The Science of SOAP

History

Ingredients

Chemistry

An introduction to the science of how things get clean

EXPLORATION CLEAN®

The American Cleaning Institute (ACI) recognizes that your understanding of the science behind cleaning products is critical to the trust you place in the cleaning products you might use every day. *The Science of Soap* is an introduction to how things get clean. Readers will find an overview of the history of soap and modern advances of detergents, details about the chemistry of cleaning and the power of the surfactant, and summaries of the variety of supporting ingredients that can often be found in cleaning products.

ACI also acknowledges a need to advance the state-of-the-science used by industry to continuously ensure soap and cleaning products are safe, effective, and sustainable. *The Science of Soap* is intended to give tomorrow's innovators a glimpse of the creative chemistries at work in soaps and detergents, inspiring them to consider pursuing careers that further advance the science of soap

ACI hopes that users of cleaning products, inquisitive students, aspiring scientists, and enthusiastic educators find *The Science of Soap* a valuable resource of information about cleaning products. We encourage you to check out **explorationclean.org** for even more resources and activities.

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What Does Clean Mean?

Introduction

Cleaning products play an essential role in daily life. They can remove dirt and stains from our clothes, dried on food from our dishes, and even germs from our hands! Let's learn more about the chemistry that makes this happen.

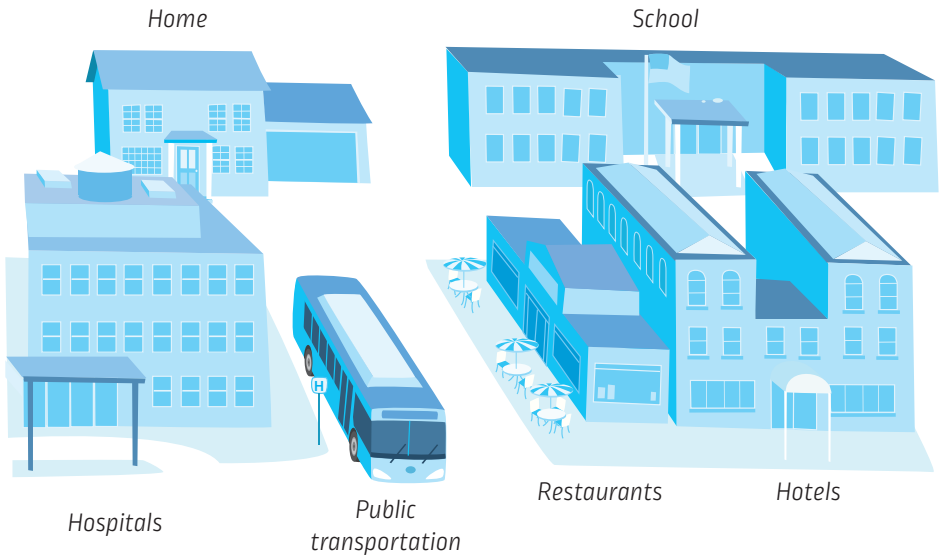
Cleaning is the process of taking something dirty—like your kitchen counter—and removing dirt, grease, and grime found on it. When we clean, we leave things better than they were when we found them. Cleaning helps remove dirt, microbes (like bacteria and viruses), small amounts of food, and many other soils that we do not want hanging around.

We clean almost everything we touch—from our bodies to our bathrooms and everything in between.

And it is not just at home! Cleaning is needed at schools, in restaurants, at hotels, on buses, and especially in hospitals. The more people or animals that go into a place, the more often it will need to be cleaned.

Types of Cleaning Products

Where Are Soaps and Detergents Used?



The History of Cleaning

So where did cleaning come from?

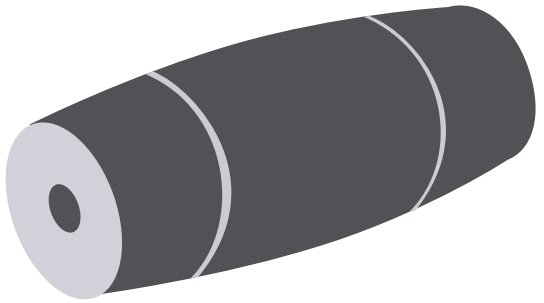
Evidence has been found that ancient Babylonians understood soap making as early as 2800 BC Archeologists have found soap-like material in historic clay cylinders from this time. These cylinders were inscribed with what we understand as saying, “fats boiled with ashes” (a method of making soap).

Records show ancient Egyptians bathed regularly. The Ebers papyrus, a medical document from about 1500 BC describes combining animal and vegetable oils with alkaline salts to form a soap-like material used for treating skin diseases, as well as for washing.

Many other ancient civilizations also used early forms of soap. Soap got its name from an ancient Roman legend about Mount Sapo. Rain would wash down the mountain mixing with animal fat and ashes, resulting in a clay mixture found to make cleaning easier.

By the 7th century, soap-making was an established art in Italy, Spain and France. These countries were early centers of soap manufacturing due to their ready supply of source ingredients, such as oil from olive trees.

But after the fall of Rome in 467 AD, bathing habits declined in much of Europe leading to unsanitary conditions in the Middle Ages. The uncleanliness of that time contributed heavily to illness, including the Black Death, which occurred in the 14th century.



There is evidence from Babylonian clay cylinder seals that soap was being made there almost 5,000 years ago.

Still there were areas of the medieval world where personal cleanliness remained important. Daily bathing was a common custom in Japan during the Middle Ages in Europe. And in Iceland, pools warmed with water from hot springs were popular gathering places on Saturday evenings.

The English began making soap during the 12th century. Commercial soap making began in the American colonies in 1600, but was for many years a household chore rather than a profession.

It was not until the 17th century that cleanliness and bathing started to come back into fashion in much of Europe, particularly in the wealthier areas.

Well into the 19th century, soap was heavily taxed as a luxury item in several countries. When the tax was removed, soap became available to most people, and cleanliness standards across societies improved.

As people became more interested in being clean, they explored new ways of making soap and experimented with new ingredients.

Nicolas Leblanc

A major step toward large-scale soap making occurred in 1791 when a French chemist, Nicholas Leblanc, patented a process for making soda ash from common salt. Soda ash is obtained from ashes and can be combined with fat to form soap. This discovery made soap-making one of America's fastest-growing industries by 1850, along with other advancements and development of power to operate factories.

The chemistry of soap manufacturing stayed essentially the same until 1916. During World War I and again in World War II, there was a shortage of animal and vegetable fats and oils that were used in making soap. Chemists had to use other raw materials instead, which were "synthesized" into chemicals with similar properties. These are what are known today as "detergents."

Today, most things we call "soap" are actually detergents. It has become so common to call detergents "soap," that most people would be confused if you asked for a "liquid hand detergent" when shopping.

Today the science of soap-making is big business. Over 60 thousand are employed in the business, including researchers exploring new ways to use chemistry to help make the world a cleaner and safer place.

Timeline of Cleaning

2800 BC	*Earliest known evidence of possible soap-making in Babylon.*
1500 BC	*Egyptians made soap-like material from oils and salts.*
300 BC	*Romans bathed regularly and used soap to keep clean.*
400	*The fall of Rome brought about a decline in clean habits.*
600	*Soap-making became an established craft in Europe.*
1100	*Italy, Spain, and France became centers of soap-making.*
1600	*Soap-makers arrived at the Jamestown colony in North America.*
1700	*Nicolas Leblanc invented a way to make soda ash from salt in 1791.*
1800	• *Michel Chevreul discovered secrets of fat and soap chemistry.* • *Ernest Solvay's discoveries reduced the cost of making soap.* • *Soap-making became America's fastest growing industry by 1850.*
1900	*German scientists invented non-soap products called detergents.*
1926	*The American Cleaning Institute is founded.*
1950	• *American scientist invented laundry detergent.* • *By 1953, the sale of detergents in the U.S. passed those of soaps.*
1960	*Introduction of stain removers and laundry powders with enzymes.*
1970	*Introduction of liquid hand soaps and fabric softeners.*
1980	*Introduction of cold water washing, dishwasher liquids, and concentrated laundry powders.*
1990	*Introduction of concentrated powders and liquids, fabric softeners, dishwashing gels, and cleaning product refills.*
2012	*Product advances continue to provide new convenient cleaning options, like the liquid laundry packet.*
Next	*What will the future bring for cleaning? That depends on the next generation of scientists, like you!*

How Cleaning Works

No matter the type of product you are using (soap or detergent), good cleaning takes a lot of energy. Three different kinds to be exact:

- Chemical energy, provided by the soap or detergent
- Mechanical energy, provided by a machine or by hand
- Thermal energy, provided by heating water

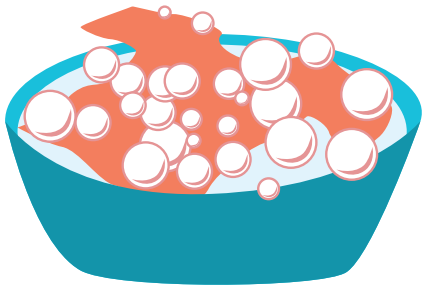
Let's look at how all these elements work together.

Assume we have a great, big, oily, greasy stain on one of our favorite shirts. Water alone is not enough to remove the stain and get our shirt clean.

Now let's add some laundry detergent.

The laundry detergent provides chemical energy. This energy is created because of the way the ingredients in the detergent interact with the stain on our shirt. You cannot see it with your eyes, but the molecules in the detergent are attracted to the stain and help pull the dirt from the shirt to the wash water.

To get something really clean takes a lot of energy. Whether this energy is used in a tub or a washing machine, chemical and mechanical energy are needed to get the best results. With detergents that work in cold water, thermal energy is optional.



Chemical energy
This is the energy in the chemical reactions in soap and detergents.

Next, let's see what happens when we add mechanical energy.

Inside a washing machine, clothes move back and forth rubbing together with other items. This is mechanical energy. The rubbing actions helps to loosen the stain and free it from the surface of our shirt. When you look in your washing machine and see laundry moving, you are watching mechanical energy in action.

Mechanical energy can even be created by hand.

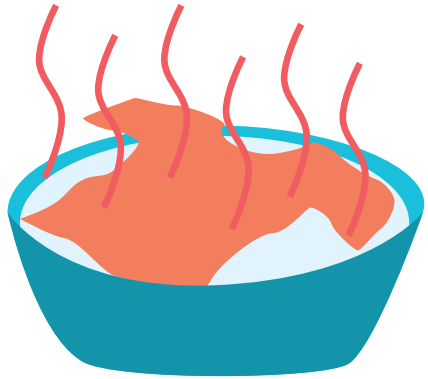
The final type of energy is thermal energy.

Thermal energy means temperature. Warm or hot water can help the stain dissolve quicker. While warm water can help speed things along, most laundry detergents today can work just as well at colder temperatures.

All three types of energy need the right amount of time to work best. The more one type of energy is used, the less others are needed.

For example, delicate clothes would be damaged by the mechanical energy of the washing machine and hotter water. So instead, we can use chemical energy—detergents—and increase time to get them clean.

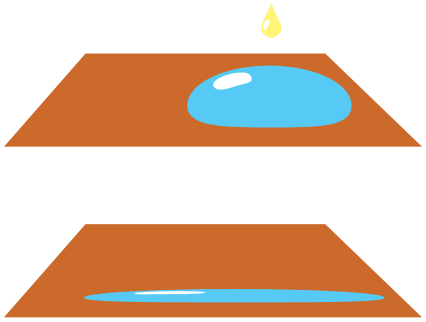
Mechanical energy
Shaking and rubbing help free dirt and stains from surfaces.



Thermal energy
Heat can speed up the reactions that help get things clean.

The Chemistry of Cleaning

Have you ever seen a bead of water sitting on a surface? This is because water has a property called surface tension. This tension causes water to form a bead on the surface of things like glass or fabric. You can see surface tension at work by placing a drop of water onto a counter top. The drop will hold its shape and will not spread.



Surfactants (yellow) cause water to lose surface tension, which is what keeps water separate from other materials.

In order to clean the dirt on our clothes, the water needs to be able to reach the surface. Water is able to get to the surface if surface tension is reduced. To do this, we use a group of chemicals called surface active agents, or *surfactants*.

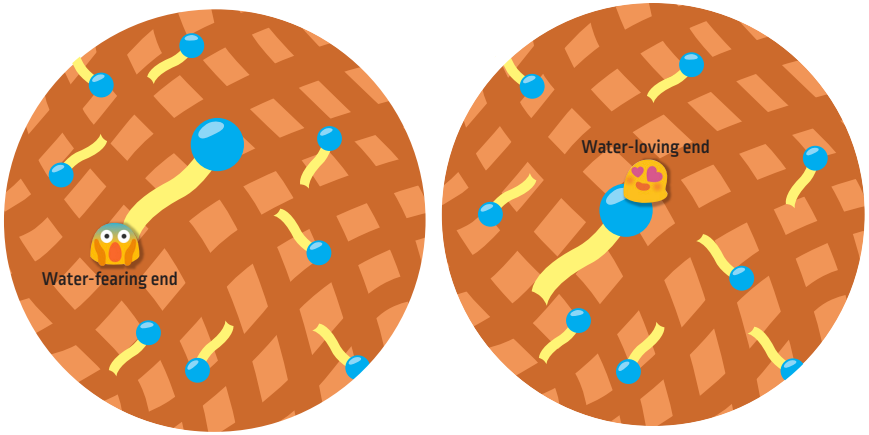
Surfactants change how water behaves. When a surfactant is added, the surface tension is reduced. Now water can spread out and wet the surface (e.g., clothes, dishes, counter tops) we are trying to clean.

Now let's look at what happens on the surface.

Every surfactant has two ends. One end wants to be in water and the other does not.

The water-fearing end is known as the hydrophobic end. Hydrophobic comes from two Greek roots, hydro- (meaning water) and -phobia (meaning fearing). Have you heard the phrase "oil and water don't mix?" This is important here!

The water-fearing end of the surfactant is made up of hydrocarbon chains. A hydrocarbon is a molecule that is made of hydrogen and



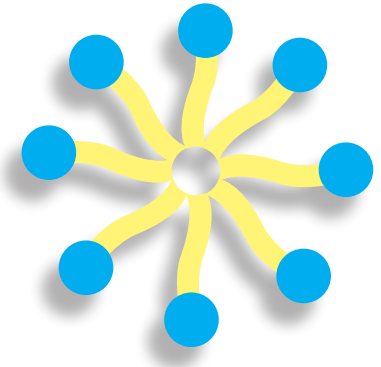
Like a magnet has two ends, one end of the surfactant is attracted to water molecules while the other is repelled.

carbon. The chains love oil and grease and will try to stay away from water.

The water-loving end is known as the hydrophilic end. We learned hydro- is a Greek root meaning 'water'. So, if -phobic means 'fearing', then -philic means loving. The water-loving end of the chemical is attracted to water.

How these two ends interact with soil and water is the secret to how a surfactant works.

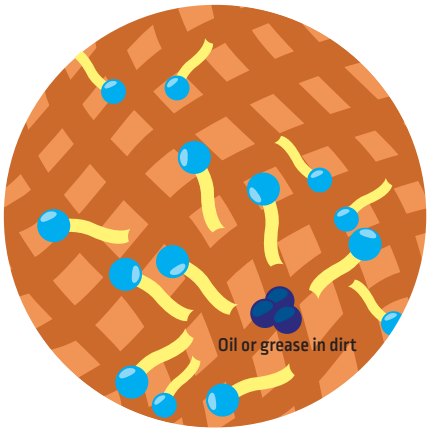
Once the surfactant is added to water, the water-fearing ends try to stay away from the water. They do this by organizing into the shape of a sphere with the water-loving ends on the outside and the water-fearing ends protected on the inside. This spherical shape of surfactants is called a micelle.



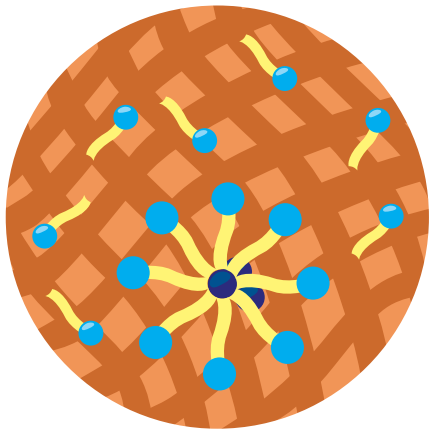
A micelle is a sphere made of surfactants. To show how surfactants behave, it is shown here as a circle.

How surfactants clean

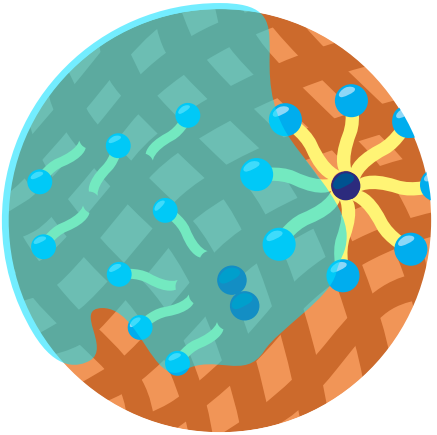
This step-by-step diagram shows a highly magnified view of how micelles of surfactants clear oil or grease in dirt off a piece of cloth.



First, the water-fearing ends of the surfactants drift toward some dirt particles.



A micelle forms around a particle. This separates the dirt from the surface it was on.



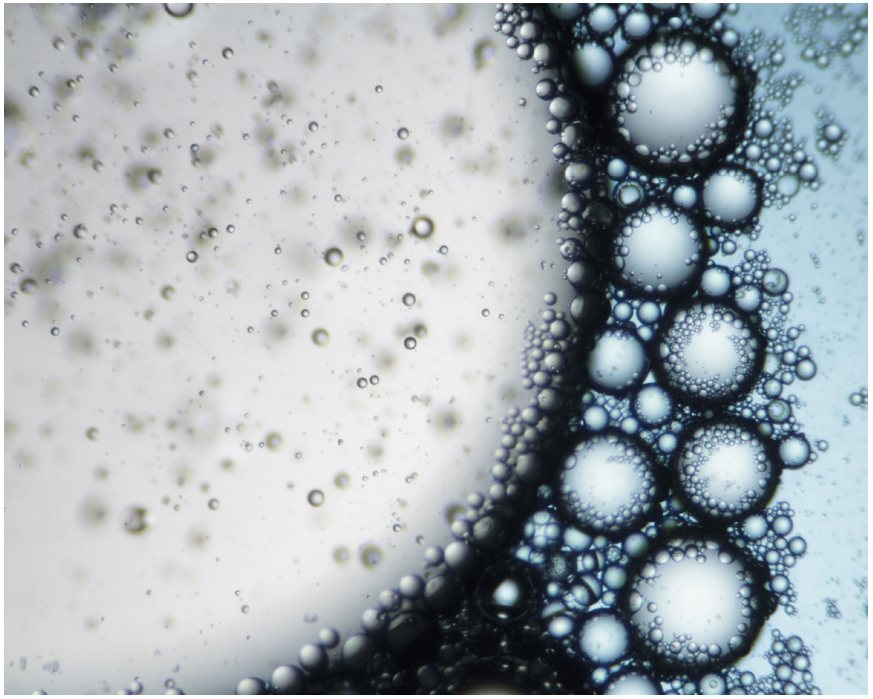
With the dirt inside the micelle, the water-loving ends of the surfactants, which are all on the outside of the micelle, are attracted to water and can be washed away, with the dirt still inside.

The micelle is important because it is what traps the soil. Remember, the inside of the micelle is hydrophobic and does not want to be near water. The soil is also hydrophobic, so it likes the environment the micelle creates.

The attraction of the soil to the inside of the surfactant micelle helps loosen the soil from its surface. Once the soil lifts off the surface, it becomes suspended in the water in the micelle. This suspension is also known as emulsification of one liquid into another. Happy inside the micelle, the soil will not settle back onto the surface.

Now that the soil is trapped in the micelle and the micelle is suspended in water, it is easy to wash the soil way.

Remember the outside of our micelle loves water. So, as we rinse, the micelle floats away and we are left with a clean surface!



Soap mixing with oil under a microscope, forming micelles.

Understanding Product Ingredients

While surfactants are the major components of cleaning products, other ingredients are added to provide a variety of functions. Each product formula is a careful balance of various ingredients that will work best for what you are trying to clean.

Let's review these other commonly used ingredients:

Surfactants

Surfactants provide most of the cleaning power in your cleaning products today, but other ingredients are also needed to make the best products possible. These ingredients help the surfactant work better on different types of soil. As we learned before, surfactants are the main force in cleaning and therefore make up a big portion of cleaning formulations.

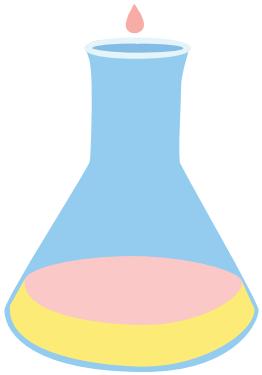
Surfactants are the most important element of the soap, but are not used in the greatest amount.

It is also important to know that some surfactants are very good at removing some types of soils, but not very good at removing others. Many cleaning products include two or more surfactants in the formula. The choice of surfactants determines where the product will work best, such as for laundry, dishes, or counter-tops.

Builders

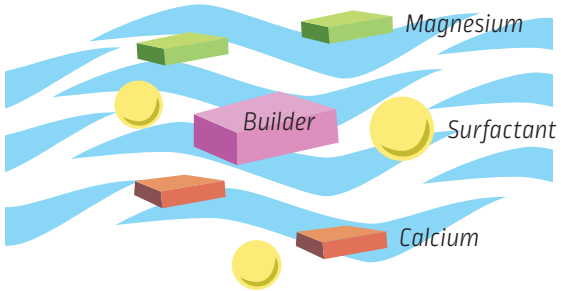
Builders are another important group of ingredients that help make cleaning products better. Builders give the surfactants a helping hand. They are found in a number of different kinds of products, but you need less of them than you do surfactants.

Builders help make the surfactant more powerful by reacting with minerals found in your home's tap water (such as calcium and magnesium). The more minerals in your water, the "harder" the water is. It is not bad to have minerals in water, but it can leave white marks on surfaces (like dishes). When calcium and magnesium are present in water, they will stop surfactants from doing their job of removing soil.

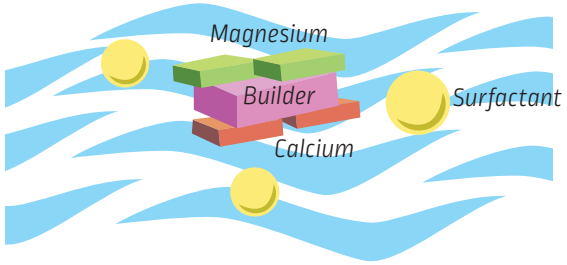


Cleaning products typically use a small amount of builders, which provide extra cleaning power.

Builders help prevent this by keeping the minerals out of the way of the surfactants. This leaves the surfactants alone to focus on the soil.



Magnesium and calcium, two minerals that are commonly found in tap water, can prevent surfactants from doing their job well.

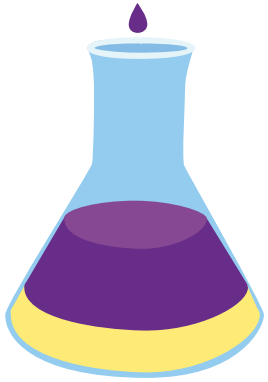


Builders attract magnesium and calcium, leaving surfactants free to do their work.

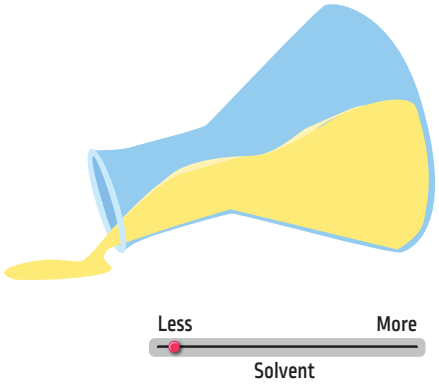
Solvents

Liquid cleaning products are solutions (chemicals dissolved in a liquid). Solvents are chemicals that help ingredients stay mixed and give cleaning products the right thickness so they are easy to use. In addition, organic solvents can help prevent liquid products from freezing in cold climates.

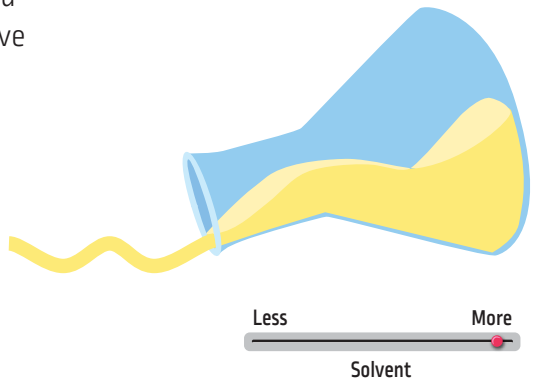
Without solvents, a product will be very thick. In some cases this might be a good thing (think of a bar of soap). But for other products, we want the liquid to pour out of the bottle. When we add solvents, we decrease the viscosity, meaning the liquid will move faster when poured out of the bottle. The solvent also helps to makes sure we do not end up with a separated solution—like when you have pulp at the bottom of your glass of orange juice.



The solvent is needed to dissolve all the other ingredients and makes up the largest percentage of cleaning solutions.



If little or no solvent is used, the cleaning solution will be thick.

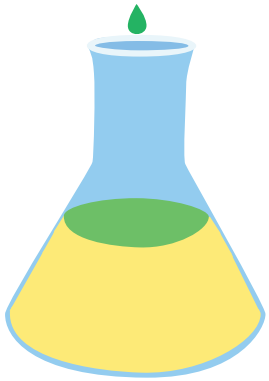


The more solvent is used, the thinner the cleaning solution will be.

Aspergillus oryzae, or Koji, is a filamentous fungus used in the industrial production of enzymes.

Enzymes

Enzymes are powerful stain removing ingredients. Their power is to break down stains—just like the enzymes in our digestive system help break down the food we eat.



Enzymes make up only a small amount of cleaning solutions but have a big impact in breaking down stains.

Enzymes are not living organisms but are created by microorganisms, like bacteria and fungi. In the laboratory, we use carefully selected microorganisms and allow them to grow in a very controlled environment. As they grow, they produce the desired enzymes.

In cleaning products, enzymes help to remove stains and help us to wash clothes in cold water.

Each enzyme is made up of amino acids placed like beads on a string. There can be anywhere between a hundred and a million amino acids for a single enzyme! The order of these amino acids determines the shape and function of the enzyme.

When added to a detergent formula, each enzyme will be attracted to a certain type of stain (like gravy or grass).

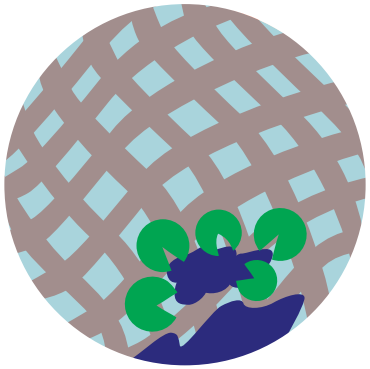
Once the enzyme finds a stain it likes, it gets to work breaking it down into smaller pieces and removing it from the surface we are trying to clean.

It is now easier for those smaller pieces to be picked up by the surfactant micelle.

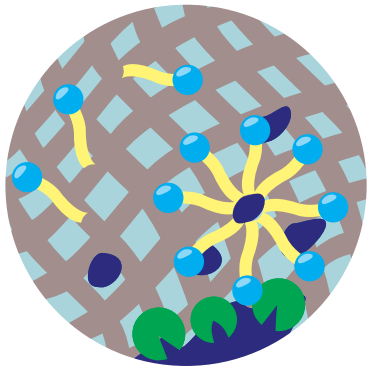
And as we learned earlier, the micelle traps the stain particles—causing them to be washed away in the rinse water, leaving a clean surface.

How enzymes clean

First, ezymes (green) are attracted to certain types of stains.



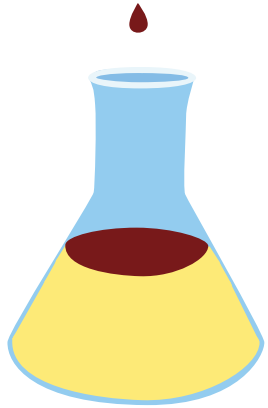
Next, enzymes break down the stain into smaller pieces.



Finally, surfactants are attracted to the loose pieces and they wash away.

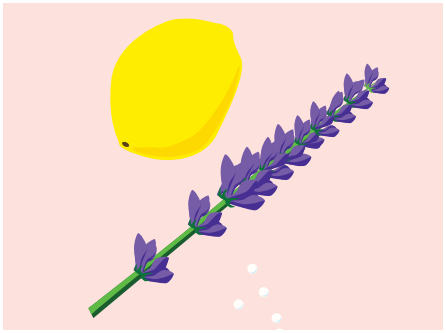
Fragrances

Fragrances are a group of ingredients that provide the cleaning product with a pleasant smell. They are not found in every product, and typically a very small amount can make a large difference in smell. In many cases, the fragrance is the driving factor for why someone decided to buy a specific product.



Fragrances are optional, but if soap has them, a little goes a long way.

A fragrance is a mix of many different substances. These ingredients may be natural compounds (that come from materials like flowers, fruit, trees, plants, or nuts), essential oils, or synthetic compounds. Lavender and lemon are two common fragrances that can be found in cleaning products.



Lavender blossoms and lemon juice are two ingredients sometimes used to make fragrant smelling soaps.

One example of how a fragrance might be created is through a process called distillation, where the material is heated until it becomes a gas, and then the fragrant part is cooled down and condensed back into a liquid to be collected.

One type of fragrance technology is called encapsulation, which means fragrances are enclosed in a type of shell until caused to burst.

Fragrances create a pleasant smell when added to a cleaning product. They can also help cover up odors from any of the other ingredients in the formula.

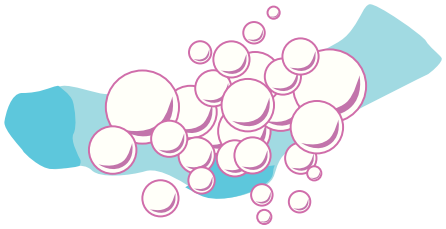
When you wash clothes with a fragranced product, they not only get clean, but the pleasant smell is transferred onto your clothes!

Fragrance makes many people enjoy using the product. This fragrance may smell different in the bottle, in the wash, and on freshly washed clothing. The smell in wash is called the "bloom."

So not only are your clothes clean, but they smell great too!

Fragrances can also be designed to stay on clothes, which allows clothes to smell cleaner and fresher for a long period of time.

How fragrances work



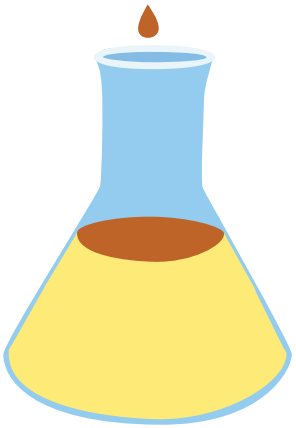
Fragrance can be encapsulated and placed in cleaning solutions.

These capsules can be released over time, giving your clothes a pleasant smell just out of the wash...

...and for a long time after.

Preservatives

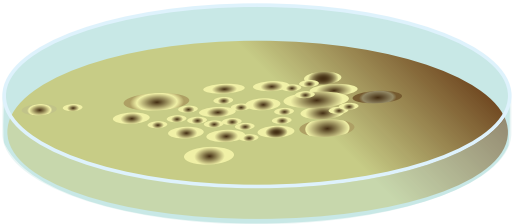
Just like it is important to prevent food from spoiling, cleaning products need to be preserved as well. Adding a small amount of a preservative protects the product from microorganisms.



Preservatives are powerful and you don't need much for soap to remain effective while it sits on your counter.

A preservative is a substance added to a cleaning product in order to make it stable and safe for a longer period of time. Without a preservative, it is possible for bacteria or fungi to grow in the product. This can cause the ingredients in the product (like surfactants and enzymes) to break down and not work as well. Adding a preservative allows a cleaning product to stay on the shelf longer, both in the store and in your home.

With preservatives

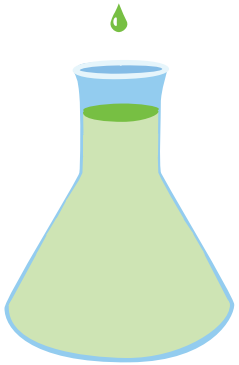


Without preservatives

This is an artist's impression of a petri dish showing what would happen to soap over time if it had no preservatives. Microorganisms could grow in the soap, making it less desirable to use.

pH Adjusters

Every cleaning product needs to be "balanced" to work well and to be safe for your skin. In order to do this, chemists use pH adjusters to make sure the product is balanced and safe for you to use. The amount used depends on the other ingredients in the formula.



pH adjusters make up twice as much of a cleaning solution as preservatives, but that still is not a lot.

What is pH? pH is how we measure if a solution is acidic (like lemon juice) or basic (like baking soda). The pH scale is read from 0 to 14, and tells us if a solution is acidic or basic. Pure water has a pH of 7, which means it's neutral.

Lemon juice is acidic with a pH of about 2. Baking soda is on the other end of the pH scale, with a value of about 9.

pH adjusters are used in cleaning products to raise or lower the pH of a solution, making it either more basic or acidic.

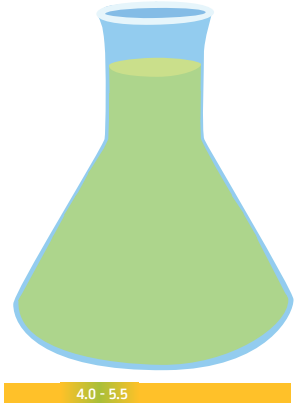
Chemists make sure that the product is effective while balancing safety, in part, by making sure the pH will not be harmful if it touches your skin.

If the pH is less than 7, then the solution is acidic. Lemon juice has a pH around 2. Our skin is slightly acidic, with a pH on average near 5. If our skin comes into contact with a chemical that is too acid it can cause itching or discomfort.

If the pH is greater than 7, then the solution is basic. For example, baking soda has a pH of around 9. If a solution is too alkaline (basic), it can also irritate your skin.

Adjusting the pH helps to keep the product working well. It also affects how the product cleans. For example, each surfactant has a different pH range in which they are the most powerful. Therefore, a chemist may want to adjust the pH to that level.

How to adjust pH

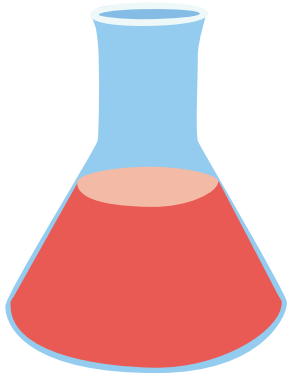


The pH adjusters raise or lower the pH of a solution, making it either more acidic or basic.

Adjusting the pH level of a solution can make it more effective at cleaning. One way of determining the pH of a solution is to use litmus paper, which turns different colors depending on the acidity of the solution.

Dyes

Dyes are sometime used to give a product a color. This can make a product more appealing to a shopper at the store.

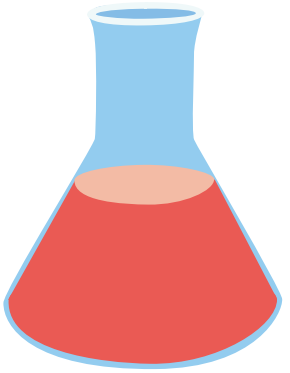


Other ingredients may not add a lot of volume, but they add important characteristics.

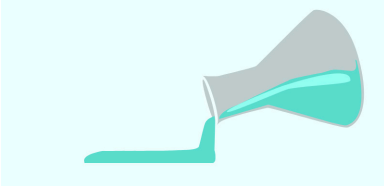
Colorful dried flowers at a market in Morocco add color and fragrance to soaps.

Thickeners

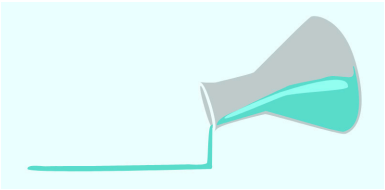
Thickeners give soap the proper viscosity (thickness), making sure it can flow out of a bottle slowly enough to avoid spills. Can you imagine trying to wash your hands with a soap that feels like water? It would run right off of your skin!



Just a little bit of thickener can change the consistency of a cleaning solution.



More thickener

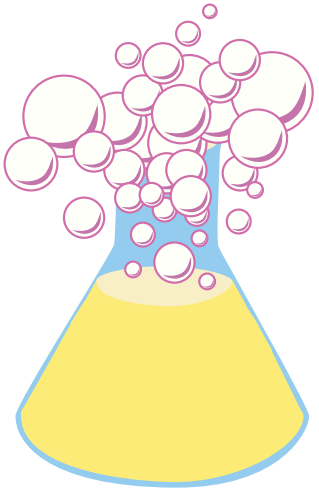


Less thickener

How thick or thin a cleaning solution is can be controlled by using more or less thickener.

Foam Enhancers

Foam Enhancers help create suds or bubbles. While not necessary for effective cleaning, many people feel bubbles show that a product is working.



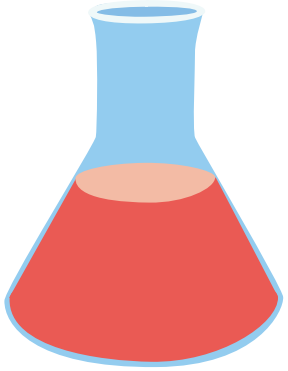
Only a little foam enhancer is needed, too much would quickly cause a mess.

Antibacterial or Disinfecting Ingredients

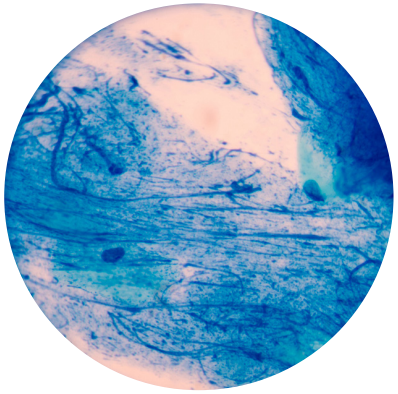
Cleaning washes away germs with any dirt and soil that is removed, but a further reduction of germs can be achieved by using additional ingredients that will actually kill germs.

Antibacterial or disinfecting ingredients can be included in a cleaning or hand hygiene product, or used separately after cleaning. Their use provides a further reduction in germs on our hands or surfaces in our homes. This reduction of germs helps to prevent people from getting sick when commonly used surfaces, such as door handles or our hands, are cleansed using these products. In environments with sick individuals or where food is prepared, this is especially important.

There are many different types of antibacterial or disinfecting ingredients. Depending on the chosen ingredient used in a product, it may be more effective on certain microbes that make us sick like bacteria, viruses or mold.



The type of product and location of use will determine if an antibacterial agent is needed and how much to add.



Microscopic images of Tuberculosis and E Coli, pathogens that can be killed by products with antibacterial or disinfecting ingredients.

The Future of Cleaning

Cleaning technology has come a long way from the ancient Babylonian way of soap-making. Today's cleaning products are the result of thoughtful design, experimentation, and safety testing.

The machines we use to clean have also improved, becoming more sustainable and friendly for our environment. So far we have been able to make new cleaning products that allow us to wash in cold water (saving energy from water heating), wash with less water, and make packaging smaller (to save material and avoid shipping extra weight).

Future scientists will have a great opportunity to continue to create new cleaning design products that will continue to keep us healthy and do even more to help protect human health and the environment. Could that scientist be you?

Through a combination of innovation and federal energy efficiency standards, the efficiency of home appliances has dramatically improved. Today's models use far less energy and water than those of a decade ago. Using less water and colder water means we can save electricity and help support our planet.

Meet the Characters of the Cleaning Court

Did you ever imagine it took so many ingredients to help soaps and detergents do their job well? Well, meet the characters of the Cleaning Court of the Kingdom of Clean. Each has a different role in making the kingdom and court run smoothly.

Some characters, such as Sir Factant and the Master Spy, N. Zyme, are critical to cleaning.

Others, such as Sally Vent, help things run smoothly and protect soaps from deteriorating.

And some of the courtiers, such as the Duke and Duchess of Scent and Count pH Adjuster, make soap more pleasant and effective to use.

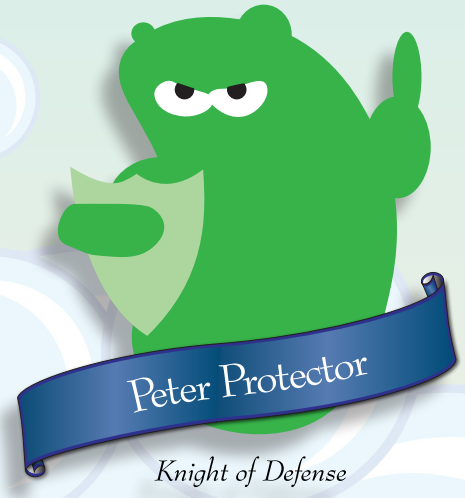
It may be easier (and more fun) for you to remember the ingredients of cleaning products and what they do by learning the names of these important characters and their roles.

Princess of Consistency

Solvent

Keeper of the Scale

pH Adjuster



Knight of Defense

Preservatives and Antimicrobials

Duke and Duchess of Scent

Fragrance

King of the Cleaning Court

Surfactant

Mistress of Chemical Reactions

Enzymes

About Us

The American Cleaning Institute® (ACI) is an organization of companies in the U.S. Cleaning Products Industry, including producers of household, industrial, and institutional cleaning products, their ingredients and finished packaging; chemical producers; and chemical distributors.

Science is at the heart of ACI and its member companies. Established in 1926, ACI is dedicated to serving the growth and innovation of the U.S. cleaning products industry by advancing the health and quality of life of people and protecting our planet.

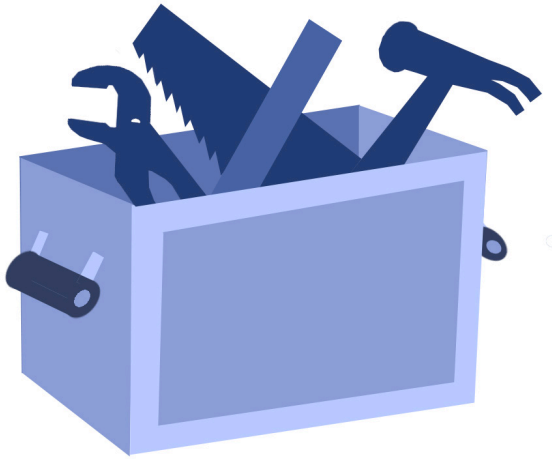
We value sound science and strive to advance public understanding of the safety and benefits of cleaning products. Our mission with this website is to demonstrate how science plays an essential role in our daily lives and from that vantage point inspire children to seek careers in STEM fields. The next generation of scientists and others in the STEM workforce are vital to the continued advancement of health and quality of life around the world.

STEM Toolbox

Are you a Parent? Teacher? Educator? Nanny? Camp Counselor? Or work with kids on a regular basis? Then this toolbox is for you!

We want to make it easy for you to use our material with your kids. Therefore, we have a number of resources for you:

- Science of Soap Activity – Hands-on activity where students "formulate" a cleaning product using colored sand
- Lesson Guide
- Student Handout
- Station Printouts
- Science of Soap Video



To access STEM resources on the web, go to ExplorationClean.org

EXPLORATION CLEAN®

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Contact Us

We would love to hear from you!
Please feel free to send along questions about our material or related to cleaning and cleaning products.
E-mail: technical@cleaninginstitute.org