



Connected Chemistry

Gas Laws Unit

Lesson 4: Exploring Gas Laws



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
- 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

1. What do all these things have in common?

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** in your own words? All the gas laws assume gases behave according to the ideal gas law model.



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



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?



Activity 3: Teacher Facilitated Discussion

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 • kPa / mol • 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.

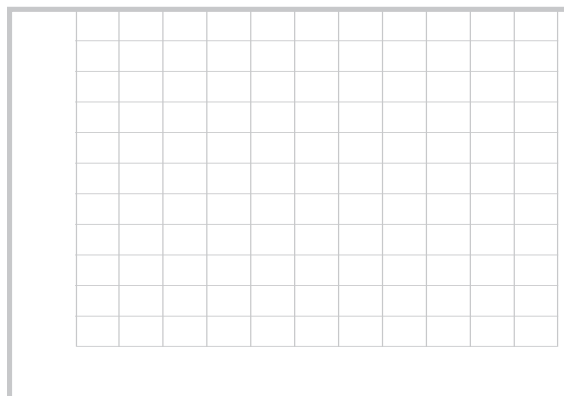
Your teacher will demonstrate how to use the gas law simulations. You will be required to collect data and to use this data to create a graph for each law. Using the data and graph, you will answer the analysis questions that follow. The bars beneath each of the variables will help you to visualize changes 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**.

Data		Submicroscopic Sketch
Trial 1		
Volume		
Pressure		
Number of moles		
Temperature		
R	8.314 L•kPa/mol•K	
Trial 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	
Key		



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											

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) \times 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 (P_1) and volume (V_1) at Trial 1 are related to the pressure (P_2) and volume (V_2) 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.

$$\underline{\hspace{2cm}} \times \underline{\hspace{2cm}} = \underline{\hspace{2cm}} \times \underline{\hspace{2cm}}$$

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.



Activity 5: Charles's Law

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**.

Data		Submicroscopic Sketch
Trial 1		
Volume		
Pressure		
Number of moles		
Temperature		
R	8.314 L•kPa/mol•K	
Trial 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	
Key		



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 temperature (T_1) and volume (V_1) at Trial 1 are related to the temperature (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.*



Activity 6: Simulating the Gas Laws - Gay-Lussac's Law

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. You may focus on just a few particles in your sketch. 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.

Data		Submicroscopic Sketch
Trial 1		
Volume		
Pressure		
Number of moles		
Temperature		
R	8.314 L•kPa/mol•K	
Trial 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	
Key		



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?



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.

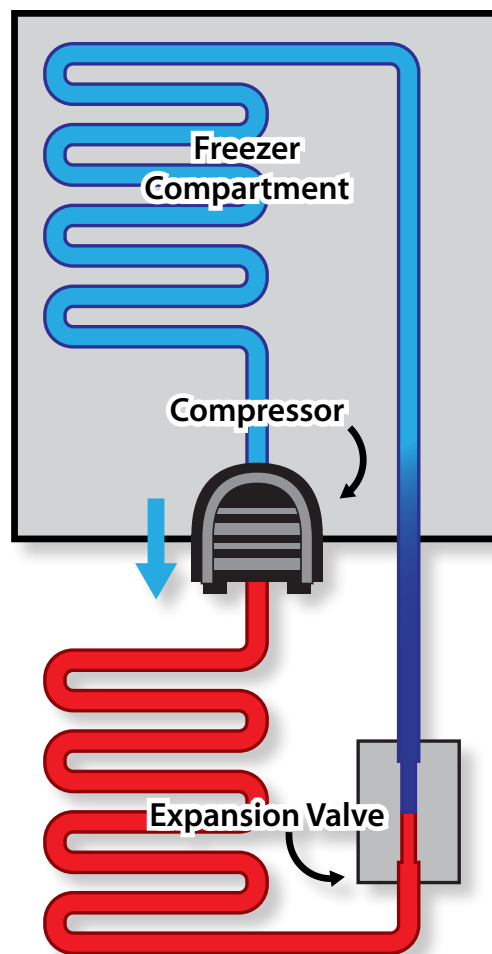


Activity 7: The Combined Gas Law

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.
4. 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**:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$



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?