

How does the body
maintain acid-base
balance?



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It is important to regulate chemical balance or homeostasis of body fluids. Acidity or alkalinity has to be regulated. An acid is a substance that lets out hydrogen ions in solution. Strong acid like hydrochloric acid release all or nearly all their hydrogen ions and weak acids like carbonic acid release some hydrogen ions. Bases or alkalis have low hydrogen ion concentration and can accept hydrogen ions in solution. Acidity or alkalinity of a solution is measured by pH. (1)

Regulation of Acid-base Balance

Body fluids are maintained within a narrow range that is slightly alkaline. The normal pH of arterial blood is 7.35 and 7.45. Acids are continually produced during metabolism. Several body systems including buffers, the respiratory system and the renal system are actively involved in maintaining the narrow pH range necessary for optimal function. Buffers help maintain acid bases balance by neutralizing excess acids and bases. The lungs and the kidneys help maintain a normal pH by either excreting or retaining acids or bases. (1)

Hydrogen ion concentration of body fluids

Hydrogen ions are continually being added to the body fluids as a result of metabolic activities. To maintain a constant (H^+) in the body fluids, input of hydrogen ions must be balanced by an equal output. On the input side only a small amount of acid capable of dissociating release H^+ is taken in with food. Most hydrogen ions in the body fluids are generated internally from metabolic activities. Normally hydrogen ions continually being added to the body fluids from three following sources:

Carbonic acid formation. The major source of H^+ is through H_2CO_3 formation metabolically produced CO_2 . Cellular oxidation of nutrients yields energy with CO_2 and H_2O as end products. Catalysed by the enzyme carbonic anhydrase, CO_2 and H_2O form H_2CO_3 which then partially dissociates to liberate free hydrogen ions and HCO_3^- .

Reaction

The reaction is reversible because it can go in either direction, depending on the concentration of the substances involved. Within the systemic capillaries, the CO_2 level in the blood increases as metabolically produced CO_2 enters from the tissues. This drives the reaction to the acid side, generating H^+ as well as HCO_3^- in the process. In the lungs, the reaction is reversed: CO_2 diffuses from the blood flowing through the pulmonary capillaries into the alveoli from which it is expired to the atmosphere. The reduction in CO_2 in the blood drives the reaction toward the CO_2 side. Hydrogen ions and HCO_3^- form H_2CO_3 which rapidly decomposes into CO_2 and H_2O once again. The CO_2 is exhaled while the hydrogen ions are incorporated into H_2O molecules. When the respiratory system is able to keep pace with the rate of metabolism, there is no net gain or loss of H^+ in the body fluids from metabolically produced CO_2 . When the rate of CO_2 removal by the lungs does not match the rate of CO_2 production at the tissue level, the resultant accumulation of CO_2 in the body leads to an excess or shortage of free H^+ in the body fluids.

Inorganic acids produced during the breakdown of nutrients. Dietary proteins and other ingested nutrient molecules that are found abundantly in meat contain a large quantity of sulfur and phosphorus. When the molecules are

broken down, sulphuric acid and phosphoric acid are produced as by-products. Being moderately strong acids, these two inorganic acids dissociate to a large extent which releases free H^+ into the body fluids. In contrast, the breakdown of fruits and vegetables produce bases that neutralize the acids originating from protein metabolism.

Organic acids resulting from intermediary metabolism. Numerous organic acids are produced during normal intermediary metabolism e. g. fatty acids are produced during fat metabolism and lactic acid is produced by muscles during heavy exercise. These acids partially separate to produce free H^+ . Hydrogen ion generation normally goes on as a result of ongoing metabolic activities. (1)

Buffer systems

Buffers prevent too many changes in pH by removing or releasing hydrogen ions. If excess hydrogen ions is present in body fluids then buffers bind with the hydrogen concentration which minimizes the changes in pH. The acidity of a buffer is immediate but limited in capacity to maintain or restore normal acid-base balance. The pH of blood plasma is around about 7.3-7.4. The pH of urine is 7 which are neutral but it can be more but certain factors can make the pH of urine go up or down. The pH of mucus can vary from organ to organ with a pH of 6.9 to 9. Lymph has a pH of 7.4 and saliva has a pH of 7.4 (2)

The phosphate buffer system

Phosphoric acid changes quickly into dihydrogen phosphate ($H_2PO_4^-$). The dihydrogen phosphate is an excellent buffer since it can either grab a

hydrogen ion or reform phosphoric acid or it can give off another hydrogen ion and become monohydrogen phosphate (HPO_4^{2-}). The figure shows that in an extremely basic condition, monohydrogen phosphate can even give up remaining hydrogen ion. If H_2PO_4^- is in acidic solution, the reaction above will go to the left and if the H_2PO_4^- is in a basic solution, the reaction proceeds to the right. Therefore the phosphate buffer system can accept or donate hydrogen ions depending on the solution it is in. (2)

The protein buffer system

Protein themselves act as buffers. Proteins are made up of amino acids and amino acids have a central carbon with four groups off of it. These four groups are carboxyl group (COOH), an amino group (NH_2), a hydrogen atom and an 'R' group. The carboxyl and amino groups are what enable proteins to act as buffers. (2)aminoac. jpg (21060 bytes)

The carboxyl group is attached to the amino acid central carbon; C-COOH . In the figure there is a carboxyl group off to the left. The carboxyl group consists of a double bond to one of the oxygen and a single bond to the hydroxyl group. The important part of the carboxyl group is the hydrogen atom within the hydroxyl group. Round about neutral pH the carboxyl group is actually COO^- instead of COOH . If the protein finds itself in a more acidic solution, the carboxyl group will be able to take on the extra hydrogen ions and return to COOH configuration. (2)

The amino group is attached to the amino acid central carbon; C-NH_2 . the amino group is shown at the right hand side of the diagram of the amino acid above. Round about neutral pH the amino group is NH_3^+ rather than just

NH₂. It actually tends to carry an extra hydrogen ion at a normal pH. Then if a protein finds itself in a more basic environment, its amino group on its amino acids can actually release their hydrogen ions and return to NH₂. Amino acids can accept or donate hydrogen ions making them excellent buffers. Any given proteins typically have hundreds of amino acids so proteins make superb buffers and they are found in high concentration in intracellular solutions. (2)protbuff. jpg (23396 bytes)

The carbonic acid system

In blood plasma, the carbonic acid and hydrogen carbonate ion equilibrium buffers the pH. In this buffer, carbonic acid (H₂CO₃) is the hydrogen ion donor (acid) and hydrogen carbonate ion (HCO₃⁻) is the hydrogen ion acceptor (base). Carbonic acid plays an important role as a buffer in maintaining pH in blood plasma.

H₂CO₃(aq) ⇌ H⁺(aq) + HCO₃⁻(aq) <http://scifun.chem.wisc.edu/chemweek/arrowdbl.gif>

The buffer functions in the same way as the phosphate buffer. Additional H⁺ is consumed by HCO₃⁻ and an additional OH⁻ is consumed by H₂CO₃. If pH falls below normal value, a condition called acidosis is produced and if the pH rises above the normal value, a condition called alkalosis is produced. The concentrations of hydrogen carbonates ions and of carbonic acid are controlled by two independent physiological systems. Carbonic acid concentration is controlled by respiration that is through the lungs. Carbonic acid is in equilibrium with dissolved carbon dioxide gas.

$\text{H}_2\text{CO}_3(\text{aq}) \rightleftharpoons \text{HCO}_3^-(\text{aq}) + \text{H}^+(\text{aq})$
 $\text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})$

An enzyme called carbonic anhydrase catalyses the conversion of carbonic acid to dissolved carbon dioxide. In the lungs, excess dissolved carbon dioxide is exhaled as carbon dioxide gas.

$\text{CO}_2(\text{aq}) \rightleftharpoons \text{CO}_2(\text{g})$

The pH Buffer system

The buffer systems guard against sudden shifts in acidity and alkalinity. The pH buffer systems are mixtures of the body's own naturally occurring weak acids and weak bases. These weak acids and bases exist in balance under normal pH conditions. The pH buffer systems can work chemically to reduce fluctuations in the pH of a solution by regulating the amount of acid and base. The most important pH buffer system in the blood involves carbonic acid which is a weak acid formed from the carbon dioxide dissolved in blood and bicarbonate ions which is the corresponding weak base.

Carbaminohaemoglobin is a compound of haemoglobin and carbon dioxide and it is one of the ways in which carbon dioxide can exist in the blood. 15-25% of the carbon dioxide is carried in the blood this way. When carbon dioxide binds to haemoglobin, Carbaminohaemoglobin is formed which will lower the haemoglobin's affinity for oxygen via the Bohr Effect. When there is no oxygen, unbound haemoglobin molecules have a greater chance of becoming Carbaminohaemoglobin. The Haldane effect relates to the increased affinity of de-oxygenated haemoglobin for H^+ offloading of oxygen to the tissues therefore results in increased affinity for the haemoglobin for

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carbon dioxide and H^+ which the body wants to get rid of which can then be transported to the lung for removal. The veins which carry deoxygenated blood back to the right atrium of the heart appear bluish due to the distinctive blue colour of carbaminohaemoglobin.

How acid-base balance is maintained including the role of the kidney and lungs as means of excreting excess acidic or basic ions

The lungs and kidneys are two major systems that work on a continuous basis to help regulate acid-base balance in the body. In the biochemical reactions above, the process are all reversible and go back and forth as the bod's needs change. The lungs can work very quickly and do their part by either retaining or getting rid of carbon dioxide by changing the rate and depth of respirations. The kidneys work much more slowly. They take hours and up to days to regulate the balance by either excreting or conserving hydrogen and bicarbonate ions. Under normal conditions these two systems work together to maintain homeostasis. The amount of acidity or alkalinity blood possesses it important. When the level of acidic compounds in the body rises then the body acidity increases to through increased intake, production or decreased elimination. When the level of basic compounds in the body falls through decreased intake, production or increased elimination. The body uses different mechanisms to control the bloods acid base balance.

Role of the lungs: the release of carbon dioxide from the lungs is a mechanism the body uses to control blood pH. Carbon dioxide is mildly acidic and it is a waste product of metabolism of oxygen. Waste products such as carbon dioxide get excreted into the blood. The blood transports carbon

dioxide into the lungs where it is exhaled. As carbon dioxide mount up in the blood the pH of the blood decreases which means acidity increases. The brain controls the quantity of carbon dioxide that is exhaled by monitoring the speed and depth of breathing. The amount of carbon dioxide that is exhaled increases the breathing to become faster and deeper. Bu adjusting the speed and depth of breathing the brain and lungs are able to regulate the blood pH minute by minute. (3)

Role of Kidneys: the kidneys are also able to affect blood pH by excreting excess acids or bases. The kidneys have some capacity to change the amount of acid or base that is excreted but because the kidneys make these modifications more slowly than the lungs do, this compensation can take several days. (3)