

Soaps and detergents are molecules selected or designed to have both polar and nonpolar regions so that they can dissolve oily or greasy dirt from a stain, and also dissolve in water to carry the material away.

10. (a)  $\text{Cl—Cl}$  nonpolar covalent  
       3.2 3.2
- (b)  $\begin{matrix} + & - \\ \text{K} & \text{I} \end{matrix}$  ionic  
       0.8 2.7
- (c)  $\begin{matrix} \delta^+ & \delta^- \\ \text{P—Cl} \end{matrix}$  polar covalent  
       2.2 3.2
- (d)  $\begin{matrix} \delta^- & \delta^+ \\ \text{O—H} \end{matrix}$  polar covalent  
       3.4 2.2
- (e)  $\begin{matrix} + & - \\ \text{Mg} & \text{O} \end{matrix}$  ionic  
       1.3 3.4
- (f)  $\begin{matrix} \delta^+ & \delta^- \\ \text{Xe—F} \end{matrix}$  polar covalent  
       2.6 4.0

### Extension

11. (a)  $\text{H—C}\equiv\text{C—C}\equiv\text{C—C}\equiv\text{N}$ , linear shape  
 (b) Astronomers detect molecules in space by spectroscopic analysis or electromagnetic radiation (light) absorbed and emitted by regions of space.
12. Empirical (measured, observed) values change as new and better methods of determining values are found. As well, the electronegativity of an atom is not an exact concept. It also varies somewhat, depending on the bonded atoms. The new values could be described as more accurate or better-defined values, but the word “true” cannot properly be applied to relative numerical values of this sort.

## 3.4 INTERMOLECULAR FORCES

### Web Activity: Canadian Achiever—Gerhard Herzberg

#### (Page 109)

- The technological device central to Herzberg’s research was the spectrograph.
- A free radical is a molecule with an unpaired valence electron. Because it has this unpaired electron, a free radical is highly reactive.
- Although he was a physicist, Herzberg was awarded the Nobel Prize in chemistry because his discoveries of the internal geometry and energy states of molecules are extremely important to chemists.

### Practice

#### (Page 109)

- (a) dipole–dipole forces and London forces  
 (b) London forces  
 (c) London forces  
 (d) dipole–dipole forces and London forces  
 (e) dipole–dipole forces and London forces  
 (f) London forces

2. (a) hydrogen fluoride; the H–F bond is more polar (electronegativity difference is greater)  
 (b) chloromethane; the C–Cl bond is more polar (electronegativity difference is greater)  
 (c) ammonia; the N–H bonds are more polar (electronegativity difference is greater)  
 (d) water; the O–H bonds are more polar (electronegativity difference is greater)
3. (a) ethane; because it has 8 more electrons (and protons) than methane  
 (b) oxygen; because it has 2 more electrons (and protons) than nitrogen  
 (c) sulfur dioxide; because it has 18 more electrons (and protons) than nitrogen dioxide  
 (d) methane and ammonia are isoelectronic, with 10 electrons each. They should have equal-strength London forces.
4. (a) Nitrogen trifluoride has the higher boiling point; nitrogen trifluoride is polar and, as a result, has dipole–dipole forces. Boron trifluoride is nonpolar (no dipole–dipole forces), and also has fewer electrons (weaker London forces).  
 (b) Chloromethane has the higher boiling point; chloromethane is polar and has dipole-dipole forces. Ethane is nonpolar (no dipole–dipole forces) and also has fewer electrons (weaker London forces).
5. Chlorine monoxide bonds are less polar than bonds in nitrogen trifluoride (possibly weaker dipole–dipole forces), and there are fewer bonds per molecule, but nitrogen trifluoride has fewer electrons than chlorine monoxide (weaker London forces). Therefore, no simple prediction is possible in this case.
6.
 

• CH <sub>3</sub> Cl	b.p. –24 °C	C <sub>2</sub> H <sub>6</sub>	b.p. –89 °C	This prediction was verified.
• NBr <sub>3</sub>	b.p. decomposes	NCl <sub>3</sub>	b.p. <71 °C	No prediction was made.
• NF <sub>3</sub>	b.p. –129 °C	Cl <sub>2</sub> O	b.p. 2 °C	No prediction was made.

### Lab Exercise 3.A: Boiling Points and Intermolecular Forces

(Page 110)

#### Purpose

The scientific purpose of this lab exercise is to test a new hypothesis based on the theory and rules for London and dipole–dipole forces.

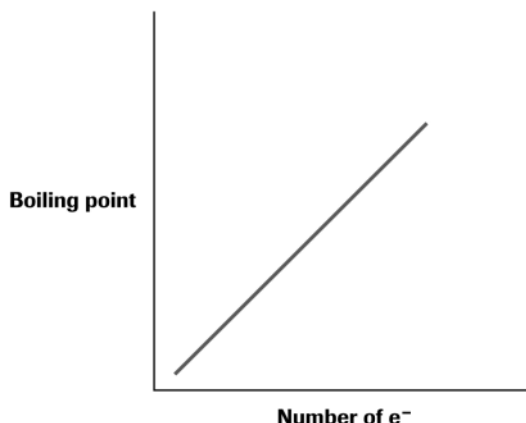
#### Problem

What is the trend in boiling points of the hydrogen compounds of the elements of each of the periodic table Groups 14 to 17?

#### Hypothesis

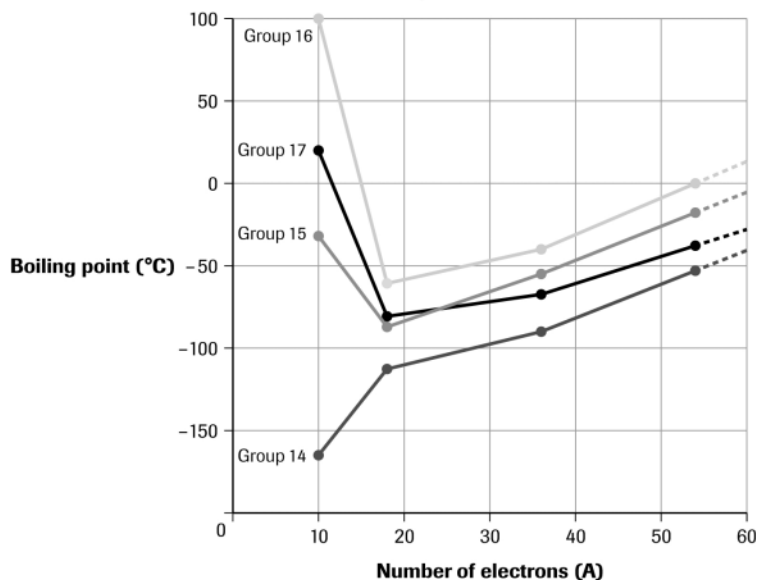
Molecules of the hydrogen compounds of one group will all be similar in shape and polarity (polar versus nonpolar). Therefore, the dipole–dipole forces between molecules for members of the same group should be similar. For example, the Group 14 hydrogen compounds all have symmetrical tetrahedral molecules and therefore should be nonpolar. The other groups have molecules that are all nonsymmetrical and therefore will be somewhat polar, producing some dipole–dipole effects. The only significant difference within a group of hydrogen compounds will be the increasing number of electrons per molecule as you go down the group. Therefore, on the basis of the rule for London forces, the strength of these forces should increase down the group and the boiling points should increase accordingly. This tendency should produce a graph that has the following general trend for each group of hydrogen compounds.

**Boiling Point Trend for Hydrogen Compounds**



### Analysis

**Boiling Points of the Hydrogen Compounds of Elements**



According to the evidence, the boiling point generally increases with increasing numbers of electrons, with some obvious exceptions such as  $\text{NH}_3$ ,  $\text{H}_2\text{O}$ , and  $\text{HF}$ .

### Evaluation

Three out of the sixteen compounds tested (about 19%) differed substantially from the prediction. For this reason, the prediction is judged to be inconclusive. The rules for intermolecular forces, in particular London forces, remain acceptable, but further tests need to be done to increase the certainty of this evaluation.

The purpose was achieved but more families of compounds of Group 14 to 17 elements need to be investigated, especially compounds of nitrogen, oxygen, and fluorine. The evidence for  $\text{NH}_3$ ,  $\text{H}_2\text{O}$ , and  $\text{HF}$  was an anomaly. It may be that hydrogen compounds of these same elements are exceptions and the London force theory has to be restricted or revised depending on the results of further tests. There may be other forces at work, or perhaps some dipole–dipole forces in the selected compounds are exceptionally strong.

### Investigation 3.3: Molecular Compound Melting Points

(Pages 110, 132)

#### Purpose

The purpose of this investigation is to test the hypothesis of a relationship between melting point and molecular size.

#### Problem

What is the relationship between molecular size and melting point?

#### Evidence

##### Experimental Cooling Data for Lauric Acid

Time (s)	Temperature (°C)	Time (s)	Temperature (°C)	Time (s)	Temperature (°C)
0	72.7	195	44.6	405	43.7
15	68.8	210	44.4	420	43.6
30	63.8	225	44.3	435	43.4
45	59.3	240	44.2	450	43.6
60	56.1	255	44.0	465	43.8
75	53.3	270	43.9	480	43.8
90	51.2	285	43.9	495	43.8
105	49.6	300	43.8	510	43.8
120	48.3	315	43.7	525	43.7
135	47.4	330	43.7	540	43.8
150	46.6	345	43.8	555	43.8
165	45.9	360	43.8	570	43.8
180	45.2	375	43.7		

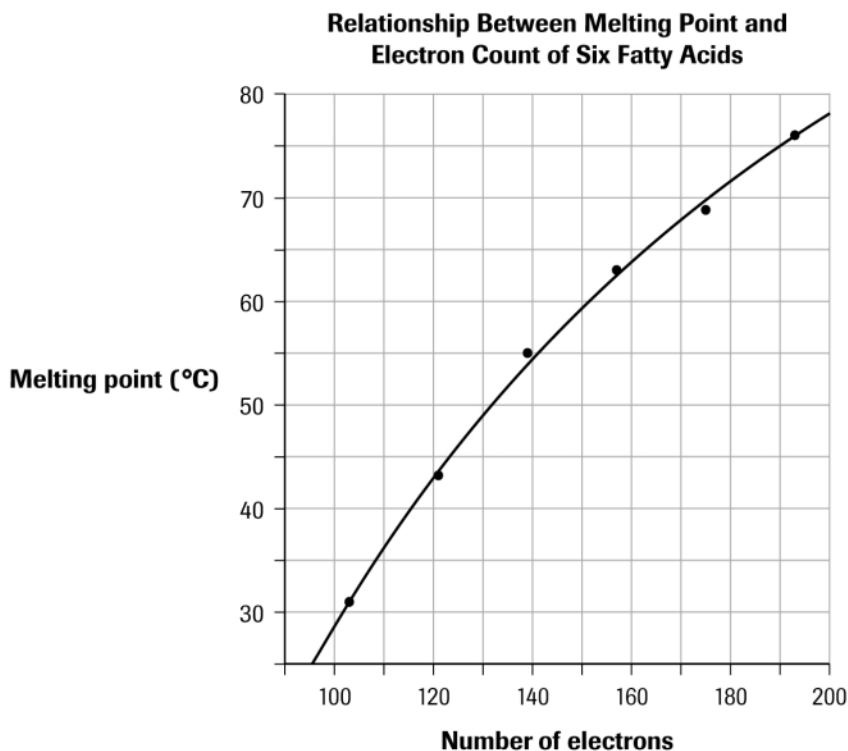
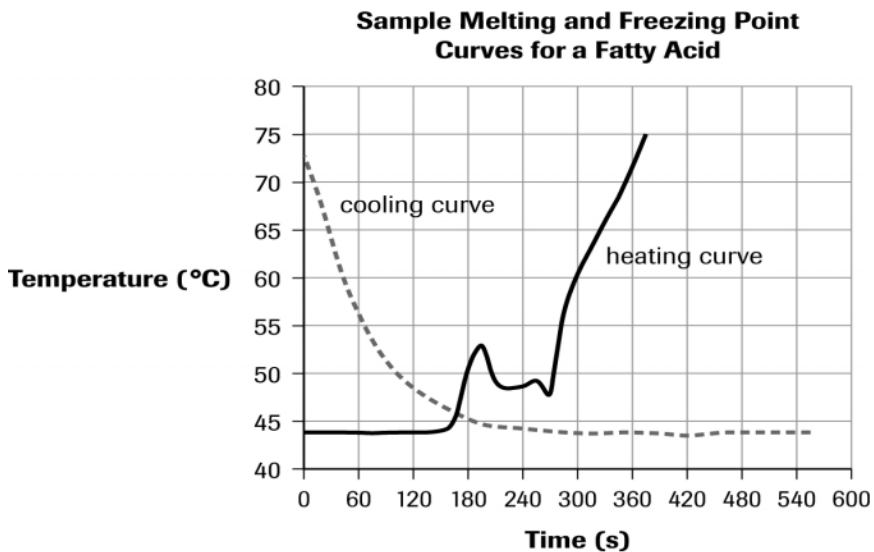
##### Experimental Heating Data for Lauric Acid

Time (s)	Temperature (°C)	Time (s)	Temperature (°C)	Time (s)	Temperature (°C)
0	43.8	135	43.8	270	47.6
15	43.8	150	43.8	285	56.7
30	43.8	165	44.6	300	60.5
45	43.8	180	50.7	315	63.1
60	43.8	195	53.0	330	65.9
75	43.7	210	48.8	345	68.4
90	43.8	225	48.4	360	71.5
105	43.8	240	48.6	375	75.0
120	43.8	255	49.2		

#### Researched Data

Fatty acid	Formula	Number of electrons	Melting point (°C)
capric	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>8</sub> COOH	103	31
lauric acid	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>10</sub> COOH	121	43.2
myristic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>12</sub> COOH	139	55
palmitic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>14</sub> COOH	157	63
stearic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>16</sub> COOH	175	68.8
arachidic	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>18</sub> COOH	193	76

## Analysis



For fatty acids, it is evident that as molar mass increases, melting point also increases. The increase in melting point could be due to the increase in London forces.

### Evaluation

The design is judged adequate to answer the problem and there are no obvious flaws. The materials could be improved by using a melting point apparatus that would allow use of very small quantities of solid. The procedure is quite time consuming but judged to be adequate because suitable evidence to answer the problem was obtained. No specialized skills were required. Sources of uncertainty include temperature measurements and whether the temperature

is accurately measuring the whole sample in the test tube. Overall I am reasonably confident of the results.

The evidence clearly supports the hypothesis, supporting the concept of a relationship between molecular size and melting point.

The investigation fulfills its purpose. Further investigations with other compounds would be necessary to increase confidence in the relationship that is under investigation.

## **Web Activity: Web Quest—Cloud Seeding**

**(Page 112)**

*[Students should research to provide information such as the following.]*

### **Title page, including purpose:**

- Purpose: to present a well-supported position on whether cloud seeding should continue.

### **Main issues:**

- Farmers benefit in two ways: the incidence of drought may be reduced by cloud seeding during dry spells, and the damage to crops by hail may be reduced by causing potential hail-producing clouds to drop some of their moisture before it can form into large hailstones.
- People are concerned that “manipulating nature” may have detrimental effects, particularly by reducing rainfall in areas that are downwind of the cloud-seeding area.

### **The science behind cloud seeding, including explanations:**

- Cloud seeding is used to induce precipitation by producing “cold rain,” which occurs when temperatures in all or parts of the clouds are colder than 0°C. In these colder regions the clouds are usually composed of both ice crystals and liquid water droplets. The ice crystals (nuclei) which form in this supercooled region grow rapidly, and bond with moisture from the surrounding cloud droplets, until their combined weight causes them to fall. These falling ice crystals may melt and bond with small liquid cloud droplets, growing to raindrops in a manner similar to the warm rain process. If the ice crystals do not melt, they may grow to large snowflakes by agglomeration and reach the ground as snow.
- Under proper conditions, cloud seeding is used to modify the size and concentrations of droplets and ice particles in the clouds.
- Adding silver iodide or salt can increase the chances of a cloud containing enough ice crystals to draw moisture out. Silver iodide is introduced in an aerosol form into the cloud because it has a similar crystalline structure to ice and is able to draw moisture from surrounding cloud droplets.

### **The scientific evidence for and against the process of cloud seeding:**

- It is difficult to establish how effective cloud seeding actually is, because precipitation level measurements are inconsistent.
- Some practitioners claim that an increase of 5% to 20% in precipitation can be expected from a well-designed and properly conducted cloud-seeding project.
- Even though recent moisture maps indicate that there have been drier than usual conditions in the Big Valley/Stettler County region, this effect cannot be directly attributed to “cloud seeding.” Changes in moisture patterns and weather phenomena are controlled by many complex factors far beyond the process of cloud seeding. There is inconclusive evidence regarding the assertion that cloud seeding robs downwind areas of moisture.

### **Summary of results of research:**

- There is no concrete evidence that cloud seeding causes droughts, nor that it has any ill effects on people or the environment. However, there is no concrete evidence on its effectiveness either.

- The ethics of allowing insurance companies to sponsor the cloud seeding project should be questioned. Companies that operate in this business promote its benefits and play down any negative effects. Others, particularly in downwind areas, are seriously concerned about the apparent impacts of cloud seeding, such as reducing rainfall.

**Recommendation on whether cloud seeding should continue in the Calgary to Red Deer Region:**

- Although the evidence is inconclusive, on balance it seems that there is sufficient cause for concern to indicate that widespread commercial cloud seeding should be stopped. The possibility that cloud seeding robs downwind areas of moisture should be further investigated through controlled studies, in several areas and over several years.

**Investigation 3.4: Hydrogen Bonding**

(Pages 113, 134)

**Purpose**

The purpose of this investigation is to test the concept of hydrogen bonding.

**Problem**

How does the temperature change upon mixing ethanol,  $C_2H_5OH(l)$ , with water compare with the temperature change upon mixing glycerol (glycerin),  $C_3H_5(OH)_3(l)$ , with water?

**Prediction**

According to the theory of energy changes associated with changes in bonding, the temperature change for the mixture of glycerol and water should be greater than the temperature change for ethanol and water. In both cases, additional hydrogen bonds would be formed between the solute molecules and water molecules. However, a glycerol molecule,  $C_3H_5(OH)_3(l)$ , has three O – H groups that can form hydrogen bonds with water molecules. An ethanol molecule,  $C_2H_5OH(l)$ , has only one O – H group that can form hydrogen bonds with water molecules. Because energy is released when bonds are formed, more hydrogen bonds should mean more energy released and a greater temperature change for glycerol and water.

**Procedure**

1. Using a 10 mL graduated cylinder, measure 10.0 mL of ethanol and place it into clean, dry, nested polystyrene cups.
2. Place a thermometer into the ethanol and measure its temperature to one decimal place.
3. Using a different 10 mL graduated cylinder, measure 10.0 mL of pure water.
4. Measure the temperature of the water in the graduated cylinder.
5. Quickly pour all of the water into the ethanol and place the lid on the cups.
6. Swirl the mixture and measure the highest temperature reached by the mixture.
7. Dispose of the mixture into the sink, and rinse and dry the calorimeter.
8. Repeat steps 1 to 7 two more times.
9. Repeat steps 1 to 8 using glycerol instead of ethanol.

**Evidence**

**Ethanol and Water Mixture**

Trial	Initial temperature (°C)	Final temperature (°C)	Temperature change (°C)
ethanol	22.2	29.2	7.1
water	22.0		
ethanol	22.0	29.2	7.2
water	22.0		
ethanol	22.2	29.2	7.0
water	22.2		

## Glycerol and Water Mixture

Trials	Initial temperature (°C)	Final temperature (°C)	Temperature change (°C)
glycerol	23.4	28.5	5.7
water	22.2		
glycerol	23.5	28.4	5.5
water	22.4		
glycerol	23.4	28.2	5.3
water	22.4		

- Glycerol was very viscous and flowed very slowly out of the graduate cylinder. It was hard to tell how long to wait for this liquid to flow out.
- The initial temperatures were averaged together before subtracting them from the final temperature.

### Analysis

According to the evidence collected, the average temperature change of the ethanol–water mixture was noticeably higher than the temperature of the glycerol–water mixture.

### Evaluation

The design is inadequate because it is flawed. The design did not take into account the fact that the same volume of two different liquids would contain different numbers of molecules. This flaw in the design needs to be corrected. The materials were of suitable quality to provide reasonable evidence. The procedure appears to be adequate because the steps were sufficiently clear and included multiple trials to increase the reliability of the evidence. The difficulty experienced with pouring the viscous glycerol could be eliminated by measuring the mass used instead of the volume. This change would also make it easier to compare or control the number of molecules of the alcohol used. I am not very certain about the evidence because of the flaw identified in the design. Measurements of the temperature and volume also provide some experimental error but this is not expected to be a major factor.

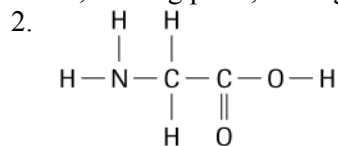
The evidence is sufficiently uncertain to make a judgment of the prediction impossible. It is hard to tell if the disagreement of the evidence with the prediction is due to the identified flaw or to other factors related to mixing and bonds breaking and forming.

The purpose of the experiment was not accomplished. The experiment needs to be redesigned and redone.

## Case Study: Current Research in Intermolecular Forces

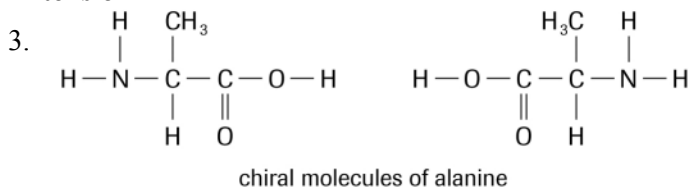
(Pages 114–115)

1. The Le Roy radius represents the theoretical boundary around a molecule. Inside the boundary, intramolecular forces (between atoms) are more important. Outside the boundary, intermolecular forces (between molecules) predominate. In studying small molecular interactions, the concepts allow for an easier analysis of the properties of the molecule, that is, melting point, boiling point, and state.



Glycine is a polar molecule that has London forces, dipole–dipole interaction, and hydrogen bonding. Glycine is therefore soluble in water because water is also a polar molecule with hydrogen bonding. In general, polar solvents dissolve polar solutes; and in particular, substances with hydrogen bonding will dissolve in solvents that have hydrogen bonding.

### Extension



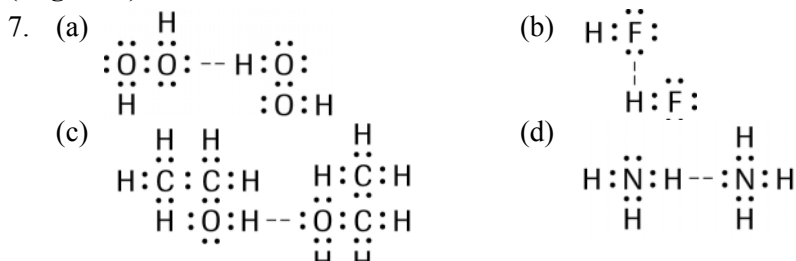
### Mini Investigation: Floating Pins

(Page 115)

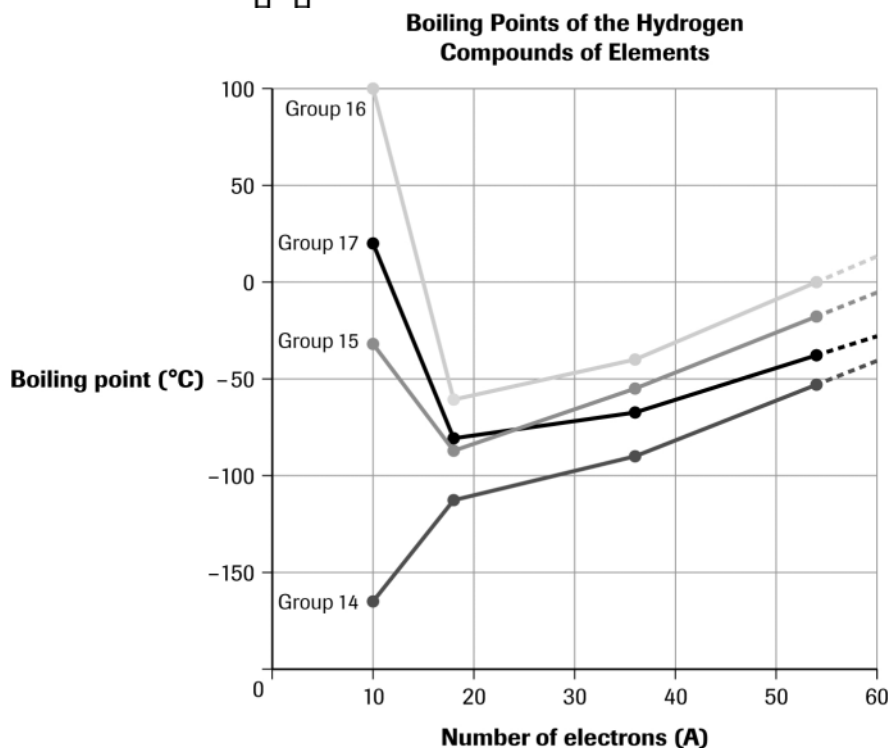
- The pin sits on the surface of the water but not on the surfaces of propanol or hexane. The evidence suggests that the intermolecular forces between water molecules are much greater than those between the molecules of either propanol or hexane. If the intermolecular forces are strong enough, the molecules at the surface act like a skin on the surface.
  - The pin drops immediately into the water, no matter which end is first. In this case, the entire weight of the pin is concentrated in a very small area. The surface tension is no longer able to support the pressure (force per unit area) exerted by the pin. When the pin is horizontal, the weight of the pin is spread out over a much larger area.
  - The pin immediately falls through the water. The detergent must reduce the surface tension of the water, perhaps by the detergent molecules coming between or separating the water molecules.

### Practice

(Page 116)



8.



- (a) If water and ammonia followed the trend of the rest of their family members, their boiling points would be the lowest in the group. The boiling point of water would be about  $-75\text{ }^{\circ}\text{C}$ , and that of ammonia would be about  $-100\text{ }^{\circ}\text{C}$ .
- (b) The boiling point of water is approximately  $175\text{ }^{\circ}\text{C}$  higher than its extrapolated value, and the boiling point of ammonia is approximately  $67\text{ }^{\circ}\text{C}$  higher than its extrapolated value.
- (c) The boiling points of water and ammonia are significantly higher because of hydrogen bonding.
- (d) The difference in (b) is much greater for water than for ammonia because the oxygen atom in water has two lone pairs of electrons, whereas the nitrogen atom in ammonia has only one lone pair of electrons. The additional lone pair of electrons on the oxygen atom give water a stronger negative dipole, which has a stronger attraction for neighbouring hydrogen atoms with a positive dipole. As well, the two lone pairs on the oxygen in water provide more sites for forming hydrogen bonds.
9. Water beading on a surface means that the surface material must have very low intermolecular attraction for water molecules. This would mean no polar areas on the surface molecules, and certainly no hydrogen bonding locations.
10. The two liquids must be something like water and oil—one polar and one nonpolar—so they will have no tendency to mix. The polar molecules attract each other more strongly and exclude the nonpolar molecules. The heat supply at the bottom makes the liquid there rise, so it must be just slightly denser than the other liquid. Thus, heating expansion causes the bottom liquid to become temporarily less dense than the other, and to rise until it cools, and falls again.
11. To investigate hydrogen bonding, you should control the other intermolecular forces, London and dipole–dipole forces, by controlling the number of electrons per molecule and the polarity. You should probably control the shapes of the molecules as well.
12. (a) Equal volumes of various liquids will be exposed to the atmosphere in a fume hood at constant temperature. The remaining volume of liquid will be measured at set time intervals. The manipulated variable is the substance; the responding variable is the volume remaining; and the fixed (restrained) variables include the time intervals, the temperature, the initial volume, the surface area, and the air movement (draft).
- (b) Some liquids to be used might include ethanol, acetic acid, and ethylene glycol (auto anti-freeze). Assuming the hydrogen bonding from OH groups is the most significant intermolecular force, we would predict that acetic acid is less volatile than ethanol because acetic acid molecules have more lone pairs available to form hydrogen bonds, and are also more polar. The ethylene glycol should be the least volatile because it has two OH groups and thus overall has stronger hydrogen bonding. (A variety of liquids, including polar and nonpolar, could be used.)
- (c) Store volatile liquids in cool, well-ventilated areas to prevent spontaneous evaporation. Store them in metal or glass containers, away from other reactive compounds. Heat gently if needed, and keep away from extreme temperatures.
13. **Prediction**  
According to the concepts and rules of intermolecular bonding, ammonia should have a high solubility in water. Both ammonia and water are polar and have multiple hydrogen bonding sites. This means that the two kinds of molecules should easily attract each other.

#### Analysis

Based on the Evidence, ammonia is very soluble in water because water is drawn very rapidly into the flask to replace the dissolved ammonia. (Note that when ammonia dissolves, the internal pressure is greatly reduced and water is forced into the flask by the greater atmospheric pressure on the outside.)

### Evaluation

The Prediction is verified, so the reasoning used to make the Prediction appears acceptable.

14. The application illustrates both adhesive and cohesive properties. For adhesion, the tree secretions form intermolecular bonds with the canoe bark to hold the pieces together and leakproof the canoe. The molecules of the bark and of the tree secretions must be polar to form dipole–dipole bonds, and may or may not have hydrogen bonds. For cohesion, there must be forces of attraction between the tree secretion molecules in order to hold them in solid form, otherwise they would evaporate. The tree secretion molecules must be polar and may or may not have hydrogen bonds.

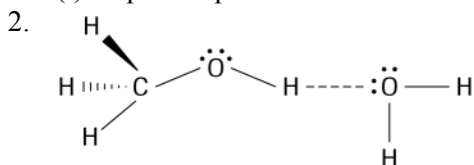
### Web Activity: Simulation—Modelling Molecules (Page 117)

(No written response is required for this activity.)

### Section 3.4 Questions

(Pages 117–118)

1. (a) London forces  
(b) hydrogen bonding, dipole–dipole and London forces  
(c) dipole–dipole and London forces  
(d) hydrogen bonding, dipole–dipole and London forces  
(e) dipole–dipole and London forces  
(f) hydrogen bonding, dipole–dipole and London forces  
(g) hydrogen bonding, dipole–dipole and London forces  
(h) dipole–dipole and London forces  
(i) dipole–dipole and London forces

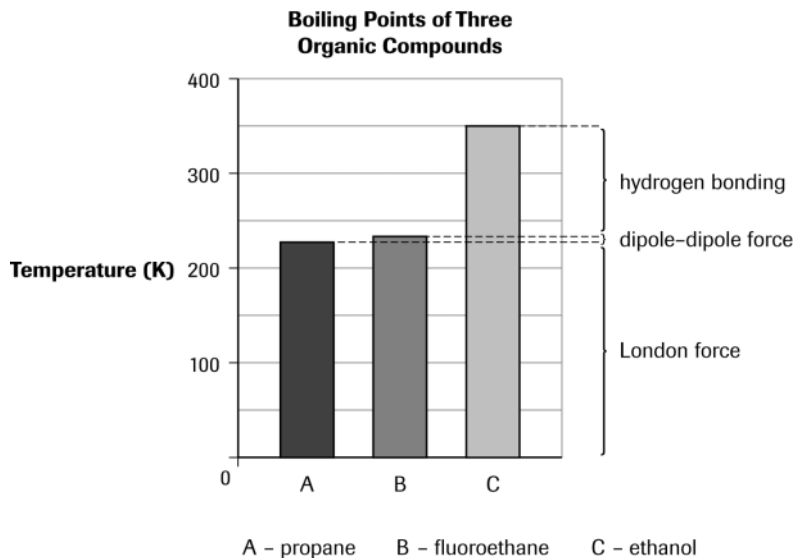


The formation of hydrogen bonds between methanol and water accounts for the high solubility of methanol in water. A hydrogen bond can form when the hydrogen atom of methanol's OH group is attracted to a lone pair on an adjacent water molecule. Similarly, hydrogen bonds can also form between the lone pairs on methanol's oxygen atom and any hydrogen on the water molecule.

3. (a) 2-chloropropane should have low or medium solubility because it is polar and water is also polar.  
(b) Propan-1-ol should have high solubility because it is not only polar but can hydrogen bond with water molecules.  
(c) Propanone should have medium solubility because it is quite polar, and so is water.  
(d) Propane should have low solubility because it is a nonpolar substance and water is polar.
4. (a) Bromine should have stronger intermolecular attractions. Both molecules are nonpolar but bromine has larger molecules with a greater number of electrons, so it should have the stronger London force.  
(b) Hydrogen chloride should have stronger intermolecular attractions. Hydrogen chloride and fluorine are isoelectronic, which means the London force should be the same. However, HCl has polar molecules so it should have additional dipole–dipole forces.  
(c) Ammonia should have stronger intermolecular attractions. Ammonia and methane are isoelectronic so the London force should be the same. Unlike methane, ammonia is polar

- and has hydrogen bonding. Ammonia therefore has additional attractions, dipole–dipole force, and hydrogen bonds.
- (d) Water should have stronger intermolecular attractions. Both molecules are polar but hydrogen sulfide is less polar. Although hydrogen sulfide has a greater number of electrons and stronger London forces, water has hydrogen bonding. This is likely much more significant than the difference in London forces.
  - (e) Silicon tetrahydride should have stronger intermolecular attractions. Both substances are nonpolar and silicon tetrahydride has more electrons per molecule, so it should have more London forces.
  - (f) Ethanol should have stronger intermolecular attractions. The two substances are isoelectronic which means the London force should be the same. Both are polar but ethanol has hydrogen bonding and chloromethane does not.
5. Ethanol should have the greater surface tension because it has the stronger intermolecular attractions. Propane and ethanol molecules are isoelectronic so the London force is the same for both. There are no other intermolecular attractions between propane molecules because they are nonpolar. However, ethanol has additional dipole–dipole attractions and hydrogen bonds between its molecules.
  6. When water freezes it expands, unlike most substances. This occurs because hydrogen bonding causes the molecules to arrange in a specific three-dimensional pattern (lattice). Water left to freeze in a pipe may cause the pipe to break.
  7. The property that creates a meniscus curve is commonly called “surface tension”. This results because the molecules on a surface are attracted both sideways and downward, but not upward, by other molecules. This unbalanced attraction causes the surface to act as though it has a “skin” and can contain slightly more water than the level of the top of the glass.
  8. Two liquids such as diethyl ether,  $\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3(\text{l})$ , and butanol,  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}(\text{l})$ , are placed in a beaker and a thin wire (or pin) is placed horizontally on the surface of each liquid. The manipulated variable is the substance; the responding variable is the action of the wire and the fixed variables include the molecular size, polarity, and temperature of the substance, and mass and size of the wire or pin.  
*(Some variations include: other combinations of liquids with isoelectronic molecules, several different densities of wires of the same length to determine the mass supported by the liquid surface, and measuring the force required to lift a specific wire or disk from the surface.)*
  9. This experimental design is judged unacceptable because it does not stipulate or make clear that comparisons must be done for different liquids using the same kind of capillary tubes of equal diameters. Also, the design does not identify the variables for the experiment.
  10. Since water does not alleviate the “hotness” of the spices, the substances responsible for the “hotness” are probably nonpolar. Sour cream alleviates the effect of the spice, presumably because sour cream contains nonpolar substances such as fat. As the spices dissolve in the sour cream, they become diluted so the “hotness” of the food is diminished.
  11. The organic compounds in order of decreasing volatility are: hexane, 1-chlorohexane, hexan-1-ol. Hexane is the most volatile because it consists of nonpolar molecules attracted to each other in the liquid state by only London forces. The two other compounds consist of polar molecules. 1-chlorohexane is less volatile because of the presence of dipole–dipole attractions. Hexan-1-ol is the least volatile due to the presence of hydrogen bonding.

12. (a), (b)

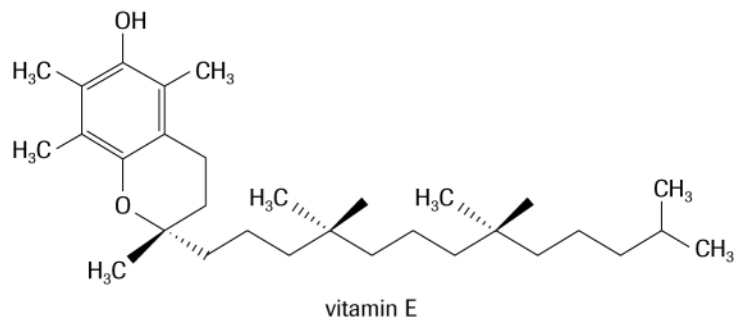
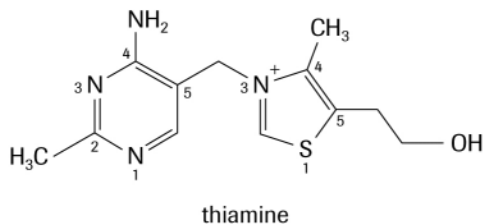


- (c) Based on the boiling point graph for these isoelectronic liquids, London force contributes most to intermolecular attraction, hydrogen bonding is usually less significant (about one-half in this example), and dipole-dipole force is almost insignificant.
13. Water is a polar substance that has all three intermolecular forces acting on it. When warm substances are placed over the permafrost, the heat from the buildings is absorbed by the solid crystalline water, causing intermolecular bonds to break. The permafrost liquefies, causing the ground on which the buildings sit to become unstable.

### Extension

14. (a) Molecules of water-soluble vitamins probably have hydrogen bonding, and are likely quite polar. Molecules of fat-soluble vitamins are probably nonpolar.

(b)



- (c) Vitamins are complex substances that react in very complicated ways with many other chemical substances in the body. A balanced diet is essential to ensure that taking vitamins can be of any benefit to an individual. Using vitamins to replace any elements of a normal diet is often ineffective, and may be very dangerous.

- (d) Vitamin C is water soluble, so it is easily excreted from the body and does not accumulate in humans. Humans are naturally adapted to handle fairly large amounts of this vitamin. Omnivores often ingest significant amounts of it from fruits and vegetables in their diets. Vitamin E is not water soluble and cannot be excreted readily. It tends to accumulate quickly to dangerous (toxic) levels if there is too much in the diet. (Large carnivores such as polar bears and lions can have so much vitamin E stored in their livers that eating the organ can be fatal to humans.)
15. Plastic cling wrap is made with a significant amount of a softening material, called a plasticizer, added to the polyvinyl chloride polymer. This causes the film to be very soft and flexible; consequently, it moulds well to any smooth surface (including itself), and the closeness of contact combined with large surface area makes the London force quite significant—the plastic wrap is “clingy.” (It is also likely that this plastic easily acquires an electrostatic charge that helps it cling to itself and nonmetallic objects.)
- Some plasticizers, particularly di-(2-ethylhexyl) adipate (DEHA), have come under fire because of suspicions that they may act as endocrine disruptors, with possible long-term harmful effects on the body. These compounds can be dissolved out of the wrap if the wrapped food contains fats and cheese would be a primary example of this. It should be noted that plasticizer molecules are liquid and nonpolar, so London forces will make them soluble in nonpolar fats.

### 3.5 STRUCTURES AND PHYSICAL PROPERTIES OF SOLIDS

#### Mini Investigation: Building an Ionic Crystal Model

(Page 122)

- (a)  $\text{Na}^+$  ions are nearest to each chloride ion. There are six sodium ions near each chloride ion that is inside the crystal lattice structure.
- (b)  $\text{Cl}^-$  ions are nearest to each sodium ion. There are six chloride ions near each sodium ion that is inside the crystal lattice structure.
- (c) Ion charges are not written because in any ionic crystal, the number of positive ions is balanced by the number of negative ions in a specific ratio, so the overall charge on the crystal is always zero.
- (d) “ $n$ ” represents the total number of sodium ions and of chloride ions in the crystal lattice.
- (e) This numbering system is not used because the sizes of crystals vary, and therefore the total number of ions in each crystal varies. We are only interested in the simplest whole-number ratio of oppositely charged ions in any crystal.
- (f) The subscript numbers in an ionic compound formula refer only to the ratio in which oppositely charged ions combine to form a neutral formula unit in the crystal.
- (g) Alternating positive and negative ions maximizes attraction and minimizes repulsion. This arrangement usually forms a cubic or other three-dimensional polygon crystal structure.

#### Practice

(Pages 122–123)

- (a)  $[\text{:C::N:}]^-$
- (b)  $[\text{:Se:}]^{2-}$
- (c)  $[\text{:O:H}]^-$