

Fluids: How thick are liquids?

Teacher Version

California Science Content Standards:

- **1. Motion and Forces: Newton's laws predict the motion of most objects.**
- 1b. Students know that when forces are balanced, no acceleration occurs; thus an object continues to move at a constant speed or stays at rest (Newton's first law).
- 1d. Students know that when one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction (Newton's third law).
- 1f. Students know applying a force to an object perpendicular to the direction of its motion causes the object to change direction but not speed (e.g., Earth's gravitational force causes a satellite in a circular orbit to change direction but not speed).

Complete List of Materials:

- 3 different colored blocks of clay
- 3 tall clear glasses or 100 mL graduated cylinders
- Water
- Vegetable oil
- Hand soap
- Stopwatch
- Ruler
- Knife
- Stopwatch
- Silly putty
- CD
- 1 Box of Cornstarch

Introduction:

Fluids are substances that can flow under an applied force. What are some examples of fluids? We often think of fluids as substances that are in the liquid phase. For example, water is a fluid. When we pour water into a glass, it conforms to the shape of the glass. Gases do this too. They are fluids because they can flow and deform in response to an applied stress or force.

Q1. Are the following items below fluids (Indicate yes or no in the space provided)?



Cheese ___ No ___



Air ___ Yes ___



Water ___ Yes ___



Toothpaste ___ Yes ___

Part I – Viscosity

Key Concepts:

- **Viscosity** tells us the resistance of a fluid on which a force is acting.
- For fluids, it basically refers to how ‘thick’ a fluid is.

Materials:

- 3 different colored blocks of clay
- 3 tall clear glasses or 100 mL graduated cylinders
- 100 mL of water
- 100 mL of vegetable oil
- 100 mL hand soap
- Stopwatch
- Ruler
- Knife

Procedure:

STUDENT VERSION ONLY

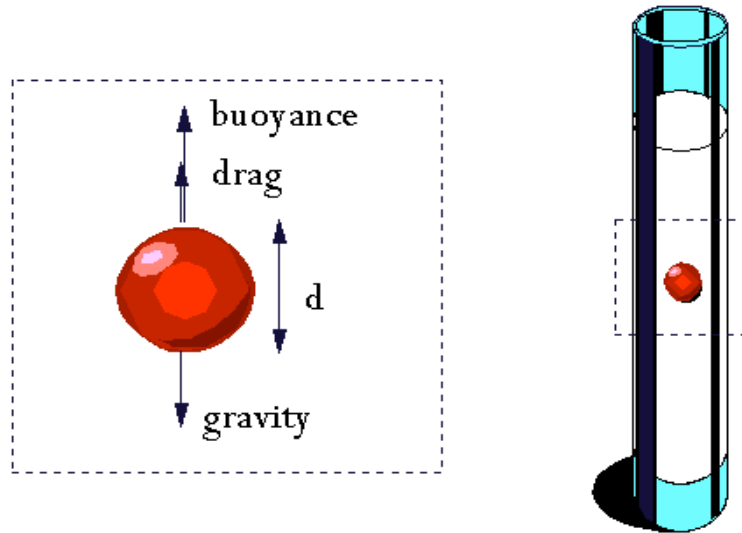
- 1) Fill three 100 ml graduated cylinders (or tall clear cups) with three different fluids: water, vegetable oil, handwashing soap.
- 2) Form 3 equally sized balls from pieces of clay.
- 3) Drop individual balls into graduated cylinders at the same time. Start the stopwatch.
- 4) Record the times it takes for the ball to hit the bottom of the glass in each liquid.

Liquid	Time (s)
Water	
Vegetable Oil	
Hand Soap	

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Objective:

In this experiment, we will drop spherical balls of clay into three fluids and calculate the viscosities of the fluids by measuring the velocities of the balls as they fall. Three forces act on a spherical ball of clay falling through a fluid: gravity, drag, and buoyancy. We will discuss drag in more detail in the next experiment:



Gravity is simply the mass of the sphere (m) multiplied by the gravitational constant g . It is the weight of the sphere.

$$Gravity = mg$$

Buoyancy (F_b) is essentially the weight of fluid that is displaced by the sphere. You can think of it as the weight of a spherical ball of the fluid. Thus, it is calculated by taking the mass of the fluid that would fill that sphere multiplied by the gravitational constant g . We can calculate the mass using the volume of the sphere, which is $(4/3)\pi r^3$ where r =radius, and the density of the liquid (ρ_{fluid}).

$$F_b = (4/3)\pi r^3 \rho_{fluid} g$$

The **drag force** is given by Stoke's Law. This law only applies for spherical objects in fluids that are flowing in a steady manner (not turbulent). Drag opposes the downward gravitational force and is dependent on the viscosity of the fluid (μ), the size of the sphere (d =diameter), and the sphere's velocity (V) as it falls through the fluid.

$$F_d = 6\pi\mu Vd$$

Assuming the sphere is falling at a constant velocity in a calm fluid, we can say that the sum of the forces pointing upwards is equal to the sum of the forces pointing downwards to get the following equation that will allow us to calculate viscosities of fluids.

$$F_b + F_d = mg$$
$$(4/3)\pi r^3 \rho_{fluid} g + 6\pi\mu Vd = m_{sphere} g$$

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- 1) Fill three 100 mL graduated cylinders (or tall clear cups) with three different fluids: water, vegetable oil, handwashing soap. The densities of these three fluids are as follows:

$$\rho_{\text{water}} = 1 \text{ g/mL} \quad \rho_{\text{vegetable oil}} = 0.894 \text{ g/mL} \quad \rho_{\text{hand soap}} = 0.932 \text{ g/mL}$$

Note: 1 mL = 1 cm³

- 2) Measure the height of the fluid in each glass using a ruler and note down the mass of each block of clay from the package.
- 3) Mold each block into a sphere and measure the diameter of the sphere using a ruler. You may splice the sphere into half using a knife to more accurately measure the diameter.
- 4) Drop individual balls into graduated cylinders at the same time. Start the stopwatch.
- 5) Record the times it takes for the ball to hit the bottom of the glass in each liquid and calculate the velocities of each ball in each liquid based upon the height of the liquid and the time.

Liquid	Time (s)	Velocity (cm/s)
Water		
Vegetable Oil		
Hand Soap		

Q2. Rank the viscosities of honey, soap, water, and oil. Which one is the most viscous or can resist flow most effectively?

Least viscous to most viscous – water, oil, soap, honey

Q3. Which ball took the longest amount of time to reach the bottom of the glass?

It should be the ball in the hand soap, as that is the most viscous substance.

Q4. Based on these results, what can we qualitatively say about the viscosities of the three liquids? Rank them from most to least viscous.

Water is the least viscous, then vegetable oil, and hand soap is the most viscous.

*Q5. What effect do you think temperature has on viscosity? (Think about maple syrup!)
increasing temperature decreases the viscosity (when you heat up maple syrup it becomes thinner and more flows more easily)*

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6) Now let's actually calculate the viscosities of the three liquids using the formula from above. Use $g = 9.8 \text{ m/s}^2$.

Remember: $(4/3)\pi r^3 \rho_{\text{fluid}} g + 6\pi\mu Vd = m_{\text{sphere}} g$

For each liquid substitute for each variable.

Convert g to cm/s^2

r = measured radius of sphere (in cm)

ρ_{fluid} = density of water was given above

g = convert 9.8 m/s^2 to $\text{cm/s}^2 = 980 \text{ cm/s}^2$.

V = velocity of sphere in the water (cm/s)

d = measured diameter of sphere (cm)

m = whatever the clay packaging says or has been weighed on the scale – be sure to convert to kg

Finally Solve for μ !

Water:

Need to add approximate values – maybe 0.089 kg m/s^2

Vegetable Oil:

Need to add approximate values – maybe 8.1 kg cm/s^2

Hand Soap

Need to add approximate values – maybe 120 kg cm/s^2

Part II – Drag

Key Concepts:

- **Drag** measures the forces that oppose the motion of an object through a fluid.
- The lower the drag on an object the faster it travels through a fluid.

*Q6. Why do you think skiers bend over when they ski? How about cars and race cars?
Why do you think they are shaped the way they are?
So that they can reduce the drag as much as possible.*



Materials:

- 2-3 different colored blocks of clay
- 3 tall clear glasses or 100 mL graduated cylinders
- 100 mL hand soap
- Stopwatch

Procedure:

- 1) Break up into two or three teams. Each team should have a particular color of clay.
- 2) With your team, mold the clay into different shapes and drop them into a 100 mL glass filled with soap observing how fast they reach the bottom of the glass.
- 3) Each team must choose 3 different shapes which they believe would travel fastest in the soap. Discuss what design considerations you put into your shapes.
- 4) Relay race with your clay shapes! Use the stopwatch to see who wins.

Team #1 Shape	Team #2 Time	Team #2 Shape	Team #2 Time	Team #3 Shape	Team #3 Time

Q7. Which shapes traveled the fastest?

Q8. Why do you think those shapes worked well? How does performance relate to drag?
better performance = less drag

Q9. What combination of fluid medium and clay shape would have produced the best performance results? How does this relate to viscosity and drag?
Least viscous solution and shape with least drag

Q10. **Thought Exercise:** Based on what you have observed with the clay shapes, rank the following from most to least drag. (1=most, 4=least)



4



2



1



3

Part III – Polymers

Key Concepts:

- A **polymer** is a large molecule chain that is made up of a repeating structural units linked by chemical bonds.
- Polymers are everywhere! What are some polymers that we use and see every day? Plastic is a polymer that we use all of the time --- in our nalgene bottles, vegetable grocery bags, and snowboards. Silly putty is also a polymer!



- How about in your body? DNA and proteins are polymers too!
- As you will observe, polymers can behave as **solids** and **liquids**. In other words, they are **viscoelastic**.
- The length of the polymer chains, the chemical structure of the repeat units, and the arrangement of the various repeat units in the polymer can affect the way the polymer behaves at different temperatures, ability to form crystal structures, and their melting points. Thus, as we will see, different polymers such as silly putty and cornstarch and water will behave differently.

Silly Putty

Materials:

- silly putty
- CD

Procedure:

- 1) Roll some of the silly putty into a ball and place it on top of the opening of a CD hole. Observe after 30 minutes.
- 2) In the meanwhile, play around with your silly putty! Pull it rapidly and slowly and observe.
- 3) Roll the silly putty into a ball and try to bounce it.

*Q11. What happened when you pulled the silly putty rapidly?
It stretches a tiny bit then breaks apart into two pieces.*

*Q12. What happened when you pull the silly putty slowly?
It stretches and stays connected.*

*Q13. Does the silly putty stretch?
Yes, especially when you pull it apart slowly.*

*Q14. Does it go back to its original shape when you release it after stretching?
No, it just stays in whatever shape you stretch it into.*

*Q15. Does it bounce?
Yes.*

*Q16. What happened to the ball of silly putty on top of the CD hole?
It sits over the hole, and then, very slowly seeps into the CD hole. It takes the whole half hour to flow into the hole.*

*Q17. Is silly putty a liquid or a solid? Does it have properties of both? What does this tell us about polymers?
Silly is a polymer and has properties of both solids and liquids. They are viscoelastic*

Cornstarch and Water

Materials:

- 1 Box of Cornstarch
- Water

Procedure:

- 1) Add 1 cup of cornstarch for every $\frac{1}{4}$ cup of water into a bowl and mix. Keep adding water until the mixture appears a little thicker than pancake batter.
- 2) Get your hands dirty! Smack the cornstarch and water mixture.
- 3) Pour it from hand to hand.
- 4) Roll it into a ball and keep rolling, then stop.

Q18. What happened when you smacked the cornstarch and water? Did it feel like a solid block or a liquid?

It feels like a solid, and your hand doesn't go into the mixture at all.

Q19. What happened when you poured it from hand to hand? Did it flow?

It flows around your hand like a liquid.

Q20. Did the cornstarch and water take the shape of a ball?

It takes the shape of a ball until you stop rolling it, then it acts like a liquid and flows back into the container.

Q21. How is the cornstarch and water like the silly putty? Do they exhibit properties of fluids or solids?

They both flow like liquids, even though the silly moves much more slowly. When they are stretched rapidly the both break apart. They both exhibit properties of solids and liquids.

Q22. What can we learn about some of the properties of polymers from these experiments?

Polymers can behave as solids and liquids and differ in behavior depending on length of chain and chemical properties of monomer units and how they interact. That is why we see different behavior with cornstarch and water and silly putty

Watch these videos to learn more about fluids!

Walking on water (and cornstarch)!

<http://www.youtube.com/watch?v=f2XQ97XHjVw>

50 lb ball of silly putty

<http://www.youtube.com/watch?v=uWYxc8xhihg>

Reversible Fluid Flow

http://www.youtube.com/watch?v=p08_KITKP50