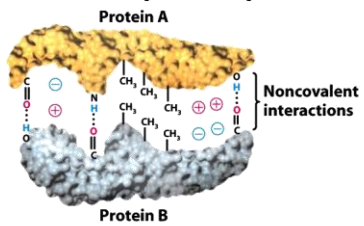


# INTRODUCTION TO THE CELL

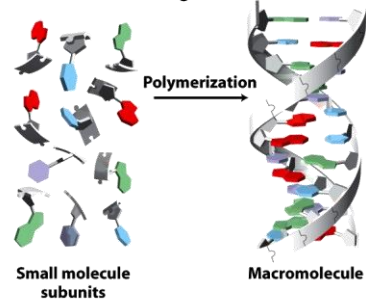
## Chemical foundations

### CHEMISTRY OF LIFE: four key concepts

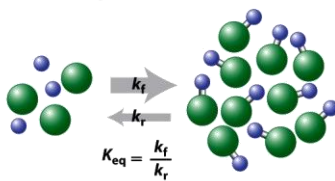
#### (a) Molecular complementarity



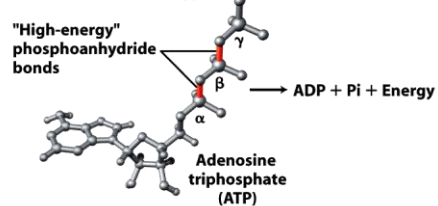
#### (b) Chemical building blocks



#### (c) Chemical equilibrium



#### (d) Chemical bond energy



# WATER

Water is **essential** for all living organisms.

1. Nearly all biological molecules assume their shape (functions) in response to the physical and chemical properties of the surrounding water
2. The medium for the majority of biochemical reactions is water
3. Water itself participates in many chemical reactions that support life

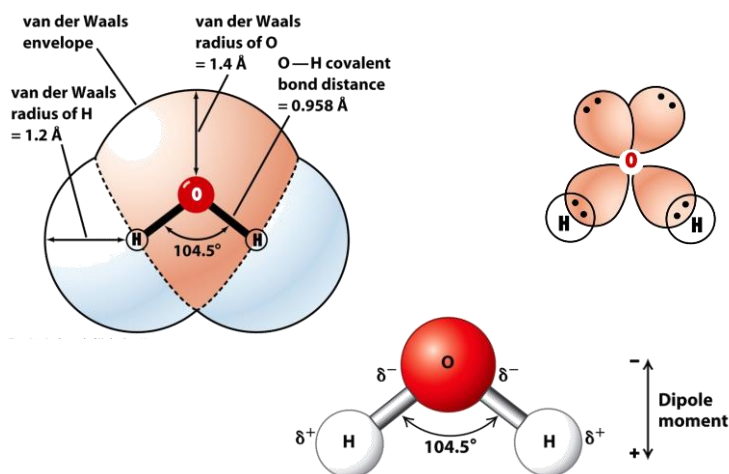
The colorless, odorless, and tasteless nature of water belies its fundamental importance to living organisms.

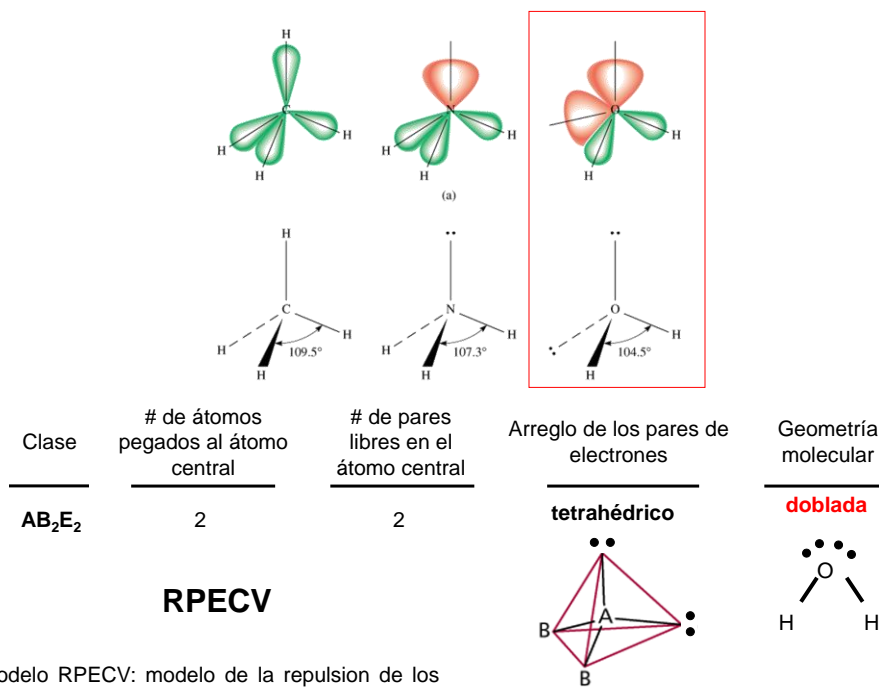
**1- Physical properties of Water:** structure of the water, water as a solvent, the hydrophobic effect, osmosis and diffusion

**2- Chemical properties of Water:** ionization of water, acid-base chemistry, buffers

## 1.1. Structure of Water

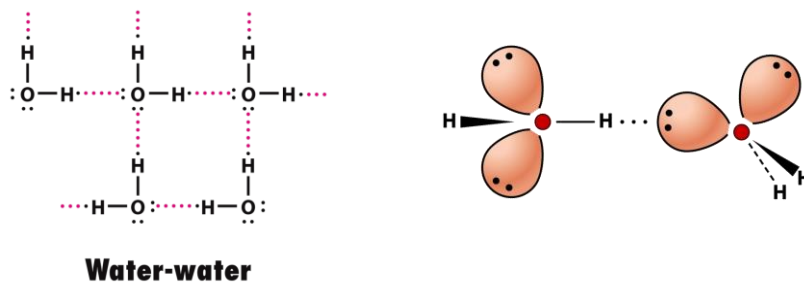
A **water molecule** consists of **two hydrogen atoms** bonded to **an oxygen atom**





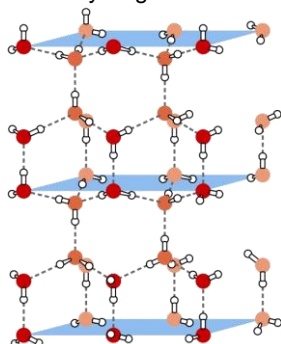
### Water molecules form hydrogen bonds

The angular geometry of the water molecule has enormous implications for living systems. Water is a polar molecule. Neighboring water molecules tend to orient themselves. The resulting directional intermolecular association is known as hydrogen bond.



### ***Ice is a crystal of hydrogen-bonded water molecules***

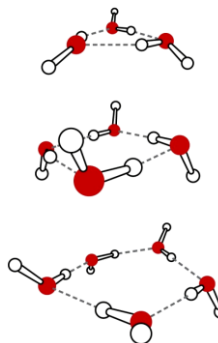
Water molecules in ice are arranged in an unusually open structure. Each water molecule is tetrahedrally surrounded by four nearest neighbors to which it is hydrogen bonded.



The cohesive nature of water is responsible for its unusual properties such as high surface tension, specific heat, and heat of vaporization..

### ***The structure of liquid water is irregular***

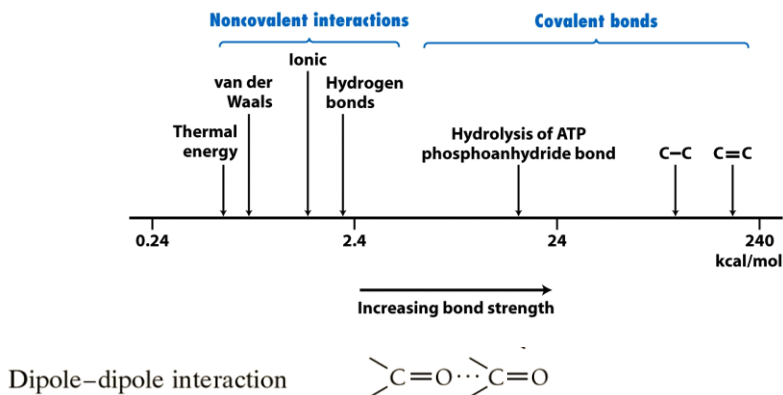
Liquid water consists of a rapidly fluctuating, 3-D network of hydrogen-bonded water molecules.



The figure shows models based on theoretical predictions and spectroscopic data.

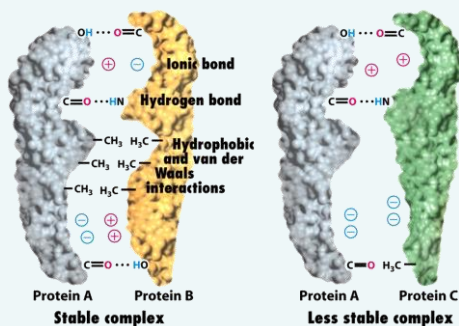
### ***Hydrogen bonds and other weak interactions in biological molecules***

The weak electrostatic forces includes ionic interactions, hydrogen bonds, and van der Waals forces. The strength of association of ionic groups of opposite charge depends on the chemical nature of the ions, the distance between them, and the polarity of the medium. The noncovalent associations between neutral molecules (*van der Waals*) arise from electrostatic interactions among permanent or induced dipoles.



## Molecular complementarity mediated via noncovalent interactions permits tight, highly specific binding of biomolecules

A **molecular complementarity** is a **lock-key fit** between **molecules** whose **shapes, charges, and other physical properties** are **complementary**. Multiple noncovalent interactions can form between complementary molecules, causing them to bind tightly.



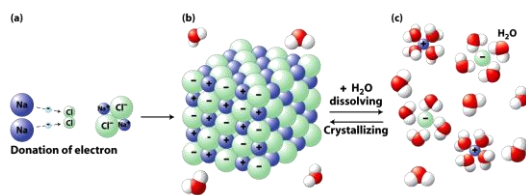
An important quantitative measure of affinity is the binding dissociation constant,  $K_d$ .

The **high degree of binding specificity** is one of the features that underlies intermolecular interactions and thus is **essential** for many **processes critical to life**.

## 1.2. Water as a solvent

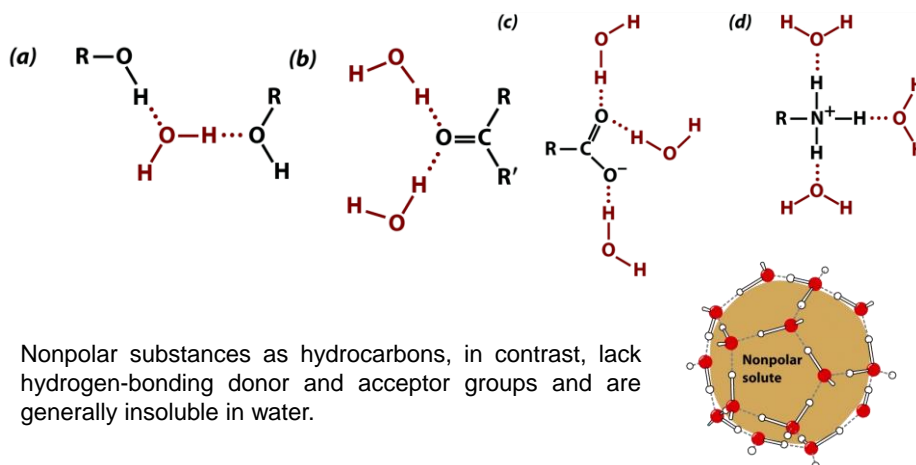
The polar character of **water** makes it an **excellent solvent** for **polar** and ionic **materials**, which are said to be **hydrophilic**. On the other hand, **nonpolar substances** are virtually **insoluble** in water and are described as **hydrophobic**. Nonpolar substances, however, are soluble in nonpolar solvents as  $CCl_4$  and hexane.

*Why do salts such as NaCl dissolve in water?* Water weakens the attractive forces between oppositely charged ions and can therefore hold the ions apart. The ion is surrounded by one or more concentric shells of oriented solvent molecules (solvated, hydrated).

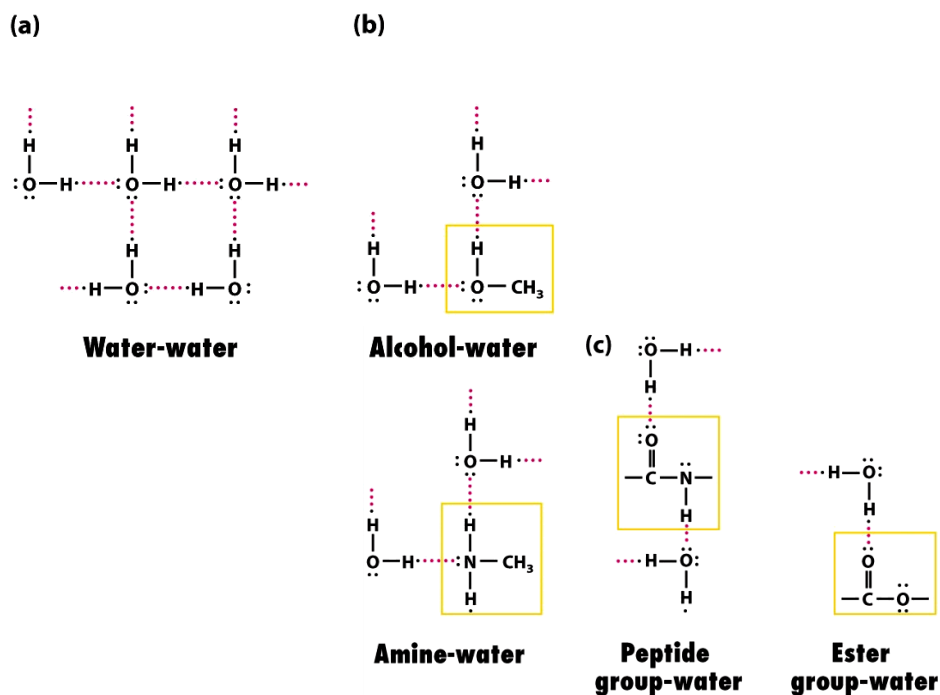


When a substance dissolves in a liquid, the mixture is termed a **solution** (**solute + solvent**)

The solubilities of polar and ionic substances are enhanced when they carry functional groups, such as hydroxyl (OH), carbonyl (C=O), carboxylate (COO<sup>-</sup>), or ammonium (NH<sub>3</sub><sup>+</sup>) groups that can form hydrogen bonds. Indeed, water-soluble biomolecules, such as proteins, nucleic acids and carbohydrates bristle with just such groups.

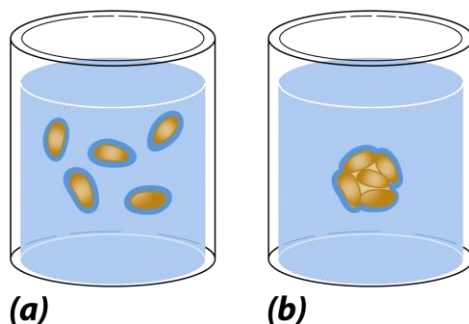


Nonpolar substances as hydrocarbons, in contrast, lack hydrogen-bonding donor and acceptor groups and are generally insoluble in water.



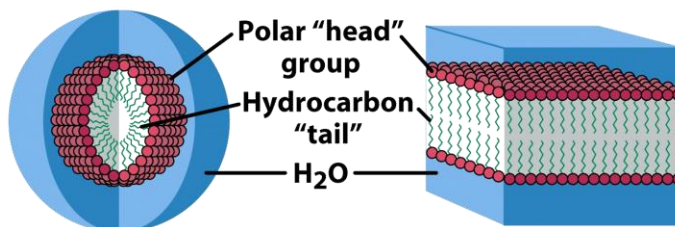
### 1.3. The hydrophobic effect

When a nonpolar substance is added to an aqueous solution, it does not dissolve but instead is excluded by the water. *The tendency of water to minimize its contacts with hydrophobic molecules is termed the hydrophobic effect.*



Aggregation of nonpolar molecules in water **minimizes** the **surface area** of the cavity and **maximizes** the **entropy** of the system

**Amphiphiles from micelles and bilayers.** Most **biomolecules** have both **polar** and **nonpolar segments** and are therefore simultaneously **hydrophilic** and **hydrophobic** (*amphiphilic* or *amphipathic*).



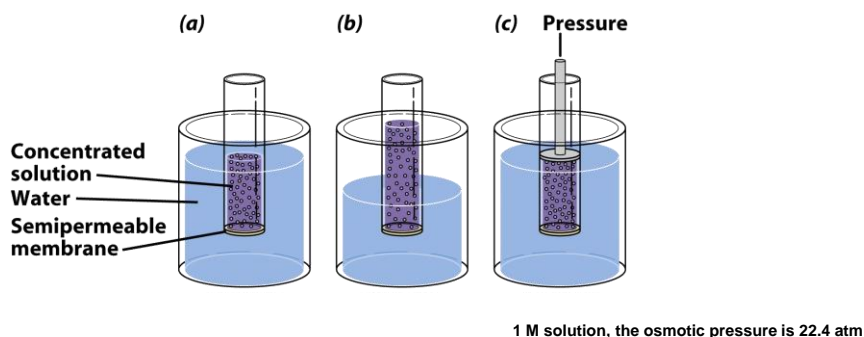
In both **micelles** and **bilayers**, the aggregate is **stabilized** by the **hydrophobic effect**

## 1.4. Water Moves by Osmosis and Solutes Move by Diffusion

The fluid inside de cells and surrounding cells in multicellular organisms is full of dissolved substances ranging from small inorganic ions to huge molecular aggregates. The concentration of these solutes affect water's colligative properties.

Punto congelamiento (disminuye), punto de ebullicion del agua (aumenta); presion de vapor y presion osmotica.

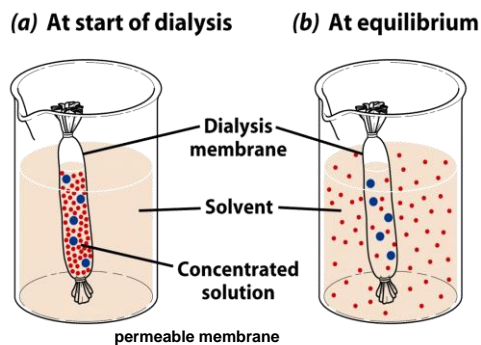
**Osmosis** is the movement of solvent from a region of high concentration to a region of relatively low concentration.



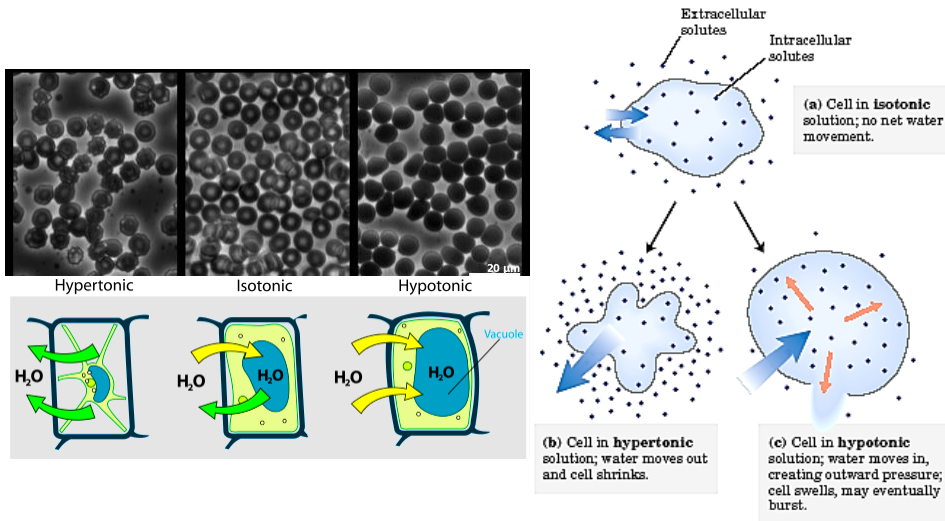
## 1.4. Water Moves by Osmosis and Solutes Move by Diffusion

The fluid inside de cells and surrounding cells in multicellular organisms is full of dissolved substances ranging from small inorganic ions to huge molecular aggregates. The concentration of these solutes affect water's colligative properties.

**Diffusion** is the random movement of solutes from an area of high concentration to an area of low concentration. The molecules diffuse the equilibrium is established.

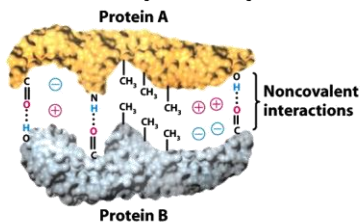




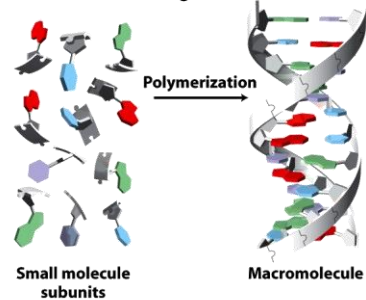


## CHEMISTRY OF LIFE: four key concepts

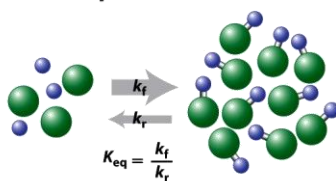
### (a) Molecular complementarity



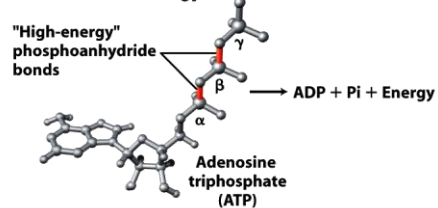
### (b) Chemical building blocks



### (c) Chemical equilibrium

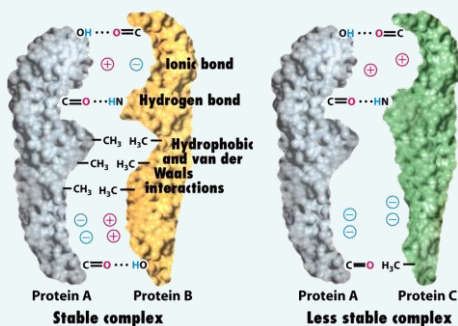


### (d) Chemical bond energy



## Molecular complementarity mediated via noncovalent interactions permits tight, highly specific binding of biomolecules

A **molecular complementarity** is a **lock-key fit** between **molecules** whose **shapes, charges, and other physical properties** are **complementary**. Multiple noncovalent interactions can form between complementary molecules, causing them to bind tightly.



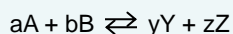
An important quantitative measure of affinity is the binding dissociation constant,  $K_d$ .

The **high degree of binding specificity** is one of the features that underlies intermolecular interactions and thus is **essential** for many **processes critical to life**.

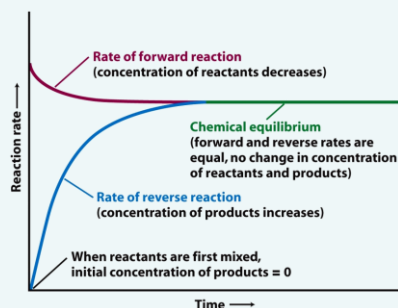
## Chemical equilibrium: equilibrium constants reflect the extent of a chemical reaction

A **chemical reaction** is **at equilibrium** when the **rate** of the **forward** reaction is **equal** to the rate of the **reverse** reaction.

For the general reaction with two reactants and two products,



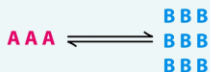
$$K_{eq} = \frac{[Y]^y [Z]^z}{[A]^a [B]^b} = \frac{k_f}{k_r}$$



The equilibrium constant  $K_{eq}$  of a reaction is a **measure** of the **extent** of the **reaction** and the **relative stabilities** of the reactants and products. The  $K_{eq}$  **depends** on the **temperature, pressure, and chemical properties** of the reactants and products but it is **independent** of the **reaction rate** and of the **initial concentrations** of reactants and products.

## Chemical reactions in cells are a steady state

### (a) Test tube equilibrium concentrations

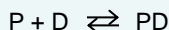


### (b) Intracellular steady-state concentrations



Within *cells*, the *linked reactions* in metabolic pathways generally *are at steady state, not equilibrium*, at which *rate of formation* of the intermediates *equals their rate of consumption* and thus the *concentrations* of the *intermediates* are *not changing*.

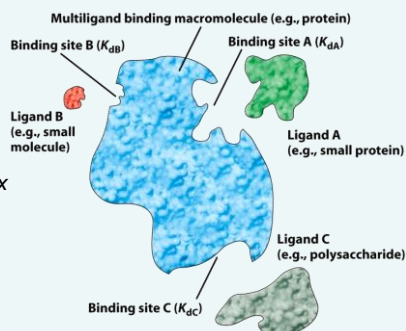
Dissociation constants of binding reactions reflect the affinity of interacting molecules.



$$K_d = \frac{[P][D]}{[PD]} = 1/K_{eq}$$

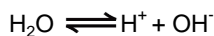
The  $K_d$  is a *measure* of the *stability* of the complex formed *between* the *molecules*.

$$\begin{array}{ll} K_d \sim 10^{-9} \text{ M} & \text{tight} \\ \sim 10^{-6} \text{ M} & \text{modestly tight} \\ \sim 10^{-3} \text{ M} & \text{weak} \end{array}$$



## 2. 1. Ionization of water

Water is a neutral molecule with a very slight tendency to ionize



*Proton jumping* is also responsible for the observation that acid-base reactions are among the fastest reactions that take place in aqueous solution.

$$K_{eq} = \frac{[H_3O^+][OH^-]}{[H_2O]}$$

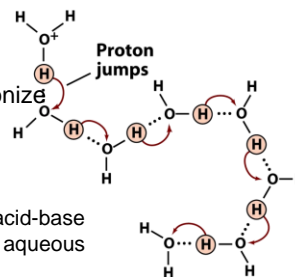
Since in the cell  $[H_2O] \sim 55 \text{ M}$  and ionization is very weak, then  $[H_2O] \sim \text{constant}$ , so we can define,

$$K_w = (55.5 \text{ M})(K_{eq}) = [H_3O^+][OH^-] \text{ "the ionic product of water"}$$

$K_{eq}$ , determined by electrical-conductivity measurements of pure water, is  $1.8 \times 10^{-16} \text{ M}$

$$(K_w)^{1/2} = [H_3O^+] = [OH^-] = 10^{-7} \text{ M}$$

The overall *acidity* of the medium greatly affects many biochemical reactions, because most biological components can function either as *bases* or *acids*.

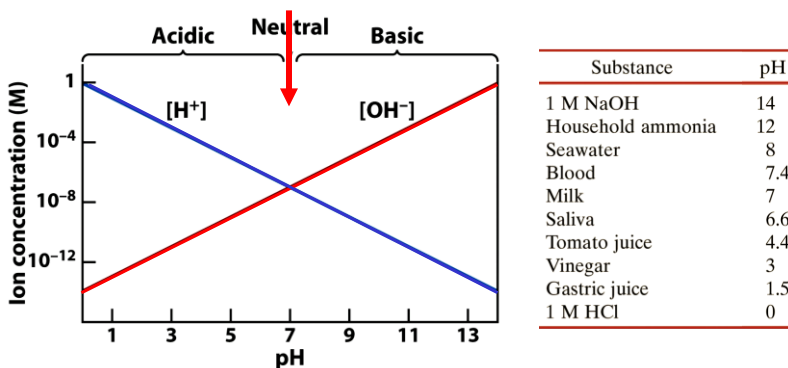


The values of  $[H^+]$  for most solutions are small and thus impractical to compare. A more practical quantity is known as the pH (Sørensen).

*pH is a measure of effective concentration of hydrogen ions in a solution.*

$$pH = -\log [H^+] = \log 1/[H^+]$$

The pH of pure water is 7.0, whereas acidic solutions have  $pH < 7.0$  and basic solutions have  $pH > 7.0$ .



1. The concentration of hydrogen ion in a solution is  $2.5 \times 10^{-5}$  M. What is the solution's pH?
2. The pH of a solution is 3.75. What is the  $[H^+]$  in the solution?
3. A solution has a pH of 4.5. What is the solution's pOH?

$$pOH = 14 - pH = -\log [OH^-]$$

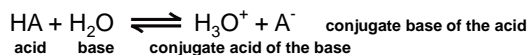
4.  $10^{-4}$  moles of  $H^+$  (as HCl) are added to 1 L of water. Calculate the final pH of the solution.

- 1-  $pH = 4.6$ ;
- 2-  $1.8 \times 10^{-4}$  M;
- 3- 9.5;
- 4-  $pH=4$ ;

## 2. 2. Acid-Base chemistry: hydrogen ions are released by acids and taken up by bases

Biomolecules have numerous functional groups that act as acids or bases and influence the pH of the medium, and their structures and reactivities are in turn influenced by the ambient pH.

**An acid can donate a proton.** An *acid* is a substance that can *donate a H<sup>+</sup>*, and a *base* is a substance that can *accept a proton* (Brønsted-Lowry definition).



The strength of an acid is specified by its dissociation constant.

$$K_{\text{eq}} = \frac{[\text{H}^+][\text{A}^-]}{[\text{H}_2\text{O}][\text{HA}]}$$

In dilute solutions, the water concentration is essentially constant,  $[\text{H}_2\text{O}] = 55.5 \text{ M}$ , and can be combined with  $K$ , which then takes the form

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]} \quad \text{Acid dissociation constant}$$

FOR BREVETY, HOWEVER, WE OMIT THE SUBSCRIPT "a"

A measure of  $K_a$  for a weak acid is given by its  $\text{p}K_a$ , which is equivalent to the negative log of  $K_a$ :

$$\text{p}K_a = -\log K_a$$

**The pH of a solution is determined by the relative concentrations of acids and bases.** The relationship between pH of a solution and the concentrations of an acid and its conjugate base is easily derived and is known as the **Henderson-Hasselbalch** equation.

$$\text{pH} = \text{p}K_a + \log \frac{[\text{A}^-]}{[\text{AH}]}$$

Table 2-4 Dissociation Constants and pK Values at 25°C of Some Acids

Acid	$K$	$\text{p}K$
Oxalic acid	$5.37 \times 10^{-2}$	1.27 ( $\text{p}K_1$ )
$\text{H}_3\text{PO}_4$	$7.08 \times 10^{-3}$	2.15 ( $\text{p}K_1$ )
Formic acid	$1.78 \times 10^{-4}$	3.75
Succinic acid	$6.17 \times 10^{-5}$	4.21 ( $\text{p}K_1$ )
Oxalate <sup>-</sup>	$5.37 \times 10^{-5}$	4.27 ( $\text{p}K_2$ )
Acetic acid	$1.74 \times 10^{-5}$	4.76
Succinate <sup>-</sup>	$2.29 \times 10^{-6}$	5.64 ( $\text{p}K_2$ )
2-( <i>N</i> -Morpholino)ethanesulfonic acid (MES)	$8.13 \times 10^{-7}$	6.09
$\text{H}_2\text{CO}_3$	$4.47 \times 10^{-7}$	6.35 ( $\text{p}K_1$ ) <sup>a</sup>
Piperazine- <i>N,N'</i> -bis(2-ethanesulfonic acid) (PIPES)	$1.74 \times 10^{-7}$	6.76
$\text{H}_2\text{PO}_4^-$	$1.51 \times 10^{-7}$	6.82 ( $\text{p}K_2$ )
3-( <i>N</i> -Morpholino)propanesulfonic acid (MOPS)	$7.08 \times 10^{-8}$	7.15
<i>N</i> -2-Hydroxyethylpiperazine- <i>N'</i> -2-ethanesulfonic acid (HEPES)	$3.39 \times 10^{-8}$	7.47
Tris(hydroxymethyl)aminomethane (Tris)	$8.32 \times 10^{-9}$	8.08
$\text{NH}_4^+$	$5.62 \times 10^{-10}$	9.25
Glycine (amino group)	$1.66 \times 10^{-10}$	9.78
$\text{HCO}_3^-$	$4.68 \times 10^{-11}$	10.33 ( $\text{p}K_2$ )
Piperidine	$7.58 \times 10^{-12}$	11.12
$\text{HPO}_4^{2-}$	$4.17 \times 10^{-13}$	12.38 ( $\text{p}K_3$ )

Source: Dawson, R.M.C., Elliott, D.C., Elliott, W.H., and Jones, K.M., *Data for Biochemical Research* (3rd ed.), pp. 424–425, Oxford Science Publications (1986); and Good, N.E., Winget, G.D., Winter, W., Connolly, T.N., Izawa, S., and Singh, R.M.M., *Biochemistry* 5, 467 (1966).

<sup>a</sup>The  $\text{p}K$  for the overall reaction  $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$ ; see Box 2-2.

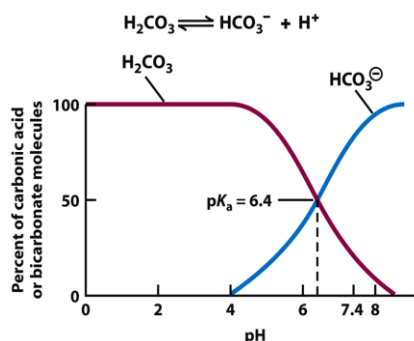
$$\text{pH} = \text{p}K_a + \log \frac{[\text{A}^-]}{[\text{AH}]}$$

Table 2-4 Dissociation Constants and pK Values at 25°C of Some Acids

Acid	K	pK
Oxalic acid	$5.37 \times 10^{-2}$	1.27 (pK <sub>1</sub> )
H <sub>3</sub> PO <sub>4</sub>	$7.08 \times 10^{-3}$	2.15 (pK <sub>1</sub> )
Formic acid	$1.78 \times 10^{-4}$	3.75
Succinic acid	$6.17 \times 10^{-5}$	4.21 (pK <sub>1</sub> )
Oxalate <sup>-</sup>	$5.37 \times 10^{-5}$	4.27 (pK <sub>2</sub> )
Acetic acid	$1.74 \times 10^{-5}$	4.76
Succinate <sup>-</sup>	$2.29 \times 10^{-6}$	5.64 (pK <sub>2</sub> )
2-(N-Morpholino)ethanesulfonic acid (MES)	$8.13 \times 10^{-7}$	6.09
H <sub>2</sub> CO <sub>3</sub>	$4.47 \times 10^{-7}$	6.35 (pK <sub>1</sub> ) <sup>a</sup>
Piperazine-N,N'-bis(2-ethanesulfonic acid) (PIPES)	$1.74 \times 10^{-7}$	6.76
H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>	$1.51 \times 10^{-7}$	6.82 (pK <sub>2</sub> )
3-(N-Morpholino)propanesulfonic acid (MOPS)	$7.08 \times 10^{-8}$	7.15
N-2-Hydroxyethylpiperazine-N'-2-ethanesulfonic acid (HEPES)	$3.39 \times 10^{-8}$	7.47
Tris(hydroxymethyl)aminomethane (Tris)	$8.32 \times 10^{-9}$	8.08
NH <sub>4</sub> <sup>+</sup>	$5.62 \times 10^{-10}$	9.25
Glycine (amino group)	$1.66 \times 10^{-10}$	9.78
HCO <sub>3</sub> <sup>-</sup>	$4.68 \times 10^{-11}$	10.33 (pK <sub>2</sub> )
Piperidine	$7.58 \times 10^{-12}$	11.12
HPO <sub>4</sub> <sup>2-</sup>	$4.17 \times 10^{-13}$	12.38 (pK <sub>3</sub> )

Source: Dawson, R.M.C., Elliott, D.C., Elliott, W.H., and Jones, K.M., *Data for Biochemical Research* (3rd ed.), pp. 424–425, Oxford Science Publications (1986); and Good, N.E., Winget, G.D., Winter, W., Connolly, T.N., Izawa, S., and Singh, R.M.M., *Biochemistry* 5, 467 (1966).

<sup>a</sup>The pK for the overall reaction  $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$ ; see Box 2-2.



The relationship between pH, pK<sub>a</sub>, and the dissociation of an acid

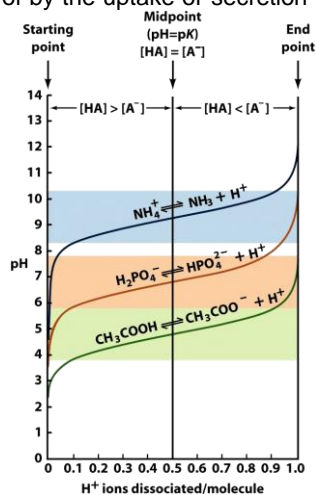
## 2. 3. Buffers: maintain the pH of intracellular and extracellular fluids

Cells have a *reservoir of weak bases and weak acids, called buffers*, which ensure that the cell's pH remains relatively constant despite small fluctuations in the amounts of H<sup>+</sup> or OH<sup>-</sup> being generated by metabolism or by the uptake or secretion of molecules and ions by the cell.

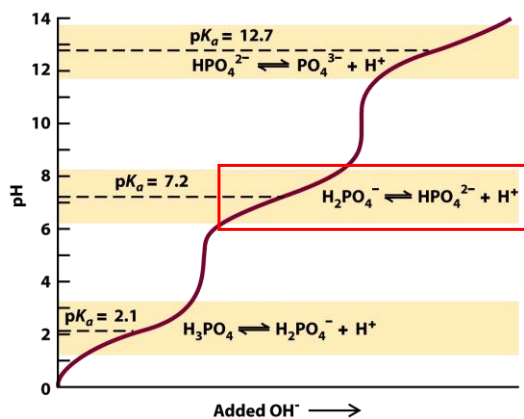
The ability of a buffer to minimize changes in pH, its *buffering capacity*, depends on the concentration of the buffer and the relationship between its pK<sub>a</sub> value and the pH.

*Titration curves* can be constructed from experimental observation or by using the Henderson-Hasselbalch equation.

1. the curves have similar shape but are shifted vertically along the pH axis
2. The pH at the midpoint of each titration is equivalent to the pK<sub>a</sub> value of its corresponding acid
3. The slope of each titration curve is much lower near its midpoint than near its wings.



Two especially important biological buffers are the phosphate and bicarbonate systems. The phosphate buffer system, which acts in the cytoplasm of all cells, consists of  $\text{H}_2\text{PO}_4^-$  as proton donor and  $\text{HPO}_4^{2-}$  as proton acceptor:



It is therefore an effective buffer in biological fluids; in mammals, for example, extracellular fluids and most cytoplasmic compartments have a pH in the range of 6.9 to 7.4.

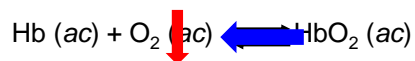
### Principio de Le Chatelier

Existe una regla general que ayuda a predecir en qué dirección se desplazará una reacción en equilibrio cuando hay un cambio de concentración, presión, volumen o temperatura. Esta regla, conocida como el *principio de Le Chatelier*, establece que **si se aplica una tensión externa a un sistema en equilibrio, el sistema se ajusta de tal manera que se cancela parcialmente dicha tensión en la medida que el sistema alcanza una nueva posición de equilibrio.**

El término "tensión" significa aquí un cambio de concentración, presión, volumen o temperatura que altera el estado de equilibrio de un sistema.

### La Química en acción La vida a grandes alturas y la producción de hemoglobina

En el cuerpo humano es necesario mantener innumerables equilibrios químicos para asegurar su bienestar fisiológico. Si las condiciones ambientales cambian, el cuerpo se debe adaptar para mantener un funcionamiento adecuado.



$$K_c = \frac{[\text{HbO}_2]}{[\text{Hb}][\text{O}_2]}$$

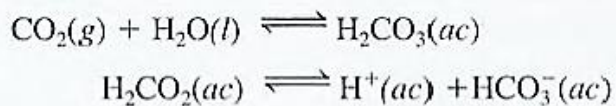
A una altitud de 3 km, la presión parcial del oxígeno es de sólo 0.14 atm, comparada con 0.2 atm a nivel del mar.

*Este cambio reduce el aporte de oxihemoglobina los tejidos y provoca hipoxia.*

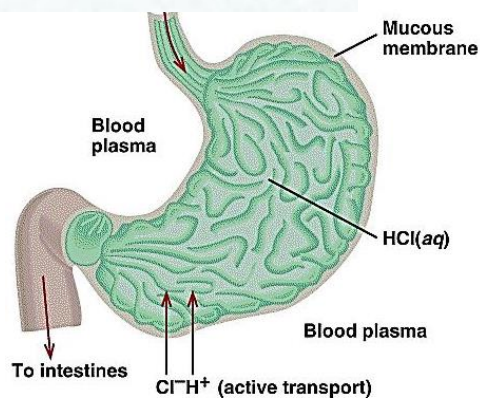


### La Química en acción: antiácidos y el balance del pH en el estómago

Los iones H<sup>+</sup> provienen del ácido carbónico (Los iones H<sup>+</sup> provienen del ácido carbónico (H<sub>2</sub>CO<sub>3</sub>) que se forma como resultado de la hidratación del CO<sub>2</sub>, un producto final del metabolismo:

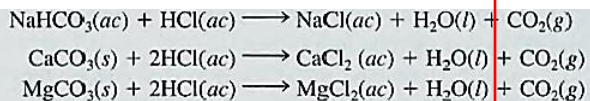


$$[\text{HCl}] = 0.03 \text{ M}$$



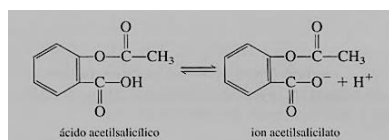


## La Química en acción: antiácidos y el balance del pH en el estómago



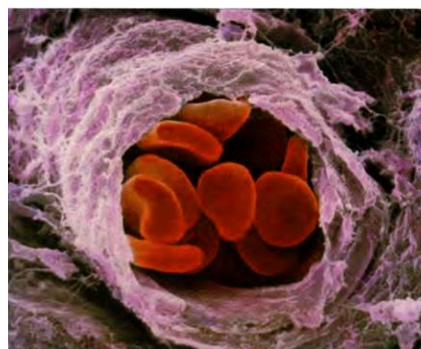
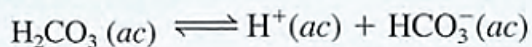
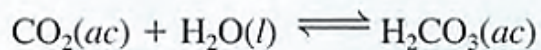
### Some Common Commercial Antacid Preparations

Commercial Name	Active Ingredients
Alka-2	Calcium carbonate
Alka-Seltzer	Aspirin, sodium bicarbonate, citric acid
Bufferin	Aspirin, magnesium carbonate, aluminum glycinate
Buffered aspirin	Aspirin, magnesium carbonate, aluminum hydroxide-glycine
Milk of magnesia	Magnesium hydroxide
Rolaids	Dihydroxy aluminum sodium carbonate
Tums	Calcium carbonate

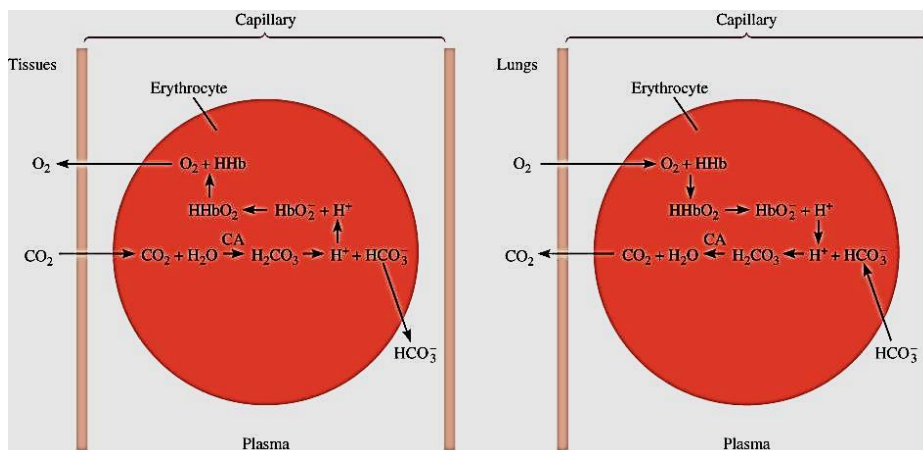


## Mantenimiento del pH de la sangre

Los eritrocitos contienen moléculas de hemoglobina, así como la enzima *anhidrasa carbónica*, la cual cataliza tanto la formación de ácido carbónico ( $\text{H}_2\text{CO}_3$ ) como su descomposición:



## Química en acción: manteniendo el pH de la sangre

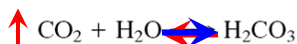


16.3

## Blood, Lungs, and Buffer: The Bicarbonate Buffer System

Bicarbonate is the most significant buffer compound in human blood. The buffering capacity of blood depends primarily on two equilibria:

1. between gaseous  $\text{CO}_2$  dissolved in the blood and carbonic acid formed by the reaction



2. between carbonic acid and bicarbonate formed by the dissociation of  $\text{H}^+$



pH of the blood falls due to metabolic production of  $\text{H}^+$   $\uparrow \text{CO}_2$

pH of the blood rises  $\uparrow \text{HCO}_3^-$

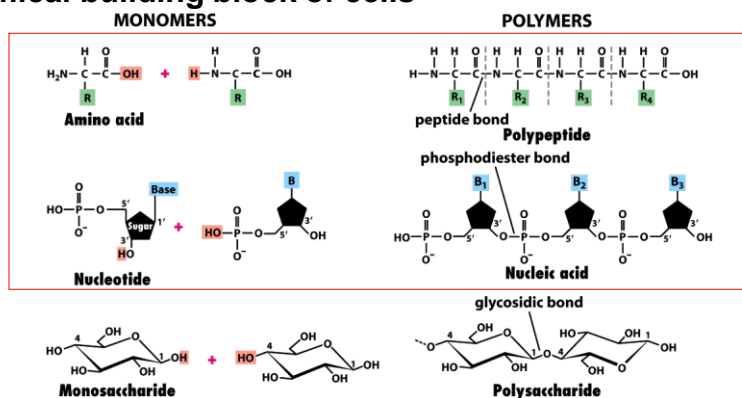
*Thus the pH of a bicarbonate buffer exposed to a gas phase is ultimately determined by the concentration of  $\text{HCO}_3^-$  in the aqueous phase and the partial pressure of  $\text{CO}_2$  in the gas phase*

Disturbances in the blood buffer system can lead to conditions known as **acidosis** (pH = 7.1) or **alkalosis** (pH = 7.6). Acid-base imbalances are best alleviated by correcting the underlying physiological problem.

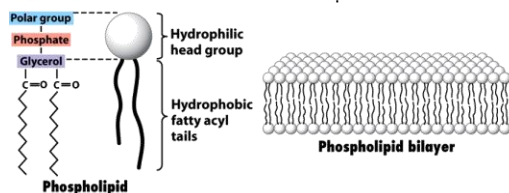
## SUMMARY

- Water is essential for all living organisms
- Water molecules can form hydrogen bonds with other molecules because they have two H atoms that can be donated and two unshared electron pairs that can act as acceptors
- Liquid water is an irregular network of water molecules that each form up to four hydrogen bonds with neighboring water molecules
- Hydrophilic substances such as ionic and polar molecules dissolve readily in water
- The hydrophobic effect is the tendency of water to minimize its contacts with nonpolar substances
- Water molecules move from regions of high concentrations to regions of low concentration by osmosis; solutes move from regions of high concentration to regions of low concentration by diffusion
- Water ionizes to  $H^+$  (which represents the hydronium ion,  $H_3O^+$ ) and  $OH^-$
- The concentration of  $H^+$  in solution is expressed as a pH value: in acidic solutions  $pH < 7$ , in basic solutions  $pH > 7$ , and in neutral solutions  $pH = 7$
- Acids can donate protons and bases can accept protons. The strength of an acid is expressed as its  $pK_a$ .
- The Henderson-Hasselbalch equation relates the pH of a solution to the  $pK_a$  and concentrations of an acid and its conjugate base.
- Buffered solutions resist changes in pH within about one pH unit of the  $pK_a$

## Chemical building block of cells



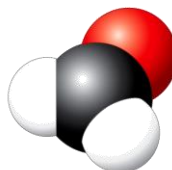
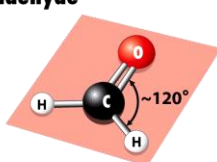
Proteins and nucleic acids are informational macromolecules: each protein and each nucleic acid has a characteristic information-rich subunit sequence.



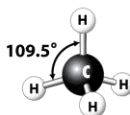
## Biomolecules Are Compounds of Carbon with a Variety of Functional Groups

Hydrogen, oxygen, carbon, nitrogen, phosphorus, and sulfur are the most abundant elements in biological molecules. All the biological **building blocks** are **organized** around the **carbon atom**, which normally forms four covalent bonds with three or four other atoms.

### (a) Formaldehyde



### (b) Methane



Chemical  
structure

Ball-and-stick  
model

Space-filling  
model

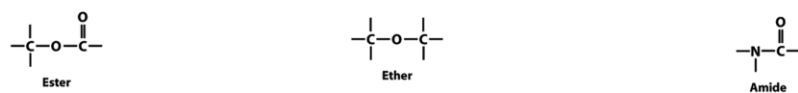
Geometry of bonds when carbon is covalently linked to three or four other atoms

Covalently linked carbon atoms in biomolecules can form linear chains, branched chains, and cyclic structures. To these carbon skeletons are added groups of other atoms, called **functional groups**, which confer specific chemical properties on the molecule.

### FUNCTIONAL GROUPS

$\text{—OH}$ Hydroxyl (alcohol)	$\begin{array}{c} \text{O} \\    \\ \text{—C—R} \end{array}$ Acyl (triacylglycerol)	$\begin{array}{c} \text{O} \\    \\ \text{—C—} \end{array}$ Carbonyl (ketone)	$\begin{array}{c} \text{O} \\    \\ \text{—C—O}^- \end{array}$ Carboxyl (carboxylic acid)
$\text{—SH}$ Sulfhydryl (Thiol)	$\text{—NH}_2$ or $\text{—NH}_3^+$ Amino (amines)	$\begin{array}{c} \text{O} \\    \\ \text{—O—P—O}^- \\   \\ \text{O}^- \end{array}$ Phosphate (phosphorylated molecule)	$\begin{array}{c} \text{O} \quad \text{O} \\    \quad    \\ \text{—O—P—O—P—O}^- \\   \quad   \\ \text{O}^- \quad \text{O}^- \end{array}$ Pyrophosphate (diphosphate)

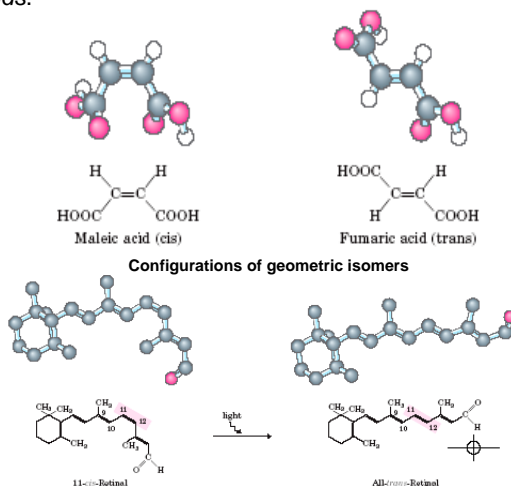
### LINKAGES



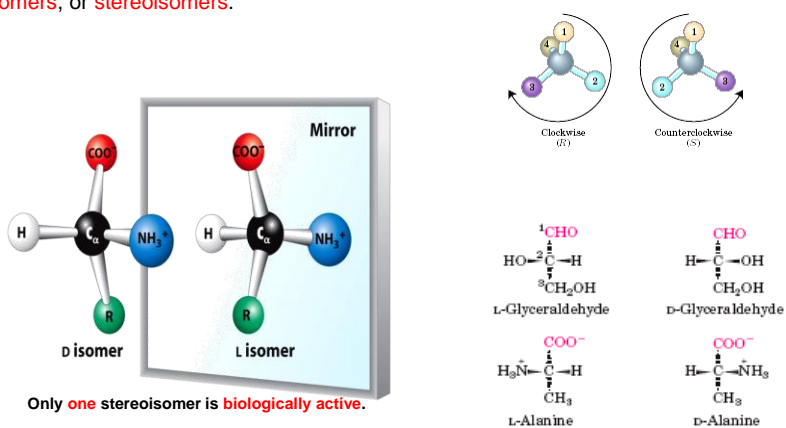
Common functional groups and linkages in biomolecules

### 3-D Structure Is Described by Configuration and Conformation

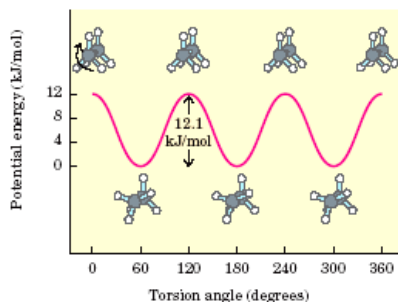
**Molecular Configuration** is conferred by the presence of either, double bond or chiral centers. *The identifying characteristic of **configurational isomers** is that they **cannot be interconverted** without temporarily breaking one or more covalent bonds.*



A carbon atom bonded to four dissimilar atoms or groups in a nonplanar configuration is said to be asymmetric. *The tetrahedral orientation of bonds formed by an **asymmetric carbon atom** can be **arranged in 3-D** in two different ways, **producing molecules that are mirror images** each other, a property called **chirality**.* Such molecules are called **optical isomers**, or **stereoisomers**.



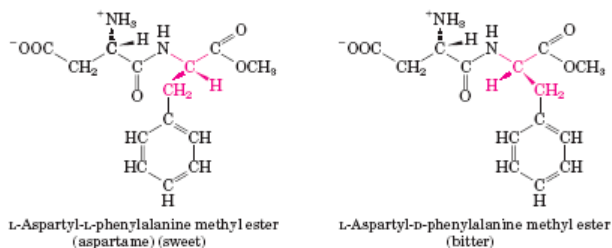
**Molecular conformation** is the spatial arrangement of **substituent groups** that, *without breaking any bonds*, are **free to assume different positions in space** because of the freedom of rotation about single bonds.



Two conformations are of special interest: the staggered, which is more stable than all others and thus predominates, and the eclipsed, which is least stable.

## Interactions between Biomolecules Are Stereospecific

**Stereospecificity**, the ability to distinguish between stereoisomers, is a property of enzymes and other proteins and a characteristic feature of the molecular logic of living cells. One striking example of the ability to distinguish stereoisomers by taste in humans.

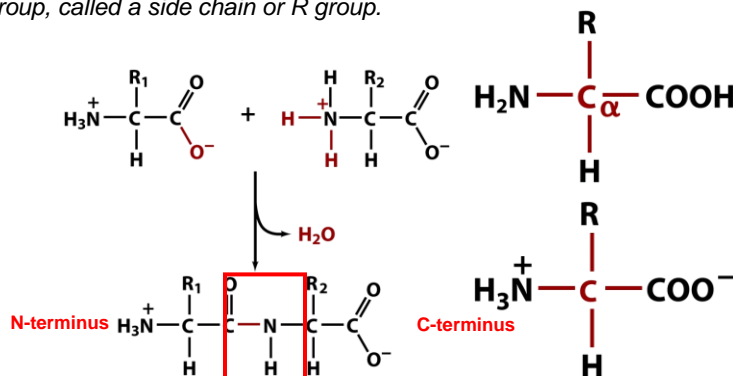


**Stereoisomers distinguishable by taste in humans**

*Interactions between biological molecules are almost invariably stereospecific: they require a complementary match between the interacting molecules.*

## Amino Acids differing only in their side chains compose proteins

The monomeric **building blocks** of **proteins** are **20 amino acids (L isomer)**, which have a characteristic structure consisting of a central  $C_{\alpha}$  bonded to four different chemical groups: an amino group, a carboxylic acid group, a hydrogen atom, and one variable group, called a side chain or R group.

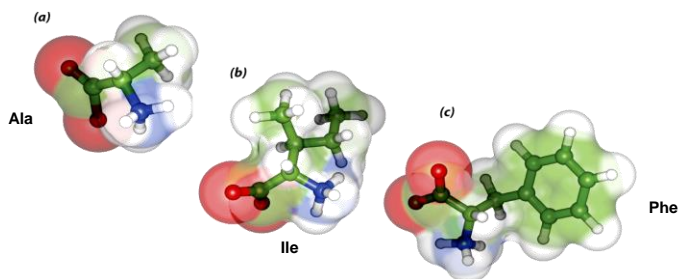


Amino acids can be **polymerized** to form chains. The resulting **CO-NH linkage**, an amide linkage, is known as a **peptide bond**.

Amino acids can be **classified** into several broad categories based on the size, shape, charge, hydrophobicity, and chemical reactivity of the side chains. According to the most common classification scheme, **by the polarities of their side chains**, there are three major types of amino acids:

1. those with **nonpolar R groups**
2. those with **uncharged polar R groups**, and
3. those with **charged polar R groups**

**1. The nonpolar amino acids side chains have a variety of shapes and sizes.** Nine amino acids are classified as having nonpolar side chains: *Gly, Ala, Val, Leu, Ile, Met, Pro, Phe, Trp*.

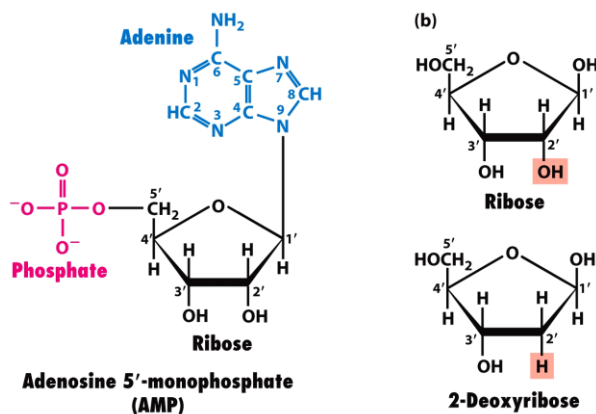


## SUMMARY

- Three major biopolymers formed by polymerization reactions (net dehydration) of basic chemical blocks are present in cells: proteins, composed of amino acids linked by peptide bonds; nucleic acids, composed of nucleotides linked by phosphodiester bonds; and polysaccharides, composed of monosaccharides linked by glycosidic bonds. Phospholipids, the fourth major chemical building block, assemble noncovalently into biembranes.
- Many molecules in cells contain at least one asymmetric carbon atom, which bonded to four dissimilar atoms. Such molecules can exist as optical isomers, designated D and L, which have different biological activities. In biological systems, nearly all sugars are D isomers, whereas nearly all amino acids are L isomers.
- Differences in size, shape, charge, hydrophobicity, and reactivity of the side chains of the 20 common amino acids determine the chemical and structural properties of proteins.
- The bases in the nucleotides composing DNA and RNA are carbon- and nitrogen-containing rings attached to a pentose sugar. They form two groups: the purines (Adenine, Guanine) and the pyrimidines (Cytosine, Thymine, and Uracil). A, G, T, and C are in DNA, and A, G, U, and C are in RNA.
- Glucose and other hexoses can exist in three forms: an open-chain linear structure, a six-member ring, and a five-member ring. In biological systems, the pyranose form of D-glucose predominates.
- Phospholipids are amphipathic molecules with a hydrophobic tail connected by a small organic molecule to a hydrophilic head. The long hydrocarbon chain of a fatty acid may contain no carbon-carbon double bond or one or more double bonds; a *cis* double bond bends the chain.

## Five different nucleotides are used to build Nucleic Acids

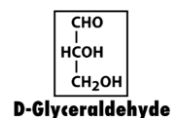
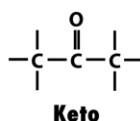
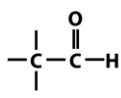
Two types of chemically similar **nucleic acids**, **DNA** and **RNA**, are *the principal genetic-information-carrying molecules of the cell*. The monomeric building blocks are called **nucleotides**, all have a common structure: a **phosphate group** linked by a phosphoester bond to a **pentose** that in turn is linked to a **nitrogen- and carbon-containing ring structure** referred as a **base**.



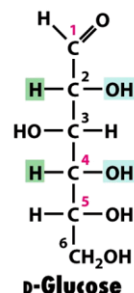


## Monosaccharides joined by glycosidic bonds from linear and branched polysaccharides

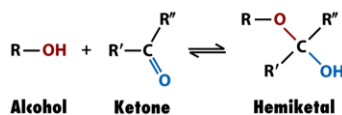
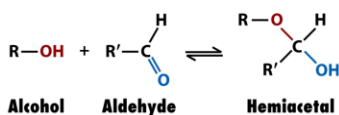
The **building blocks** of the **polysaccharides** are the simple sugar, or **monosaccharides**, which are **aldehyde or ketone derivatives of straight-chain polyhydroxy alcohols containing at least three carbon atoms**. They are classified according to the chemical nature of their carbonyl group and the number of their C atoms. Hexoses and pentoses are the most common monosaccharides.



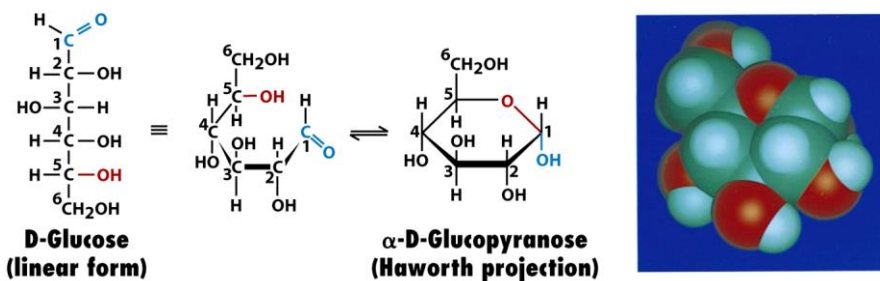
The **aldohexose D-Glucose** has the formula (C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>), **two** of its six C atoms are **chiral centers**, so D-glucose is one of **16** possible **stereoisomers**. D-glucose is the principal external source of energy for most cells in higher organisms and **can exist in three different forms**: a **linear structure** and **two different hemiacetal ring structures**.



**Configuration and conformation:** alcohols react with the carbonyl groups of aldehydes and ketones to form hemiacetals and hemiketals.



The hydroxyl and either the aldehyde or ketone functions of **monosaccharides** can likewise react **intramolecularly to form cyclic hemiacetals and hemiketals**. The configurations of the substituents of each C atom are represented by their Haworth projections. When a monosaccharide cyclizes, the carbonyl C, called the **anomeric carbon**, becomes a chiral center with two possible configurations (anomers).



**α-** OH of the anomeric C is on the opposite side of the sugar ring from the CH<sub>2</sub>OH group at the chiral center that designates the D configuration

## Lipids and biological membranes

Lipids are a diverse group of molecules that are soluble in organic solvents and, in contrast to other major types of biomolecules, do not form polymers. In general, lipids perform three biological functions:

1. lipid molecules in the form of lipid bilayers are essential components of biological membranes
2. lipids containing hydrocarbon chains serve as energy stores
3. many intra- and intercellular signaling events involve lipid molecules

### Lipids classification

fatty acids, triacylglycerols, glycerophospholipids, sphingolipids, and steroids

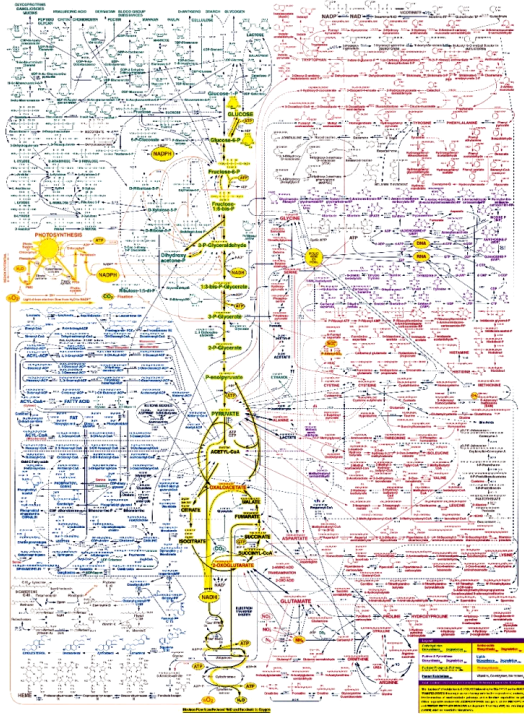
### Lipid bilayers

why bilayers form, lipid mobility



## SUMMARY

- Three major biopolymers formed by polymerization reactions (net dehydration) of basic chemical blocks are present in cells: proteins, composed of amino acids linked by peptide bonds; nucleic acids, composed of nucleotides linked by phosphodiester bonds; and polysaccharides, composed of monosaccharides linked by glycosidic bonds. Phospholipids, the fourth major chemical building block, assemble noncovalently into biomembranes.
- Many molecules in cells contain at least one asymmetric carbon atom, which is bonded to four dissimilar atoms. Such molecules can exist as optical isomers, designated D and L, which have different biological activities. In biological systems, nearly all sugars are D isomers, whereas nearly all amino acids are L isomers.
- Differences in size, shape, charge, hydrophobicity, and reactivity of the side chains of the 20 common amino acids determine the chemical and structural properties of proteins.
- The bases in the nucleotides composing DNA and RNA are carbon- and nitrogen-containing rings attached to a pentose sugar. They form two groups: the purines (Adenine, Guanine) and the pyrimidines (Cytosine, Thymine, and Uracil). A, G, T, and C are in DNA, and A, G, U, and C are in RNA.
- Glucose and other hexoses can exist in three forms: an open-chain linear structure, a six-member ring, and a five-member ring. In biological systems, the pyranose form of D-glucose predominates.
- Phospholipids are amphipathic molecules with a hydrophobic tail connected by a small organic molecule to a hydrophilic head. The long hydrocarbon chain of a fatty acid may contain no carbon-carbon double bond or one or more double bonds; a *cis* double bond bends the chain.



The processes by which biological molecules are broken down and resynthesized from a complex, yet highly regulated, network of interdependent enzymatic reactions that are collectively known as life.

Designed by Donald Nicholson

**Metabolism**, the overall process through which living systems acquire and use free energy to carry out their various functions, is divided into two parts:

1. catabolism or degradation
2. anabolism or biosynthesis

