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*Image courtesy of Tamaryin Godinho*

# Beyond solids and liquids: the science of slime

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Is it a solid? Is it a liquid? It's slime! Make slime to explore viscoelasticity and then complete a material science design challenge.

## Introduction

Matter is conventionally classified into three fundamental states: solids, liquids, and gases. Nevertheless, it is clear that there are some materials that do not fit perfectly into only one category, and Activity 1 encourages students to explore this.

One material that does not fit neatly into any of these categories is one that students are probably familiar with: the rubbery polymer slime! In Activity 2, students make slime with safe ingredients and explore the property of viscoelasticity. This introduces the idea of classifying materials according to their response to stress forces.

Finally, Activity 3 presents a team challenge, where students need to tailor their polymer to a particular application.

# Activity 1: Classifying materials

It is commonly accepted that solids have fixed shapes and liquids flow. Upon observing everyday items, like toothpaste, dual behaviour becomes apparent: under stress, such as pressure, it deforms, showing liquid-like characteristics; yet, if the stress is insufficient, it retains its shape like a solid. Accurately measuring the interplay between solid and liquid-like properties in a material is essential for determining its suitability in various applications.

**Estimated time**: 30 min
**Target age**: 9 to 16 years old.

## Materials

- Objects with different stress responses (e.g., wood, metal, glue, ketchup, polystyrene, plasticine, playdough, squeezy rubber balls, gummy sweets, jelly, bubble gum, foam, sponge toothpaste…)
- Materials assessment charts (one per student/group for each material)
- Materials summary table
- Paper and a pen
- The viscoelasticity infosheet

## Procedure

1. Recap what the students know about solids, liquids, and gases.
2. Present one of the materials that doesn't neatly fit these categories, such as plasticine, and ask students what kind of material they think it is and why. Perhaps not all materials are easily classified as solid or liquid.
3. Hand out the materials assessment charts (one per group) and distribute the objects, or let students select some from the front desk. Students can work individually or in groups.
4. Students should use the assessment charts to try to determine whether their objects are solid or liquid by touching, stretching, and trying to deform them, and fill in the assessment table.
5. At the end, each student or group should fill out the materials summary table.
6. Have a class discussion where students compare their results. Do they reach the same conclusions? It should be clear that, based on their observable properties, some materials are easily classified either as solids or as liquids, but there are others that seems to have properties of both.
7. Hand out the viscoelasticity infosheet to place the observations in context and set the scene for the next activity.

## Discussion

For students aged 12 and over, further discussion can be addressed on how temperature could alter the viscoelastic properties and how they would describe the effort that needs to be applied to deform each material (hard or soft effort, slow or fast, big or small area of effort application).

Materials with different mechanical responses

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# Activity 2: Create your own slime

Rubbery polymer slime is a popular toy and making it is a fun experiment. It is formed through the chemical reaction between polyvinyl alcohol (PVOH) polymer molecules derived from the polyvinyl acetate (PVA) molecules present in school glue, baking soda, and borate anions present in contact lens solution.[1]

*Image courtesy of Tamaryin Godinho*

In this activity, students can make slime from scratch with easy-to-find and safe ingredients. By slightly varying the proportions of the reagents, it is possible to obtain materials with different behaviours, from viscous liquid to elastic solid. This provides an opportunity to explore chemical reactions, polymers, and mechanical characterization.

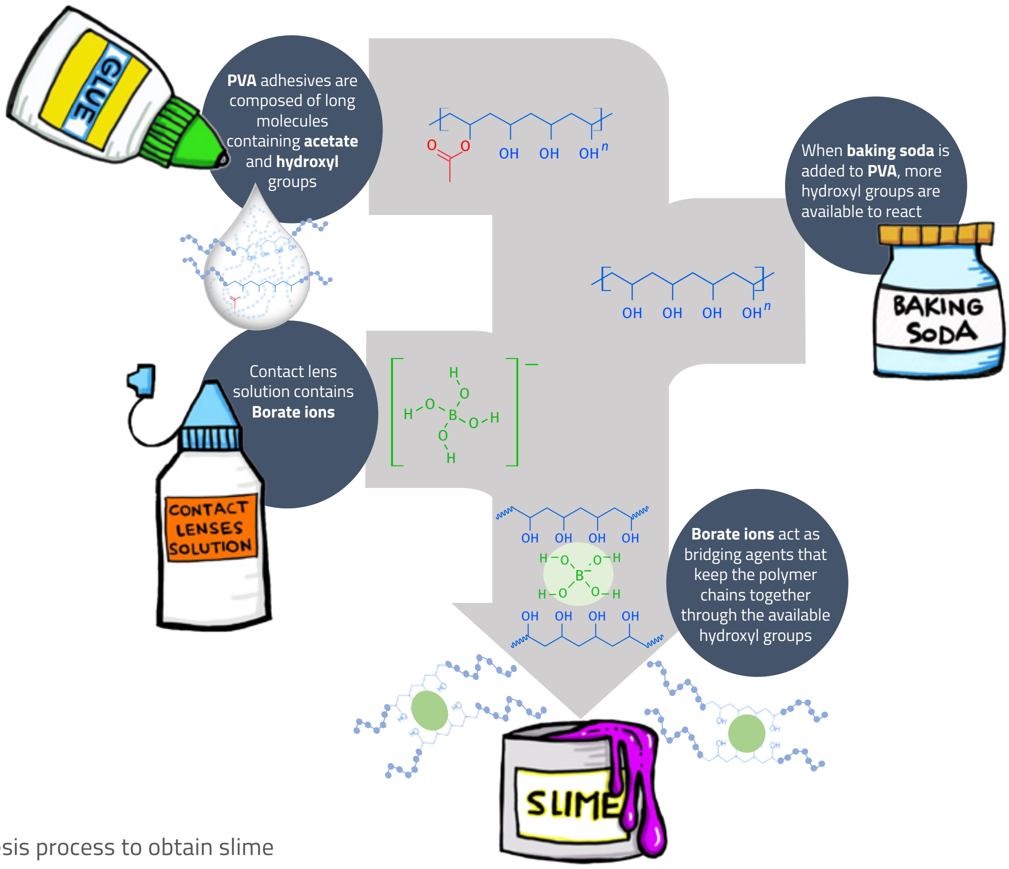
**Estimated time:** 60 min

**Target age:** This activity can be performed at different depth levels with students from 9 to 16 years old.

## Safety notes

Students should wash their hands at the end of the experiment. If they have sensitive skin or cuts on their hands, they should wear disposable gloves.

## The chemistry of making slime



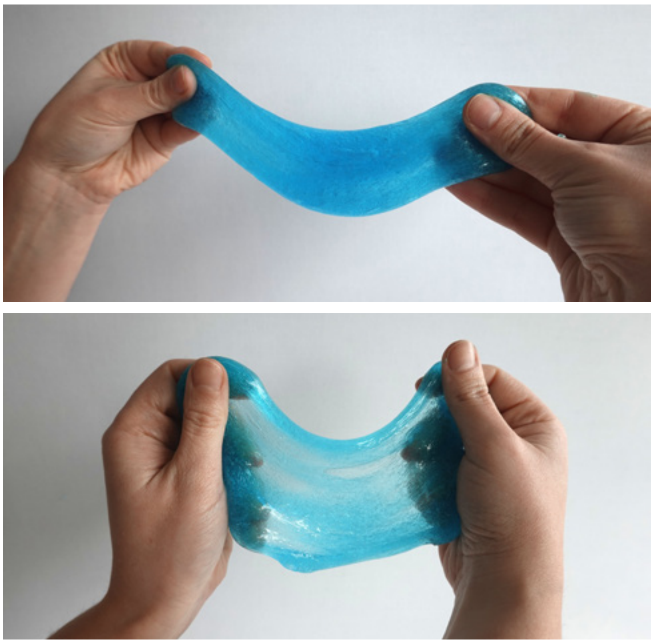


Synthesis process to obtain slime

*Image courtesy of the authors*

## Materials

- Chemistry of slime infosheet
- Activity 2 worksheet
- Materials assessment tables (one per group)
- School glue (composed of polyvinyl acetate dispersion in water)
- Sodium bicarbonate
- Contact lens solution (that contains boric acid, the essential ingredient)
- 100 ml beaker or glass
- Two different syringes, falcon tubes, or measuring cylinders (for the glue and the contact lens solution)
- Stirring rod or spatula
- Food colouring or a water-soluble dye, such as fluorescein (optional)
- Containers with caps to save the slime for several days



Slimy material

*Image courtesy of Tamaryin Godinho*

## Procedure

Before starting, four groups are required, preferably composed of two to three students each. By following the guide, they will obtain materials with different mechanical responses by using different proportions of reactants.

1. Introduce the activity and hand out the chemistry of slime infosheet.
2. Then hand out the Activity 2 worksheets. Have each group highlight or underline the table row that applies to their group.
3. Using the syringe, students measure 10 ml of glue and put it in the beaker.
4. They then add the amount of water indicated in Table 1 for their group to the same beaker.
5. A pinch of sodium bicarbonate is added, and the solution is stirred to dissolve it.
6. Optional: A small drop of food colouring or dye can be added at this stage if desired. However, be aware that this can change the properties of the material, so only a small amount should be added, and the same dye should be added to all the samples. Slime batches of different colours should not be directly compared.
7. They then add the amount of contact lens solution indicated in table 1 for their group.
8. The mixture is stirred vigorously for several minutes to ensure the components are thoroughly mixed.
9. After waiting (without further stirring) for 5 min, students can take the slime out of the container and play with it for a few minutes to feel its properties, before rolling it into a ball.
10. They should then analyze its properties using the materials assessment chart and then add their slime to the summary table.
11. If students want to add one drop of food colouring or dye, they should register the properties before and after its addition.
12. After 30 min, the materials are collected, and the spreading test is performed. Each material is rolled into a ball and placed simultaneously on a table. After some minutes, the materials will spread on the surface under gravity at different velocities, showing different spreading areas.
13. As a class, compare the results for the different materials (**1–4**). What is the effect of adding a higher proportion of contact lens solution to the formulation? Or a higher proportion of water?

| Group | Glue | Water | Contact lens solution |
|---|---|---|---|
| **1** | 10 ml | 0 ml | 3 ml |
| **2** | 10 ml | 0 ml | 5 ml |
| **3** | 10 ml | 5 ml | 3 ml |
| **4** | 10 ml | 5 ml | 5 ml |

Table 1: Reactant amount for the slime synthesis.

## Discussion

The slime is deformable and very flexible. The mechanical response depends on the type of stress applied and the timescale considered. When left undisturbed, it flows, behaving like a viscous liquid, but when subjected to constant stress, like when you roll it into a ball with your hands, it can maintain its shape. If you hit it hard enough, like throwing it to the ground, it doesn't spread on the surface, acting more like an elastic solid.

Students aged 12 and above can also consider how other properties, such as flexibility, stickiness, hardness, and re-boundability, are affected by the different formulations.

## Activity 3: Application challenge!

After the experience acquired on synthesizing and testing different slime formulations, students are challenged to design a slime material with a particular balance between viscous and elastic behaviour that makes it suitable for one of two proposed applications.


*Image courtesy of Tamaryin Godinho*

**Estimated time:** 90 min
**Target age:** >12 years old.

### Safety notes

As Activity 2.

### Materials

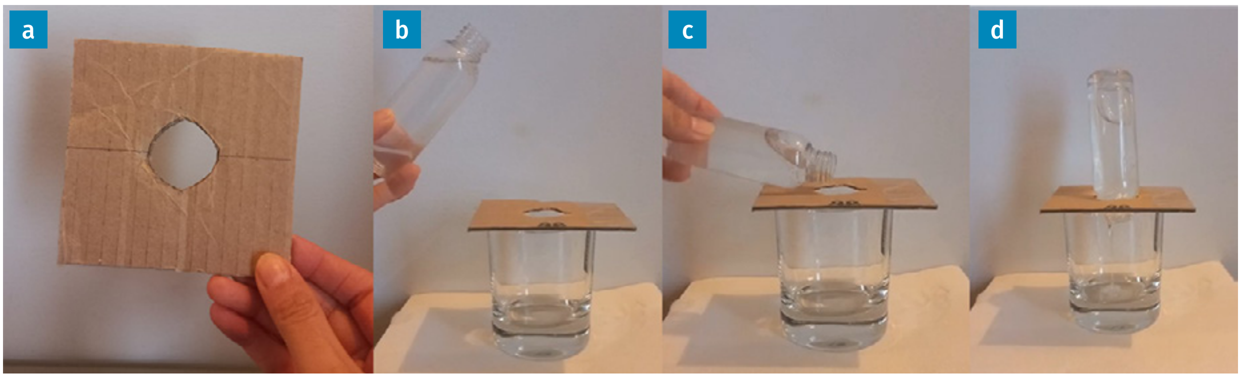
- Activity 3 worksheet
- School glue (composed of poly vinyl acetate dispersion in water)
- Sodium bicarbonate
- Contact lens solution (which contains boric acid, the essential ingredient)
- 100 ml beaker or glass
- Two different syringes, falcon tubes, or volumetric tubes (for the glue and the contact lens solution)
- Stirring rod or spatula
- Food colouring or a water-soluble dye, such as fluorescein (optional)
- Containers with caps to save the slime for several days
- Balance
- Ruler to measure the bouncing height
- 50 ml jar, with 1.5 cm diameter opening or hole in the cap (one per group doing the sauce challenge)

### Procedure

1. Divide the students into groups of three.
2. Hand out Activity 3 worksheets and present the task to design a slime material with properties that make it suitable for one of the following applications:
   - **Jelly sauce:** for a food application, a jelly sauce should be pourable from a container with a small opening.
   - **Bouncing ball**: for a fun application, a ball of material should bounce as high as possible.

   They should use the same basic slime synthesis procedure as for Activity 2, along with the information learned about how changing the recipe affects the properties.

### Flowability test




**a** One piece of cardboard can be used as a support for the bottle.
**b** The container is filled with the material to test.
**c** The bottle is turned over to pour the material.
**d** The bottle is placed vertically while the pouring time is registered.

*Image courtesy of the authors*

3. Optional: all the students discuss, propose, and define experimental testing procedures (e.g., the number of experiments to be considered in the final decision). Otherwise, introduce the testing procedures given in the steps 4 and 5.
4. To test the **jelly sauce**, a 50 ml jar or bottle is filled with the material, which is then turned upside down over a larger container with a cardboard support to hold it in place. A stopwatch is used to time how long it takes for the bottle to empty. Alternatively, the containers can be weighed before the experiment and again after a set time, such as 2 min. If the challenge is run like a competition, the group with the shortest time to drain the bottle, or the most sauce in the second container after the set time, wins.
5. To test the **bouncing ball,** 20 g of the material is formed into a ball and dropped from a height of 1 m. By recording a video with a phone from a frontal position, using a metre scale on the wall as a reference, it can be determined how high the ball bounces. For a competition format, the highest bounce wins.
6. Give the students 60 min to produce, test, and refine the formulation of their materials following the instructions in the guide. The students then all come together and the materials are tested in front of the class.
   Note: the slime tends to stiffen with time, so the final materials should ideally be tested a similar time after they are produced.

*Image: Alessandro e Damiano/Wikimedia, CC BY 4.0*

## Discussion

Encourage students to reflect on the viscoelastic properties of everyday materials, especially foods. Can they list substances that are stretchy, viscous, bouncy, and so forth? What about traditional foods? In which cases have these properties been deliberately designed for a particular function or edible property (like chewiness)?

Ketchup is a particularly interesting example to consider, since it is a non-Newtonian fluid that shows shear-thinning properties, which is why it doesn't easily pour out of the bottle but does when you shake the bottle (see the resources for more information).

Overall, these activities should provide an opportunity to explore the properties of materials; introduce field of materials design; and the scientific method, for example, designing experiments, changing one variable at a time, and defining tests for relevant properties. «

# References

[1] Experiment on how to create slime with PVA: https://edu.rsc.org/experiments/pva-polymer-slime/756.article

# Resources

- Read about materials science and its engineers.
- Discover the secrets of the viscosity of fluids.
- Learn about the science of ketchup and its unlikely physics.
- Watch a video about viscoelasticity.
- Understand the science of slime.
- Engage your students in this activity to create Oobleck.
- Watch a video on the science of corn starch and water.
- Experiment with phase transitions in water: CERN (2021) States of matter & phase transitions. *Science in School* **51**.

- Extract rubber from the roots of the Russian dandelion: Göbel M, Gröger M (2018) Turning dandelions into rubber: the road to a sustainable future. *Science in School* **43**: 31–36.
- Explore the processes materials science engineers use when selecting fabrics by designing a parachute: Miranda I (2023) How do materials science engineers choose fabrics for parachutes? *Science in School* **61**.
- Read about how shark skin has inspired designers and engineers: Wegner C, Dumcke R, Tönnesmann N (2017) Design inspiration: the secrets of shark skin. *Science in School* **41**: 19–23.
- Discover how to make sure oil and water stay mixed: Chiappisi L (2019) Limoncello and the science of emulsions. *Science in School* **48**.
- Read an article about the environmental effects of food packaging: Barlow C (2022) Plastic food packaging: simply awful, or is it more complicated? *Science in School* **56**.
- Encourage students to explore the principles of form and function by engaging with biomimetic design: Toro S (2021) Biomimicry: linking form and function to evolutionary and ecological principles. *Science in School* **52**.

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