CHAPTER 13
LIQUIDS

SOLUTIONS TO REVIEW QUESTIONS

1. At 0°C, all three substances, H₂S, H₂Se, and H₂Te, are gases, because they all have boiling points below 0°C.

2. Liquids are made of particles that are close together, they are not compressible and they have definite volume. Solids also exhibit similar properties.

3. Liquids take the shape of the container they are in. Gases also exhibit this property.

4. The water in both containers would have the same vapor pressure, for it is a function of the temperature of the liquid.

5. Vapor pressure is the pressure exerted by a vapor when it is in equilibrium with its liquid. The liquid molecules on the surface and the gas molecules above the liquid are the important players in vapor pressure. One liter of water will evaporate at the same rate as 100 mL of water if they are at the same temperature and have the same surface area. The liquid and vapor in both cases will come to equilibrium in the same amount of time and they will have the same vapor pressure. Vapor pressure is a characteristic of the type of liquid, not the number of molecules of a liquid.

6. In Figure 13.5, it would be case (b) in which the atmosphere would reach saturation. The vapor pressure of water is the same in both (a) and (b), but since (a) is an open container the vapor escapes into the atmosphere and doesn’t reach saturation.

7. If ethyl ether and ethyl alcohol were both placed in a closed container, (a) both substances would be present in the vapor, for both are volatile liquids; (b) ethyl ether would have more molecules in the vapor because it has a higher vapor pressure at a given temperature.

8. Rubbing alcohol feels cold when applied to the skin, because the evaporation of the alcohol absorbs heat from the skin. The alcohol has a fairly high vapor pressure (low boiling point) and evaporates quite rapidly. This produces the cooling effect.

9. (a) Order of increasing rate of evaporation: mercury, acetic acid, water, toluene, benzene, carbon tetrachloride, methyl alcohol, bromine.
   (b) Highest boiling point is mercury. Lowest boiling point is bromine.

10. As temperature increases, molecular velocities increase. At higher molecular velocities, it becomes easier for molecules to break away from the attractive forces in the liquid.

11. The pressure of the atmosphere must be 1.00 atmosphere, otherwise the water would be boiling at some other temperature.

12. The thermometer would be at about 70°C. The liquid is boiling, which means its vapor pressure equals the confining pressure. From Table 13.7, we find that ethyl alcohol has a vapor pressure of 543 torr at 70°C.
13. At 30 torr, H₂O would boil at approximately 29°C, ethyl alcohol at 14°C, and ethyl ether at some temperature below 0°C.

14. (a) At a pressure of 500 torr, water boils at 88°C.  
(b) The normal boiling point of ethyl alcohol is 78°C.  
(c) At a pressure of 0.50 atm (380 torr), ethyl ether boils at 16°C.

15. Water boils when its vapor pressure equals the prevailing atmospheric pressure over the water. In order for water to boil at 50°C, the pressure over the water would need to be reduced to a point equal to the vapor pressure of the water (92.5 torr).

16. In a pressure cooker, the temperature at which the water boils increases above its normal boiling point, because the water vapor (steam) formed by boiling cannot escape. This results in an increased pressure over water and, consequently, an increased boiling temperature.

17. Vapor pressure varies with temperature. The temperature at which the vapor pressure of a liquid equals the prevailing pressure is the boiling point of the liquid.

18. Ammonia would have a higher vapor pressure than SO₂ at −40°C because it has a lower boiling point (NH₃ is more volatile than SO₂).

19. As the temperature of a liquid increases, the kinetic energy of the molecules as well as the vapor pressure of the liquid increases. When the vapor pressure of the liquid equals the external pressure, boiling begins with many of the molecules having enough energy to escape from the liquid. Bubbles of vapor are formed throughout the liquid and these bubbles rise to the surface, escaping as boiling continues.

20. 34.6°C, the boiling point of ethyl ether. (See Table 13.1)

21. The potential energy is greater in the liquid water than in the ice. The heat necessary to melt the ice increases the potential energy of the liquid, thus allowing the molecules greater freedom of motion. The potential energy of steam (gas) is greater than that of liquid water.

22. Based on Figure 13.3:  
(a) Line BC is horizontal because the temperature remains constant during the entire process of melting. The energy input is absorbed in changing from the solid to the liquid state.  
(b) During BC, both solid and liquid phases are present.  
(c) The line DE represents the change from liquid water to steam (vapor) at the boiling temperature of water.

23. Apply heat to an ice-water mixture, the heat energy is absorbed to melt the ice (heat of fusion), rather than warm the water, so the temperature remains constant until all the ice has melted.

24. Ice at 0°C contains less heat energy than water at 0°C. Heat must be added to convert ice to water, so the water will contain that much additional heat energy.

25. The boiling liquid remains at constant temperature because the added heat energy is being used to convert the liquid to a gas, i.e., to supply the heat of vaporization for the liquid at its boiling point.
26. Intermolecular forces are the attractive forces between molecules. These forces hold molecules together to form liquids and solids. Intramolecular forces are forces between atoms in a molecule. These forces hold the atoms in a molecule together.

27. Polar bonds are covalent bonds in which atoms do not share electrons equally.

28. The ability of a molecule to form instantaneous dipoles is most dependant on its number of electrons.

29. The heat of vaporization of water would be lower if water molecules were linear instead of bent. If linear, the molecules of water would be nonpolar. The relatively high heat of vaporization of water is a result of the molecule being highly polar and having strong dipole-dipole and hydrogen bonding attraction for other water molecules.

30. Ethyl alcohol exhibits hydrogen bonding; ethyl ether does not. This is indicated by the high heat of vaporization of ethyl alcohol, even though its molar mass is much less than the molar mass of ethyl ether.

31. Although a linear water molecule would be non-polar due to its symmetry, the individual O—H bonds would still be polar meaning that the hydrogen’s would still be able to form hydrogen bonds. The number of possible hydrogen bonds would not change. The overall intermolecular attractive force would be lower though due to its non-polar nature.

32. Water, at 80°C, will have fewer hydrogen bonds than water at 40°C. At the higher temperature, the molecules of water are moving faster than at the lower temperature. This results in less hydrogen bonding at the higher temperature.

33. H₂NCH₂CH₂NH₂ has two polar NH₂ groups. It should, therefore, show more hydrogen bonding and a higher boiling point (117°C) versus 49°C for CH₃CH₂CH₂NH₂.

34. Water has a relatively high boiling point because there is a high attraction between molecules due to hydrogen bonding.

35. HF has a higher boiling point than HCl because of the strong hydrogen bonding in HF (F is the most electronegative element). Neither F₂ nor Cl₂ will have hydrogen bonding, so the compound, F₂, with the lower molar mass, has the lower boiling point.

36. Prefixes preceding the word hydrate are used in naming hydrates, indicating the number of molecules of water present in the formulas. The prefixes used are:

- **mono** = 1
- **di** = 2
- **tri** = 3
- **tetra** = 4
- **penta** = 5
- **hexa** = 6
- **hepta** = 7
- **octa** = 8
- **nona** = 9
- **deca** = 10

37. ![H₂O](image)

38. Melting point, boiling point, heat of fusion, heat of vaporization, density, and crystal structure in the solid state are some of the physical properties of water that would be very different, if the molecules were linear and nonpolar instead of bent and highly polar. For example, the boiling point, melting point, heat of fusion and heat of vaporization would be lower because linear molecules have no dipole moment and the attraction among molecules would be much less.
39. Physical properties of water:
   (a) melting point, 0°C
   (b) boiling point, 100°C (at 1 atm pressure)
   (c) colorless
   (d) odorless
   (e) tasteless
   (f) heat of fusion, 335 J/g (80 cal/g)
   (g) heat of vaporization, 2.26 kJ/g (540 cal/g)
   (h) density = 1.0 g/mL (at 4°C)
   (i) specific heat = 4.184 J/g°C

40. For water, to have its maximum density, the temperature must be 4°C, and the pressure sufficient to keep it liquid, \(d = 1.0 \text{ g/mL}\)

41. Ice floats in water because it is less dense than water. The density of ice at 0°C is 0.915 g/mL. Liquid water, however, has a density of 1.00 g/mL. Ice will sink in ethyl alcohol, which has a density of 0.789 g/mL.

42. If the lake is in an area where the temperature is below freezing for part of the year, the expected temperature would be 4°C at the bottom of the lake. This is because the surface water would cool to 4°C (maximum density) and sink.

43. The formation of hydrogen and oxygen from water is an endothermic reaction, due to the following evidence:
   (a) Energy must continually be provided to the system for the reaction to proceed. The reaction will cease when the energy source is removed.
   (b) The reverse reaction, burning hydrogen in oxygen, releases energy as heat.
SOLUTIONS TO EXERCISES

1. \( \text{CH}_3\text{Br} < \text{CH}_3\text{Cl} < \text{CH}_3\text{F} \)

2. \( \text{H}_2\text{Se} < \text{H}_2\text{S} < \text{H}_2\text{O} \)

3. \( \text{CCl}_4 < \text{CBr}_4 < \text{Cl}_4 \)

4. \( \text{CO}_2 < \text{SO}_2 < \text{CS}_2 \)

5. In which of the following substances would you expect to find hydrogen bonding?
   (a) \( \text{C}_3\text{H}_7\text{OH} \) will hydrogen bond; one of the hydrogens is bonded to oxygen.
   (b) \( \text{H}_2\text{O}_2 \) will hydrogen bond; hydrogen is bonded to oxygen.
   (c) \( \text{CHCl}_3 \) will not hydrogen bond; hydrogen is not bonded to fluorine, oxygen, or nitrogen.
   (d) \( \text{PH}_3 \) will not hydrogen bond; hydrogen is not bonded to fluorine, oxygen, or nitrogen.
   (e) \( \text{HF} \) will hydrogen bond; hydrogen is bonded to fluorine.

6. (a) \( \text{HI} \) will not hydrogen bond; hydrogen is not bonded to fluorine, oxygen, or nitrogen.
   (b) \( \text{NH}_3 \) will hydrogen bond; hydrogen is bonded to nitrogen.
   (c) \( \text{CH}_2\text{F}_2 \) will not hydrogen bond; hydrogen is not bonded to fluorine, oxygen, or nitrogen.
   (d) \( \text{C}_2\text{H}_5\text{OH} \) will hydrogen bond; one of the hydrogens is bonded to oxygen.
   (e) \( \text{H}_2\text{O} \) will hydrogen bond; hydrogen is bonded to oxygen.

7. (a) \( \text{C}_3\text{H}_7\text{OH} \)
   (b) \( \text{H}_2\text{O}_2 \)
   (c) \( \text{HF} \)

8. (a) \( \text{C}_2\text{H}_5\text{OH} \)
   (b) \( \text{NH}_3 \)
   (c) \( \text{H}_2\text{O} \)

9. The adhesive forces between the cotton fabric of the T-shirt and the water are stronger than the cohesive forces between water molecules causing the water to absorb into the fabric. The cohesive forces between water molecules is stronger than the adhesive forces between the raincoat fabric and water causing the water to bead up on the raincoat.

10. Water forming beaded droplets is an example of cohesive forces. The water molecules have stronger attractive forces for other water molecules than they do for the surface.
11. (a) barium bromide dihydrate
    (b) aluminum chloride hexahydrate
    (c) iron(III) phosphate tetrahydrate

12. (a) magnesium ammonium phosphate hexahydrate
    (b) iron(II) sulfate heptahydrate
    (c) tin(IV) chloride pentahydrate

13. \(25.0\, g\, \text{Na}_2\text{CO}_3 \cdot 10\, \text{H}_2\text{O} \left(\frac{1\, \text{mol}}{286.2\, g}\right) = 0.0874\, \text{mol} \, \text{Na}_2\text{CO}_3 \cdot 10\, \text{H}_2\text{O}\)

14. \(25.0\, g\, \text{Na}_2\text{B}_4\text{O}_7 \cdot 10\, \text{H}_2\text{O} \left(\frac{1\, \text{mol}}{381.4\, g}\right) = 0.0655\, \text{mol} \, \text{Na}_2\text{B}_4\text{O}_7 \cdot 10\, \text{H}_2\text{O}\)

15. (a) \(125\, g\, \text{MgSO}_4 \cdot 7\, \text{H}_2\text{O} \left(\frac{1\, \text{mol}}{246.5\, g}\right) \left(\frac{7\, \text{mol} \, \text{H}_2\text{O}}{1\, \text{mol} \, \text{MgSO}_4 \cdot 7\, \text{H}_2\text{O}}\right) \left(\frac{18.02\, g}{\text{mol}}\right) = 64.0\, g\, \text{H}_2\text{O}\)
    (b) \(125\, g\, \text{MgSO}_4 \cdot 7\, \text{H}_2\text{O} \left(\frac{1\, \text{mol}}{246.5\, g}\right) \left(\frac{1\, \text{mol} \, \text{MgSO}_4}{1\, \text{mol} \, \text{MgSO}_4 \cdot 7\, \text{H}_2\text{O}}\right) \left(\frac{120.4\, g}{\text{mol}}\right) = 61.1\, g\, \text{MgSO}_4\)

16. (a) \(125\, g\, \text{AlCl}_3 \cdot 6\, \text{H}_2\text{O} \left(\frac{1\, \text{mol}}{241.4\, g}\right) \left(\frac{6\, \text{mol} \, \text{H}_2\text{O}}{1\, \text{mol} \, \text{AlCl}_3 \cdot 6\, \text{H}_2\text{O}}\right) \left(\frac{18.02\, g}{\text{mol}}\right) = 56.0\, g\, \text{H}_2\text{O}\)
    (b) \(125\, g\, \text{AlCl}_3 \cdot 6\, \text{H}_2\text{O} \left(\frac{1\, \text{mol}}{241.4\, g}\right) \left(\frac{1\, \text{mol} \, \text{AlCl}_3}{1\, \text{mol} \, \text{AlCl}_3 \cdot 6\, \text{H}_2\text{O}}\right) \left(\frac{133.3\, g}{\text{mol}}\right) = 69.0\, g\, \text{AlCl}_3\)

17. \(\%\, \text{H}_2\text{O} = \left(\frac{6\, \text{H}_2\text{O}}{1\, \text{CoCl}_2 \cdot 6\, \text{H}_2\text{O}}\right) = \left(\frac{(6)(18.02\, g)}{(238.0\, g)}\right)(100) = 45.43\%\, \text{H}_2\text{O}\)

18. Assume 1 mol of the compound which contains 2 mol of water.

\(\%\, \text{H}_2\text{O} = \left(\frac{g\, \text{H}_2\text{O}}{g\, \text{CaSO}_4 \cdot 2\, \text{H}_2\text{O}}\right)(100) = \left(\frac{(2)(18.02\, g)}{(172.2\, g)}\right)(100) = 20.93\%\, \text{H}_2\text{O}\)

19. Assume 100. g of the compound.

\((0.2066)(100.\, g) = 20.66\, g\, \text{Fe}\) \((0.3935)(100.\, g) = 39.35\, g\, \text{Cl}\)

\((0.3999)(100.\, g) = 39.99\, g\, \text{H}_2\text{O}\)

\((20.66\, g\, \text{Fe}) \left(\frac{1\, \text{mol}}{55.85\, g}\right) = 0.3699\, \text{mol} \, \text{Fe}\)

\(0.3699\)

\(= \frac{0.3699}{0.3699} = 1.000\)

\((39.35\, g\, \text{Cl}) \left(\frac{1\, \text{mol}}{35.45\, g}\right) = 1.110\, \text{mol} \, \text{Cl}\)

\(1.110\)

\(= \frac{1.110}{0.3699} = 3.001\)

\((39.99\, g\, \text{H}_2\text{O}) \left(\frac{1\, \text{mol}}{18.02\, g}\right) = 2.219\, \text{mol} \, \text{H}_2\text{O}\)

\(2.219\)

\(= \frac{2.219}{0.3699} = 5.999\)

The empirical formula is \(\text{FeCl}_3 \cdot 6\, \text{H}_2\text{O}\)
20. Assume 100. g of the compound.

\[
\begin{align*}
(0.2469)(100. \text{ g}) &= 24.69 \text{ g Ni} & (0.2983)(100. \text{ g}) &= 29.83 \text{ g Cl} \\
(0.4548)(100. \text{ g}) &= 45.48 \text{ g H}_2\text{O} \\
\end{align*}
\]

\[
\begin{align*}
(24.69 \text{ g Ni}) \left( \frac{1 \text{ mol}}{58.69 \text{ g}} \right) &= 0.4207 \text{ mol Ni} & 0.4207 &= 1.000 \\
(29.83 \text{ g Cl}) \left( \frac{1 \text{ mol}}{35.45 \text{ g}} \right) &= 0.8415 \text{ mol Cl} & 0.8415 &= 2.000 \\
(45.48 \text{ g H}_2\text{O}) \left( \frac{1 \text{ mol}}{18.02 \text{ g}} \right) &= 2.524 \text{ mol H}_2\text{O} & 2.524 &= 6.000 \\
\end{align*}
\]

The formula is \( \text{NiCl}_2 \cdot 6 \text{ H}_2\text{O} \)

21. Energy \( (E_a) \) to heat the water to steam from \( 15^\circ \text{C} \rightarrow 100^\circ \text{C} \)

\[
E_a = (m)(\text{specific heat})(\Delta t) = (275 \text{ g}) \left( \frac{4.184 \text{ J}}{\text{g}^\circ \text{C}} \right) (85^\circ \text{C}) = 9.8 \times 10^4 \text{ J}
\]

Energy \( (E_b) \) to convert water at \( 100^\circ \text{C} \) to steam: heat of vaporization = \( 2.26 \times 10^3 \text{ J/g} \)

\[
E_b = (m)(\text{heat of vaporization}) = (275 \text{ g})(2.26 \times 10^3 \text{ J/g}) = 6.22 \times 10^5 \text{ J}
\]

\[
E_{\text{total}} = E_a + E_b = (9.8 \times 10^4 \text{ J}) + (6.22 \times 10^5 \text{ J}) = 7.20 \times 10^5 \text{ J}
\]

22. Energy \( (E_a) \) to cool the water from \( 35^\circ \text{C} \rightarrow 0^\circ \text{C} \)

\[
E_a = (m)(\text{specific heat})(\Delta t) = (325 \text{ g}) \left( \frac{4.184 \text{ J}}{\text{g}^\circ \text{C}} \right) (35^\circ \text{C}) = 4.8 \times 10^4 \text{ J}
\]

Energy \( (E_b) \) to convert water to ice: heat of fusion = \( 335 \text{ J/g} \)

\[
E_b = (m)(\text{heat of fusion}) = (325 \text{ g})(335 \text{ J/g}) = 1.09 \times 10^5 \text{ J}
\]

\[
E_{\text{total}} = E_a + E_b = (4.8 \times 10^4 \text{ J}) + (1.09 \times 10^5 \text{ J}) = 1.57 \times 10^5 \text{ J}
\]

23. Energy released in cooling the water: \( 25^\circ \text{C} \) to \( 0^\circ \text{C} \)

\[
E = (m)(\text{specific heat})(\Delta t) = (300. \text{ g}) \left( \frac{4.184 \text{ J}}{\text{g}^\circ \text{C}} \right) (25^\circ \text{C}) = 3.1 \times 10^4 \text{ J}
\]

Energy required to melt the ice

\[
E = (m)(\text{heat of fusion}) = (100. \text{ g})(335 \text{ J/g}) = 3.35 \times 10^4 \text{ J}
\]

Less energy is released in cooling the water than is required to melt the ice. Ice will remain and the water will be at \( 0^\circ \text{C} \).

24. Energy to heat the water = energy to condense the steam

\[
(300. \text{ g}) \left( \frac{4.184 \text{ J}}{\text{g}^\circ \text{C}} \right) (100. \text{ } ^\circ \text{C} - 25^\circ \text{C}) = (m)(2259 \text{ J/g})
\]

\[
m = 42 \text{ g} \text{ (grams of steam required to heat the water to } 100. \text{ } ^\circ \text{C}) \text{ 42 g of steam are required to heat } 300. \text{ g of water to } 100. \text{ } ^\circ \text{C}. \text{ Since only 35 g of steam are added to the system, the final temperature will be less than 100. } ^\circ \text{C}. \text{ Not sufficient steam.}
\]
25. Energy lost by warm water = energy gained by the ice

\[ x = \text{final temperature} \]

\[
\text{mass}(H_2O) = (1.5 \text{ L } H_2O) \left( \frac{1000 \text{ mL}}{\text{L}} \right) \left( \frac{1.0 \text{ g}}{\text{mL}} \right) = 1500 \text{ g}
\]

\[
(1500 \text{ g}) \left( \frac{4.184 \text{ J}}{\text{g}^\circ \text{C}} \right) (75^\circ \text{C} - x) = (75 \text{ g}) \left( \frac{335}{\text{J/ g}} \right) + (75 \text{ g}) \left( \frac{4.184 \text{ J}}{\text{g}^\circ \text{C}} \right) (x - 0^\circ \text{C})
\]

\[
(4.707 \times 10^5 \text{ J}) - (6276x \text{ J/}^\circ \text{C}) = 2.51 \times 10^4 \text{ J} + 313.8x \text{ J/}^\circ \text{C}
\]

\[
4.46 \times 10^5 \text{ J} = 6.5898 \times 10^3 \text{ x J/}^\circ \text{C}
\]

\[ x = 68^\circ \text{C} \]

26. \[ E = (m)(\text{heat of fusion}) \]

\[(500. \text{ g})(335 \text{ J/g}) = 167,000 \text{ J needed to melt the ice} \]

\[ 9560 \text{ J} < 167,500 \text{ J} \]

Since 167,500 J are required to melt all the ice, and only 9560 J are available, the system will be at 0^\circ \text{C}. It will be a mixture of ice and water.

27. Water forms droplets because of surface tension, or the desire for a droplet of water to minimize its ratio of surface area to volume. The molecules of water inside the drop are attracted to other water molecules all around them, but on the surface of the droplet the water molecules feel an inward attraction only. This inward attraction of surface water molecules for internal water molecules is what holds the droplets together and minimizes their surface area.

28. Steam molecules will cause a more severe burn. Steam molecules contain more energy at 100^\circ \text{C} than water molecules at 100^\circ \text{C} due to the energy absorbed during the vaporization stage (heat of vaporization).

29. The alcohol has a higher vapor pressure than water and thus evaporates faster than water. When the alcohol evaporates it absorbs energy from the water, cooling the water. Eventually the water will lose enough energy to change from a liquid to a solid (freeze).

30. When one leaves the swimming pool, water starts to evaporate from the skin of the body. Part of the energy needed for evaporation is absorbed from the skin, resulting in the cool feeling.

31. \[ (a) \text{ From } 0^\circ \text{C to } 40.0^\circ \text{C solid X warms until at } 40.0^\circ \text{C it begins to melt. The temperature remains at } 40.0^\circ \text{C until all of X is melted. After that, liquid X will warm steadily to } 65^\circ \text{C where it will boil and remain at } 65^\circ \text{C until all of the liquid becomes vapor. Beyond } 65^\circ \text{C, the vapor will warn steadily until } 100^\circ \text{C.} \]
(b) Joules needed (0°C to 40°C) = (60. g)(3.5 J/g°C)(40.°C) = 8400 J
Joules needed at 40°C = (60. g)(80. J/g) = 4800 J
Joules needed (40°C to 65°C) = (60. g)(3.5 J/g°C)(25°C) = 5300 J
Joules needed at 65°C = (60. g)(190 J/g) = 11,000 J
Joules needed (65°C to 100°C) = (60. g)(3.5 J/g°C)(35°C) = 7400 J
Total Joules needed = 37,000 J

(Each step rounded to two significant figures)

32. During phase changes (ice melting to liquid water or liquid water evaporating to steam), all the heat energy is used to cause the phase change. Once the phase change is complete the heat energy is once again used to increase the temperature of the substance.

33. As the temperature of a liquid increases, the molecules gain kinetic energy thereby increasing their escaping tendency (vapor pressure).

34. Since boiling occurs when vapor pressure equals atmospheric pressure, the graph in Figure 13.7 indicates that water will boil at about 78°C or 172°F at 330 torr pressure.

35. CuSO₄ (anhydrous) is greenish white. When exposed to moisture, it turns bright blue forming CuSO₄·5H₂O. The color change is an indicator of moisture in the environment.

36. MgSO₄·7H₂O Na₂HPO₄·12H₂O

37. For the noble gases the boiling point increases as the molar mass increases. This suggests that boiling points are directly related to molar masses. This is consistent with an increase in dispersion forces with an increase in molar mass which would result in an increase in boiling point.

38. The elevation in Santa Fe is much higher than in Santa Barbara. This means that the air pressure is also lower. Since the boiling temperature of water is dependent on the atmospheric pressure, it will be lower in Santa Fe than in Santa Barbara. Boiling the eggs for 8 minutes at a lower pressure will result in undercooked eggs.

39. Water is a very polar molecule. Glass, an oxide of silicon, is composed of polar silicon-oxygen bonds. Because both water and glass are composed of polar molecules there are strong intermolecular forces between them which create a strong adhesive force. The water climbs up the walls of the graduated cylinder in order to maximize the water-glass interactions resulting in a downward curving meniscus. When water is poured into a plastic cylinder the intermolecular forces between water and the non-polar hydrocarbons composing the plastic are very weak. The cohesive forces between water molecules are stronger than the adhesive forces with the plastic resulting in an almost flat meniscus which minimizes interactions between the water and the plastic.

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>drops/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>30</td>
<td>52</td>
</tr>
<tr>
<td>50</td>
<td>87</td>
</tr>
<tr>
<td>70</td>
<td>104</td>
</tr>
</tbody>
</table>
As the temperature increases the rate of flow increases. As the amount of energy in the honey increases, the individual molecules have enough energy to overcome the strong intermolecular forces holding them together allowing the liquid to flow more easily.

41. The wax on the floors is composed of long chain hydrocarbons which are very non-polar. When polar water is spilled on the floor it will bead up to minimize contact with the non-polar wax. When the non-polar hexane is spilled on the floor it will spread out so that it has more contact with the non-polar wax.

42. (a) The boiling point of acetic acid is approximately 119°C and the melting point is approximately 18°C according to this diagram.

(b) and (c)

43. (a) Melt ice: \( E_a = (m)(\text{heat of fusion}) = (225 \text{ g})(335 \text{ J/g}) = 7.54 \times 10^4 \text{ J} \)
(b) Warm the water: \( E_b = (m)(\text{specific heat})(\Delta t) = (225 \text{ g}) \left(\frac{4.184 \text{ J}}{\text{g}^\circ \text{C}}\right)(100^\circ \text{C}) = 9.41 \times 10^4 \text{ J} \)
(c) Vaporize the water:
   \( E_c = (m)(\text{heat of vaporization}) = (225 \text{ g})(2259 \text{ J/g}) = 5.08 \times 10^5 \text{ J} \)
   \( E_{\text{total}} = E_a + E_b + E_c = 6.78 \times 10^5 \text{ J} \)
   \( (6.78 \times 10^5 \text{ J}) \left(\frac{1 \text{ cal}}{4.184 \text{ J}}\right) = 1.62 \times 10^5 \text{ cal} \)

44. The heat of vaporization of water is 2.26 kJ/g.
   \( (2.26 \text{ kJ/g}) \left(\frac{18.02 \text{ g}}{\text{mol}}\right) = 40.7 \text{ kJ/mol} \)

45. \( E = (m)(\text{specific heat})(\Delta t) = (250. \text{ g}) \left(\frac{0.096 \text{ cal}}{\text{g}^\circ \text{C}}\right)(150. - 20.0^\circ \text{C}) = 3.1 \times 10^3 \text{ cal}(3.1 \text{ kcal}) \)
46. Energy liberated when steam at 100.0°C condenses to water at 100.0°C

\[(50.0 \text{ mol steam}) \left( \frac{18.02 \text{ g}}{\text{mol}} \right) \left( \frac{2.26 \text{ kJ}}{\text{g}} \right) \left( \frac{1000 \text{ J}}{1 \text{ kJ}} \right) = 2.04 \times 10^6 \text{ J} \]

Energy liberated in cooling water from 100.0°C to 30.0°C

\[(50.0 \text{ mol H}_2\text{O}) \left( \frac{18.02 \text{ g}}{\text{mol}} \right) \left( \frac{4.184 \text{ J}}{\text{g} \cdot \text{°C}} \right) (100.0^\circ\text{C} - 30.0^\circ\text{C}) = 2.64 \times 10^5 \text{ J} \]

Total energy liberated = \(2.04 \times 10^6 \text{ J} + 2.64 \times 10^5 \text{ J} = 2.30 \times 10^6 \text{ J} \)

47. Energy to warm the ice from −10.0°C to 0°C

\[(100. \text{ g}) \left( \frac{2.01 \text{ J}}{\text{g} \cdot \text{°C}} \right) (10.0^\circ\text{C}) = 2010 \text{ J} \]

Energy to melt the ice at 0°C

\[(100. \text{ g})(335 \text{ J/g}) = 33,500 \text{ J} \]

Energy to heat the water from 0°C to 20.0°C

\[(100. \text{ g}) \left( \frac{4.184 \text{ J}}{\text{g} \cdot \text{°C}} \right) (20.0^\circ\text{C}) = 8370 \text{ J} \]

\[E_{\text{total}} = 2010 \text{ J} + 33,500 \text{ J} + 8370 \text{ J} = 4.39 \times 10^4 \text{ J} = 43.9 \text{ kJ} \]

48. \(2 \text{H}_2\text{O}(l) \rightarrow 2 \text{H}_2(g) + \text{O}_2(g)\)

The conversion is \(\text{L O}_2 \rightarrow \text{mol O}_2 \rightarrow \text{mol} \text{H}_2\text{O} \rightarrow \text{g} \text{H}_2\text{O}\)

\[ (25.0 \text{ L O}_2) \left( \frac{1 \text{ mol O}_2}{22.4 \text{ L}} \right) \left( \frac{2 \text{ mol H}_2\text{O}}{1 \text{ mol O}_2} \right) \left( \frac{18.02 \text{ g}}{\text{mol}} \right) = 40.2 \text{ g H}_2\text{O} \]

49. The conversion is

\[ \frac{\text{mol}}{\text{day}} \rightarrow \frac{\text{molecules}}{\text{day}} \rightarrow \frac{\text{molecules}}{\text{hr}} \rightarrow \frac{\text{molecules}}{\text{min}} \rightarrow \frac{\text{molecules}}{\text{s}} \]

\[ \left( \frac{1.00 \text{mol H}_2\text{O}}{\text{day}} \right) \left( \frac{6.022 \times 10^{23} \text{ molecules}}{\text{mol}} \right) \left( \frac{1.00 \text{day}}{24 \text{hr}} \right) \left( \frac{1 \text{ hr}}{60 \text{ min}} \right) \left( \frac{1 \text{ min}}{60 \text{ s}} \right) = 6.97 \times 10^{18} \text{ molecules} \text{H}_2\text{O}/\text{s} \]

50. Liquid water has a density of 1.00 g/mL.

\[d = \frac{m}{V} = \frac{18.02 \text{ g}}{1.00 \text{ g/mL}} = 18.0 \text{ mL} \quad \text{(volume of 1 mole)} \]

1.00 mole of water vapor at STP has a volume of 22.4 L (gas)
51. \[2 \text{H}_2(g) + \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O}(g)\]

(a) \[
(80.0 \text{ mL H}_2) \left(\frac{1 \text{ mL O}_2}{2 \text{ mL H}_2}\right) = 40.0 \text{ mL O}_2 \text{ react with 80.0 mL of H}_2
\]
Since 60.0 mL of O\(_2\) are available, some oxygen remains unreacted.
(b) 60.0 mL – 40.0 mL = 20.0 mL \text{O}_2 \text{ unreacted.}

52. Energy absorbed by the student when steam at 100\(\degree\)C changes to water at 100\(\degree\)C

\[
(1.5 \text{ g steam}) \left(\frac{2.26 \text{ kJ}}{\text{g}}\right) = 3.4 \text{ kJ} \quad (3.4 \times 10^3 \text{ J})
\]
Energy absorbed when water cools from 100\(\degree\)C to 20.0\(\degree\)C

\[
E = (m)(\text{specific heat})(\Delta t) = (1.5 \text{ g}) \left(\frac{4.184 \text{ J}}{\text{g} \cdot \text{C}}\right) (100.0 \degree \text{C} - 20.0 \degree \text{C}) = 5.0 \times 10^2 \text{ J}
\]
\[
E_{\text{total}} = 3.4 \times 10^3 \text{ J} + 5.0 \times 10^2 \text{ J} = 3.9 \times 10^3 \text{ J}
\]

53. (a) won’t hydrogen bond – no hydrogen in the molecule
(b) will hydrogen bond

\[
\text{CH}_3 - \overset{\ddots}{\text{O}} - \overset{\ddots}{\text{H}} - \overset{\ddots}{\text{O}} - \overset{\ddots}{\text{CH}_3}
\]
(c) won’t hydrogen bond; no hydrogen covalently bonded to a strongly electronegative element
(d) will hydrogen bond

\[
\text{H} - \overset{\ddots}{\text{O}} - \overset{\ddots}{\text{H}} - \overset{\ddots}{\text{H}} - \overset{\ddots}{\text{H}}
\]
(e) won’t hydrogen bond; hydrogen must be attached to N, O, or F

54. During the fusion (melting) of a substance the temperature remains constant so a temperature factor is not needed.

55. Energy needed to heat Cu to its melting point:

\[
E = (50.0 \text{ g})(0.385 \text{ J/g} \cdot \text{C})(1083\degree \text{C} - 25.0\degree \text{C}) = 2.04 \times 10^4 \text{ J}
\]
Energy needed to melt the Cu.

\[
E = (50.0 \text{ g})(134 \text{ J/g}) = 6.70 \times 10^3 \text{ J}
\]
\[
E_{\text{total}} = 2.04 \times 10^4 \text{ J} + 6.70 \times 10^3 \text{ J} = 2.71 \times 10^4 \text{ J}
\]

56. Energy released by the soup to convert ice at 0\(\degree\)C to water at 0\(\degree\)C.

\[
(75 \text{ g ice}) \left(\frac{335 \text{ J}}{\text{g}}\right) = 2.5 \times 10^4 \text{J}
\]
Energy released by soup to increase temperature of water from 0°C to 87°C.

\[ E = (m)(\text{specific heat})(\Delta t) \]

\[ E = (75 \text{ g}) \left( \frac{4.184 \text{ J}}{\text{g}^\circ\text{C}} \right)(87^\circ\text{C}) = 2.7 \times 10^4 \text{J} \]

\[ E_{\text{total}} = 2.5 \times 10^4 \text{J} + 2.7 \times 10^4 \text{J} = 5.2 \times 10^4 \text{J} \]

57. \[ 2 \text{H}_2\text{O}(l) \rightarrow 2 \text{H}_2(g) + \text{O}_2(g) \]

58. At 500 torr, water will boil at approximately 88°C or 190°F
   At 300 torr, water will boil at approximately 76°C or 169°F
   At 100 torr, water will boil at approximately 51°C or 124°F

59. The mass of borax in the box is 2467.4 g - 492.5 g = 1974.9 g borax

   \[ 1974.9 \text{ g} \times \frac{1 \text{ lb}}{453.6 \text{ g}} = 4.35 \text{ lb borax} \]

   The borax in the box is a hydrate. If it is left to sit out on a hot summer day in Phoenix, Arizona some of the water of hydration may be lost resulting in a reduction in mass. You may have started with the correct amount of borax, but some of the water has evaporated leaving you with less mass.

   If 5 lb of borax were heated to drive off all of the waters of hydration, the remaining solid would have a mass of

   \[ (5.0 \text{ lb}) \left( \frac{453.6 \text{ g}}{1 \text{ lb}} \right) \left( \frac{1 \text{ mol Na}_2\text{B}_4\text{O}_7}{381.4 \text{ g}} \right) \left( \frac{1 \text{ mol Na}_2\text{B}_4\text{O}_7 \cdot 10 \text{H}_2\text{O}}{1 \text{ mol}} \right) \left( \frac{201.2 \text{ g}}{1 \text{ mol}} \right) \left( \frac{1 \text{ lb}}{453.6 \text{ g}} \right) = 2.63 \text{ lb Na}_2\text{B}_4\text{O}_7 \]

   The mass lost was less than the mass of water in the borax.

60. A lake freezes from the top down because the density of water as a solid is lower than that of the liquid, causing the ice to float on the top of the liquid. Since the liquid remains below the solid, marine, and aquatic life continues.

61. Heat lost by warm water = heat gained by ice

   \[ m = \text{grams of ice to lower temperature of water to 0.0^\circ\text{C}}. \]

   \[ (120. \text{ g}) \left( \frac{4.184 \text{ J}}{\text{g}^\circ\text{C}} \right)(45^\circ\text{C} - 0.0^\circ\text{C}) = (m)(351 \text{J/g}) \]

   \[ 68 \text{ g} = m \text{ (grams of ice melted)} \]

   68 g of ice melted. Therefore, 150. g – 68 g = 82 g ice remain.