Skills to Develop

- Define these terms: solution, solute, and solvent.
- Distinguish solutions, mixtures, and colloids.
- Describe various types of solutions.
- Distinguish unsaturated, saturated, and supersaturated solutions.

**Solutions** are homogeneous mixtures. The major component is called **solvent**, and the minor components are called **solute**. If both components in a solution are 50%, the term solute can be assigned to either component. When gas or solid material dissolves in a liquid, the gas or solid material is called the solute. When two liquids dissolve in each other, the major component is called the **solvent** and the minor component is called the **solute**.

Many chemical reactions are carried out in solutions, and solutions are also closely related to our everyday lives. The air we breathe, the liquids we drink, and the fluids in our body are all solutions. Furthermore, we are surrounded by solutions such as the air and waters (in rivers, lakes and oceans).

On the topic of solutions, we include the following sections.

1. Types of Solutions: gaseous, liquid and solid solutions are based on the states of the solution.
2. Solution Stoichiometry: expressing concentration in various units (mass per unit volume, moles per unit volume, percentage and fractions), reaction stoichiometry calculations involving solutions.
3. Solutions of Electrolytes: solutions of acids, bases, and salts in which the solutes dissociate into positive and negative hydrated ions.
4. Metathesis or Exchange Reactions: reaction of electrolytes leading to neutral molecules, gases, and solids.

Solving problems of solution stoichiometry requires the concepts introduced in stoichiometry, which also provides the basis for the discussion on reactions.

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**Types of Solutions**

At the molecular level, molecules and ions of a solute are completely mixed with and interact with those of the solvent when a solute dissolves in a solvent. This type of mixing is **homogeneous** because no boundary is visible in the entire solution. In a mixture, differences may exist between regions or parts of the whole system.

Material exists in three states: solid, liquid, and gas. Solutions exist in all these states:

1. Gaseous mixtures are usually homogeneous and all gas mixtures are **gas-gas solutions**. For quantitative treatment of this type of solutions, we will devote a unit to gases. The atmosphere is a gaseous solution that consists of nitrogen, oxygen, argon, carbon dioxide, water, methane, and some other minor components, but its water and carbon dioxide contents may vary depending on the temperature and place.
2. When molecules of gas, solid or liquid are dispersed and mixed with those of liquid, the homogeneous (uniform) states are called **liquid solutions**. Solid, liquid and gas dissolve in liquid to form liquid solutions. In general, the terms solution and liquid solution are synonymous. Gases and liquid solutions have attracted the attention of most chemists, while material scientists and engineers are more interested in the manufacture and properties of solid solutions.
Solubility

The maximum amount of a substance dissolved in a given volume of solvent is called **solubility**. Often, the solubility in water is expressed in gram/100 mL. For example, the solubilities of some common substances are given in the Table of Solubility.

A solution that has reached the maximum solubility is called a **saturated solution**. Often, another phase such as gas, liquid, or solid of the solute is present and in contact within the solution. In general, there is no net change in the amount of solute dissolved, but the system is by no means static. In fact, the solute is constantly being dissolved and deposited at an equal rate. Such a phenomenon is called **equilibrium**.

In case another phase is not present, a solution may be **unsaturated or supersaturated**. Yes, due to what can be attributed to a kinetic factor, a solution may stay supersaturated for a long time. When promoted by a seed, a solution may start to precipitate quickly. Sodium acetate has a very high solubility at say 270 K. In fact, it can dissolve in the water of crystallization similar to melting. When cooled, such a solution stays in a **meta-stable state**. When a seeding crystal is present or started due to the surface of another medium, the entire solution will solidify. During the crystallization process, heat is evolved, and the solution becomes warm. Thus, such a solution, when properly packaged, has been used as hand warmer packs for skiers.

One useful classification of materials is polarity. Substances such as \(\text{H}_2\), \(\text{O}_2\), \(\text{N}_2\), \(\text{CH}_4\), \(\text{CCl}_4\) etc. are called **non-polar compounds**, whereas \(\text{H}_2\text{O}\), \(\text{NH}_3\), \(\text{CH}_3\text{OH}\), \(\text{NO}\), \(\text{CO}\), \(\text{HCl}\), \(\text{H}_2\text{S}\), \(\text{PH}_3\) etc. are called **polar compounds**.

Note: A Very Useful Rule

Like dissolves like.

Polar materials dissolve polar materials whereas non-polar materials will mix and become true solutions. An additional factor to consider is the hydrogen bonding. For example, ethanol and water are completely miscible at any proportion due to the extensive hydrogen bonding among their molecules.

Electrolytes or ionic substances are soluble in water due to hydration. Due to the strong polarity of the water molecule, the positive and negative ions are pushed apart. In general, reasonable size ions are believed to have six water molecules around them, but these water molecules readily exchange with those in the medium.

There are many applications of this rule. On the small scale, personal hygiene and household cleaning requires various types of cleaning agents. As a challenge is the research and development of cleaning agents in industry, where you can find jobs or hire experts to do the R&D.

Other factor such as temperature and pressure also affects the solubility of a solvent. Thus, in specifying solubility, one
Properties of Solutions

Properties of a solution are very different from those of pure forms of its components. For example, only pure water freezes or solidifies at 273 K, and boils at 373 K. The freezing point of ocean water is lower. Would you expect the boiling point of a salt solution to be lower? Actually, it's higher!

In Canada, we use a solution of equal volumes of ethylene glycol and water as engine coolant, because such a solution will not freeze until the temperature drops to really low. What is the proper mixture to use? Are you using your antifreeze properly? Deicing of airplane wings in the winter is also an interesting application of solutions; so is the use of salt on icy road.

A quantitative study of the physical properties of solutions is usually given in a course in *thermodynamics*, and we only mention some of the applications here just to raise your awareness of the solution.

Key Words

- solution, solute, solvent
- solubility, unsaturated solution, saturated solution, supersaturated solution
- polar substance, non-polar substance
- gaseous solution, liquid solution, solid solution

Problems

1. **Is milk a solution or a mixture?**

   Hint: mixture

   Milk may appear to be a homogeneous mixture to the unaided eye, but the tiny oil and protein droplets in the system make milk appear as white. Actually, milk is a *colloid*, a term explained in the Glossary within the Handbook Menu.

   **Skill:**
   Distinguish a solution from a mixture.

2. **Red brass consists of 90% copper and 10% zinc, whereas bronze consists of 90% copper and 10% tin. What is or are the solvent(s) in these alloys?**

   Hint: copper

   **Skill:**
   Define and illustrate the terms solvent and solute.

3. **Which of the following are solid solutions?**
a. ice from salt water at 272 K
b. solid from copper and zinc melt
c. solid calcium carbonate from reaction of carbon dioxide and calcium oxide
d. ice crystals from cold and moist air
e. 18 K gold

Hint: b & e
The impurities in ice are ignored in the spirit of this problem.

Skill:
Describe solid, liquid, and gas solutions.

4. The solubility of salt is 35.7 g per 100 mL of water at 298 K. What is the percentage of salt in a saturated solution?

Hint: 26%

Skill:
Describe and illustrate saturated and unsaturated solutions.

5. Sea water contains many ions in addition to sodium and chloride ions. When gradually evaporated, the first salt to precipitate is $\text{CaCO}_3$ (present to the extent of 0.12 g/L), followed by $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ (1.75 g/L), then $\text{NaCl}$ (29.7 g/L), $\text{MgSO}_4$ (2.48 g/L), $\text{MgCl}_2$ (3.32 g/L), $\text{NaBr}$ (0.55 g/L), and $\text{KCl}$ (0.53 g/L). According to the description, when solid sodium chloride starts to form, the solution is a saturated solution of what?

Hint: calcium carbonate, calcium sulfate, and $\text{NaCl}$.

Skill:
Apply chemical principle to describe natural phenomena.

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