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

Ionic and Molecular Compounds

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

Chemical Reactions and Stoichiometry

- Types of Chemical Reactions
- Relative Mass and the Mole
- Mole Ratios
- Limiting and Excess Reactants

Properties of Gases

- Gas Variables

Solubility and Solutions

- Saturated and Unsaturated Solutions
- Solubility
- Molarity

Thermochemistry

- Calorimetry
- Bond Energy

Equilibrium

- Equilibrium

Acids and Bases

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

Oxidation and Reduction

- Oxidation and Reduction
- The Activity Series
- Batteries

POGIL AP* Chemistry Activities

Gas Variables

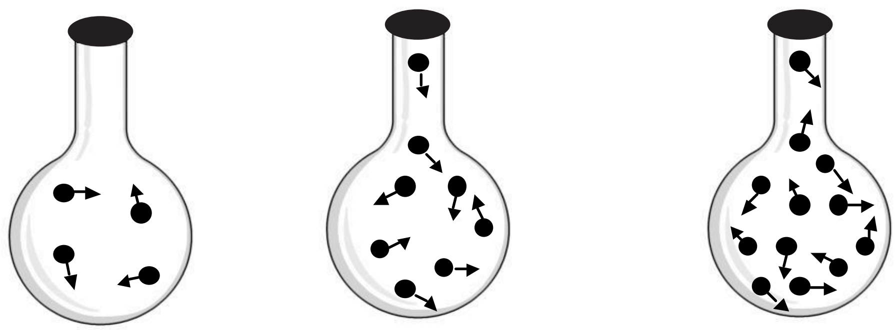
How are the variables that describe a gas related?

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.

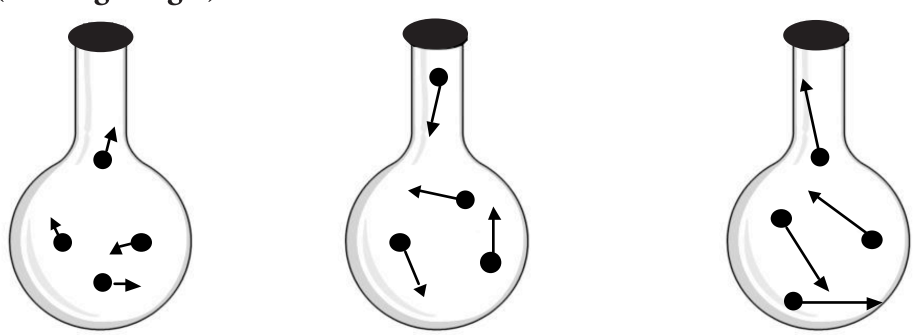
Model 1 – Gases in a Nonflexible Container

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.

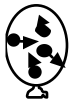
11. For each experiment in Model 1, determine the relationship between the independent and dependent variables, and write an algebraic expression for the relationship using variables that relate to the experiment ($P_{internal}$, V, T or n). Use *k* as a proportionality constant in each equation.

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

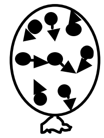
STOP

Model 2 – Gases in a Flexible Container

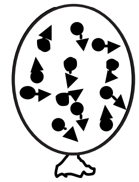
Experiment C
(Adding more gas)



C1
Volume = 1 unit
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K

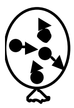


C2
Volume = 2 units
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K

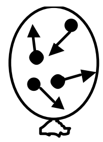


C3
Volume = 3 units
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K

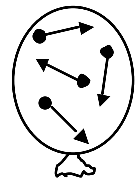
Experiment D
(Heating the gas)



D1
Volume = 1 unit
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 200 K

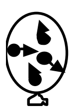


D2
Volume = 2 units
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 400 K

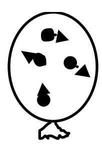


D3
Volume = 3 units
External pressure = 1 atm
Internal pressure = 1 atm
Temperature = 600 K

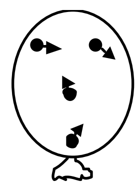
Experiment E
(Reducing the external pressure on the gas)



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?

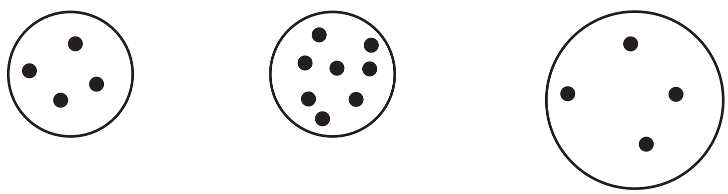
19. If Experiment E of Model 2 were done in a nonflexible container, would there be any change to the internal pressure of the flask when the external pressure was reduced? Explain.

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

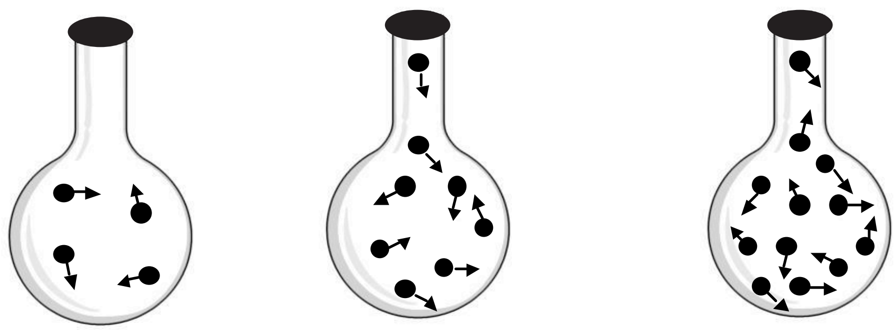
How are the variables that describe a gas related?

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.

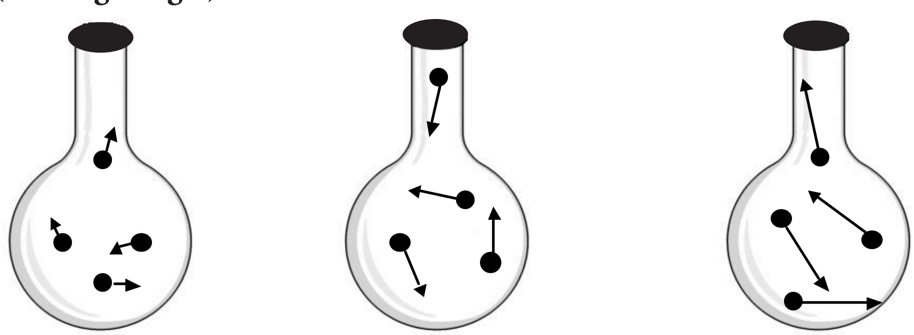
Model 1 – Gases in a Nonflexible Container

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.

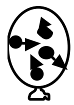
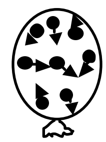
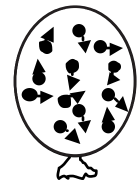
11. For each experiment in Model 1, determine the relationship between the independent and dependent variables, and write an algebraic expression for the relationship using variables that relate to the experiment ($P_{internal}$, V, T or n). Use *k* as a proportionality constant in each equation.

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

STOP

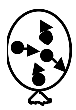
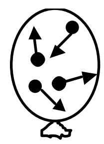
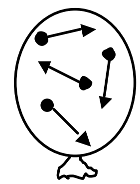
Model 2 – Gases in a Flexible Container

Experiment C
(Adding more gas)

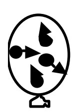
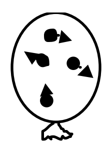
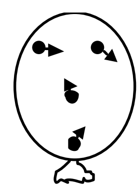
C1	C2	C3
Volume = 1 unit	Volume = 2 units	Volume = 3 units
External pressure = 1 atm	External pressure = 1 atm	External pressure = 1 atm
Internal pressure = 1 atm	Internal pressure = 1 atm	Internal pressure = 1 atm
Temperature = 200 K	Temperature = 200 K	Temperature = 200 K

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.

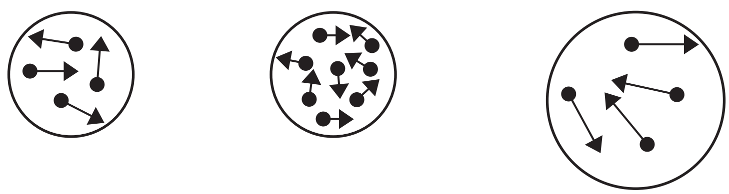
No—as the external pressure is decreased, there would be no change in the volume of gas or the internal pressure because the nonflexible container would contain the gas.

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.

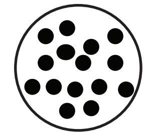


Middle *Lowest temperature* *Highest temperature*

STOP

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