# 8.3 The Dissolving Process

**Figure 1** Arctic Fulmar

Toxic bird droppings. That is what researchers discovered as they studied the Arctic Fulmar, a small seabird that nests on Devon Island in the High Arctic (**Figure 1**). The area near the Fulmar nesting areas was rich in nitrogen—as you would expect in an area with bird excrement everywhere. The researchers did not, however, expect their samples to contain toxic industrial chemicals including mercury (from burning coal), PCBs (used in electrical equipment), and DDT (a pesticide). How did these pollutants find their way to the Arctic? The most logical source of the contamination is Fulmar excrement. This led researchers to conclude that the Fulmars' diet of plankton and small fish is tainted with pollutants. These organisms likely absorbed the pollutants from seawater. Researchers also tested large Arctic marine mammals: seals, polar bears, and other animals also contained dissolved pollutants. The highest concentrations of pollutants occurred in the fat of these animals. This evidence suggests that the pollutants are more soluble in fat than in the aqueous fluids in these animals. Moreover, the highest concentration of dissolved pollutants was found in the carnivores at the top of the Arctic food chain (**Figure 2**). This discovery of pollutants in marine mammals is of particular concern because these animals are an important part of the traditional diet of the Aboriginal peoples of the Arctic.

**Figure 2** Traces of industrial pollutants have been detected in the fatty tissues of Arctic organisms. Carnivores higher on the food chain showed the greatest concentration of these toxins.

## The Dissolving of Ionic Compounds

To understand why a substance may be more soluble in one solvent than another, we should examine the dissolving process at the molecular level. First, we will review the changes that occur as sodium chloride, NaCl, dissolves. In order to dissolve, the ionic bonds within the sodium chloride crystal must be broken. Recall that ionic bonds are so strong that not even a Bunsen burner flame can melt sodium chloride. And yet, sodium chloride readily dissolves in water at room temperature. Furthermore, the resulting solution conducts electricity—proof that ions are released when the sodium chloride dissolves. Why can water break apart a sodium chloride crystal and a Bunsen burner flame cannot?

**WEB LINK**

To see an animation of the dissolving process,

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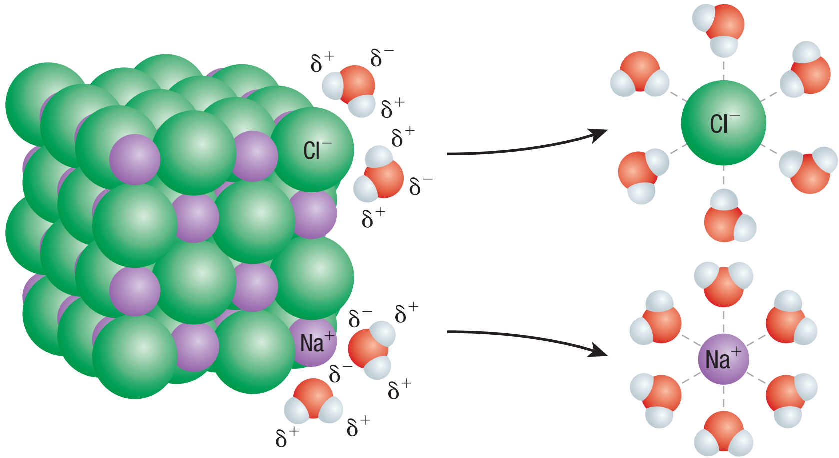
Recall that water is highly polar. As the molecules approach the crystal, they reorient themselves because the negative (oxygen) end of each molecule is attracted to a nearby positively charged sodium ion. Likewise, the positive (hydrogen) end is attracted to the chloride ion. What happens next is like a tug of war: water–ion attractions are pulling ions away from the crystal while ionic bonds are holding the ions together. If water wins the struggle, as is usually the case with sodium chloride, the crystal dissolves (**Figure 3**). If not, the crystal remains as an undissolved solid.




sodium chloride → sodium cations + chloride anions

**Figure 3** When a sodium chloride crystal is placed in water, water molecules are attracted to the sodium cations and chloride anions. These attractions pull the ions away from the crystal. Once in solution, each ion is surrounded by a layer of water molecules in a process called hydration.

As the ions leave the crystal, they become surrounded by a sphere of water molecules. This process is called **hydration**. Hydration helps to stabilize the ions in the solution, preventing them from attracting each other.

**hydration** the process in which ions are surrounded by water molecules

The process in which ions separate from ionic crystals, becoming individual ions, is called **dissociation**. The following equations represent the dissociation of sodium chloride and sodium carbonate:

**dissociation** the separation of individual ions from an ionic compound as it dissolves in water

$$NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$$

$$Na_2CO_3(s) \rightarrow 2\ Na^+(aq) + CO_3^{2-}(aq)$$

The symbol (aq) in these equations indicates that the ions are hydrated, or dissolved in water. Note that water is not included in the chemical equations because it does not undergo a chemical change during the reaction. However, it is necessary for dissociation to occur. Also note that polyatomic ions, such as carbonate, $CO_3^{2-}$, stay intact rather than breaking apart into their constituent atoms.

## Tutorial 1 Writing Dissociation Equations

Here are some points to consider when writing dissociation equations:

- Only ionic compounds undergo dissociation.
- When writing dissociation equations, the solid compound is always written on the left side of the equation and the ions it releases are written on the right.

### Sample Problem 1: Writing a Dissociation Equation

Write a chemical equation for the dissociation of potassium phosphate, $K_3PO_4(s)$.

**Step 1.** Determine the chemical formulas and number of each ion in the compound, keeping each polyatomic ion intact.

$3\ K^+$ $PO_4^{3-}$

**Step 2.** Write the chemical equation (compound on the left; aqueous ions on the right).

$$K_3PO_4(s) \rightarrow 3\ K^+(aq) + PO_4^{3-}(aq)$$

## Practice

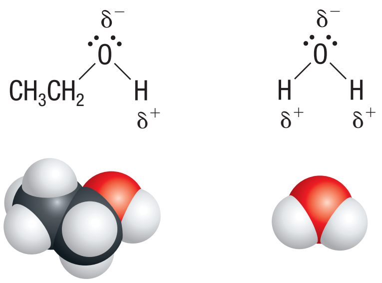
1. Write dissociation equations for the following solid compounds: T/I C
   (a) calcium chloride, $CaCl_2$
   (b) ammonium nitrite, $NH_4NO_2$
   (c) iron(III) hydroxide, $Fe(OH)_3$
   (d) aluminum sulfate, $Al_2(SO_4)_3$

## The Dissolving of Molecular Compounds

**miscible** able to mix to form a solution; usually describing liquids that mix with each other in all proportions to form a solution

**immiscible** unable to mix to form a solution; usually describing liquids that do not readily mix

Molecular compounds vary in how easily they dissolve in water. Some, such as glucose, $C_6H_{12}O_6$, and ethanol, $C_2H_5OH$, mix readily with water to form solutions. Others, like oil, do not. Liquids that mix with each other in all proportions are said to be **miscible**. Liquids that do not mix, like oil and water, are **immiscible**. Why is ethanol miscible in water while most other organic compounds are immiscible? We can explain this difference in miscibility (solubility) by comparing the shapes of ethanol and water molecules (**Figure 4**). Both compounds consist of V-shaped molecules and each of the molecules has a central oxygen atom. Water contains two highly polar O–H bonds while ethanol contains one O–H bond. Therefore, both compounds can form hydrogen bonds with neighbouring molecules. They can also form hydrogen bonds with each other when they are mixed. These attractions between molecules allow water and ethanol to mix to form an aqueous solution (**Figure 5**).




(a) (b)

**Figure 4** (a) Ethanol and (b) water are V-shaped polar molecules with a central oxygen atom.

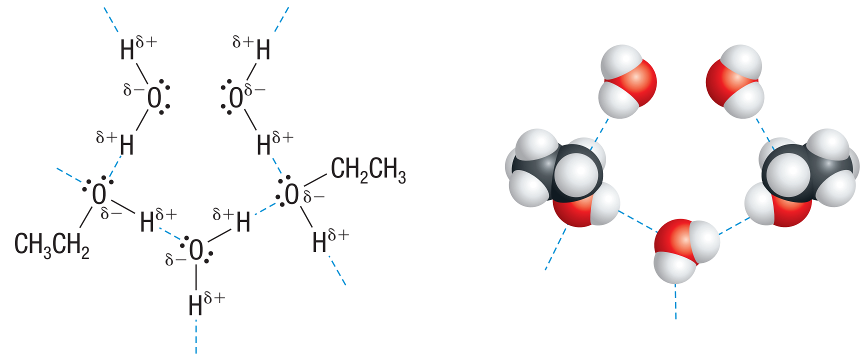



**Figure 5** Hydrogen bonding between ethanol and water molecules allows these liquids to form a solution.

The presence of several polar O–H bonds also explains why sugars such as glucose readily dissolve in water (**Figure 6**). The human body relies on this property to function properly. Glucose is the most common energy-rich "fuel" used by body cells. Brain cells rely exclusively on glucose as a fuel. Since these cells are not capable of storing glucose, they rely on the bloodstream to bring them a steady supply. This is why it is essential that glucose is water soluble.

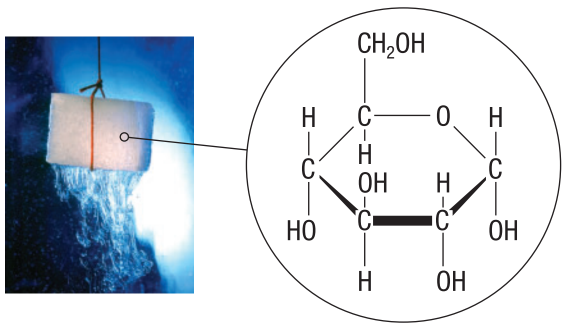



**Figure 6** As glucose dissolves, the density of the solution around the cube changes, creating visible ripples in the solution. Glucose is water soluble because of its 5 highly polar O–H bonds. The oxygen atoms, with their partial negative charges, form hydrogen bonds with the hydrogen atoms of water molecules.

## Water and Oil Do Not Mix

Although water has been called the universal solvent, there are many substances that it does not mix with. Hydrocarbons, including those found in crude oil, are immiscible with water (**Figure 7(a)**). Crude oil is generally less dense than water, so much of it floats on the surface. This is an advantage during an oil spill. Provided the ocean is calm, some of the oil can be skimmed off the surface (**Figure 7(b)**).

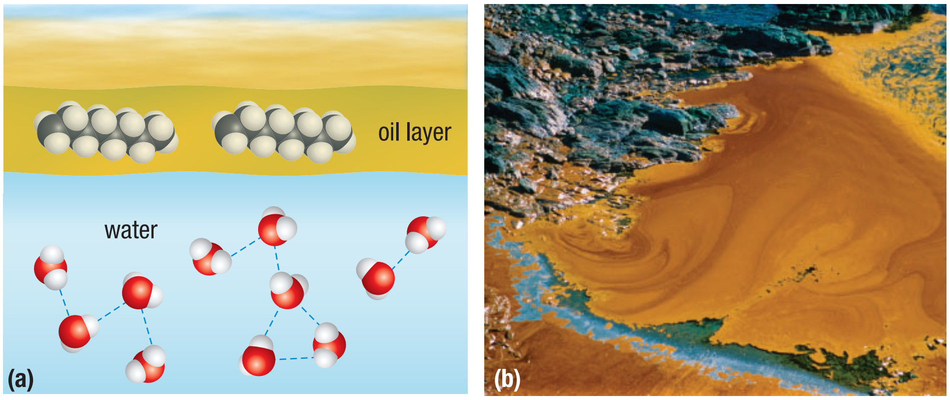



**Figure 7** (a) Oil and water are immiscible liquids. The hydrogen bonds between water molecules are too strong to allow oil molecules to penetrate the water layer. (b) When oil is released into the ocean, the less dense parts float on the surface of the water.

WEB **LINK**

On April 20, 2010, BP's *Deepwater Horizon* oil rig exploded in the Gulf of Mexico. For months, oil leaked into the ocean. To find out more about this oil spill and the clean-up efforts,

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To explain why hydrocarbons are immiscible in water, we can examine the structure of a typical hydrocarbon, hexane, $C_6H_{14}$ (**Figure 8**). Its molecules consist of hydrogen atoms connected to a long backbone of carbon atoms.

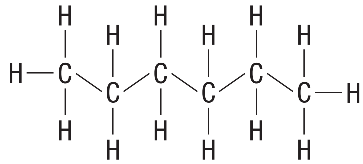

**Figure 8** Hexane is one of the hydrocarbons in oil. Like all hydrocarbons, hexane is non-polar.

Recall that the electronegativity of an atom describes its ability to attract electrons within a chemical bond. In Unit 1, you learned that the electronegativity difference between carbon and hydrogen is small. This makes the carbon–hydrogen bond almost non-polar. Recall that molecules that contain only non-polar bonds are always non-polar. (In Chapter 2 we classed them as non-polar molecular compounds.) In addition, many hydrocarbon molecules are symmetrical in shape. This is why hydrocarbons such as hexane are non-polar. The only attractive forces between hydrocarbon molecules are London dispersion forces—the weakest of all intermolecular attractions. However, since hydrocarbon molecules tend to be quite large and regular in shape, these London forces hold the non-polar molecules together quite strongly. However, there are almost no attractive forces between hydrocarbon molecules and water molecules. As a result, water and hexane do not mix.

Some substances are soluble in hydrocarbons. Solid iodine, $I_2$, for example, readily dissolves in hydrocarbon solvents to give a purple solution (**Figure 9(a)**). This is possible because both solute and solvent consist of non-polar molecules. London dispersion forces loosely attract the iodine molecules to the hydrocarbon, allowing iodine to dissolve.

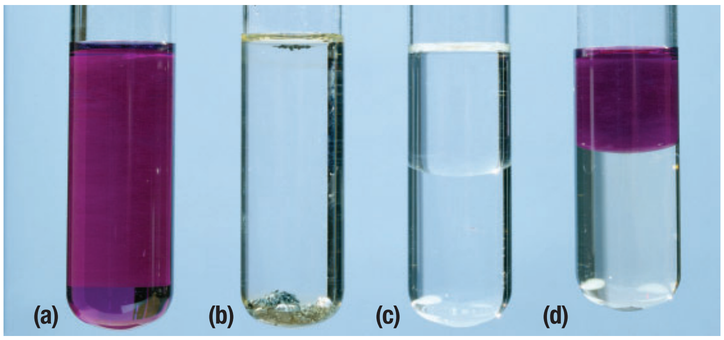


**Figure 9** Iodine is soluble in some liquids but not in others. (a) Iodine dissolves readily in hexane to form a purple solution. (b) Iodine does not dissolve readily in water, a polar solvent. (c) Water and hexane form an immiscible mixture. (d) Iodine dissolves much more readily in hexane than it does in water.

CAREER LINK

Toxicology is study of toxins, or poisons, and how they affect the body. To find out about working as a toxicologist,

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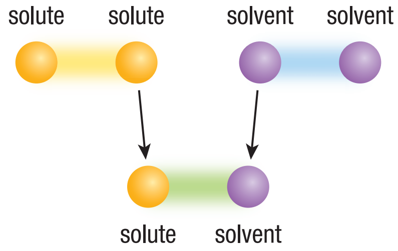


**Figure 10** Solute–solvent attractions must overcome the attractions within both solute and solvent in order for the solute to dissolve.

Now we can explain why industrial pollutants such as DDT are fat soluble. Both DDT and fat are non-polar covalent compounds. Once a non-polar substance, such as a pollutant, dissolves in fatty tissue, it tends to stay there and accumulate. Over the years the compound builds up in the fat of Arctic animals. If DDT were water soluble, it would be flushed out of the body. The same is true for fat-soluble vitamins: they remain stored in our fatty tissue until our bodies break them down.

## Like Dissolves Like

In the previous examples, we saw that solutes dissolve when the attractive forces between solute and solvent are stronger than the attractive forces within either the solute or the solvent (**Figure 10**). Ionic compounds and polar covalent compounds dissolve in polar solvents due to the strength of these solute–solvent attractions. Non-polar solutes do not dissolve in polar solvents because the solute–solvent attractions are weak compared to the attractions between solvent molecules. Non-polar solutes do, however, dissolve in non-polar solvents. These solubility generalizations can be summarized by the statement "like dissolves like." In other words, solutes dissolve in solvents of similar polarity.

Seeking relief from the heat of eating chili peppers is an interesting application of "like dissolves like". Capsaicin is the compound responsible for the "burning sensation" of a chili pepper. Capsaicin stimulates the cells in the tongue responsible for sensing heat so that the brain interprets that the tongue is burning. If you want quick relief from chili "burn," try drinking milk rather than cold water. The fat in milk and capsaicin are both nonpolar. Fat dissolves capsaicin off the tongue.

## Surfactants

**surfactant** a compound that can reduce the surface tension of a solvent; surfactants have both a hydrophobic part and a hydrophilic part

We can "encourage" oil and water to mix with the help of a class of chemicals called "surface acting agents" or surfactants. A **surfactant** is a substance that acts on the surface of a liquid, reducing surface tension. Soaps and detergents are the most familiar surfactants. They reduce the surface tension of water by breaking down the hydrogen bonding network at the surface. This allows a polar solvent such as water to mix with a non-polar liquid like oil. Millions of litres of surfactants were used to disperse the 2010 oil spill in the Gulf of Mexico.

Soaps and detergents are cleaning agents. Soaps are made by reacting animal fats or vegetable oils with a concentrated base. Detergents are made from petrochemicals. The most common types of soap and detergent are very long molecules. A typical soap or detergent is a compound that dissociates in water to form two ions. The cation is usually a sodium ion. The anion is a long structure with a charged "head" and a long, non-polar hydrocarbon "tail" (**Figure 11**).

CAREER LINK

Surfactant scientist are interested in the role of surfactants in many different situations, from oil spills to washing machines. To learn more about this career and the training required,

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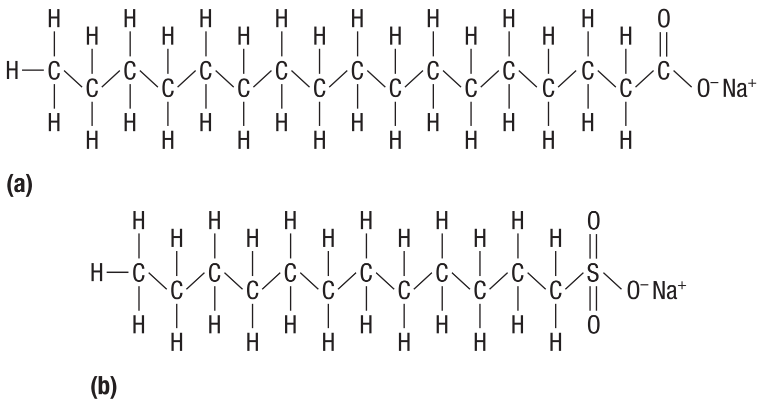

**Figure 11** (a) Sodium stearate is used to make bars of soap. (b) Sodium lauryl sulfate is a typical detergent used in toothpaste and shampoo. Both dissolved anions have similar structures: a long hydrocarbon chain with a charged end.

Once a detergent dissolves, the negatively charged end of its anion attracts the polar water molecules while the non-polar hydrocarbon end does not. As a result, we say that the charged end of the anion is hydrophilic or "water-loving." The hydrocarbon end is hydrophobic or "water-fearing." An oily stain on your shirt contains non-polar molecules. When laundry is being washed, the hydrophobic end of the detergent ion attaches to grease. Agitation of the washing machine jostles water molecules back and forth. As they move about, water molecules pull detergent ions along with them. This helps to detach the oil stain from the fabric (**Figure 12**). Once in the water, the oil particle is coated by a layer of detergent ions. This prevents oil and grease from reattaching to the fabric.

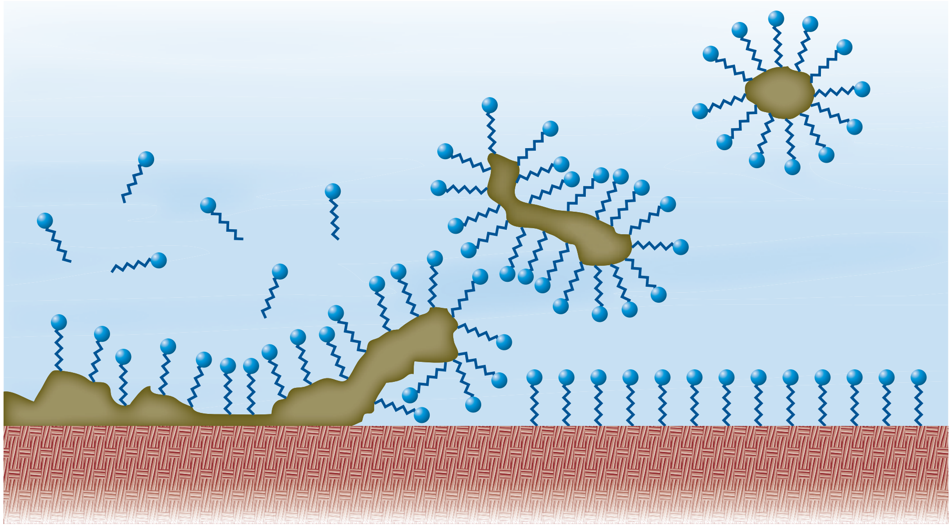

**Figure 12** The hydrophobic tails of the detergent ions bond to the grease globule while the hydrophilic ends are attracted to the surrounding water molecules. As the grease is dislodged, it becomes coated with more detergent ions.

## Mini **Investigation**

### Exploring Selective Solubility

**Skills:** Predicting, Performing, Observing, Analyzing, Communicating

SKILLS HANDBOOK A1.2, A2.4

At the beginning of this section you read about researchers finding certain compounds stored in the fatty tissue of Arctic mammals. This implies that these compounds are more soluble in fat than in water. In this activity you will use three familiar substances to model this concept. Specifically, you will compare the solubility of iodine, $I_2$, in two different solvents. Figure 9 shows the purple colour of dissolved iodine, $I_2(s)$. Pure solid iodine, however, is too dangerous to use. Instead, you will use a mixture called Lugol's solution: an aqueous solution of iodine, water, and potassium iodide, KI. The iodide ion, $I^-$, reacts with iodine, $I_2$, to form a brown-coloured ion, $I_3^-$, which readily dissolves in water:

| $I_2(s)$ | + | $I^-(aq)$ | $\rightarrow$ | $I_3^-(aq)$ |
|---|---|---|---|---|
| (purple) | | (colourless) | | brown |

**Equipment and Materials:** chemical safety goggles; lab apron; test tube with stopper; distilled water; mineral oil; dropper bottles of Lugol's solution.

Lugol's solution will stain skin. Any spills on the skin, in the eyes, or on clothing should be washed immediately with cool water. Report any spills to your teacher.

1. Put on your chemical safety goggles and lab apron.
2. Add distilled water to the test tube until it is about one-quarter full.
3. Add an equal volume of mineral oil to the test tube. Allow the two liquids to settle for a few seconds. Record your observations.
4. Add 5 drops of Lugol's solution to the test tube.
5. Stopper and shake the test tube for about 10 s and then allow its contents to settle. Compare the colour of the two layers.
6. Dispose of the contents of the test tube as directed by your teacher.

A. What observation suggests that dissolved iodine was produced during the activity? T/I

B. What evidence suggests that most of the compounds in mineral oil are non-polar? T/I

C. Use the concept of molecular polarity to explain the observed differences in the solubility of iodine. T/I A

## Research This

### The Search for Greener Solvents

**Skills:** Researching, Analyzing, Evaluating, Communicating, Defining the Issue, Defending a Decision    SKILLS HANDBOOK 5.1

Solvents are the workhorses of many important chemical processes. They dissolve reactants, transport materials from one location to another, and facilitate the separation of one chemical from another. For example, soybean oil is traditionally extracted from soybeans by soaking the beans in the solvent hexane. Since both soybean oil and hexane are non-polar, soybean oil dissolves in hexane. Hexane can be recovered by heating the mixture to boil off the hexane and then condensing the hexane vapour in a process called distillation (**Figure 13**). The liquid remaining in the heating vessel is pure soybean oil. The disadvantage of distillation is that it requires a great deal of energy.

Advances in green chemistry may soon provide a greener way to perform this extraction. Dr. Philip Jessop at Queen's University in Kingston, Ontario is developing solvents that have switchable solubilities. The hydrophobic form of the solvent can be used to extract the oil from the soybeans. The solvent can then be made hydrophilic by bubbling carbon dioxide into it. This causes the solvent and soybean oil to separate into two layers. The oil layer is then drained away. Warming the solvent removes the carbon dioxide, converting the solvent back to its hydrophobic form so that it can be used again.

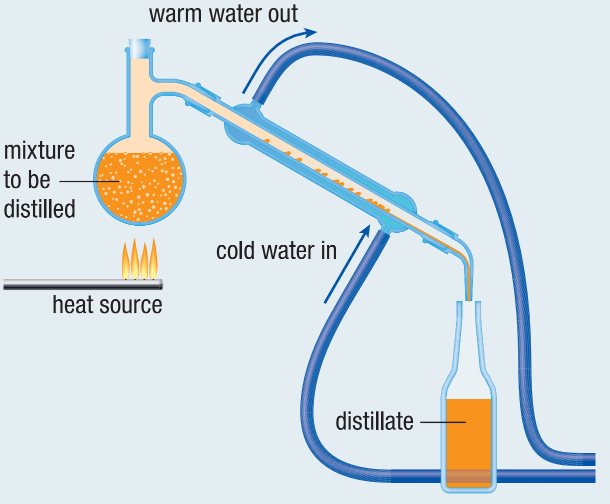


**Figure 13** Distillation apparatus

A. Research another application of green solvents. Identify the advantages of using these solvents over traditional solvents used for this process. T/I A

B. Summarize your findings in a brochure that could be used to interest investors in the solvent and its applications. T/I C

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## 8.3 Summary

- For a substance to dissolve, solute–solvent attractions must overcome the attractions within both solute and solvent.
- Ionic compounds dissociate as they dissolve, releasing their ions into solution.
- The symbol (aq) after a chemical formula means that the dissolved entity is surrounded by a sphere of water molecules.
- Solutes dissolve in solvents of similar polarities. ("Like dissolves like.") Ionic and polar covalent compounds are soluble in polar solvents. Non-polar covalent compounds are soluble in non-polar solvents.
- Miscible liquids mix to form a solution.
- Immiscible liquids do not mix.
- Surfactants are compounds that reduce the surface tension of a solvent. Surfactant ions have a hydrophilic end that is attracted to water and a hydrophobic end that is repelled by water.

## 8.3 Questions

1. The opening paragraph stated that the pesticide DDT was detected in the fatty tissues of Arctic mammals. K/U T/I
   (a) Based on this evidence, is DDT a polar or non-polar substance?
   (b) Predict the relative solubilities of DDT in water and hexane, $C_6H_{14}$. Justify your prediction.
2. What attractions must be overcome before a solute can dissolve in a solvent? K/U
3. Why is water capable of dissolving sodium chloride but hexane, $C_6H_{14}$, is not? K/U
4. Water is sometimes called "the universal solvent." Do you think that this is a valid description? Explain your answer. K/U A
5. Why is hydration a necessary part of dissolving? K/U
6. Write a chemical equation for the dissociation of each of the following compounds: T/I
   (a) calcium nitrate, $Ca(NO_3)_2$
   (b) potassium perchlorate, $KClO_4$
   (c) ammonium carbonate, $(NH_4)_2CO_3$
   (d) iron(III) sulfite, $Fe_2(SO_3)_3$
7. Distinguish between the terms "miscible" and "immiscible" using two household examples. K/U
8. Explain what is meant by the expression "like dissolves like." K/U
9. Predict which compound in each of the following pairs is more soluble in water. Why? K/U T/I
   (a) $CH_3OCH_3$ or $CH_3OH$
   (b) $Na_2CO_3$ or $CO_2$
10. Predict which of these liquids is more miscible with water: methanol, $CH_3OH$, or dichloromethane, $CH_2Cl_2$. Why? T/I
11. Iodine, $I_2$, is a purple solid at room temperature. Corn oil is a yellow liquid. Identical volumes of water, corn oil, and a crystal of iodine are added to the same test tube. The test tube is then stoppered and shaken. Predict the appearance of the test tube after its contents have settled. T/I
12. Lipstick stains on fabric can be difficult to remove (**Figure 14**). Soaking the fabric in water generally does not work. Instead, some people recommend covering the stain with hairspray or petroleum jelly first before washing. Use the concept of polarity to explain why this might work. T/I

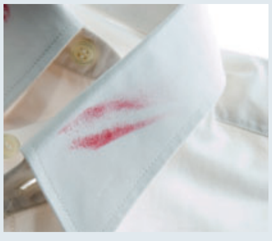

**Figure 14** Apply your understanding of molecular polarity to help remove this stain.

13. **Table 1** gives the solubilities of several alcohols. The higher the solubility value, the greater the quantity of solute that will dissolve in the solvent.

**Table 1** Solubility of Five Alcohol Compounds in Water

| Name | Formula | Solubility (g/100 g $H_2O$ at 20 °C) |
|---|---|---|
| ethanol | $CH_3CH_2OH$ | miscible |
| 1-propanol | $CH_3CH_2CH_2OH$ | miscible |
| 1-butanol | $CH_3CH_2CH_2CH_2OH$ | 7.9 |
| 1-pentanol | $CH_3CH_2CH_2CH_2CH_2OH$ | 2.7 |
| 1-hexanol | $CH_3CH_2CH_2CH_2CH_2CH_2OH$ | 0.6 |

   (a) Based on these data, identify one factor that affects the solubility of alcohols in water.
   (b) Predict how the solubility of 1-octanol, $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2OH$, compares with the alcohols in Table 1.
   (c) How could you analyze the data in Table 1 to find the solubility of 1-octanol? Try it. T/I C
14. Describe why the cleaning action of soaps and detergents is an application of "like dissolves like." T/I
15. Vitamin A and vitamin C are both important nutrients. Vitamin A is fat soluble while vitamin C is water soluble. Some people take vitamin supplements to ensure that they are getting enough of both vitamins. Too much vitamin A can be toxic. If you consume it in its natural form, it can also turn your skin orange! Why is it easier to overdose on vitamin A than on vitamin C? A
16. Persistent organic pollutants (POPs) are a class of organic pollutants that adversely affect human health and the environment in many places around the world. Investigate some of the pollutants that are classified as POPs. Research some of their adverse effects. Give three reasons why these compounds are appearing in locations far from where they were originally used. T/I A
17. "We are the land and the land is us. When our land and animals are poisoned, so are we." These are the words of Sheila Watt-Clutier, Canadian member of the Inuit Circumpolar Conference, in 2001. Traces of DDT have been detected in the Arctic, despite the fact that Canada banned its use decades ago. Scientists set about trying to find out how it got there and the potential health effects on the people of Canada's North. What did they discover? How have Inuit responded to the research? Read at least two articles on this topic and write an abstract to summarize each one. T/I C A

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