendency to reversibly accept an H⁺ ion from water, increasing the quantity of free OH⁻ ions.

