CHEMISTRY: IT'S IN OUR BLOOD

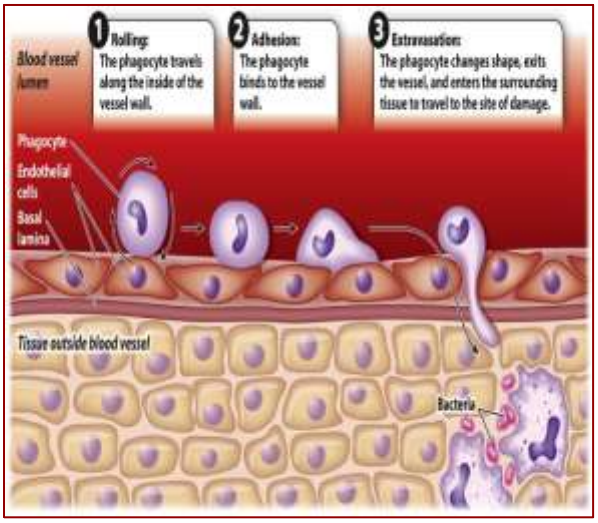
WHAT IS BLOOD?

According to Americasblood.org, blood is the red fluid that circulates through the body's vessels, including arteries and veins [1]. That statement is widely known, but many components of blood are not, including what its functions are, what it's made of, and more. Firstly, the basics of blood: one unit of blood is made up of white blood cells, red blood cells, platelets, and plasma. Plasma makes up about 50%, while the cells make up the remainder. With this being said, there is no way to make blood, but it can be donated from person to person [1].

The overall function of blood is to transport oxygen and other nutrients throughout the body [2]. Also, there are two types of blood which relate to how they move throughout the body. Arterial blood rushes from the heart, and contains oxygen that is transported to tissues. Venous blood also contains oxygen, but much less, it also contains carbon dioxide which is taken from tissues, and transported via blood veins to the lungs where it can be exhaled [3]. Of the many components of blood, each part acquires its own specific function.

WHAT ARE ITS COMPONENTS?

White blood cells travel out of the arteries and veins to tissues, where they fight infection. White blood cells use phagocytosis to digest possibly harmful particles, including bacteria. There are two types of white blood cells, and each performs different tasks. Neutrophilic cells are the smaller type; these cells attack the infection by ingesting the bacteria, right away. While monocytes, the larger of the two, are at the infection site about three days prior. Monocytes then find and phagocytose bacteria, foreign particles, and other dead cellular particles [4].



Depiction of white blood cells leaving the blood stream to stop bacteria in the epithelial layer. [4]

Red blood cells carry hemoglobin, which gives the cell the ability to carry and deliver oxygen all over the body. Hemoglobin also allows red blood cells to carry carbon dioxide and remove it from the body [1]. For the red blood cells to carry oxygen, the oxygen enters the lungs, where it binds to protein hemoglobin through an ion-induced dipole force. The red blood cells transport the hemoglobin and oxygen and free or release the oxygen throughout the body, in places like tissues. To remove carbon dioxide a similar but opposite reaction takes place. The carbon dioxide is picked up in the tissues, by red blood cells, then released in the lungs or gills where the carbon dioxide is exhaled or excreted [5].

Plasma is the liquid part of blood that carries the cells. Plasma is 92% water but also contains albumin, fibrinogen, and globulins. The plasma uses the protein globulin to transport nutrients and water to the tissues [1]. Fibrinogen, a protein in plasma, helps the blood clot or coagulate. Lastly, plasma regulates blood pressure and volume with the help of albumin [6].

HOW CAN WE EXPLAIN BLOOD'S COLOR?

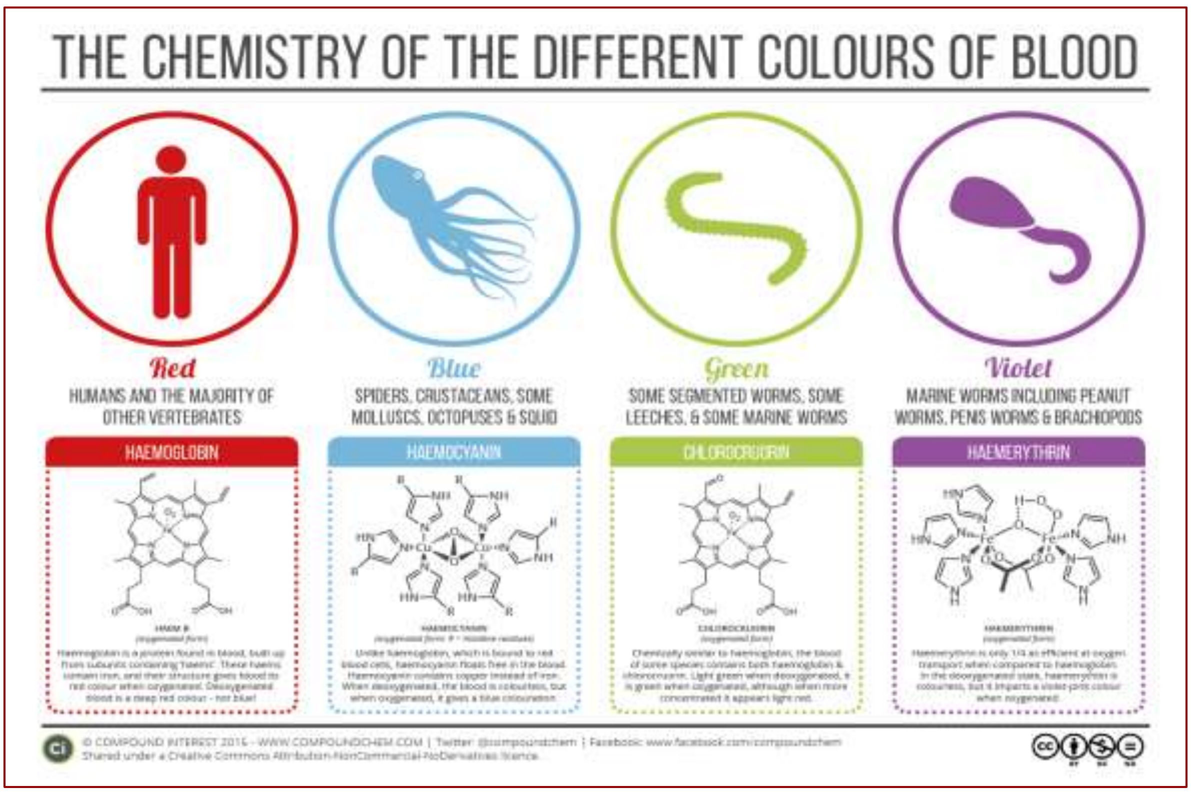
At large, human blood and most other vertebrates' blood is red because red blood cells contain hemoglobin. Hemoglobin is a protein made of four small groups called hemes. Each heme is rich in iron. This, along with the structure of the hemes being an alternating double-single bonded carbon structure, causes the units to absorb light and be visible in the red part of the visible spectrum. It is in fact a myth that when blood is blue when it is in the body. To explain, iron modifies the absorbency of light. When hemoglobin is oxygenated it looks like a red color, as everyone has seen, but when it is deoxygenated blood looks a slightly darker but still red color. This is a result of iron atoms changing the absorbency of the spectrum [7].

Some species do exhibit different colors of blood. Blue blood is not a myth entirely, just in relation to human blood. Blood can portray a blue, green, or purple color in different species [7].

Some common creatures that have **blue** blood are octopuses, squid, spiders, and crustaceans. Instead of hemoglobin being the oxygen transporter in the blood stream, these creatures use a similar protein, hemocyanin. (The differences in the structures of the proteins of each blood color can be seen below.) Hemocyanin obtains copper atoms instead of iron, which modifies the light spectrum in a different way. When creatures with blood of these components is looks colorless when deoxygenated, and blue when it is in the presence of oxygen [7].

Green blood is possible too. Some types of worms and leeches exhibit green blood. If one were to go out to the street on a rainy day and squish a worm, a green fluid could seep out. Organisms with green blood acquire chlorocruorin as their protein to aid in transportation. The only difference between chlorocruiorin and hemoglobin is that chlorocruorin has an aldehyde group in place of a vinyl group. The deoxygenated blood is a light green color, the oxygenated blood is a darker green color, but when the blood is highly concentrated it looks light red. Some organisms have both chlorocruiorin and hemoglobin, their blood obtains a red color [7].

Lastly, some creatures even have **purple** blood. Some common species with violet blood are marine worms, peanut worms, and brachiopods. The blood in these organisms contains hemerythrin, which contains iron atoms like hemoglobin. But hemerythrin is a less effective protein than hemoglobin in relation to transporting and storing oxygen. When the blood is deoxygenated it looks colorless because of the compound does not absorb light. But when blood is in the presence of oxygen it looks bright violet or pink because of how iron modifies the absorbency and how iron reacts with oxygen, but the structure of the compound changes the way iron changes the visible spectrum [7].

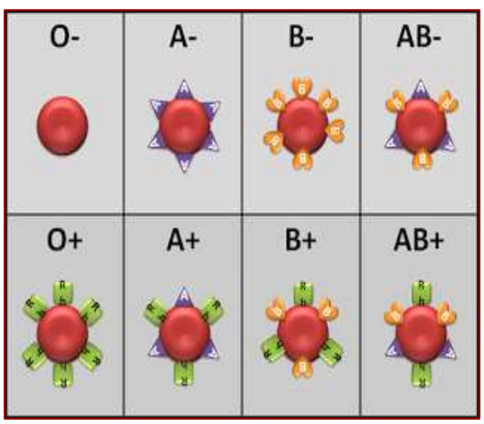


Different proteins cause living organisms to have various hues of blood. [1]

WHY DOES BLOOD SMELL?

The scent of blood is determined by a couple of factors, including the blood itself and what the blood is in contact with. Like mentioned before, blood is full of iron atoms. These atoms produce a metallic smell when they are oxidized by the materials in the air. Also, when blood interacts with the fat lipids of the skin, a metallic smell protrudes. This smell is like when someone lifts metal weights, causing their hands smell like metal after. Just as the metal weights and the skin on someone's hands produce a metal smell, so does the skin and iron filled blood when they are in contact [7].

WHAT IS A BLOOD TYPE?

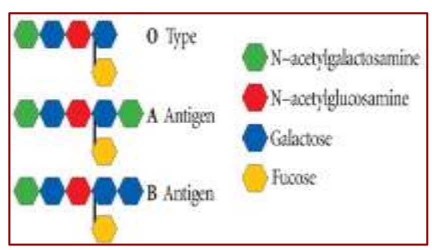


The 8 different blood types pictured [10].

There are 8 different of blood types. This is denoted by the letters A, B and O, showing the presence or absence of that antigen, as well as a + or –, which corresponds to the presence or absence of the Rhesus (Rh) factor [8]. The Rh factor is another antigen. Antigens are surface markers on the cell that can stimulate an immune response and they are used by immune system cells to differentiate between self and non-self-cells. Bacteria, viruses, and all cells that move through your bloodstream have antigens. Antigens on blood cells are made of different carbohydrates, and there are only slight differences between the A, B, and O sugars. Because these carbohydrate chains are so similar, they are treated as a group [9].

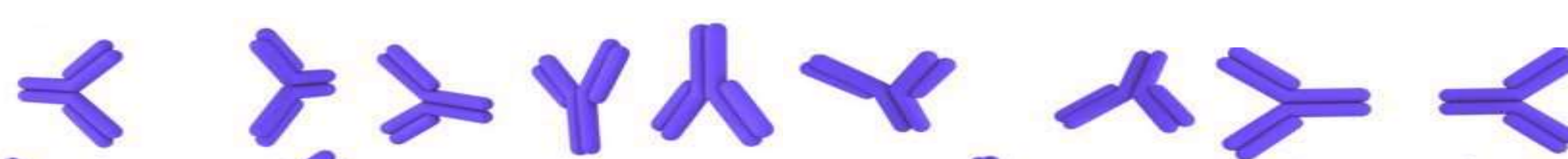
The Rh blood group system includes 50 different antigens; however, the most important, D. Rh positive and Rh negative refer to this specific antigen and whether it is present on the exterior of the red blood cell [15].

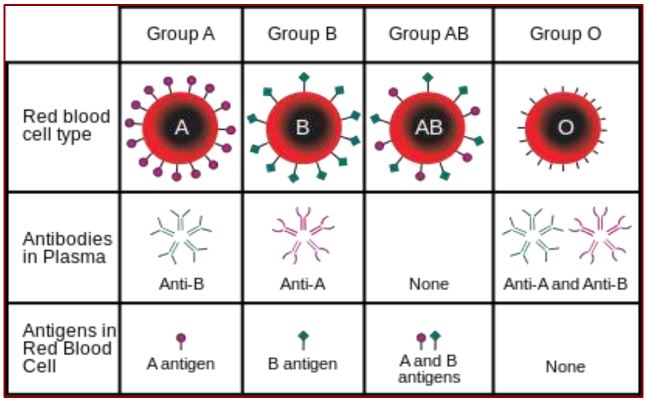
There is a small difference between these three antigens [13].



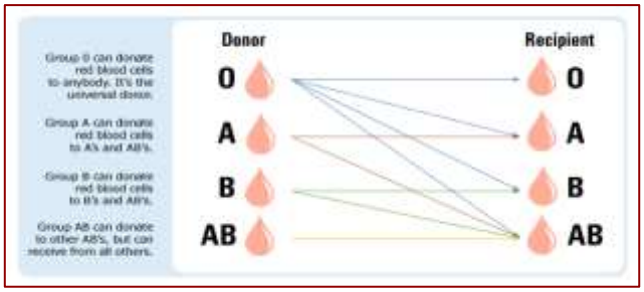
ANTIBODIES

Antibodies are proteins excreted by a type of immune cells. Also known as immunoglobin, these proteins are Y shaped and have different molecule configurations on the prongs that forms weak bonds with the corresponding antigen. When the antibodies attach to antigens, it is a signal to other parts of the immune system that a foreign invader has entered the body and that the correct immune cells need to kill the invader. Read more about the immune system here and here.





This chart depicts the different antigens and antibodies corresponding to each blood type [12].

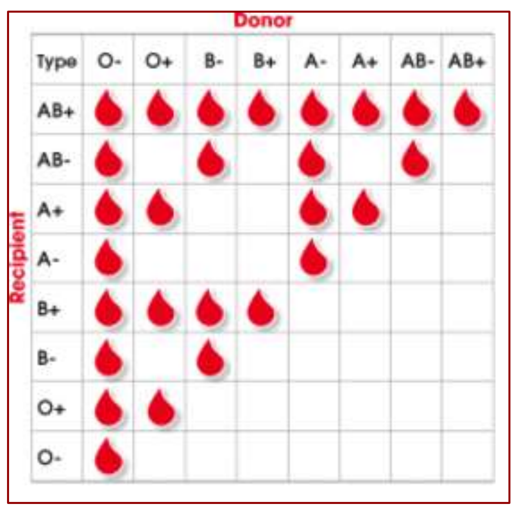


The above infographic shows what types of blood can be donated to recipients of different blood types [8].

In addition to being incredibly important to the immune system, antibodies are also a pivotal part of the blood, as they are the main component in determining whether a blood donor and recipient are compatible. People with A blood types carry the antibodies for B blood types. For instance, say a person with type A blood is given type B blood. They have the B antibodies, so their immune system will target the donated blood and that blood will be destroyed. This is extremely detrimental; it nullifies the effect of the transfusion, as well as greatly strains the recipient's immune system, leading to death in most cases. This condition is called acute immune hemolytic reaction (AIH) [11]. AIH occurs if type O people receive A, B, or AB blood. Group AB can receive any blood type. Groups A and B can receive A or B, respectively, and type O.

THE RH FACTOR

The Rh factor also plays a large part in compatability. Someone with Rh + blood, if the ABO type matches, can receive Rh – blood because the Rh – does not trigger an immune response, therefore AIH is avoided. The opposite, however, does trigger an immune response. People with Rh – blood will reject Rh + blood because the antibodies that attach to the Rh + antigens are present in their bloodstream. Combine the Rh and the ABO blood typing, and the chart to the left is produced. This chart shows what types of blood are compatable to different Rh and ABO types.



The below infographic details what types of blood recipients can obtain [14].

The national distribution of blood types for the US is below [8]. O + is the most common blood type among Americans, with A + being the second most common. AB – is the rarest.

	Caucasian	African- American	Latino-American	Asian-American
O +	37%	47%	53%	39%
O -	8%	4%	4%	1%
A +	33%	24%	29%	27%
A -	7%	2%	2%	0.5%
B +	9%	18%	9%	25%
B -	2%	1%	1%	0.4%
AB +	3%	4%	2%	7%
AB -	1%	0.3%	0.2%	0.1%

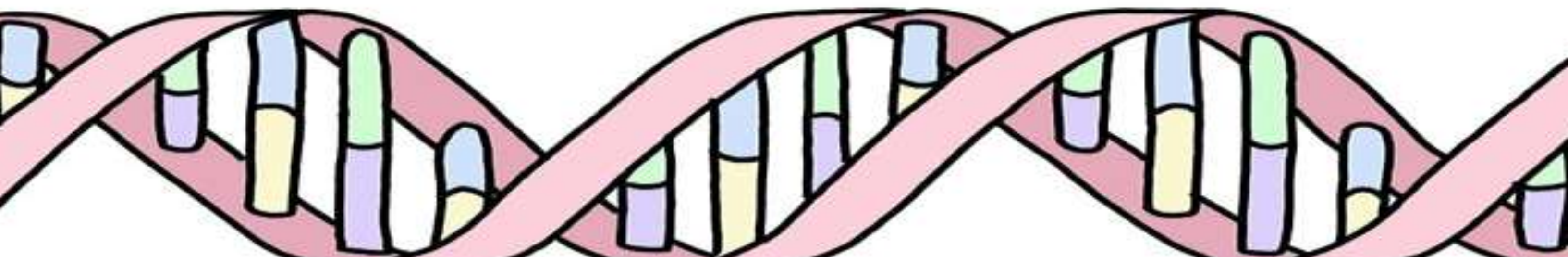
GENETIC INFLUENCES

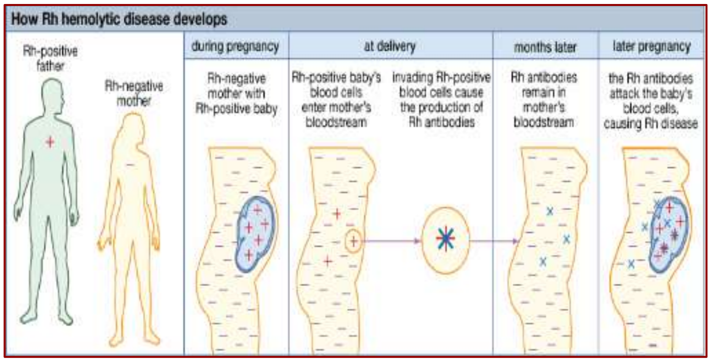
Blood types are determined by the genetics of your parents. Each parent donates one copy of an allele. Two alleles make up one gene. A and B are codominant genes, which means that they can be expressed at the same time if an A allele and B allele are present. Type O expresses when neither allele code for A or B. If two alleles for the same blood type are present, then only that type of antigen is expressed. If a parent donates an A allele and the other parent donates an O allele, then the child has blood type A, as the A allele is dominant. The B allele is dominant as well.

Parent 1	Parent 2	Baby's possible blood types
A	A	A, O
A	B	A, B, AB, O
A	AB	A, B, AB
A	O	A, O
B	B	B, O
B	AB	A, B, AB
B	O	B, O
AB	AB	A, B, AB
AB	O	A, B
O	O	O

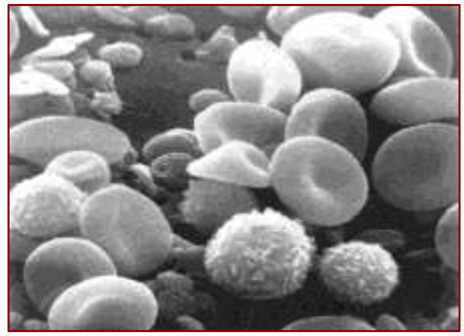
This table shows the possible blood types of the child based on the blood type of the parent [16].

The Rh factor is extremely important in the health of the baby if the mother is Rh – and the father is Rh +. It does not affect the first baby, but it does affect the following ones. If the baby is Rh +, then when the mother gives birth, some of the baby's blood gets mixed with hers. Because she is Rh -, her body will attach antibodies to the baby's blood because it thinks those red blood cells are foreign invaders. Those antibodies will stay in her bloodstream, poised to latch on to other Rh + invaders. If she has a second child with Rh + blood, her body will start dispatching an immune response against her baby. This is called Rh Hemolytic Disease, and it now can be treated with medication, especially if caught early in the pregnancy.





This infographic shows how the mother's immune system can react when a Rh + father and Rh – mother have more than one Rh + child [17].

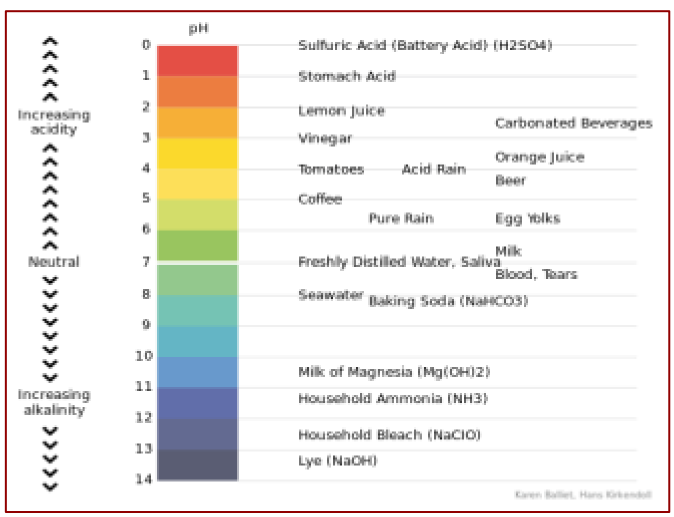


Electron Microscope picture of a healthy adult's blood. The snowball-like cells are the white blood cells, the large disks are the red blood cells, and the small disks are platelets [18].

Every day, people's lives are saved through blood transfusions and knowledge about antibodies and antigens. Both the Rh and ABO blood typing systems are incredibly important in this, as the goal is to save someone through blood transfusions, not give them acute immune hemolytic reaction. Test your knowledge about blood typing and play a game about saving patients through transfusions here!

HOW IS BLOOD PH MAINTAINED?

The human body is a wonderfully complex organism, and this complexity must be maintained via careful organization and regulation. Our blood must be kept within a very specific pH range: between about 7.35-7.45 (with 7.4 being optimal) [20]. This means that blood is slightly alkaline, or basic. Your cells can not function properly if your blood pH rises above 7.8 or falls below 6.8; you can become very sick or even die [21]. Clearly, maintaining pH within this small range is crucial. How is this accomplished?



A comparison of blood pH to pH values of other common solutions. [22]

BUFFER SYSTEMS

At the simplest level, the pH of blood is maintained via acid-base buffer systems. These systems prevent large pH changes and keep blood pH within the necessary range under abnormal circumstances. The most important buffer system in the blood (and the one we will discuss here) is a carbonic acid-bicarbonate buffer system. In this system, bicarbonate ions (HCO_3^-) and hydrogen ions (H^+) are in equilibrium with carbonic acid (H_2CO_3). Bicarbonate and carbonic acid are found naturally within the blood. In addition, carbonic acid can decompose into CO_2 and H_2O with the enzyme carbonic anhydrase, creating another reaction in equilibrium [23]. This yields the following overall equation:

$$H^+ (aq) + HCO_3^- (aq) \rightleftharpoons H_2CO_3 (aq) \rightleftharpoons H_2O (l) + CO_2 (g)*$$

*Note: this is an acceptable but simplified form of this reaction. For the purposes of this section, it will sufficiently and more simply demonstrate the necessary concepts. More information on the expanded version of this equation can be found here [23] and here [24].

The strength of a base in defined by its concentration of OH^- ions. If the blood becomes too basic, the acid in the buffer (H_2CO_3) neutralizes hydroxide (OH^-), producing H^+, which reacts with the OH^- to form water, and HCO_3^-. Acid strength is defined by H^+ concentration. If the blood becomes too acidic, the base in the buffer (HCO_3^-) neutralizes hydrogen ions (H^+), producing H_2CO_3 [25]. Ultimately, the goal of these reactions is to return the system to Le Chatelier equilibrium. By effectively balancing the amounts of H^+/OH^-, the buffer restrains pH within the necessary range.

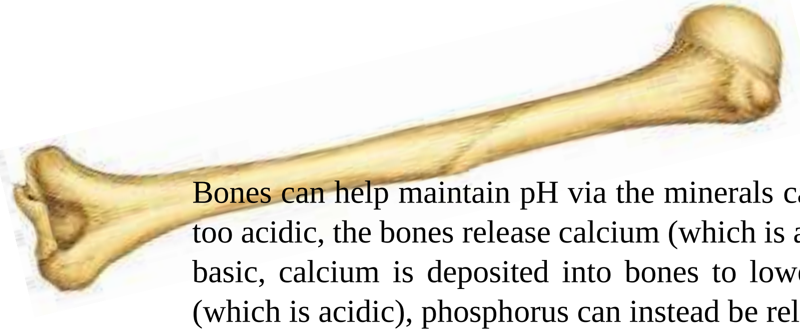
Relationships Among [H⁺], [OH⁻], and pH, at 25°C

Solution Type	$[H^+]$ (*M*)	$[OH^-]$ (*M*)	pH Value
Acidic	$> 1.0 \times 10^{-7}$	$< 1.0 \times 10^{-7}$	< 7.00
Neutral	$= 1.0 \times 10^{-7}$	$= 1.0 \times 10^{-7}$	$= 7.00$
Basic	$< 1.0 \times 10^{-7}$	$> 1.0 \times 10^{-7}$	> 7.00

The strength of an acid relies on H+ concentration, while the strength of a base relies on OH- concentration. [26]

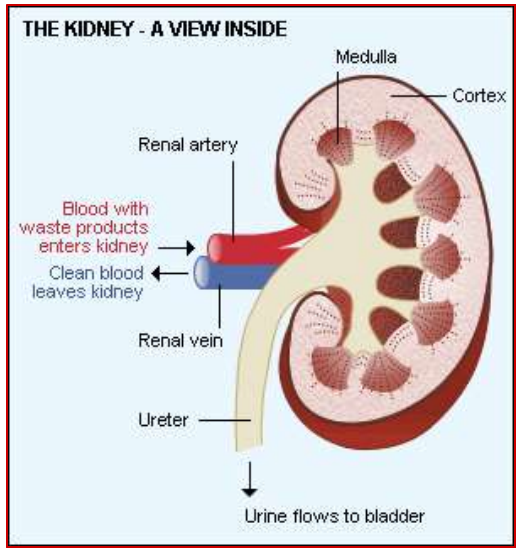
REGULATION BY MAJOR ORGANS

To fully understand the non-acid-base reaction, we must expand our discussion's scope. Capillaries do not exist in a vacuum; that is, blood cannot be accurately examined independently of other bodily structures. The human body is an intricate network which must integrate its individual components into one operational machine. The buffer system we've discussed is the most essential mechanism of pH regulation. However, the blood's pH is partially maintained via four main organs: the skeleton, the kidneys, the lungs, and the brain.

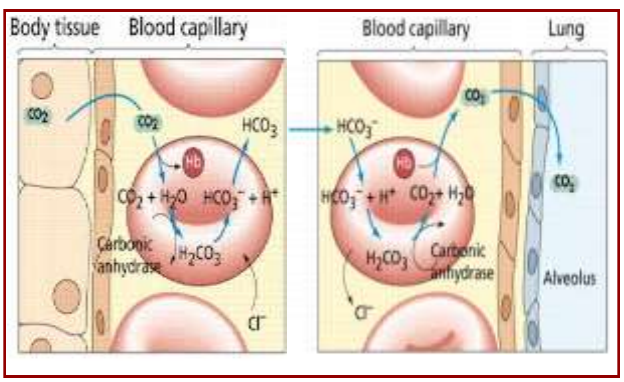


Bones can help maintain pH via the minerals calcium and phosphorus. When the blood becomes too acidic, the bones release calcium (which is alkaline) to raise pH. When the blood becomes too basic, calcium is deposited into bones to lower pH; since calcium is balanced by phosphorus (which is acidic), phosphorus can instead be released into the bloodstream [27].

One of the main purposes of the kidneys is to filter our blood, reserving necessary components and disposing of waste products in urine. The kidneys also play a role in pH regulation. If the blood becomes too acidic, they can reabsorb bicarbonate (HCO_3^-) that has been previously filtered or produce more. This bicarbonate reacts with the excessive H^+ ions (acid) to maintain equilibrium with carbonic acid and raise pH back toward the optimal value. Alternatively, H^+ ions can be secreted in the urine. If the blood becomes too basic, the kidneys excrete bicarbonate in urine, leaving free H+ ions with no way to convert back to H_2CO_3 and subsequently lowering the pH. These processes are relatively slow, which make them more suited for routine management than reaction to sudden changes [28].



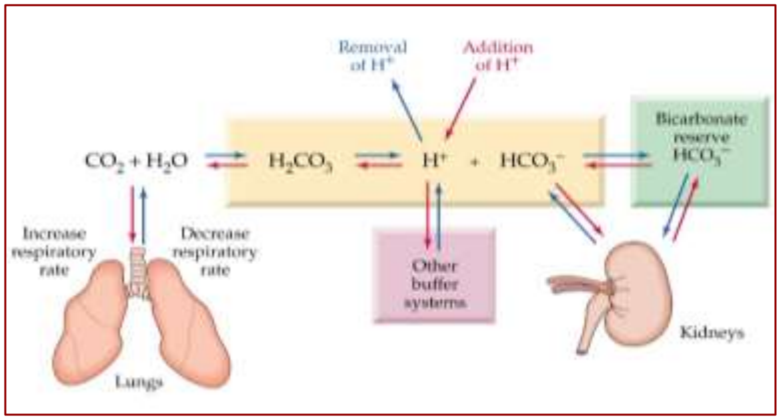
The kidneys filter blood, disposing of waste in urine. [29]



The reactions involved in carbon dioxide's transportation to the lungs via the bloodstream. [31] [32]

In terms of fast-acting responses to pH change, the lungs are much more effective. It is common knowledge that we inhale oxygen (O_2) and exhale carbon dioxide (CO_2). This is because our cells use O_2 as fuel for cellular respiration, a metabolic process which provides energy. CO_2 is a slightly acidic waste product of this process. It enters the bloodstream to be transported to the lungs and exhaled. The brain controls the rate of ventilation, or breathing. By controlling the amount and rate of CO_2 exhalation, the brain and lungs help prevent its build up [30].

For a demonstration of some of these organs in action, let's examine the body's responses to pH changes due to exercise. Have you ever felt short of breath while running? When we exercise, our bodies require more energy than normal, so metabolism must work overtime. The increased demand for O_2 for cellular respiration can be difficult to meet, which is why we inhale and exhale more frequently. This results in a much larger amount of waste CO_2. If exercise becomes especially strenuous, oxygen deprivation may cause muscle cells to switch from aerobic (requiring oxygen) respiration to anaerobic fermentation, which produces lactic acid. These factors temporarily lower blood pH, and this is where the second reaction from above ($H_2CO_3 \rightleftharpoons H_2O + CO_2$) becomes relevant. The excess CO_2 will cause an imbalance in the reaction's equilibrium, leading to above average production of carbonic acid (which will then produce more H+ ions due to the first reaction) until equilibrium is re-established. The buffer system will combat as much acidity as possible, but if the acidity exceeds this system's capacity, it will be removed over time by the lungs (exhalation of excess CO_2) and the kidneys (excretion of H^+) [23]. Lactic acid is broken down later, its components used in metabolic processes [33].

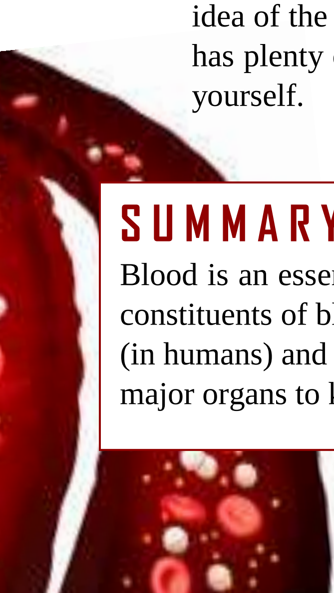


The lungs and kidneys interact with the buffer system in the blood to maintain pH. [34]

ACIDOSIS AND ALKALOSIS

Even with safeguards in place, the body has its limits. Certain factors, including stress, medications, and chronic illnesses, can lead to slight, long-term blood acidity or alkalinity. These conditions fall into two categories: respiratory and metabolic. Respiratory acidosis occurs when the lungs do not expel CO_2 properly, leading to a buildup in the bloodstream. Respiratory alkalosis is when rapid breathing causes excessive CO_2 expulsion. Metabolic acidosis occurs when the kidneys cannot excrete acid from the body sufficiently. And, as you may have guessed, metabolic alkalosis is when the kidneys either excrete too much acid or send too much bicarbonate back into the bloodstream [20].

The good news for those with long-term alkalosis or acidosis is that there are countermeasures that can combat these issues, like eating a well-balanced diet and staying hydrated [35]. Although the idea of the body maintaining such a tiny blood pH range may seem scary, never fear—your body has plenty of defense mechanisms to keep you functioning healthily, so long as you take care of yourself.



SUMMARY/TLDR

Blood is an essential component of our bodies and has many unique functions and properties. The different constituents of blood keep distinct parts of our bodies up and running. Blood is distinguishable by its red hue (in humans) and metallic smell. The blood utilizes complex buffer systems and works in tandem with several major organs to keep its pH around 7.4, which is necessary to sustain cell survival.

APPENDIX

Phagocytosis - the ingestion of a smaller cell, bacteria, microorganism, or other foreign particle by one cell. The cell that does the phagocytosing surrounds the other cell and protrudes through the cytoplasm until the material is completely surrounded. Then the cell is engulfed when the phagocyte closes its membrane and forms a vacuole.

Hemoglobin - the protein which transfers oxygen in vertebrate's blood. Each of hemoglobin's four subunits consist of a heme attached to an iron atom.

Ion-induced dipole force - the attraction that occurs when an ion bonds with nonpolar molecule or a dipole within an atom. This weak attraction causes a partial positive charge and a partial negative charge on the atom that bonds with the ion.

Coagulation - the process of a fluid changing to solid or partial solid. In relation to blood this is the process of clotting or solidifying the fluid blood to stop the blood from flowing when it leaves the body. This is common when someone gets a wound cut.

Buffer system – A buffer system is designed to resist pH changes upon the addition of an acid or a base. Buffer solutions are specialized for particular pH ranges; a suitable buffer for one environment may not be effective in another.

A buffer tends to be composed of a weak acid and its conjugate base (typically in the form of a salt) or vice versa. The buffer mentioned above, for example, has carbonic acid as its weak acid and sodium bicarbonate as the conjugate base—although the sodium ions dissociate in the aqueous solution and, therefore, are of little importance to this discussion. *Weak* is the key word here, as weak acids do not tend to release large numbers of H^+ ions into the surrounding solution. When an acid is added to the solution, the associated H^+ ions bond with the conjugate base to form more weak acid; this affects pH less significantly than having free H^+ ions in the solution. When a base is added, however, the weak acid dissociates to its conjugate base and H^+ ions. The ions bond to the OH^- ions associated with the base, neutralizing them by forming H_2O. [36]

Le Chatelier's Principle – Given a chemical reaction in equilibrium, this principle states that changing the conditions of one side of the reaction (such as reactant concentration) will cause the reaction to shift to counteract the change and re-establish equilibrium. The following equation will be used for demonstrative purposes:

$$A + B \rightleftharpoons C + D$$

If, for example, the concentration of A is increased, the reaction will shift right so that A reacts with B, producing more of C and D until equilibrium is re-established. Decreasing the concentration of A would have the opposite effect; the reaction will shift left so that C and D react to increase the concentration of A. While concentration changes are the example most relevant to the blood buffer system, changes in pressure and temperature can also shift the direction of reaction. Note that this principle does not *explain* why these changes occur; it just helps us understand what the changes are. [37]

REFERENCES

[1] What is Blood? www.americasblood.org/about-blood/what-is-blood.aspx (Accessed Nov 12, 2017).

[2] Taneja A. Blood: Functions, Properties and Groups www.biologydiscussion.com/blood/blood-functions-properties-and-groups/44044. (Accessed November 12, 2017)

[3] Ledger, P. What Is Blood. *Friends' Intelligencer (1853-1910)* [Online] **1858**, *15,* Page 319.

[4] Morris, James; Hartl, Daniel. *Biology: How Life Works*, Second Edition; 2016, Page 296.

[5] The Editors of Encyclopædia Britannica. Blood: Functions, Properties and Groups www.britannica.com/science/red-blood-cell. (Accessed Nov 12, 2017).

[6] American Red Cross. Plasma http://www.redcrossblood.org/learn-about-blood/blood-components/plasma (accessed Nov 19, 2017).

[7] Brunning, A. The Chemistry of the Colours of Blood http://www.compoundchem.com/2014/10/28/coloursofblood/ (Accessed Nov 12, 2017).

[8] Blood Types http://www.redcrossblood.org/learn-about-blood/blood-types.html (accessed Nov 19, 2017).

[9] Antigen https://www.britannica.com/science/antigen (accessed Nov 19, 2017).

[10] Rh Factor http://www.scienceinspirations.com/2017/08/Rh-factor.html (accessed Nov 19, 2017).

[11] Blood transfusion https://www.mayoclinic.org/tests-procedures/blood-transfusion/details/risks/cmc-20326166 (accessed Nov 19, 2017).

[12] ABO blood group system https://en.wikipedia.org/wiki/ABO_blood_group_system (accessed Nov 19, 2017).

[13] Criswell, D. ABO Blood and Human Origins http://www.icr.org/article/abo-blood-human-origins/ (accessed Nov 19, 2017).

[14] What are blood groups? https://www.nzblood.co.nz/give-blood/about-blood/what-are-blood-groups/ (accessed Nov 19, 2017).

[15] Avent, N. D.; Reid, M. E. The Rh blood group system: a review http://www.bloodjournal.org/content/95/2/375?sso-checked=true (accessed Nov 19, 2017).

[16] Blood Types http://genetics.thetech.org/ask/ask199 (accessed Nov 19, 2017).

[17] Genetic Drift http://www.biozoomer.com/2011/03/genetic-drift.html (accessed Nov 19, 2017).

[18] Scanning Electron Microscope Image of Blood Cells https://visualsonline.cancer.gov/details.cfm?imageid=2129 (accessed Nov 19, 2017).

[19] Berkman, E. M.; Lawler, S. D. The Importance Of Antigens and Antibodies https://www.britannica.com/science/blood-group/The-importance-of-antigens-and-antibodies#toc256884 (accessed Nov 19, 2017).

[20] Acid-Base Balance and Blood pH http://www.psychologicalharassment.com/acidbase-balance.htm (accessed Nov 1, 2017).

[21] Fong, K. How Does A Buffer Maintain pH? https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Acids_and_Bases/Buffers/How_Does_A_Buffer_Maintain_Ph%3F (accessed Nov 1, 2017).

[22] Kirkendoll, H. File: Power of Hydrogen (pH) chart.svg https://commons.wikimedia.org/wiki/File:Power_of_Hydrogen_(pH)_chart.svg (accessed Nov 1, 2017).

[23] Casiday, R.; Frey, R. Blood, Sweat, and Buffers: pH Regulation During Exercise http://www.chemistry.wustl.edu/~edudev/LabTutorials/Buffer/Buffer.html (accessed Nov 1, 2017).

[24] Kahlon, A.; Lower, S. The Hydronium Ion https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Acids_and_Bases/Acids_and_Bases_in_Aqueous_Solutions/The_Hydronium_Ion (accessed Nov 1, 2017).

[25] Chemistry of buffers and buffers in our blood https://www.khanacademy.org/test-prep/mcat/chemical-processes/acid-base-equilibria/a/chemistry-of-buffers-and-buffers-in-blood (accessed Nov 1, 2017).

[26] Solutions, Acids, Bases, & Salts https://mrdchemdwiki.wikispaces.com/Solutions,+Acids,+Bases,+%26+Salts (accessed Nov 10, 2017).

[27] Our skeleton and blood acidity (pH) http://anograiner.com/skeleton-blood-acidity-ph/ (accessed Nov 1, 2017).

[28] Acid-Base Balance https://courses.lumenlearning.com/boundless-ap/chapter/acid-base-balance/ (accessed Nov 1, 2017).

[29] Life is in the Blood http://altered-states.net/barry/newsletter397/ (accessed Nov 10, 2017).

[30] Lewis, J. L. Overview of Acid-Base Balance - Hormonal and Metabolic Disorders http://www.merckmanuals.com/home/hormonal-and-metabolic-disorders/acid-base-balance/overview-of-acid-base-balance (accessed Nov 1, 2017).

[31] Carbonic-Acid Bicarbonate Buffer System https://fmss12uchemd.wordpress.com/2013/05/06/carbonic-acid-bicarbonate-buffer-system/ (accessed Nov 10, 2017).

[32] Properties of Enzymes https://samantharamjit.wordpress.com/2013/03/28/properties-of-enzymes/ (accessed Nov 10, 2017).

[33] Brennan, J. What Happens to Lactic Acid After Exercise? https://www.livestrong.com/article/544580-what-happens-to-lactic-acid-after-exercise/ (accessed Nov 1, 2017).

[34] lungs and kidneys relation with the bicarbonate buffer system http://wps.prenhall.com/wps/media/objects/376/385232/Media-Portfolio/chapter_10/10.html (accessed Nov 10, 2017).

[35] Foroutan, R. Alkaline Diet: Does pH Affect Health and Wellness? https://foodandnutrition.org/may-june-2016/alkaline-diet-ph-affect-health-wellness/ (accessed Nov 1, 2017).

[36] Wyman, E. Buffer System in Chemistry: Definition & Overview http://study.com/academy/lesson/buffer-system-in-chemistry-definition-lesson-quiz.html (accessed Nov 10, 2017).

[37] Clark, J. Le Chatelier's Principle https://www.chemguide.co.uk/physical/equilibria/lechatelier.html (accessed Nov 10, 2017).