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Demonstration

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Demonstration of the Coagulation and Diffusion of Homemade Slime Prepared Under Acidic Conditions without Borate

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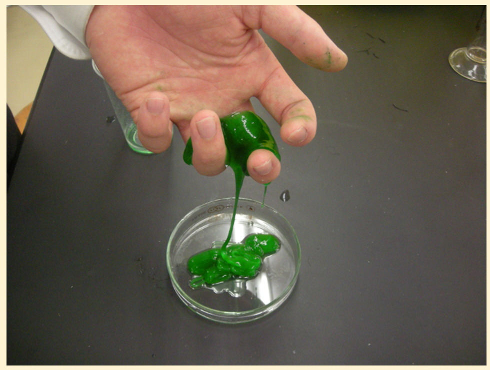
Supporting Information

ABSTRACT: Poly(vinyl alcohol) (PVA) precipitates in many kinds of aqueous salt solutions. While sodium sulfate, a coagulant for PVA fiber, precipitates PVA to yield a white rigid gel, coagulation of PVA with aluminum sulfate, a coagulant for water treatment, yields a slime-like viscoelastic fluid. One type of homemade slime is prepared under basic conditions with borate. The method reported in this paper is carried out under acidic conditions with materials that are used for water treatment. Through this demonstration, students can learn about chemical interactions through the coagulation and diffusion of slime. This demonstration can be carried out in 30 min.



KEYWORDS: *High School/Introductory Chemistry, Polymer Chemistry, Problem Solving/Decision Making, Applications of Chemistry*

INTRODUCTION

Despite its stickiness, both adults and children have been fascinated with slime; slime has been prepared at science events, school, and homes for fun and educative purposes. One type of homemade slime can be prepared using poly(vinyl alcohol) (PVA) and sodium tetraborate (borax) under basic conditions.[1,2]

Cross-linking reagents are used to convert a linear polymer into a three-dimensional-network polymer. Cross-link of linear polymer often results in an insoluble and rigid polymer. Most three-dimensional-network polymers cross-linked with strong bonds, e.g., covalent and ionic bonds, are not fluid. For instance, the following cross-link reactions yield rigid gels: (1) bivalent cations cross-link sodium alginate through ionic bonds to form a rigid hydrogel; (2) formaldehyde cross-links with PVA by covalent bonds to yield a rigid gel.

On the other hand, polymers cross-linked with weak bonds, e.g., hydrogen bonding and bonding via van der Waals forces and hydrophobic effects, often yield a labile network that is fluid or a sol−gel reversible hydrogel. For instance, gelatin sol transits to gel cross-linked with hydrogen bonds and forms a helical structure. This hydrogel again transits to sol at high temperature.

Although most three-dimensional-network polymers are not fluid, the addition of sodium tetraborate to PVA solution results in a viscoelastic fluid owing to the formation of weak bonds to the OH groups of PVA.

In this study, we examined a new preparation method for homemade slime. In our approach, we focused on coagulants used for treating wastewater and wet spinning, which is a manufacturing process for creating fibers. Sodium sulfate is a well-known coagulant for PVA, and it is used in the coagulation bath of PVA before wet spinning of vinylon fibers. Aluminum sulfate is used in water treatment. Other salts such as sodium chloride, calcium chloride, and magnesium sulfate also coagulate PVA, depending on the zeta potential. The zeta potential refers to the electrostatic potential on the surface of a colloid, and colloids with low zeta potentials tend to coagulate. The relative power of coagulation depends on the kind of salt used as the coagulant.[3] Although the coagulation mechanism has been discussed in many reports,[4] it is not easy to understand for high school students. In this context, we demonstrate the utility of PVA coagulation in preparing a slime-like viscoelastic fluid.

The demonstration of coagulation and diffusion of the slime-like viscoelastic fluid offers a simple method for teaching about formation and dissociation of chemical bonds. Through this demonstration, students can learn about chemical bonds. Moreover, viscoelastic fluids form an important material in various sciences.[5] With our approach, students are also made aware of the different coagulation properties of different salts.

PREPARATION FOR DEMONSTRATION

Preparation of Various Cross-Linked Polymers

Prior to the demonstration of the coagulation of PVA with aluminum sulfate, the students were asked about the various kinds of chemical interactions. To learn about various chemical

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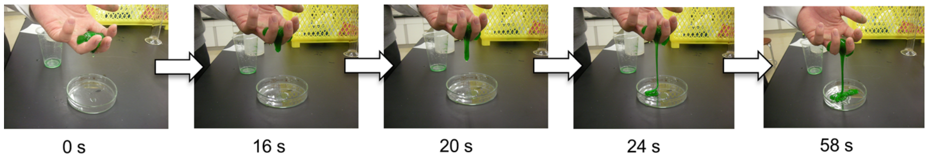

Figure 1. Slime-like viscoelastic fluid. Coagulation of PVA with $Al_2(SO_4)_3$ yields slime-like viscoelastic fluid. Green food coloring was added to PVA beforehand to yield green slime.

bonds, students prepared various types of well-known hydrogels (see Supporting Information). First, as an example of an ionic bond, sodium alginate was cross-linked with calcium chloride to yield a rigid hydrogel. Alginate is known as a strong chelator of divalent cations due its special structure, which can be illustrated via the "egg-box model."[6] Second, as an example of strong cross-linkage, PVA was cross-linked with glutaraldehyde to yield a rigid gel. Third, as an example of intermolecular hydrogen bonding, we prepared gelatin solution. Gelatin is a denatured form of collagen and provides a thermosensitive sol−gel reversible hydrogel. Cooling a gelatin solution increases the stability of the hydrogen-bond-cross-linked polypeptide chains, leading to the formation of a helical structure. In the study, the students examined the gelation of gelatin hydrogel. Fourth, as a viscoelastic fluid, a PVA−borate system slime was prepared. It is believed that sodium tetraborate chelates PVA through hydrogen bonds[1] or reversible covalent bonds[7] to form "di-diol" complexes to yield slime.

The different cross-links of a linear polymer yield different gel features; the type of cross-linking affects the gel features. In the study, students were asked to recognize the chemical bond in question via tactile examination (via touch) of various gels. The students made hypothesis related to how the chemical interaction would affect the tactile of the gel. The hypothesis was "weak cross-linkage will make slime". The preparation of various cross-linked polymer takes one 50 min class period.

Coagulation of PVA

To initiate the coagulation of PVA, 12 mL of each of the various salt solutions (20%) was added to 10 mL of commercially available PVA laundry starch (to which we added green food coloring in order to obtain green slime) in a plastic cup. PVA laundry starch with 8% PVA was used in this experiment. The mixtures were vigorously stirred with a chopstick to yield precipitants. After washing the precipitants with deionized water, the students tactilely examined them (Figure 1). The coagulation conditions observed with each of the salts are summarized in Table 1. The properties of the precipitants listed in Table 1 (sample nos. 1 to 5) were compared with those of the slime prepared with PVA laundry starch and sodium tetraborate (sample no. 6, Table 1).

Table 1. Coagulation Conditions of PVA

No.	Salt[a]	Precipitant Properties
1	NaCl	low viscosity fluid
2	$CaCl_2 \cdot 2H_2O$	low viscosity fluid
3	$Na_2SO_4 \cdot 10H_2O$	rigid
4	$MgSO_4 \cdot 7H_2O$	low viscosity fluid
5	$Al_2(SO4)_3 \cdot 14{-}18H_2O$	slime-like viscoelastic fluid
6	$Na_2B_4O_7 \cdot 10H_2O$	slime

[a] A volume of 12 mL of 20% salt solution was added to 10 mL of PVA laundry starch.

Dissociation of Slime

The coagulation of PVA in water with $Al_2(SO_4)_3$ proceeds under acidic pH (sample no. 5, Table 1). A shift in the pH from acidic to basic reduces the coagulation force, thereby leading to dissociation of the slime. To demonstrate this process experimentally, we added $NaHCO_3$ (sat) to slime no. 5 (Table 1) placed in a Petri dish, which caused the slime to divide into many small lumps along with the production of CO_2 bubbles.

■ RESULTS AND DISCUSSION

Coagulation of PVA

In general, coagulation proceeds by the neutralization of negatively charged colloids by an inorganic salt (Figure 2), which accelerates coagulation and flocculation of the colloid by van der Waals forces. The coagulation proceeds via intermolecular interactions between the coagulant and polymer colloid, e.g., dipole−dipole, dipole-induced dipole−dipole, and dipole-induced dipole−dipole-induced−dipole interactions.

With regards to our study, from Table 1, we note that coagulation with sodium sulfate afforded a white rigid gel. In contrast, coagulation with magnesium sulfate, sodium chloride, and calcium chloride yielded low-viscosity precipitants. Coagulation with aluminum sulfate resulted in a slime-like viscoelastic fluid.

Aluminum sulfate is the best coagulant among all the salts studied because it exhibits a specific behavior in water. Aluminum salts, i.e., aluminum sulfate and polyaluminum chloride (PAC), form positively charged polynuclear aluminum−hydroxo complexes in water, and the complexes neutralize negatively charged colloid surfaces. The electrically neutralized colloids coagulate via van der Waals forces and sediments. A primary feature of polynuclear aluminum−hydroxo complexes is gelatin-like tactility. This feature of the complex may be one of the reasons why PVA coagulated by aluminum sulfate affords a slime-like viscoelastic fluid.

Dissociation of Slime

Adding $NaHCO_3$ (saturated) to slime caused the slime to divide into many small lumps along with the production of CO_2 bubbles (Figure 3). The pH is an important factor for coagulation, because a shift in the pH changes the zeta potential. The slime diffused via the neutralization reaction described by eq 1.

$$Al_2(SO4)_3 + 6NaHCO_3 \rightarrow 2Al(OH)_3 + 6CO_2 + 3Na_2SO_4 \quad (1)$$

The students learned about chemical interactions through the coagulation and diffusion of borate-free slime-like viscoelastic fluid. The demonstration of the coagulation and diffusion of viscoelastic fluid can be carried out in 30 min.

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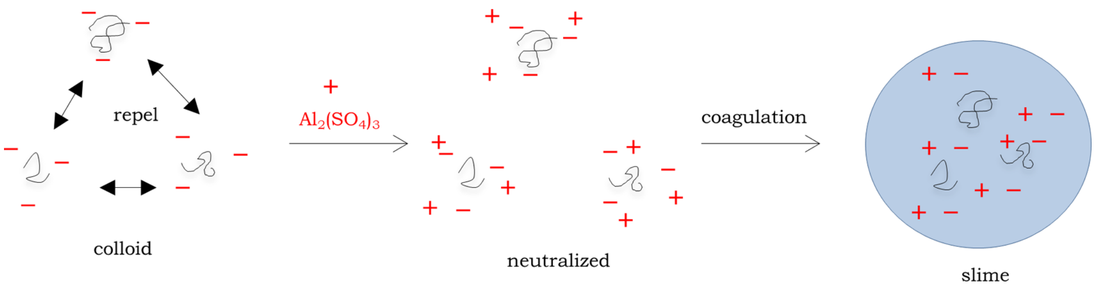

Figure 2. Coagulation mechanism.

Figure 3. Slime (No. 5, Table 1) dissociated with sat. $NaHCO_3$ to form small lumps with the release of CO_2.

■ HAZARDS

Here, we mention that as per safety data sheets (SDSs), the salts used in this study are categorized as causing "serious eye damage/eye irritation," except for magnesium sulfate. Experimenters should avoid contact of aluminum sulfate with the eyes. Further, hands should be washed with water after the demonstration. Wearing protective grooves and clothing are recommended.

■ CONCLUSION

We demonstrated the preparation of a borate-free slime-like viscoelastic fluid under acidic conditions via a coagulation mechanism and by using reagents that are utilized for water treatment. This demonstration aided students to learn about various intermolecular forces and chemical bonds through the coagulation and diffusion of slime.

After the demonstration, the students discussed the optimization of the slime-making conditions in the context that the coagulation efficiency depends on pH and other factors. They presented their experiences of slime-making at a conference organized by the Fukuoka Society of Environmental Education. They discussed the mechanisms of slime-like viscoelastic fluid formation at the conference. The students subsequently began to investigate their originally prepared slime via their discussion of chemical bonds and the chemical structures of cross-linked polymers.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00272.

Detailed information regarding the experimental procedure and instructor notes (PDF, DOC)

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Notes

The authors declare no competing financial interest.

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