How Does Soap Work?

All of our life we have been told that we need to use soap before eating, after going to the bathroom, etc. Have you ever wondered if it works? Or better yet, why it works?

First, we must ask ourselves…. What does dirty mean?

What are we trying to clean with soap? Some examples include dried food burnt onto dishes or dust/mud covered on your skin; the examples are endless, but these all have a common factor…they are all infused with oil.

This grime is hard to wash off with water, simply because water molecules are more attracted to one another than they are to oil. Oil and water don't mix; thus, they separate into two. We have been taught this since elementary school, with lots of demonstrations. Oil molecules are large and awkward; they are not polar, so water, a very polar molecule, can’t bond with it. This is why when you have dirt on your hands, and try to use only water to wash it off, it does not work. Or, when you try to wash a greasy pan with only water, it just runs off without removing the dirt and grime because the oily particles can’t bond with water. [3]

Soap isn’t new by any means; thousands of years ago, people figured out how to make a substance that overcame the deep hatred between oil and water, thus, creating soap. See “The History of Soap” to learn more about how soap dates back to ancient Roman times. Today, soap is a major business; it looks a lot nicer and smells better, too.

Nonetheless, it's the same product.

Soap works by breaking up the oil into smaller drops, so it can mix with the water. The principle of soap works because soap is made up of molecules with two very different ends. One is hydrophilic, and it is this end of the soap molecule that loves water. This is the "salt" end of the soap; it is ionic and soluble in water. The hydrophobic end does not mix with water, and is therefore repelled by it. [1]
Since soap molecules have both properties of non-polar and polar molecules, the soap acts as an *emulsifier*, or something that is capable of diffusing one liquid into another unmixable liquid. [2]

When you mix soap and water, the soap molecules position themselves into micelles, or tiny clusters. The hydrophilic part of the soap molecules points out, whereas the hydrophobic parts group together on the inside. The hydrophobic parts don't come into contact with the water at all, due to the repulsion.

These collect the oil particles in the center, as shown in the figure. [2] The oil is trapped in the soap, and then when water is washed over your hands, the hydrophilic parts are attracted to water, taking the soap, and the grime connected to the soap with it.

Here is a fun, interactive game to learn more about how your hands get dirty and the chemistry behind soap… [http://www.discoverwater.org/soap-and-water-science/](http://www.discoverwater.org/soap-and-water-science/)

### Is Hand Sanitizer a Viable Option?

Through the evolution of soaps, a faster alternative to washing your hands came about -- alcohol-based hand sanitizers. The popularity of hand sanitizer increased after the H1N1 flu outbreak.

The alcohol located in hand sanitizers can substitute as an alternative to triclosan, an important ingredient in antibacterial soap. All of these products are not extremely more effective than using warm water and regular hand soap. While they don’t work when hands are extremely dirty, they can be useful in a pinch, those times when soap and water is not available.

Ethanol, Isopropanol, or a mixture make up the alcohol content, which is the main active ingredient in hand sanitizers. These ingredients are sterilizers that kill germs by dissolving their essential proteins. The dissolving upsets cell activity of the germ, allowing it to die. [7] The alcohol kills bacteria by removing the oil on the surface of your skin, and most have a moisturizing agent to prevent dry hands.[6]
Hand sanitizers can be very dangerous to young children. According to US poison control, there was more than 16,000 calls concerning children under 12 swallowing hand sanitizer with these hazardous active ingredients in 2103 alone. [6] Since the advent, new and more fun twists have been placed on hand sanitizers. Bright colors, yummy scents, and bubbles or glitter entice children to the bottles. However, these seemingly yummy and popular items can contain 40% to 95% alcohol content, which means that a little amount can hurt children.

Due to the concern with these harmful alcohols, hand sanitizers without alcohol are now increasing in popularity. The main active ingredient in these is benzalkonium chloride, which was previously used as a wound antiseptic. When researching the effectiveness of these hand sanitizers versus the traditional option, they found a reduction in illness, but most tests are still inclusive due to the various factors.

How Do We Clean the Most Important Parts of Our Bodies: Our Faces?

Another important question, how do we get our faces clean? Everyone has struggled with acne throughout their teenage years, and there is nothing more frustrating. When you go to the store to find something to get rid of it, there are many choices. Which one will work? We all have had terrible products that make our faces even worse than where they started. How do we clean something so delicate without completely drying it out?

The chemistry behind face soap is the same of that behind normal soap, but has a much trickier mission. When cleaning skin, the soap has to remove all dirt and oil, while unclogging pores without destroying the skin’s moisture barrier. One method to properly clean skin is to use surfactant-based products; these can help remove oils, dirt, and makeup. Super harsh surfactant-based cleansers are terrible for skin because this soap can’t differentiate between the good and bad lipids to clean. A common misconception concerning oil on faces is the oilier a person is, the less a person needs to use moisturizers to replenish what the cleansers strip. This could not be more wrong. Skin produces oil when you over-cleanse or do not re-add the important moisture to the skin. Using a mild cleanser or a solvent-based cleanser allows the oils to be dissolved without removing the lipids, thus not effecting the skin’s barrier. These bad lipids can be removed with these cleansers and warm water, face cloths, or cotton, which allows the skin not to be over-dried. When the skin is cleansed properly, oil production is minimized, limiting acne or other issues with the skin. [5]
The history of soap dates back to the time of the ancient Babylonians, around 2800 B.C. Evidence for the invention of soap by the Babylonians can be found on inscriptions detailing the recipe for soap on clay containers. This recipe combined fats mixed with wood ash and water and was used by the Babylonians to wash wool and cotton prior to weaving the fibers into cloth. [8]. Every documented civilization since the Babylonians made use of soap to varying degrees and for varying purposes. For instance, the Egyptians, in 1550 B.C., combine natural oils with alkaline salts to form a soap substance used to treat skin diseases and sores and to clean the body. The ancient Romans in the first century A.D. expanded the use of soap to include cleaning statues and clothing. [10] The first evidence of soap as we know it today was created by Arabic chemists in the seventh century by mixing vegetable and aromatic oils with sodium lye (NaOH). This recipe has largely gone unchanged to present date. As time progressed, the demand for soap rose along with the increasing awareness of the importance of personal hygiene. By the twentieth century, breakthroughs in chemical engineering, such as

An ancient Babylonian clay cylinder detailing a recipe for soap. [9]
chemical hexachloroprene in the 1940s, the company was forced to stop using the chemical in the 1970s due to dangerous side effects. In particular, dermal exposure to hexachloroprene was found to cause nausea, vomiting, diplopia (commonly known as double vision), and many other unpleasant symptoms. Additionally, the chemical causes brain damage in infants by causing brain edema (a dangerous accumulation of fluid on the brain) and degeneration of spongy white brain matter which, in combination, can lead to paralysis and death. [12] Forced with finding a replacement to hexachloroprene, the Dial corporation turned to David Poshi and Peter Divone. Mr. Poshi and Mr. Divone are credited with discovering the first safe recipe for antibacterial soap which included triclosan as an antibacterial agent and was patented in 1984. [13]

Triclosan is categorized as a phenylether, or chlorinated bisphenol (which is a double alternating carbon ring structure surrounded with chlorine atoms); it has a high solubility, meaning it is easily dissolved in an aqueous solution, and a low permeability, meaning that it cannot easily pass through a material without physically or chemically altering the molecule. The effectiveness of triclosan at killing bacteria depends upon the concentration of the chemical. At low concentrations, triclosan is bacteriostatic (i.e. it stops the growth of bacteria but does not kill them; however, at high concentrations, triclosan is bactericidal (i.e. it kills the bacteria). Triclosan works as a competitive inhibitor to the enoyl-acyl carrier protein reductase enzyme (ENR), which is essential in synthesizing fatty acids in bacteria. Since fatty acids are required for the formation of cell membranes and reproduction, triclosan effectively prevents the bacteria from growing or reproducing. Triclosan does not affect fatty acid synthesis in humans since we do not possess the ENR enzyme. [14] Triclosan recently has been found to be detrimental to both health and the environment. In particular several studies have shown that triclosan is an endocrine disruptor resulting in reproductive and developmental issues. Triclosan has also been found to end up in wastewater due to its widespread use in household products which can lead to the chemical reacting with chlorine in waste water treatment plants to form chloroform. These findings led the Food and Drug Administration to ban the use of triclosan in antibacterial soap in 2016. Unfortunately, triclosan is still found in over 2,000 household products ranging from toothpaste to face wash to laundry detergent resulting in more than 75% of Americans testing positive for triclosan in their urine samples. [15]

Despite the benefits of the widespread use of antibacterial soap for the past three decades, current data suggests that the use of triclosan has actually contributed to the rise of antibiotic resistance. Bacteria are resistant to a biocide (such as triclosan) when the bacteria survive concentrations of the biocide that would normally kill most bacteria of the same species. Antimicrobial resistance is such an important issue because resistance is an inherited trait—meaning that the genetic basis for the resistance to an antimicrobial product is passed on to the next generation of bacteria—thereby preventing the future effectiveness of the product. [16] Scientists have also found that antibacterial soap weakens the human immune system and kills beneficial bacteria that live on the skin’s surface since triclosan indiscriminately kills bacteria. The issue of antimicrobial resistance has led many scientists to encourage the shift from antibacterial to plain soap which can be as
effective in cleaning hands without exacerbating the issue of resistance.

Although soap has led to vast improvements in quality of life since its invention in ancient Babylonian times due to its cleansing and surfactant properties, the widespread use of soap has also had several recently discovered unintended consequences such as the negative health effects and environmental damage caused by triclosan, a prevalent ingredient in antibacterial soap, and the rise of antibiotic resistance, a serious issue facing modern healthcare. What is the best solution to prevent the spread of these unintended consequences? Take a page out of the book of the Babylonians and use plain old soap.

## Alternatives in Antibacterial Soap

Today, antibacterial soap seems commonplace in homes, schools, restaurants and stores. Antibacterial soap made its entrance in 1984, thanks to David Poshi and Peter Divone, who patented the first antibacterial soap. As a result, most antibacterial soaps contain triclosan, even to this day. (See “How was it Invented” for more information.) Although triclosan was the first recognized antibacterial agent that was intergrated quickly to produce antibacterial soap, there were another antibacterial agents used as well. Triclocarban, C,H,Cl,N,O, is also another common antibacterial agent, and has similar properties to triclosan. Like triclosan, triclocarban works as an inhibitor to an important enzyme in bacteria, fungi and plants – enoyl-(acyl carrier protein). This disruption causes cell membrane synthesis, preventing bacteria from growing. It has been found to be particularly effective against Gram positive bacteria. Triclocarban has almost been found in antibacterial soap as often as triclosan. [18]

However, with concerns of bacterial resistance, the Food and Drug Administration has issued a rule that potentially harmful antibacterial active ingredients can no longer be sold or marketed to consumers, which includes triclosan and triclocarban, as of 2016. [20] It has been linked to different types of cancer, and to be related to hormonal disruption, and is generally unsafe for the environment.

In turn, soap companies have turned to looking for alternative antibacterial agents. Before this rule instated by the FDA, most liquid soaps contained triclosan while bar soaps tended to contain triclocarban. Now, the search has started for other effective, safer antibacterial chemicals. People have began to turn to other antibacterials, which include pine oil, chlorhexidine, alcohol and nanosilver. Pine oil is a disinfectant and antiseptic, made from multitudes of species of pines. Chlorhexidine is also an antiseptic, and is commonly utilized in hospitals. Its use is much like alcohol, as it is commonly used to cleanse wounds or clean the skin before shots. [21] Nanosilver has also been used as an alternative, but like triclocarban and tricosan, it has raised concern. It works by releasing silver particles (Ag+), which has antimicrobial properties. However, when these particles are released, there is the potential of the contamination of water, the effects on aquatic life, and air pollution. [22] However, these are only chemical alternatives – there are also natural alternatives.

These natural alternatives mostly include essential oils. Two main essential antibacterials include thyme and lavender. Thyme is a potent antibacterial agent, as well as lavender. A Polish study tested both of these oils, and found that they were effective against strains of bacteria, specifically Staphylococcus Enterococcus, Escherichia and Pseudomonas. [23] These bacteria
are commonly used to illustrate and monitor antibiotic resistance of substances. Thyme and lavender are not the only popular essential oils – rosemary and peppermint are used as well. Rosemary and peppermint also have similar properties to thyme and lavender. Additionally, most essential oils often contain organism that fight bacteria, and some can even have anti-fungal properties as well. Essential oils are less harsh than chemicals, and produce a pleasant smell without even adding another chemical. [24]

These are a few of the most common alternatives to triclosan and triclocarban. However, there has been a new, natural alternative that has arrived onto the antibacterial soap scene – chalcone. This compound is found in many plants, and it is essential to help make flavonoids: molecules best known for providing the vivid pigment and color to flowers, fruits and vegetables. Aside from their contributions to the coloring of plants, chalcone has antibacterial properties, and can be used against various pathogens. Like essential oils, chalcone is naturally occurring, but it is fairly new in comparison to other alternatives. [25]

Despite all of these shifts and efforts to move towards more natural antibacterials, companies have also focused on using and experimenting with other chemicals. These chemicals include benzalkonium chloride, benzethonium chloride and chloroxylenol, and all three were not included on the FDA’s 2016 ban for antibacterials. [27] Benzalkonium chloride, or BAC for short, is a common, non-alcohol based active ingredient in many household products, like antibacterial soap. It has a broad level of activity, but generally how BAC combats bacteria by penetrating into the bacterial cell, and interacting with intracellular target sites. In more detail, BAC has both hydrophobic and hydrophilic parts, meaning that parts of the molecule are polar, and other parts are non-polar. As a result, this allows BAC to enter the bacterial cell by pulling apart the plasma membrane. This causes cell leakage and lysis, as well as disrupting important cell synthesis processes like ATP synthesis. [28] Chloroxylenol works in a similar way, by disrupting the cell membrane and inhibiting cell processes. [29] Benzethonium chloride is closely related to benzalkonium chloride, and works in the same way. However, like triclosan, albeit not as in depth as triclosan, it has been studied and cited to have been linked to asthma and other diseases. The FDA cites all three of these chemicals as needing more research to be done to determine their effects on humans and the environment. [30]

In all, there are multitudes of different types of antibacterial soap, and the antibacterial agents that are put within them, whether that may be a processed chemical like chlorhexidine, or a more natural alternative like essential oils. Some of these chemicals still need further testing, and may be just as detrimental to humans and the environment as triclosan and triclocarban. Others seem to be a positive, and safer path for better and more natural soaps. Despite all of this, antibacterial soaps are still developing, and it is unknown as to how they will change and evolve in the future.

How Is Soap Made?

The process of producing antibacterial soap begins with two key questions: will it safely kill bacteria, and will it cleanse the skin? This opens a plethora of doors to considerations regarding what organisms need to be killed, how quickly they should be killed, the speed of foaming and cleansing, and how the soap makes your skin feel. When the chemists are formulating antibacterial soaps, they must keep all of these factors in mind when establishing a
repeatable and dependable formula for a finished product. While the exact nature of the formula will vary depending on the company in question, deionized (distilled) water will always be the primary and most abundant ingredient in soap. In fact, it may comprise roughly 40-80% of the soap’s composition. Water is used because it is an excellent carrier molecule and solvent for the other ingredients prescribed in the formula. More specifically, deionized water is useful, because it lacks any ions or molecules that may bond with/disrupt the actual needed substances in the soap. Of course, using just the hydrogen bonds in water will not remove any hydrophobic, also known as water-hating, gunk or bacteria from your hands.

You’ll need something much more capable of emulsifying and mixing all of the nasty debris on the skin so that it can be carried away by the water. This is accomplished by the usage of animal or vegetable oils and an aqueous strong-base solution (such as sodium or potassium hydroxide) called lye. These oils are primarily triglycerides, which often times are are what comes to mind when one mentions lipids in a biological and chemical context. A triglyceride contains three fatty acids, which are just carboxylic acid chains attached to a single glycerol molecule. A glycerol molecule simply contains 3 Carbons, 8 Hydrogens, and 3 Oxygens. In the production of soap, the triglyceride molecules will be added to water in order to hydrolyze the three fatty acids off. Then the next step in the production process is to bond the lye to the three fatty acids. To form the crude soap structure. In large scale industrial production, this is done in stainless steel tanks that can hold as much 3,000 Gallons of soap! At these early steps in production, highly precise changes in temperature must occur at specific times to ensure that the reactions can occur at the desired rate and that the solution does not become to emulsified. A basic chemical equation that demonstrates the combination of fatty acids and a lye is, \((C_{18}H_{35}O_2)_3C_3H_5 + 3 \text{NaOH} \rightarrow C_3H_5(OH)_3 + 3 \text{C}_{18}H_{35}O_2\text{Na}\). With this basic mixture of water, oils, and lye combined in these massive containers, the next step is to actually make the soap antibacterial, and to make it smell, appear, and feel like the soap we are used to pumping into our hands several times a day.

Here is a shredded sample of sodium hydroxide lye. It is important to notice the chalky texture that contributes to the hydrophobic properties of soap.

In order to create a bacteria slaying household item, chemists use specialized organic molecules, filled with an abundance of carbon, hydrogen, and more specifically chlorine, which is deadly to these tiny creatures, but relatively safe for us if used in appropriate amounts. Specifically, the favorite molecules of use are, 3,4,4'-trichlorocarbanilide (commonly called triclocarban) and 2-hydroxy-2',4,4'-trichlorodiphenyl ether (commercially known as triclosan). These molecules are also known as aromatic molecules. This means that they are cyclic and planar molecules with conjugated (alternating) double bonds within the rings. This allows the carbons to be numbered in a sequence. These numbers are then utilized to show where atoms such as chlorine protrude off of. What makes these molecules workable within soaps is that they are soluble in basic solutions. If we remember one of the base components of soap, lye, a strong base such as sodium hydroxide that easily dissociates in water to form highly basic solutions, then this works perfectly in helping dissolve these molecules.

Next when taking a look at the antibacterial soap making process, the next major step is adding the appropriate ingredients to make the soap smell and feel pleasant. This way, there is
more incentive to wash one’s hands, but you should be doing that anyways! The first challenge is
the scent or the aroma of the soap. The lye and oil solutions do not necessarily combine to form
the most pleasant odor, so companies and chemists must find certain chemicals to make the soap
smell better without hindering its function. This is accomplished by the addition of fragrance
oils. Many of these oils can be synthetic, but often come from plant and animal parts, such as the
leaves of lavender flowers. [37] The exact chemical composition of these fragrance oils varies
greatly, but they all function as oils within the chemical mixture to help ensure the soap solution
stays basic and can emulsify hydrophobic substances on the hand. Another key identifying aspect
of soap is its ability to form bubbles. The bubbles of soap themselves are caused by a spherical
layer of soap film encapsulating the water in the solution. The film consists of a thin sheet of
water sandwiched between two layers of soap molecules. One end of each soap molecule is
hydrophilic, or attracted to water. The other end consists of a hydrophobic hydrocarbon chain
that tends to avoid water. The hydrophobic ends of the soap molecules crowd to the surface,
trying to avoid the water, and stick out away from the layer of water molecules. As a result,
water molecules separate from each other. The increased distance between the water molecules
causes a decrease in surface tension, enabling bubbles to form. The primary agent in making
soap produce more bubbles is a carbon compound called Glycerin (C₃H₅(OH)₃). [38] The
hydrogen bonds formed with water by this molecule make it slightly more difficult for the water
to evaporate in the bubble forming process. So, the soap and water solution becomes frothier for
longer. Finally, once the chemists approve the final mixture, the soap solution is bottled up in
plastic containers and sent to stores across the world to help keep hands nice and clean.

Appendix

**Antiseptic**: An agent that kills or inhibits the growth of bacteria on external surfaces of the body.

**Competitive Inhibitor**: A type of inhibitor that binds to the active site of an enzyme preventing
the intended substrate from binding and prevents the substrate from working.

**Disinfectant**: An agent that destroys bacteria primarily on inanimate objects.

**Emulsifier**: A substance that is capable of spreading one liquid into another unmixable liquid
through emulsion.

**Endocrine Disruptor**: Chemicals that interfere with the body’s endocrine system.

**Gram Positive Bacteria**: Bacteria that have a thick cell wall that is made of a protein called
peptidoglycan.

**Hydrophilic**: The tendency of a substance to mix with water.

**Hydrophobic**: The tendency of a substance to not mix or repel water.

**Lye**: A strong alkaline solution, especially of potassium or sodium hydroxide. More specifically,
lyes are strong bases that contribute to the hydrophobic nature of soap. This allows the soap to be
easily rinsed off your hands when it comes into contact with water. Lyes are commonly used for
washing or cleansing in not only soaps, but a lot of other industrial processes.

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