

The Connected Chemistry Curriculum

Adknowledgements

The Connected Chemistry Curriculum modules and technology included in this manual were developed through a collaborative process with contributions from the individuals listed below.

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System Requirements

The Connected Chemistry Curriculum has a software component (a set of *Simulations*) which is available at The Connected Chemistry Curriculum website, <u>connchem.org</u>. This software is necessary to use the curriculum, and is open-source and free of charge.

Besides the CCC software, you will need:

- A personal computer of recent vintage, with an OpenGL-enabled graphics card.
- **A 13" screen (or larger), with at least 1280 × 800 (WXGA) pixel resolution** For most computer monitors this is not a problem. Projectors, on the other hand, sometimes only manage VGA resolution (640 x 480), which will not allow sufficient room for our Simulations.
- The latest Java runtime environment (JRE) As of this writing, the latest JRE is Java 6, version 29. Java is free of charge: http://www.java.com/en/download/
- **Macintosh OS X 10.6 (Snow Leopard) or later, or Windows 7 or later** Earlier versions of the Macintosh OS or Windows may run, but may suffer performance issues. The software should also run on Linux. None of these options have been tested, however, so make sure you run all simulations before using them live in the classroom.



Troubleshooting

Please consult The Connected Chemistry Curriculum website (<u>connchem.org</u>) for up-to-date troubleshooting information, and to download software



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Welcome to *The Connected Chemistry Curriculum*! The Connected Chemistry Curriculum, or CCC, is designed to help students learn about chemistry by directly exploring the submicroscopic level of matter and phenomena that form the basis of study in chemistry. Educators designed CCC using direct feedback from teachers, students and researchers. CCC uses computer-based simulations to provide a unique submicroscopic perspective of the chemical world for students.

Activity Icons

These icons will be found throughout the teacher and student manuals. The icons designate the purpose/theme of the activity or section.



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Student's Lesson at a Glance

Lesson Summary

This lesson contains four activities. Students explore the air composing the Earth's atmosphere to learn that the atmosphere is a heterogeneous mixture, while the air on ground level is a homogeneous mixture of many gases. Students classify gases as monatomic, diatomic, or molecular in structure. Students examine the density of gases and how gases create homogeneous mixtures. Students also utilize the periodic table to help identify trends for gases. The next activity in the lesson walks students through the physical properties of air with simulation and sketching activities about the compression, volume, and diffusion of gases. The final activity requires students to defend their small group's answers for three different claims about gases.

SWBAT (Student will be able to)

- Understand that gases can exist as pure compounds or as a mixture of compounds
- Understand that the air surrounding the Earth is a mixture of gases
- Determine the major components of air

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.



CCC Reminder

- Mixtures do not necessarily need to be made up of liquids and solids. Mixtures can also be made up of gases.
- You may need to refer back to the Matter unit to review how solids and liquids are represented at the submicroscopic level.
- Many questions ask you to write down what you think, to make predictions, or to explain why you think the way you do. The only wrong answer is an answer that is left blank.
- Make sure to include keys for your sketches. A periodic table is available in the back of your workbook to use.

Notes

Homework

Upcoming Quizzes/Tests



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Activity 1: Connecting

On the Earth, there is a natural resource that is necessary to support life for many organisms, yet this resource is often invisible to the naked eye. The *atmosphere* that surrounds Earth is unique to our planet; it has lifesustaining qualities not found elsewhere in our solar system. Some people assume that the atmosphere surrounding Earth consists of only oxygen because many organisms need this gas to survive. Instead, the atmosphere is a *homogeneous* mixture of several different kinds of gases. These gases easily mix with one another, because unlike liquids and solids, large spaces exist between the molecules in a gas.



The table below shows the six major components of air. In the highlighted column, make an educated guess about what percentage of each gas is present in the air. For your sketch, assume twenty total molecules. For example, if you estimate air is 50% carbon dioxide, 50% of twenty is ten, so draw ten molecules of CO_2 .

| Gas | % Estimate of Composition | Actual % | Sketch a submicroscopic representation of air based on your estimation of percentages |
|----------------|------------------------------|----------|---|
| Nitrogen | | | |
| Oxygen | | | |
| Argon | | | |
| Carbon Dioxide | | | |
| Neon | | | |
| Other Gases | | | |
| | Total: 10 | 0% | |
| | | Кеу | |
| | | | |
| | | | |

1. Your teacher will provide you with the correct percentages. Were you surprised by the data your teacher provided? *Explain your thinking*.



Some of the gases that were previously mentioned are a cause of concern for the livelihood of

the planet. For the past 30 years, scientists have been researching the consequences of climate change.

The unique properties and behavior of certain gases has helped sustain life on Earth for millions of years. *Greenhouse gases* trap the energy provided by the sun. When greenhouse gases such as carbon dioxide, methane, ozone, and water vapor are in proper ratios, these gases help make Earth habitable. However, the exponential growth of a fossil fuel-reliant population has upset the balance of optimal levels of greenhouse gases and caused the average global temperature to rise. This change in global climate is known as *climate change*.



- 2. Why do you think the gases responsible for climate change are called "greenhouse gases"?
- 3. What do you think are the consequences if air were composed of a heterogeneous mixture?
- 4. Gas is one state of matter. From the submicroscopic perspective, how does gas differ in terms of the arrangement of its molecules, compared to a solid or a liquid?
- 5. What are some characteristics of gases that other states of matter do not have? *Hint: Think about water in all three states of matter.*



Activity 2: Questions to Think About - Structure of Gases

Part 1

Gases can be classified into three different categories based on their atomic structures.

Look at the three gases in the table below and classify them with one of the following three *terms*: **Molecular Compound**, **Monatomic**, or **Diatomic Molecule**.

| Picture | Name | Classification |
|------------|-------------------|----------------|
| | Helium | |
| \bigcirc | Fluorine | |
| | Carbon Dioxide | |

- 6. Considering its location in the periodic table, to which family does helium belong?
- 7. Based on periodic trends, what assumptions can we make about the atomic structure of the elements in the last column of the periodic table?
- 8. How is the *halogen* family of gases classified?
- 9. Using your drawings in the table on the next page, rank the balloon, water, and coin from least to most dense.



Part 2

The following activity will help you discover the unique properties of gases.

On your teacher's desk is a beaker of water with a copper coin and a balloon filled with oxygen placed inside. The coin sinks while the balloon floats. Look at the demonstration of each component and sketch as directed.

| | Macroscopic Picture | Submicroscopic sketch of substance |
|--------------------------------------|---------------------|------------------------------------|
| Balloon filled with <u>oxygen</u> | | |
| Beaker filled with <u>water</u> | | |
| Penny made of <u>copper</u> | | |
| | Key | у |
| | | |

Part 3: Use Simulation 1, Set 1

Your teacher is going to add two different types of gas molecules to the simulation. Create sketches as directed.

| Create a submicroscopic sketch from the simulation at time 15 s. | 10. Which gases were added to the simulation? |
|--|--|
| | 11. What type of mixture was formed by the gases? |
| | 12. The gases in the simulation are considered diatomic molecules. Why is carbon dioxide not considered a diatomic molecule? |
| Кеу | |

13. Gases combine easily with one another. What are the potential helpful or harmful consequences?

Part 1: Use Simulation 1, Set 2

The following activity will help you discover the unique properties of gases.

Gases can be compressed. Watch as your teacher uses the simulation. Pay close attention to how volume changes over time as the size of the box is changed. Create a sketch before and after as directed.

| Create a submic before box is | roscopic sketch compressed | Create a submic after box is | croscopic sketch compressed |
|----------------------------------|-------------------------------|---------------------------------|--------------------------------|
| Moles of gas molecules | | Moles of gas molecules | |
| Volume of container | | Volume of container | |
| Volume of the gas | | Volume of the gas | |
| Actual volume of gas | | Actual volume of gas | |
| | К | ey | |

14. How did the moles of gas molecules change over time?

- 15. How did the volume of the container change over time?
- 16. How did the volume of the gas change over time?
- 17. How did the actual volume of the gas change over time?
- 18. Using your sketches, explain how the submicroscopic characteristics of a gas allow it to be stored in small metal tanks for hospital use or for diving in the ocean.
- 19. In the CCC simulations, your focus is on the submicroscopic view of the particles. How does the piston in the simulation violate this view?

Part 2: Continue to use Simulation 1, Set 2

Your teacher is going to add more gas to the simulation. Create sketches as directed.

| Create a submicroscopic sketch at time 0 s. | | Create a submicroscopic sketch at time 30 s. | | Create a submicroscopic sketch at time 60 s. | |
|--|--|--|------|--|--|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Molesofgas | | Molesofgas | | Molesofgas | |
| Volume of | | Volume of | | Volume of | |
| container | | container | | container | |
| Volumeof | | Volumeof | | Volumeof | |
| gas | | gas | | gas | |
| Actualvolume | | Actualvolume | | Actualvolume | |
| of gas | | of gas | | of gas | |
| | | Ke | ey 🛛 | | |
| | | | | | |
| | | | | | |

- 20. What happened to the moles of gas over time?
- 21. How does the number of moles change the volume of the gas?

- 22. How did the actual volume of the gas change over time?
- 23. How did the volume of the container change over time?
- 24. What is the relationship between concentration and the amount of moles present in the container?
- 25. When is the concentration of helium greatest? When is it lowest?
- 26. Explain any difference or similarity between the volume of the container, the volume of the gas, and the actual volume of gas.
- 27. Using your values, calculate the concentration of helium from your 60 second trial.

Part 3

The glass bulb below contains a monatomic ideal gas, sealed in the bulb on the left. On the right no monatomic gas is present.

Sketch what will happen to the gas after the valve is opened.

28. Explain why you sketched the gas the way that you did.

29. Using your submicroscopic sketches, explain why when someone makes popcorn or walks in a room wearing perfume, other people in the room can smell the popcorn or the perfume.

Lesson Reflection Question

30. Explain what happens to the molarity of the gas in the left bulb after the valve was opened.

Activity 4: Teacher Facilitated Discussion

A group of students debate some information they read on the Internet about gases.

In your small group, decide if the claims these students make are true or false. Circle your response and be prepared to defend your claim with evidence. Consider what you know about solutions, pure substances, and pressure to help guide your decision-making.

Claim 1: Air is a solution.

31. This statement is true or false. Support your claim with evidence.

Claim 2: Air is a pure substance.

32. This statement is true or false. *Support your claim with evidence*.

Claim 3: Highly compressed gases inside metal tanks and containers can be dangerous.

33. This statement is true or false. *Support your claim with evidence*.

Student's Lesson at a Glance

Lesson Summary

This lesson contains three activities. The Connecting Activity reminds students that gases are matter and, like all other phases of matter, gases are in constant motion. The Kinetic Molecular Theory (KMT) describes this constant motion. Students simulate KMT by throwing a gas molecule in a closed container and observing the changes in the system. Using the simulations, students then explore the five postulates of KMT. In the final step of the exploration, students symbolically represent the energy exchange during collisions and determine the relationships between kinetic energy and the temperature of a system. In the final activity of the lesson, the teacher formally defines postulates for the students to record.

SWBAT (Student will be able to)

• Understand the Kinetic Molecular Theory as it applies to gases.

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.

CCC Reminder

- Vectors are arrows that show both the direction and velocity of an object. The longer the vector, the faster the object is going. Vectors will be useful in drawing the motion of gas molecules in your sketches. In CCC, colored arrows represent the kinetic energy of the molecule or atom. Red represents an increased kinetic energy, black represents no change in kinetic energy, and blue represents a decreased level of kinetic energy. Vectors should be included in the keys when you produce your sketches.
- There are five postulates in the Kinetic Molecular Theory. Try to identify what each of the postulates could be based on your observations.

Notes

Homework

Upcoming Quizzes/Tests

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Activity 1: Connecting

1. Describe how you think molecules inside birthday balloons move and interact with each other.

One of the first lessons students may learn in chemistry is on the topic of the nature of matter. Often, students are asked to provide examples of matter from their everyday observations. Some examples might include the walls of a classroom, a piece of gum, a can of soda, the tires on a car, a person, an ink pen, and many other answers. However, sometimes students do not list gases as a form of matter. What about the gases that fill a room, a car tire, or a sealed bag of chips?

Gases exist everywhere, like the steam formed in a shower, the air inflating our lungs, and the helium in birthday balloons. Recall that scientists often have to use models to better understand these complex phenomena. In the universe, there are numerous types of gases that interact. To better understand the complexity of gases, scientists need to simplify their observations with the use a *model* called an **ideal gas**. The ideal gas model approximates the behavior of a real gas across a limited range of temperatures and pressures. Scientists use the ideal gas model to predict the behavior of real gases. You will learn more

about how real gases behave at very high pressures and low temperatures in Lesson 5.

Using the model of an ideal gas to describe all real gases is convenient but has some limitations. Descriptions of real gases, such as helium, oxygen, or carbon dioxide, will be close enough that any errors are compensated for easily. **Kinetic Molecular Theory** (**KMT**) is the theory helping to explain the behavior of the molecules in an ideal gas. KMT consists of five **postulates** (or parts).

2. By breaking apart the name of the Kinetic Molecular Theory, what do you think the theory is about?

In prior lessons, the concept that matter is always in motion (even as a solid) may have been discussed. Gases are no exception. KMT helps to accurately describe the *interactions*, *motion*, *attraction*, and *energy* of a gas.

- 3. Is air an example of matter? *Explain*.
- 4. Kinetic energy is the energy of motion. What do you already know about matter supporting the idea that all matter has kinetic energy?
- 5. Based on your observations from the macroscopic world, how do you know that gases move?

Part 1: Use Simulation 2, Set 1.

In this simulation, you will explore the five parts of Kinetic Molecular Theory. The simulation contains one diatomic gas. Make sure the heat level is set at zero.

- 6. How are the molecules moving in the simulation?
- 7. What quantitative measurements do the simulation's monitors provide?

Enable tracking to turn on the tracking line. By checking the box, you will turn on a colored line that follows the path of one molecule.

8. How do molecular collisions affect molecular velocity? *Support your claim with evidence*.

9. As the molecules collide, how do changes in molecular velocity affect the average kinetic energy of the system?

Following your teacher's demonstration, use the simulation to "grab" one gas molecule with the cursor and "throw" it into the side of the container.

- 10. How does the molecule move when you "throw" it?
- 11. Using the monitors, explain how you change the kinetic energy of the molecule when you "throw" it?
- 12. Using the monitors, did the kinetic energy of the entire simulation change? *Support your claim with evidence*.
- 13. State at least two ways that throwing one molecule changed the system. *Support your claims with evidence*.
- 14. How would "throwing" 10 or more molecules change the system?

Part 2: Continue to use Simulation 2, Set 1.

15. Describe the appearance, location, interaction and motion of the molecules in the simulation.

16. Do the bromine gas molecules chemically react with one another? *Support your claim with evidence*.

17. What are your observations of the volume of the container and the volume of the gas?

18. Did the total kinetic energy of the system change over time? *Explain*.

Part 3: Continue to use Simulation 2, Set 1.

Turn the tracking on for one molecule of gas. Make sure the heat level is adjusted back to zero.

19. What happens when two gas molecules collide?

20. What happens to the kinetic energy of each of the molecules during the collision? *Support your claim with evidence.*

21. What happens to a molecule when it hits the side of the container?

- 22. How is the velocity of the gas molecule affected by the collision with the "hot" container bottom?
- 23. As the temperature of the system increases, what happens to the rest of the gas molecules?
- 24. Temperature is dependent on how much heat is added or taken away from the system. Are heat and temperature the same thing? *Explain*.

Part 4: Continue to use Simulation 2, Set 1.

25. Prior to the gas molecules colliding, how would you describe their velocities?

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- 26. What happens to the velocity of a gas molecule when it collides with a cool wall?
- 27. As the temperature of the system decreases as heat is removed. What happens to the the gas molecules in the system?

Part 5

The diagrams below show a gas molecule involved in a collision. Remember that you can use vectors to show direction and velocity of gas molecules. The *length* of a vector represents velocity.

The *colors* in the simulation and your sketches are symbolic as they represent changes in energy or the relative velocity of the system. **Red** represents increased energy, **Blue** represents decreased energy and **Black** represents an even exchange in energy.

You do not need to redraw the wall.

- Increased energy, fast velocity
- Even level of energy, medium velocity

Using arrows to represent changes in energy, create sketches of the four different types of collisions, after the collision occurs. You do not need to redraw the wall.

Recall from the Matter Unit that molecules are always moving. In the case of solids, with organized structures, this motion is exhibited as vibrations. The "fuzzy" molecules in the diagrams below represent vibration. For example, solid silicon dioxide (glass) molecules that have more energy in them from heat energy being added will have more vibration so they are represented with more fuzziness.

| Gas <i>before</i> collision with hot wall | Gas <i>before</i> collision with room temp. wall | Gas <i>before</i> collision with cold wall | Two gas molecules <i>before</i> collision |
|--|--|---|---|
| | | | |
| | | | |
| Gas <i>after</i> collision with hot wall | Gas <i>after</i> collision with room temp. wall | Gas <i>after</i> collision with cold wall | Two gas molecules <i>after</i> collision |
| | | | |
| | | | |
| | | | |

- 28. When a molecule hits a wall with a lower energy level than the molecule has, how is the molecule affected? *Explain*.
- 29. When a molecule hits a wall with a higher energy level than the molecule has, how is the molecule affected? *Explain*.
- 30. If the average kinetic energy increases, the temperature of the environment *increases* or *decreases* (*circle one*).
- 31. The average kinetic energy of a system is *directly* or *indirectly* (*circle one*) related to temperature.

Lesson Reflection Question

32. Using your experience with the simulations, describe what you think are the five postulates of KMT.

Part 1: Use Simulation 2, Set1

The five postulates of KMT can be derived using the computer simulations. You have already explored these postulates in the previous activity. Follow along with your teacher as the key points from the simulation are reviewed and complete the chart below with the formally stated postulates. Complete the questions following the table and fill in the table on the next page by creating sketches of the postulates.

| Postulate | Kinetic Molecular Theory |
|-----------|--------------------------|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |

33. Considering that gas molecules move quickly and have little attraction to each other, what would happen if the molecules slowed down?

34. Looking at the simulation, what variables could affect how gases behave?

| Postulate 1: Submicroscopic Sketch | Postulate 2: Submicroscopic Sketch |
|------------------------------------|------------------------------------|
| Postulate 3: Submicroscopic Sketch | Postulate 4: Submicroscopic Sketch |
| Postulate 5: Submicroscopic Sketch | Кеу |

Student's Lesson at a Glance

Lesson Summary

This lesson contains six activities. Students begin their exploration of pressure through the exploration of how air pressure affects weather patterns and conditions. Following a teacher demonstration of the simulation, students add more gas molecules to discover the relationship between the number of wall collisions and pressure. In the next activity, teachers will introduce students to how pressure is calculated regarding force and surface area. Students calculate pressure exerted by different shoes. Students explore Dalton's Law of Partial Pressure. Using knowledge gained from the simulation, students derive how partial pressure is calculated. Finally, students analyze two real-world scenarios of pressure and make a conclusion based on their prior knowledge of pressure.

SWBAT (Student will be able to)

- Identify the SI units for force, pressure and area
- Generate the equation for pressure and use this equation to perform calculations
- Calculate the total pressure of a mixture of gas using Dalton's Law of Partial Pressure
- Understand how pressure is measured

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.

CCC Reminder

- In the gas laws, there are two common mathematical relationships that exist.
- The first relationship is a direct relationship. When the independent variable increases, the dependent variable also increases proportionally. When the independent variable decreases, the dependent variable decreases proportionally.
- The second relationship is an inverse or indirect relationship. When the independent variable increases, the dependent variable decreases. When the independent variable decreases, the dependent variable increases.
- Make sure to write out all calculations and include units so you can easily check your work.
- In this book, pressure is measured in units called kilopascals (kPa). Volume is measured in liters (L). Temperature for all gas laws equations must be in Kelvin (K).
- If you need to convert °C into °Kelvin, the formula is °Kelvin = °Celsius + 273.

Notes

Homework

Upcoming Quizzes/Tests

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Activity 1: Connecting

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1. How do you think pressure and molecules are related?

Go outside on a windy day; you might find yourself being pushed around by an invisible force.

Wind is caused by air moving from an area of high pressure to an area of low pressure. Meteorologists use a weather map to help explain the weather. On the map are big H's and L's, representing areas of high (H) and low (L) air pressure which cause changes in the wind and weather.

Air pressure is the force exerted on an object by all the air molecules surrounding it. The more molecules present, the greater the pressure

on an object. Conversely, fewer molecules equal less pressure on an object. This is also why pressure changes with altitude; the higher you are, the fewer molecules exist in the area.

Pressure is measured using an instrument called a *barometer*. The normal range of air pressure on earth is between 980 to 1050 mbar (millibars). In the simulations, you have seen pressure in kilopascals (kPa). The table below provides conversions to help you see the relationship between this reading and your simulations.

A low pressure system is an area where the atmospheric pressure is lower than the surrounding area. Low pressure systems can generate high winds as air moves from a high-pressure area to a lowpressure area. As the winds blow, warm air rises; this causes clouds and precipitation to form, such as thunderstorms and tornadoes. A highpressure system is an area where the atmospheric pressure is greater than the surrounding area.

| mbar 950 | kPa 95 | |
|-----------------------------|-----------|--|
| 980 | 98 | |
| 1000 | 100 | |
| 1050 | 105 | |
| Conversion: 1 kPa = 10 mbar | | |

These locations tend to experience clear skies

and calm weather. No cloud protection can result in extreme high and low temperatures.

Gases play a major role in the Earth's climate. Scientists study the pressure exerted by gases to better predict the changes in weather and to prepare for natural disasters.


- 1. Using the barometer in the picture, what would you expect the weather outside to be at 980 mb?
- 2. What would you expect the weather outside to be at 1050 mb?
- 3. The relationship between moles of air molecules and pressure is: *inversely proportional* or *directly proportional* (*Circle one and please explain why this statement is true.*)



- 4. The air on top of a mountain is said to be "thin." Do you think this means more molecules or less molecules? *Support your answer.*
- 5. Would the "thin" air on top of a mountain be at a low or high pressure, based on your answer to the previous question? *Support your answer*.
- 6. The inner ear is an air pressure regulator, which helps you to maintain balance and transmit sound. How does air pressure affect the inner ear while flying or driving through the mountains?



7. Based on your answer for the previous three questions, the relationship between *altitude* and pressure is *inversely proportional* or *directly proportional*. (*Circle one and please explain why this statement is true.*)



Activity 2: Teacher Demonstration

Your teacher will take the cap off a syringe and pull the plunger out of the syringe. Your teacher will then drop a mini marshmallow into the syringe, push the plunger into the syringe until the plunger barely touches the marshmallow, then replace the cap. If there is no cap the teacher will use his or her thumb to plug the tip. Your teacher will then pull the plunger out.

8. What happened to the marshmallow?

Your teacher will then push the plunger in.

- 9. What happened to the marshmallow when the plunger was pushed back in?
- 10. What variables do you think are represented in the demonstration? How did the variables change? *Support your claim with evidence.*

11. What do you think the relationship between the variables is? Support your claim with evidence.

12. What external conditions could effect the results of the demonstration?



13. How do you think this demonstration helps to explain shaving cream behavior?



Activity 3: Student Exploration and Simulations of Pressure

On the side of an average car tire, a label reads 35 psi. This number indicates that the ideal pressure inside the tire should be 35 pounds per square inch (psi). The pressure of a system is caused by gas molecules hitting the side of a container. Air pressure, in a closed container like a tire, is related to the force generated by a given quantity of gas molecules hitting the container's walls. A single gas molecule has very little mass and will not hit the container's walls with much force. If there are not enough molecules in the container, they will not hit the walls at the same time. However, when there are enough molecules in a container, a large group of molecules can exert significant force on the walls. Pressure, represented by the symbol *P*, is the effect of the force of many gas molecules' collisions applied to a specific surface area.



- 14. What do you expect to happen to pressure if molecules have more collisions with the wall of the tire? Why?
- 15. If a tire is fully inflated, explain what is happening with regard to the quantity and velocity of the gas molecules?

16. How are the quantity and velocity of gas molecules connected with pressure?



Simulation: Continue to use Simulation 3, **Set 1** In the simulation, add five gas molecules. Record collisions and pressure from the monitors. Record collisions and pressure from the monitors after five seconds.

17. In your small group, continue adding 5 molecules at a time for four more unique trials. Record the number of gas molecules, collisions and pressure after five seconds from the monitors in the table below.

| Trial # | Number of gas molecules | Number of collisions with wall after 5 sec | Pressure (kPa) |
|---------|----------------------------|---|----------------|
| 1 | 5 | | |
| 2 | 10 | | |
| 3 | 15 | | |
| 4 | 20 | | |
| 5 | 25 | | |

18. On the two graphs provided, graph the number of collisions vs. the pressure and the number of gas molecules vs. the pressure. *Make sure to label units on your graphs*.

| Collisions/Pressure | | | Molecules/Pressure | | | | | | |
|---------------------|--|--|--------------------|--|--|--|--|--|--|
| | | | | | | | | | |
| | | | | | | | | | |
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| | | | | | | | | | |



19. Considering your data from the simulation, describe the relationship between the number of collisions and pressure.

20. When gas molecules hit the wall of the container, what happens to their velocities? *Explain*.

- 21. While observing the simulation, collisions between gas molecules and the walls of the container are elastic. Using the terms *velocity* and *kinetic energy*, explain what "elastic" means.
- 22. If a tire gets "low," what does this indicate about the pressure inside the tire?
- 23. What does the low pressure of the system indicate about the moles of molecules?

24. What does low pressure indicate about the velocity of the molecules?



Activity 4: Calculating Pressure

25. When standing in line, it is easy to have your foot stepped on accidentally by the person in front of you. Would it be worse to be stepped on by a 180 pound man wearing work boots with broad heels, or a 125 pound woman wearing pumps with stiletto heels? *Explain your choice*.



Pressure is force applied to a certain area. Like other

measurements in science, such as temperature,

pressure can be measured in several different ways. Pressure can be measured in *kilopascals* (kPa), *atmospheres* (atm), or *pounds per square inch* (psi). The formula used to calculate pressure is:

Pressure (psi) =
$$\frac{Force \text{ (lbs.)}}{Area (in^2)}$$
 or $P = \frac{F}{A}$

All matter near the surface of the Earth is attracted downward because of the great mass of the planet. Gravity is the force of attraction between the masses of all types of matter. Air molecules are composed of matter; therefore, air is also pulled by gravity. The air that is pulled down by the gravity of the Earth exerts a force on everything that the gas molecules collide with.

How much air pressure is exerted on your body? Calculating the amount of pressure on every inch of your body would be difficult without exact measures. Consider instead a 10 inch by 10 inch section of your back. At sea level the air pressure is 15 psi.

• First calculate the area:

$length \times width = area$

10 in \times 10 in = 100 in².

• Second, by substituting values into the formula, we know that:

$$15 \text{ psi} - \frac{F}{100 \text{ in}^2}$$





• Substitute values from word problem and solve for F

F = 1500 lb

This means that 1500 pounds are pressing on that section of your back; the pressure inside our body is about the same as the pressure outside. The net difference between the pressure is zero (Khounsary, 2009). If there were no air inside your body to push back, the total air pressure on your body would crush you!

Let's return to the scenario of someone stepping on your foot. You can determine the pressure exerted by either person with the same equation. The shoe heel of the 125-pound person is 1 in². The heel of the 180-pound person's boot is 12 in².

26. From this information, calculate the pressure exerted on your foot. Based on your calculations, explain who you would rather have step on your foot.



Activity 5: Dalton's Law of Partial Pressure

Simulation: Use Simulation 4, Set 1.

In the previous simulations of this unit, only one gas has been examined at a time. Dalton's Law uses a combination of gases.

Keep the temperature and the volume of the container constant for *each trial.*

For each trial, run the simulation for each gas, collect data from the simulation's monitors, and finally reset the simulation. After you have recorded data for each gas, run the simulation with all of the gases combined. Finally, answer the analysis questions.

| Trial | Data | Helium | Oxygen | Chlorine | Carbon Dioxide | Combined Gases |
|-------|------------------------|--------|--------|----------|-------------------|-------------------|
| | Temperature | | | | | |
| 1 | Pressure | | | | | |
| | Volume of container | | | | | |
| | Temperature | | | | | |
| 2 | Pressure | | | | | |
| | Volume of container | | | | | |
| | Temperature | | | | | |
| 3 | Pressure | | | | | |
| | Volume of container | | | | | |

27. Based on the trials you completed, how is combined pressure calculated?



28. Considering the combined gases' behavior, how is the change in pressure explained?

29. If the volume of the container is fixed, could you combine an unlimited number of gases? *Support your claim with evidence*.

Lesson Reflection Question

30. Based on what you have learned in the lesson, how has your definition of pressure changed?



Activity 6: Teacher Facilitated Discussion

A person is given a hammer and a very dull axe, both of which have the same weight. These tools are used to try to crack a log in half.

31. Explain what tool would be best for the job using the terms *pressure*, *force*, and *area* to support your selection. *Be prepared to discuss your answer aloud*.

A designer of race cars knows that fast-moving air creates an area of low pressure. To make cars go faster, the bodies of cars are made of extremely lightweight materials and utilize tail fins to direct air flow.

The tail fin on a race car provides downward pressure when the car travels forwards.



32. From the two choices below, with all other qualities held equal, which car would win a race? *Circle one of the scenarios below. Support your selection with evidence, and be prepared to share your answer aloud.*





Student's Lesson at a Glance

Lesson Summary

This two-day lesson contains eight activities. In the Connecting Activity, students explore the factors affecting gases, including temperature, pressure, volume, and the number of particles on a system. Students then explore gas laws, including Avogadro's, Charles's, Boyle's, Gay-Lussac's, the Combined Gas, and the Ideal Gas Law. Students begin with the derivation of the gas laws Boyle's, Charles's, and Gay-Lussac's. By exploring the relationships between two factors at a time, students derive all of the remaining gas laws and see how the Ideal Gas Law was created. Special emphasis is placed on graphic analysis and construction.

Next, students use the Ideal Gas Law simulation to collect data for Boyle's, Charles's and Gay-Lussac's Laws. For each law they graph data and use it to analyze relationships between the variables of volume, pressure, and temperature. Students derive equations for these laws from their exploration and from the data they have gathered. Following their introduction to Boyle's and Charles's Laws, students explore the Combined Gas Law through the concept of refrigeration. In the final activity, students tie all of the laws together by reviewing relationships between variables and identify the relationship of the other gas laws to the Ideal Gas law.

SWBAT (Student will be able to)

- Understand the basis of the gas laws
- Correctly distinguish between Boyle's, Charles's, Dalton's, Gay-Lussac's, and the Ideal Gas Law
- Apply gas laws to perform calculations
- Explain the effects of pressure, volume, and temperature on gases
- Classify the relationships between pressure, volume, and temperature as inverse or direct
- Explain, using specific examples, how pressure and gas laws can be observed in real-world conditions

CCC Reminder

• Make sure to record units on all data collected from simulations.



Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.

Notes

Homework

Upcoming Quizzes/ Tests

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Activity 1: Connecting

Imagine the following scenarios:

- A bunch of birthday balloons popping in a hot car
- A flat tire on a very cold day
- A hot air balloon taking off
- 1. What do all these things have in common?

- A shaken can of soda being opened
- A kernel of popcorn popping
- An airbag activating after a car crash
- A man using a can of shaving cream

Scientists have formulated laws based on observations of how gases behave. The gas laws account for the relationships among temperature, pressure, volume, and the number of gas particles within a system. Applying a knowledge of gas laws makes possible many of the comforts and advances to which we are accustomed. Our knowledge of gas laws allows us to experience conveniences that make our lives easier. These conveniences include the ability to blow up air mattresses while we are traveling, to keep our homes cool using air conditioners, to provide a smooth ride using suspension systems on some cars, to build homes more quickly with air-powered tools like pneumatic nailers, to dive deep in the ocean, to turn on a light with electricity from steam powered turbines, and to watch a football game from an aerial view courtesy of blimps hovering over the stadium.

In this lesson, you will explore seven gas laws. **Avogadro's Law** helps make the study of the other six laws possible. Avogadro determined that equal volumes of gases at the same temperature and pressure contain the same number of molecules, regardless of their chemical nature and physical properties. Avogadro's Law allows us to assume that all gases behave similarly under the same conditions of volume, temperature, and pressure.

- 2. What are the factors that affect how gases behave?
- 3. All the gas laws assume gases are *ideal*. What is an **ideal gas**? All the gas laws assume gases behave according to the ideal gas law model. In your own words, describe an ideal gas.



4. In what other ways do we use gases in modern life?

H₂O

Activity 2: Teacher Demonstration

Your teacher has three balloons blown up to the same size. Your teacher will push one balloon into ice water and hold for several minutes. Your teacher will hold another in the steam of a beaker of boiling water. Your teacher will use the third balloon as the control for comparison.

- 5. Compare the cold water balloon and the hot water balloon to the control balloon. Do you see a difference? If so, what is the difference?
- 6. What variables do you think are represented by this demonstration? *Support your claim with evidence*.
- 7. What do you think is the relationship between the variables? How did the variables change? *Support your claim with evidence.*
- 8. How does this activity help explain changes in tire pressure in different climates?





The Ideal Gas Law is a combination of pressure, volume, number of molecules, and temperature into one mathematical relationship which can be used with any ideal gas. The Ideal Gas Law equation is represented as the following equation:

PV = nRT

P = pressure (in kPa),

V = volume (in L),

n = moles of molecules (mol),

 $R = 8.3145 L \cdot kPa / mol \cdot K$

T = temperature in K (convert from °C and °F)

All the other gas laws can be combined to create the Ideal Gas Law. The Ideal Gas Law is complex. However, if we explore the relationships between two factors at a time, we can derive all remaining gas laws to see how the Ideal Gas Law was created.

Your teacher will demonstrate how to use the gas law simulations. You will be required to collect data and to use this data to create a graph for each law. Using the data and graph, you will answer the analysis questions that follow. To help remind you of the connection between the Ideal Gas Law and the other gas laws, the Ideal Gas Law equation is represented in the corner of the simulations. The bars beneath each of the variables will help you to visualize changes to the variables manipulated.

For each gas law you explore, you will be looking at two variables. The first variable, which can be directly changed, is the **independent variable**. The second variable, which cannot be changed directly, is the **dependent variable**.

All other variables remain constant, and are locked in the simulation.



- 9. The variable that is being manipulated or changed is called the **independent/dependent** variable. *(Circle one.)*
- 10. The variable that cannot be changed directly, but rather relies on the other, is called the the **independent/dependent** variable. (*Circle one.*)
- 11. Place the independent variable and dependent variable on this graph to show which belongs on the X-axis and which belongs on the Y-axis.



12. Why is it important to change only one variable at a time?





Activity 4: Boyle's Law

Simulation: Use Simulation 5, Set 1

Your teacher will demonstrate how to manipulate the volume of the container to discover how the *pressure* of the system is affected. Using the simulation, your teacher will create five unique trials with different starting volumes. No other variables will be manipulated. The teacher will pause the simulation between trials. Students create submicroscopic sketches and fill in data, including keys and labels. The teacher will run each trial for at least 30 seconds.

The relationship between volume and pressure is known as **Boyle's Law***.*

| Da | ita | Submicroscopic Sketch |
|-----------------|-------------------|-----------------------|
| Tria | al 1 | |
| Volume | | |
| Pressure | | |
| Number of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |
| Tria | al 2 | |
| Volume | | |
| Pressure | | |
| Number of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |



| Da | ita | Submicroscopic Sketch |
|-----------------|-------------------|-----------------------|
| Tria | al 3 | |
| Volume | | |
| Pressure | | |
| Number of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |
| Tria | al 4 | |
| Volume | | |
| Pressure | | |
| # of moles | | |
| Temperature | | |
| R | 8.314 L∙kPa/mol∙K | |
| Tria | al 5 | |
| Volume | | |
| Pressure | | |
| Number of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |
| | | Кеу |
| | | |
| | | |



Create a graph from the data you collected in the simulations. Include a title and label the axes with units. Correctly identify the independent and dependent variable by labeling the appropriate axis.

| | Provide a Title | | | | | | | | |
|---|-----------------|--|--|--|--|--|--|--|--|
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13. What happens to pressure as the volume of the system increases?

14. What happens to pressure as the volume of the system decreases?

- 15. According to the simulations of Boyle's Law the relationship between pressure and volume is *directly proportional* or *inversely proportional* (*Circle one*).
- 16. Considering the collisions of the gas molecules at different volumes, how can pressure changes be explained?



17. Calculate pressure multiplied by volume for all five trials.

| Trial | Pressure (kPa) × Volume (L) = |
|-------|-------------------------------|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |

18. Using your results from the previous question, derive the formula for Boyle's Law, to describe how the pressure (P₁) and volume (V₁) at Trial 1 are related to the pressure (P₂) and volume (V₂) at Trial 2.

Hint: Consider the fact that an initial and final measurement is needed for both volume and pressure. Use the variables P_1 , P_2 , V_1 , V_2 to fill in the blanks in the equation below.

_____X____=____X____

19. If you transfer all the gas from a large storage tank to a much smaller tank, what could be the possible consequences? Support your claim with evidence using the terms volume and pressure.





Simulation: Use Simulation 5, Set 2

Following your teacher's demonstration, you will manipulate the heat added to the system which changes the **temperature** to discover how **volume** is affected. Use the simulation to create five unique trials by adjusting the heat level to change the temperature of the system. Do not change any other variables. Run each trial for 30 seconds. Pause the simulation in between trials. Use the simulation to create submicroscopic sketches and fill in the data, including labels. The relationship between temperature and volume is known as **Charles's Law**.

| Da | ata | Submicroscopic Sketch |
|-----------------|-------------------|-----------------------|
| Tria | al 1 | |
| Volume | | |
| Pressure | | |
| Number of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |
| Tria | al 2 | |
| Volume | | |
| Pressure | | |
| Number of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |



| Da | ita | Submicroscopic Sketch |
|-----------------|-------------------|-----------------------|
| Tria | al 3 | |
| Volume | | |
| Pressure | | |
| Number of moles | | |
| Temperature | | |
| R | 8.314 L∙kPa/mol∙K | |
| Tria | al 4 | |
| Volume | | |
| Pressure | | |
| # of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |
| Tria | al 5 | |
| Volume | | |
| Pressure | | |
| Number of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |
| | К | ey |



Create a graph from the data you collected in the simulations. Include a title and label the axes with units. Identify the independent and dependent variable by labeling the appropriate axis.

| Provide a Title | 20. What happens to the volume of the gas as the temperature of the system increases? |
|-----------------|---|
| | 21. What happens to the volume of the gas as the temperature of the system decreases? |

- 22. According to the simulations and Charles's Law, the relationship between temperature and volume is *directly proportional* or *inversely proportional*. (*Circle one.*)
- 23. Based on the behavior of the gas molecules at different temperatures, how can changes in the volume of the gas be explained?



Calculate volume divided by temperature for all 5 trials.

| Trial | Volume (L) / Temperature (K) = |
|-------|--------------------------------|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |

=

24. Using your results in the previous question, derive the formula for Charles's Law, to describe how the pressure (T_1) and volume (V_1) at Trial 1 are related to the pressure (T_2) and volume (V_2) at Trial 2.

Hint: Consider the fact that an initial and final measurement is needed for both volume and temperature. Use the variables T_1 , T_2 , V_1 , V_2 to fill in the blanks in the equation below.

25. How does Charles's Law help to explain how a flat tire could occur on a very cold day, even though there may not be a leak? *Support your claim with evidence using the terms volume and temperature*.





Simulation: Use Simulation 5, Set 3

Following your teacher's demonstration, you will manipulate the heat added to the system which changes the **temperature** to discover how **pressure** is affected. Use the simulation to create five unique trials by adjusting the heat level to change the temperature of the system. Do not change any other variables. Run each trial for 30 seconds. Pause the simulation in between trials. The relationship between temperature and pressure is known as **Gay-Lussac's Law**. Reset the simulation after collecting data and creating sketches; failure to reset the simulations will prevent the temperature from changing correctly.

Use the simulation to create submicroscopic sketches and fill in the table, including labels. Use vectors in your drawings to show the direction and velocity. Remember that color indicates the level of energy of the molecule: **blue** for a lower level of energy, **black** for an average level of energy, and **red** for a higher level of energy.

| Da | ita | Submicroscopic Sketch |
|-----------------|-------------------|-----------------------|
| Tria | al 1 | |
| Volume | | |
| Pressure | | |
| Number of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |
| Tria | al 2 | |
| Volume | | |
| Pressure | | |
| Number of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |



| Data | | Submicroscopic Sketch |
|-----------------|-------------------|-----------------------|
| Trial 3 | | |
| Volume | | |
| Pressure | | |
| Number of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |
| Trial 4 | | |
| Volume | | |
| Pressure | | |
| # of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |
| Trial 5 | | |
| Volume | | |
| Pressure | | |
| Number of moles | | |
| Temperature | | |
| R | 8.314 L•kPa/mol•K | |
| Кеу | | |



Create a graph from the data you collected in the simulations. Include a title and label the axes with units. Identify the independent and dependent variable by labeling the appropriate axis.

| Provide a Title | 26. What happens to the pressure of the system as the temperature of the system increases? |
|-----------------|--|
| | 27. What happens to the pressure of the system as the temperature of the system decreases? |

28. Considering your data from the simulation, describe the relationship between temperature and pressure.

29. Based on the behavior of gas molecules at different temperatures, how can changes in the pressure of the system be explained?

59



30. Calculate pressure divided by temperature for all 5 trials.

| Trial | Pressure (kPa) / Temperature (K) = |
|-------|---------------------------------------|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |

_____= _____

31. Using your results in the previous question, derive the formula for Gay-Lussac's Law to describe how the pressure (P_1) and temperature (T_1) at Trial 1 are related to the pressure (P_2) and temperature (T_2) at Trial 2. Use the variables T_1 , T_2 , P_1 , P_2 to fill in the blanks in the equation below.

Hint: Consider that an initial and final measurement is needed for both pressure and temperature.

32. How does Gay-Lussac's Law help to explain why balloons may burst in the back of a hot car? *Support your claim with evidence using the terms pressure and temperature.*



Recall that the Ideal Gas Law is a combination of pressure, volume, number of molecules, and temperature into one mathematical relationship that can be used with any ideal gas.

33. Circle the components of the Ideal Gas Law which are important to Boyle's law:

PV = nRT

34. Circle the components of the Ideal Gas Law which are important to Charles's law:

PV = nRT

35. Circle the components of the Ideal Gas Law which are important to Gay-Lussac's law:

PV = nRT

The questions below help to summarize the relationships between the three variables explored in Boyle's, Charles's, and Gay-Lussac's Laws.

36. Describe all of the relationships that exist between pressure, volume, and temperature and explain why they exist at the submicroscopic level.



Activity 7: The Combined Gas Law

How does a refrigerator keep food at the right temperature? The inventors of the modern refrigerator developed technology that relies on the mathematical relationships between temperature, volume, and pressure.

A refrigerator uses a continuous cycle of pressure, volume, and temperature changes. To keep your food at a safe temperature, the refrigerator uses ammonia gas in the following steps:

- 1. The compressor reduces the volume of a quantity of ammonia gas. The temperature of the compressed gas increases as it is pressurized.
- 2. The metal coils on the back of the refrigerator allow the hot ammonia gas to release heat. The coils are very hot to touch. As the ammonia gas cools, the gas condenses into ammonia liquid at high pressure.
- 3. The high-pressure ammonia liquid flows through the expansion valve. An expansion valve can be thought of as a small hole. On one side of the hole is high-pressure ammonia liquid. On the other side of the hole is a low-pressure area, because the compressor is removing gas from that side.
- The liquid ammonia immediately boils and vaporizes, which causes a large drop in temperature. The very cold ammonia gas circulates in tubes



behind the walls inside the refrigerator. The cold liquid absorbs heat from the walls of the refrigerator. The heat on the walls was transferred from the foods in the refrigerator by the air molecules. As heat is removed, the food cools so it can be preserved.

- 5. The cold ammonia gas is sucked up by the compressor, and the cycle repeats. (Marshall, 2009)
- 37. In Step 1, what variable is being manipulated and how does it change the ammonia gas?

38. Explain two ways in which gases help to make refrigerators work.



- 39. Refrigerators do not produce cold, but rather remove heat so food cools. *True* or *False*? *Support your claim with evidence*.
- 40. When a refrigerator door is opened would the velocity of air molecules inside the refrigerator *increase* or *decrease*. (*Circle one.*) Support your claim with evidence.
- 41. Explain how putting a hot pot of soup in a refrigerator could make the machine use more energy and increase the chance of food poisoning.

Independently, Charles's and Boyle's Laws cannot fully explain the phenomenon of refrigeration. For a more detailed model, the two equations are combined into one equation. The Combined Gas Law is used when there is a final and initial value for volume, pressure and temperature. The number of moles of the gas remains constant.

- 42. Write the equation for **Charles's Law**, and explain why this relationship exists at the submicroscopic level.
- 43. Write the equation for **Boyle's Law**, and explain why this relationship exists at the submicroscopic level.



Lesson Reflection Question

44. After learning equations for the gas laws, a student explains to a classmate that a tire's pressure decreases in the winter because PV = nRT. Explain why this is not a complete answer and help the student correct his response.

When these two laws are combined they maintain the same relationships between variables. The combination yields the **Combined Gas Law:**

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$



Activity 8: Putting It All Together

With your team, select a scenario from those listed below. Research the scenario your team selects. Answer the guiding question and explain how altitude, temperature, pressure, volume and the number of molecules may effect the scenario.

45. Mel is traveling from Chicago, IL (elevation 597 ft) to Denver, CO (elevation 5,183 ft) to visit her cousin who lives in the mountains. While her cousin is at work, Mel bakes a cake. When she takes the cake out of the oven, she notices that it looks flat because the cake has not risen in the pan. What happened to the cake?

46. Airplane cabins are pressurized, but people's ears still pop when they take off or land. Why?



47. A diver was exploring deep underwater caves. Unfortunately, he realized he was running low on air. He surfaced very quickly, but started feeling ill immediately and was sent for hyperbaric oxygen therapy. What made him sick?



48. Athletes who wish to gain a competitive edge for endurance events sometimes train at high altitudes. Why?

49. Cars are cooled with a combination of liquid and air in their radiators. On hot summer days, many cars can be seen along side of the expressway because they have overheated. The radiator cap, where cooling liquids are added, warns against removing it while the engine is warm. Why?

Solve the problems below using your knowledge of gas laws. Make sure to pay special attention to the units in the problems and convert as needed.





50. If you have 5.6 liters of gas in a piston at a pressure of 1.5 atm and compress the gas until its volume is 4.8 L, what will the new pressure inside the piston be?

51. I have 130 liters of gas in a piston at a temperature of 250 °C. If I cool the gas until the volume decreases to 85 liters, what will temperature of the gas be?

52. A gas occupies 1.5 L at 850 mm Hg and 15°C. At what pressure will this gas occupy 2.5 L at 30.0°C?

53. Calculate the pressure (atm) of 0.0108 mol of methane (CH_4) in a 0.265 L flask at 37 °C.

54. A steel cylinder contains a mixture of nitrogen, oxygen, and carbon dioxide gases. The total pressure in the tank is 2280 torr. The partial pressures of the nitrogen gas and oxygen gas are 950 torr and 1025 torr, respectively. What is the partial pressure of carbon dioxide within the mixture?


Student's Lesson at a Glance

Lesson Summary

This lesson has three activities. In the final lesson of this unit, students explore how ideal gases differ from real gases. Using the Connecting Activity, students learn that variations between conceptual and real-world gases could have serious consequences for global conditions. Acknowledging Van der Waal's variation on the Ideal Gas Law, attraction of the molecules is factored to accurately explore real world gases. Students calculate the ideal volume of air at different altitudes with provided data and use calculated values compared with actual volume. Students identify relationships existing between altitude, pressure, temperature, and density. In the final activity, students apply gas laws to conditions observed in a lab. The lab further solidifies connections between real-world situations and gas laws.

SWBAT (Student will be able to)

- Explain why some gases do not behave like ideal gases under certain conditions
- Explain, using specific examples, how pressure and gas laws can be observed in real-world conditions

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.



CCC Reminder

- The Ideal Gas Law is a model. In this unit you will compare this model to how real gases behave. You may want to look back in the Matter unit to review why models are useful, but have specific limitations.
- When completing the gas law lab stations, make sure to follow directions closely and keep accurate notes of your observations.
- The Ideal Gas Law requires the use of the gas law constant (R). The value for R changes depending on the units that are needed in the problem. Make sure you are using the correct value for R.

Notes

Homework

Upcoming Quizzes/Tests

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Activity 1: Connecting

1. What do you think is the difference between a real gas and the model of an ideal gas?

Chemists work in many different environments all over the world. Since temperature and air

pressure may vary, it is necessary to have standard reference conditions for experimentation. Standard temperature and pressure (STP) in chemistry represents normal conditions for comparing the volumes of gases at sea level. **Avogadro's Law** states the volume occupied by an ideal gas is proportional to the amount of molecules in the container. Therefore, 1 mole of any gas at STP has the volume of 22.4 L.

Recall that the model of an ideal gas approximates the behavior



of a real gas across a limited range of temperatures and pressures. The behavior of real gases may not necessarily be explained by the **Ideal Gas Law** under all conditions. For example, the mathematical model PV = nRT does not hold true for gases that are massive or voluminous. In these cases, attractions between the real gas molecules must be taken into account. Johannes Diderik van der Waals proposed a variation on the Ideal Gas Law in 1873, which unlike the Ideal Gas Law, factors in attraction between molecules.

Why should we know the difference between how real and ideal gases behave? To utilize gases for practical applications, it is important to understand how gases behave in extreme conditions. People rely on many products from extreme environments like the Arctic, which starts at the North pole and ends at the Arctic Circle. The Arctic has long, cold winters reaching temperatures of 233 K; however, the *wind chill* can be much lower. Mining in the Arctic yields uranium, nickel, copper, zinc, silver, gold, and diamonds. Large amounts of oil and natural gas are also piped and carried to countries all over the world. The waters in the Arctic are also home to many popular seafoods, including crab and cod.

To obtain these resources, companies use machines of all types. Many of the heavy resources must be transferred from stationary locations onto ships, trucks and trains. Engineers must calculate how real gases behave at very low temperatures and pressures so that the machines work properly. Without modified calculations for real gases, many of the resources we enjoy would be become harder to obtain, which would make them more expensive.

2. What conditions could make a real gas violate the gas laws?

3. Scientists use words such as *obey*, *violate*, and *behavior* to describe the movement of molecules. Do gas molecules make conscious decisions about how to behave, or is the behavior of gases a result of external factors? *Support your claim with evidence*.



Activity 2: Comparing Real and Ideal Gases

Using the Ideal Gas Law, **PV = nRT***, calculate the ideal volume for air from 0 to 5,000 feet. Convert* °*C into Kelvin.*

Part 1: Average measures of 1 mole of air at different altitudes

| Altitude (feet) | Pressure (kPa) | Temp (°C) | Temp (K) | Density (kg/m³) | ldeal Volume (L) | Actual Volume (L) | | |
|--------------------|-------------------|-------------------------------|----------|--------------------|---------------------|----------------------|--|--|
| -5000 | 120.5 | | | | | | | |
| -4000 | 116.5 | Varies depending on location. | | | | | | |
| -3000 | 112.7 | | | | | | | |
| -2000 | 108.8 | | | | | | | |
| -1000 | 105.0 | | | | | | | |
| 0 | 101.3 | 15 | | 1.20 | | 0.203 | | |
| 1000 | 97.63 | 8.5 | | 1.12 | | 0.191 | | |
| 2000 | 94.19 | 2 | | 1.01 | | 0.178 | | |
| 3000 | 90.81 | -4.5 | | 0.91 | | 0.159 | | |
| 4000 | 87.49 | -11.0 | | 0.82 | | 0.145 | | |
| 5000 | 84.33 | -17.5 | | 0.74 | | 0.132 | | |

4. If you are at a negative altitude, where is one place on Earth you could be located?

5. The relationship between altitude and pressure is *inverse* or *direct* (*circle one*).

- 6. The relationship between altitude and density is *inverse* or *direct* (*circle one*).
- 7. Explain at the submicroscopic level your answers to #5 and #6.

- 8. The relationship between pressure and temperature is *inverse* or *direct* (*circle one*).
- 9. The relationship between temperature and volume is *inverse* or *direct* (*circle one*).
- 10. The relationship between altitude and volume is *inverse* or *direct* (*circle one*).
- 11. Considering your calculations for volume using the Ideal Gas Law, how do the actual volumes compare?
- 12. What are the limitations of using the Ideal Gas Law in all conditions based on the evidence from the data collected?

Part 2: Use Simulation 3, Set 1

Compare a real gas to an ideal gas in the simulation by clicking on the Real or Ideal button to change the view.

13. In the simulation, what is the difference between a real and an ideal gas?

14. If you lower the temperature in the simulation, what is the difference between a real and ideal gas?

Lesson Reflection Question

15. How has your understanding of the ideal gas model changed? Explain your answer with evidence.

Activity 3: Capstone

Use the Kinetic Molecular Theory postulates to help explain the relationships that are modeled by the Gas Laws. *Be sure to discuss Boyles's Law, Charles's Law, and Gay-Lussac's Law.*

| Kinetic Molecular Theory Postulate | How it relates to Boyles's Law | How it relates to Charles's Law | How it relates to Gav-Lussac's Law |
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1. Discuss the limitations of the Kinetic Molecular Theory model that help explain what we see in real gas behavior under certain conditions.

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| Name | Symbol | Atomic Number | Atomic Weight |
|------------|--------|------------------|---------------|
| Hydrogen | Н | 1 | 1.00794 |
| Helium | He | 2 | 4.00260 |
| Lithium | Li | 3 | 6.941 |
| Boron | В | 5 | 10.811 |
| Carbon | С | б | 12.0107 |
| Nitrogen | Ν | 7 | 14.0067 |
| Oxygen | 0 | 8 | 15.9994 |
| Fluorine | F | 9 | 18.9984 |
| Sodium | Na | 11 | 22.9898 |
| Magnesium | Mg | 12 | 24.3050 |
| Aluminum | Al | 13 | 26.9815 |
| Silicon | Si | 14 | 28.0855 |
| Phosphorus | Р | 15 | 30.9738 |
| Sulfur | S | 16 | 32.065 |
| Chlorine | Cl | 17 | 35.453 |
| Potassium | К | 19 | 39.0983 |
| Calcium | Ca | 20 | 40.078 |
| Chromium | Cr | 24 | 51.9961 |
| Manganese | Mn | 25 | 54.9380 |
| Iron | Fe | 26 | 55.845 |
| Copper | Cu | 29 | 63.54 |
| Zinc | Zn | 30 | 65.38 |
| Bromine | Br | 35 | 79.904 |
| Silver | Ag | 47 | 107.8682 |
| Tin | Sn | 50 | 118.710 |
| lodine | l. | 53 | 126.904 |
| Gold | Au | 79 | 196.967 |
| Mercury | Hg | 80 | 200.59 |
| Lead | Pb | 82 | 207.2 |