POGIL Chemistry Activities

Introduction to Chemistry

- Safety First
- Fundamentals of Experimental Design
- Organizing Data
- Significant Digits and Measurement
- Significant Zeros
- Classification of Matter

Atomic and Electron Structure

- Isotopes
- Ions
- Average Atomic Mass
- Coulombic Attraction
- Electron Energy and Light
- Electron Configurations

The Periodic Table

- Cracking the Periodic Table Code
- Periodic Trends

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- Polyatomic Ions
- Naming Molecular Compounds
- Naming Acids
- Molecular Geometry

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- Mole Ratios
- Limiting and Excess Reactants

Properties of Gases

- Gas Variables

Solubility and Solutions

- Saturated and Unsaturated Solutions
- Solubility
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Thermochemistry

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Equilibrium

- Equilibrium

Acids and Bases

- Acids and Bases
- Strong versus Weak Acids
- Calculating pH

Oxidation and Reduction

- Oxidation and Reduction
- The Activity Series
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POGIL Biology Activities

Nature of Science

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- Analyzing and Interpreting Scientific Data

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- Properties of Water
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Cells and Cellular Processes

- Prokaryotic and Eukaryotic Cells
- Organelles in Eukaryotic Cells
- Cell Size
- Membrane Structure and Function
- Transport in Cells
- Photosynthesis: What's in a Leaf?
- Cellular Respiration
- Photosynthesis and Respiration
- The Cell Cycle
- Mitosis

Genetics

- Meiosis
- DNA Structure and Replication

Evolution

- Evidence for Evolution
- Biological Classification
- Evolution and Selection

Ecology

- Nutrient Cycles
- Ecological Relationships
- Biomes of North America
- Energy Transfer in Living Organisms
- Ecological Pyramids
- Succession
- Population Distribution
- Population Growth

Body Systems

- The Spread of Pathogens
- Human Blood Cell Typing
- The Circulatory System

Gas Variables

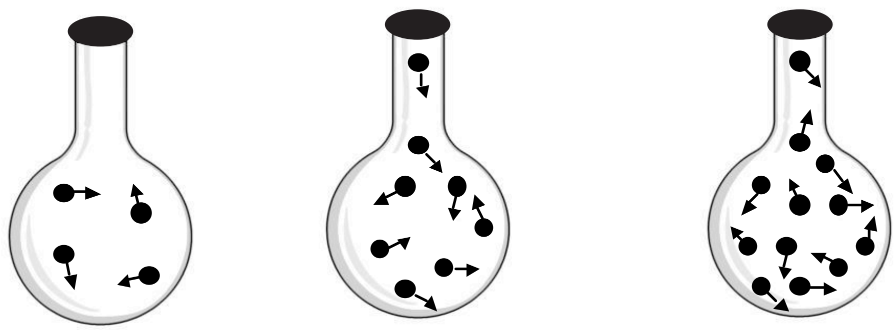
How are the variables that describe a gas related?

Why?

Imagine buying a balloon bouquet at a party store. How will the helium gas in the bouquet behave if you carry it outside on a hot summer day? How will it behave if you carry it outside during a snowstorm? What happens if the balloons are made of latex, which can stretch? What happens if the balloons are made of Mylar®, which cannot stretch? What if you add just a small amount of gas to each balloon? What if you add a lot of gas? In this activity, you will explore four variables that quantify gases—pressure (P), volume (V), temperature (T), and moles (n) of gas. These four variables can be related mathematically so that predictions about gas behavior can be made.

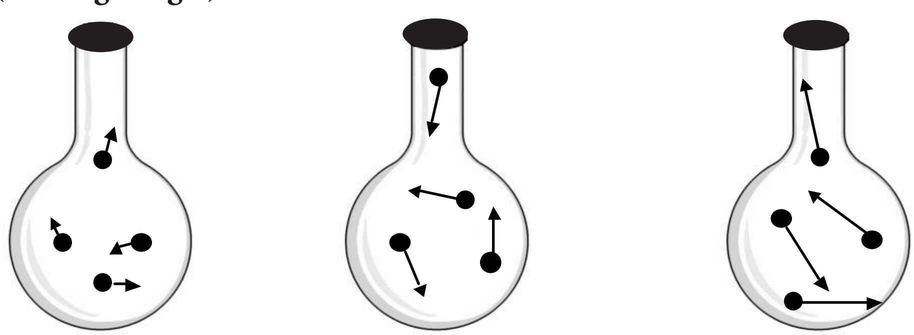
Model 1 – Gases in a Nonflexible Container

Experiment A (Adding more gas)



A1	A2	A3
Volume = 1 unit	Volume = 1 unit	Volume = 1 unit
External pressure = 1 atm	External pressure = 1 atm	External pressure = 1 atm
Internal pressure = 1 atm	Internal pressure = 2 atm	Internal pressure = 3 atm
Temperature = 200 K	Temperature = 200 K	Temperature = 200 K

Experiment B (Heating the gas)



B1	B2	B3
Volume = 1 unit	Volume = 1 unit	Volume = 1 unit
External pressure = 1 atm	External pressure = 1 atm	External pressure = 1 atm
Internal pressure = 1 atm	Internal pressure = 2 atm	Internal pressure = 3 atm
Temperature = 200 K	Temperature = 400 K	Temperature = 600 K

**Note:* Volume in this model is recorded in *units* rather than liters because 4 molecules of gas at the conditions given would occupy a very small space (~1×10^{-22} μL). The particles shown here are much larger compared to the space between them than actual gas particles.

1. In Model 1, what does a dot represent?

2. Name two materials that the containers in Model 1 could be made from that would ensure that they were "nonflexible?"

3. In Model 1, the length of the arrows represents the average kinetic energy of the molecules in that sample. Which gas variable ($P_{internal}$, V, T or n) is most closely related to the length of the arrows in Model 1?

4. Complete the following table for the two experiments in Model 1.

	Experiment A	**Experiment B**
Independent Variable		
Dependent Variable		
Controlled Variable(s)		

5. Of the variables that were controlled in both Experiment A and Experiment B in Model 1, one requires a nonflexible container. Name this variable, and explain why a nonflexible container is necessary. In your answer, consider the external and internal pressure data given in Model 1.

Read This!

Pressure is caused by molecules hitting the sides of a container or other objects. The pressure changes when the molecules change *how often* or *how hard* they hit. A nonflexible container is needed if the gas sample is going to have an internal pressure that is different from the external pressure. If a flexible container is used, the internal pressure and external pressure will always be the same because they are both pushing on the sides of the container equally. If either the internal or external pressure changes, the flexible container walls will adjust in size until the pressures are equal again.

6. Name the two factors related to molecular movement that influence the pressure of a gas.

7. Provide a molecular-level explanation for the increase in pressure observed among the flasks of Experiment A.

8. Provide a molecular-level explanation for the increase in pressure observed among the flasks of Experiment B.

9. Predict what would happen to the volume and internal pressure in Experiment A of Model 1 if a flexible container were used.

10. Predict what would happen to the volume and internal pressure in Experiment B of Model 1 if a flexible container were used.

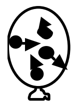
11. For each experiment in Model 1, determine the relationship between the independent and dependent variables, and write an algebraic expression for the relationship using variables that relate to the experiment ($P_{internal}$, V, T or n). Use *k* as a proportionality constant in each equation.

	Experiment A	**Experiment B**
Direct or Inverse Proportion?		
Algebraic Expression		

STOP

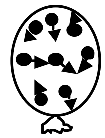
Model 2 – Gases in a Flexible Container

Experiment C (Adding more gas)



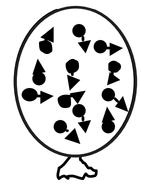
C1

Volume = 1 unit
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K



C2

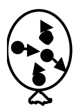
Volume = 2 units
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K



C3

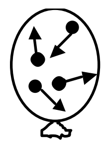
Volume = 3 units
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K

Experiment D (Heating the gas)



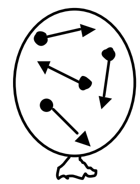
D1

Volume = 1 unit
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K



D2

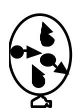
Volume = 2 units
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 400 K



D3

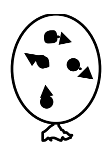
Volume = 3 units
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 600 K

Experiment E (Reducing the external pressure on the gas)



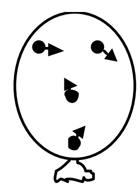
E1

Volume = 1 unit
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K



E2

Volume = 2 units
External pressure = 0.50 atm
Internal pressure = 0.50 atm
Temperature = 200 K



E3

Volume = 3 units
External pressure = 0.33 atm
Internal pressure = 0.33 atm
Temperature = 200 K

12. Consider the gas samples in Model 2.

    a. Name two materials that the containers in Model 2 could be made from that would ensure that they were "flexible"?

    b. What is always true for the external and internal pressures of a gas in a flexible container?

13. Complete the following table for the three experiments in Model 2.

	Experiment C	Experiment D	Experiment E
Independent Variable			
Dependent Variable			
Controlled Variable(s)			

14. Provide a molecular level explanation for the increase in volume among the balloons in Experiment C. (How often and/or how hard are the molecules hitting the sides of the container?)

15. Provide a molecular level explanation for the increase in volume among the balloons in Experiment D.

16. Provide a molecular level explanation for the increase in volume among the balloons in Experiment E.

STOP 17. Compare Experiment A of Model 1 with Experiment C of Model 2. How are these two experiments similar and how are they different in terms of variables?

18. Compare Experiment B of Model 1 with Experiment D of Model 2. How are these two experiments similar and how are they different in terms of variables?

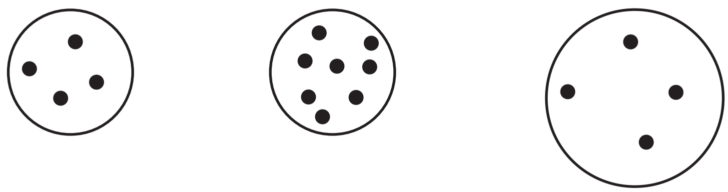
19. If Experiment E of Model 2 were done in a nonflexible container, would there be any change to the internal pressure of the flask when the external pressure was reduced? Explain.

20. For each experiment in Model 2, determine the relationship between the independent and dependent variables, and write an algebraic expression for the relationship using variables that relate to those in the experiment ($P_{internal}$, V, T or n). Use *k* as a proportionality constant in each equation.

Constant Pressure

	Experiment C	**Experiment D**	**Experiment E**
Direct or Inverse Proportion?			
Algebraic Expression			

21. The three samples of identical gas molecules below all have the same internal pressure. Rank the samples from lowest temperature to highest temperature, and add arrows of appropriate size to illustrate the average kinetic energy of the molecules in the samples.



Extension Questions

22. Draw a sample of gas that is colder than all three of the samples in Question 21. Explain why you are sure that it is colder.

23. Four of the relationships you investigated in Models 1 and 2 are named after scientists who discovered the relationships. Use the Internet or your textbook to match each of the scientists below with the appropriate law. Write the algebraic expression that describes the law in the box below each name.

Robert Boyle	Jacques Charles	Guillaume Amontons	Amedeo Avogadro

Read This!

Chemists combine all of the relationships seen in Models 1 and 2 into one law—the **Ideal Gas Law**. It is one equation that describes gas behavior and the relationship among all four variables, P, V, T, and n. In the Ideal Gas Law the proportionality constant is represented by the letter R (rather than the generic *k*).

24. Circle the algebraic equation below that best combines all of the relationships you identified among P, V, T, and n in this activity.

$P = RTnV$ $PT = RnV$ $PV = nRT$ $PTV = Rn$

Gas Variables

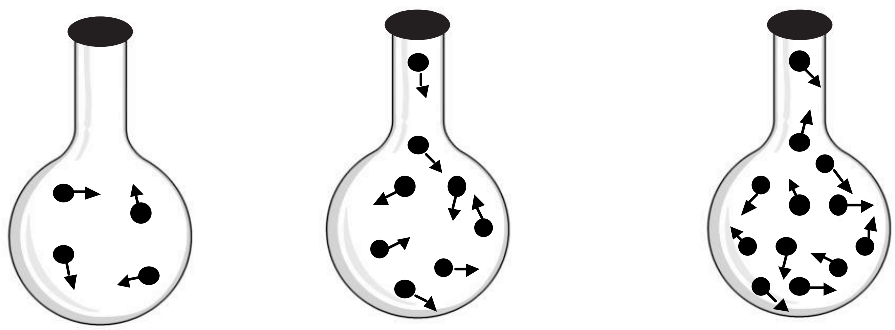
How are the variables that describe a gas related?

Why?

Imagine buying a balloon bouquet at a party store. How will the helium gas in the bouquet behave if you carry it outside on a hot summer day? How will it behave if you carry it outside during a snowstorm? What happens if the balloons are made of latex, which can stretch? What happens if the balloons are made of Mylar®, which cannot stretch? What if you add just a small amount of gas to each balloon? What if you add a lot of gas? In this activity, you will explore four variables that quantify gases—pressure (P), volume (V), temperature (T), and moles (n) of gas. These four variables can be related mathematically so that predictions about gas behavior can be made.

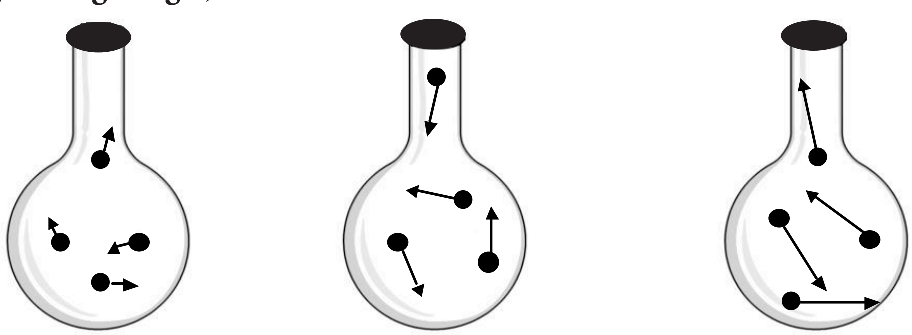
Model 1 – Gases in a Nonflexible Container

Experiment A (Adding more gas)



A1	A2	A3
Volume = 1 unit	Volume = 1 unit	Volume = 1 unit
External pressure = 1 atm	External pressure = 1 atm	External pressure = 1 atm
Internal pressure = 1 atm	Internal pressure = 2 atm	Internal pressure = 3 atm
Temperature = 200 K	Temperature = 200 K	Temperature = 200 K

Experiment B (Heating the gas)



B1	B2	B3
Volume = 1 unit	Volume = 1 unit	Volume = 1 unit
External pressure = 1 atm	External pressure = 1 atm	External pressure = 1 atm
Internal pressure = 1 atm	Internal pressure = 2 atm	Internal pressure = 3 atm
Temperature = 200 K	Temperature = 400 K	Temperature = 600 K

**Note:* Volume in this model is recorded in *units* rather than liters because 4 molecules of gas at the conditions given would occupy a very small space (~1×10^{-22} μL). The particles shown here are much larger compared to the space between them than actual gas particles.

1. In Model 1, what does a dot represent?

   A gas atom or molecule.

2. Name two materials that the containers in Model 1 could be made from that would ensure that they were "nonflexible?"

   Glass and metal are nonflexible.

3. In Model 1, the length of the arrows represents the average kinetic energy of the molecules in that sample. Which gas variable ($P_{internal}$, V, T or n) is most closely related to the length of the arrows in Model 1?

   Temperature is related to average kinetic energy, and thus to the length of the arrows.

4. Complete the following table for the two experiments in Model 1.

	Experiment A	**Experiment B**
Independent Variable	*Moles or number of molecules*	*Temperature*
Dependent Variable	*Internal pressure*	*Internal pressure*
Controlled Variable(s)	*Volume, temperature, and the external pressure*	*Volume, moles or number of molecules, and external pressure*

5. Of the variables that were controlled in both Experiment A and Experiment B in Model 1, one requires a nonflexible container. Name this variable, and explain why a nonflexible container is necessary. In your answer, consider the external and internal pressure data given in Model 1.

   Controlling the volume requires a nonflexible container because any time the internal pressure is different from the external pressure the container would expand or contract if it were flexible. You need a nonflexible container to contain a gas with an internal pressure that differs from the external pressure.

Read This!

Pressure is caused by molecules hitting the sides of a container or other objects. The pressure changes when the molecules change *how often* or *how hard* they hit. A nonflexible container is needed if the gas sample is going to have an internal pressure that is different from the external pressure. If a flexible container is used, the internal pressure and external pressure will always be the same because they are both pushing on the sides of the container equally. If either the internal or external pressure changes, the flexible container walls will adjust in size until the pressures are equal again.

6. Name the two factors related to molecular movement that influence the pressure of a gas.

   How hard the molecules hit and how often they hit the sides of the container.

7. Provide a molecular-level explanation for the increase in pressure observed among the flasks of Experiment A.

   As more molecules are added to a flask, they hit the sides of the flask more often and increase the pressure.

8. Provide a molecular-level explanation for the increase in pressure observed among the flasks of Experiment B.

   As the gas molecules are heated, their average kinetic energy increases. They hit the sides of the container more often and also harder, which increases the pressure.

9. Predict what would happen to the volume and internal pressure in Experiment A of Model 1 if a flexible container were used.

   As more gas molecules were added, the internal pressure would increase at first. That would push the sides of the flexible container outward, causing the volume to expand until the pressure equalized.

10. Predict what would happen to the volume and internal pressure in Experiment B of Model 1 if a flexible container were used.

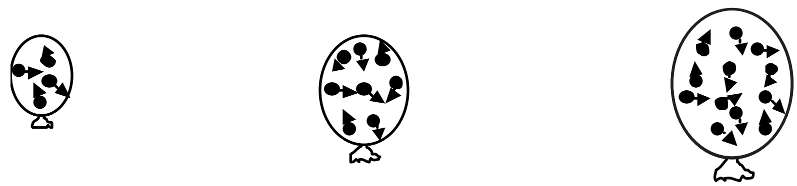
    As the gas molecules are heated, the internal pressure would increase at first. That would push the sides of the flexible container outward, causing the volume to expand until the pressure equalized.

11. For each experiment in Model 1, determine the relationship between the independent and dependent variables, and write an algebraic expression for the relationship using variables that relate to the experiment ($P_{internal}$, V, T or n). Use *k* as a proportionality constant in each equation.

	Experiment A	**Experiment B**
Direct or Inverse Proportion?	*Direct*	*Direct*
Algebraic Expression	$P = kn$	$P = kT$

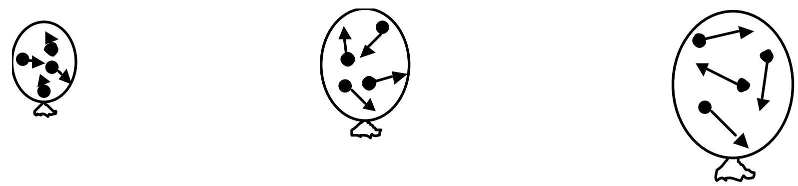
Model 2 – Gases in a Flexible Container

Experiment C
(Adding more gas)



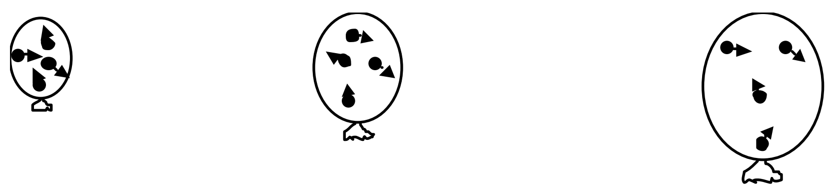
C1	C2	C3
Volume = 1 unit	Volume = 2 units	Volume = 3 units
External pressure = 1 atm	External pressure = 1 atm	External pressure = 1 atm
Internal pressure = 1 atm	Internal pressure = 1 atm	Internal pressure = 1 atm
Temperature = 200 K	Temperature = 200 K	Temperature = 200 K

Experiment D
(Heating the gas)



D1	D2	D3
Volume = 1 unit	Volume = 2 units	Volume = 3 units
External pressure = 1 atm	External pressure = 1 atm	External pressure = 1 atm
Internal pressure = 1 atm	Internal pressure = 1 atm	Internal pressure = 1 atm
Temperature = 200 K	Temperature = 400 K	Temperature = 600 K

Experiment E
(Reducing the external pressure on the gas)



E1	E2	E3
Volume = 1 unit	Volume = 2 units	Volume = 3 units
External pressure = 1 atm	External pressure = 0.50 atm	External pressure = 0.33 atm
Internal pressure = 1 atm	Internal pressure = 0.50 atm	Internal pressure = 0.33 atm
Temperature = 200 K	Temperature = 200 K	Temperature = 200 K

12. Consider the gas samples in Model 2.

    a. Name two materials that the containers in Model 2 could be made from that would ensure that they were "flexible"?

    Latex and rubber are flexible materials.

    b. What is always true for the external and internal pressures of a gas in a flexible container?

    The internal pressure is equal to the external pressure.

13. Complete the following table for the three experiments in Model 2.

	Experiment C	Experiment D	Experiment E
Independent Variable	*Moles or number of molecules*	*Temperature*	*External pressure*
Dependent Variable	*Volume*	*Volume*	*Volume*
Controlled Variable(s)	*Temperature* *External pressure*	*Moles or number of molecules* *External pressure*	*Moles or number of molecules* *Temperature*

14. Provide a molecular level explanation for the increase in volume among the balloons in Experiment C. (How often and/or how hard are the molecules hitting the sides of the container?)

As more gas molecules are added, they hit more often, increasing the internal pressure of the gas. This pushes on the sides of the container increasing the volume. As the volume increases, the gas molecules hit less often, reducing the internal pressure to the point that it matches the external pressure again.

15. Provide a molecular level explanation for the increase in volume among the balloons in Experiment D.

As the gas molecules are heated, they hit more often and harder increasing the internal pressure of the gas. This pushes on the sides of the container increasing the volume. As the volume increases, the gas molecules hit less often, reducing the internal pressure to the point that it matches the external pressure again.

16. Provide a molecular level explanation for the increase in volume among the balloons in Experiment E.

As the external pressure is decreased, the higher internal pressure pushes on the sides of the container. As the volume increases, the gas molecules hit less often, reducing the internal pressure to the point that it matches the external pressure again.

STOP

17. Compare Experiment A of Model 1 with Experiment C of Model 2. How are these two experiments similar and how are they different in terms of variables?

The independent variable in both experiments is moles of gas. However, in experiment A, pressure is the dependent variable (nonflexible container), while in experiment C, volume is the dependent variable (flexible container).

18. Compare Experiment B of Model 1 with Experiment D of Model 2. How are these two experiments similar and how are they different in terms of variables?

The independent variable in both experiments is temperature. However, in experiment B, pressure is the dependent variable (nonflexible container) and in experiment D, volume is the dependent variable (flexible container).

19. If Experiment E of Model 2 were done in a nonflexible container, would there be any change to the internal pressure of the flask when the external pressure was reduced? Explain.

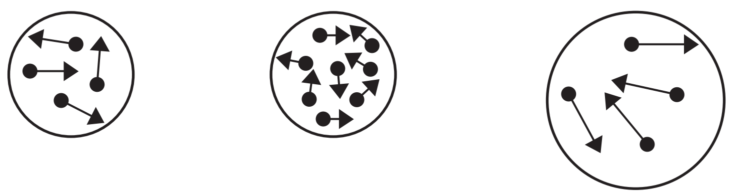
No—as the external pressure is decreased, there would be no change in the volume of gas or the internal pressure because the nonflexible container would contain the gas.

20. For each experiment in Model 2, determine the relationship between the independent and dependent variables, and write an algebraic expression for the relationship using variables that relate to those in the experiment ($P_{internal}$, V, T or n). Use *k* as a proportionality constant in each equation.

Constant Pressure

	Experiment C	**Experiment D**	**Experiment E**
Direct or Inverse Proportion?	*Direct*	*Direct*	*Inverse*
Algebraic Expression	$V = kn$	$V = kT$	$V = \frac{k}{P}$

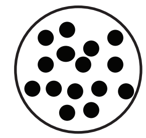
21. The three samples of identical gas molecules below all have the same internal pressure. Rank the samples from lowest temperature to highest temperature, and add arrows of appropriate size to illustrate the average kinetic energy of the molecules in the samples.



Middle *Lowest temperature* *Highest temperature*

Extension Questions

22. Draw a sample of gas that is colder than all three of the samples in Question 21. Explain why you are sure that it is colder.



Answers will vary.

This gas sample has the same volume as the "coldest" sample in Question 21, but it has more molecules.

23. Four of the relationships you investigated in Models 1 and 2 are named after scientists who discovered the relationships. Use the Internet or your textbook to match each of the scientists below with the appropriate law. Write the algebraic expression that describes the law in the box below each name.

Robert Boyle	Jacques Charles	Guillaume Amontons	Amedeo Avogadro
$PV = k$	$V = kT$	$P = kT$	$V = kn$

Read This!

Chemists combine all of the relationships seen in Models 1 and 2 into one law—the **Ideal Gas Law**. It is one equation that describes gas behavior and the relationship among all four variables, P, V, T, and n. In the Ideal Gas Law the proportionality constant is represented by the letter R (rather than the generic *k*).

24. Circle the algebraic equation below that best combines all of the relationships you identified among P, V, T, and n in this activity.

$P = RTnV$ $PT = RnV$ $PV = nRT$ $PTV = Rn$

Teacher Resources – Gas Variables

Learning Objectives

1. Compare and contrast how gases behave in nonflexible containers versus flexible containers.
2. Determine if two gas variables have a direct or inverse proportional relationship based on given data.
3. Explain the relationships among gas variables on a molecular level by describing changes in how hard and how often molecules are hitting.

Prerequisites

1. Students should be able to identify the independent, dependent, and controlled variables in an experiment.
2. Students should be familiar with direct and inverse proportions, including the basic mathematical relationships and how to calculate the proportionality constant (k).
3. Students should be familiar with the kinetic molecular theory—that the molecules in a substance have varying speed, but that the average kinetic energy of the molecules is proportional to the absolute temperature.
4. Students should be able to convert Kelvin temperatures into Celsius.
5. Students should be familiar with moles as a unit for counting molecules in a sample.

Assessment Questions

1. Select the equation below that gives the correct relationship between the internal pressure of a gas and the volume of a flexible container.

   a. $P = k/v$

   b. $P = kV$

   c. $V = kP$

   d. $k = p/V$

2. Explain, on the molecular level, the change in internal pressure of a gas sample in a nonflexible container when the temperature is raised.
3. Explain, on the molecular level, the change in volume in a flexible container when more gas is added.

Assessment Target Responses

1. *a.*
2. *When the temperature of a gas is increased, the average kinetic energy of the molecules increases. This makes the gas molecules hit harder and more often, which increases the pressure.*

3. *When more gas molecules are added to a flexible container, the molecules hit the sides of the container more often, raising the internal pressure of the gas. This pushes the walls of the container out, increasing the volume. As the volume increases, the gas molecules have more space to move in, and they hit the sides of the container less often, reducing the pressure. When the container is large enough that the internal and external pressures are again equal, the container stops expanding.*

Teacher Tips

- Students will need to have a good understanding of independent, dependent, and controlled variables to answer several of the questions in this activity. It would be a good idea to review these terms before beginning the activity.
- Students need to have a good understanding of direct and inverse relationships between variables before beginning this activity. Review the equations for these relationships as well as the effect on the data (maybe show graphs of each) to remind students of what they have learned in their math courses. You may want to point out that an inverse relationship ($y = k/x$) is not the same as a negative correlation ($y = -kx$), as students often confuse the two.
- This activity should supplement lab activities relating to gas law relationships. At the very least, students should be given a syringe and pressure probe to gather data for Boyle's law. The Flinn Scientific activity-stations laboratory kit, *Properties of Gases and Gas Laws,* Catalog No. AP7092, uses four self-contained "mini-labs" that students complete to investigate Diffusion of Gas Molecules, Atmospheric Pressure, Boyle's Law, and Charles's Law. Flinn Scientific also offers *Boyle's Law in a Bottle,* Catalog No. AP6855, which uses "pressurized" soda bottles and syringes.
- In most cases students can see how changing the volume of a gas or the number of particles in a gas sample will change how often the particles will hit the sides of the container. However, the effect of temperature is more difficult for them to understand. Temperature has a double effect—molecules hit the sides more often as well as harder. This may require a class discussion at Question 8. This is also a good time to point out that molecules of differing masses all produce the same pressure under the same temperature, moles, and volume conditions, even though their speeds are different. A smaller molecule will not hit with as much force, but it hits more often because it is moving faster. A larger molecule will hit with a lot of force, but not as often because it is moving slower.
- There are several web-based simulations (accessed January 2012) that can supplement a unit on gas laws.

  This Web site is very clear and interactive: http://phet.colorado.edu/en/simulation/gas-properties It includes many teacher-developed lesson plans for use with the simulation.

  On this site, tell students to skip all text and play with the simulations at the bottom of each web page: http://www.chm.davidson.edu/vce/GasLaws/index.html

  Here is a site where you may peruse and choose appropriate simulations:
  http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animationsindex.htm

Notes

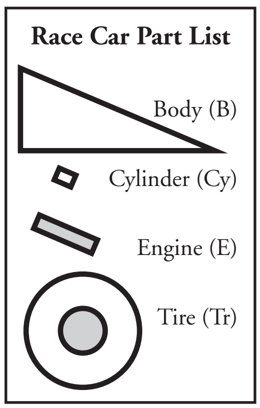
Limiting and Excess Reactants

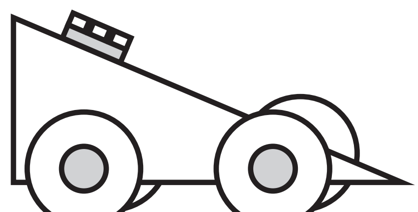
Is there enough of each chemical reactant to make a desired amount of product?

Why?

If a factory runs out of tires while manufacturing cars, production stops. No more cars can be fully built without ordering more tires. A similar thing happens in a chemical reaction. If there are fixed amounts of reactants to work with in a chemical reaction, one of the reactants may be used up first. This prevents the production of more products. In this activity, you will look at several situations where the process or reaction is stopped because one of the required components has been used up.

Model 1 – Assembling a Race Car





Race Car

1. How many of each part are needed to construct 1 complete race car?

   Body (B) Cylinder (Cy) Engine (E) Tire (Tr)

2. How many of each part would be needed to construct 3 complete race cars? Show your work.

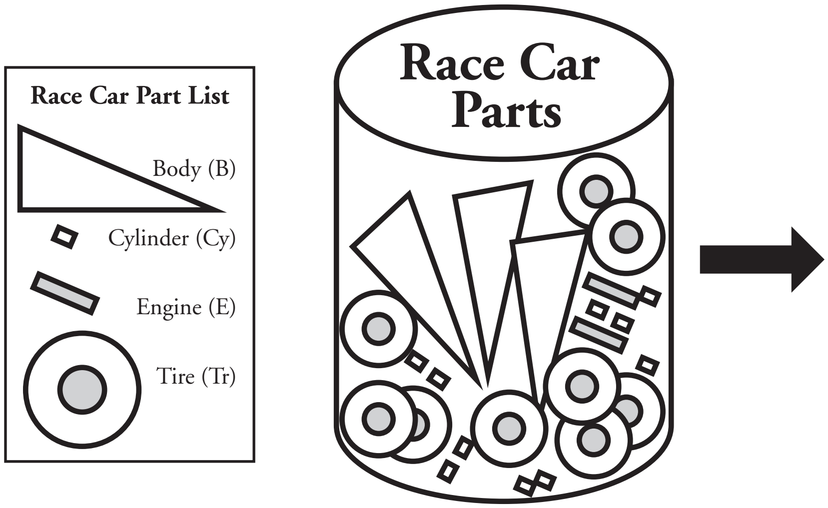
   Body (B) Cylinder (Cy) Engine (E) Tire (Tr)

3. Assuming that you have 15 cylinders and an unlimited supply of the remaining parts:
   a. How many complete race cars can you make? Show your work.

   b. How many of each remaining part would be needed to make this number of cars? Show your work.

STOP

Model 2 – Manufacturing Race Cars



Container A

4. Count the number of each Race Car Part present in Container A of Model 2.

   Body (B) Cylinder (Cy) Engine (E) Tire (Tr)

5. Complete Model 2 by drawing the maximum number of cars that can be made from the parts in Container A. Show any excess parts remaining also.

6. A student says "I can see that we have three car bodies in Container A, so we should be able to build three complete race cars." Explain why this student is incorrect in this case.

7. Suppose you have a very large number (dozens or hundreds) of tires and bodies, but you only have 5 engines and 12 cylinders.

   a. How many complete cars can you build? Show your work.

   b. Which part (engines or cylinders) limits the number of cars that you can make?

8. Fill in the table below with the maximum number of complete race cars that can be built from each container of parts (A–E), and indicate which part limits the number of cars that can be built. Divide the work evenly among group members. Space is provided below the table for each group member to show their work. Have each group member describe to the group how they determined the maximum number of complete cars for their container. Container A from Model 2 is already completed as an example.

1 B + 3 Cy + 4 Tr + 1 E = 1 car

Container	Bodies	Cylinders	Tires	Engines	Max. Number of Completed Cars	Limiting Part
A	3	10	9	2	2	Engines
B	50	12	50	5		
C	16	16	16	16		
D	4	9	16	6		
E	20	36	40	24		

9. The Zippy Race Car Company builds toy race cars by the thousands. They do not count individual car parts. Instead they measure their parts in "oodles" (a large number of things).

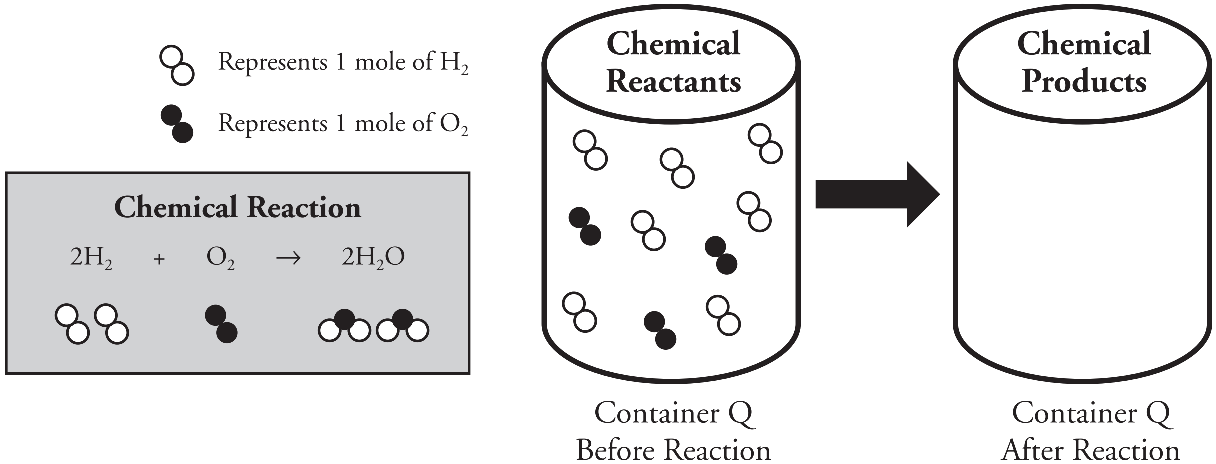
   a. Assuming the inventory in their warehouse below, how many race cars could the Zippy Race Car Company build? Show your work.

Body (B)	Cylinder (Cy)	Engine (E)	Tire (Tr)
4 oodles	5 oodles	8 oodles	8 oodles

   b. Explain why it is not necessary to know the number of parts in an "oodle" to solve the problem in part *a*.

10. Look back at the answers to Questions 8 and 9. Is the component with the smallest number of parts always the one that limits production? Explain your group's reasoning.

Model 3 – Assembling Water Molecules



11. Refer to the chemical reaction in Model 3.

   a. How many moles of water molecules are produced if one mole of oxygen molecules completely reacts?

   b. How many moles of hydrogen molecules are needed to react with one mole of oxygen molecules?

12. Complete Model 3 by drawing the maximum moles of water molecules that could be produced from the reactants shown, and draw any remaining moles of reactants in the container after reaction as well.

   a. Which reactant (oxygen or hydrogen) limited the production of water in Container Q?

   b. Which reactant (oxygen or hydrogen) was present in excess and remained after the production of water was complete?

13. Fill in the table below with the maximum moles of water that can be produced in each container (Q–U). Indicate which reactant limits the quantity of water produced—this is the **limiting reactant**. Also show how much of the other reactant—the **reactant in excess**—will be left over. Divide the work evenly among group members. Space is provided below the table for each group member to show their work. Have each group member describe to the group how they determined the maximum number of moles of water produced and the moles of reactant in excess. Container Q from Model 3 is already completed as an example.

$2H_2 + O_2 \rightarrow 2H_2O$

Container	Moles of Hydrogen	Moles of Oxygen	Max. Moles of Water Produced	Limiting Reactant	Reactant in Excess
Q	7	3	6	O_2	1 mole H_2
R	8	3			
S	10	5			
T	5	5			
U	8	6			

14. Look back at Questions 12 and 13. Is the reactant with the smaller number of moles always the limiting reactant? Explain your group's reasoning.

15. Below are two examples of mathematical calculations that could be performed to find the limiting reactant for Container U in Question 13.

$8 \text{ mol } H_2 \left(\frac{2 \text{ mol } H_2O}{2 \text{ mol } H_2} \right) = 8 \text{ mol } H_2O$ $6 \text{ mol } O_2 \left(\frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2} \right) = 12 \text{ mol } H_2O$ Hydrogen makes the lesser amount of product, so it is the limiting reactant.	$8 \text{ mol } H_2 \left(\frac{1 \text{ mol } O_2}{2 \text{ mol } H_2} \right) = 4 \text{ mol } O_2$ needed There are 6 moles of O_2 present, which is more than enough, so H_2 must be the limiting reactant.

a. Do both calculations give the same answer to the problem?

b. Which method was used most by your group members in Question 13?

c. Which method seems "easier," and why?

d. Did your group use any other method(s) of solving this problem that were scientifically and mathematically correct? If so, explain the method.

Extension Questions

16. Consider the synthesis of water as shown in Model 3. A container is filled with 10.0 g of H_2 and 5.0 g of O_2.

    a. Which reactant (hydrogen or oxygen) is the limiting reactant in this case? Show your work. *Hint:* Notice that you are given reactant quantities in mass units here, not moles.

    b. What mass of water can be produced? Show your work.

    c. Which reactant is present in excess, and what mass of that reactant remains after the reaction is complete? Show your work.

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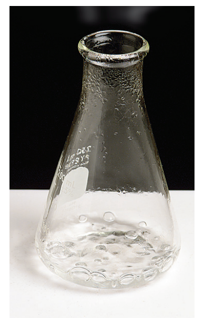
Balloon in the Bottle

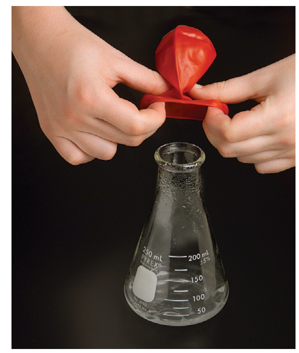
Introduction

Heat some water in a flask, then attach a balloon, cool the flask, and watch as the balloon collapses into the flask. An easy-to-perform variation of the common *Crush the Can* demonstration of atmospheric pressure.

Concepts

- Pressure differential
- Vacuum





Materials

Erlenmeyer flask, borosilicate glass, 250-mL

Balloon, latex, 11-inch size (size to fit flask)

Hot plate or Bunsen burner

Ice bath or cold running water

Water, 25 mL

Safety Precautions

Always practice a demonstration before presenting it to students. Be careful of the hot glass and steam. Wear chemical splash goggles and heat-resistant gloves.

Procedure

1. Add approximately 25 mL of water to a 250-mL Erlenmeyer flask. Heat the water using a hot plate, Bunsen burner or other heat source.
2. As the water comes to a boil and steam begins to rise out of the flask, remove the flask from the heat. Quickly place the balloon over the mouth of the flask.
3. Place the flask under cold running water and the balloon will be pushed into the flask until it fills the entire flask. If the balloon stretches too much, it may break.

Tips

- Use a borosilicate (e.g., Pyrex®) flask with a heavy-duty rim. Do not use an economy-choice flask. Check the flask for chips or cracks before use.
- Stretch out the balloon by inflating and deflating it before using it.
- The demonstration works best if the balloon is centered on the opening when placed over the mouth of the flask. It also helps if the balloon is slightly pushed into the flask when it begins to collapse. If not, it may collapse onto itself and not get drawn into the flask. The demonstration will work without holding it under cold water, but it takes longer to cool the glass and condense the water vapor.
- A hard-boiled, shelled egg can also be used in place of the balloon. A larger flask may be needed depending on the size of the egg.

Discussion

The *Balloon in the Bottle* demonstration is an easy-to-perform variation of the common *Crush the Can* demonstration. Both demonstrations rely on the creation of a pressure differential caused by the condensation of water vapor inside a closed system. As the water vapor cools and condenses, the molecules move more slowly, and a partial vacuum is formed since no more air can enter the flask. The pressure outside the flask is still at atmospheric pressure (approximately 14.7 lb/in^2). This pressure difference will cause the balloon to be pushed into the flask. The balloon is not “sucked” into the flask—it is pushed in by the greater atmospheric pressure that exists outside the closed system. The balloon will continue to be pushed into the flask until the pressure inside the closed system is approximately equal to the atmospheric pressure.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation

Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter, understanding of motions and forces

Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, motions and forces

Reference

Shakhashiri, B. Z. *Chemical Demonstrations: A Handbook for Teachers in Chemistry;* University of Wisconsin: Madison; Vol. 2, pp 6–8.

Materials for *Balloon in the Bottle* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP1900	Balloons, Latex, pkg/20
AP7234	Hot Plate, Flinn, 7″ × 7″
GP3045	Erlenmeyer Flask, Borosilicate Glass, 250-mL

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Crush the Can Demonstration

Introduction

Here's a pressure-packed demonstration that will convince students that air exerts significant pressure!

Concepts

- Pressure differential
- Atmospheric pressure

Materials

Aluminum beverage can, 12-oz, several
Bunsen burner
Support stand and ring
Large bucket
Tap water
Tongs
Wire gauze square

Safety Precautions

Be careful of the hot can and the steam created by heating the water in the can. Wear goggles and protective gloves during the demonstration.

Procedure

1. Clear off the demonstration area; it may get wet.
2. Rinse out an empty 12-oz aluminum beverage can.
3. Set up a Bunsen burner underneath a ring and support stand.
4. Fill the bucket or large container with water so it is about half-full.
5. Add approximately 5–10 mL of tap water to the beverage can.
6. Place the wire gauze square on the ring and the aluminum beverage can on the wire gauze square. Heat the can until the water begins to boil.
7. Allow steam (or the condensed water vapor students associate with steam) to fill the can and begin to rise out of the can.
8. Let the steam escape from the can for about 1–2 minutes. Point out the steam to the students.
9. Turn off the heat.
10. Immediately, pick up the can using tongs and flip it upside-down into the bucket of water. This step may require some practice—the key is to seal off the opening of the can as quickly as possible with the water in the bucket.
11. The can will immediately be crushed, making a loud noise and sending water splashing out of the bucket.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
MS-PS1 Matter and Its Interactions
PS1.A: Structure and Properties of Matter
MS-PS2 Motion and Stability: Forces and Interactions
PS1.A: Forces and Motions
PS1.B: Types of Interactions
Disciplinary Core Ideas: High School
HS-PS1 Matter and Its Interactions
PS1.A: Structure and Properties of Matter
HS-PS2 Motion and Stability: Forces and Interactions
PS1.A: Forces and Motion
PS1.B: Types of Interactions

Science and Engineering Practices
Asking questions and defining problems
Constructing explanations and designing solutions
Developing and using models

Crosscutting Concepts
Cause and effect
Systems and system models
Structure and function

Tips

- Have several cans cleaned and ready to go—your students will want you to repeat this demonstration because it will happen so fast. They will also be amazed at how fast it occurs.
- Practice this demonstration first before showing it to the students. The noise and water splash may surprise you the first time.
- Make sure the water boils long enough to fill the can with water vapor.
- For a larger-scale *Crush the Can* demonstration, purchase Flinn's Collapsing Can Demonstration Kit, Catalog No. AP4695. This kit contains a large 1-gallon can that makes a more impressive demonstration.
- To demonstrate the magnitude of atmospheric pressure, consider purchasing Flinn's Atmosphere Bar, Catalog No. AP5882. The Atmosphere bar is a 1-in^2 by 52 inches long steel bar that weighs 14.7 lbs. Students will be amazed at how heavy the bar is when they try to lift it.

Discussion

The tremendous pressure required to crush the can comes from the differential in pressure that exists between the outside of the can (normal air pressure) and the partial vacuum created inside the can by the condensing water vapor. As soon as the can is inverted and placed into the water, the can becomes a closed system. The water vapor inside the can begins to condense due to the cold water entering the can. The pressure differential is caused by the condensation of the water vapor inside the closed system as the can cools. The pressure on the outside of the can remains at atmospheric pressure (14.7 lb/in^2) while the pressure inside the can is significantly reduced as the water vapor condenses. Remember that the can is not "sucked in"—it is the greater pressure on the outside of the can that pushes in on the can and crushes it. The total pressure exerted on the outside of the can may be calculated by determining the surface area of the outside of the can and multiplying this area by atmospheric pressure per unit area.

Materials for *Crush the Can Demonstration* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP4695	Collapsing Can Demonstration Kit
AP5882	Atmosphere Bar
AP8350	Wire Gauze Squares, Steel, 4″ × 4″
AP8226	Support Stand, 4″ × 6″
AP8230	Support Ring with Rod Clamp, 2″

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

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Lung Model

Hands-on Activity

Introduction

We breathe twenty-four hours a day, every day, without consciously thinking about it. What causes air to rush into our lungs and then rush out again?

Concepts

- Differential air pressure
- Boyle's Law
- Exhalation and Inhalation

Materials

Balloon, large
Balloon, small
Plastic cup with hole, transparent
Rubber stopper, 1-hole
Scissors

Safety Precaution

Wear protective goggles when working with balloons as they may snap off when stretched. Follow all laboratory safety guidelines.

Procedure

1. Place the small balloon over the large end of the one-hole stopper as shown in Figure 1.
2. Insert the rubber stopper securely into the hole from the inside of the plastic cup.
3. Use sharp scissors to cut the large balloon as shown in Figure 2.
4. Have a lab partner hold the cup containing the small balloon. Stretch the large balloon over the end of the cup. Your final model should look like Figure 1.
5. Carefully move the center of the large balloon up and down. Do not pull or push too hard.

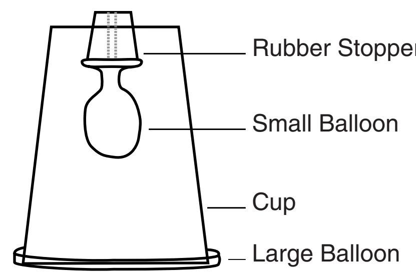

Figure 1. Completed Model

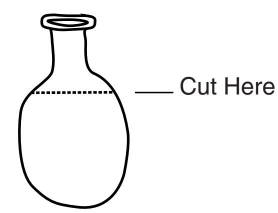

Figure 2. Cutting Large Balloon

Disposal

Students can take their models home and teach family members about lung functioning or you can reuse all the materials for additional classes.

Tips

- Make one of the models prior to the class operation. Practice stretching the large balloon over the bottom of the cup. Students might need assistance at this step. Be sure to cut the balloon just below the neck of the balloon. If the balloon is cut too close to the center, it will rip easily.
- This model, like any model, has its limitations. The real breathing mechanism, as described in the discussion section, points out the multiple contractions involved in breathing. Be sure students realize that, even though this model is fun to operate and does illustrate the general principle of breathing, it doesn't show all of the muscles involved in breathing. Be sure to read the discussion carefully and augment your class discussion as appropriate for your students and your class goals.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12

Evidence, models, and explanation

Form and function

Content Standards: Grades 5–8

Content Standard C: Life Science, structure and function in living systems

Content Standard F: Science in Personal and Social Perspectives; personal health

Content Standards: Grades 9–12

Content Standard C: Life Science, matter, energy, and organization in living systems

Content Standard F: Science in Personal and Social Perspectives; personal and community health

Discussion

The human breathing mechanism is, in principle, a simple concept. The nervous/muscular coordination, however, is complex. The basic principle is that muscular contractions alter the size of the internal chest cavity and create an air pressure differential between the inside of the chest cavity and the atmospheric air pressure outside the body. When the atmospheric air pressure outside the body is greater than inside the lungs, air enters the lungs. When the pressure is greater inside the lungs than outside the body, air leaves the lungs.

Two sets of muscles are basically involved in breathing. Intercostal muscles between the ribs and certain thoracic muscles can contract and relax which results in the raising and lowering of the rib cage. The contraction of the rib cage muscles causes the rib cage to be raised and the chest cavity to enlarge. (See Figure 2A — Inspiration.) While this is happening, the diaphragm (a very strong muscle) simultaneously contracts. This contraction lowers the diaphragm making the internal chest cavity even larger. Because of this chest cavity expansion, the air pressure inside the chest cavity is reduced and becomes less than the outside atmospheric pressure — air rushes into the lungs. These muscle contractions are alternately followed by a relaxation of the diaphragm and rib cage muscles which results in a decrease in the chest cavity size and an increase in air pressure inside the lung cavity. This increased pressure results in air being expelled from the lungs. (See Figure 2B — Expiration.)

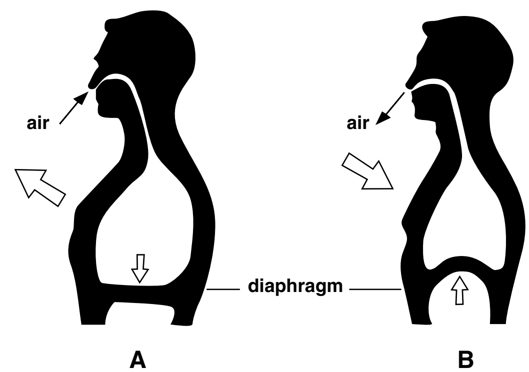

Figure 2 A. Inspiration — diaphragm contracted and chest muscles contracted raising rib cage causing increased volume and decreased air pressure.

Figure 2 B. Expiration — diaphragm relaxed and chest muscles relaxed lowering rib cage and causing decreased volume and increased air pressure.

In summary, changes in the size of the chest cavity affect the air pressure in the lungs. When the chest expands, the pressure within the chest falls. Because of this reduced air pressure, air is forced in from the outside, where it is under greater atmospheric pressure. When the chest cavity is reduced, the internal pressure becomes greater than the atmospheric pressure and air is forced out of the breathing passages. The autonomically controlled, rhythmic increase and decrease in the chest cavity's volume is the mechanical "pump" that drives air into and out of the lungs.

The *Lung Model—Student Laboratory Kit* is available from Flinn Scientific, Inc.

Catalog No.	Description
FB1442	Lung Model—Student Laboratory Kit
FB1110	Functioning Lung Model

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Cartesian Diver Design Challenge

Introduction

Cartesian divers are great toys that can be used to teach important science concepts. Several variations of Cartesian divers are on the market. Imagine that you and your classmates are members of a research and development team at a toy company and are challenged to design a new Cartesian diver toy. Can you design a toy that includes at least three divers that will descend and ascend in a particular order?

Concepts

- Density
- Buoyancy

Materials

Beaker, 600-mL or plastic cup

Hex nut, ¼-inch

Hot-melt glue gun and glue stick (optional)

Pipets, disposable plastic, graduated

Plastic soda bottle, clear, 1- or 2-L with cap

Scissors

Safety Precautions

The materials used in the standard activity are considered nonhazardous. Exercise caution when handling the hot glue gun. Wipe up any water spills immediately. Please follow all normal laboratory safety guidelines.

Standard Diver Preparation

1. Cut off all but 15 mm of the pipet stem (see Figure 1).

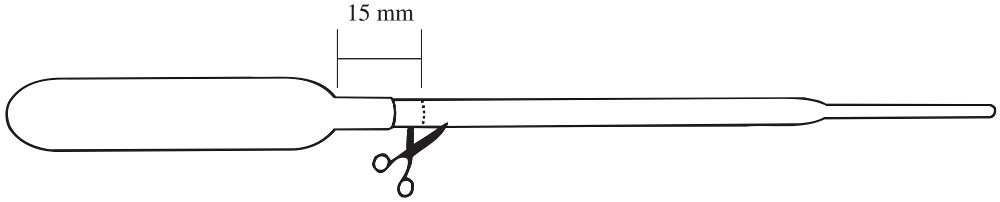

Figure 1. Cutting the Pipet

2. Screw the nut securely onto the pipet stem. The hex nut will make its own threads as it goes.
3. Fill the 600-mL beaker approximately ⅘ full with tap water.
4. Place the pipet–nut diver assembly into the beaker of water and observe that it floats rather buoyantly in an upright position with the hex nut acting as ballast.
5. Squeeze out some of the air and draw water up into the pipet. Now check the buoyancy. If too much water is drawn up into the diver, it will sink. If this happens, simply lift it out of the water, squeeze out a few drops of water and let air back in to replace the water. Using this technique, adjust the amount of water in the assembly so that it just barely floats. (In other words, fine-tune the assembly's density to make it slightly less than that of water.)

Variation: Closed-System Diver

1. Follow steps 1–5 in the *Standard Diver Preparation* section.
2. Remove the diver from the beaker and squeeze out one or two drops of water. Using a cotton swab or paper towel, pat dry the inside rim of the open stem.
3. Holding the bulb with the stem end upward, squeeze the bulb very slightly to expel a very small amount of air. Hold the squeeze while carefully placing a drop of hot-melt glue in the stem opening of the diver, and then relax the squeeze. The drop of hot glue will be pulled into the stem (see Figure 2).

4. Wait 1–2 minutes for the drop of glue to harden and seal the mouth of the diver.

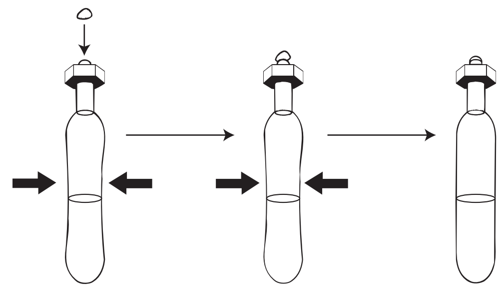

Figure 2.

Procedure

1. Place the standard diver assembly in a plastic 1-or 2-L bottle that has been *completely* filled with water and securely screw on the cap (see Figure 3).
2. Test the standard diver by squeezing the bottle and observe any changes in the position or behavior of the Cartesian diver.
3. Release the “squeeze” and observe any “return” behavior of the diver.
4. Repeat the process and propose an explanation for the results.
5. Test the closed-system diver in the 1-or 2-L bottle. Observe and record its behavior as you squeeze and release the bottle.
6. Does the behavior or action of the closed-system diver reinforce or change your proposed explanation for the results observed in the standard diver test?

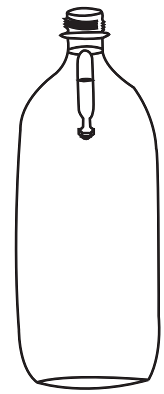

Figure 3.

Design Challenge

The challenge is to design a Cartesian diver toy with three or more divers that will descend in a pre-determined order. The toy should have a “theme” that enhances the design.

1. Form a working group with 2-3 other students and consider the following questions relating to the effects of density and buoyancy on the properties of a Cartesian diver.
   a. Can the density of the diver be quantified?
   b. Is the relationship between the amount of water in a diver and its density linear?
   c. Should the divers be open (standard) or closed? What are the advantages and disadvantages of each type?
   d. Will the temperature of the water or the temperature of the room affect the results?
   e. Does the size of the bottle matter?
2. Students should then plan, discuss, test, and evaluate their designs.
   a. Decide upon the number of divers to include and determine the theme of the toy—other than density, why are the divers descending in a particular order?
   b. Discuss and design a procedure to test the divers.
   c. List any safety concerns and the precautions that will be implemented to keep yourself, your classmates, and your instructor safe during testing.
   d. Consider the strengths and limitations of your design.
   e. How will the testing data be recorded?
   f. How will you analyze the data to determine a successful design?
   g. Review your design, safety precautions, procedure, data tables, and proposed analysis with your instructor prior to testing the design.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
- MS-PS1 Matter and Its Interactions
  - PS1.A: Structure and Properties of Matter
- MS-PS2 Motion and Stability: Forces and Interactions
  - PS2.A: Forces and Motion
- MS-ETS1 Engineering Design
  - ETS1.B: Developing Possible Solutions
  - ETS1.C: Optimizing the Design Solution

Disciplinary Core Ideas: High School
- HS-PS2 Motion and Stability: Forces and Interactions
  - PS2.A: Forces and Motion

Science and Engineering Practices
- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluation, and communicating information

Crosscutting Concepts
- Patterns
- Cause and effect
- Systems and models
- Structure and function
- Stability and change

Tips

- It is considerably more convenient to adjust the density of the diver and to test for flotation in a 600-mL beaker or in a cup of water, rather than in the bottle itself.
- It is advisable to fill the plastic bottle completely with water. If the bottle contains too much air, then when the bottle is squeezed, the work will go into compressing the large air space at the top of the bottle rather than the smaller air pocket in the diver.
- This assembly is formally known as a Cartesian diver after René Descartes, a 17th century French mathematician.
- The manufacturers of plastic pipets change their designs and specifications occasionally. Therefore, the hex-nut size of ¼ -inch may not exactly fit the pipet. In this case, wrap the stem of the pipet near the bulb with clear tape to increase its diameter.
- One advantage to the closed-system diver is that a drop or two of food coloring may be added before sealing the pipet stem with hot-melt glue. The main disadvantage is that the bulb must be reopened if any adjustments need to be made to the density. One method it to heat a stiff wire in a flame and use the hot end to melt a hole in the plug of glue.
- Instructors may want to limit the number of divers included in the challenge. Up to ten divers in a 2-L bottle is possible, but squeezing the bottle enough to get all the divers to descend may be difficult.
- Students may need one or two examples of a theme for multiple descending divers—numbered divers that descend in order, lettered divers that spell a word or secret message, etc.
- Show students a few manufactured or homemade variations of the standard Cartesian diver before presenting the Design Challenge. Two manufactured variations, *Squidy* and *Hook Cartesian Divers* are available from Flinn Scientific (Catalog Nos. AP8721 and AP4548, respectively).
- A *Cartesian Diver Construction—Super Value Kit* is available from Flinn Scientific (Catalog No. AP9082). Enough pipets and hex nuts are provided to build 100 Cartesian divers. A *Cartesian Diver Design Challenge—Guided-Inquiry Kit* (Catalog No. AP7926) is also available and includes instructions and materials for three different design challenges.
- A video of this activity, *Cartesian Diver-sions*, presented by Bob Becker, is available for viewing as part of the Flinn Scientific “Best Practices for Teaching Chemistry” Teacher Resource Videos. Please visit the Flinn Website at http://www.flinnsci.com for viewing information. The activity is found with the *Gas Laws* videos.

Discussion

The sinking and rising of a standard Cartesian diver can be explained in two ways.

1. Consider the diver assembly to consist of the pipet bulb, the hex nut, and the air and water inside. As the bottle is squeezed, water is forced up into the assembly (because the air pocket inside the bulb is compressible, but the water in the bottle is not). This adds to the mass of the diver assembly without changing the volume, thus increasing the density of the diver assembly (density = mass/volume).
2. On the other hand, consider the diver assembly to consist of the bulb, the hex nut, and the air inside, but not the water—it is part of the surrounding fluid. As the bottle is squeezed, it compresses the air pocket and thus decreases the total volume of the diver. Since the mass remains constant, the diver assembly's density increases.

Either way, when the Cartesian diver's density increases, it becomes greater than that of the surrounding water, and the diver sinks. When the pressure is released, the compressed air pocket inside the bulb pushes the extra water back out, and the diver assembly assumes its original density, which is slightly less than the density of the water, and it rises to the surface.

The closed-system diver responds differently to the increased pressure since the glue plug prevents water from entering the diver. When the bottle is squeezed, the sides of the pipet bulb curve inward, decreasing the volume. With no change in mass, the density increases and the diver sinks.

Acknowledgment

Special thanks to Bob Becker, Kirkwood High School, Kirkwood, MO for providing the idea and the instructions for this activity to Flinn Scientific.

Cartesian diver drawings provided by Susan Gertz.

References

Sarquis, M. & Sarquis, J. L. *Fun with Chemistry: A Guidebook of K–12 Activities;* Institute for Chemical Education, University of Wisconsin: Madison, 1993; Vol. 2; pp. 123–140.

Materials for *Cartesian Diver Design Challenge* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP7926	Cartesian Diver Design Challenge—Guided-Inquiry Kit
AP9082	Cartesian Diver Construction—Super Value Kit
AP8721	Squidy—Cartesian Diver
AP4548	Hook—Cartesian Diver

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Marshmallow in a Vacuum

Boyle's Law

Introduction

Help students explore and understand Boyle's Law with this simple demonstration. See how a change in pressure affects the volume of a marshmallow. Students will easily remember the relationship between pressure and volume after participating in this activity.

Concepts

- Pressure
- Volume
- Boyle's law
- Gas laws

Materials

Syringe, without needle, plastic, 30-mL

Miniature marshmallow, fresh

Felt-tip pen (optional)

Syringe tip cap (optional)

Safety Precautions

Although the materials used in this activity are considered nonhzardous, please observe all normal laboratory safety guidelines. Food-grade items that have been brought into the laboratory are considered laboratory chemicals and are for lab use only. Do not taste or ingest any materials in the chemistry laboratory. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. If desired, use a felt-tip pen to draw a happy face on the end of a miniature marshmallow.
2. Remove the end cap from the tip of a 30-mL plastic syringe.
3. Remove plunger from the syringe and insert the marshmallow into the syringe.
4. Place plunger back in syringe so the volume reading is approximately at the 15-mL mark.
5. Place a syringe tip cap over the tip of the syringe. Pull the plunger out—decreasing the pressure inside the syringe. The marshmallow should expand as its volume increases.
6. Now push the syringe in—increasing the pressure inside the syringe. The marshmallow should shrink as its volume decreases.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. The marshmallow should be removed from syringe and put into the trash according to Flinn Suggested Disposal Method #26a. Clean work area and wash hands thoroughly with soap and water before leaving the laboratory.

Tips

- A finger may be used to "seal" the syringe instead of a syringe tip cap, if needed.
- Compare the marshmallow from the syringe to a fresh marshmallow.

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Discussion

When the syringe plunger is pulled out, the volume of the chamber increases but the amount of gas remains constant because it is in a closed system. This causes the pressure inside the syringe chamber to decrease. The lower pressure on the marshmallow causes its volume to increase according to Boyle's Law. The expansion is due to the many trapped air bubbles (like small "internal balloons") within the marshmallow that are initially at atmospheric pressure. As the pressure outside these air bubbles (within the chamber) is reduced, the bubbles will expand to many times their original volume in order to equilibrate the pressure on either side of the bubble wall. Thus, as the pressure decreases ($P\downarrow$), volume increases ($V\uparrow$) in an inverse relationship according to the following equations.

$$PV = nRT$$ *Equation 1 – Ideal Gas Law*

$$P_1 \times V_1 = P_2 \times V_2$$ *Equation 2 – Boyle's Law*

This increase in volume makes for a memorable visual event and a great stimulus for the discussion of the elements of Boyle's Law. Students can visualize the loss in pressure and easily see the increase in volume.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Marshmallow in a Vacuum* activity, presented by Jesse Bernstein, is available in *Boyle's Law*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Marshmallow in a Vacuum* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP1732	Syringe, 30-mL
AP1297	Felt-tip Pen, Black
AP8958	Syringe Tip Cap

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.