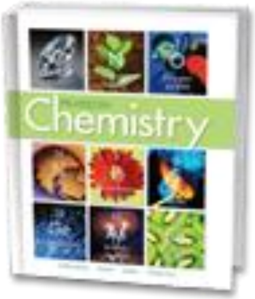


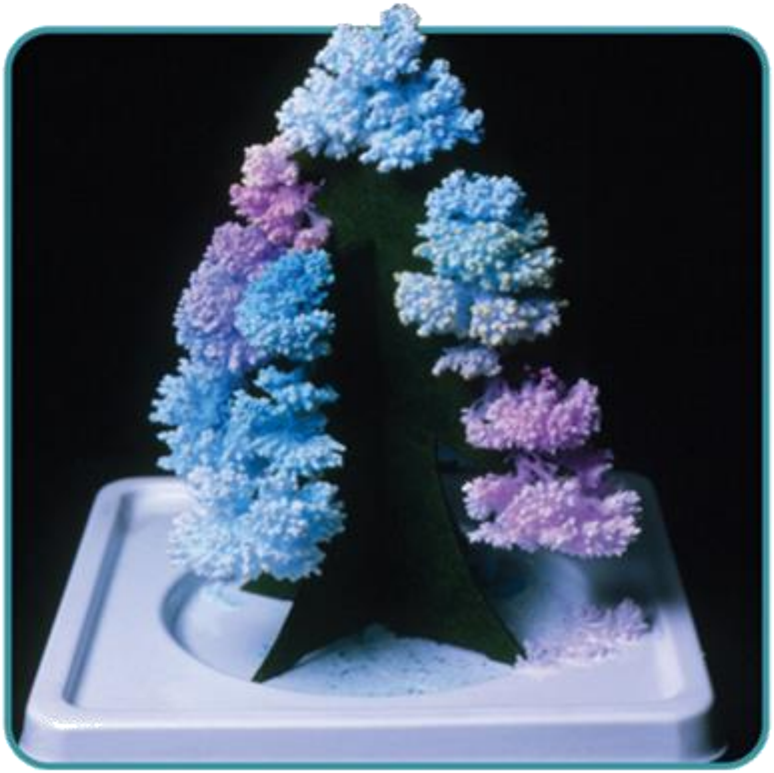
Chapter 16
Solutions

16.1 Properties of Solutions

16.2 Concentrations of Solutions
16.3 Colligative Properties of Solutions
16.4 Calculations Involving Colligative Properties

How can you grow a tree made out of crystals?

Remember, the crystallization of a solute from solution is a physical change that is different from freezing.



Solution Formation

What factors affect how fast a substance dissolves?

Granulated sugar dissolves faster than sugar cubes, and both granulated sugar and sugar cubes dissolve faster in hot tea or when you stir the tea.

The compositions of the solvent and the solute determine whether or not a substance will dissolve.

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Factors that affect how fast a substance dissolves include:

- Agitation
- Temperature
- Particle size of the solute

Agitation

If the contents of the glass are stirred, the crystals dissolve more quickly.

- The dissolving process occurs at the surface of the sugar crystals.
- Stirring speeds up the process because fresh solvent (the water) is continually brought in contact with the surface of the solute (sugar).

Agitation

Agitation (stirring or shaking) affects only the rate at which a solid solute dissolves.

- It does not influence the amount of solute that will dissolve.
- An insoluble substance remains undissolved regardless of how vigorously or for how long the solvent/solute system is agitated.

Temperature

Temperature also influences the rate at which a solute dissolves.

- Sugar dissolves much more rapidly in hot tea than in iced tea.

Temperature

At higher temperatures, the kinetic energy of water molecules is greater than at lower temperatures, so the molecules move faster.

- The more rapid motion of the solvent molecules leads to an increase in the frequency of the force of the collisions between water molecules and the surfaces of the sugar crystals.

Particle Size of the Solute

The rate at which a solute dissolves also depends upon the size of the solute particles.

- The smaller particles in granulated sugar expose a much greater surface area to the colliding water molecules.

Particle Size of the Solute

The dissolving process is a surface phenomenon.

- The more surface area of the solute that is exposed, the faster the rate of dissolving.

Checkpoint

Which of the following will not speed up the rate at which a solid solute dissolves?

A. Increasing the temperature

B. Stirring the mixture

C. Crushing the solute

D. Decreasing the temperature

Checkpoint

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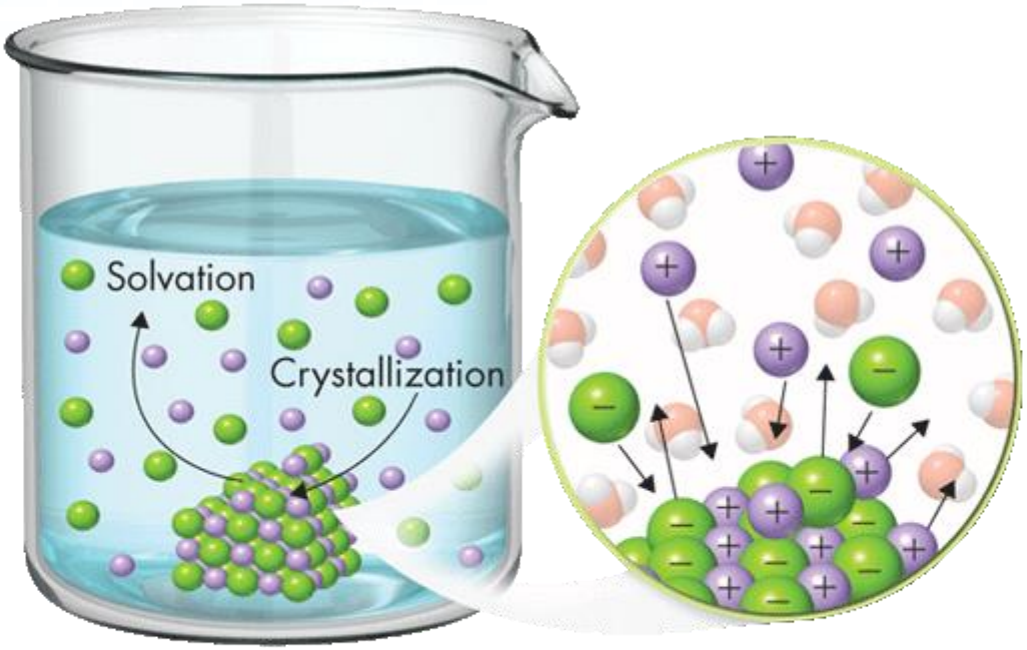
Solubility

How can you describe the equilibrium in a saturated solution?

What is happening in this figure?



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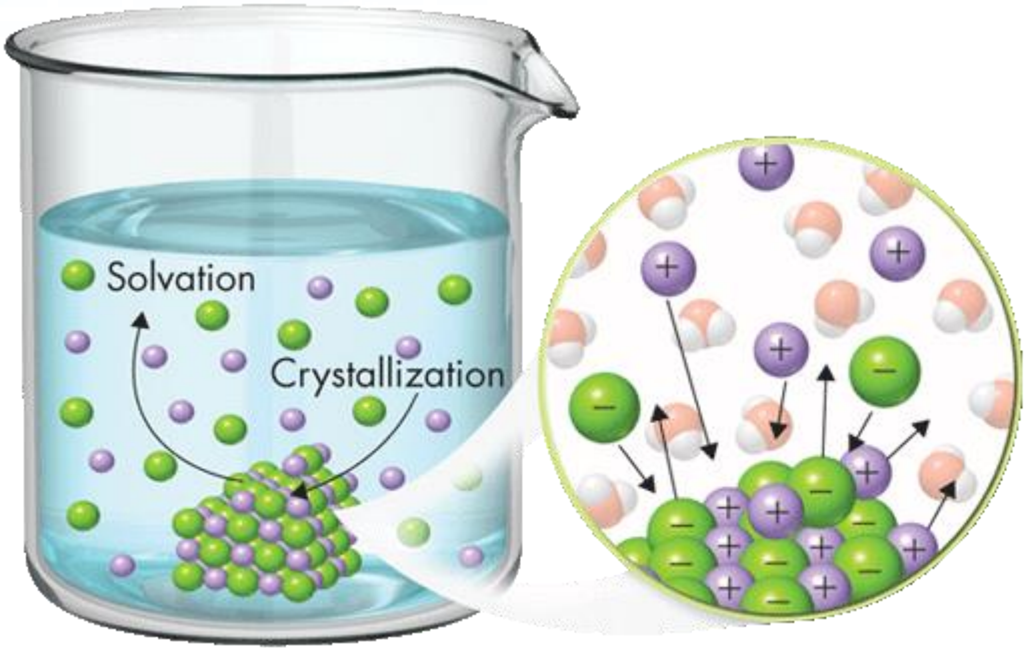
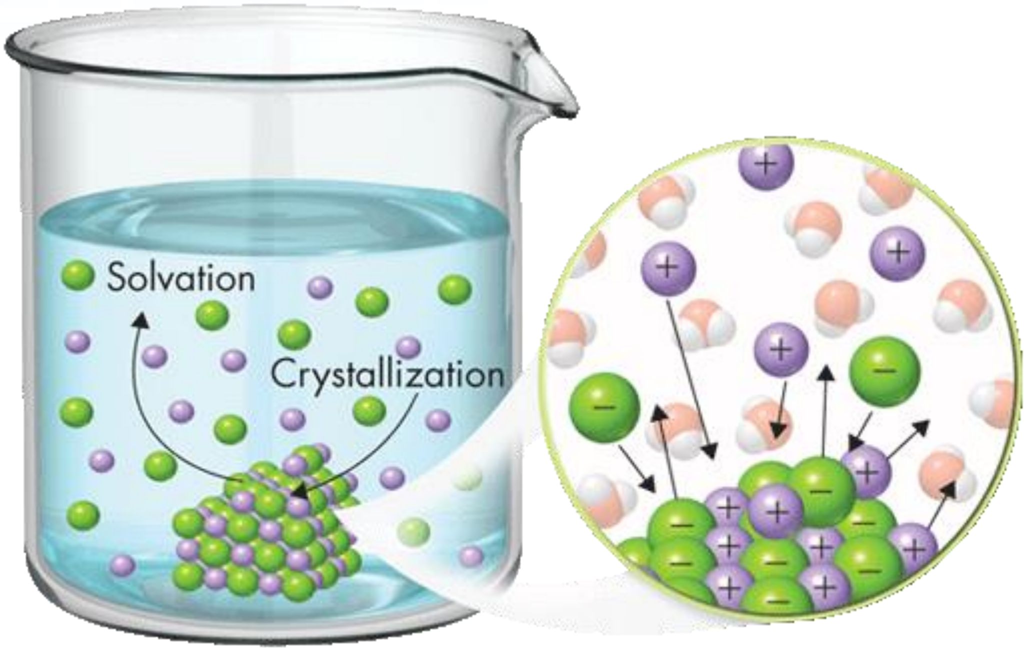


- Particles move from the solid into the solution.
- Some dissolved particles move from the solution back to the solid.
- Because these two processes occur at the same rate, no net change occurs in the overall system.

Such a solution is said to be saturated.



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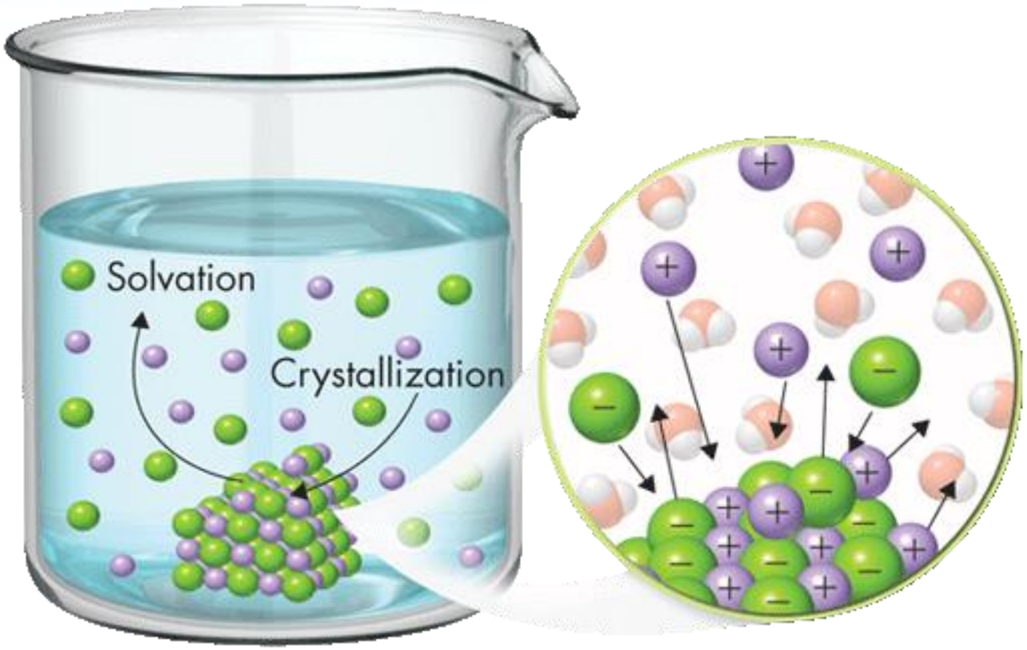


- A **saturated solution** contains the maximum amount of solute for a given quantity of solvent at a constant temperature and pressure.

In a saturated solution, a state of dynamic equilibrium exists between the solution and any undissolved solute, provided that the temperature remains constant.

The **solubility** of a substance is the amount of solute that dissolves in a given quantity of a solvent at a specified temperature and pressure to produce a saturated solution.

- Solubility is often expressed in grams of solute per 100 g of solvent (g/100 g H_2O).
- Sometimes the solubility of a gas is expressed in grams per liter of solution (g/L).

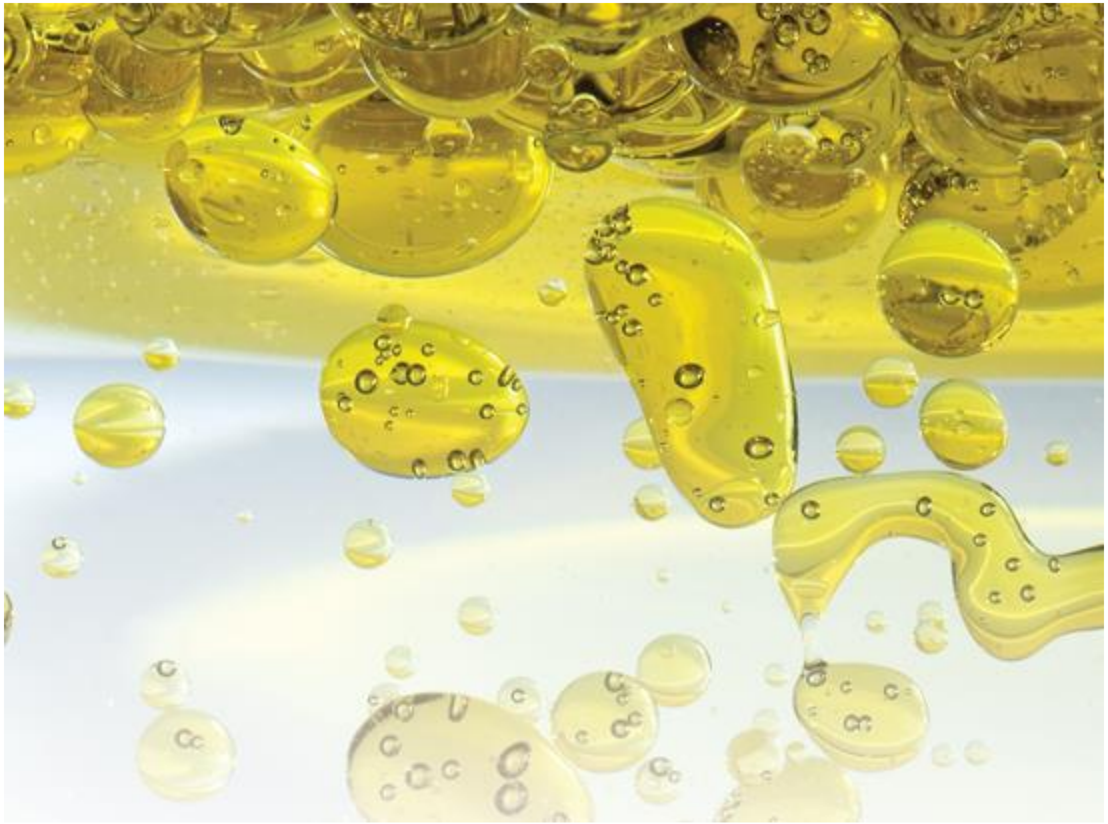
A solution that contains less solute than a saturated solution at a given temperature and pressure is an **unsaturated solution**.

- If additional solute is added to an unsaturated solution, the solute will dissolve until the solution is saturated.

Some liquids—for example, water and ethanol—are infinitely soluble in each other.

- Two liquids are **miscible** if they dissolve in each other in all proportions.

Liquids that are insoluble in each other are **immiscible**.



- Oil and water are examples of immiscible liquids.

Checkpoint

The solubility of a substance is often expressed as which of the following?

A. grams of solute per 100 liters of solvent

B. grams of solute per 1 cm^3 of solvent

C. grams of solute per 100 grams of solvent

D. grams of solute per 100 grams of solution

Checkpoint

The solubility of a substance is often expressed as which of the following?

A. grams of solute per 100 liters of solvent

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C. grams of solute per 100 grams of solvent

D. grams of solute per 100 grams of solution

PEARSON

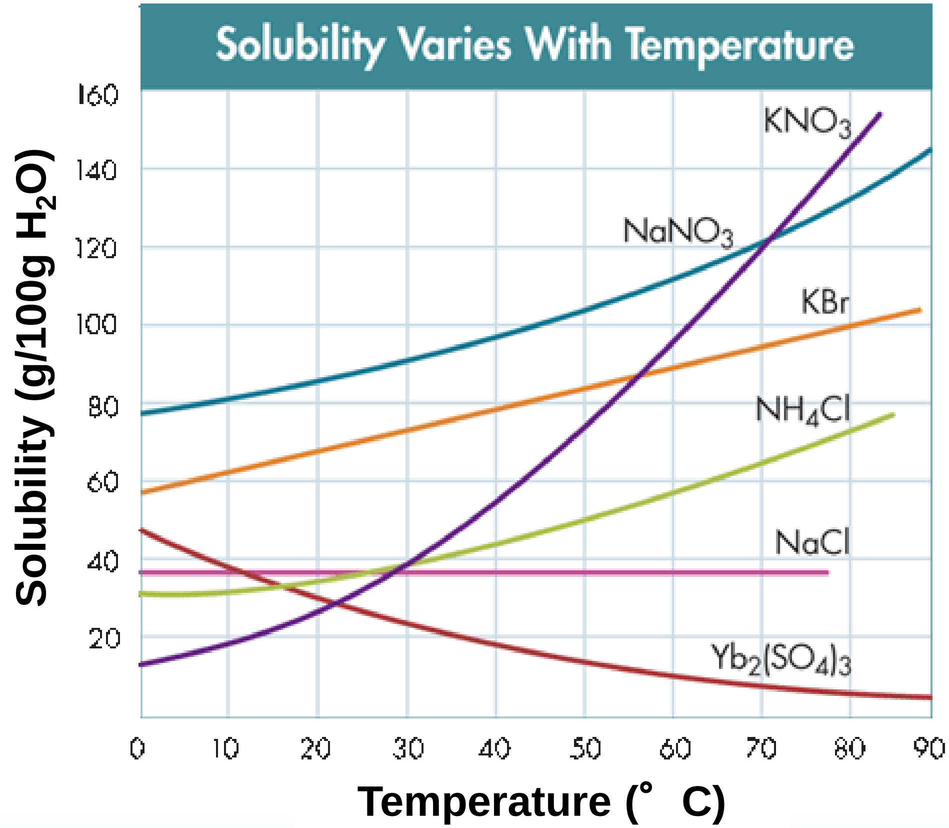
Factors Affecting Solubility

What factors affect the solubility of a substance?

Temperature affects the solubility of solid, liquid, and gaseous solutes in a solvent; both temperature and pressure affect the solubility of gaseous solutes.

Temperature

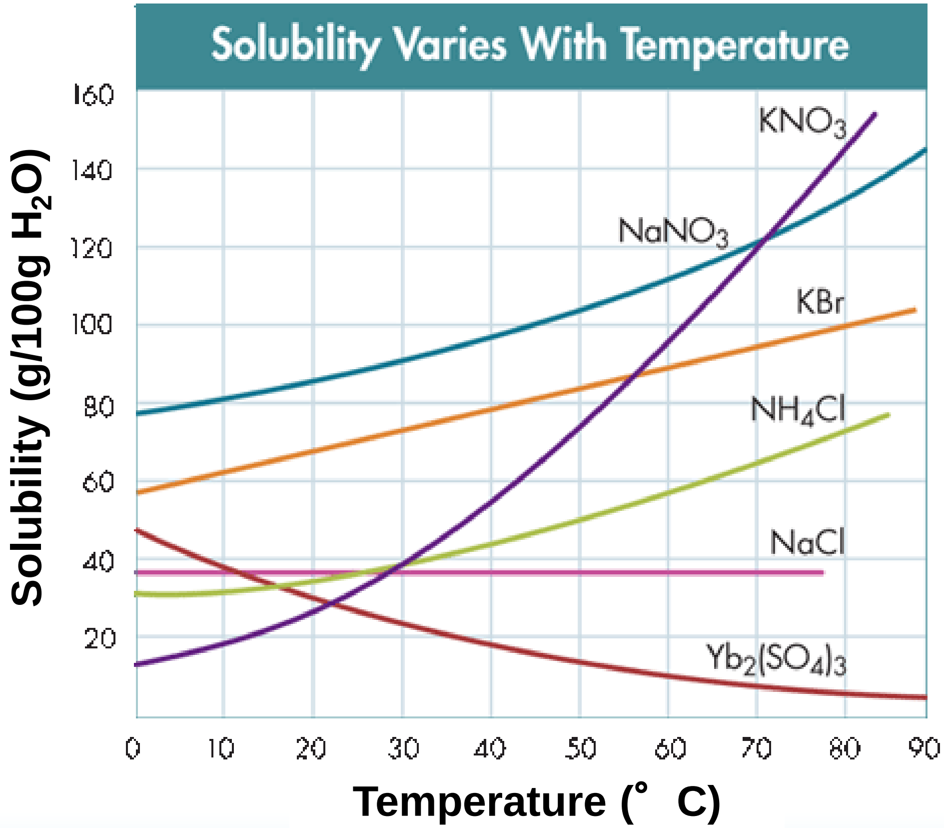
The solubility of most solid substances increases as the temperature of the solvent increases.



Temperature

The solubility of most solid substances increases as the temperature of the solvent increases.

- For a few substances, solubility decreases with temperature.



Solubilities of Substances in Water at Various Temperatures					
		Solubility (g/100 g H_2O)			
Substance	**Formula**	**0° C**	**20° C**	**50° C**	**100° C**
Barium hydroxide	$Ba(OH)_2$	1.67	31.89	—	—
Barium sulfate	$BaSO_4$	0.00019	0.00025	0.00034	—
Calcium hydroxide	$Ca(OH)_2$	0.189	0.173	—	0.07
Potassium chlorate	$KClO_3$	4.0	7.4	19.3	56.0
Potassium chloride	KCl	27.6	34.0	42.6	57.6
Sodium chloride	NaCl	35.7	36.0	37.0	39.2
Sodium nitrate	$NaNO_3$	74	88.0	114.0	182
Aluminum chloride	$AlCl_3$	30.84	31.03	31.60	33.32
Silver nitrate	$AgNO_3$	122	222.0	455.0	733
Sucrose (table sugar)	$C_{12}H_{22}O_{11}$	179	230.9	260.4	487
Hydrogen	H_2	0.00019	0.00016	0.00013	0.0
Oxygen	O_2	0.0070	0.0043	0.0026	0.0
Carbon dioxide	CO_2	0.335	0.169	0.076	0.0

Temperature

A **supersaturated solution** contains more solute than it can theoretically hold at a given temperature.

- The crystallization of a supersaturated solution can be initiated if a very small crystal, called a seed crystal, of the solute is added.

The rate at which excess solute deposits upon the surface of a seed crystal can be very rapid.

The solution is clear before a seed crystal is added.

Crystals begin to form immediately after the addition of a seed crystal.

Excess solute crystallizes rapidly.

How do you think crystal-growing kits work? Use what you know about solubility and supersaturated solutions to explain your answer.

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Crystal-growing kits usually begin with a supersaturated solution. When a seed crystal is added to the solution, crystals rapidly begin to grow because the supersaturated solution contains more solute than is theoretically possible.

Temperature

The effect of temperature on the solubility of gases in liquid solvents is opposite that of solids.

- The solubilities of most gases are greater in cold water than in hot.

Pressure

Changes in pressure have little effect on the solubility of solids and liquids, but pressure strongly influences the solubility of gases.

- Gas solubility increases as the partial pressure of the gas above the solution increases.

Pressure

Carbonated beverages are a good example.

- These drinks contain large amounts of carbon dioxide (CO_2) dissolved in water.
- Dissolved CO_2 makes the liquid fizz and your mouth tingle.

Pressure

Carbonated beverages are a good example.

- The drinks are bottled under a high pressure of CO_2 gas, which forces larger amounts of the gas into solution.

Pressure

Carbonated beverages are a good example.

- When the container is opened, the partial pressure of CO_2 above the liquid decreases.
- Immediately, bubbles of CO_2 form in the liquid and escape from the open bottle.

Pressure

How is the partial pressure of carbon dioxide gas related to the solubility of CO_2 in a carbonated beverage?

Pressure

How is the partial pressure of carbon dioxide gas related to the solubility of CO_2 in a carbonated beverage?

- The relationship is described by **Henry's law**, which states that at a given temperature, the solubility (*S*) of a gas in a liquid is directly proportional to the pressure (*P*) of the gas above the liquid.

Pressure

- As the pressure of the gas above the liquid increases, the solubility of the gas increases.
- As the pressure of the gas decreases, the solubility of the gas decreases.

Pressure

You can write the relationship in the form of an equation.

$$\frac{S_1}{P_1} = \frac{S_2}{P_2}$$

- S_1 is the solubility of a gas at one pressure, P_1.
- S_2 is the solubility at another pressure, P_2.

Using Henry's Law

If the solubility of a gas in water is 0.77 g/L at 3.5 atm of pressure, what is its solubility (in g/L) at 1.0 atm of pressure? (The temperature is held constant at 25° C.)

1 Analyze **List the knowns and the unknown.**

Use Henry's law to solve for the unknown solubility.

KNOWNS	UNKNOWN
P_1 = 3.5 atm	S_2 = ? g/L
S_1 = 0.77 g/L	
P_2 = 1.0 atm	

2 Calculate **Solve for the unknowns.**

- State the equation for Henry's law.

$$\frac{S_1}{P_1} = \frac{S_2}{P_2}$$

Isolate S_2 by multiplying both sides by P_2:

$$P_2 \times \frac{S_1}{P_1} = \frac{S_2}{\cancel{P_2}} \times \cancel{P_2}$$

- Solve Henry's law for S_2. Substitute the known values and calculate.

$$S_2 = \frac{S_1 \times P_2}{P_1} = \frac{0.77 \text{ g/L} \times 1.0 \cancel{\text{ atm}}}{3.5 \cancel{\text{ atm}}} = 0.22 \text{ g/L}$$

3 Evaluate **Does the result make sense?**

- The new pressure is approximately one-third of the original pressure.
- So, the new solubility should be approximately one-third of the original.
- The answer is correctly expressed to two significant figures.

Checkpoint

Explain why an opened container of a carbonated beverage is more likely to go flat sitting on the counter than in the refrigerator.

Checkpoint

Explain why an opened container of a carbonated beverage is more likely to go flat sitting on the counter than in the refrigerator.

The solubility of a gas in a liquid increases with decreasing temperature. More carbon dioxide will remain in solution at the colder temperature found in the refrigerator.

- **Factors that determine how fast a substance dissolves are stirring, temperature, and surface area.**

- **In a saturated solution, a state of dynamic equilibrium exists between the solution and any undissolved solute, provided that the temperature remains constant.**

- **Temperature affects the solubility of solid, liquid, and gaseous solutes in a solvent; both temperature and pressure affect the solubility of gaseous solutes.**

Henry's law: $$\frac{S_1}{P_1} = \frac{S_2}{P_2}$$

- **saturated solution:** a solution containing the maximum amount of solute for a given amount of solvent at a constant temperature and pressure; an equilibrium exists between undissolved solute and ions in solution
- **solubility:** the amount of a substance that dissolves in a given quantity of solvent at specified conditions of temperature and pressure to produce a saturated solution

- **unsaturated solution:** a solution that contains less solute than a saturated solution at a given temperature and pressure
- **miscible:** describes liquids that dissolve in each other in all proportions
- **immiscible:** describes liquids that are insoluble in each other; oil and water are immiscible

- **supersaturated solution:** a solution that contains more solute than it can theoretically hold at a given temperature; excess solute precipitates if a seed crystal is added
- **Henry's law:** at a given temperature, the solubility of a gas in a liquid is directly proportional to the pressure of the gas above the liquid

END OF 16.1