Math Tutor

Algebraic Rearrangements of Gas Laws

When you solve problems in chemistry, it's usually a bad idea to just start entering numbers into a calculator. Instead, doing a little pencil-and-paper work beforehand will help you eliminate errors. When using the gas laws, you do not need to memorize all of the equations because they are easily derived from the equation for the combined gas law.

Study the table below. In each of Boyle's, Charles's, and Gay-Lussac's laws, one of the quantities—*T*, *P*, or *V*—does not change. By simply eliminating that factor from the equation, you obtain the equation for one particular gas law.

The conditions stated in the problem should make clear which factors change and which are held constant. This information will tell you which law's equation to use.

GAS LAW	HELD CONSTANT	CANCELLATION	RESULT
combined gas law	none	$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$	$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
Boyle's law	temperature	$\frac{P_1V_1}{\cancel{T_1}} = \frac{P_2V_2}{\cancel{T_2}}$	$P_1V_1 = P_2V_2$
Charles's law	pressure	$\frac{\cancel{P_1}V_1}{T_1} = \frac{\cancel{P_2}V_2}{T_2}$	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
Gay-Lussac's law	volume	$\frac{P_1\cancel{V_1}}{T_1} = \frac{P_2\cancel{V_2}}{T_2}$	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$

Sample Problem

A cylinder of nitrogen gas has a volume of 35.00 L at a pressure of 11.50 atm. What pressure will the nitrogen have if the contents of the cylinder are allowed to flow into a sealed reaction chamber whose volume is 140.0 L and if the temperature remains constant?

1 ANALYZE

Start with the combined gas law, and cancel the temperature, which does not change.

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

You want to know the new pressure in the chamber, so solve for P_2.

$$\frac{P_1V_1}{V_2} = \frac{P_2\cancel{V_2}}{\cancel{V_2}}; \frac{P_1V_1}{V_2} = P_2$$

2 SOLVE

The resulting equation to use in solving the problem is

$$P_2 = \frac{P_1V_1}{V_2} = \frac{(11.50\text{ atm})(35.00\text{ L})}{140.0\text{ L}} = 2.875\text{ atm.}$$

Practice Answers in Appendix E

1. A sample of gas has a pressure P_1 at a temperature T_1. Write the equation that you would use to find the temperature, T_2, at which the gas has a pressure of P_2.
2. An ideal gas occupies a volume of 785 mL at a pressure of 0.879 atm. What volume will the gas occupy at the pressure of 0.994 atm?

CHAPTER 11 Summary

BIG IDEA The gas laws describe mathematical relationships among the pressure, temperature, volume, and quantity of gases.

SECTION 1 Gases and Pressure

KEY TERMS

- pressure
- newton
- barometer
- millimeters of mercury
- atmosphere of pressure
- pascal
- partial pressure
- Dalton's law of partial pressures

- The kinetic-molecular theory of gases describes an ideal gas. The behavior of real gases is nearly ideal except at very high pressures and low temperatures.
- A barometer measures atmospheric pressure.
- Dalton's law of partial pressures states that in a mixture of unreacting gases, the total pressure equals the sum of the partial pressures of each gas.

SECTION 2 The Gas Laws

KEY TERMS

- Boyle's law
- absolute zero
- Charles's law
- Gay-Lussac's law
- combined gas law

- Boyle's law states the inverse relationship between the volume and the pressure of a gas:

$$PV = k$$

- Charles's law illustrates the direct relationship between a gas's volume and its temperature in kelvins:

$$V = kT$$

- Gay-Lussac's law represents the direct relationship between a gas's pressure and its temperature in kelvins:

$$P = kT$$

- The combined gas law, as its name implies, combines the previous relationships into the following mathematical expression:

$$\frac{PV}{T} = k$$

SECTION 3 Gas Volumes and the Ideal Gas Law

KEY TERMS

- Gay-Lussac's law of combining volumes of gases
- Avogadro's law
- standard molar volume of a gas
- ideal gas law
- ideal gas constant

- Gay-Lussac's law of combining volumes states that the volumes of reacting gases and their products at the same temperature and pressure can be expressed as ratios of whole numbers.
- Avogadro's law states that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules.
- The volume occupied by one mole of an ideal gas at STP is called the standard molar volume, which is 22.414 10 L.
- Charles's law, Boyle's law, and Avogadro's law can be combined to create the ideal gas law:

$$PV = nRT$$

SECTION 4 Diffusion and Effusion

KEY TERM

- Graham's law of effusion

- Gases diffuse, or become more spread out, due to their constant random molecular motion.
- Graham's law of effusion states that the relative rates of effusion of gases at the same temperature and pressure are inversely proportional to the square roots of their molar masses.

CHAPTER 11 Review

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SECTION 1

Gases and Pressure

REVIEWING MAIN IDEAS

1. State the assumptions that the kinetic-molecular theory makes about the characteristics of gas particles.
2. What is an ideal gas?
3. **a.** Why does a gas in a closed container exert pressure?
   b. What is the relationship between the area a force is applied to and the resulting pressure?
4. **a.** Why does a column of mercury in a tube that is inverted in a dish of mercury have a height of about 760 mm at sea level?
   b. The density of water is approximately 1/13.5 the density of mercury. What height would be maintained by a column of water inverted in a dish of water at sea level?
   c. What accounts for the difference in the heights of the mercury and water columns?
5. **a.** Identify three units used to express pressure.
   b. Convert one atmosphere to millimeters of mercury.
   c. What is a pascal?
   d. What is the SI equivalent of one standard atmosphere of pressure?
6. **a.** Explain what is meant by the partial pressure of each gas within a mixture of gases.
   b. How do the partial pressures of gases in a mixture affect each other?

PRACTICE PROBLEMS

7. If the atmosphere can support a column of mercury 760. mm high at sea level, what height of a hypothetical liquid whose density is 1.40 times the density of mercury could be supported?
8. Convert each of the following into a pressure reading expressed in torrs.
   a. 1.25 atm
   b. 2.48×10^{-3} atm
   c. 4.75×10^{4} atm
   d. 7.60×10^{6} atm
9. Convert each of the following into the unit specified.
   a. 125 mm Hg into atmospheres
   b. 3.20 atm into pascals
   c. 5.38 kPa into millimeters of mercury
10. Three of the primary components of air are carbon dioxide, nitrogen, and oxygen. In a sample containing a mixture of only these gases at exactly 1 atm, the partial pressures of carbon dioxide and nitrogen are given as $P_{CO_2} = 0.285$ torr and $P_{N_2} = 593.525$ torr. What is the partial pressure of oxygen?
11. A gas sample is collected over water at a temperature of 35.0°C when the barometric pressure reading is 742.0 torr. What is the partial pressure of the dry gas?

SECTION 2

The Gas Laws

REVIEWING MAIN IDEAS

12. How are the volume and pressure of a gas at constant temperature related?
13. Explain why pressure increases as a gas is compressed into a smaller volume.
14. How are the absolute temperature and volume of a gas at constant pressure related?
15. How are the pressure and absolute temperature of a gas at constant volume related?
16. Explain Gay-Lussac's law in terms of the kinetic-molecular theory.
17. State the combined gas law.

PRACTICE PROBLEMS

18. Use Boyle's law to solve for the missing value in each of the following:
   a. $P_1 = 350.0$ torr, $V_1 = 200.0$ mL, $P_2 = 700.0$ torr, $V_2 = ?$
   b. $V_1 = 2.4 \times 10^5$ L, $P_2 = 180$ mm Hg, $V_2 = 1.8 \times 10^3$ L, $P_1 = ?$
19. Use Charles's law to solve for the missing value in each of the following:
   a. $V_1 = 80.0$ mL, $T_1 = 27°C$, $T_2 = 77°C$, $V_2 = ?$
   b. $V_1 = 125$ L, $V_2 = 85.0$ L, $T_2 = 127°C$, $T_1 = ?$
   c. $T_1 = -33°C$, $V_2 = 54.0$ mL, $T_2 = 160.0°C$, $V_1 = ?$

20. A sample of air has a volume of 140.0 mL at 67°C. At what temperature would its volume be 50.0 mL at constant pressure?

21. The pressure exerted on a 240.0 mL sample of hydrogen gas at constant temperature is increased from 0.428 atm to 0.724 atm. What will the final volume of the sample be?

22. A sample of hydrogen at 47°C exerts a pressure of 0.329 atm. The gas is heated to 77°C at constant volume. What will its new pressure be?

23. A sample of gas at 47°C and 1.03 atm occupies a volume of 2.20 L. What volume would this gas occupy at 107°C and 0.789 atm?

24. The pressure on a gas at −73°C is doubled, but its volume is held constant. What will the final temperature be in degrees Celsius?

25. A flask contains 155 cm^3 of hydrogen that was collected under a pressure of 22.5 kPa. What pressure would have been required for the volume of the gas to have been 90.0 cm^3, assuming the same temperature?

26. A gas has a volume of 450.0 mL. If the temperature is held constant, what volume would the gas occupy if the pressure were
a. doubled? (Hint: Express P_2 in terms of P_1.)
b. reduced to one-fourth of its original value?

27. A sample of oxygen that occupies 1.00×10^6 mL at 575 mm Hg is subjected to a pressure of 1.25 atm. What will the final volume of the sample be if the temperature is held constant?

28. To what temperature must a sample of nitrogen at 27°C and 0.625 atm be taken so that its pressure becomes 1.125 atm at constant volume?

29. A gas has a volume of 1.75 L at −23°C and 150.0 kPa. At what temperature would the gas occupy 1.30 L at 210.0 kPa?

30. A gas at 7.75×10^4 Pa and 17°C occupies a volume of 850.0 cm^3. At what temperature, in degrees Celsius, would the gas occupy 720.0 cm^3 at 8.10×10^4 Pa?

31. A meteorological balloon contains 250.0 L He at 22°C and 740.0 mm Hg. If the volume of the balloon can vary according to external conditions, what volume would it occupy at an altitude at which the temperature is −52°C and the pressure is 0.750 atm?

32. The balloon in the previous problem will burst if its volume reaches 400.0 L. Given the initial conditions specified in that problem, determine at what temperature, in degrees Celsius, the balloon will burst if its pressure at that bursting point is 0.475 atm.

33. The normal respiratory rate for a human being is 15.0 breaths per minute. The average volume of air for each breath is 505 cm^3 at 20.0°C and 9.95×10^4 Pa. What is the volume of air at STP that an individual breathes in one day? Give your answer in cubic meters.

SECTION 3

Gas Volumes and the Ideal Gas Law

REVIEWING MAIN IDEAS

34. **a.** What are the restrictions on the use of Gay-Lussac's law of combining volumes?
b. At the same temperature and pressure, what is the relationship between the volume of a gas and the number of molecules present?

35. **a.** In a balanced chemical equation, what is the relationship between the molar ratios and the volume ratios of gaseous reactants and products?
b. What restriction applies to the use of the volume ratios in solving stoichiometry problems?

36. According to Avogadro,
a. what is the relationship between gas volume and number of moles at constant temperature and pressure?
b. what is the mathematical expression denoting this relationship?

37. What is the relationship between the number of molecules and the mass of 22.4 L of different gases at STP?

38. **a.** In what situations is the ideal gas law most suitable for calculations?
b. When using this law, why do you have to pay particular attention to units?

39. **a.** Write the equation for the ideal gas law.
b. What relationship is expressed in the ideal gas law?

PRACTICE PROBLEMS

40. Suppose a 5.00 L sample of O_2 at a given temperature and pressure contains 1.08×10^{23} molecules. How many molecules would be contained in each of the following at the same temperature and pressure?
- **a.** 5.0 L H_2
- **b.** 5.0 L CO_2
- **c.** 10.0 L NH_3

41. How many moles are contained in each of the following at STP?
- **a.** 22.4 L N_2
- **b.** 5.60 L Cl_2
- **c.** 0.125 L Ne
- **d.** 70.0 mL NH_3

42. Find the mass, in grams, of each of the following at STP.
- **a.** 11.2 L H_2
- **b.** 2.80 L CO_2
- **c.** 15.0 mL SO_2
- **d.** 3.40 cm^3 F_2

43. Find the volume, in liters, of each of the following at STP.
- **a.** 8.00 g O_2
- **b.** 3.50 g CO
- **c.** 0.0170 g H_2S
- **d.** 2.25×10^5 kg NH_3

44. Acetylene gas, C_2H_2, undergoes combustion to produce carbon dioxide and water vapor. If 75.0 L CO_2 is produced,
- **a.** how many liters of C_2H_2 are required?
- **b.** what volume of H_2O vapor is produced?
- **c.** what volume of O_2 is required?

45. Assume that 0.504 g of H_2 gas at STP reacts with excess CuO according to the following equation:

$$CuO(s) + H_2(g) \rightarrow Cu(s) + H_2O(g)$$

Make sure the equation is balanced before beginning your calculations.
- **a.** How many liters of H_2 react?
- **b.** How many moles of Cu are produced?
- **c.** How many grams of Cu are produced?

46. If 13.2 g of methane, CH_4, undergoes complete combustion at 0.961 atm and 140°C, how many liters of each product would be present at the same temperature and pressure? How many grams of each product will be present?

47. If air is 20.9% oxygen by volume,
- **a.** how many liters of air are needed for complete combustion of 25.0 L of octane vapor, C_8H_{18}?
- **b.** what volume of each product is produced?

48. Methanol, CH_3OH, is made by causing carbon monoxide and hydrogen gases to react at high temperature and pressure. If 4.50×10^2 mL CO and 8.25×10^2 mL H_2 are mixed,
- **a.** which reactant is present in excess?
- **b.** how much of that reactant remains after the reaction?
- **c.** what volume of CH_3OH is produced, assuming the same pressure?

49. Calculate the pressure, in atmospheres, exerted by each of the following:
- **a.** 2.50 L HF containing 1.35 mol at 320.0 K
- **b.** 4.75 L NO_2 containing 0.86 mol at 300.0 K
- **c.** 5.50×10^4 mL CO_2 containing 2.15 mol at 57°C

50. Calculate the volume, in liters, occupied by each of the following:
- **a.** 2.00 mol H_2 at 300.0 K and 1.25 atm
- **b.** 0.425 mol NH_3 at 37°C and 0.724 atm
- **c.** 4.00 g O_2 at 57°C and 0.888 atm

51. Determine the number of moles of gas contained in each of the following:
- **a.** 1.25 L at 250.0 K and 1.06 atm
- **b.** 0.80 L at 27°C and 0.925 atm
- **c.** 7.50×10^2 mL at −50.0°C and 0.921 atm

52. Find the mass of each of the following.
- **a.** 5.60 L O_2 at 1.75 atm and 250.0 K
- **b.** 3.50 L NH_3 at 0.921 atm and 27°C
- **c.** 125 mL SO_2 at 0.822 atm and −5°C

SECTION 4

Diffusion and Effusion

REVIEWING MAIN IDEAS

53. Describe in your own words the process of diffusion.

54. At a given temperature, what factor determines the rates at which different molecules undergo diffusion and effusion?

55. Ammonia, NH_3, and alcohol, C_2H_6O, are released together across a room. Which will you smell first?

PRACTICE PROBLEMS

56. Quantitatively compare the rates of effusion for the following pairs of gases at the same temperature and pressure:
- **a.** hydrogen and nitrogen
- **b.** fluorine and chlorine

57. What is the ratio of the average velocity of hydrogen molecules to that of neon atoms at the same temperature and pressure?

58. At a certain temperature and pressure, chlorine molecules have an average velocity of 324 m/s. What is the average velocity of sulfur dioxide molecules under the same conditions?

Mixed Review

REVIEWING MAIN IDEAS

59. A mixture of three gases, A, B, and C, is at a total pressure of 6.11 atm. The partial pressure of gas A is 1.68 atm; that of gas B is 3.89 atm. What is the partial pressure of gas C?

60. A child receives a balloon filled with 2.30 L of helium from a vendor at an amusement park. The temperature outside is 311 K. What will the volume of the balloon be when the child brings it home to an air-conditioned house at 295 K? Assume that the pressure stays the same.

61. A sample of argon gas occupies a volume of 295 mL at 36°C. What volume will the gas occupy at 55°C, assuming constant pressure?

62. A sample of carbon dioxide gas occupies 638 mL at 0.893 atm and 12°C. What will the pressure be at a volume of 881 mL and a temperature of 18°C?

63. At 84°C, a gas in a container exerts a pressure of 0.503 atm. Assuming the size of the container has not changed, at what temperature in degrees Celsius would the pressure be 1.20 atm?

64. A weather balloon at Earth's surface has a volume of 4.00 L at 304 K and 755 mm Hg. If the balloon is released and the volume reaches 4.08 L at 728 mm Hg, what is the temperature?

65. A gas has a pressure of 4.62 atm when its volume is 2.33 L. If the temperature remains constant, what will the pressure be when the volume is changed to 1.03 L? Express the final pressure in torrs.

66. At a deep-sea station that is 200 m below the surface of the Pacific Ocean, workers live in a highly pressurized environment. How many liters of gas at STP must be compressed on the surface to fill the underwater environment with 2.00×10^7 L of gas at 20.0 atm? Assume that temperature remains constant.

67. An unknown gas effuses at 0.850 times the effusion rate of nitrogen dioxide, NO_2. Estimate the molar mass of the unknown gas.

68. A container holds 265 mL of chlorine gas, Cl_2. If the gas sample is at STP, what is its mass?

69. Suppose that 3.11 mol of carbon dioxide is at a pressure of 0.820 atm and a temperature of 39°C. What is the volume of the sample, in liters?

70. Compare the rates of diffusion of carbon monoxide, CO, and sulfur trioxide, SO_3.

71. A gas sample that has a mass of 0.993 g occupies 0.570 L. Given that the temperature is 281 K and the pressure is 1.44 atm, what is the molar mass of the gas?

72. How many moles of helium gas would it take to fill a balloon to a volume of 1000.0 cm^3 when the temperature is 32°C and the atmospheric pressure is 752 mm Hg?

73. A gas sample is collected at 16°C and 0.982 atm. If the sample has a mass of 7.40 g and a volume of 3.96 L, find the volume of the gas at STP and the molar mass.

CRITICAL THINKING

74. Applying Models
- **a.** Why do we say the graph in **Figure 2.2** illustrates an inverse relationship?
- **b.** Why do we say the data plotted in **Figure 2.4** indicate a direct relationship?

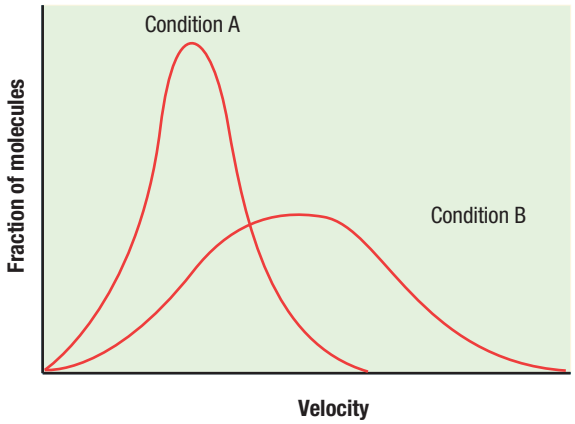
75. Inferring Conclusions If all gases behaved as ideal gases under all conditions of temperature and pressure, solid or liquid forms of these substances would not exist. Explain.

76. Relating Ideas Pressure is defined as force per unit area. Yet Torricelli found that the diameter of the barometer dish and the surface area of contact between the mercury in the tube and in the dish did not affect the height of mercury that was supported. Explain this seemingly inconsistent observation in view of the relationship between pressure and surface area.

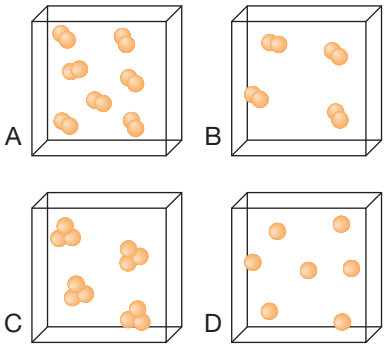
77. Evaluating Methods In solving a problem, what types of conditions involving temperature, pressure, volume, or number of moles would allow you to use
a. the combined gas law?
b. the ideal gas law?

78. Evaluating Ideas Gay-Lussac's law of combining volumes holds true for relative volumes at any proportionate size. Use Avogadro's law to explain why this proportionality exists.

79. Interpreting Graphics The graph below shows velocity distribution curves for the same gas under two different conditions, A and B. Compare the behavior of the gas under conditions A and B in relation to each of the following:
a. temperature
b. average kinetic energy
c. average molecular velocity
d. gas volume
e. gas pressure



80. Interpreting Concepts The diagrams below represent equal volumes of four different gases.



Use the diagrams to answer the following questions:
a. Are these gases at the same temperature and pressure? How do you know?
b. If the molar mass of gas B is 38 g/mol and that of gas C is 46 g/mol, which gas sample is denser?
c. To make the densities of gas samples B and C equal, which gas should expand in volume?
d. If the densities of gas samples A and C are equal, what is the relationship between their molar masses?

RESEARCH AND WRITING

81. Design and conduct a meteorological study to examine the interrelationships among barometric pressure, temperature, humidity, and other weather variables. Prepare a report explaining your results.

82. Conduct library research on attempts made to approach absolute zero and on the interesting properties that materials exhibit near that temperature. Write a report on your findings.

83. How do scuba divers use the laws and principles that describe the behavior of gases to their advantage? What precautions do they take to prevent the bends?

84. Explain the processes involved in the liquefaction of gases. Name some substances that are gases under normal room conditions and that are typically used in the liquid form. Explain why this is so.

85. Write a summary describing how Gay-Lussac's work on combining volumes relates to Avogadro's study of gases. Explain how certain conclusions about gases followed logically from consideration of the work of both scientists.

USING THE HANDBOOK

86. Review the melting point data in the properties tables for each group of the *Elements Handbook* (Appendix A). What elements on the periodic table exist as gases at room temperature?

87. Review in the *Elements Handbook* (Appendix A) the listing of the top 10 chemicals produced in the United States. Which of the top 10 chemicals are gases?

88. Most elements from Groups 1, 2, and 13 will react with water, acids, or bases to produce hydrogen gas. Review the common reactions information in the *Elements Handbook* (Appendix A), and answer the following questions:

- **a.** What is the equation for the reaction of barium with water?
- **b.** What is the equation for the reaction between cesium and hydrochloric acid?
- **c.** What is the equation for the reaction of gallium with hydrofluoric acid?
- **d.** What mass of barium would be needed to react with excess water to produce 10.1 L H_2 at STP?
- **e.** What masses of cesium and hydrochloric acid would be required to produce 10.1 L H_2 at STP?

89. Group 1 metals react with oxygen to produce oxides, peroxides, or superoxides. Review the equations for these common reactions in the *Elements Handbook* (Appendix A), and answer the following:

- **a.** How do oxides, peroxides, and superoxides differ?
- **b.** What mass of product will be formed from a reaction of 5.00 L O_2 with excess sodium? The reaction occurs at 27°C and 1 atm.

ALTERNATIVE ASSESSMENT

90. The air pressure of car tires should be checked regularly for safety reasons and for prevention of uneven tire wear. Find out the units of measurement on a typical tire gauge, and determine how gauge pressure relates to atmospheric pressure.

91. During a typical day, record every instance in which you encounter the diffusion or effusion of gases (for example, when smelling perfume).

92. **Performance** Qualitatively compare the molecular masses of various gases by noting how long it takes you to smell them from a fixed distance. Work only with materials that are not dangerous, such as flavor extracts, fruit peels, and onions.

93. **Performance** Design an experiment to gather data to verify the ideal gas law. If your teacher approves of your plan, carry it out. Illustrate your data with a graph, and determine if the data are consistent with the ideal gas law.