Continued—

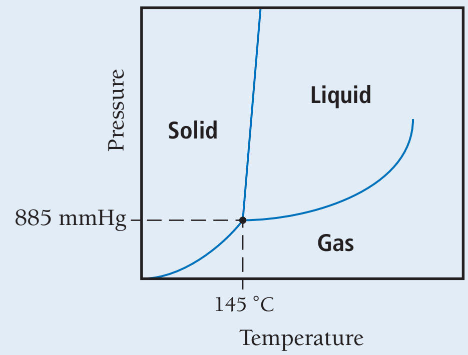
Q8. The vapor pressure of a substance is measured over a range of temperatures. A plot of the natural log of the vapor pressure versus the inverse of the temperature (in kelvin) produces a straight line with a slope of -3.46×10^3 K. Find the enthalpy of vaporization of the substance.
MISSED THIS? *Read Section 12.5*

a) 2.40×10^{-3} kJ/mol
b) 28.8 kJ/mol
c) 0.416 kJ/mol
d) 3.22 kJ/mol

Q9. Acetic acid has a normal boiling point of 118 °C and a ΔH_{vap} of 23.4 kJ/mol. What is the vapor pressure (in mmHg) of acetic acid at 25 °C?
MISSED THIS? *Read Section 12.5; Watch IWE 12.5*

a) 2.92×10^{-39} mmHg
b) 7.16×10^3 mmHg
c) 758 mmHg
d) 80.6 mmHg

Q10. Consider the phase diagram shown here. A sample of the substance in the phase diagram is initially at 175 °C and 925 mmHg. What phase transition occurs when the pressure is decreased to 760 mmHg at constant temperature?
MISSED THIS? *Read Section 12.8; Watch KCV 12.8*



a) solid to liquid
b) liquid to gas
c) solid to gas
d) liquid to solid

Answers: 1. (a) **2.** (d) **3.** (d) **4.** (b) **5.** (a) **6.** (c) **7.** (a) **8.** (b) **9.** (d) **10.** (b)

CHAPTER 12 IN REVIEW

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CONCEPTS

Solids, Liquids, and Intermolecular Forces (12.1, 12.2, 12.3)

- The forces that hold molecules or atoms together in a liquid or solid are intermolecular forces. The strength of the intermolecular forces in a substance determines its state.
- Dispersion forces are present in all elements and compounds; they arise from the fluctuations in electron distribution within atoms and molecules. These are the weakest intermolecular forces, but they are significant in molecules with high molar masses.
- Dipole–dipole forces, generally stronger than dispersion forces, are present in all polar molecules.
- Hydrogen bonding occurs in polar molecules that contain hydrogen atoms bonded directly to fluorine, oxygen, or nitrogen. These are among the strongest intermolecular forces.
- Ion–dipole forces occur when ionic compounds are mixed with polar compounds, and they are especially important in aqueous solutions.

Surface Tension, Viscosity, and Capillary Action (12.4)

- Surface tension results from the tendency of liquids to minimize their surface area in order to maximize the interactions between their constituent particles, thus lowering potential energy. Surface tension causes water droplets to form spheres and allows insects and paper clips to "float" on the surface of water.
- Viscosity is the resistance of a liquid to flow. Viscosity increases with increasing strength of intermolecular forces and decreases with increasing temperature.

- Capillary action is the ability of a liquid to flow against gravity up a narrow tube. It is the result of adhesive forces, the attraction between the molecules and the surface of the tube, and cohesive forces, the attraction between the molecules in the liquid.

Vaporization and Vapor Pressure (12.5, 12.7)

- Vaporization, the transition from liquid to gas, occurs when thermal energy overcomes the intermolecular forces present in a liquid. The opposite process is condensation. Vaporization is endothermic and condensation is exothermic.
- The rate of vaporization increases with increasing temperature, increasing surface area, and decreasing strength of intermolecular forces.
- The heat of vaporization (ΔH_{vap}) is the heat required to vaporize one mole of a liquid.
- In a sealed container, a liquid and its vapor come into dynamic equilibrium, at which point the rate of vaporization equals the rate of condensation. The pressure of a gas that is in dynamic equilibrium with its liquid is its vapor pressure.
- The vapor pressure of a substance increases with increasing temperature and with decreasing strength of its intermolecular forces.
- The boiling point of a liquid is the temperature at which its vapor pressure equals the external pressure.
- The Clausius–Clapeyron equation expresses the relationship between the vapor pressure of a substance and its temperature and can be used to calculate the heat of vaporization from experimental measurements.
- When a liquid is heated in a sealed container, it eventually forms a supercritical fluid, which has properties intermediate between a liquid and a gas. This occurs at critical temperature and critical pressure.

Fusion and Sublimation (12.6, 12.7)

- Sublimation is the transition from solid to gas. The opposite process is deposition.
- Fusion, or melting, is the transition from solid to liquid. The opposite process is freezing.
- The heat of fusion (ΔH_{fus}) is the amount of heat required to melt one mole of a solid. Fusion is endothermic.
- The heat of fusion is generally less than the heat of vaporization because intermolecular forces do not have to be completely overcome for melting to occur.

Phase Diagrams (12.8)

- A phase diagram is a map of the states of a substance as a function of its pressure (*y*-axis) and temperature (*x*-axis).
- The regions in a phase diagram represent conditions under which a single stable state (solid, liquid, gas) exists.
- The lines represent conditions under which two states are in equilibrium.
- The triple point represents the conditions under which all three states coexist.
- The critical point is the temperature and pressure above which a supercritical fluid exists.

The Uniqueness of Water (12.9)

- Water is a liquid at room temperature despite its low molar mass. Water forms strong hydrogen bonds, resulting in its high boiling point.
- The polarity of water enables it to dissolve many polar and ionic compounds and even nonpolar gases.
- Water expands upon freezing, so ice is less dense than liquid water. Water is critical both to the existence of life and to human health.

EQUATIONS AND RELATIONSHIPS

Clausius–Clapeyron Equation: Relationship between Vapor Pressure (P_{vap}), the Heat of Vaporization (ΔH_{vap}), and Temperature (T) (12.5)

$$\ln P_{vap} = \frac{-\Delta H_{vap}}{RT} + \ln \beta \quad (\beta \text{ is a constant})$$

$$\ln \frac{P_2}{P_1} = \frac{-\Delta H_{vap}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

LEARNING OUTCOMES

Chapter Objectives	Assessment
Determine the intermolecular forces acting between molecules (12.2), (12.3)	Example 12.1 **For Practice** 12.1 **Exercises** 35–38
Predict physical properties based on intermolecular forces (12.4)	Example 12.2 **For Practice** 12.2 **Exercises** 39–52
Perform calculations using the heat of vaporization (12.5)	Example 12.3 **For Practice** 12.3 **For More Practice** 12.3 **Exercises** 53–60
Calculate the heat of vaporization and vapor pressure using the Clausius–Clapeyron equation (12.5)	Examples 12.4, 12.5 **For Practice** 12.4, 12.5 **Exercises** 61–66
Perform calculations using the heat of fusion (12.6)	**Exercises** 67–70
Calculate heats related to heating and cooling curves (12.7)	**Exercises** 71–72
Identify physical properties of a compound from its phase diagram (12.8)	**Exercises** 73–78
Describe the physical properties of water (12.9)	**Exercises** 79–82

EXERCISES

Mastering Chemistry provides end-of-chapter exercises, feedback-enriched tutorial problems, animations, and interactive activities to encourage problem-solving practice and deeper understanding of key concepts and topics.

REVIEW QUESTIONS

1. Explain why water drops are spherical in the absence of gravity.

2. Why are intermolecular forces important?

3. What are the main properties of liquids (in contrast to gases and solids)?

4. What are the main properties of solids (in contrast to liquids and gases)?

5. What is the fundamental difference between an amorphous solid and a crystalline solid?

6. What factors cause transitions between the solid and liquid state? The liquid and gas state?

7. Describe the relationship between the state of a substance, its temperature, and the strength of its intermolecular forces.

8. From what kinds of interactions do intermolecular forces originate?

9. Why are intermolecular forces generally much weaker than bonding forces?

10. What is the dispersion force? What does the magnitude of the dispersion force depend on? How can you predict the magnitude of the dispersion force for closely related elements or compounds?

11. What is the dipole–dipole force? How can you predict the presence of dipole–dipole forces in a compound?

12. How is the polarity of a liquid generally related to its miscibility with water?

13. What is hydrogen bonding? How can you predict the presence of hydrogen bonding in a compound?

14. What is the ion–dipole force? Why is it important?

15. What is surface tension? How does surface tension result from intermolecular forces? How is it related to the strength of intermolecular forces?

16. What is viscosity? How does viscosity depend on intermolecular forces? What other factors affect viscosity?

17. What is capillary action? How does it depend on the relative strengths of adhesive and cohesive forces?

18. Explain what happens in the processes of vaporization and condensation. Why does the rate of vaporization increase with increasing temperature and surface area?

19. Why is vaporization endothermic? Why is condensation exothermic?

20. How is the volatility of a substance related to the intermolecular forces present within the substance?

21. What is the heat of vaporization for a liquid, and why is it useful?

22. Explain the process of dynamic equilibrium. How is dynamic equilibrium related to vapor pressure?

23. What happens to a system in dynamic equilibrium when it is disturbed in some way?

24. How is vapor pressure related to temperature? What happens to the vapor pressure of a substance when the temperature is increased? Decreased?

25. Define the terms *boiling point* and *normal boiling point*.

26. What is the Clausius–Clapeyron equation, and why is it important?

27. Explain what happens to a substance when it is heated in a closed container to its critical temperature.

28. What is sublimation? Give a common example of sublimation.

29. What is fusion? Is fusion exothermic or endothermic? Why?

30. What is the heat of fusion, and why is it important?

31. Examine the heating curve for water in Section 12.7 (Figure 12.36). Explain why the curve has two segments in which heat is added to the water but the temperature does not rise.

32. Examine the heating curve for water in Section 12.7 (Figure 12.36). Explain the significance of the slopes of each of the three rising segments. Why are the slopes different?

33. What is a phase diagram? Draw a generic phase diagram and label its important features. What is the significance of crossing a line in a phase diagram?

34. How do the properties of water differ from those of most other substances?

PROBLEMS BY TOPIC

Intermolecular Forces

35. Determine the kinds of intermolecular forces that are present in each element or compound.
MISSED THIS? *Read Section 12.3; Watch KCV 12.3*
a. N_2 **b.** NH_3 **c.** CO **d.** CCl_4

36. Determine the kinds of intermolecular forces that are present in each element or compound.
a. Kr **b.** NCl_3 **c.** SiH_4 **d.** HF

37. Determine the kinds of intermolecular forces that are present in each element or compound.
MISSED THIS? *Read Section 12.3; Watch KCV 12.3*
a. HCl **b.** H_2O **c.** Br_2 **d.** He

38. Determine the kinds of intermolecular forces that are present in each element or compound.
a. PH_3 **b.** HBr **c.** CH_3OH **d.** I_2

39. Arrange these compounds in order of increasing boiling point. Explain your reasoning.
MISSED THIS? *Read Section 12.3; Watch KCV 12.3, IWE 12.1, 12.2*
a. CH_4 **b.** CH_3CH_3 **c.** CH_3CH_2Cl **d.** CH_3CH_2OH

40. Arrange these compounds in order of increasing boiling point. Explain your reasoning.
a. H_2S **b.** H_2Se **c.** H_2O

41. In each pair of compounds, pick the one with the higher boiling point. Explain your reasoning.
MISSED THIS? *Read Section 12.3; Watch KCV 12.3, IWE 12.2*
a. CH_3OH or CH_3SH **b.** CH_3OCH_3 or CH_3CH_2OH
c. CH_4 or CH_3CH_3

42. In each pair of compounds, pick the one with the higher boiling point. Explain your reasoning.
a. NH_3 or CH_4 **b.** CS_2 or CO_2
c. CO_2 or NO_2

43. In each pair of compounds, pick the one with the higher vapor pressure at a given temperature. Explain your reasoning. **MISSED THIS?** *Read Sections 12.3, 12.5; Watch KCV 12.3, 12.5*
a. Br_2 or I_2 **b.** H_2S or H_2O **c.** NH_3 or PH_3

44. In each pair of compounds, pick the one with the higher vapor pressure at a given temperature. Explain your reasoning.
a. CH_4 or CH_3Cl
b. $CH_3CH_2CH_2OH$ or CH_3OH
c. CH_3OH or H_2CO

45. Determine whether each pair of compounds forms a homogeneous solution when combined. For those that form homogeneous solutions, indicate the type of forces that are involved. **MISSED THIS?** *Read Section 12.3*
a. CCl_4 and H_2O
b. KCl and H_2O
c. Br_2 and CCl_4
d. CH_3CH_2OH and H_2O

46. Determine whether each pair of compounds forms a homogeneous solution when combined. For those that form homogeneous solutions, indicate the type of forces that are involved.
a. $CH_3CH_2CH_2CH_2CH_3$ and $CH_3CH_2CH_2CH_2CH_2CH_3$
b. CBr_4 and H_2O
c. $LiNO_3$ and H_2O
d. CH_3OH and $CH_3CH_2CH_2CH_2CH_3$

Surface Tension, Viscosity, and Capillary Action

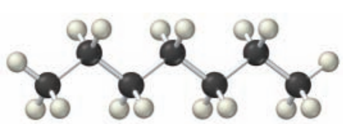
47. Which compound would you expect to have greater surface tension: acetone $[(CH_3)_2CO]$ or water (H_2O)? Explain. **MISSED THIS?** *Read Section 12.4*

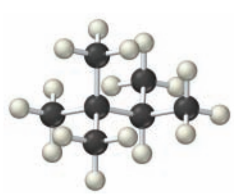
48. Water (a) "wets" some surfaces and beads up on others. Mercury (b), in contrast, beads up on almost all surfaces. Explain this difference.

(a) (b)

49. The structures of two isomers of heptane are shown. Which of these two compounds would you expect to have the greater viscosity? **MISSED THIS?** *Read Section 12.4*

Compound A

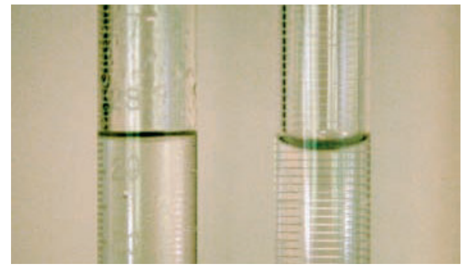




Compound B

50. Explain why the viscosity of multigrade motor oils is less temperature-dependent than that of single-grade motor oils.

51. Water in a glass tube that contains grease or oil residue displays a flat meniscus (left), whereas water in a clean glass tube displays a concave meniscus (right). Explain this observation. **MISSED THIS?** *Read Section 12.4*



52. When a thin glass tube is put into water, the water rises 1.4 cm. When the same tube is put into hexane, the hexane rises only 0.4 cm. Explain.

Vaporization and Vapor Pressure

53. Which evaporates more quickly: 55 mL of water in a beaker with a diameter of 4.5 cm or 55 mL of water in a dish with a diameter of 12 cm? Is the vapor pressure of the water different in the two containers? Explain. **MISSED THIS?** *Read Section 12.5; Watch KCV 12.5*

54. Which evaporates more quickly: 55 mL of water (H_2O) in a beaker or 55 mL of acetone $[(CH_3)_2CO]$ in an identical beaker under identical conditions? Is the vapor pressure of the two substances different? Explain.

55. Spilling room-temperature water over your skin on a hot day cools you down. Spilling room-temperature vegetable oil over your skin on a hot day does not. Explain the difference. **MISSED THIS?** *Read Section 12.5; Watch KCV 12.5*

56. Why is the heat of vaporization of water greater at room temperature than it is at its boiling point?

57. The human body obtains 915 kJ of energy from a candy bar. If this energy were used to vaporize water at 100.0 °C, how much water (in liters) could be vaporized? (Assume the density of water is 1.00 g/mL.) **MISSED THIS?** *Read Section 12.5; Watch KCV 12.5, IWE 12.3*

58. A 100.0-mL sample of water is heated to its boiling point. How much heat (in kJ) is required to vaporize it? (Assume a density of 1.00 g/mL.)

59. Suppose that 0.95 g of water condenses on a 75.0-g block of iron that is initially at 22 °C. If the heat released during condensation goes only to warming the iron block, what is the final temperature (in °C) of the iron block? (Assume a constant enthalpy of vaporization for water of 44.0 kJ/mol.) **MISSED THIS?** *Read Section 12.5; Watch KCV 12.5, IWE 12.3*

60. Suppose that 1.15 g of rubbing alcohol (C_3H_8O) evaporates from a 65.0-g aluminum block. If the aluminum block is initially at 25 °C, what is the final temperature of the block after the evaporation of the alcohol? Assume that the heat required for the vaporization of the alcohol comes only from the aluminum block and that the alcohol vaporizes at 25 °C.

61. This table displays the vapor pressure of ammonia at several different temperatures. Use the data to determine the heat of vaporization and normal boiling point of ammonia. **MISSED THIS?** *Read Section 12.5*

Temperature (K)	Pressure (torr)
200	65.3
210	134.3
220	255.7
230	456.0
235	597.0

62. This table displays the vapor pressure of nitrogen at several different temperatures. Use the data to determine the heat of vaporization and normal boiling point of nitrogen.

Temperature (K)	Pressure (torr)
65	130.5
70	289.5
75	570.8
80	1028
85	1718

63. Ethanol has a heat of vaporization of 38.56 kJ/mol and a normal boiling point of 78.4 °C. What is the vapor pressure of ethanol at 15 °C?
MISSED THIS? *Read Section 12.5; Watch IWE 12.5*

64. Benzene has a heat of vaporization of 30.72 kJ/mol and a normal boiling point of 80.1 °C. At what temperature does benzene boil when the external pressure is 445 torr?

65. Carbon disulfide has a vapor pressure of 363 torr at 25 °C and a normal boiling point of 46.3 °C. Find ΔH_{vap} for carbon disulfide.
MISSED THIS? *Read Section 12.5; Watch IWE 12.5*

66. Methylamine has a vapor pressure of 344 torr at −25 °C and a boiling point of −6.4 °C. Find ΔH_{vap} for methylamine.

Sublimation and Fusion

67. How much energy is released when 65.8 g of water freezes?
MISSED THIS? *Read Section 12.6*

68. Calculate the amount of heat required to completely sublime 50.0 g of solid dry ice (CO_2) at its sublimation temperature. The heat of sublimation for carbon dioxide is 32.3 kJ/mol.

69. An 8.5-g ice cube is placed into 255 g of water. Calculate the temperature change in the water upon the complete melting of the ice. Assume that all of the energy required to melt the ice comes from the water.
MISSED THIS? *Read Section 12.6*

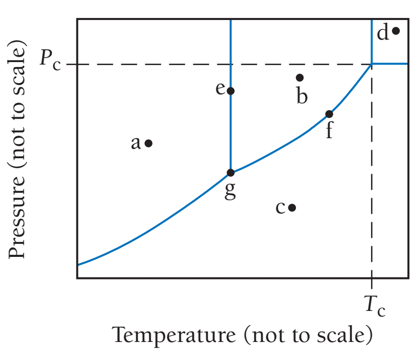
70. How much ice (in grams) would have to melt to lower the temperature of 352 mL of water from 25 °C to 5 °C? (Assume the density of water is 1.0 g/mL.)

71. How much heat (in kJ) is required to warm 10.0 g of ice, initially at −10.0 °C, to steam at 110.0 °C? The heat capacity of ice is 2.09 J/g·°C, and that of steam is 2.01 J/g·°C.
MISSED THIS? *Read Section 12.7; Watch KCV 12.7*

72. How much heat (in kJ) is evolved in converting 1.00 mol of steam at 145 °C to ice at −50 °C? The heat capacity of steam is 2.01 J/g·°C, and that of ice is 2.09 J/g·°C.

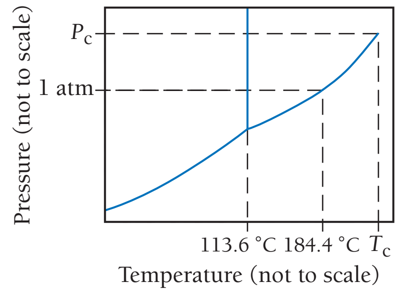
Phase Diagrams

73. Consider the phase diagram shown here. Identify the states present at points *a* through *g*.
MISSED THIS? *Read Section 12.8; Watch KCV 12.8*



74. Consider the phase diagram for iodine shown here.

a. What is the normal boiling point for iodine?
b. What is the melting point for iodine at 1 atm?
c. What state is present at room temperature and normal atmospheric pressure?
d. What state is present at 186 °C and 1.0 atm?

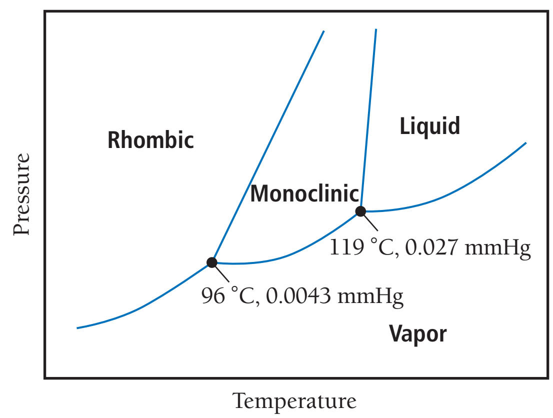


75. Nitrogen has a normal boiling point of 77.3 K and a melting point (at 1 atm) of 63.1 K. Its critical temperature is 126.2 K, and its critical pressure is 2.55×10^4 torr. It has a triple point at 63.1 K and 94.0 torr. Sketch the phase diagram for nitrogen. Does nitrogen have a stable liquid state at 1 atm?
MISSED THIS? *Read Section 12.8; Watch KCV 12.8*

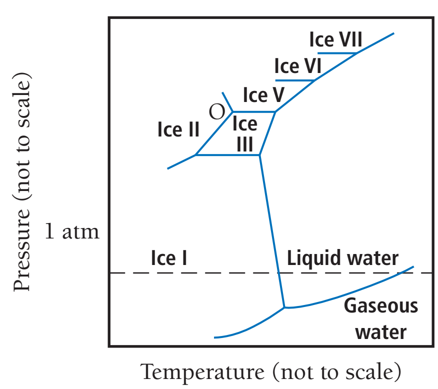
76. Argon has a normal boiling point of 87.2 K and a melting point (at 1 atm) of 84.1 K. Its critical temperature is 150.8 K, and its critical pressure is 48.3 atm. It has a triple point at 83.7 K and 0.68 atm. Sketch the phase diagram for argon. Which has the greater density, solid argon or liquid argon?

77. The phase diagram for sulfur is shown here. The rhombic and monoclinic states are two solid states with different structures.
MISSED THIS? *Read Section 12.8; Watch KCV 12.8*

a. Below what pressure does solid sulfur sublime?
b. Which of the two solid states of sulfur is more dense?



78. The high-pressure phase diagram of ice is shown here. Notice that, under high pressure, ice can exist in several different solid forms. What three forms of ice are present at the triple point marked O? How does the density of ice II compare to ice I (the familiar form of ice)? Would ice III sink or float in liquid water?



The Uniqueness of Water

79. Water has a high boiling point given its relatively low molar mass. Why?
MISSED THIS? *Read Section 12.9*

80. Water is a good solvent for many substances. What is the molecular basis for this property, and why is it significant?

81. Explain the role of water in moderating Earth's climate.
MISSED THIS? *Read Section 12.9*

82. How is the density of solid water compared to that of liquid water atypical among substances? Why is this significant?

CUMULATIVE PROBLEMS

83. Explain the observed trend in the melting points of the hydrogen halides.

HI	−50.8 °C
HBr	−88.5 °C
HCl	−114.8 °C
HF	−83.1 °C

84. Explain the observed trend in the boiling points of these compounds.

H_2Te	−2 °C
H_2Se	−41.5 °C
H_2S	−60.7 °C
H_2O	100 °C

85. The vapor pressure of water at 25 °C is 23.76 torr. If 1.25 g of water is enclosed in a 1.5-L container, will any liquid be present? If so, what mass of liquid?

86. The vapor pressure of CCl_3F at 300 K is 856 torr. If 11.5 g of CCl_3F is enclosed in a 1.0-L container, will any liquid be present? If so, what mass of liquid?

87. Examine the phase diagram for iodine shown in Figure 12.39(a). What state transitions occur as we uniformly increase the pressure on a gaseous sample of iodine from 0.010 atm at 185 °C to 100 atm at 185 °C? Make a graph, analogous to the heating curve for water shown in Figure 12.36. Plot pressure versus time during the pressure increase.

88. Carbon tetrachloride displays a triple point at 249.0 K and a melting point (at 1 atm) of 250.3 K. Which state of carbon tetrachloride is more dense, the solid or the liquid? Explain.

89. Four ice cubes at exactly 0 °C with a total mass of 53.5 g are combined with 115 g of water at 75 °C in an insulated container. If no heat is lost to the surroundings, what is the final temperature of the mixture?

90. A sample of steam with a mass of 0.552 g and at a temperature of 100 °C condenses into an insulated container holding 4.25 g of water at 5.0 °C. Assuming that no heat is lost to the surroundings, what is the final temperature of the mixture?

91. Draw a heating curve (such as the one in Figure 12.36) for 1 mole of methanol beginning at 170 K and ending at 350 K. Assume that the values given here are constant over the relevant temperature ranges.

Melting point	176 K
Boiling point	338 K
ΔH_{fus}	2.2 kJ/mol
ΔH_{vap}	35.2 kJ/mol
$C_{s,\ solid}$	105 J/K
$C_{s,\ liquid}$	81.3 J/mol · K
$C_{s,\ gas}$	48 J/mol · K

92. Draw a heating curve (such as the one in Figure 12.36) for 1 mol of benzene beginning at 0 °C and ending at 100 °C. Assume that the values given here are constant over the relevant temperature ranges.

Melting point	5.4 °C
Boiling point	80.1 °C
ΔH_{fus}	9.9 kJ/mol
ΔH_{vap}	30.7 kJ/mol
$C_{s,\ solid}$	118 J/mol·K
$C_{s,\ liquid}$	135 J/mol·K
$C_{s,\ gas}$	104 J/mol·K

93. Air conditioners not only cool air but dry it as well. A room in a home measures 6.0 m × 10.0 m × 2.2 m. If the outdoor temperature is 30 °C and the partial pressure of water in the air is 85% of the vapor pressure of water at this temperature, what mass of water must be removed from the air each time the volume of air in the room is cycled through the air conditioner? (Assume that all of the water must be removed from the air.) The vapor pressure for water at 30 °C is 31.8 torr.

94. A sealed flask contains 0.55 g of water at 28 °C. The vapor pressure of water at this temperature is 28.35 mmHg. What is the minimum volume of the flask in order that no liquid water be present in the flask?

95. Based on the phase diagram of CO_2 shown in Figure 12.39(b), describe the state changes that occur when the temperature of CO_2 is increased from 190 K to 350 K at a constant pressure of (a) 1 atm, (b) 5.1 atm, (c) 10 atm, and (d) 100 atm.

96. Consider a planet where the pressure of the atmosphere at sea level is 2500 mmHg. Does water behave in a way that can sustain life on the planet?

CHALLENGE PROBLEMS

97. Liquid nitrogen can be used as a cryogenic substance to obtain low temperatures. Under atmospheric pressure, liquid nitrogen boils at 77 K, allowing low temperatures to be reached. However, if the nitrogen is placed in a sealed, insulated container connected to a vacuum pump, even lower temperatures can be reached. Why? If the vacuum pump has sufficient capacity and is left on for an extended period of time, the liquid nitrogen will start to freeze. Explain.

98. Given that the heat of fusion of water is −6.02 kJ/mol, the heat capacity of $H_2O(l)$ is 75.2 J/mol · K, and the heat capacity of $H_2O(s)$ is 37.7 J/mol · K, calculate the heat of fusion of water at −10 °C.

99. The heat of combustion of CH_4 is 890.4 kJ/mol, and the heat capacity of H_2O is 75.2 J/mol · K. Find the volume of methane measured at 298 K and 1.00 atm required to convert 1.00 L of water at 298 K to water vapor at 373 K.

100. Two liquids, A and B, have vapor pressures at a given temperature of 24 mmHg and 36 mmHg, respectively. We prepare solutions of A and B at a given temperature and measure the total pressures above the solutions. We obtain these data:

Solution	Amt A (mol)	Amt B (mol)	*P* (mmHg)
1	1	1	30
2	2	1	28
3	1	2	32
4	1	3	33

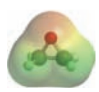
Predict the total pressure above a solution of 5 mol A and 1 mol B.

101. Three 1.0-L flasks, maintained at 308 K, are connected to each other with stopcocks. Initially, the stopcocks are closed. One of the flasks contains 1.0 atm of N_2; the second, 2.0 g of H_2O; and the third, 0.50 g of ethanol, C_2H_6O. The vapor pressure of H_2O at 308 K is 42 mmHg, and that of ethanol is 102 mmHg. The stopcocks are then opened and the contents mix freely. What is the pressure?

102. Butane (C_4H_{10}) has a heat of vaporization of 22.44 kJ/mol and a normal boiling point of −0.4 °C. A 250-mL sealed flask contains 0.55 g of butane at −22 °C. How much butane is present as a liquid? If the butane is warmed to 25 °C, how much is present as a liquid?

CONCEPTUAL PROBLEMS

103. The following image is an electrostatic potential map for ethylene oxide, $(CH_2)_2O$, a polar molecule. Use the electrostatic potential map to predict the geometry for how one ethylene oxide molecule interacts with another. Draw structural formulas, using the 3D bond notation introduced in Section 11.4, to show the geometry of the interaction.



104. One prediction of global warming is the melting of global ice, which may result in coastal flooding. A criticism of this prediction is that the melting of icebergs does not increase ocean levels any more than the melting of ice in a glass of water increases the level of liquid in the glass. Is this a valid criticism? Does the melting of an ice cube in a cup of water raise the level of the liquid in the cup? Why or why not? In response to this criticism, scientists have asserted that they are not worried about melting icebergs, but rather the melting of ice sheets that sit on the continent of Antarctica. Would the melting of this ice increase ocean levels? Why or why not?

105. The rate of vaporization depends on the surface area of the liquid. However, the vapor pressure of a liquid does not depend on the surface area. Explain.

106. Substance A has a smaller heat of vaporization than substance B. Which of the two substances will undergo a larger change in vapor pressure for a given change in temperature?

107. The density of a substance is greater in its solid state than in its liquid state. If the triple point in the phase diagram of the substance is below 1.0 atm, which will necessarily be at a lower temperature, the triple point or the normal melting point?

108. A substance has a heat of vaporization of ΔH_{vap} and a heat of fusion of ΔH_{fus}. Express the heat of sublimation in terms of ΔH_{vap} and ΔH_{fus}.

109. Examine the heating curve for water in Section 12.7 (Figure 12.36). If heat is added to the water at a constant rate, which of the three segments in which temperature is rising will have the least steep slope? Why?

110. A root cellar is an underground chamber used to store fruits, vegetables, and even meats. In extreme cold, farmers put large vats of water into the root cellar to prevent the fruits and vegetables from freezing. Explain why this works.

111. Suggest an explanation for the observation that the heat of fusion of a substance is always smaller than its heat of vaporization.

112. Refer to Figure 12.36 to answer each question.

a. A sample of steam begins on the line segment labeled 5 on the graph. Is heat absorbed or released in moving from the line segment labeled 5 to the line segment labeled 3? What is the sign of *q* for this change?

b. In moving from left to right along the line segment labeled 2 on the graph, heat is absorbed, but the temperature remains constant. Where does the heat go?

c. How would the graph change if it were for another substance (other than water)?

QUESTIONS FOR GROUP WORK

Active Classroom Learning

Discuss these questions with the group and record your consensus answer.

113. The boiling points of three compounds are tabulated here.

	Molar Mass	Boiling Point
2-hexanone	100.16	128 °C
heptane	100.20	98 °C
1-hexanol	102.17	156 °C

Answer the following questions without looking up the structures for these molecules: Which compound experiences hydrogen bonding? Which compound is polar but is unable to experience hydrogen bonding? Which is neither polar nor capable of hydrogen bonding? Explain your answers.

114. The vapor pressure for pure water and pure acetone is measured as a function of temperature. In each case, a graph of the log of the vapor pressure versus $1/T$ is found to be a straight line. The slope of the line for water is −4895 K, and the slope of the line for acetone is −3765 K. Determine ΔH_{vap} for each substance. Account for the difference by discussing the molecular structure of the two molecules.

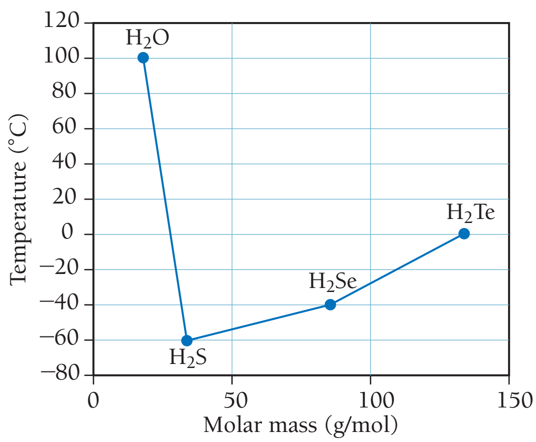
115. Based on the heating curve for water, does it take more energy to melt a mole of water or to boil a mole of water? Does it take more energy to warm the solid, the liquid, or the gas by 10 °C? Explain your answers clearly.

116. Sketch the phase diagram for carbon dioxide. If you have carbon dioxide at 1.0 atm and 25 °C, could you make it a liquid by cooling it down? How could you make it a liquid at 25 °C? If you increase the pressure of carbon dioxide that is at body temperature (37 °C), will it ever liquefy?

DATA INTERPRETATION AND ANALYSIS

Intermolecular Forces of Group 6A Hydrides

117. We have seen that molar mass and molecular structure influence the boiling point of a substance. We can see these two factors at work in the boiling points of the group 6A hydrides shown in the following graph.



▲ Boiling Point versus Molar Mass of Group 6A Hydrides

In order to disentangle the effects of molar mass and molecular structure on the boiling point, consider the data in the following table.

Compound	Molar Mass (g/mol)	*n*-Boiling Point (°C)	Dipole Moment (D)	Polarizability (10^{-24} cm^3)
H_2O	18.01	100	1.85	1.45
H_2S	34.08	−60	1.10	3.81
H_2Se	80.98	−42.2	0.41	4.71
H_2Te	129.6	−2.2	0.22	5.01

Use the information in the graph and the table to answer the following questions.

a. Does molar mass alone correlate with the trend in the boiling points for the group 6A hydrides?

b. Which boiling points in the graph correlate with polarizability? What type of intermolecular force correlates with polarizability?

c. Use the data in the table to explain the anomalously high boiling point of water.

Cc ANSWERS TO CONCEPTUAL CONNECTIONS

States of Matter

12.1 **(c)** Gases are compressible because the atoms or molecules in a gas are separated by large distances. An increase in pressure forces the atoms or molecules closer together, reducing the gas's volume.

State Changes

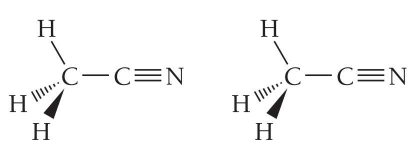
12.2 **(a)** When water boils, it simply changes state from liquid to gas. Water molecules do not decompose during boiling.

Dispersion Forces

12.3 **(c)** I_2 has the highest boiling point because it has the highest molar mass. Since the halogens are all similar in other ways, we expect I_2 to have the greatest dispersion forces and therefore the highest boiling point (and in fact it does).

Dipole–Dipole Interaction

12.4 **(a)**



Since acetonitrile is polar, the more negative end (in the electrostatic potential map) is attracted to the positive end (in the electrostatic potential map) of its neighbor.

Intermolecular Forces and Boiling Point

12.5 **(a)** CH_3OH. The compounds all have similar molar masses, so the dispersion forces are similar in all three. CO is polar, but because CH_3OH contains H directly bonded to O, it has hydrogen bonding, resulting in the highest boiling point.

Vaporization

12.6 **(d)** The rate of vaporization increases with increasing temperature and with increasing surface area. This sample has the combined highest temperature and highest surface. (The 250-mL beaker has a greater diameter than the 100-mL beaker, and therefore the water is spread out over a greater area.)

Vapor Pressure

12.7 **(b)** Although the *rate of vaporization* increases with increasing surface area, the *vapor pressure* of a liquid is independent of surface area. An increase in surface area increases both the rate of vaporization and the rate of condensation—the effects exactly cancel, and the vapor pressure does not change.

Boiling Point

12.8 **(a)** According to Figure 12.28, water has a vapor pressure of 200 torr at about 66 °C, so at an external pressure of 200 torr, water boils at 66 °C.

Cooling of Water with Ice

12.9 **(b)** The warming of the ice from −10 °C to 0 °C absorbs only 20.9 J/g of ice. The melting of the ice, however, absorbs about 334 J/g of ice. (You can obtain this value by dividing the heat of fusion of water by its molar mass.) Therefore, the melting of the ice produces a larger temperature decrease in the water than does the warming of the ice.

Phase Diagrams

12.10 **(b)** The solid will sublime into a gas. Since the pressure is below the triple point, the liquid state is not stable.