Expressing the Concentration of Substances in Solution

A solution consists of one or more substances (Solutes) that are dissolved in a liquid (Solvent). If the liquid is water, it is called an aqueous solution (aqua = water).
The concentration of a solution specifies the amount of a solute dissolved in a specific volume of liquid. We can express the amount of solute added in 2 basic ways:

(1) by weight,
(2) by number of particles

Expressing the Amount of Solute by Weight:

I. Ratios

Ratios indicate the proportion of solute (in grams) per volume of liquid (in milliliters). The following are some examples:

(1) A vial labeled 1:1,000 Adrenalin would contain 1.0 gram of epinephrine per 1,000 ml (1 liter) of solution.
(2) A hypodermic cartridge labeled 1:50 Xylocaine would contain 1.0 gram of lidocaine per 50 ml of solution.

Try the following for practice:

1) How would you prepare a 1:100 NaCl solution?
2) How would you prepare a 1:20 Glucose solution?
3) If a reagent bottle contains 10 grams of NaCl dissolved in 1,000 ml of solution, what would its concentration be (expressed as a simple ratio)?
4) How would you prepare 1.0 liter of a 1:20 Glucose solution?
5) How would you prepare 10 ml of a 1:100 Adrenaline solution?

II. Percent (%)

Percents indicate the amount of solute (in grams) per 100 ml (deciliter, dL) of solution. The following are some examples:

(1) A reagent bottle labeled 3% saline would contain 3.0 grams of NaCl per 100 ml of solution.
(2) Betadine, an antiseptic used for preparing the operative site, contains 1.0 % active Iodine, that is, 1.0 gram of Iodine per 100 ml of solution.
(3) The hospital infusion bottles labeled D_5W (Dextrose, 5%, in water) contains 5.0 grams of Dextrose (D-Glucose) per 100 ml of solution.
(4) An ampule that is labeled 7.5 % sodium bicarbonate would contain 7.5 grams of $NaHCO_3$ per 100 ml of solution.
(5) A vial labeled 0.1 % Adrenaline would contain 0.1 gm of epinephrine per 100 ml of solution.
(6) The normal total protein concentration in blood plasma is 7 %. That means that there is 7 gm of protein per 100 ml of blood plasma.

The concentrations of particular solutes in body fluids are often so small that they are expressed in mg%. The following are some examples:

(1) The normal concentration of glucose in blood plasma is 80 mg%. This means that there is 80 mg of glucose per 100 ml (or dL) of blood plasma.
(2) The normal concentration of cholesterol in blood plasma is 200 mg%. This means that there is 200 mg of cholesterol per 100 ml of blood plasma.

When the solute is a gas, the concentration is often expressed in ml % (ml of gas per 100 ml of solution). Example: The normal total O_2 concentration in arterial blood is 20 ml %. This means that there is 20 ml of O_2 per 100 ml of blood.

Try the following for practice:

1) How would you prepare a 2% Xylocaine solution?
2) How would you prepare a 0.9% saline solution?
3) If a reagent bottle contains 50 grams of Glucose dissolved in 1.0 L of solution, what would its concentration be (expressed as a %)?
4) If a vial contains 0.01 gm of Adrenaline dissolved in 10 ml of solution, what would its concentration be (expressed as in %)?
5) How would you prepare 100 ml of 5% D_5W (Dextrose, 5%, in water)?
6) How would you prepare 1.0 L of a 10% Calcium Chloride ($CaCl_2$) solution?

Expressing the Amount of Solute by Number of Particles

Moles and Molar Concentration (A ‘mole’ = 6×10^{23})

The amount of a substance is often expressed in moles. Expressing the amount of something in moles is much like expressing it in dozens. Just like a dozen is equal to 12 items, a mole is equal to 6×10^{23} items (Avogadro’s number). Just as we can talk about a dozen cookies, or a dozen eggs, or a dozen pencils, we can also talk about a mole of helium (He) atoms, or a mole of hydrogen ions (H^+), or a mole of NaCl molecules, or even a mole of cookies!

When we express the amount of something in dozens, or in moles, we are describing the total number of items. Two dozen would be equal to 24 items, while 2 moles would be equal to $2 \times (6 \times 10^{23})$ or 12×10^{23} items. Likewise, 1/3 of a dozen would be equal to 4 items, and correspondingly 1/3 of a mole would be equal to $1/3 \times (6 \times 10^{23})$ or 2×10^{23} items.

By expressing the amount of something by the total number of items, it is easy to predict how many sets of items you could have. For example, by taking 1 dozen pens and 1 dozen pencils, you could prepare 1 dozen ‘pen-and-pencil’ sets. Similarly, by taking 1 mole of sodium ions (Na^+) and 1 mole of chloride ions (Cl^-), you could have 1 mole of NaCl molecules. Alternatively, by taking 1 mole of calcium ions (Ca^{++}) and 2 moles of chloride ions (Cl^-), you could have 1 mole of $CaCl_2$ molecules.

The weight of a mole, for any chemical, is equal to the chemical's weight in grams. For example, 1 mole of sodium ions (Na^+) would weigh 23 grams (from the Periodic Table). One mole of chloride ions (Cl^-) would weigh 35.5 grams (again, from the Periodic Table). Therefore, 1 mole of NaCl molecules would weigh (23 + 35.5) = 58.5 grams. Thus:

3 moles of NaCl molecules would weigh (3 x 58.5) or 175.5 grams

½ mole (0.5 mole) of NaCl molecules would weigh (1/2 x 58.5) or 29.25 grams

1/10 mole (0.1 mole) of NaCl molecules would weigh (0.1 x 58.5) or 5.85 grams

1/100 mole (0.01 mole) of NaCl molecules would weigh (0.01 x 58.5) or 0.585 grams

A similar comparison would be the fact that if 1 dozen cookies weighs 6 oz, then ½ dozen cookies would weigh (1/2 x 6 oz) or 3 oz.

1 mole of $CaCl_2$ would weigh (40 + 2(35.5)) or 111 grams.

Often the number of items is expressed in millimoles, which is just 1/1000 of a mole.
One millimole would be equal to 1/1000 x (6×10^{23}) = 6×10^{20} items.

Note that:
1 millimole = 1/1000 of a mole, so 1 millimole of NaCl would weigh 1/1000 the weight of 1 mole of NaCl or (1/1000 x 58.5) grams or 58.5 mg.

Thus:
5 millimoles of NaCl molecules would weigh (5 x 58.5 mg) = 292.5 mg.

150 millimoles of NaCl molecules would weigh (150 x 58.5 mg) = 8,775 mg = 8.775 gm

½ millimole (0.5 millimole) of NaCl molecules would weigh (0.5 x 58.5 mg) = 29.25 mg

Try the following for practice:

1a) What is the chemical weight of lithium chloride (LiCl)?

1b) How much would 0.5 moles of LiCl weigh?

1c) How much would 2 moles of LiCl weigh?

2a) Calculate the chemical weight of ammonium chloride (NH_4Cl).

2b) How much would 0.15 mole of NH_4Cl weigh?

2c) How much would 100 millimoles of NH_4Cl weigh?

3a) Calculate the chemical weight of glucose ($C_6H_{12}O_6$).

3b) How much would 0.3 mole of glucose weigh?

3c) How much would 5 millimoles of glucose weigh?

Molar Concentration

Molar (M) concentrations, like % concentration, is another way to express the amount of a solute in a given volume of liquid. Molar concentration (molarity) is the number of moles of a solute dissolved per 1,000 ml (1.0 L) of solution. If a reagent bottle is labeled 2 M NaCl, it would contain 2 moles of NaCl per 1,000 ml of solution.

You could prepare a 2 M NaCl solution by weighing out (2 x chemical weight of NaCl in grams = 2 x 58.6 gm) = 117 grams of NaCl and adding enough liquid to give a solution volume of 1,000 ml.

Often the concentration may be expressed as milliMolar (mM), which is simply the number of millimoles of a solute dissolved in every 1,000 ml of solution. The following are some additional examples:

(1) A reagent bottle labeled 1/6 M NH_4Cl would contain 1/6 mole of NH_4Cl per 1,000 ml of solution. You could prepare a 1/6 M NH_4Cl solution by weighing out (1/6 x chemical weight of NH_4Cl in grams = 1/6 x 53.5) = about 8.9 grams of NH_4Cl and adding enough liquid to give a solution volume of 1,000 ml.

(2) A reagent bottle labeled 0.15 M NaCl would contain 0.15 mole of NaCl per 1,000 ml of solution. You could prepare a 0.15 M NaCl solution by weighing out (0.15 x chemical weight of NaCl in grams = 0.15 x 58.5 g) = about 8.8 grams of NaCl and adding enough liquid to give a solution volume of 1,000 ml.

(3) A reagent bottle labeled 0.3 M glucose would contain 0.3 mole of glucose per 1,000 ml of solution. You could prepare a 0.3 M glucose solution by weighing out (0.3 x chemical weight of glucose in grams = 0.3 x 180 gm) = 54 grams of glucose and adding enough liquid to give a solution volume of 1,000 ml.

(4) The normal concentration of phosphorus (P) in blood plasma is 1 mM. This means that there is 1 millimole of phosphorus per 1,000 ml of blood plasma. You could prepare a 1 mM phosphorus solution by weighing out (1 x chemical weight of P in milligrams = 1 x 31 mg) = 31 mg of phosphorus and adding enough liquid to give a solution volume of 1,000 ml.

Try the following for practice:

1) How would you prepare a 1.5 M NaCl solution?
2) A 1.5 M NaCl solution would be equivalent to what % concentration? (This is easy, so stay calm! Hint: look at your answer to number 1 right above. Since it is expressed in grams/1,000 ml, how would this concentration be expressed in grams/ 100 ml?)
3) How would you prepare a 150 mM NaCl solution?
4) How would you prepare a 0.5 M sucrose ($C_{12}H_{22}O_{11}$) solution?
5) How would you prepare a 0.2 M LiCl (lithium chloride) solution?
6) A 0.2 M LiCl solution would be equivalent to what % concentration?
7) How would you prepare a 0.3 M glucose solution?
8) A 0.3 M glucose solution would be equivalent to what % concentration?

The relationship between millimoles/L and milliequivalent/L

While a 1 mM solution of Na^+ and a 1 mM solution of Ca^{++} both have the same number of items (6×10^{23}), the 1 mM Ca^{++} actually has twice as many electrical charges in solution. Therefore, the concentration of inorganic ions in body fluids (also referred to as minerals or electrolytes) is usually expressed in milliequivalents/1,000 ml (mEq/L). This unit takes into account the electrical charge (valence) on the ion:

# of milliequivalents = # millimoles x valence

Thus, 1 millimole of Na^+ would be equal to (1 millimole x 1) = 1 milliequivalent.
1 millimole of Ca^{++}, however, would be equal to (1 millimole x 2) = 2 milliequivalents.

Conversely, to convert from milliequivalents to millimoles:

# of millimoles = # of milliequivalents / valence

Try the following for practice:

(I) Express the following electrolyte concentrations in mEq/L:

1) 150 millimoles Na^+/L

2) 5 millimoles K^+/L

3) 2.5 millimoles Ca^{++}/L

4) 60 millimoles HCO_3^-/L

5) 1 millimole HPO_4^{--}/L

(II) Express the following electrolyte concentrations in millimoles/L:

1) 150 mEq Na^+/L

2) 5 mEq K^+/L

3) 105 mEq Cl^-/L

4) 1.5 mEq Mg^{++}/L

5) 28 mEq HCO_3^-/L

Problems:

1a) How would you prepare a 1:10 $NaHCO_3$ solution?
1b) How would you prepare 100 ml of a 1:10 $NaHCO_3$ solution?
1c) How would you prepare 1.0 L of a 1:10 $NaHCO_3$ solution?

2a) How would you prepare a 1:1,000 Adrenalin solution?
2b) How would you prepare 100 ml of a 1:1,000 Adrenalin solution?

3a) How would you prepare a 5.5 % $MgSO_4$ (Epsom salt) solution?
3b) How would you prepare 10 ml of a 5.5 % $MgSO_4$ solution?
3c) How would you prepare 1.0 L of a 5.5 % $MgSO_4$ solution?

4a) How would you prepare a 10 mg % Digoxin solution?
4b) How would you prepare 10 ml of a 10 mg% Digoxin solution?
4c) How would you prepare 1.0 ml of a 10 mg% Digoxin solution?

5) A hospital IV bottle contains 1,000 ml of 0.45 % NaCl and 2.5 % dextrose.
(a) How many grams of NaCl are in the bottle?
(b) How many grams of dextrose are in the bottle?

6a) How would you prepare a 1 mM $NaHCO_3$ solution?
6b) How would you prepare 100 ml of a 1 mM $NaHCO_3$ solution?
6c) What % concentration is a 1 mM $NaHCO_3$ solution?

7a) What % concentration is a 0.15 M $NaHCO_3$ solution?

You will need these atomic weights from the periodic table to do your calculations.
H = 1.0 Li = 7.0 C = 12.0 N = 14.0 O = 16.0 Na = 23.0 Mg = 24.3 Cl = 35.5
S=32.0