Chapter 13

SOLUTIONS ARE EVERYWHERE!

Just as gases are important in our lives, so are solutions. We need to drink solutions and our bodies function by means of solutions. This chapter will introduce some of the unique terminology used in the study of solutions. Also, it will be shown how quantitative solution measurements can be made.

13.1 Background

Though oxygen is the most immediately vital to our survival, water is the next requirement in importance. But we rarely consume pure water, usually we prefer to consume solutions which contain such substances as sugar (as in soft drinks) or caffeine (in tea or coffee). Inside our bodies, ions and molecules are transported to their destination by means of the fluid that we call blood plasma (Figure 13.1).

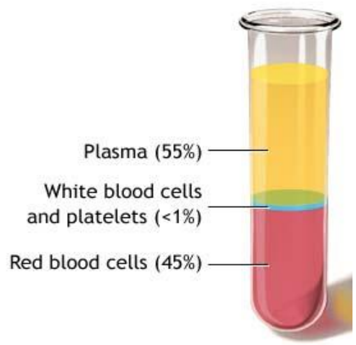

Figure 13.1 Our blood plasma conveys dissolved ions and molecules to where they are needed in the body.

We live on the blue planet – the only inner planet in our solar system to have substantial proportions of water. In fact, 70% of the surface of our planet is covered by water. Again, the water is not 100% H_2O, seawater contains significant concentrations of sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^+) cations, and chloride (Cl^-) and sulfate (SO_4^{2-}) anions (see Figure 13.2). There are also many other ions in seawater in smaller proportions. So-called 'fresh water' always contains some ions, most often calcium (Ca^{2+}) cations and hydrogen carbonate (HCO_3^-) anions, together with quantities of other ions.

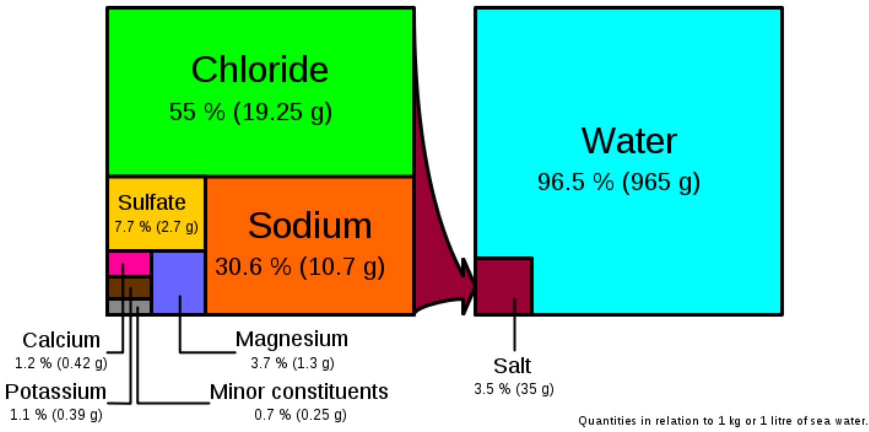

Figure 13.2 One kilogram of seawater contains about 35 g of dissolved ions.

13.2 Solution Terminology

There are specific terms associated with solution chemistry. In Chapter 2, Section 2.6 Classification of Matter, a ***solution*** (or homogenous mixture) is defined as two or more components with a uniform composition but a variable set of physical and chemical properties. These properties depend upon the proportion of the components in the mixture. Typically, there is a much higher proportion of one component. The major component is named the ***solvent***, while the lesser component is called the ***solute***.

There are some additional terms which differ depending upon whether the solute is a solid or a liquid:

If a solid dissolves in a solute, the solid is said to be ***soluble***; if it does not dissolve, it is said to be ***insoluble***.

If a liquid dissolves in a solute, the liquid is said to be ***miscible***; if it does not dissolve, it is said to be ***immiscible***.

The maximum quantity of a substance that will dissolve in a specific volume of solution is called the ***solubility*** of that substance. When that maximum quantity has been dissolved, the solution is said to be ***saturated***. For solids, we can define whether only a small quantity will dissolve, or a large quantity will dissolve. This terminology is shown in Table 13.1.

Table 13.1 Solubility terminology

Solubility per Litre	**>100 g**	**100 – 10 g**	**10 g – 1 g**	**<1 g**
Term	Very soluble	Soluble	Slightly soluble	Insoluble

13.3 Concentration of a Solution

In the previous section, the terminology of solution formation was described while this section will introduce the quantitative aspects of solutions. The proportion of solute in the solution is called the solution ***concentration***. If there is a high proportion of solute, then the solution is said to be ***concentrated***. If there is a low proportion of solute, then the solution is said to be ***dilute***.

MOLAR CONCENTRATION

For most solutions, the concentration is measured in terms of the number of moles of solute contained in a specific volume of solution – usually one litre. The relationship can be expressed in a ratio as:

$$\text{molar concentration, c} = \frac{\text{moles of solute, n (mol)}}{\text{volume of solution, v (L)}}$$

Three examples will illustrate the use of this formula:

EXAMPLE 13.1

0.320 mol of sodium chloride is dissolved in water to give 2.75 L of the solution. What is the concentration of the solution.

Answer

Strategy	Relationship
mol/vol of NaCl → conc NaCl	c = n/v

$$\text{Concentration NaCl} = \frac{0.320\ \text{mol}}{2.75\ \text{L}} = 0.116\ \text{mol} \cdot \text{L}^{-1}$$

Of course, in the laboratory, mass is measured, not moles. So in calculations, there is usually the first step to convert mass to moles. The next two calculations include the mass→mol step.

EXAMPLE 13.2

13.9 g of magnesium sulfate are dissolved in water to give 125 mL of solution. What is the concentration of the solution.

Answer

Strategy	Relationship
Mass of $MgSO_4$ → mole of $MgSO_4$	1 mol ≡ 120.4 g
mol/vol of $MgSO_4$ → conc $MgSO_4$	c = n/v

$$\text{Mol of MgSO}_4 = 13.9\text{ g MgSO}_4 \times \left(\frac{1\text{ mol}}{120.4\text{ g}}\right) = 0.115\text{ mol MgSO}_4$$

$$\text{Concentration MgSO}_4 = \frac{0.115\text{ mol}}{0.125\text{ L}} = 0.924\text{ mol}\cdot\text{L}^{-1}$$

Example 13.3

What volume of a 2.00 mol·L^{-1} solution of calcium chloride contain 50.0 g of the solute?

Answer

Strategy	Relationship
Mass of $CaCl_2$ → mole of $CaCl_2$	1 mol ≡ 111.0 g
mol/conc of $CaCl_2$ → vol $CaCl_2$	v = n/c

$$\text{Mol of CaCl}_2 = 50.0\text{ g CaCl}_2 \times \left(\frac{1\text{ mol}}{111.0\text{ g}}\right) = 0.450\text{ mol CaCl}_2$$

$$\text{Volume CaCl}_2 = \frac{0.450\text{ mol}}{2.00\text{ mol}\cdot\text{L}^{-1}} = 0.225\text{ L}$$

Ion Concentration

In Chapter 9, Section 9.8, Net Ionic Equations, it was shown how in any solution, the constituent ions are moving independently, Thus a solution of sodium chloride is actually a solution of sodium ions and chloride ions. For many solutions, it is necessary to give the concentrations of individual ions. As an example, intravenous solutions (IVs) used in hospitals have specific formulations in terms of ion concentration. One IV solution is Lactated Ringer's Solution, used to restore fluid levels after blood loss resulting from trauma, surgery, or a burn injury. The composition of this solution is given in Table 13.2. Hartmann's Solution is sometimes used for the same purpose and it has the same mixture of ions, but with slightly different ion concentrations.

Table 13.2 The ion composition of Lactated Ringer's Solution used as an intravenous fluid.

Ion	**Concentration**
Sodium, Na^+	0.1300 mol·L^{-1}
Chloride, Cl^-	0.1090 mol·L^{-1}
Lactate, $C_3H_5O_3^-$	0.0280 mol·L^{-1}
Potassium, K^+	0.0040 mol·L^{-1}

Calcium, Ca^{2+}	0.0015 mol·L^{-1}

As ion concentrations are particularly important, Example 13.4 shows how they may be calculated.

Example 13.4

Calculate the concentration of sodium ion when 7.06 g of sodium phosphate is dissolved in water to give 125 mL of solution.

Answer

Strategy	Relationship
Mass of Na_3PO_4 → mole of Na_3PO_4	1 mol ≡ 164.0 g
Mole of Na_3PO_4 → mole of Na^+	1 mol Na_3PO_4 = 3 mol Na^+
mol/vol of Na^+ → conc Na^+	c = n/v

$$\text{Mol of Na}_3\text{PO}_4 = 7.06\ \text{g Na}_3\text{PO}_4 \times \left(\frac{1\ \text{mol}}{164.0\ \text{g}}\right) = 4.30 \times 10^{-2}\ \text{mol Na}_3\text{PO}_4$$

$$\text{mol Na}^+ = 4.30 \times 10^{-2}\ \text{mol Na}_3\text{PO}_4 \times \left(\frac{3\ \text{mol Na}^+}{1\ \text{mol Na}_3\text{PO}_4}\right) = 0.129\ \text{mol Na}^+$$

$$\text{Concentration Na}^+\ \text{ion} = \frac{0.129\ \text{mol}}{0.125\ \text{L}} = 1.03\ \text{mol} \cdot \text{L}^{-1}$$

13.4 Standard Solutions

In the laboratory, ***standard solutions*** are often used. Standard solutions are solutions of precise (and accurate) concentration. Such solutions are used to determine the concentration of other solutions. This will be discussed in Chapter 14, Section 14.4 Volumetric Analysis. To prepare a standard solution, an analytical balance is necessary for the mass measurements. Also, it is important to ensure that the molar mass calculated must have at least as many significant figures as that recorded for the mass measurement.

Volumetric Flasks

Standard solutions are usually prepared in a ***volumetric flask*** (Figure 13.3). These flasks come in sizes from 1 mL to 2 L. Part-way up the neck of a volumetric flask there is a line that has been etched in the glass. When the flask is filled so that the bottom of the ***meniscus*** (the curved water surface) is just touching that line, then the flask is filled precisely to that volume. For example, filling a 10 mL volumetric flask to that line means that the flask contains precisely 10.00 mL of solution.

Figure 13.3 (left) Three different sizes of volumetric flasks. The etched line can be seen about one-third of the way up the neck of each flask and (right) a close-up of the etched line and the solution meniscus.

PREPARING A STANDARD SOLUTION

To prepare a standard solution, a series of steps must be followed.

1. The correct size of volumetric flask must be chosen and the flask rinsed with deionized water.
2. The theoretical mass of solute is calculated (a sample calculation is given below as Example 13.5).
3. The required mass is placed in a weighing boat, weighed, and then poured carefully into the volumetric flask. The weighing boat is then re-weighed to obtain the precise mass of solute that has been added to the flask. This is weighing by difference (see Chapter 3, Section 3.7 Significant Figures in Calculations).
4. Deionized water is added to the flask until the flask is about one-third filled. The flask is then gently swirled until all the solute has dissolved.
5. More deionized water is added carefully until the bottom of the meniscus is just level with the etched mark on the stem of the flask.
6. The flask is then tightly capped and inverted several times to ensure thorough mixing. The standard solution is now ready to use.

Here is a sample calculation:

EXAMPLE 13.5
What mass of sodium carbonate is required to make 250.0 mL of a standard 0.2000 mol·L^{-1} solution.
Answer

Strategy	Relationship
Vol/conc of Na_2CO_3 → mole of Na_2CO_3	n = c × v
Mole of Na_2CO_3 → mole of Na_2CO_3	1 mol ≡ 106.0 g

$$\text{Mol of } Na_2CO_3 = 0.2000 \text{ mol} \cdot L^{-1} \times 0.2500 \text{ L} = 5.000 \times 10^{-2} \text{ mol}$$

$$\text{Mass of } Na_2CO_3 = 5.000 \times 10^{-2} \text{ mol } Na_2CO_3 \times \left(\frac{106.0 \text{ g}}{1 \text{ mol}}\right) = 5.300 \text{ g } Na_2CO_3$$

13.5 Dilution of a Solution

In the soft drink and other industries, it is less expensive to ship the concentrate containing flavourings, colourings, sugar, and so on, dissolved in the smallest volume of water possible. Then, at regional or local factories, the concentrate is mixed with water (and carbon dioxide added if the drink is carbonated) and bottled for sale. Similarly, for chemicals in the laboratory, a concentrated solution might have to be diluted for a particular purpose. In this Section, the procedure will be described. For high precision dilutions, a pipet is usually used and so this will be discussed first.

VOLUMETRIC PIPETS

A ***volumetric pipet*** (English spelling, pipette) is designed for the specific purpose of transferring a precise volume of solution from one container to another. It consists of a central glass cylinder with a narrow glass tube at each end (Figure 13.4). One glass tube narrows to a tip. This tip is the end placed in a solution.

Figure 13.4 In volumetric analysis, a precise volume of a solution is transferred to another container using a volumetric pipet.

To “suck’ a solution up into the pipet, the mouth of a squeezed rubber bulb is placed over the upper end. As the pressure on the rubber bulb is released, liquid will flow up into the cylinder and then into the upper glass tube. Like the neck of a volumetric flask, the upper glass tube of a pipet has an etched glass line. However, with a pipet, the meniscus of the solution is first sucked up about 2 cm beyond the line. The bulb is quickly removed and the index finger placed over the pipet end instead. The solution level should still be above the etched mark on the pipet. By gently moving the finger and letting small quantities of air enter the tube, the meniscus can be adjusted downwards until the bottom of the meniscus is level with the etched mark.

Figure 13.4 Using a rubber bulb to collect a solution in a volumetric pipet.

Usually, the solution is transferred from a beaker to a volumetric flask (Figure 13.5). The tip of the pipet is placed in the volumetric flask and the finger removed. The solution will empty from the pipet under the effect of gravity. There will be some solution still in the tip and often a drop hanging from the tip. The tip of the pipet is touched to the solution surface to remove the drop. A small quantity remains in the tip. That quantity is left in the pipet. The precise volume of solution delivered by the pipet corresponds to the volume when filled to the etched mark, minus the small volume in the tip.

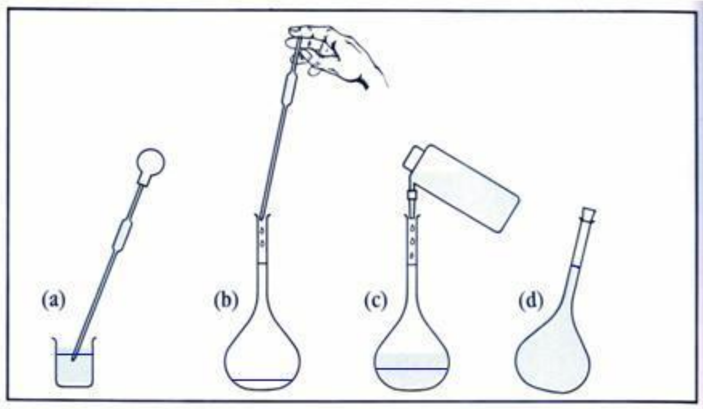

Figure 13.5 Transferring a volume of solution using a volumetric pipet. (a) sucking up the solution into the pipet using a rubber bulb; (b) after replacing the bulb with a finger and adjusting the volume, the solution is released into the volumetric flask; (c) water is added, the flask swirled, and water added up to the meniscus; (d) the flask is capped and shaken.

Pipets are manufactured in a wide range of sizes, the most commonly used having a capacity of 10 mL and 25 mL. Though this is the volume stated on the pipet, the volume is actually much more precise. For any volume measurements made with a pipet, in terms of precision, these values should be quoted as 10.00 mL and 25.00 mL.

DILUTION CALCULATIONS

Suppose a volume, v_{conc}, of a solution of concentration, c_{conc}, is measured out. It will contain a certain number of moles, n_{conc}. The number of moles can be found from:

$$n_{conc} = c_{conc} \times v_{conc}$$

The measured quantity of solution is placed in a container and water is added until the volume is v_{dil} and the concentration, c_{dil}. The number of moles of solute, n_{dil}, will be:

$$n_{dil} = c_{dil} \times v_{dil}$$

In the dilution process, the number of moles of solute has remained the same, all that has happened is the addition of water. Expressing this mathematically:

$$n_{conc} = n_{dil}$$

In which case, the first two relationships can be equated:

$$c_{conc} \times v_{conc} = c_{dil} \times v_{dil}$$

Thus for dilution problems, and dilution problems only, this simple formula can be used to find one of the terms if the other three are known. Example 13.6 illustrates this type of calculation.

Example 13.6

A volume of 10.00 mL of 5.000 mol·L^{-1} hydrochloric acid is placed in a 1.000 L volumetric flask and the flask is filled to the mark with water. What is the concentration of the solution in the volumetric flask?

Answer

As this is a dilution problem, the dilution relation can be used:

$$c_{conc} \times v_{conc} = c_{dil} \times c_{dil}$$

$$c_{dil} = \frac{c_{conc} \times v_{conc}}{v_{dil}} = \frac{(5.000\ \text{mol} \cdot \text{L}^{-1}) \times (1.000 \times 10^{-2}\ \text{L})}{1.000\ \text{L}}$$
$$= 5.000 \times 10^{-2}\ \text{mol} \cdot \text{L}^{-1}$$

13.6 Where Next?

In Chapter 12, it was shown how pressure, volume, and temperature of a gas can be used to calculate the number of moles of the gas. In Chapter 13, it has been shown how volume and concentration of a solution can be used to calculate moles of a solute. In Chapter 14, these two calculation types will be combined with the stoichiometry calculations introduced in Chapter 11. In this way, you will see how the different types of calculations are used to quantitatively analyze unknown samples.