Vapor pressure. The pressure exerted by vapor in equilibrium with its liquid is the vapor pressure of the liquid. Vapor pressure increases as liquid temperature increases (Section 7.11).

Boiling and boiling point. Boiling is a form of evaporation in which bubbles of vapor form within the liquid and rise to the surface. The boiling point of a liquid is the temperature at which the vapor pressure of the liquid becomes equal to the external (atmospheric) pressure exerted on the liquid. The boiling point of a liquid increases or decreases as the prevailing atmospheric pressure increases or decreases (Section 7.12).

Intermolecular forces. Intermolecular forces are forces that act between a molecule and another molecule. The three principal types of intermolecular forces in liquids are dipole–dipole interactions, hydrogen bonds, and London forces (Section 7.13).

Hydrogen bonds. A hydrogen bond is an extra-strong dipole–dipole interaction between a hydrogen atom covalently bonded to a very electronegative atom (F, O, or N) and a lone pair of electrons on another small, very electronegative atom (F, O, or N) (Section 7.13).

KEY REACTIONS AND EQUATIONS

1. Boyle's law (Section 7.4)

$$P_1V_1 = P_2V_2 \qquad (n, T \text{ constant})$$

2. Charles's law (Section 7.5)

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \qquad (n, P \text{ constant})$$

3. Combined gas law (Section 7.6)

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \qquad (n \text{ constant})$$

4. Ideal gas law (Section 7.7)

$$PV = nRT$$

5. Ideal gas constant (Section 7.7)

$$R = 0.0821 \text{ atm} \cdot \text{L/mole} \cdot \text{K}$$

6. Dalton's law of partial pressures (Section 7.8)

$$P_{\text{Total}} = P_1 + P_2 + P_3 + \cdots$$

EXERCISES *and* PROBLEMS

The members of each pair of problems in this section test similar material.

Kinetic Molecular Theory of Matter (Section 7.1)

7.1 Using kinetic molecular theory concepts, answer the following questions.
- a. What type of energy is related to cohesive forces?
- b. What effect does temperature have on the magnitude of disruptive forces?
- c. What is the general effect of cohesive forces on a system of particles?
- d. What type of potential energy is particularly important when considering the physical states of matter?

7.2 Using kinetic molecular theory concepts, answer the following questions.
- a. What type of energy is related to disruptive forces?
- b. What effect does temperature have on the magnitude of cohesive forces?
- c. What is the general effect of disruptive forces on a system of particles?
- d. How do molecules transfer energy from one to another?

Kinetic Molecular Theory and Physical States (Section 7.2)

7.3 Indicate the state of matter to which each of the following characterizations applies. There may be more than one correct answer for some characterizations.
- a. Disruptive forces and cohesive forces are of about the same magnitude.
- b. Disruptive forces are significantly less than cohesive forces.
- c. Kinetic energy dominates over potential energy.
- d. Kinetic energy is significantly less than potential energy.

7.4 Indicate the state of matter to which each of the following characterizations applies. There may be more than one correct answer for some characterizations.
- a. Disruptive forces are significantly greater than cohesive forces.
- b. Cohesive forces are significantly less than disruptive forces.
- c. Potential energy dominates over kinetic energy.
- d. Kinetic energy and potential energy are of about the same magnitude.

7.5 With which of the states of matter is each of the following relative characterizations best associated? There may be more than one correct answer for some characterizations.
- a. Indefinite shape and indefinite volume
- b. Very small thermal expansion
- c. Small thermal expansion
- d. High density

7.6 With which of the states of matter is each of the following relative characterizations best associated? There may be more than one correct answer for some characterizations.
- a. Moderate thermal expansion
- b. Definite volume and indefinite shape
- c. Small compressibility
- d. Low density

Gas Law Variables (Section 7.3)

7.7 Identify the gas law variable with which each of the following measurements is associated.
a. 7.4 moles b. 3.70 L c. 173 mm Hg d. 32.3 K

7.8 Identify the gas law variable with which each of the following measurements is associated.
a. 343 K b. 6.7 mL c. 673 torr d. 0.23 mole

7.9 Carry out the following pressure unit conversions using the dimensional-analysis method of problem solving.
a. 735 mm Hg to atmospheres
b. 0.530 atm to millimeters of mercury
c. 0.530 atm to torr
d. 12.0 psi to atmospheres

7.10 Carry out the following pressure unit conversions using the dimensional-analysis method of problem solving.
a. 73.5 mm Hg to atmospheres
b. 1.75 atm to millimeters of mercury
c. 735 torr to atmospheres
d. 1.61 atm to pounds per square inch

Boyle's Law (Section 7.4)

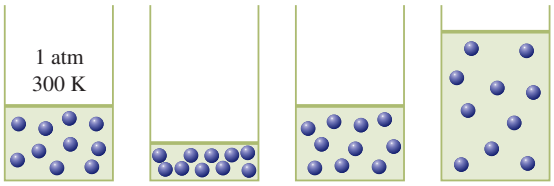
7.11 At constant temperature, a sample of 6.0 L of O_2 at 3.0 atm pressure is compressed until the volume decreases to 2.5 L. What is the new pressure, in atmospheres?

7.12 At constant temperature, a sample of 6.0 L of N_2 at 2.0 atm pressure is allowed to expand until the volume reaches 9.5 L. What is the new pressure, in atmospheres?

7.13 A sample of ammonia (NH_3), a colorless gas with a pungent odor, occupies a volume of 3.00 L at a pressure of 655 mm Hg and a temperature of 25°C. What volume, in liters, will this NH_3 sample occupy at the same temperature if the pressure is increased to 725 mm Hg?

7.14 A sample of nitrogen dioxide (NO_2), a toxic gas with a reddish-brown color, occupies a volume of 4.00 L at a pressure of 725 mm Hg and a temperature of 35°C. What volume, in liters, will this NO_2 sample occupy at the same temperature if the pressure is decreased to 125 mm Hg?

7.15 Diagram I depicts a gas, in a cylinder of variable volume, at the conditions specified in the diagram. Which of the diagrams II through IV depicts the result of doubling the pressure at constant temperature and constant number of moles of gas?



7.16 Using the diagrams given in Problem 7.15, which of the diagrams II through IV correctly depicts the result of halving the pressure at constant temperature and constant number of moles of gas?

Charles's Law (Section 7.5)

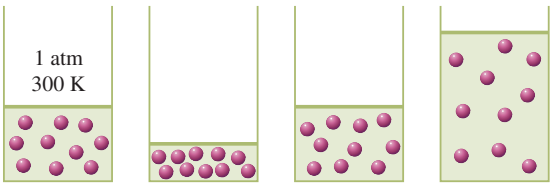
7.17 At atmospheric pressure, a sample of H_2 gas has a volume of 2.73 L at 27°C. What volume, in liters, will the H_2 gas occupy if the temperature is increased to 127°C and the pressure is held constant?

7.18 At atmospheric pressure, a sample of O_2 gas has a volume of 55 mL at 27°C. What volume, in milliliters, will the O_2 gas occupy if the temperature is decreased to 0°C and the pressure is held constant?

7.19 A sample of N_2 gas occupies a volume of 375 mL at 25°C and a pressure of 2.0 atm. Determine the temperature, in degrees Celsius, at which the volume of the gas would be 525 mL at the same pressure.

7.20 A sample of Ar gas occupies a volume of 1.2 L at 125°C and a pressure of 1.0 atm. Determine the temperature, in degrees Celsius, at which the volume of the gas would be 1.0 L at the same pressure.

7.21 Diagram I depicts a gas, in a cylinder of variable volume, at the conditions specified in the diagram. Which of the diagrams II through IV depicts the results of decreasing the Kelvin temperature by a factor of two at constant pressure and constant number of moles of gas?



7.22 Using the diagrams given in Problem 7.21, which of the diagrams II through IV correctly depicts the result of increasing the Kelvin temperature by a factor of two at constant pressure and constant number of moles of gas?

Combined Gas Law (Section 7.6)

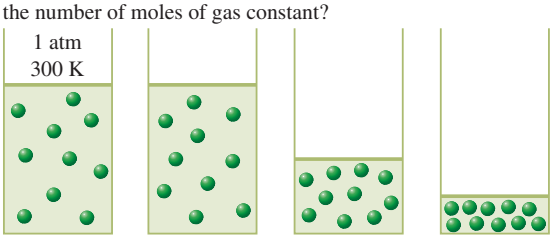
7.23 Rearrange the standard form of the combined gas law equation so that each of the following variables is by itself on one side of the equation.
a. T_1 b. P_2 c. V_1

7.24 Rearrange the standard form of the combined gas law equation so that each of the following variables is by itself on one side of the equation.
a. V_2 b. T_2 c. P_1

7.25 A sample of carbon dioxide (CO_2) gas has a volume of 15.2 L at a pressure of 1.35 atm and a temperature of 33°C. Determine the following for this gas sample.
a. Volume, in liters, at $T = 35$°C and $P = 3.50$ atm
b. Pressure, in atmospheres, at $T = 42$°C and $V = 10.0$ L
c. Temperature, in degrees Celsius, at $P = 7.00$ atm and $V = 0.973$ L
d. Volume, in milliliters, at $T = 97$°C and $P = 6.70$ atm

7.26 A sample of carbon monoxide (CO) gas has a volume of 7.31 L at a pressure of 735 mm Hg and a temperature of 45°C. Determine the following for this gas sample.
a. Pressure, in millimeters of mercury, at $T = 357$°C and $V = 13.5$ L
b. Temperature, in degrees Celsius, at $P = 1275$ mm Hg and $V = 0.800$ L
c. Volume, in liters, at $T = 45$°C and $P = 325$ mm Hg
d. Pressure, in atmospheres, at $T = 325$°C and $V = 2.31$ L

7.27 Diagram I depicts a gas, in a cylinder of variable volume, at conditions given in the diagram. Which of the diagrams II through IV correctly depicts the result of doubling the pressure and doubling the Kelvin temperature of the gas while keeping the number of moles of gas constant?



7.28 Using the diagrams given in Problem 7.27, which of the diagrams II through IV correctly depicts the result of doubling the pressure and halving the Kelvin temperature of the gas while keeping the number of moles of gas constant?

Ideal Gas Law (Section 7.7)

7.29 What is the temperature, in degrees Celsius, of 5.23 moles of helium (He) gas confined to a volume of 5.23 L at a pressure of 5.23 atm?

7.30 What is the temperature, in degrees Celsius, of 1.50 moles of neon (Ne) gas confined to a volume of 2.50 L at a pressure of 1.00 atm?

7.31 Calculate the volume, in liters, of 0.100 mole of O_2 gas at 0°C and 2.00 atm pressure.

7.32 Calculate the pressure, in atmospheres, of 0.100 mole of O_2 gas in a 2.00-L container at a temperature of 75°C.

7.33 Determine the following for a 0.250-mole sample of CO_2 gas.
a. Volume, in liters, at 27°C and 1.50 atm
b. Pressure, in atmospheres, at 35°C in a 2.00-L container
c. Temperature, in degrees Celsius, at 1.20 atm pressure in a 3.00-L container
d. Volume, in milliliters, at 125°C and 0.500 atm pressure

7.34 Determine the following for a 0.500-mole sample of CO gas.
a. Pressure, in atmospheres, at 35°C in a 1.00-L container
b. Temperature, in degrees Celsius, at 5.00 atm pressure in a 5.00-L container
c. Volume, in liters, at 127°C and 3.00 atm
d. Pressure, in millimeters of mercury, at 25°C in a 2.00-L container

Dalton's Law of Partial Pressures (Section 7.8)

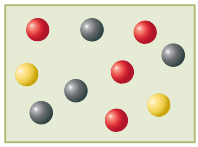
7.35 The total pressure exerted by a mixture of O_2, N_2, and He gases is 1.50 atm. What is the partial pressure, in atmospheres, of the O_2, given that the partial pressures of the N_2 and He are 0.75 and 0.33 atm, respectively?

7.36 The total pressure exerted by a mixture of He, Ne, and Ar gases is 2.00 atm. What is the partial pressure, in atmospheres, of Ne, given that the partial pressures of the other gases are both 0.25 atm?

7.37 A gas mixture contains O_2, N_2, and Ar at partial pressures of 125, 175, and 225 mm Hg, respectively. If CO_2 gas is added to the mixture until the total pressure reaches 623 mm Hg, what is the partial pressure, in millimeters of mercury, of CO_2?

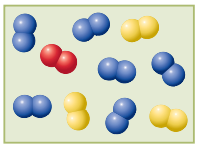
7.38 A gas mixture contains He, Ne, and H_2S at partial pressures of 125, 175, and 225 mm Hg, respectively. If all of the H_2S is removed from the mixture, what will be the partial pressure, in millimeters of mercury, of Ne?

7.39 The following diagram depicts a gaseous mixture of neon (red spheres), argon (black spheres), and krypton (yellow spheres).



If the total pressure in the container is 6.0 atm, what is the partial pressure, in atm, of the following?
a. Neon b. Argon c. Krypton

7.40 The following diagram depicts a gaseous mixture of O_2 (red spheres), N_2 (blue spheres), and Cl_2 (yellow spheres).



Assuming that the gases do not react with each other, what is the total pressure, in atm, in the container if the partial pressure of the O_2 gas is 2.0 atm?

Changes of State (Section 7.9)

7.41 Indicate whether each of the following is an exothermic or an endothermic change of state.
a. Sublimation b. Melting c. Condensation

7.42 Indicate whether each of the following is an exothermic or an endothermic change of state.
a. Freezing b. Evaporation c. Deposition

7.43 Indicate whether the liquid state is involved in each of the following changes of state.
a. Sublimation b. Melting c. Condensation

7.44 Indicate whether the solid state is involved in each of the following changes of state.
a. Freezing b. Deposition c. Evaporation

Evaporation of Liquids (Section 7.10)

7.45 What are the two ways in which the escape of high-energy molecules from the surface of a liquid during the process of evaporation affects the liquid?

7.46 What are the two general requirements that must be met before a molecule can escape from the surface of a liquid during the evaporation process?

7.47 How does an increase in the temperature of a liquid affect the rate of evaporation of the liquid?

7.48 How does an increase in the surface area of a liquid affect the rate of evaporation of the liquid?

Vapor Pressure of Liquids (Section 7.11)

7.49 Indicate whether or not each of the following statements about an equilibrium state is true or false.
a. For systems in a state of equilibrium, two opposite processes take place at equal rates.
b. A liquid–vapor equilibrium situation is an example of a physical equilibrium state.

7.50 Indicate whether or not each of the following statements about an equilibrium state is true or false.
a. For systems in a state of equilibrium, no net macroscopic changes can be detected.
b. For a liquid–vapor equilibrium situation the two opposite processes occurring are evaporation and condensation.

7.51 What is the relationship between the temperature of a liquid and the vapor pressure of that liquid?

7.52 What is the relationship between the strength of the attractive forces in a liquid and the liquid's vapor pressure?

7.53 What term is used to describe a substance that readily evaporates at room temperature because of a high vapor pressure?

7.54 What term is used to describe gaseous molecules of a substance at a temperature and pressure at which we ordinarily would think of the substance as a liquid or solid?

Boiling and Boiling Point (Section 7.12)

7.55 Indicate whether each of the following statements concerning boiling or boiling point is true or false.
a. The process of boiling is a form of evaporation.
b. The boiling point of a liquid heated in an open container is determined by atmospheric pressure.
c. The normal boiling point of a liquid is the temperature at which it boils when the liquid is at sea level.
d. At a pressure of 760 mm Hg, all liquids boil at the same temperature.

7.56 Indicate whether each of the following statements concerning boiling and boiling point is true or false.
a. A liquid can be made to boil at temperatures higher than its normal boiling point.
b. A liquid can be made to boil at temperatures lower than its normal boiling point.
c. In a boiling liquid, vapor formation occurs within the body of the liquid.
d. To compare the boiling points of two different liquids the external pressure should be the same.

7.57 What is the relationship between external pressure and the boiling point of a liquid?

7.58 What is the relationship between location (elevation) and the boiling point of a liquid?

Intermolecular Forces in Liquids (Section 7.13)

7.59 Describe the molecular conditions necessary for the existence of a dipole–dipole interaction.

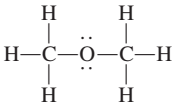
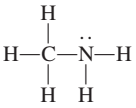
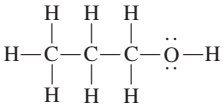
7.60 Describe the molecular conditions necessary for the existence of a London force.

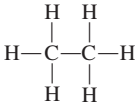
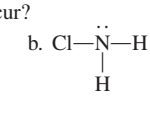
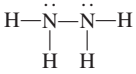
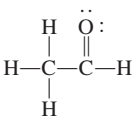
7.61 In liquids, what is the relationship between boiling point and the strength of intermolecular forces?

7.62 In liquids, what is the relationship between vapor pressure magnitude and the strength of intermolecular forces?

7.63 For liquid-state samples of the following diatomic substances, classify the dominant intermolecular forces present as London forces, dipole–dipole interactions, or hydrogen bonds.
a. H_2 b. HF c. CO d. F_2

7.64 For liquid-state samples of the following diatomic substances, classify the dominant intermolecular forces present as London forces, dipole–dipole interactions, or hydrogen bonds.
a. O_2 b. HCl c. Cl_2 d. BrCl

7.65 In which of the following substances, in the pure liquid state, would hydrogen bonding occur?
a. 
b. 
c. 
d. 

7.66 In which of the following substances, in the pure liquid state, would hydrogen bonding occur?
a. 
b. 
c. 
d. 

7.67 How many hydrogen bonds can form between a single water molecule and other water molecules?

7.68 How many hydrogen bonds can form between a single ammonia molecule (NH_3) and other ammonia molecules?

ADDITIONAL PROBLEMS

7.69 A sample of NO_2 gas in a 575-mL container at a pressure of 1.25 atm and a temperature of 125°C is transferred to a new container with a volume of 825 mL.
a. What is the new pressure, in atmospheres, if no change in temperature occurs?
b. What is the new temperature, in degrees Celsius, if no change in pressure occurs?
c. What is the new temperature, in degrees Celsius, if the pressure is increased to 2.50 atm?

7.70 A sample of NO_2 gas in a nonrigid container at a temperature of 24°C occupies a certain volume at a certain pressure. What will be its temperature, in degrees Celsius, in each of the following situations?
a. Both pressure and volume are doubled.
b. Both pressure and volume are cut in half.
c. The pressure is doubled and the volume is cut in half.
d. The pressure is cut in half and the volume is tripled.

7.71 Match each of the listed restrictions on variables to the following gas laws: *Boyle's law, Charles's law,* and *the combined gas law.* More than one answer may be correct in a given situation.
a. The number of moles is constant.
b. The pressure is constant.
c. The temperature is constant.
d. Both the number of moles and the temperature are constant.

7.72 Suppose a helium-filled balloon used to carry scientific instruments into the atmosphere has a volume of 1.00×10^6 L at 25°C and a pressure of 752 mm Hg at the time it is launched. What will be the volume of the balloon, in liters, when, at a height of 37 km, it encounters a temperature of −33°C and a pressure of 75.0 mm Hg?

7.73 What is the pressure, in atmospheres, inside a 4.00-L container that contains the following amounts of O_2 gas at 40.0°C?
a. 0.72 mole b. 4.5 moles c. 0.72 g d. 4.5 g

7.74 How many molecules of hydrogen sulfide (H_2S) gas are contained in 2.00 L of H_2S at 0.0°C and 1.00 atm pressure?

7.75 A 1.00-mole sample of dry ice (solid CO_2) is placed in a flexible sealed container and allowed to sublime. After complete sublimation, what will be the container volume, in liters, at 23°C and 0.983 atm pressure?

7.76 A piece of Ca metal is placed in a 1.00-L container with pure N_2. The N_2 is at a pressure of 1.12 atm and a temperature of 26°C. One hour later, the pressure has dropped to 0.924 atm

and the temperature has dropped to 24°C. Calculate the number of grams of N_2 that reacted with the Ca.

7.77 A gas mixture containing He, Ne, and Ar exerts a pressure of 3.00 atm. What is the partial pressure of each gas present in the mixture under the following conditions?
a. There is an equal number of moles of each gas present.
b. There is an equal number of atoms of each gas present.
c. The partial pressures of He, Ne, and Ar are in a 3:2:1 ratio.
d. The partial pressure of He is one-half that of Ne and one-third that of Ar.

7.78 Under which of the following "pressure situations" will a liquid boil?
a. Vapor pressure and atmospheric pressure are equal.
b. Vapor pressure is less than atmospheric pressure.
c. Vapor pressure = 635 mm Hg, and atmospheric pressure = 735 mm Hg.
d. Vapor pressure = 735 torr, and atmospheric pressure = 1.00 atm.

7.79 The vapor pressure of PBr_3 reaches 400 mm Hg at 150°C. The vapor pressure of PI_3 reaches 400 mm Hg at 57°C.
a. Which substance should evaporate at the slower rate at 100°C?
b. Which substance should have the lower boiling point?
c. Which substance should have the weaker intermolecular forces?

7.80 In each of the following pairs of molecules, indicate which member of the pair would be expected to have the higher boiling point.
a. Cl_2 and Br_2 b. H_2O and H_2S
c. O_2 and CO d. C_3H_8 and CO_2

Multiple-Choice Practice Test

7.81 Which of the following statements is correct, according to kinetic molecular theory?
a. Solids have small compressibilities because there is very little space between particles.
b. In the gaseous state, attractive forces between particles are of about the same magnitude as disruptive forces.
c. An increase in temperature means an increase in potential energy.
d. Gases have high densities because the particles are widely separated.

7.82 How many times larger or smaller in size is the mm Hg pressure unit compared to the atmosphere pressure unit?
a. 100 times larger b. 100 times smaller
c. 760 times larger d. 760 times smaller

7.83 Charles's law involves which of the following?
a. An inverse proportion b. A constant volume
c. A constant temperature d. A constant pressure

7.84 A sample of 20.0 liters of nitrogen gas is under a pressure of 20.0 atm. If the volume of this gas is decreased to 5.00 liters at constant temperature, what will the new pressure be?
a. 80.0 atm b. 40.0 atm
c. 10.0 atm d. 5.00 atm

7.85 Which of the following gas laws has the mathematical form $PV = nRT$?
a. Dalton's law of partial pressures
b. Ideal gas law
c. Combined gas law
d. Boyle's law

7.86 In which of the following pairs of state changes is the final state (solid, liquid, or gas) the same for both members of the pair?
a. Sublimation and evaporation
b. Condensation and freezing
c. Deposition and melting
d. Sublimation and condensation

7.87 Molecules of a liquid can pass into the vapor phase only under which of the following conditions?
a. Atmospheric pressure is less than 640 mm Hg.
b. The vapor pressure of the liquid is greater than the atmospheric pressure.
c. The temperature of the liquid exceeds the liquid's normal boiling point.
d. The molecules have sufficient kinetic energy to overcome the intermolecular forces in the liquid.

7.88 Liquids boil at lower temperatures at higher elevations because
a. The intermolecular forces are weaker.
b. The intramolecular forces are weaker.
c. The atmospheric pressure is greater.
d. The vapor pressure at which boiling occurs is lower.

7.89 Which of the following is an intermolecular force that occurs between all molecules?
a. Hydrogen bonding
b. Weak dipole–dipole interaction
c. Strong dipole–dipole interaction
d. London force

7.90 Which of the following statements concerning intermolecular forces is *correct*?
a. Dipole–dipole interaction strength increases with molecular polarity.
b. Hydrogen bonding occurs only between nonpolar hydrogen-containing molecules.
c. London forces are extra-strong dipole–dipole interactions.
d. Substances in which hydrogen bonding is present usually have high vapor pressures.