LESSON 29: Solid or Liquid?

ESTIMATED TIME **Setup:** 5 minutes | **Procedure:** 10–15 minutes

- **DESCRIPTION**
  Mix cornstarch and water to demonstrate the properties of a non-Newtonian fluid.

- **OBJECTIVE**
  This lesson demonstrates the properties of a non-Newtonian fluid. Students experiment with a new substance to determine its state of matter. The lesson can be simplified to address the basic states of matter and the obstacles that can arise when classifying matter.

- **CONTENT TOPICS**
  Scientific inquiry; states of matter; properties of matter (viscosity); mixtures; force

- **MATERIALS**
  - ❑ Box of cornstarch (16 oz)
  - ❑ Water
  - ❑ Large bowl
  - ❑ Large spoon
  - ❑ Cake pans
  - ❑ Plastic bag (for dispoal)

Always remember to use the appropriate safety equipment when conducting your experiment. Refer to the ***Safety First*** section in the ***Resource Guide*** on pages 421–423 for more detailed information about safety in the classroom.

Jump ahead to page 358 to view the Experimental Procedure.

NATIONAL SCIENCE EDUCATION STANDARDS SUBJECT MATTER

This lesson applies both *Dimension 1: Scientific and Engineering Practices* and *Dimension 2: Crosscutting Concepts* from "A Framework for K–12 Science Education," established as a guide for the updated National Science Education Standards. In addition, this lesson covers the following Disciplinary Core Ideas from that framework:

- PS1.A: Structure and Properties of Matter
- ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World (see ***Analysis & Conclusion***)

OBSERVATION & RESEARCH

BACKGROUND

Matter exists primarily as a solid, liquid, or gas on the earth. **Solids** have a definite volume and a definite shape. Examples of solids are chairs, books, dishes, and cornstarch. **Liquids** have a definite volume but no definite shape. Examples of liquids are water and orange juice. **Gases** have no definite shape and no definite volume. Examples of gases are the oxygen we breathe and the helium that fills balloons.

Along with differences in shape and volume, the different states of matter have other unique properties. Liquids and gases are considered fluids. A **fluid** is any substance made up of particles that flow or move freely. A fluid easily changes shape when a force is applied. For example, if you push on a balloon filled with gas, you can easily change its shape. Likewise, if you push on a balloon filled with water, you can change the water balloon's shape as well.

The "thickness" of a fluid is described by a property called viscosity. **Viscosity** is a measure of a fluid's (generally a liquid's) resistance to flow. The higher the viscosity of a fluid, the slower it will flow. For example, honey has a high viscosity; therefore, it flows very slowly when poured out of a container. Honey is considered a viscous liquid—one with a high viscosity.

Most fluids are classified as Newtonian fluids (after the famous scientist and mathematician Sir Isaac Newton). When temperature remains constant, a **Newtonian fluid** has a viscosity that remains constant, regardless of any

applied force or the rate of flow. Thus, a Newtonian fluid will continue to flow and act in its usual manner no matter what forces are applied. Water is an example of a Newtonian fluid. No matter how fast you stir, pour, or disturb the water, it will have the same viscosity.

On the contrary, a **non-Newtonian fluid** is one that has a viscosity that varies based on the force applied or how fast an object is moving through the liquid. Depending on the exact non-Newtonian fluid, it may become more or less viscous when a force is applied. When a force is applied to some non-Newtonian fluids, they exhibit properties of a solid. For other non-Newtonian fluids, exerting a force makes it flow quicker or easier. Examples of non-Newtonian fluids are ketchup, yogurt, gravy, and cornstarch "paste."

As you will see in this lesson, a non-Newtonian fluid can be made by mixing cornstarch and water (making a cornstarch paste). This mixture will act as a fluid under normal conditions, but if a force is applied, the mixture will exhibit properties of a solid. Applying a force to the mixture drastically increases its viscosity. If you apply a constant force to the mixture, eventually the pressure will equalize, and the mixture will act like a liquid again.

FORMULAS & EQUATIONS

Pure water is comprised of two hydrogen atoms and one oxygen atom.

The chemical formula for pure water is $\mathbf{H_2O}$.

This formula illustrates that a molecule of water is comprised of two hydrogen atoms and one oxygen atom.

Cornstarch is made up of starch granules separated from the mature grains of corn. It is a very fine white to slightly yellowish powder. Starches are complex sugars (polysaccharides) made up of glucose molecules, and there are many different sizes and structures for these glucose polymers. The two main types of starch are amylose and amylopectin. Generally, cornstarch consists of 25% amylose and 75% amylopectin.

The chemical formula for a basic starch molecule is $(\mathbf{C_6H_{10}O_5})_n$. *The* n *stands for any number of molecules.*

Therefore, starches are complex polymer chains of carbon, hydrogen, and oxygen.

CONNECT TO THE *YOU BE THE CHEMIST* CHALLENGE

For additional background information, please review CEF's Challenge study materials online at http://www.chemed.org/ybtc/challenge/study.aspx.

- Additional information on states and properties of matter can be found in the Classification of Matter section of CEF's *Passport to Science Exploration: The Core of Chemistry*.

HYPOTHESIS

▶When pressure is applied to a mixture of cornstarch and water, its viscosity will change, causing it to exhibit properties of a solid.

Fun Fact

If a pool is filled with the non-Newtonian cornstarch mixture outlined in this lesson, a person can actually run across it.

LESSON 29: Solid or Liquid?

DIFFERENTIATION IN THE CLASSROOM

LOWER GRADE LEVELS/BEGINNERS

DESCRIPTION

Mix cornstarch and water to discuss properties of matter.

OBJECTIVE

This lesson introduces ways to classify matter and discusses some challenges to classifying matter.

OBSERVATION & RESEARCH

Matter exists primarily as a solid, liquid, or gas on the earth. The motion of the particles within a solid, liquid, and gas are different. For example, the molecules of H_2O move differently in the form of ice than they do in the form of water vapor.

The particles in a **solid** are generally locked into place giving the solid substance a definite shape and volume. The particles are held together tightly. However, the particles are not completely still. They do move but not freely. They only vibrate slightly in place. Examples of solids are chairs, books, dishes, and cornstarch.

Particles in a **liquid** are not as close as particles in a solid, and they move more freely. The particles roll over each other, which is why liquids flow. However, liquids still experience weak forces of attraction. These attractive forces make the liquid particles remain fairly close to one another as they slide past one another. Therefore, liquids do not have definite shapes, but they have definite volumes. They take the shape of the vessel that contains them, filling the bottom of the container first. Examples of liquids are water and orange juice.

The particles in a **gas** are spaced far apart. They do not have strong bonds or attractions between them. Therefore, they move about freely and rapidly in random directions. Particles in a gas can move over very large distances and go much farther than liquids without touching another particle. Gases do not have a definite shape or volume. If a gas is put into a container, it will take the shape of the container, filling that container completely. Examples of gases are the oxygen we breathe and the helium that fills balloons.

Liquids and gases are fluids. A **fluid** is any substance made up of particles that flow or move freely. A fluid easily changes shape when a force is applied. For example, if you push on a balloon filled with gas, you can easily change its shape. Likewise, if you push on a balloon filled with water, you can change the water balloon's shape.

Not all matter is easily classified as a solid, liquid, or a gas. Peanut butter, gravy, and the cornstarch mixture made in this experiment are all unique types of matter. They are known as non-Newtonian fluids because they can exhibit different properties based on the amount of force applied. The cornstarch mixture behaves as a liquid under normal conditions, but when a force is applied, it behaves as a solid.

HIGHER GRADE LEVELS/ADVANCED STUDENTS

Perform the experiment as described on page 358, but discuss viscosity in greater detail. For Newtonian fluids, viscosity changes with temperature. In general, increasing the temperature of the fluid decreases its viscosity. At room temperature, honey flows relatively slowly. However, if you heat up the honey, it will flow more easily.

Another option is to discuss the concept of shear stress. **Shear stress** is a pressure or force in the structure of a substance that arises when its layers are shifted horizontally in relation to each other. Students can imagine a flowing liquid as a group of liquid layers sliding past each other. A liquid's resistance to flow arises because of the "friction" between those layers. According to Newton, the slower a layer slides over another layer, the less resistance it experiences. If the speed doubles, so does the resistance. If there was no difference in the speeds of the layers, the liquid would have no resistance to flow. Liquids that follow this model are Newtonian fluids. On the other hand, in some fluids, if the speed of the layers sliding past one another doubles, the resisting force does not double. When this happens, the fluid may experience less resistance (like ketchup) or more than double the resistance (like the cornstarch mixture). These are the non-Newtonian fluids.

CONNECT TO THE *YOU BE THE CHEMIST* CHALLENGE

For additional background information, please review CEF's Challenge study materials online at http://www.chemed.org/ybtc/challenge/study.aspx.

- Additional information on states and properties of matter can be found in the Classification of Matter section of CEF's *Passport to Science Exploration: The Core of Chemistry*.

LESSON 29: Solid or Liquid?

EXPERIMENTATION

As the students perform the experiment, challenge them to identify the independent, dependent, and controlled variables, as well as whether there is a control setup for the experiment. (Hint: If you change the amount of water in the mixture, does the mixture behave differently?) Review the information in the ***Scientific Inquiry*** section on pages 14–16 to discuss variables.

EXPERIMENTAL PROCEDURE

1. Mix cornstarch and water in a bowl, using about a quarter of the box of cornstarch at a time, until you have a uniform gooey consistency. If you smack your hand on the mixture and cause significant splashing, the mixture has too much water. Simply add more corn starch. If the mixture is grainy, add more water.
2. Pour the mixture into a cake pan. You are now ready to test the properties of the fluid.
3. Smack the mixture and observe its reaction. It should not splash.
4. Scoop up some of the mixture and hold your hand over the cake pan. Open your fingers and watch as the mixture flows through your fingers. You can also lift some of the mixture in a spoon. Then tilt the spoon to watch the mixture flow out.

It may be easier to mix the cornstarch and water and get a uniform consistency if you use your hands. Gloves should be worn to protect your hands and minimize the mess.

DO NOT pour the mixture down the drain when disposing of it! The cornstarch and water will eventually separate and the thick cornstarch can clog the pipes. Pour the mixture into a plastic bag, and throw it away in a trash can. You can also choose to let the mixture sit until it separates. Then, carefully pour off some of the water, and pour the rest of the mixture into a plastic bag and throw it away.

To reduce waste, you can do the experiment as a demonstration.

NOTES

DATA COLLECTION

Have students record data in their science notebooks or on the following activity sheet. In which state of matter is the cornstarch? In which state of matter is water? In which state of matter is the cornstarch mixture? You can use the chart in the activity sheet (or a similar one of your own) for students to record their data.

LESSON 29: Solid or Liquid?

ANALYSIS & CONCLUSION

Use the questions from the activity sheet or your own questions to discuss the experimental data. Ask students to determine whether they should accept or reject their hypotheses. Review the information in the ***Scientific Inquiry*** section on pages 14–16 to discuss valid and invalid hypotheses.

ASSESSMENT/GOALS

Upon completion of this lesson, students should be able to …

- Apply a scientific inquiry process and perform an experiment.
- Distinguish between the different states of matter.
- Define and give examples of fluids.
- Explain the property of viscosity and provide examples of liquids with high and low viscosities.
- Compare and contrast Newtonian and non-Newtonian fluids.
- Understand the effects of forces on the viscosity of a non-Newtonian fluid.
- Identify ways to change the viscosity of a fluid (see ***Differentiation in the Classroom***).
- Explain the concept of shear stress (see ***Differentiation in the Classroom***).

MODIFICATIONS/EXTENSIONS

Modifications and extensions provide alternative methods for performing the lesson or similar lessons. They also introduce ways to expand on the content topics presented and think beyond those topics. Use the following examples, or have a discussion to generate other ideas as a class.

- Prepare the mixture before the lesson, and use a pan of water for comparison. Pour both of the fluids into separate containers to show that they behave similarly. Stick your fingers in both to demonstrate the fluid properties. Now ask the students what will happen if you smack each of the fluids. Students will be surprised to see that there is no splatter when you smack the cornstarch mixture! Then, let them touch the water and cornstarch mixture. See if they can figure it out what is occurring.
- Start a discussion about a crowded hallway. Is it more difficult to move through a crowded hallway when other people are moving in different directions? How do they get through the crowd? Do they run or walk slowly? Point out that it is usually easiest to find an open path between all of the people and move through slowly. If you ran straight into the crowd, you would most likely slam into another person and not get very far. Explain that the particles in the cornstarch mixture act like a large crowd of people in a hallway. Pressing your hand into the mixture slowly allows the particles to move out of the way. However, smacking the mixture quickly doesn't allow the particles to slide past one another and move out of the way.

REAL-WORLD APPLICATIONS

- Non-Newtonian fluids like the cornstarch mixture and gravy become more resistant to flow as a force is applied. When you smack the cornstarch mixture, it behaves as a solid. Likewise, stirring gravy more quickly, causes the gravy to thicken. Other non-Newtonian fluids, like ketchup, become less resistant when a force is applied. If you stir or shake a bottle of ketchup, it becomes easier to pour out of the container.
- Quicksand is a non-Newtonian fluid that behaves like ketchup. It will become less viscous when a force is applied. Moving your legs slowly in the quicksand will apply a steady force. This force reduces the resistance of the quicksand and creates a space between your legs and the sand so the water can flow and loosen the sand. Therefore, you can get out by slowly moving toward solid ground.

  The belief that moving in quicksand will make a person sink completely is a myth. Struggling will cause you to sink a bit as the quicksand flows more easily, but it will not cause you to sink completely. People are less dense than quicksand, so they will only sink to about waist level. However, quicksand can still be dangerous. It is often found near the ocean or sea, so a person caught in quicksand can drown as the tides rise, if he or she does not get out in time. Panicking and moving too quickly can create other problems. If you stop moving, the quicksand will behave like a solid, trapping you inside. If someone tugs on you quickly, you could get seriously injured.

COMMUNICATION

Discuss the results as a class and review the activity sheet. Review the information in the ***Scientific Inquiry*** section on pages 14–16 to discuss the importance of communication to scientific progress.

LESSON 29 ACTIVITY SHEET: Solid or Liquid?

OBSERVE & RESEARCH

1. Write down the materials you observe. _____

_____

_____

2. Predict how these materials may be used. _____

_____

_____

3. Define the following key terms. Then, provide an example of each by writing the example or drawing/pasting an image of the example.

Term	Definition	Example (write or add image)
Solid		
Liquid		
Gas		
Fluid		
Viscosity		
Newtonian fluid		
Non-Newtonian fluid		

4. Consider how force applied to a mixture of cornstarch and water may affect how the mixture behaves and why.

▶**Write your hypothesis.** _____

_____

_____

LESSON 29 ACTIVITY SHEET: Solid or Liquid?

PERFORM YOUR EXPERIMENT

1. Mix cornstarch and water in a bowl until you have a uniform, gooey consistency. If you smack the mixture with your hand and there is significant splashing, the mixture has too much water. You must add more cornstarch. If the mixture is too dry, add more water.

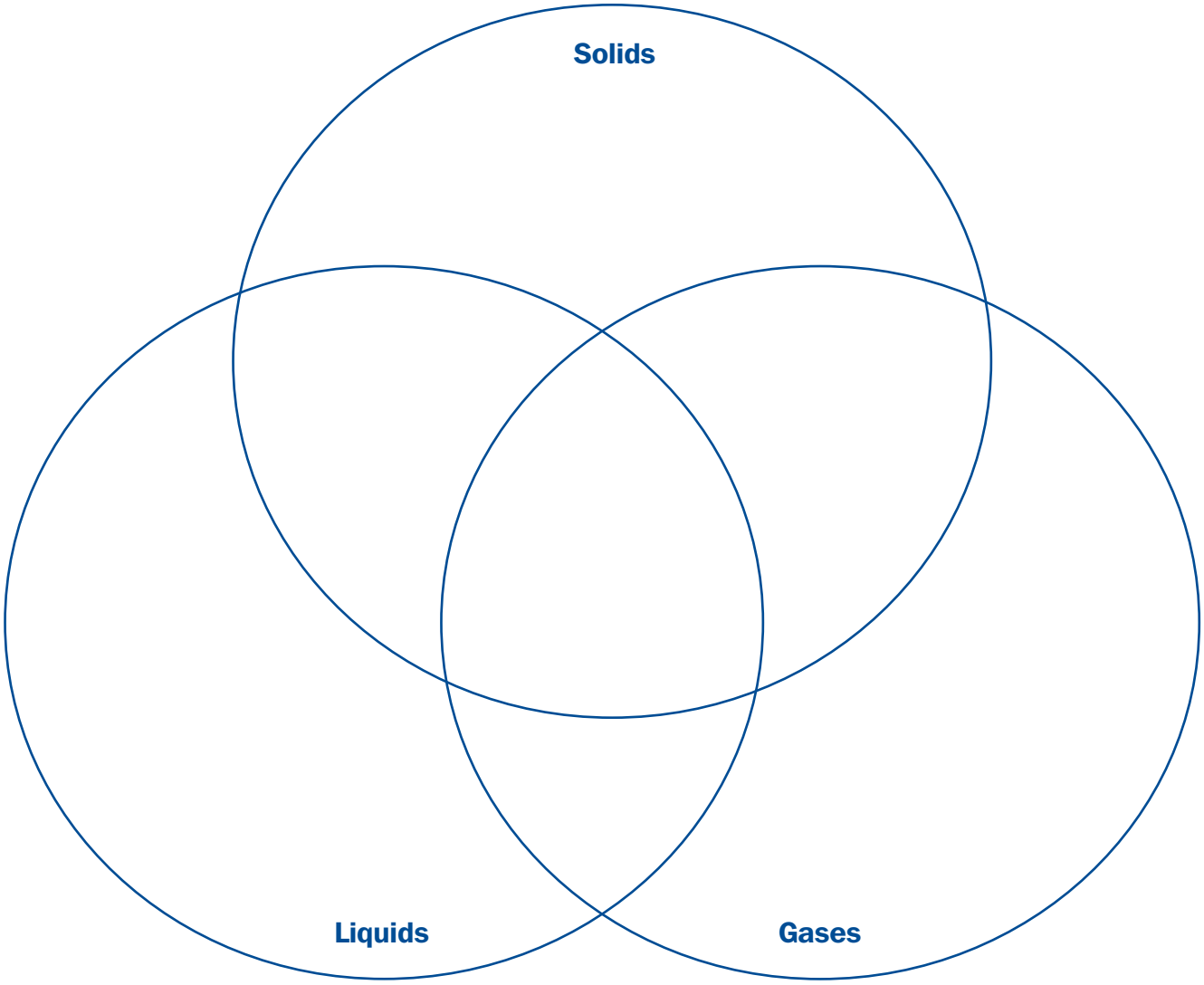
2. Pour the mixture into a cake pan.

3. Smack the mixture, and observe what happens.

4. Scoop up some of the mixture in your hand, and hold it over the cake pan. Then, open your fingers, and watch what happens. You can also lift some of the mixture in a spoon. Then tilt the spoon to watch the mixture flow out.

ANALYZE & CONCLUDE

1. Compare and contrast solids, liquids, and gases using the diagram below.



LESSON 29 ACTIVITY SHEET: Solid or Liquid?

2. Describe the properties of the cornstarch. Is it a solid, liquid, or gas? _____

_____

_____

3. Describe the properties of the water. Is it a solid, liquid, or gas? _____

_____

_____

4. Describe the properties of the mixture. How does it feel? _____

_____

_____

5. What happens when you smack the mixture? _____

_____

_____

6. Do you think the mixture is a solid, liquid, or gas? Why? _____

_____

_____

7. Is your hypothesis valid? Why or why not? If not, what would be your next steps? _____

_____

_____

LESSON 29 ACTIVITY SHEET: Solid or Liquid?

EXPAND YOUR KNOWLEDGE—ADVANCED

1. Define the following key term. Then, provide an example of it by writing the example or drawing/pasting an image of the example.

Term	Definition	Example (write or add image)
Shear stress		

2. How can the viscosity of a Newtonian fluid change? Provide an example. _____

_____

_____

3. Humans have a non-Newtonian fluid that runs throughout their bodies. What do you think it is and why? _____

_____

_____

LESSON 29 ACTIVITY SHEET: Solid or Liquid?

ANSWER KEY: *Below are suggested answers. Other answers may also be acceptable.*

OBSERVE & RESEARCH

1. Write down the materials you observe. Cornstarch, water, bowl, spoon, cake pans, plastic bag ...

2. Predict how these materials may be used. Cornstarch may be used in cooking. Water may be used for drink, clean, or bathe. A bowl and spoon may be used to stir a mixture. Cake pans may be used to hold a substance. Together, these materials may be used to explore states and properties of matter.

3. Define the following key terms. Then, provide an example of each by writing the example or drawing/pasting an image of the example.

Term	Definition	Example (write or add image)
Solid	A state of matter characterized by a definite volume and definite shape.	
Liquid	A state of matter that has a definite volume but no definite shape; a liquid will take the shape of the container that holds it, filling the bottom first.	
Gas	A state of matter that has no definite volume or shape; a gas will take the shape of the container that holds it, filling the entire container.	
Fluid	Any substance made up of particles that flow or move freely, such as a liquid or gas.	
Viscosity	The measure of a fluid's thickness or resistance to flow.	
Newtonian fluid	A fluid that has a constant viscosity at a constant temperature, regardless of any applied force or rate of flow.	
Non-Newtonian fluid	A fluid that does not have a constant viscosity; the viscosity of a non-Newtonian fluid varies based on the force applied or how fast an object is moving through the liquid.	

4. Consider how force applied to a mixture of cornstarch and water may affect how the mixture behaves and why.

▶**Write your hypothesis.** When a force is applied to a mixture of cornstarch and water, its viscosity will change, causing it to exhibit properties of a solid.

LESSON 29 ACTIVITY SHEET: Solid or Liquid?

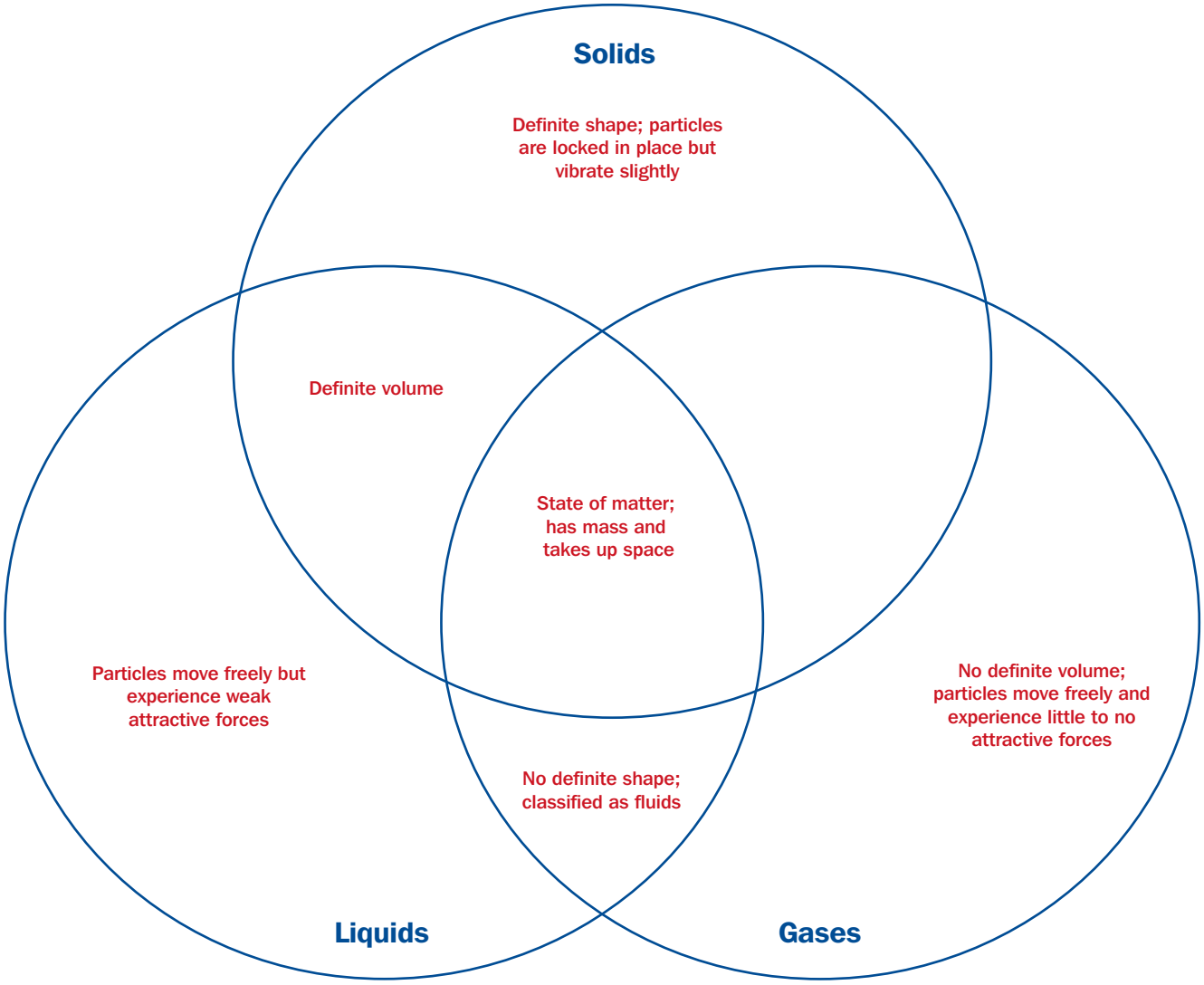
ANSWER KEY: *Below are suggested answers. Other answers may also be acceptable.*

PERFORM YOUR EXPERIMENT

1. Mix cornstarch and water in a bowl until you have a uniform, gooey consistency. If you smack the mixture with your hand and there is significant splashing, the mixture has too much water. You must add more cornstarch. If the mixture is too dry, add more water.
2. Pour the mixture into a cake pan.
3. Smack the mixture, and observe what happens.
4. Scoop up some of the mixture in your hand, and hold it over the cake pan. Then, open your fingers, and watch what happens. You can also lift some of the mixture in a spoon. Then tilt the spoon to watch the mixture flow out.

ANALYZE & CONCLUDE

1. Compare and contrast solids, liquids, and gases using the diagram below.



LESSON 29 ACTIVITY SHEET: Solid or Liquid?

ANSWER KEY: *Below are suggested answers. Other answers may also be acceptable.*

2. Describe the properties of the cornstarch. Is it a solid, liquid, or gas? Cornstarch is a solid. It is a powdery substance with a white or yellowish color.

3. Describe the properties of the water. Is it a solid, liquid, or gas? Water is a liquid that is clear and flows easily.

4. Describe the properties of the mixture. How does it feel? The mixture feels soft but sticky. It flows like a fluid when you move your finger or a spoon through the mixture.

5. What happens when you smack the mixture? The mixture exhibits properties of a solid. Applying pressure will increase the mixture's viscosity.

6. Do you think the mixture is a solid, liquid, or gas? Why? The mixture is not easily classified. It is considered a non-Newtonian fluid, so it is a special type of liquid. This specific mixture exhibits properties of a solid when a force is applied.

7. Is your hypothesis valid? Why or why not? If not, what would be your next steps?

Answer 1: Valid because the data support my hypothesis.

Answer 2: Invalid because the data do not support my hypothesis. I would reject my hypothesis and could form a new one, such as …

LESSON 29 ACTIVITY SHEET: Solid or Liquid?

ANSWER KEY: *Below are suggested answers. Other answers may also be acceptable.*

EXPAND YOUR KNOWLEDGE—ADVANCED

Have students complete this section if you used the advanced differentiation information, or challenge them to find the answers to these questions at home and discuss how these terms relate to the experiment in class the next day.

1. Define the following key term. Then, provide an example of it by writing the example or drawing/pasting an image of the example.

Term	Definition	Example (write or add image)
Shear stress	A pressure or force in the structure of a substance that arises when its layers are shifted horizontally in relation to each other.	

2. How can the viscosity of a Newtonian fluid change? Provide an example. The viscosity of a Newtonian fluid can be changed by changing the temperature. For example, if honey is heated, it will flow more easily.

3. Humans have a non-Newtonian fluid that runs throughout their bodies. What do you think it is and why? Blood is a non-Newtonian fluid in the human body. Its viscosity can change with changes in pressure or shear stress.