



Buffering systems in the human body

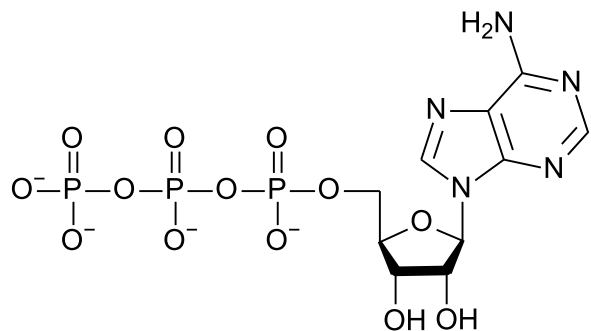
Buffering in blood is crucial to our survival. The pH of blood must be kept constant for normal body functions to work. If blood becomes too acidic, or too basic, then enzymes and proteins are unable to function.

Normal blood pH is 7.4. If it drops below 6.8, or rises above 7.8, respiratory and cardiac function are compromised, the blood-clotting process changes, and death may occur.

What causes changes in blood pH?

Muscles in the body need 'fuel' to work. This fuel is a chemical called adenosine triphosphate (ATP) that consists of an adenine nucleotide bonded to three phosphates. The body's cells only store enough ATP to last about three seconds, so systems in the body produce it when it is required.

There are three main systems that produce cellular ATP: two are anaerobic (no oxygen required); and one is aerobic (requires oxygen).

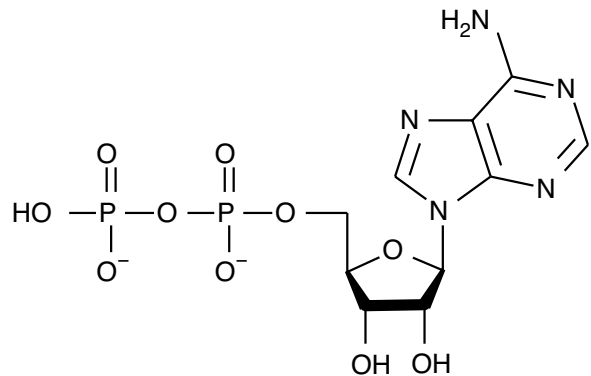


Adenosine triphosphate (ATP)

phosphagen system (anaerobic)



A high-energy compound in the muscles called creatine phosphate donates a phosphate that can combine with ADP to form ATP very quickly. This reaction is catalysed by creatine kinase. The supply of creatine phosphate only lasts about 8 to 10 seconds, so it's useful for a quick sprint.



Adenosine diphosphate (ADP)

glycogen-lactate system (anaerobic)



ATP is produced from glucose before the cardiovascular system has responded to changes in movement.

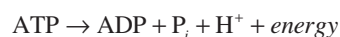
respiration (aerobic)



After about two minutes of moderate exercise, the cardio-respiratory system is able to deliver sufficient oxygen to working muscles and get rid of the carbon dioxide that is produced. The products of aerobic metabolism, H_2O and CO_2 , react together to form carbonic acid that dissociates into hydrogen ions and hydrogencarbonate:



Energy required for muscle contraction in the body comes from hydrolysis of ATP. When a molecule of ATP is hydrolysed one phosphate breaks off, to produce adenosine diphosphate (ADP), a free phosphate ion (P_i), a hydrogen ion (H^+), and a large amount of energy.



No matter which system the body uses to produce ATP, hydrolysis of ATP to ADP produces excess H^+ ions. We know that the body must maintain a stable pH in order to function.

How does the body achieve this?

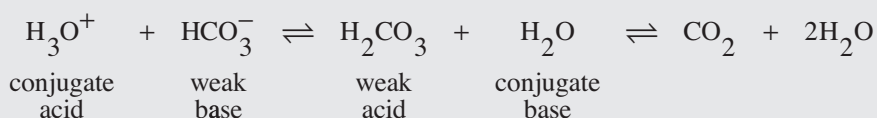
pH buffering in the blood

Red blood cells play an important role in the removal of excess hydrogen ions in the body. This is achieved by a carbonic acid/hydrogencarbonate buffering system.

This buffer system can be represented as an equation:



It can be rewritten to show the involvement of water:



Like all buffers, this system consists of weak acid/base conjugate pairs.

When muscles produce H^+ ions, equilibrium shifts to the right. This can be explained by Le Chatelier's principle:

If a chemical system at equilibrium experiences a change in concentration, temperature, volume, or partial pressure, then equilibrium shifts to counteract the imposed change and a new equilibrium is established.

When the new equilibrium is established, H^+ ion concentration will be only slightly higher than it was initially, HCO_3^- concentration will have dropped, and CO_2 and H_2O concentrations will have increased.

This buffer works well because concentrations of the buffer components HCO_3^- and CO_2 (formed from H_2CO_3) are much greater than concentration of H^+ ions. This means that changes in the concentration of H^+ ions have little effect on the pH of blood.

Other body organs play important roles in this buffer system. The lungs get rid of most of the H^+ ions produced by metabolism by removing carbon dioxide and driving the reaction forward. The kidneys also remove H^+ ions that are excreted in urine.

The kidneys are also involved in regulation of pH of body fluids through a complex interaction of H^+ , HCO_3^- , H_2O , CO_2 and ions such as Na^+ .

Buffering capacity

Blood, like all buffers, has a finite buffering capacity. This means that there is a limit to how much it can stabilise pH. This limit can be reached during high-intensity exercise. For example, the body of an athlete who sprints for more than about 90 seconds will produce a large amount of hydrogen ions by aerobic respiration. Their lungs may not be able to remove carbon dioxide quickly enough to drive the buffering reaction forward and keep the pH level down. The kidneys are also slow to respond, and bicarbonate ions may be used too quickly for the body to stabilise them. If the pH of the body gets too low, the athlete will have to slow down or stop, limiting their performance. Over the last few years, scientists have investigated chemical means of increasing the buffering capacity of blood, most commonly by doping with hydrogencarbonate (which can cause problems such as nausea and diarrhoea) and more recently with beta alanine.



Reference

Robergs, R. A., Ghiasvand, F., Parke, D. (2004). Biochemistry of exercise-induced metabolic acidosis. *American Journal of Physiology – Regulatory, Integrative and Comparative Physiology*, **287**, R502-R516.