

The Science of Slime!

By Brian Rohrig

It oozes between your fingers when you pick it up, yet doesn't stick to your skin. It comes in a variety of colors, usually green. At times it acts like a liquid, but at other times it appears to be a solid. It can be made to glow in the dark, or fluoresce under a black light. What is this strange substance? If you guessed slime (or simply read the title), you are correct!

Making slime is an annual tradition for many high school chemistry students. It is also a very popular activity that high school students can do with younger children. There are numerous ways to make slime, but the end result is always a cool concoction that can provide hours of fun, act as a great stress reliever, and provide a platform for learning many important chemical principles.

What is slime?

For our purposes, slime will be defined as any non-Newtonian fluid. If this term sounds hopelessly technical, please read on—it is actually quite simple to understand! To understand what this term means, it is important to examine the theories of Isaac Newton (1642–1727), one of the greatest scientists who ever lived. He made many revolutionary discoveries in the fields of mathematics, motion, and gravity. But he also did a lot of work with fluids.

Newtonian fluids and viscosity

Newton observed that the viscosity of fluids is affected only by temperature. Viscosity refers to a fluid's resistance to flow. The more viscous a substance, the slower it flows. Ketchup is more difficult to pour than water, because ketchup is more viscous. And peanut butter is more viscous than ketchup. It is important not to confuse viscosity with density. Oil is usually more viscous than water, yet oil is less dense and floats on top of water.

If a fluid is heated, it tends to become less viscous, and if cooled, it tends to become more viscous. The colder the temperature, the more viscous the fluid becomes, hence the saying "slower than molasses in January". As the temperature drops, your car may be more difficult to start because the engine oil has become more viscous.

Testing for viscosity

A simple way to test for viscosity is to take two tall graduated cylinders containing equal volumes of two liquids. If you simultaneously drop a ball bearing in each cylinder, the one that takes the longest to fall will be the more

viscous liquid. Another way to test for viscosity is to pour two liquids simultaneously through two small-mouthed funnels. The more viscous fluid will take longer to pass through the funnel.



Non-Newtonian fluids and viscosity

Although the precise definition is somewhat complex, liquids that pour and behave like water, oil and alcohol, for example, are called Newtonian fluids. Some liquids, however, do not obey Newton's model of viscosity, because their viscosity can be affected by factors other than temperature. These fluids are termed non-Newtonian fluids. It's not that Newton didn't understand how fluids behave. It's likely that he never had the opportunity to observe any fluids that behaved otherwise.

The viscosity of a non-Newtonian fluid can generally be affected by the application of what is called a shear stress. Examples of shear stresses are squeezing, stirring, agitating, or applying mechanical pressure to the



surface of a fluid. Any of these things can greatly affect the viscosity of a non-Newtonian substance. But you can agitate water (a Newtonian substance) all day long, and its viscosity will not be affected. Put another way: you can stir a beaker of water for hours and when you are finished, it won't flow any better or worse than if you hadn't stirred it.

Shear thinning

There are two basic behaviors of non-Newtonian fluids. One type is termed shear thinning. Shear-thinning fluids decrease in

viscosity when a shear stress is applied. A familiar example of a shear-thinning substance is ketchup. When the ketchup won't come out of the bottle, what do you do? You whack the bottom of the bottle with your hand until it comes out. Whacking the bottle makes the ketchup move, it becomes less viscous, and then it flows out of the bottle faster. Other shear-thinning fluids include margarine, gelatin, mayonnaise, honey, mustard, shaving cream, and Elmer's glue. The ink used in astronaut pens, which can write upside down, is a shear-thinning fluid.

Sometimes these fluids immediately return to their original "thicker" condition when you stop stirring, but for other fluids it will take some time. Ketchup, for example, will take awhile, but will eventually return to its original state.

Shear thickening

The second type of behavior observed in non-Newtonian fluid is shear thickening. Shear-thickening fluids increase in viscosity when a shear stress is applied. Quicksand is an excellent example of a shear-thickening substance. If you struggle while caught in quicksand, it will become more viscous, strengthening its hold on you and making it more difficult to escape. If trapped in quicksand, it is best simply to relax, since your body is less dense than quicksand and will easily float in it.

It is easy to make homemade quicksand. Add some water to cornstarch until no dry powder remains. It will look like a liquid. But if you

place a glob of it in your hand and squeeze, it will become a solid! When you stop squeezing, it will become a liquid again.

If you pour some in a cup and then poke at it quickly with your finger, your finger will bounce off. But if you poke it slowly with your finger, you can easily touch the bottom of the cup. The viscosity of the cornstarch-water mixture increases as the shear stress increases.

The military and body armor manufacturers have actually had some success exploiting this behavior to develop more comfortable "liquid" body armor. This experimental soft body armor—a combination of the bulletproof material Kevlar and a shear-thickening liquid—hardens and resists when hit by a bullet or sharp object.

Another example of a shear-thickening substance is Silly Putty. If Silly Putty is pulled apart slowly, it can be stretched a great distance. But if you attempt to pull it apart quickly, it will break. A large shear stress makes it more viscous, causing it to break easily. If you hit a hunk of Silly Putty quickly with a hammer, the hammer will bounce off. Yet, a ball of Silly Putty can easily be flattened with your thumb if the pressure is applied slowly. In essence, large shear stresses cause the Silly Putty to become so viscous that it acts like a solid.

The synovial fluid in the joints of your elbows and knees is shear thickening. Normally this fluid is not very viscous, allowing the joints to move freely. However, a sud-



Slime made from borax and white glue shear thickens.

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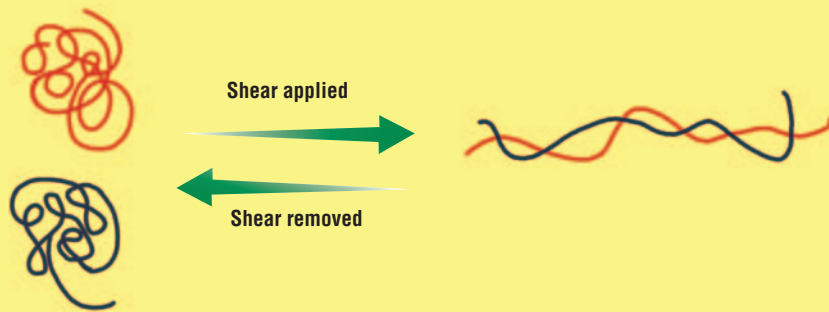
den stress to these joints, such as from a twist or a blow, will cause this fluid to suddenly become much more viscous. This sudden increase in viscosity will cushion the blow, protecting the joint from further injury.

As was true for shear-thinning fluids, some shear-thickening fluids take awhile to return to their original state after stirring,

while others do it immediately. If a ball of Silly Putty is left to set on the table for a few minutes, it will flow into a puddle, becoming less viscous. Silly Putty, therefore, is actually a liquid, since it will eventually assume the shape of its container. Most types of slime are shear-thickening fluids, as you will see when you make your own slime.

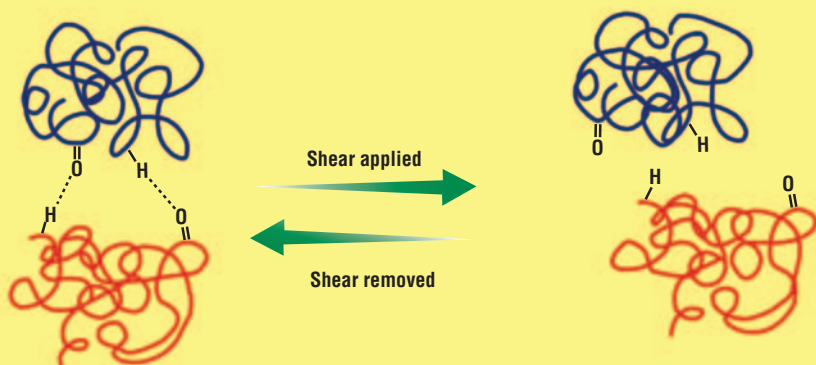
Two simple polymer cases for shear thickening and shear thinning.

Shear thickening



Applying a shear force can cause random coils of a polymer to unwind and become entangled with each other, raising the viscosity. When the force is removed, the polymer returns to the favored random coil state.

Shear thinning



Applying a shear force breaks hydrogen bonds (or other secondary structures) and allows the polymer strands to flow more easily past each other. When force is removed, the hydrogen bonds between the polymer strands form again.

Polymers—Giant molecules

Most types of slime, including Silly Putty and the cornstarch–water slime, are examples of polymers. A polymer is composed of very large chains of molecules that are composed of repeating units known as monomers. A single polymer molecule may comprise hundreds of thousands of monomers. The monomers may be identical, or they may vary. Common synthetic polymers are rubber, plastic, and nylon. Common natural polymers are starch, DNA, and some proteins.

Cross-linking—The key to slime formation

One variety of slime that can be easily made in the lab involves the addition of a saturated solution of sodium tetraborate decahydrate ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$), commonly known as borax, to a solution of white glue and water. White glue is an example of a polymer—it is made of long chains of polyvinyl acetate molecules. These chains slide past one another fairly easily, enabling the glue to be poured from the bottle. But when the borax is added to the glue, a highly viscous, very resilient form of slime is formed. This slime can be stretched, pulled, beaten, and shaped.

This type of slime forms as a result of cross-linking between the protein molecules of the glue and the borate ions ($\text{B}(\text{OH})_4^-$) of the borax solution. Cross-linking involves the formation of bonds that tend to link together large molecules in such a way that they are no longer free to slide past one another. The large protein molecules in the glue already have trouble moving past each other; the glue has to be squeezed from the bottle, it doesn't gush out. The borate ions link the big molecules to each other, making even bigger molecules, and it becomes even more difficult for them to slide past one another. The result is a tangled mass that we know and love as slime. ▲

ACTIVITY

How to make slime!

To make a great variety of slime, use the following procedure. The slime forms because of cross-linking between the protein molecules of white glue and the borate ions of borax.

1. Make a saturated borax solution by adding 1 g of borax to 25 mL of water. Stir thoroughly until the borax has completely dissolved.
2. In a disposable plastic cup, add 50 mL of white glue and 50 mL of water. Stir thoroughly. (You may use more or less glue, as long as you maintain a 50:50 ratio between the glue and water.)
3. If desired, add a few drops of food coloring and stir thoroughly.
4. Using an eyedropper, add the borax solution a few drops at a time to the glue–water mixture and stir thoroughly with a stirring rod. The slime will collect on the stirring rod. Continue adding the borax solution until most of the glue–water mixture has turned into slime. Be careful not to add too much borax solution, or the slime will become too stiff. A good rule of thumb is to quit adding the borax solution when there is still a little glue–water mixture left in the bottom of the cup. This way, you will not add too much borax.
5. Remove the slime from the stirring rod with your fingers and work it with your hands until it is no longer sticky. The more you work it with your hands, the nicer its consistency. Store it in a Ziploc bag.
6. The excess borax solution can be poured down the drain and the cups disposed of in the trash.

Try a variation! To make fluorescent slime that will fluoresce brilliantly under a black light, prepare some fluorescent water to use in place of the ordinary water that is added to the glue. Prepare the fluorescent water by removing the tip from a fluorescent highlighter and placing it in a beaker containing up to 500 mL of water. After a few minutes, the water will be highly fluorescent. When this water is used to make slime, the slime will be highly fluorescent under a black light.

Brian Rohrig is a chemistry teacher at Jonathan Alder High School in Plain City, OH. His newest book: *Pure Slime—50 Incredible Ways to Make Slime Using Household Substances*, can be purchased at www.fizzbangscience.com.



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