SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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National Science Education Standard—Physical Science

Structure and Properties of Matter

Solids, liquids, and gases differ in the distances and angles between molecules or atoms and therefore the energy that binds them together. In solids the structure is nearly rigid; in liquids molecules or atoms move around each other but do not move apart; and in gases molecules or atoms move almost independently of each other and are mostly far apart

Teacher Materials

Learning Sequence Item:

908

Solids, Liquids, and Gases

August 1996
Adapted by: Brett Pyle and Linda W. Crow

Solids, Liquids, and Gases: Empirical Laws and Kinetic Theory. Students should determine the mass, volume, and density of a substance in each of its states and explain the changes using the particulate model. They should observe and contrast the physical properties of solids, liquids, and gases, and propose models that can account for the observations *(Chemistry, A Framework for High School Science Education, p. 60).*

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4. Marshmallow Madness
5. Sugar Problem

This micro-unit was adapted by **Brett Pyle** (Grady Middle School, Houston) and
Linda W. Crow (Baylor College of Medicine, Houston)

908

Learning Sequence

Solids, Liquids, and Gases: Empirical Laws and Kinetic Theory. Students should determine the mass, volume, and density of a substance in each of its states and explain the changes using the particulate model. They should observe and contrast the physical properties of solids, liquids, and gases, and propose models that can account for the observations *(Chemistry, A Framework for High School Science Education, p. 60).*

Science as Inquiry	Science and Technology	Science in Personal and Social Perspectives	History and Nature of Science
Presto Denso! **Activity 1** Density of a Gas **Activity 2** The Big Squeeze **Activity 3** Building a Model **Activity 4** Phase Properties **Assessment 1** Compression of Gases: Part A **Assessment 2** Compression of Gases: Part B **Assessment 3** Marshmallow Madness **Assessment 4** Sugar Problem **Assessment 5** Density of Ice vs. Water and Its Effects **Reading 1**			

Suggested Sequence of Events

Event # 1

Lab Activity

1. Presto Denso! (60 minutes)

Alternate or Additional Activity

2. Density of a Gas (60 minutes)

Event #2

Lab Activity

3. The Big Squeeze (60 minutes)

Event #3

Lab Activity

4. Building a Model (30 minutes)

Event #4

Readings from Science as Inquiry, Science and Technology, Science in Personal and Social Perspectives, and History and Nature of Science

The following reading is included in the student version of the unit:

Reading 1 Density of Ice vs. Water and Its Effects

Suggested additional readings:

Allen, E.R., "Operation Volcano-Buster." *Science World,* Vol. 49, No. 5, 1992, pp. 6–9.

Campbell, N.A., *Biology,* 2nd Edition, p. 42. Redwood City, Calif.: The Benjamin Cummings Publishing Co., Inc., 1990.

Pool, R., "Super Fluff." *Discover* Magazine, Vol. 11, No. 8, 1990, p. 26.

Assessment items can be found at the back of this volume.

Assessment Recommendations

This teacher materials packet contains a few items suggested for classroom assessment. Often, three types of items are included. Some have been tested and reviewed, but not all.

1. Multiple choice questions accompanied by short essays, called justification, that allow teachers to find out if students really understand their selections on the multiple choice.

2. Open-ended questions asking for essay responses.

3. Suggestions for performance tasks, usually including laboratory work, questions to be answered, data to be graphed and processed, and inferences to be made. Some tasks include proposals for student design of such tasks. These may sometimes closely resemble a good laboratory task, since the best types of laboratories are assessing student skills and performance at all times. Special assessment tasks will not be needed if measures such as questions, tabulations, graphs, calculations, etc., are incorporated into regular lab activities.

Teachers are encouraged to make changes in these items to suit their own classroom situations and to develop further items of their own, hopefully finding inspiration in the models we have provided. We hope you may consider adding your best items to our pool. We also will be very pleased to hear of proposed revisions to our items when you think they are needed.

Teacher Sheet

Science as Inquiry

Presto Denso!

What is the density of liquid and solid paraffin?

Overview:

In this activity students determine the density of paraffin in solid and liquid form. The focus is to have students begin to understand the difference between solids, liquids and gases. Hot paraffin can be dangerous, so caution students to be aware of this problem!

Materials:

Per lab group:

paraffin chunk (at least 3 cm × 3 cm × 3 cm)
balance (digital or pan)
graduated cylinder (large enough to hold paraffin chunk)
heat source (candle or propane torch)
bottle cap or other small metal container
paper clip or pin
waxed paper (optional, for variation)
white glue (optional, for variation)
water

Procedure:

Students first measure the mass and volume of paraffin in its solid and liquid states. Based on these measurements they then calculate the density in each state. They should conduct measurements on the solid state first. Volume can be calculated by water displacement. Note that paraffin floats so students will need a pin or straightened paper clip to hold it just below the surface. If students are unfamiliar with how to determine the volume of an irregular solid, provide them with a copy of the technique sheet "How to Determine the Volume of an Irregularly Shaped Solid."

Next, students determine mass and volume of paraffin in the liquid state. Volume should be measured first. Have them use a small metal container such as a bottle cap. If bottle caps are used, be sure students remove the plastic liner with a knife to avoid melting of the plastic later. Next, have them fill a graduated cylinder with a known volume of water and pour water into the bottle cap until full. They then measure the amount removed from the graduated cylinder to determine the volume of the bottle cap. After emptying and drying the bottle cap, students should heat the cap slightly and hold a flame near the paraffin. The paraffin is allowed to melt and drip into the bottle cap. When the bottle cap is full, students should carefully place it on the scale and determine its mass.

Students should also record observations of the top surface of the paraffin as it cools. Initially, while the paraffin is still liquid, the top surface will be flat. As it cools a depression will form in the center as the volume decreases during solidification.

After data have been collected and density calculated, discuss with students the significance of the information. They should understand that these measurements can be generalized to most other substances, and they should come to the conclusion that for most substances the solid phase is denser than the liquid phase. They should be able to explain in their own words that this is due to the particles of the substance being packed closer together.

Background:

In this lab we start leading students toward evidence of the particulate theory of matter. An actual discussion of this model should wait until a later activity. For this activity it is important for the students to develop an understanding that solids, in general, are more dense than liquids.

The ancient Greeks were the first to record a theory of the atom. Democritus used the word "atom" to describe particles of matter. These particles (atoms) could not be divided further. He used his atom idea to explain many properties of substances, including density. Dense materials had atoms packed closely together while less dense materials had atoms more loosely packed. Strictly by changing the ways in which the atoms were scattered or collected, Democritus was able to explain some other well-known phenomena, such as how moisture collects on the outside of a container of cold water and how crystals form.

Remind students to be careful when heating the paraffin so as not to drip it on themselves. Propane torches have the advantage of being able to be directed and pointed more easily than candles. Bunsen burners will work equally well. Gas flames have an advantage over candles in that they will not leave any black residue on the paraffin. The bottle cap can be heated slightly before starting. This will prolong the time it takes the paraffin to solidify to allow more time for the mass to be taken.

Variations:

Another substance that shows density differences is white glue. It can be poured out in strips on waxed paper and allowed to dry. The mass and volume measurements can be done fairly easily. The volume in the solid state can be determined by water displacement (the glue will not dissolve immediately in water after it has hardened).

Adapted from:
Joesten, M., D.O. Johnston, J. Netterville, and J. Wood, *World of Chemistry*. Philadelphia, Penn.: Saunders College Publishing, 1991.

an alternative/additional activity for Event 1

Teacher Sheet

Science as Inquiry

Density of a Gas

What is the density of a gas?

Overview:

Students determine the mass, volume, and density of a gas in this lab activity. In the process of determining these measurements, students are able to observe the compressibility of gases.

Materials:

Per lab group:

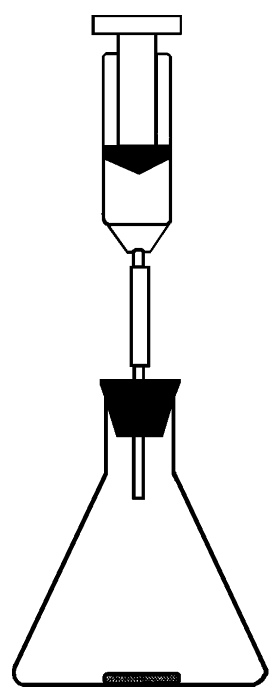
flask, 250-mL
stopper (one-holed with tube inserted)
plastic tubing , ~2–3 cm
plastic syringe, 50–60 mL
Alka-Seltzer® tablet
water
balance (digital or pan)
graduated cylinder
balloon, small (optional, for variation)

Procedure:

Students experimentally measure the mass and volume of CO_2 gas produced in a reaction between water and Alka-Seltzer. They then change the volume of the gas using the syringe to observe the variability in density of the gas due to its compressibility.

Students first need to determine the volume of the entire flask. To do this, have them fill the entire flask with water and insert the stopper, allowing the excess water to flow out. They then remove the stopper and measure the volume of the water with the graduated cylinder. This represents the interior volume of the flask that the gas can occupy.

Have students dry the interior of the flask and place the Alka-Seltzer tablet at the bottom. They then place 30 mL of water in the syringe and take the mass of the entire water-syringe setup. Next they connect the syringe to the tubing leading to the flask (see figure).



Have them push the water out of the syringe into the flask and let the Alka-Seltzer react. They then measure the mass again (it should not change). They should note the volume of the gas (total volume of the flask minus the volume of water added). They then pull the syringe out to 50 mL. They should note the total volume of the gas and take the mass of the entire setup again (it should not change). Finally, they should remove the stopper, releasing the excess CO_2 , and take the mass of the entire setup again. They should see a drop in mass that represents the mass of the CO_2 gas.

Have students determine the density of the gas when the syringe was pushed in and when it was pulled out. This should lead to a discussion of the problems of determining density of a gas. The volume is very variable due to its compressibility. You can discuss what the density of the CO_2 gas was after the students released it into the room.

You should also discuss with students the problem of measuring the density of water when it is a gas (water vapor). How could you measure its volume and mass without it condensing? How hot would it have to be?

Background:

Most students have had a great deal of experience with substances changing from the solid phase to the liquid phase. Gases, however, behave somewhat differently than solids and liquids. A gas normally expands to fill the container that it is in so that its volume is equal to the volume of the container. This means that gases are highly compressible. Pressure can cause a gas to compress and its volume to decrease.

All of the connections on the apparatus will need to be tight to avoid leakage as the pressure builds. However, if there is leakage you can still determine the mass of the gas from the difference in masses of the apparatus from before the water was forced into the flask to the end of the experiment when the flask was opened.

Variations:

A common experiment demonstrating that gases have mass is to take the mass of an empty balloon and the mass of the same balloon after it has been blown up. You could use this method, but determining the volume is a bit more difficult. A small balloon could be submerged in a beaker, but the accuracy would not be good. You could measure the circumference and assume a perfectly spherical balloon to calculate volume. Changing the volume to change the density could be done by heating or cooling the balloon.

Adapted from:

Brown, T., H.E. LeMay, Jr., and B. Bursten, *Chemistry—The Central Science*. New Jersey: Prentice Hall, 1994.

Science as Inquiry

The Big Squeeze

What is the density of a gas?

Overview:

In this activity, students try to compress a solid (sand), a liquid (water), and a gas (air).

Materials:

Per lab group:

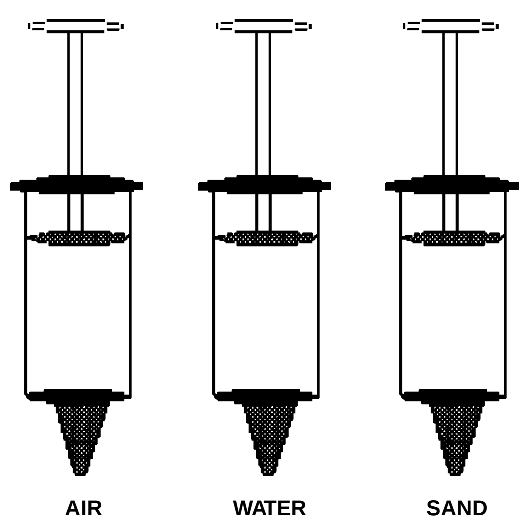
plastic syringes, 60-mL or greater, 3
water, 50 mL
sand, 50 mL
air, 50 mL
heat source (candle, Bunsen burner, or propane torch)
monofilament fishing line
cubes (wood, metal, or plastic), 3 (optional, for variation)

Procedure:

Have students fill three syringes with 35 mL of sand, water, and air (Figure 1). These volumes can vary depending on the size of syringes used as long as all of them have equal volumes. In addition, it may be easier for you to construct these syringe devices.

To do this procedure using air and water, students should submerge the end of the syringe into the substance, air or water, and carefully pull back the plunger to a preestablished volume. The syringe should be filled to that volume level with either the air or water. After the syringes are filled, have students seal the ends by melting the tips in a heat source.

Figure 1
60-mL syringes with 35 mL of material



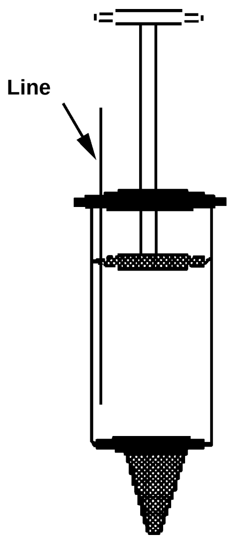


Figure 2

For the sand the procedure is somewhat different (Figure 2). First have the students melt the tip of the syringe. They should then pull the plunger completely out of the syringe and carefully pour sand into the open syringe. Suggest that they gently tap the side of the syringe to settle the sand down tightly. Before they replace the plunger, have them lay a short length of monofilament line inside the syringe. They then replace the plunger, catching the line between the edge of the plunger and the syringe tube, and squeeze down on the plunger to evacuate any trapped air. It will escape through the small opening created by the line. Finally, they should gently remove the line. Students should be sure that the syringe ends with the same volume as the other syringes. It may be easier to make up the sand syringe first and match the air and water syringe volumes to it.

Next, students try to push the plunger of each syringe down further. Part of what they will observe is that the plunger of the syringe containing air will be pushed further down. Air is more compressible than the sand and water. Since they are sealed, these syringes could be used for many classes and saved for following years.

Background:

In this lab we start leading students toward the development of the particulate model of matter; that is, that all matter is composed of particles that are, at least, jiggling. In 1827 Robert Brown discovered that when he mixed pollen grains with water they were constantly jiggling. A similar phenomenon can be observed by examining smoke particles through a microscope. The term Brownian motion was used to describe this jiggling event.

The air (gas) can be compressed more than the sand and water. Students should be able to explain how this compressing occurs.

The model building activity in the next event will ask students to demonstrate with words or drawings what is occurring in solids, liquids and gases. In this activity most students will observe that air can be squashed/compressed, whereas sand and water cannot. Some students may even observe that when they let go of the plunger in the air syringe, it comes back up on its own.

As revealed by the Children's Learning in Science (CLIS) Project, common explanations that students often give include:

Air is compressible/you can squash it.
You cannot squash solids and liquids.
Air is not dense but sand and water are.
Sand is too packed together.

Student explanations using the particulate model are less common. Some examples are:

Sand and water molecules are packed more closely together than air molecules.
Air particles are further apart than sand particles.

However, at this time refrain from just telling students about the particulate theory of matter. Allow them to speculate and predict. A following micro-unit (925) will build on these experiences and ask students to provide a more correct explanation.

Variations:

This syringe setup could be varied by using different viscosities of liquids. Another experience along this line of thinking is to give students three cubes that are identical in size but vary in composition (wood, metal, and plastic). Ask them to explain how the cubes can be the same yet different.

Adapted from:
Children's Learning in Science Project (CLIS), *Particulate Theory of Matter*. England: University of Leeds, 1990.
Driver, R., *Children's Ideas in Science*. Penn.: Open University Press, 1993.
Kirkpatrick, L. D., and G.F. Wheeler, *Physics, A World View*. Philadelphia, Penn.: Saunders College Publishing, 1995.

Teacher Sheet

Science as Inquiry

Building a Model

How do solids, liquids, and gases look inside?

Overview:

This activity builds on Activity 3. Using their previous experiences, students draw and explain how solids, liquids, and gases behave. They will need to explain what solids, liquids, and gases look like inside.

Materials:

Per lab group:

paper, 1 large sheet (butcher paper, flip-chart paper, etc.)
markers/colored pencils

Procedure:

Students should work in groups to come up with a model that explains what solids, liquids, and gases are like inside, and why they behave as observed in the previous activities.

Give each group a large piece of paper and markers. Ask them to describe their model with diagrams or words. Post these models and have groups present them to the class.

This activity is intended to encourage students to use their past knowledge to attempt to build a model. It is not expected that they will be able (at this time) to invent a correct model for the behavior of matter.

A later micro-unit (925) will continue to expose students to experiences with the particulate model. As students present their models, discuss each of them and its impact on the behavior of solids, liquids, and gases. Make no attempt to give students the right answer.

Background:

According to research conducted by Driver, et al. (1993), most students correctly:

1. Use a particulate model rather than a continuous model. The continuous model would indicate that neither solids nor liquids nor gases are compressible. This idea would not be supported by the syringe activity. In addition, Democritus (early Greek) proposed that this continuous model would allow for matter to be divided into smaller and smaller divisions but remain the original homogenous material.
2. Have some idea that there is a packing of particles in solids, liquids, and gases.
3. Suggest that the particles are small.

Examples of common incorrect ideas held by students are:

1. There is a gradation in the packing of particles (very close in solids, a little further apart in liquids, and even further apart in gases).
2. There is air between particles, not a vacuum.

3. Particles may be different shapes or sizes in solids, liquid, and gases. Some students think they are irregular in shape. There is sometimes confusion between particles and cells (think of the use of the term nucleus).

4. Particles melt or expand when heated and behave in a macroscopic fashion.

5. Particles of solids are not constantly vibrating; particles of liquids are moving only if the liquid is shaken.

Variations:

If students prefer, they could act out the behavior of solids, liquids, and gases. Also, different liquids and solids could be used and their behavior compared to students' previous observations. Water could be used as an anomaly since ice is less dense than liquid water.

Adapted from:
Children's Learning in Science Project (CLIS), *Particulate Theory of Matter*, England: University of Leeds, 1990.
Driver, R., *Children's Ideas in Science*. Penn.: Open University Press, 1993.

Science as Inquiry

Phase Properties

Item:

One way to categorize a substance is by its physical properties. Imagine you were given several dozen samples and told to categorize them as either solid, liquid, or gas. Which physical properties would be characteristic of liquids?

A. definite composition, indefinite mass
B. definite density, indefinite volume
C. definite volume, indefinite shape
D. definite shape, definite volume

Justification:

What phase of matter has no definite volume?

Answer:

C. Liquids have a definite volume but no definite shape; solids have a definite volume and a definite shape; gases have no definite volume and no definite shape.

Science as Inquiry

Compression of Gases: Part A

Item:

Large amounts of gas can be stored and transported in small volumes because they can be compressed. Solids and liquids, however, compress very little. How would the particulate model explain this difference?

Answer:

Students should describe particles of gases as being further apart than particles of solids and liquids.

Science as Inquiry

Compression of Gases: Part B

Item:

Large amounts of gas can be stored and transported in small volumes because they can be compressed. Solids and liquids, however, compress very little. Why would we choose to store and transport gases in this compressed manner?

Answer:

If gases were not compressed they would take up huge amounts of space, and they would be difficult to transport.

Science as Inquiry

Marshmallow Madness

Item:

An ordinary marshmallow can be easily squeezed into a smaller shape. How can this solid marshmallow be compressed?

Answer:

A marshmallow also contains a great deal of air. When you squeeze it, it compacts because the air is squeezed out.

Science as Inquiry

Sugar Problem

Item:

Performance assessment.

Materials

hot tap water, 1 cup
sugar, 1/2 cup
container to hold both the water and sugar
measuring cups

Procedure

Mix the water and sugar together. Measure the volume of the sugar-water and compare it to the volumes of water and sugar. Explain any differences.

Answer:

There is air between the sugar crystals. When dissolved, this air is no longer present and the total volume is less than the volume of the water plus the volume of the sugar.

Consumables

Item	Quantity (per lab group)	Activity
air	50 mL	3
Alka-Seltzer® tablet	1	2*
balloon, small (optional, for variation)	1	2*
bottle cap or other small metal container	1	1
paper, large (e.g., butcher or flip-chart paper)	1 sheet	4
heat source (candle, Bunsen burner, or propane torch)	1	1, 3
markers/colored pencils	—	4
monofilament fishing line	—	3
paper clip or pin	1	1
paraffin chunk, 3 cm × 3 cm × 3 cm	1	1
plastic tubing	~2–3 cm	2*
plastic syringe, 50- to 60-mL	1	2*
plastic syringe, 60-mL or greater	3	3
sand	50 mL	3
water	—	2*
water	50 mL	3
waxed paper (optional, for variation)	—	1
white glue (optional, for variation)	—	1

Non-Consumables

Item	Quantity (per lab group)	Activity
balance (digital or pan)	1	1, 2*
cubes (wood, metal, or plastic) (optional, for variation)	3	3
flask, 250-mL	1	2*
graduated cylinder, large	1	1, 2*
stopper, 1-holed with tube inserted	1	2*

*indicates alternative or additional activity

Key:
1. Presto Denso!
2. Density of a Gas
3. The Big Squeeze
4. Building a Model

Continued

Activity Sources

Brown, T., H. E. LeMay, Jr., and B. Bursten, *Chemistry—The Central Science*. New Jersey: Prentice Hall, 1994.

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Kirkpatrick, L.D. and G.F. Wheeler, *Physics, A World View*. Philadelphia, Penn.: Saunders College Publishing, 1995.

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