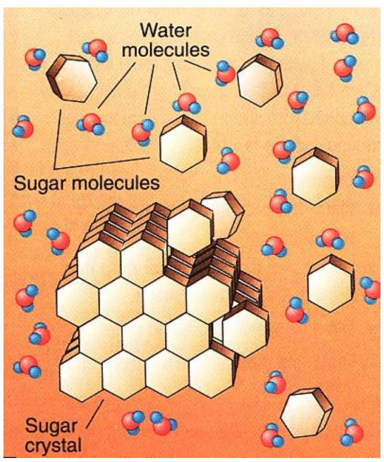
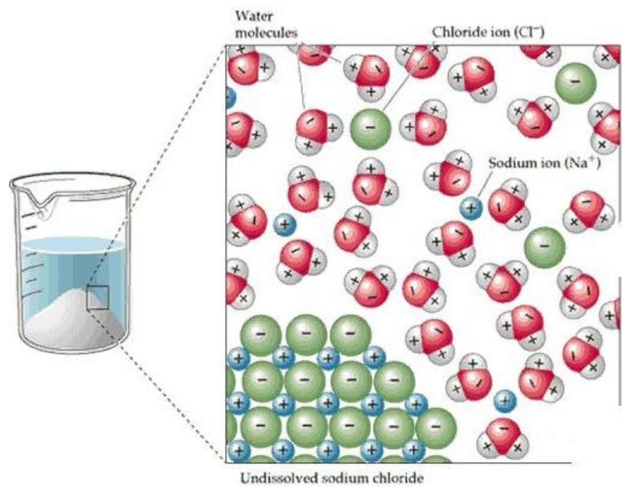
Section (3)
Factors Affecting solvation

Types of bonds

- **Between atoms**
  - **Ionic**
  - **covalent**
- **between molecules**
  - **London dispersion force**
  - **Dipole-Dipole Attractive Forces**
  - **Hydrogen bond**

Solvation: the process of **surrounding solute particles with solvent particles in water** to form a solution.

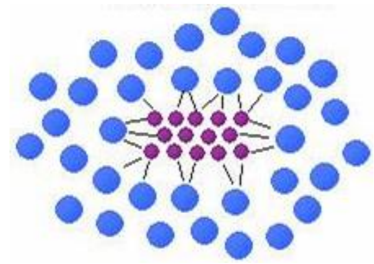




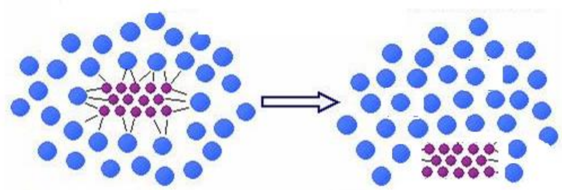
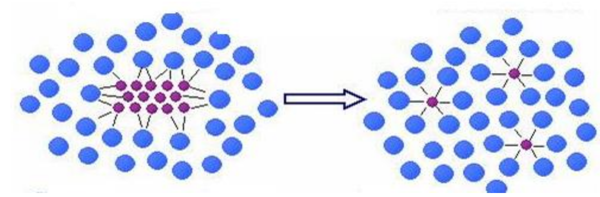
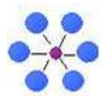
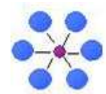
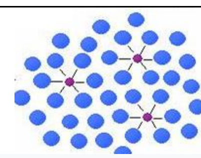
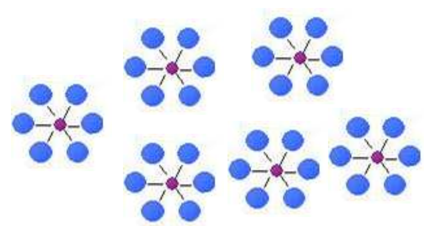
NaCl is an ionic compound that dissolves in water
AgI silver chloride is an insoluble ionic compound in water

Table sugar (sucrose) is a covalent compound that dissolves in water
The oil is a covalent compound insoluble in water

Explanation of the solvation process: The solute particles are pulled from the solid, and surrounded by solvent particles.



There are two probabilities

solvation does not occur	solvation occurs
	
  The **attraction force** between the particles of the solute itself > The attraction force between the particles of solute and the solvent.	  The attraction force between the solute particles and the solvent > The attraction force between the particles of the solute itself
 The solute particles **will not** separate from each other.	 Solvent particles attract and dissolved solute particles and separate it.
solvation process will not occur	Particles of solute which are surrounded by solvent particles; go away from solid solute = solvation occurred 

The solvation process depends on:

1 - Polarity of the compounds

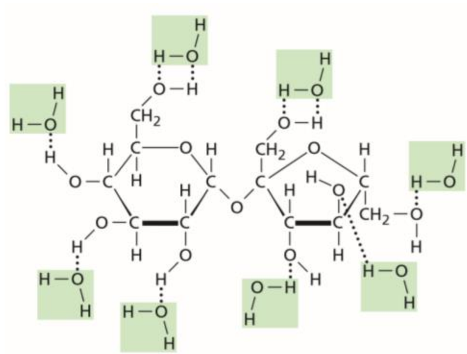
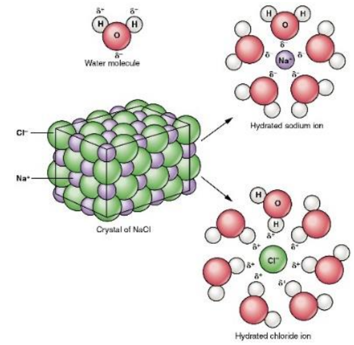
2 - the type of bond of the dissolved solute.

Factors affecting the solvation process:

1 – Heat　　2 - Pressure (for gases)　　3 - Polarity

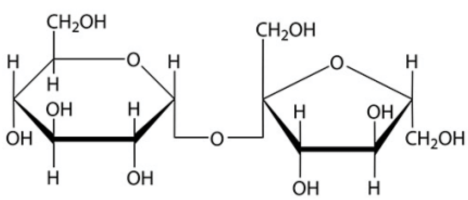
The general rule of solubility: likes dissolves likes

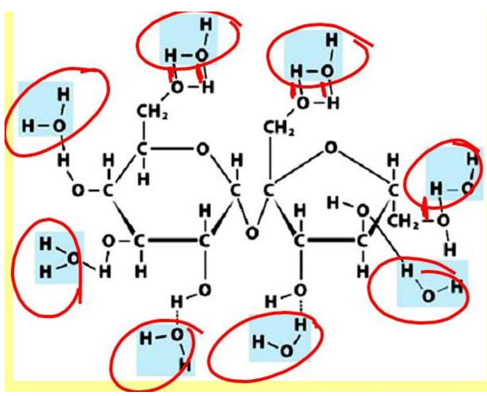
Comparison of soluble ionic and covalent compounds

solutions of **molecular compounds**	solutions of **ionic compounds**
	

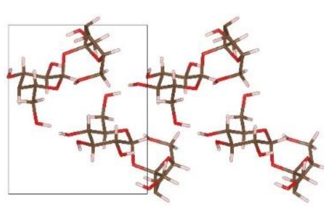
note: 1 - water molecules are (polar / in constant motion (described by kinetic molecular theory)

Explain: table sugar (sucrose) dissolves in water.
Sucrose contains 8 polar O-H groups, which make hydrogen bond with water.



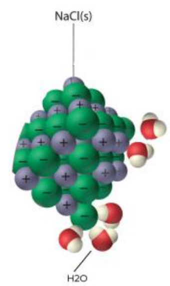


Attraction forces between polar water molecule and polar sucrose molecules > attraction force among sucrose molecules.

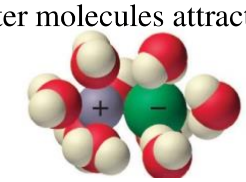


Sucrose molecule leave the crystal and become solvated by water molecule.

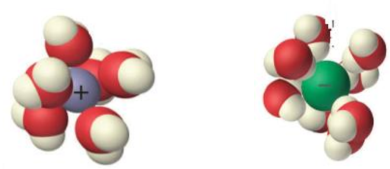
Explain: When a crystal of ionic compound such as NaCl is placed in water, the water molecule collide with the surface of the crystal**.**



The negative charged ends of the water molecules attract the positive sodium ions **and** positive charged ends of the water molecules attract negative chloride ions.

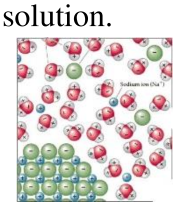


The attraction between the dioples and the ions > the attraction among the ions in the crystal.
So: the solvated ions leave the surface.



The water molecules surround the ions, and the solvated ions move into the solution.

Then: the process continues to the next crystal surface, until the crystal dissolves



explain : oil does not form solution with water

Oil is a substance made of C , H(non-polar) , and the water molecule is polar , and “like dissolves like” As attraction force between oil molecules (London dispersion force) **>** arrtaction force between water and oil.

Explain: **benzene can dissolve oil?**

As oil and benzene are non-polar molecules , attracted to each other by London dispersion force “like dissolves like”

Explain: gypsum $CaSO_4.2H_2O$ is insoluble in water.

Because the attraction forces between the ions in the gypsum **>** The attraction between the dioples and the ions.

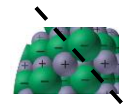
Note: the discoveries of specific solutions and mixtures, such as **plaster** made out of gypsum have contributed to the development of many products and processes.

Heat of solution: the overall energy change that occurs during the solution formation.

Heat

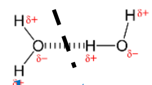
Released	**Absorbed**
Reaction release energy	Reaction absorb energy
Exothermic reaction	Endothermic reaction

Heat of solution explanation:



Energy is needed to overcome the forces of attraction between molecules of

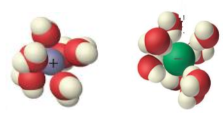
- solute- solute



- Solvent - solvent

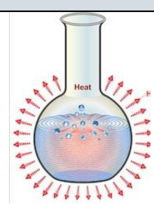
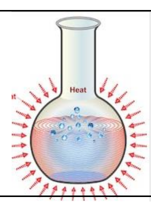
(absorbed energy)
(Crystalline grid energy)

Energy released when the solute is bonded to the solvent

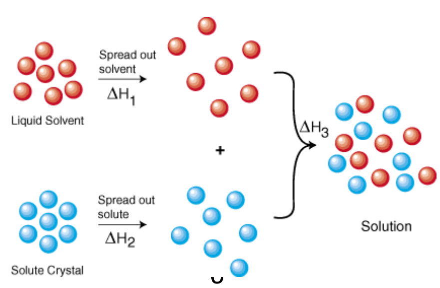


(released energy)
(Hydration energy)

Reaction energy = crystalline grid energy + hydration energy

example	observation		Solvation thermodynamically	explanation
Solvation of calcium chloride $CaCl_2$ in water		beaker temperature increases	Exothermic	**Hydration Energy > Crystalline Grid Energy**
Solvation of ammonium nitrate NH_4NO_3 in water		beaker temperature decreases	Endothermic	**Crystalline Grid Energy > Hydration Energy**

Discuss the corresponding figure



:

Factors that affect solvation:

Solvation occurs only when: solute and solvent particles come in contact with other.

How to increase the rate of solvation? By increasing the **number of collisions** between solute and solvent, by using the following methods:

A – Agitation **B – Surface area** **C – Temperature**

As follow:

A – Agitation = stirring or shaking:

Agitation make dissolved solute particles moves away from the contact surface more quickly, then new **collisions between solute and solvent occur**.

B – Surface area = breaking the solute into small pieces will increase its surface area **then** more collisions.

↑ Surface area → ↑ more collisions

Explain: granulated sugar dissolved in water more quickly than an equal amount of sugar in cube form?

Answer: Due to increasing the number of surfaces in the granulated sugar, which lead to increasing number of collisions with water molecules, then increasing solvation.

C – Temperature

Effect of Temperature when	
Gas dissolves in liquid (↑temperature of the liquid→↓solvation of gas)	**Solid dissolves in liquid** (↑temperature of the liquid→↑solvation of solid)
Explain: a carbonated soft drink lose its fizz (CO_2) faster at room temperature than when cold. Increasing temperature → ↑kinetic energy of gas particles → ↑ gas escaping from solution → ↓ less solvation.	**Explain:** sugar can be dissolved in hot tea rather than in cold tea ? Increase the temperature → ↑kinetic energy of solvent particles → ↑Collisions between solvent and solute → ↑ solvation.

Solubility: **the maximum amount of solute dissolved in a limited amount of solvent at specific temperature**. (….. g solute / 100g H_2O)

The solubility of a solute depends on: nature of solute and solvent

How solubility occur?

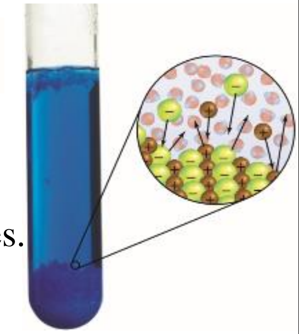


Figure 14 In a saturated solution, the rate of solvation equals the rate of crystallization. The amount of dissolved solute does not change.

When a solute is added to a solvent

1 - Solvent particles collide with the solute's surface particles

2 – Solute particles begin to mix randomly among the solvent particles.

3 – Solute particles are carried away from the crystal.

4 – As the number of solvated particles increase, collisions between solvated particles and the remaining crystal increase.

5 – **Some colliding solute particles rejoin the crystal (crystalize)**

6 – as solvation continue, the crystallization rate increases while the solvation rate remains constant.

7 – depending on the amount of solute: dynamic equilibrium might be occur between solvation and crystallization.

Note: at constant temperature and depending on amount of solute:

Low quantity of solute: rate of solvation > rate of crystallization

High quantity of solute: there is a case of dynamic equilibrium between solvation and crystallization, i.e.: rate of solvation = rate of crystallization. (At STP)

1 – Unsaturated solution: solution that contains less dissolved solute for a given temperature and pressure than a saturated solution.

2 –saturated solution: solution that contains maximum amount of dissolved solute for a given amount of solvent at a specific temperature and pressure.

3 –saturated solution: solution that contains more dissolved solute than a saturated solution at the same temperature and pressure.

Temperature and supersaturated solution:

↑Solvent temperature → ↑ kinetic Energy of particle → ↑more frequent collisions between solvent and solute → ↑ Solubility

i.e.: Solubility at high temp. > Solubility at low temp.

Discuss the table:

solute	temperature	Solubility ….g / 100 g H_2O
CaCl2	10°C	64g
	27°C	100g

Important note: The solubility of some materials decreases **as rising** temperature, but remains constant after reaching a certain temperature.

Example: Cerium Sulphate $Ce_2(SO_4)_3$

Solubility discussion at different temperatures

Very Important Notes:

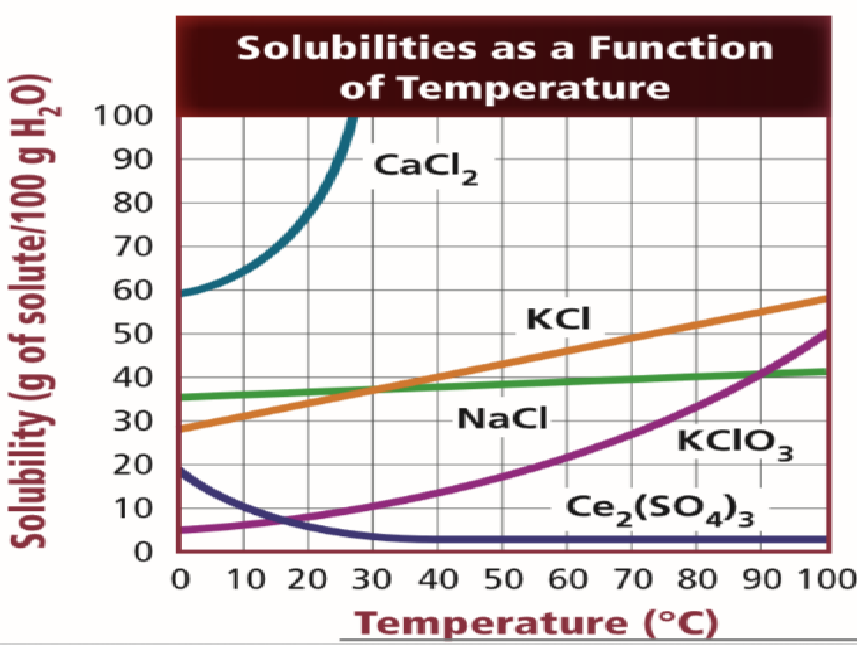
1 - Solubility changes when temperature changes.

2 - Some substances become more soluble when temperature increases.

3 - Most materials increase their solubility when the temperature rises.

4 - Some materials decrease their solubility when the temperature rises.

Figure 15 The solubilities of several substances as a function of temperature are shown in this graph.



Discuss the following:

Solubility in g/100 mL H_2O		
Solid	**0°C**	**100°C**
$Ca(CH_3COO)_2$	37.4	29.7
KNO_3	13.3	24.7

Because the solubility of calcium acetate decreases as the temperature increases, it begins to crystallize out of the solution at higher temperatures. The solubility of potassium nitrate increases dramatically at higher temperatures.

Analysis

1. Do the observations agree with your predictions? Most students will predict that both substances will dissolve when heated.
2. Is the slope of potassium nitrate's solubility curve positive or negative? positive
3. Is the slope of the calcium acetate's solubility curve positive or negative? negative

Table 4 Solubilities of Solutes in Water at Various Temperatures

Substance	Formula	Solubility (g/100 g H_2O)*			
		0°C	20°C	60°C	100°C
Aluminum sulfate	$Al_2(SO_4)_3$	31.2	36.4	59.2	89.0
Barium hydroxide	$Ba(OH)_2$	1.67	3.89	20.94	–
Calcium hydroxide	$Ca(OH)_2$	0.189	0.173	0.121	0.076
Lithium sulfate	Li_2SO_4	36.1	34.8	32.6	–
Potassium chloride	KCl	28.0	34.2	45.8	56.3
Sodium chloride	NaCl	35.7	35.9	37.1	39.2
Silver nitrate	$AgNO_3$	122	216	440	733
Sucrose	$C_{12}H_{22}O_{11}$	179.2	203.9	287.3	487.2
Ammonia*	NH_3	1130	680	200	–
Carbon dioxide*	CO_2	1.713	0.878	0.359	–
Oxygen*	O_2	0.048	0.031	0.019	–

* L/1 L H_2O of gas at standard pressure (101 kPa)

How to make a supersaturated solution?

1 – Make a saturated solution at high temperature and then cooled slowly.

2 – The slow cooling allows the excess solute to remain dissolved in solution at lower temperature.

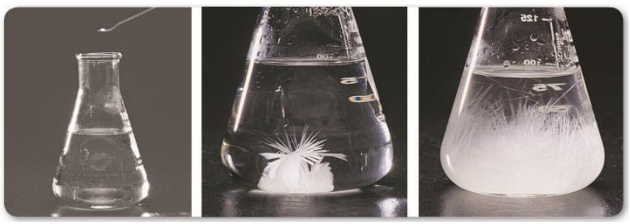
3 – add a tiny amount of solute (seed crystal); the excess solute precipitates quickly.

Note: to precipitate the extra solute, solution undergoes a physical shock, such as:

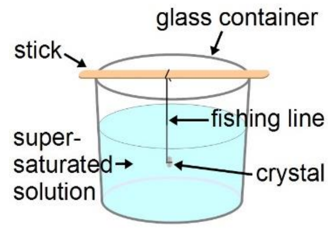
a . Scratch the inside of the container

b . Stirring or tapping the container

Figure 16 When a seed crystal is added to a supersaturated solution, the excess solute crystallizes out of the solution.



Another idea:



Applications: cloud seeding

Silver iodide (AgI) is used to seed air that is supersaturated with water vapor

Causes the water particles to come together and form droplets that might fall to earth as a rain.

Note: rock candy and mineral deposits at the edges of mineral springs, are both formed from supersaturated solutions.

Figure 17 Hot spring mineral deposits are an example of crystals that formed from supersaturated solutions.

Solubility of gases: ↑temperature → ↓gas solubility ex : O_2 , CO_2 **Why?**

As: ↑temperature → ↑ kinetic energy of gas → ↑ escaping from a solution

Pressure and Henry's law:

Discussion: Increased pressure over solution → Increased solubility of gaseous in a solvent or a solution.

Example: carbonated beveragas (It is an example of a compressed gas in a liquid and above its surface)

Carbonated beveragas contain carbon dioxide gas CO_2dissolved in aqueous solution at higher pressure than atmospheric pressure.

At opening Carbonated beveragas can:

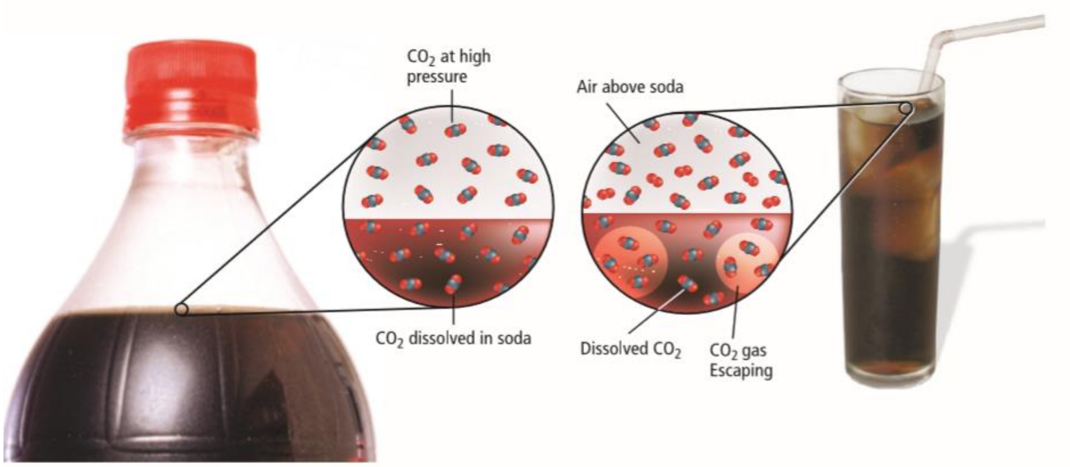
The CO_2 pressure inside the can > the pressure outside the case

So: CO_2 bubbles escape from the solution to the surface

The process continues until the solution loses all CO_2 gas, and the solution becomes tasteless

Figure 18 Carbon dioxide (CO_2) is dissolved in soda. Some CO_2 also is found in the gas above the liquid.

Explain ***Why does the carbon dioxide escape from the solution when the cap is removed?***



The pressure above the solution of a closed soda bottle keeps excess carbon dioxide from escaping the solution.

The pressure above the solution decreases when the cap is removed, which decreases the solubility of the carbon dioxide.

Henry's law: **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**.

Example: A closed soda water bottle where pressure over the solution keeps CO_2 dissolved in the solution at constant temperature.

$$S \propto P \rightarrow S = \text{constant} \times P \rightarrow \frac{S}{P} = \text{constant} \rightarrow \frac{S_1}{P_1} = \frac{S_2}{P_2}$$

EXAMPLE 5

HENRY'S LAW If 0.85 g of a gas at 4.0 atm of pressure dissolves in 1.0 L of water at 25°C, how much will dissolve in 1.0 L of water at 1.0 atm of pressure and the same temperature?

0.21 g/L

APPLICATIONS

36. If 0.55 g of a gas dissolves in 1.0 L of water at 20.0 kPa of pressure, how much will dissolve at 110.0 kPa of pressure?

37. A gas has a solubility of 0.66 g/L at 10.0 atm of pressure. What is the pressure on a 1.0-L sample that contains 1.5 g of gas?

38. **Challenge** The solubility of a gas at 7.0 atm of pressure is 0.52 g/L. How many grams of the gas would be dissolved per 1.0 L if the pressure increased 40.0 percent?

36. 3.0 g/L
37. 23 atm
38. 0.73 g/L

SECTION 3 REVIEW

Section Summary

- The process of solvation involves solute particles surrounded by solvent particles.
- Solutions can be unsaturated, saturated, or supersaturated.
- Henry's law 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.

39. MAINIDEA **Describe** factors that affect the formation of solutions.

40. **Define** *solubility*.

41. **Describe** how intermolecular forces affect solvation.

42. **Explain** on a particle basis why the vapor pressure of a solution is lower than that of the pure solvent.

43. **Summarize** If a seed crystal is added to a supersaturated solution, how would you characterize the resulting solution?

44. **Make and Use Graphs** Use the information in **Table 4** to graph the solubilities of aluminum sulfate, lithium sulfate, and potassium chloride at 0°C, 20°C, 60°C, and 100°C. Which substance's solubility is most affected by increasing temperature?

SECTION 3 REVIEW

39. Surface area, temperature, and pressure affect the formation of solutions.

40. Solubility refers to the maximum amount of solute that can dissolve in a given amount of solvent at a particular temperature and pressure.

41. The attractive forces between solute and solvent particles overcome the forces holding the solute particles together, thus pulling the solute particles apart.

42. When a solvent contains a solute, fewer solvent particles occupy the surface. Fewer particles escape into the gaseous state.

43. After the excess solute particles crystallize out of solution, the solution is saturated.

44. Refer to the Solution Manual for the graph. Aluminum sulfate shows the greatest change in solubility over the temperature range.

SECTION 3

Mastering Concepts

86. Describe the process of solvation.

87. What are three ways to increase the rate of solvation?

88. Explain the difference between saturated and unsaturated solutions.

Mastering Problems

89. At a pressure of 1.5 atm, the solubility of a gas is 0.54 g/L. Calculate the solubility when the pressure is doubled.

90. At 4.5 atm of pressure, the solubility of a gas is 9.5 g/L. How much gas, in grams, will dissolve in 1 L if the pressure is reduced by 3.5 atm?

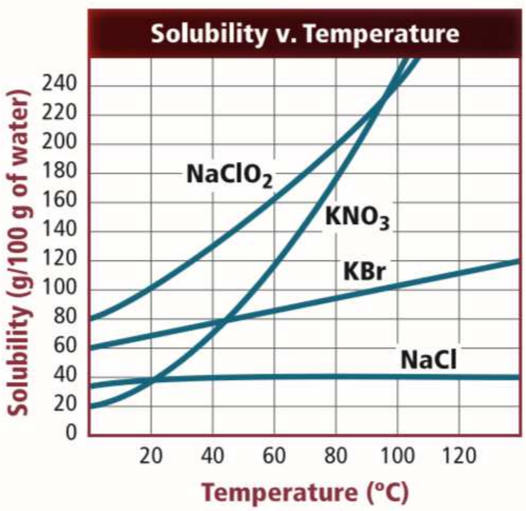


Figure 26

91. Using **Figure 26,** compare the solubility of potassium bromide (KBr) and potassium nitrate (KNO_3) at 80°C.

92. The solubility of a gas at 37.0 kPa is 1.80 g/L. At what pressure will the solubility reach 9.00 g/L?

93. Use Henry's law to complete **Table 8.**

Table 8 Solubility and Pressure

Solubility (g/L)	Pressure (kPa)
2.9	?
3.7	32
?	39

94. Soft Drinks The partial pressure of CO_2 inside a bottle of soft drink is 4.0 atm at 25°C. The solubility of CO_2 is 0.12 mol/L. When the bottle is opened, the partial pressure drops to 3.0×10^{-4} atm. What is the solubility of CO_2 in the open drink? Express your answer in grams per liter.

86. A solute introduced into a solvent is surrounded by solvent particles. Due to the attraction between solute and solvent particles, solute particles are pulled apart and surrounded by solvent particles. Once separated, solute particles disperse into solution.

87. increase the temperature of the solvent, increase the surface area of the solute, agitation

88. A saturated solution contains the maximum amount of solute under a given set of conditions. An unsaturated solution contains less than the maximum amount.

Mastering Problems

89. 1.1 g/L

90. 2.1 g

91. The solubility of KBr is 95 g/100 g H_2O. The solubility of KNO_3 is nearly twice as high at the same temperature, at nearly 170 g/100 g H_2O.

92. 185 kPa

93. 25 kPa; 4.5 g/L

94. 4.0×10^{-4} g/L