Homeostasis is the property of a system, either open or closed, that regulates its internal environment and tends to maintain a stable, constant condition. Much disease results from disturbance of homeostasis.

Acid-base homeostasis is the part of human homeostasis concerning the proper balance between acids and bases. The blood's acid-base balance is precisely controlled, because even a minor deviation from the normal range can severely affect many organs.
Acids and bases

**Brønsted-Lowry acid-base theory**

An acid is a substance whose molecules donate positive hydrogen ions (protons) to other molecules or ions. When dissolved in pure water, acid molecules will transfer a hydrogen ion to a water molecule or to a cluster of several water molecules. This increases the concentration of H\(^+\) ions in the solution. (HCl, H\(_2\)SO\(_4\))

A base is a substance whose molecules accept hydrogen ions from other molecules. When dissolved in pure water, base molecules will accept a hydrogen ion from a water molecule, leaving behind an increased concentration of OH\(^-\) ions in the solution. (NaOH, KOH)
Rate of chemical reaction is defined as the quantity of a reactant consumed or the quantity of a product formed in unit time.

For a chemical reaction

$$n \, A + m \, B \rightarrow C + D,$$

the rate equation or rate law is a mathematical expression used in chemical kinetics to link the rate of a reaction to the concentration of each reactant. It is of the kind:

$$r = \frac{d \, C}{dt} = -\frac{1}{n} \frac{d \, A}{dt} = k \, A^n \, B^m$$
Self-ionization of water

The molecules in pure water auto-dissociate into hydronium and hydroxide ions

\[ 2 \text{H}_2\text{O} \leftrightarrow \text{H}_3\text{O}^+ + \text{OH}^- \]

Equilibrium: \( r_1 = r_2 \)

\[ K_c = \frac{[\text{H}_3\text{O}^+][\text{OH}^-]}{[\text{H}_2\text{O}]^2} \quad [\text{H}_3\text{O}^+] = [\text{OH}^-] = 1.0 \times 10^{-7} \text{ M} \]

\[ [\text{H}_2\text{O}] = 55.35\text{ M} \]

\[ K_w = [\text{H}_3\text{O}^+][\text{OH}^-] \quad K_w = 10^{-14} \text{ at } 25^\circ\text{C} \]
Le Chatelier's principle: Any change in status quo prompts an opposing reaction in the responding system. 

Any disturbance of the system will be compensated by a shift in the chemical equilibrium according to Le Chatelier's principle.

2 H₂O → H₃O⁺ + OH⁻
H₃O⁺ + OH⁻ → 2 H₂O

Regardless of the source of the H₃O⁺ and OH⁻ ions in water, the product of the concentrations of these ions at equilibrium at 25 °C is always 1.0 × 10⁻¹⁴.
pH is a measure of the acidity or basicity of a solution.

Danish biochemist S.P.L. Sorenson (1909)

\[ \text{pH} = -\log [\text{H}_3\text{O}^+] \quad \text{pOH} = -\log [\text{OH}^-] \]

\[ \text{pH} + \text{pOH} = 14 \]

Strong acids: the \( \text{H}_3\text{O}^+ \) and \( \text{OH}^- \) ion concentrations

\[
\left[ \text{OH}^- \right] = \frac{K_w}{\left[ \text{H}_3\text{O}^+ \right]} = \frac{10^{-14}}{0.01} = 10^{-12}
\]
Acidity of different liquids

<table>
<thead>
<tr>
<th>Acidity Level</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>gastric fluid, carbonated beverages, vinegar, orange juice, beer, coffee, egg yolks, milk</td>
</tr>
<tr>
<td>1</td>
<td>battery acid, lemon juice, pure rain (H₂O in equilibrium with atmospheric CO₂), seawater, baking soda (NaHCO₃ solution)</td>
</tr>
<tr>
<td>2</td>
<td>household ammonia (NH₃)</td>
</tr>
<tr>
<td>3</td>
<td>household bleach (NaClO solution)</td>
</tr>
<tr>
<td>4</td>
<td>household lye (NaOH solution)</td>
</tr>
<tr>
<td>5</td>
<td>milk of magnesia (Mg(OH)₂) solution, milk, blood</td>
</tr>
</tbody>
</table>

Hydrangea blossoms are either pink or blue, depending on soil acidity.

**pH-indicator paper**
Titration is a common laboratory method of quantitative chemical analysis that is used to determine the unknown concentration of a known reactant. Because volume measurements play a key role in titration, it is also known as volumetric analysis.

[Graph: Titration Curve (oxalic acid/NaOH)]

- pH
- Volume of NaOH added (ml)
The processes of metabolism generate hydrogen ions.

The body's acid-base balance is tightly regulated. Several buffering agents that reversibly bind hydrogen ions and impede any change in pH exist. For humans to survive, the pH of the blood must be maintained between 7.35 and 7.45.

pH<7.2: acidosis  
reason: chronic diseases  
(diabetes)

PH>7.5: alkalosis  
reason: hyperventilation
Acid ionization equilibrium constant $K_a$

\[ \text{HA} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{A}^- \]

\[ K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]} \]

Values of $K_a$ can be used to estimate the relative strengths of acids. By definition, a compound is classified as a strong acid when $K_a$ is larger than 1.

$K_a$ (HCl) = 10^6, \quad K_a$ (H$_3$PO$_4$) = 7.1 × 10$^{-3}$

Neutralization is the reaction between an acid and a base, producing a salt: \( \text{NaOH} + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O} \)
In chemistry, an electrolyte is any substance containing free ions that make the substance electrically conductive. The most typical electrolyte is an ionic solution. Electrolytes commonly exist as solutions of acids, bases or salts.

\[ \text{NaCl}_{(s)} \rightarrow \text{Na}^{+}_{(aq)} + \text{Cl}^-_{(aq)} \]

Electrolyte solutions are normally formed when a salt is placed into a solvent such as water and the individual components dissociate due to the thermodynamic interactions between solvent and solute molecules, in a process called solvation. It is also possible for substances to react with water when they are added to it, producing ions

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{HCO}_3^- \]
Electrolytes in human organism

In physiology, the primary ions of electrolytes are sodium ($\text{Na}^+$), potassium ($\text{K}^+$), calcium ($\text{Ca}^{2+}$), magnesium ($\text{Mg}^{2+}$), chloride ($\text{Cl}^-$), hydrogen phosphate ($\text{HPO}_4^{2-}$), and hydrogen carbonate ($\text{HCO}_3^-$). All known higher lifeforms require a subtle and complex electrolyte balance between the intracellular fluid and extracellular fluid. For example, muscle contraction is dependent upon the presence of $\text{Ca}^{2+}$, $\text{Na}^+$, and $\text{K}^+$. Without sufficient levels of these key electrolytes, muscle weakness or severe muscle contractions may occur.

Electrolyte balance is maintained by oral, or in emergencies, intravenous intake of electrolyte-containing substances, and is regulated by hormones, generally with the kidneys. Serious electrolyte disturbances, such as dehydration and overhydration, may lead to cardiac and neurological complications.
Electrolyte solutions

\[ \text{K}_A \rightarrow \text{K}^+ + \text{A}^- \rightarrow K_d = \frac{[\text{K}^+][\text{A}^-]}{\text{K}_A} \]

Strong acids and strong bases dissociate in a solution almost completely. Hence the dissociation studies are important only with respect to weak acids and weak bases.

The degree of dissociation is a fraction of the total number of moles of electrolyte that dissociates into ions in an aqueous solution when equilibrium is reached. It is represented by \( \alpha \)

Low of dilution

\[ K_d = \frac{[\text{K}^+][\text{A}^-]}{\text{K}_A} = \frac{\alpha^2}{1 - \alpha} C \rightarrow \alpha \sim \sqrt{\frac{K_d}{C}} \]
Weak acids at equilibrium

\[ \text{HAc} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{Ac}^- \]

Initial:  
\[
\begin{array}{ccc}
0.1\text{M} & 0 & 0 \\
\end{array}
\]

Equilibrium:  
\[
\begin{array}{ccc}
0.1-x & x & x \\
\end{array}
\]

\[ K_a = 1.8 \times 10^{-5} = \frac{x^2}{0.1 - x} \quad \rightarrow \quad x \sim \sqrt{0.1 \times K_a} \sim 0.0013 \]

\[
\left[ \text{H}_3\text{O}^+ \right] = \sqrt{K_a \text{C}_a}
\]
Hydrolysis is a chemical process in which a certain molecule is split into two parts by the addition of a molecule of water.

\[ \text{NaAc} + \text{H}_2\text{O} \rightarrow \text{Na}^+ + \text{OH}^- + \text{HAc} \]

In living systems, most biochemical reactions, including ATP hydrolysis, take place during the catalysis of enzymes. The catalytic action of enzymes allows the hydrolysis of proteins, fats, oils, and carbohydrates.
Salts of weak acids

Calculate the pH of a 0.030 M solution of sodium benzoate \((\text{C}_6\text{H}_5\text{CO}_2\text{Na})\) in water from the value of \(K_a\) for benzoic acid \((\text{C}_6\text{H}_5\text{CO}_2\text{H})\): \(K_a = 6.3 \times 10^{-5}\).

\[
\text{NaBz} + \text{H}_2\text{O} \rightleftharpoons \text{Na}^+ + \text{HBz} + \text{OH}^-
\]

\[
K_b = \frac{\text{HBz} \left[\text{OH}^-\right]}{\text{Bz}^-} = \frac{K_w}{K_a} = 1.6 \times 10^{-10}
\]

\[
K_b = \frac{x^2}{0.03 - x}
\]

\[
x \sim \sqrt{0.03 \times 1.6 \times 10^{-10}} \sim 2.2 \times 10^{-6}
\]

\[
\text{pH} = 14 + \log x \sim 8.34
\]
A buffer solution is an aqueous solution consisting of a mixture of a weak acid and its conjugate base or a weak base and its conjugate acid. It has the property that the pH of the solution changes very little when a small amount of acid or base is added to it.

\[
\text{HX} + \text{H}_2\text{O} \leftrightarrow \text{X}^- + \text{H}_3\text{O}^+ \\
\text{Acid} \quad \text{Conjugate base}
\]

\[
\text{NH}_3 + \text{H}_2\text{O} \leftrightarrow \text{NH}_4^+ + \text{OH}^- \\
\text{Base} \quad \text{Conjugate acid}
\]
Henderson Hasselbalch equation

\[ K_a = \frac{[H_3O^+][A^-]}{HA} \]

\[ \log K_a = \log [H_3O^+] + \log [A^-] - \log HA \]

Henderson-Hasselbalch equation

\[ pH = pK_a + \log \frac{[A^-]}{HA}, \quad pK_a = -\log K_a \]
Buffer solution is able to retain almost constant pH when small amount of acid/base is added. Quantitative measure of this resistance to pH changes is called buffer capacity.

Buffer capacity is the maximum amount of either strong acid or strong base that can be added before a significant change in the pH.

1. Buffer capacity of a weak acid reaches its maximum value when pH = pK_a
2. Buffer capacity is directly proportional to the analytical concentration of the acid.
1. Carbonic acid – bicarbonate buffer:
   \[ \text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{HCO}_3^- + \text{H}^+ \]
   (the most important buffer system in the body)

2. Amino acid and protein buffer

3. Haemoglobinous (Hb) buffer
   (Hb is not only important in the carriage of oxygen to the tissues but also in the transport of CO\(_2\) and in buffering hydrogen ions)