The Not-So-Fun Parts of Exercise

Jump to:

SLEEVES GETTING DAMP?

The Chemical Explanation of Sweat

Sweat is often thought of in a negative connotation, usually associated with bad odor or excessive moisture, but sweating is an important bodily function that regulates homeostasis in the body. Specifically, sweat plays a large role in maintaining ideal conditions in the body's temperature and pH levels (Science Editor, 2013).

THE PROCESS OF SWEATING

The biological process of sweating is known as perspiration, while the chemical aspect of it is known as evaporative cooling. The body's temperature rises significantly above homeostasis [1], or its ideal conditions, and the brain recognizes this change (Scheve, 2010). To counteract this, the brain activates a negative feedback loop [2]. When the feedback loop is activated, the brain sends out signals to dilate, or widen, blood vessels throughout the body. The blood vessels give off heat when dilated, which causes sweat glands to work faster and produce more sweat (Science Editor, 2013).

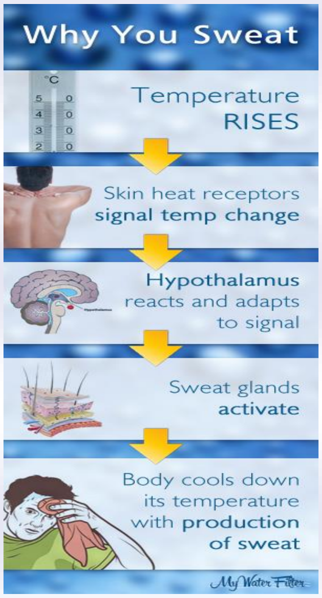

Figure 1. Why do you Sweat

WHAT AM I SWEATING OUT?

Sweat consists primarily of water and makes up 99% of the substance. The purpose of water in sweat is to change phases to cool down the body, which will be described in detail below (Sid Robinson, 1954). Sweat also consists of sodium chloride is secreted by sweat glands when the body is dehydrated, which allows water to be reabsorbed and counteracts dehydration. It also allows the body to regulate the salt content in the body, and can release sodium chloride if salt levels are toxically high within the body (Sid Robinson,1954). Other trace elements in sweat include potassium, calcium and magnesium (T. Verde, 1982). There are two different types of sweat glands: eccrine and apocrine. Eccrine sweat glands are found all over the body except the lips, palms and soles of the feel. Apocrine sweat glands are found specifically where there are many hair follicles, such as the scalp, underarms and genitals. Although the components of sweat from both glands are the same, the percent composition of each varies. Apocrine glands may also produce sweat that contain fatty acids and protein by products which results in thicker, plasma like sweat (Griffin, Is your excessive sweating caused by a medical problem? , 2005)

HOW DOES SWEAT COOL ME DOWN?

From a chemical standpoint, evaporative cooling can be understood using kinetic energy [4] and phase transitions. Each water molecule has a distinct kinetic energy but the average kinetic energy of all the water molecules is used to calculate temperature. Molecules that have a significantly higher kinetic energy than other water molecules can overcome the intermolecular forces found between molecules and can break their intermolecular hydrogen bonds and escape into their gaseous phase, or water vapor. Since the molecules with the highest kinetic energies are released, the average kinetic energy of the molecules decreases, causing the surface of evaporative cooling to also decrease. The remaining water exists in the liquid form in the pores of the skin at the temperature of homeostasis for the body (Khan Academy, 2005)

Click here for a video describing the process of evaporative cooling.

HOW DOES SWEAT MAINTAIN PH

Sweat has a pH range that ranges from 4 to 5.5, meaning it is moderately acidic. This acidity can be largely attributed to the lactic acid found in sweat. The moderate acidity of sweat helps fight body odor (Ella H. Fishberg, 1932). Body odor is caused by bacteria present at the skin's surface to break down sweat. If not killed, the bacteria can begin to grow pathogenic bacteria or fungi. The acidity of sweat kills the bacteria, preventing the growth of harmful bacteria and fungi (Underwood, 2017). Lactic acid found in sweat also plays a large role in muscle metabolism. When exercising, the muscles in the body expand and contract. To recover from this breakdown, they produce lactic acid. Increased production of lactic acid can have toxic effects on the body and must be regulated by buffers in the body (Rachel Casiday, 2007) Buffers regulate change in pH. A buffer [3] maintains pH by interacting with a strong acid or base to neutralize its effects. If a strong base is added to a buffer, then the weak acid in the solution will release its proton to convert the base into a water molecule and produce a conjugate base. Likewise, if a strong acid is added to a buffer, then the weak base will interact with the proton release by the strong acid to produce a weak acid. Lactic acid reacts with sodium bicarbonate to ensure that the pH of blood and sweat does not decrease (Mancini, 2011)

AM I SWEATING TOO MUCH?

Although sweating is a beneficial process for the body, an excessive amount of sweating can indicate an underlying medical condition. Excessive sweating is known medically as hyperhidrosis. There are two types of hyperhidrosis. Primary focal hyperhidrosis is of no medical concern, and refers to the localized overactivity sweat glands when perspiration is not required. This condition is believed to be caused by a malfunction in the nervous system where the brain incorrectly sends a signal to the sweat glands (Mayo Clinic, 2015). This condition is also speculated to be hereditary. Secondary hyperhidrosis is less common, but more serious. It refers to excessive sweating all over the body and often indicates medical issues such as thyroid issues, diabetes, heart failure, Parkinson's and even cancers like leukemia and lymphoma (Griffin, Is your excessive sweating caused by a medical problem?, 2005).

BREATHING HARD?

The Role of Oxygen in Exercise

(Click on Figures to visit their Source Cites)

It is commonly known that breathing heavily is an almost unavoidable part of exercise. It is also generally known that heavy breathing is the body's way of delivering more oxygen to the cells within it. However, what is lesser known is why. To completely understand oxygen's role in exercise, there needs to be an understanding of the body's increased needs outside periods of rest for oxygen.

There are four mains reasons why there is an increased need for oxygen during exercise. Every one of these can stem back to what exactly is happening to someone's body as they expend energy. There becomes an increase in energy requirements, a decrease in blood oxygen reserves, a decrease in partial pressure within the body, and an increase in carbon dioxide that the body produces.

INCREASE IN ENERGY REQUIREMENT

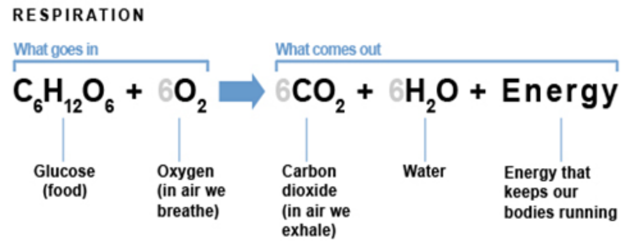

Figure 1: Chemical Reaction of Glucose and Oxygen to Carbon Dioxide, Water, and Energy Through Respiration

Probably the first and most obvious thing that happens to someone's body as they expend energy through exercise is there are increased energy requirements. Oxygen and glucose, as seen and defined in Figure 1, are your body's basic energy building blocks. Even at rest, your body needs them to make your heart pump blood, to make your lungs inhale and exhale, and to allow every other organ and cell to function as designed (LeBoeuf-Little par 2). Every one of these activities takes energy that must be replaced in part by taking in more oxygen to complete the chemical reaction. This chemical reaction, seen in Figure 1, takes 6 parts oxygen for every one part glucose. When you exercise, these processes move more vigorously than when you are at rest. In turn, they need more energy, so they produce more of the chemical energy molecule adenosine triphosphate (ATP). ATP consists of an adenine ring (5), a ribose sugar, and three phosphate groups as seen in Figure 2. You need oxygen to produce ATP, so the more ATP you produce, the more oxygen your body requires.

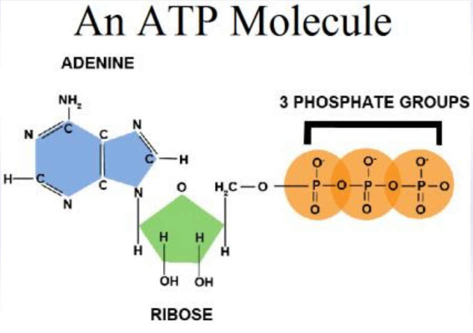

Figure 2: The Composition of an ATP Molecule

DECREASE IN BLOOD OXYGEN RESERVES

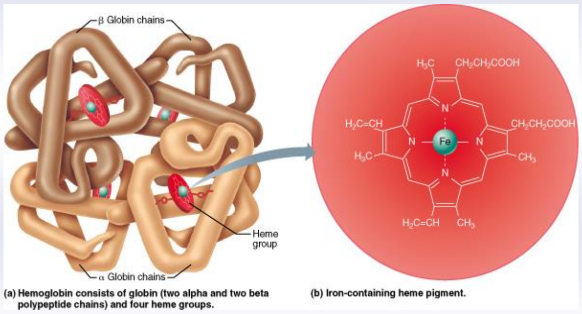

Figure 3: The Hemoglobin Molecule and Heme Group

The next relatively obvious thing that happens to someone's body that creates a need for oxygen as they exercise is their blood oxygen reserves decrease significantly. Whether at rest or exercising, oxygen reaches muscles and cells by means of the bloodstream. About 98.5% of oxygen dissolved into the bloodstream becomes reversely(6) bound to the blood's hemoglobin molecules (*non-covalently* (7)) (LeBoeuf-Little par 4). Hemoglobin travels to tissue around the body to give up oxygen to the cells. This binding occurs in each hemoglobin molecule's four heme groups with iron atoms at their centers seen in Figure 3. The non-covalent bonding of the oxygen to this iron is incited by the oxygen pressure in the capillaries(8) of the lungs increasing as a breath is taken and is also what creates the red color in oxygenated blood (McDowall par 1). While at rest, only approximately 20-25% of the hemoglobin molecules give up their bound oxygen to tissues, leaving the rest remaining in the bloodstream in reserve. As exercise begins, however, these reserves are used up and oxygen-hemoglobin saturation in the bloodstream drops significantly. More oxygen is then required to make up for this loss.

DECREASE IN PARTIAL PRESSURE

The next thing that would create a need for oxygen in someone's body as they exert energy through exercise is the decrease in partial pressure within the body. a mixture of gases or substances (in this case the bloodstream), each gas contributes partially to the total pressure of the mixture This contribution is called the partial pressure. The partial pressure is the pressure of the gas (in this case oxygen) if it were alone in a container of the same volume and temperature of the mixture. As oxygen leaves the bloodstream and enters tissues, the pressure of the bloodstream contributed by oxygen (the partial pressure of oxygen AKA: PO_2) drops. At lower PO_2 levels, the red blood cells make more of a substance called 2,3-diphosphoglycerate (LeBoeuf-Little par 5). This is a salt created by the red blood cells to help unbind oxygen from hemoglobin. So, in the case where there is less than the normal amount of oxygen in the bloodstream, red blood cells try to correct that by making more 2,3-diphosphoglycerate. The increased presence of this substance helps alter the structure of hemoglobin such that it gives up its bound oxygen more readily, meaning oxygen must be replenished much more quickly as it is released much more quickly.

INCREASE IN CARBON DIOXIDE

The last thing that would create a need for oxygen in someone's body as they exercise is the increase in carbon dioxide (CO_2) within the body. As seen in Figure 1, carbon dioxide is a primary waste product in the creation of natural energy in the body. In 1904, Christian Bohr discovered that increased concentrations of CO_2 encourage hemoglobin to release oxygen molecules much like 2,3-diphosphoglycerate. Similar to the effect of 2,3-diphosphoglycerate, this principle, the Bohr effect, makes it easy for exercising muscles and tissues to receive the oxygen from the bloodstream in increased amounts (LeBoeuf-Little par 6). However, again like the effect of 2,3-diphosphoglycerate, it also means oxygen supplies must be replenished much more quickly.

Overall, it can be concluded that oxygen plays a significant role in exercise, and many factors contribute to why the body needs more during it. This is why aerobic exercise in the presence of sufficient oxygen is immensely more preferable as opposed to anaerobic exercise ("Aerobic" par 1). This is also why much research has been done tracking the amount oxygen that is in the atmosphere in correlation with an athlete's physical performance. One 2014 study by *The Journal of Strength and Conditioning Research* even found that with slightly elevated oxygen levels, performance was improved by up to 14% (Dupont par 6). So, breathing hard might not be the most pleasant part of exercise, but it without a doubt is not only important but integral to the long run goals.

SMELL BAD?

The Chemistry Behind Body Odor

Body odor is a universal experience, whether it be due to exercising at the gym or walking up Daisy Hill on a hot day. Humans work hard to eliminate their body odor by spending millions of dollars on deodorants and antiperspirants, but to accomplish this goal it is important to understand what makes up our odor and how those chemicals interact with each other and their environment. While everyone has their own unique scent, the same chemicals are often found in body odor coming from different parts of the body (Griffith).

VOLATILE COMPOUNDS

Odors in general are often created by volatile sulfur compounds (VSC) or volatile organic compounds. A sulfur compound is any molecule that contains sulfur, and an organic compound is a compound containing carbon. In order for a compound to be described as volatile the compound must have a low boiling point so it easily evaporates into the air, and eventually enter human noses (Volatile Organic Compounds). To learn more about volatile organic compounds and their use, click here (Volatile Organic Compounds).

A major factor in determining the volatility of a compound is the intermolecular forces (1) that compound possesses. Intermolecular forces are the forces that exist between molecules. The type of intermolecular force a molecule has depends on its structure, and there are many different types of these forces. The intermolecular forces that all molecules have are called dispersion forces, and these forces are relatively weak compared to the other intermolecular forces.

Another important intermolecular force is the hydrogen-bond, and this force is found in any molecule that has an H bonded to a fluorine, oxygen, or nitrogen. These three elements are very electronegative, which means that they attract electrons, so when they bond with hydrogen a separation of charge is created in the molecule. One side will be positive, and one side will be negative due to the electronegative element attracting electrons. The hydrogen bond refers to the interaction between the positive end of one molecule with an H bond and the negative molecule of a separate molecule with an H bond.

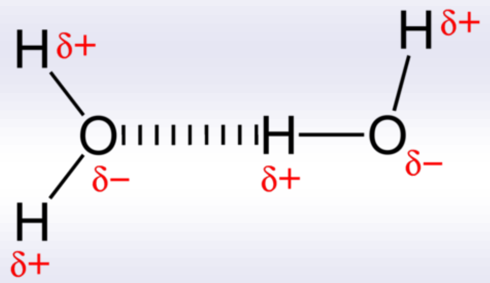

Figure 1: The attraction between hydrogen bonds

These hydrogen bonds are often viewed as very strong intermolecular forces. If a compound has strong intermolecular forces, it will have a higher boiling point, evaporate less easily, and not be considered volatile. Volatile compounds will have weaker intermolecular forces, so they evaporate more easily. While there are more intermolecular forces than just the two described above, these two will play the largest role in the properties of the molecules described below. This video explains in greater detail the different types of intermolecular forces and how the structures of molecules relates to these forces (Intermolecular forces).

UNDERARM ODOR

Body odor starts with sweat and perspiration, and that perspiration provides an environment for the bacteria that live on the skin to live and grow in. It is these bacteria that live on the human skin that produce the odor smelled after a workout (Kieger). These bacteria gain nourishment from the sweat generated during exercise or other activities, and then release a waste product. This waste product is the source of human body odor, and its chemical composition varies depending on what part of the body the bacteria live on because different body parts provide different living conditions.

For example, there are approximately one million bacteria per square centimeter found in underarms (Griffith). There are three main molecules that make up the body odors produced by your underarms: 3-Methyl-2-hexenoic acid ($C_7H_{12}O_2$), 3-Methyl-3-Sulfanylhexan-1-ol ($C_7H_{16}OS$), and 3-Hydroxy-3-Methylhexanoic Acid ($C_7H_{14}O_3$) (Griffith). The figure to the right shows the structures of these molecules, and can also be found here (The Chemistry of Body Odors).

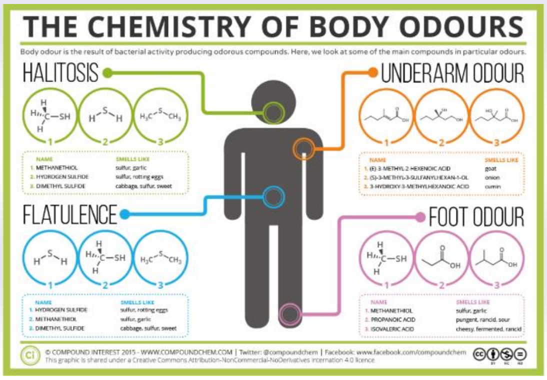

Figure 2: Structure of Molecules

$C_7H_{12}O_2$ is an unsaturated short-chain fatty acid, which means it has at least one double bond within the fatty acid chain. This fatty acid is secreted by the underarms, and is described as having a “goat-like” odor (Griffith). $C_7H_{16}OS$ is the second most common molecule released by the bacteria who live on the underarms of humans. This molecule is described as having an “onion-like” odor (Griffith). $C_{17}H_{14}OS$ is the third of the three most common molecules found to cause body odor from the underarms, and this molecule is described as having a “cumin-like” odor (Griffith). Due to the structure of these molecule as shown in the infographic linked above, these molecules have dispersion forces and only one hydrogen bond (O-H). This would classify these molecules as having relatively weak intermolecular forces and explain how they evaporates easily and then finds their way into human noses to cause odor.

OLFACTION

Now that there is a basic understanding of three molecules that create body odor from a specific part of the body (the underarm), it is time to discuss what happens when an odor is "smelled". This process is referred to as olfaction. The human sense of smell is part of the sensory system, and it is powered by specialized cells whose function is to process smells. These cells are referred to as olfactory sensory neurons, and they are found in tissues high within the nose. These cells are connected directly to the brain, and they have receptors that are stimulated by odors (National Center for Biotechnology Information). Once these neurons detect a smell by it binding to one of their receptors, they send a signal to the brain which then processes and identifies the smell. The major pathway in which smells reach these neurons is through the nostrils, and this more easily applies to the discussion of body odors above. However, these neurons can also be reached while eating, and this can alter how the flavors of certain foods are determined. This video provides a more detailed look at olfaction and how the process works (Olfaction). These neurons and the brain are constantly communicating back and forth to identify and understand the smells of the world, even unpleasant smells such as body odor.

DOUBTFUL OF YOUR DOVE?

How Deodorants and Antiperspirants Work

INTRODUCTION

Deodorant and antiperspirant are everyday items that are used with little to no consideration of how they work. Although both are effective, they vary in many ways, including how they reduce body odor, prevent sweat, and their overall chemistry. Deodorants eliminate odor by attacking the bacteria that produce unpleasant scents (Brunning). Most deodorants contain antibacterial that target, inhibit, and kill bacteria (Brunning). Bacteria undergo many biological processes that use up resources and produce waste products. Since the bacteria's waste products cause the odor, the death of the bacteria prevents the processes that produce this waste from occurring. Alternatively, the purpose of antiperspirants is to prevent sweat altogether (Brunning). Antiperspirants

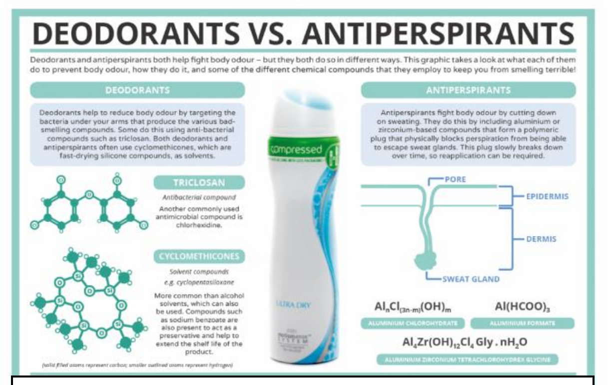

Figure 1: comparison of deodorants and antiperspirants (Brunning).

contain metallic compounds, generally aluminum or zirconium-based, that block sweat from exiting the body (Brunning). These compounds create plugs that obstruct the pores that allow scent to escape the body (Brunning). Therefore, antiperspirants prevent any external production of odor, trapping it all in the body. This prevents the diffusion of the scent from the body to the surrounding atmosphere. To learn more about how deodorants and antiperspirants differ click here (Brunning).

ACTIVE INGERDIENTS OF DEODORANT

Different types of deodorant contain varying active ingredients but originally deodorants were made with acids or alcohols (Boyd). Acids and alcohols are polar, meaning that electrons are not evenly shared, causing them to dissolve in polar solvents. Alcohol kills bacteria through denaturing (10) proteins and dissolving the plasma membrane (How does ethyl alcohol kill bacteria?). The alcohols used are polar while the lipid membrane is partially polar and partially nonpolar. This leads to the alcohol group to associate with the polar portions of the membrane, causing the nonpolar portions to fall apart (How does ethyl alcohol kill bacteria?). Alcohol has since become a less common active ingredient, due to it drying skin (Boyd). More recently, triclosan has emerged as the prevalent antibacterial in deodorants. Triclosan is a bacteriostatic molecule, meaning it prevents microorganisms from growing, and it also kills bacteria (Triclosan). Triclosan does this by blocking the active site where the enzyme that allows for fatty acid synthesis in bacteria (Triclosan). This causes the bacteria to be unable to divide and grow. Triclosan is a strong inhibitor of bacterial processes that are necessary for survival. For more information about triclosan, including its molecular structure, click here (Triclosan).

ACTIVE INGREDIENTS OF ANTIPERSPIRANTS

One of the most common ingredients in antiperspirants is aluminum chloralhydrate (Boyd). Aluminum chloralhydrate and other aluminum compounds work through because the skin absorbs the gel and molecular contents of the antiperspirant, including ions, which causes cells to fill with water (Boyd). This leads to swelling, which then causes the blockage of pores. To learn more about how these aluminum compounds form a barrier, click here (Boyd). Zirconium

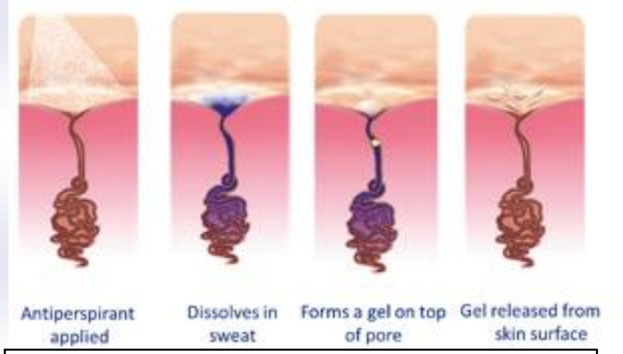

Figure 2: a chart showing how antiperspirants work (About Antiperspirants and Deodorants).

is also present in many antiperspirants and acts in the same way as aluminum, to prevent sweating. Cyclomethicone is also used to block the site where sweat exits the body (Brunning). Cyclomethicone is a silicon based compound that is significantly larger than aluminum and zirconium (Boyd). This size and inability to reorient in a useful way prevents cyclomethicone from completely dissolving into the skin, but it is still effective at blocking the pores that releases sweat (Boyd). Most of the active ingredients in antiperspirants act similarly. For more information on how antiperspirants work, click here (About Antiperspirants and Deodorants).

HEALTH CONCERNS

The chemical composition of deodorants and antiperspirants have greater effects than just killing bacteria and preventing odor. They also impact users' health, especially when in large concentrations. There are strict guidelines for the concentration of substances, meaning that there cannot be greater than a certain proportion of the designated substance in the whole product. Since aluminum-based compounds can be absorbed by the skin, this presents some concern regarding the safety of products containing aluminum. The aluminum can impact hormones and some claim that they alter estrogen receptors, causing changes in cell growth (Chowdhury). Additionally, there are citations that aluminum can be linked to Alzheimer's disease (Boyd). However, both claims have been discredited. The FDA strictly monitors the concentration of active ingredients, ensuring that they are not strong enough to harm users, while the American Chemical Society has cited many studies that demonstrate the lack of linkage between these products and Alzheimer's (Boyd). Similarly, the safety of triclosan has become a focus of many studies. Triclosan is considered to be non-toxic but it can cause irritation, rashes due to photoallergic contact dermatitis, and it also is absorbed into the body in large quantities (Boyd). In numerous studies, triclosan has been found in greater than expected concentrations in the body, and has illustrated impacts on hormones, especially the thyroid hormone (Boyd). This leads to the lowering of body temperature and other unexpected and unwanted consequences, due to the inhibiting of the hormones (Boyd). Triclosan and other common compounds in deodorants and antiperspirants have also been linked to antibiotic resistance (Triclosan). The triclosan disinfects and destroys bacteria's' membranes due to protein denaturing. Triclosan has also been linked to promoting bacterial resistance, due to studies by the American Medical Association that have shown how triclosan enables new bacteria to flourish (Chowdhury).

ENVIRONMENTAL CONCERNS

Deodorants and antiperspirants also impact the environment. Cyclomethicone has been strictly watched in Europe, due to concerns that it may be harmful to the planet (Boyd). Cyclomethicone is not very water-soluble, so it takes a long time to decompose, causing more pollution than other compounds that are biodegradable (Brunning). Currently, there are studies to test the toxicity of cylcomethicone and to investigate if there any long term effects that harm the ecosystem and wildlife (Brunning). Similarly, triclosan has been found in large concentrations in many residential drains (Triclosan). As triclosan remains in ecosystems, it decomposes into products with greater lipophilicity (11), meaning that it will take even longer to degrade in polar substances, such as water (Triclosan). These products are absorbed by the marine life that reside in these waters, causing molecular harm (Triclosan). Ultimately, many chemicals and compounds present in deodorants and antiperspirants harm the environment.

APPENDIX

SWEAT:

1. Homeostasis: the stable and regulated condition of an organism's internal environment and equilibrium

2. Negative feedback loop: decreases the function the function or output of a reaction. This is used as an internal controller for maintaining homeostasis in the body's temperature, pH and other internal variables

3. Buffer: A buffer is a solution of a weak conjugate acid or base pair (either a weak acid and its conjugate base or a weak base and it conjugate acid). Weak bases and acids do not dissociate completely in an aqueous solution. These buffers are important to the body, as they can resist change in the body's pH from the addition of basic or acidic chemical components

4. Kinetic Energy: energy an object possesses due to its motion

OXYGEN:

5. Ring: a ring is an ambiguous term referring either to a simple cycle of atoms and bonds in a molecule or to a connected set of atoms and bonds in which every atom and bond is a member of a cycle (also called a ring system)

6. Reversely: no chemical bonds are formed between the two molecules hence the association, although existing, is so weak that it is fully reversible ("Ring" par 1).

7. Non-covalent: A non-covalent interaction differs from a covalent bond in that it does not involve the sharing of electrons, but rather involves more dispersed variations of electromagnetic interactions between molecules or within a molecule ("Non-covalent" par 1).

8. Capillaries: Fine branching blood vessels. The smallest type of blood vessels.

BODY ODOR:

9. Intermolecular Forces: the sum of all the forces between two neighboring molecules dependent on the way structure of molecules

DEODORANT AND ANTI- PERSPIRANT:

10. Denature – disrupt the molecular properties and structure, often through excessive heating

11. Lipophilicity – the ability to dissolve or be soluble in lipids

REFERENCES

SWEAT

ChemCollective. (n.d.). *How Buffers Work*. Retrieved from ChemCollective: http://chemcollective.org/activities/tutorials/buffers/buffers3

Chemistry Libretexts. (2017, February 13). *Inroduction to Buffers*. Retrieved from https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Acids_and_Bases/Buffers/Introduction_to_Buffers

Ella H. Fishberg, W. B. (1932). *Acid- Base Blance in Sweat*.

Griffin, R. M. (2005). *Is your Excessive Sweating Caused by a Medical Problem*. Retrieved from WebMD: https://www.webmd.com/skin-problems-and-treatments/features/is-your-excessive-sweating-caused-by-a-medical-problem#2

Khan Academy. (2015, July 1). *Evaporative Cooling*. Retrieved from Khan Academy: https://www.khanacademy.org/science/biology/water-acids-and-bases/water-as-a-solid-liquid-and-gas/v/evaporative-cooling

Khan Academy. (2015, July 3). *Introduction to Buffers*. Retrieved from https://www.khanacademy.org/science/biology/water-acids-and-bases/acids-bases-and-ph/v/buffer-system

Mancini, L. A. (2011). *Using bicarbonate to biffer lactic acid in athletes*. Retrieved from Doctor of Fitness: http://doctoroffitness.com/resources/fitness-articles/item/q-a-using-bicarbonate-to-buffer-lactic-acid-in-athletes-2

Mayo Clinic. (October, 14 2015). *Excessive Sweating*. Retrieved from Mayo Clinic: https://www.mayoclinic.org/symptoms/excessive-sweating/basics/causes/sym-20050780

Rachel Casiday, R. F. (2007, July). *Blood, Sweat, and Buffers: pH Regulation during Excercise*. Retrieved from Washington University: http://www.chemistry.wustl.edu/~edudev/LabTutorials/CourseTutorials/bb/Buffer/Buffers.pdf

Scheve, T. (2010, September 27). *What is in Sweat?* Retrieved from HowStuffWorks.com: https://health.howstuffworks.com/wellness/men/sweating-odor/what-is-in-sweat.html

Science Editor. (2013, November 7). *The science behind sweating*. Retrieved from The California Aggie: https://theaggie.org/2013/11/07/the-science-behind-sweating/

Sid Robinson, A. H. (1954). Chemical Composition of Sweat. *Physiological Review*, 202-220.

SparkNotes Editors. (n.d.). *SparkNote on Acids and Bases: Buffers*. Retrieved from Sparknotes. com: http://www.sparknotes.com/chemistry/acidsbases/buffers/section1.rhtml

T. Verde, R. J. (1982). Sweat composition in exercise and in heat. *Journal of Applied Physiology*, Vol. 53.

Underwood, C. (2017, August 14). *Body Odors and pH Balances*. Retrieved from Livestrong.com: https://www.livestrong.com/article/264776-body-odors-ph-balances/

OXYGEN

"Aerobic vs. Anaerobic: What Is The Difference? :: Provided by MyFoodDiary.com."*MyFoodDiary.com*, 2017, www.myfooddiary.com/resources/ask_the_expert/aerobic_vs_anaerobic.asp.

Dupont, Doug. "More Oxygen Means Better Recovery." *Breaking Muscle*, 27 July 2017, breakingmuscle.com/fitness/more-oxygen-means-better-recovery.

LeBoeuf-Little, Nicole. "Why Does the Body Need More Oxygen When We Exercise?"*LIVESTRONG.COM*, Leaf Group, 14 Aug. 2017, www.livestrong.com/article/389650-why-does-the-body-need-more-oxygen-when-we-exercise/.

McDowall, Jennifer. "Hemoglobin." *The European Bioinformatics Institute*, www.ebi.ac.uk/interpro/potm/2005_10/Page1.htm.

"Non-Covalent Interactions." *Wikipedia*, Wikimedia Foundation, 3 Nov. 2017, en.wikipedia.org/wiki/Non-covalent interactions.

"Ring (Chemistry)." *Wikipedia*, Wikimedia Foundation, 11 Oct. 2017, en.wikipedia.org/wiki/Ring_(chemistry).

BODY ODOR

The Chemistry of Body Odors - Sweat, Halitosis, Flatulence & Cheesy Feet http://www.compoundchem.com/2014/04/07/the-chemistry-of-body-odours-sweat-halitosis-flatulence-cheesy-feet/ (accessed Nov 16, 2017).

Griffiths, S. The science of SMELL: Chemistry teacher's homemade infographics reveal the whiff truth behind feet and armpits http://www.dailymail.co.uk/sciencetech/article-2604264/Why-breath-smells-armpits-reek-Infographic-explains-chemistry-body-odours-including-flatulence-cheesy-feet.html (accessed Nov 16, 2017).

Intermolecular forces https://www.khanacademy.org/science/biology/chemistry--of life/chemical-bonds-and-reactions/v/intermolecular-forces-and-molecular-bonds (accessed Nov 16, 2017).

Kiger, P. J. 10 Sources of Body Odor That Aren't Just Sweat https://health.howstuffworks.com/skin-care/underarm-care/problems/10-sources-body-odor-not-sweat.htm (accessed Nov 16, 2017).

National Center for Biotechnology Information https://www.ncbi.nlm.nih.gov/ (accessed Nov 16, 2017).

Olfaction - structure and function https://www.khanacademy.org/science/health-and-medicine/nervous-system-and-sensory-infor/taste-gustation-and-smell-olfaction-2014-03-27t18:46:12.074z/v/olfaction-structure-and-function (accessed Nov 16, 2017).

Volatile organic compound https://en.wikipedia.org/wiki/Volatile_organic_compound (accessed Nov 16, 2017).

DEODORANTS AND ANTIPERSPIRANTS

About Antiperspirants and Deodorants http://www.antiperspirantsinfo.com/en/antiperspirants-and-deodorants/about-antiperspirants-and-deodorants.aspx (accessed Nov 16, 2017).

Boyd, C. WHICH CHEMICALS MAKE DEODORANTS AND ANTIPERSPIRANTS WORK? https://www.chemservice.com/news/2014/08/which-chemicals-make-deodorants-and-antiperspirants-work/ (accessed Nov 16, 2017).

Brunning, A. The Chemistry of Deodorants vs. Antiperspirants http://www.compoundchem.com/2015/09/21/deodorants-antiperspirants/ (accessed Nov 16, 2017).

Chowdhury, A. Effects of Deodorant on Health and Environment http://greencleanguide.com/effects-of-deodorant-on-health-and-environment/ (accessed Nov 16, 2017).

How does ethyl alcohol kill bacteria? http://scienceline.ucsb.edu/getkey.php?key=2160 (accessed Nov 16, 2017).

Triclosan http://emerald.tufts.edu/med/apua/consumers/personal_home_21_4240495089.pdf (accessed Nov 16, 2017).