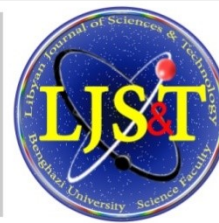




Faculty of Science - University of Benghazi

Libyan Journal of Science & Technology

(Formerly known as Journal of Science & Its Applications)

journal home page: www.sc.uob.edu.ly/pages/page/77

Designing simple equations to fully understand the conversions among common concentration units: An overview

Issa Korbag*, Salma Mohamed Saleh

Department of Chemistry, Faculty of Arts and Sciences, University of Benghazi, Al Kufrah, Libya

ARTICLE INFO

Article history:

Received 17 May 2017

Revised 20 July 2017

Accepted 01 August 2017

Available online 24 August 2017

Keywords:

Concentration units; conversions; ppt; ppm; ppb; pptr

* Corresponding author:

E-mail address: issa.omar@uob.edu.ly

I.M. Korbag

ABSTRACT

Chemists express solution concentrations in a number of ways and the beginning analytical chemist should be familiar with some of the common expressions and units of measure employed. Concentration units can be a source of confusion for students. This article presents a treatment on this topic that may help students understand the differences between these units. We have reviewed here the common concentration units that chemists use. Their use in quantitative volumetric calculations is treated in more details. We have also designed simple equations to fully understand the calculations for concentration units and conversion between them. This article provides a quick, handy solution and a practical training for chemists, technicians, scientists, students, teachers, or engineers to overcome the problem of time-consuming, difficult, and often inaccurate conversion calculations.

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1. Introduction

In the study of chemistry, it is quite common to encounter both extremely large quantities and extremely small ones. Chemists traditionally express concentrations of ions or compounds in molarity (moles per liter) or molality (moles per 1000 g of solvent). This is not always so with the biochemist/life-science discipline. Their concentration is often expressed as parts per million (ppm). Water and air pollution, for example, are often expressed as ppm. When chemists and life scientists come together in meetings and chemists express an effective concentration as 2.3×10^{-4} M, the expression often has little meaning to the life scientist who thinks in terms of ppm. Inevitably, when these groups interact, one of two questions is quickly voiced, "What is that in ppm?" or "What is that in moles per liter?" On-the-spot conversion calculations are time-consuming, difficult, and often inaccurate (Sunberg, 1986). We are looking to make chemistry simple, easy for student, teacher, chemist, analyst and scientist. We are trying our best starting from small principles in chemistry. We found some chemists are making some mistakes in calculation. This simple article is a practical training for chemist, technicians or scientist for solutions calculations. There are a number of different ways of expressing solute concentration that are commonly used. Some are more useful than others in quantitative calculations. The choice of units to use in a given situation depends on the chemical, where it is located (e.g., air, water and soil/sediments) and often on how the measurement will be used (Chemiasoft, 2011; Christian *et al.*, 2014). It is therefore necessary to become familiar with the units used and methods for converting among different sets of units. We will review here the common concentration units that chemists use. Their use in quantitative volumetric calculations is treated in more detail.

This article is written to be readable by anyone who has an idea in basic principles of general chemistry and readily understood by a general audience. It will help students, teachers, chemists, scientists and engineers ... *etc* who are working in chemistry field to fully understand the calculations for concentration units and conversion between them. Here is a

refresher of how concentrations by molarity (M), normality (N), percent (%), parts per thousand (ppt), parts per million (ppm), parts per billion (ppb) and parts per trillion (pptr) are calculated.

2. Definitions of common concentration units

2.1. Percent composition (%): It is also known as parts per hundred (pph) and defined as units of solute per 100 units of sample. Percent of a solution can be expressed in several ways. Three common methods are weight percent (% w/w), volume percent (% v/v) and weight-to-volume percent (% w/v).

2.1.1. Percentage by mass (%w/w): It is defined as the number of grams of solute present in 100grams of solution.

2.1.2. Percentage volume for volume (%v/v): It is defined as the number of milliliters of solute per 100 mL of solution. Normally used where the solute is a liquid.

2.1.3. Percentage weight for volume (%w/v): It is defined as the number of grams of solute per 100 mL of solution. Normally used where the solute is a solid.

2.2. Trace concentrations: Trace concentrations are usually given in smaller units, such as parts per thousand (ppt, ‰), parts per million (ppm), parts per billion (ppb), or parts per trillion (pptr). These are calculated in a manner similar to parts per hundred (Christian *et al.*, 2014).

2.2.1. Parts per thousand (ppt): It is also known as strength of a solution and defined as the amount of the solute in grams, present in one liter of the solution.

2.2.2. Parts per million (ppm): This means the mass ratios of grams of solute (grams of substance) to one million of total solution or mixture (sample). For very dilute solutions, parts per million (ppm) is a convenient way to express concentration.

2.2.3. Parts per billion (ppb): This means the mass ratios of grams of solute (grams of substance) to one billion grams of total solution or mixture (sample).

2.2.4. Parts per trillion (pptr): This means the mass ratios of grams of solute (grams of substance) to one trillion grams of total

solution or mixture (Christian *et al.*, 2014; Harvey, 2000; Sanagi *et al.*, 2007; Skoog *et al.*, 2014).

All of the above start by calculating the fractional composition and then multiplied by representative quantity as shown below.

$$\frac{\text{amount of solute}}{\text{amount of solution}} \times \text{representative quantity} \begin{cases} 10^2 \rightarrow \text{parts per hundred, pph (\%)} \\ 10^3 \rightarrow \text{parts per thousand, ppt (\%)} \\ 10^6 \rightarrow \text{parts per million, ppm} \\ 10^9 \rightarrow \text{parts per billion, ppb} \\ 10^{12} \rightarrow \text{parts per trillion, pptr} \end{cases}$$

2.3. Ity concentrations: It represents the concentration units ending with suffix "ity" such as molarity (M), normality (N), formality (F), and molality (m). We will only discuss molarity and normality in this tutorial article.

2.3.1. Molarity: A very useful means of expressing concentration in the laboratory is **molarity (M)**, the number of moles of solute dissolved per liter of solution.

2.3.2. Normality: it is defined as the number of equivalents of solute per liter of solution.

3. Common relative expressions of concentration units

We can report the results of analysis in many ways, and the beginning analytical chemist should be familiar with some of the common expressions and units of measure employed. Results will nearly always be reported as *concentration*, on either a weight or a volume basis: the quantity of analyte per unit weight or per volume of sample (Christian *et al.*, 2014). The units used for the analyte will vary as shown in Table 1.

Table 1

Common relative expressions of concentration units

Expression	Abbreviation	w/w	w/v	v/v
Parts per hundred	pph (%)	g/100g	g/100mL	mL/100mL
Parts per thousand	ppt (%)	g/kg	g/L	mL/L
		mg/g	mg/mL	μL/mL
		μg/mg	μg/μL	nL/μL
		ng/μg	ng/nL	pL/nL
Parts per million	ppm	pg/ng	pg/pL	
		mg/kg	mg/L	μL/L
		μg/g	μg/mL	nL/mL
		ng/mg	ng/μL	pL/μL
Parts per billion	ppb	pg/μg	pg/nL	
		μg/kg	μg/L	nL/L
		ng/g	ng/mL	pL/mL
Parts per trillion	pptr*	pg/mg	pg/μL	
		ng/kg	ng/L	pL/L
		pg/g	pg/mL	

*pptr is used instead of ppt to avoid confusion.

We shall first review the common units of weight and volume in the metric system and then describe methods of expressing results. The gram (g) is the basic unit of mass and is the unit employed most often in macro analyses. For small samples or trace constituents, chemists use smaller units. The milligram (mg) is 10^{-3} g, the microgram (μ g) is 10^{-6} g, the nanogram (ng) is 10^{-9} g, and the picogram (pg) is 10^{-12} g. The basic unit of volume is the liter (L). The milliliter (mL) is 10^{-3} L and is used commonly in volumetric analysis. The microliter (μ L) is 10^{-6} L (10^{-3} mL), the nanoliter (nL) is 10^{-9} L (10^{-6} mL), and the picoliter (pL) is 10^{-12} L (10^{-9} mL) (Christian *et al.*, 2014; Harvey, 2000; Sanagi *et al.*, 2007; Skoog *et al.*, 2014). Fig.1 shows the relationships between metric conversions.

Practices:

1. A 2.6 g sample of plant tissue was analyzed and found to contain 3.6 μ g zinc. What is the concentration of zinc in the plant in ppt, ppm, ppb, and pptr?

To answer this question, use the information in Table 1 and Fig. 1.

a. Concentration in ppt (ppt = mg/g, g/kg, μ g/mg, ng/ μ g, or pg/ng)

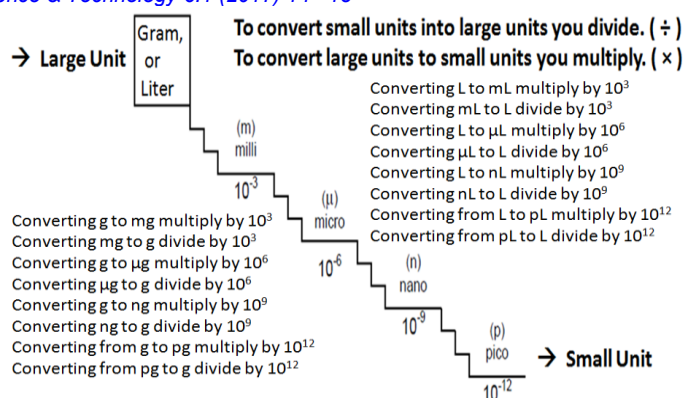


Fig. 1. Relationships among metric conversions

$$\text{Cppt} = \frac{3.6 \times 10^{-3} \text{ mg}}{2.6 \text{ g}} = 1.3846 \times 10^{-3} \text{ mg/g} = 1.4 \times 10^{-3} \text{ ppt, or}$$

$$\text{Cppt} = \frac{3.6 \times 10^{-6} \text{ g}}{2.6 \times 10^{-3} \text{ kg}} = 1.3846 \times 10^{-3} \text{ g/kg} = 1.3846 \times 10^{-3} \text{ ppt} \approx 1.4 \times 10^{-3} \text{ ppt, or}$$

$$\text{Cppt} = \frac{3.6 \mu\text{g}}{2.6 \times 10^3 \text{ mg}} = 1.3846 \times 10^{-3} \mu\text{g/mg} = 1.3846 \times 10^{-3} \text{ ppt} \approx 1.4 \times 10^{-3} \text{ ppt, or}$$

$$\text{Cppt} = \frac{3.6 \times 10^3 \text{ ng}}{2.6 \times 10^6 \mu\text{g}} = 1.3846 \times 10^{-3} \text{ ng}/\mu\text{g} = 1.3846 \times 10^{-3} \text{ ppt} \approx 1.4 \times 10^{-3} \text{ ppt, or}$$

$$\text{Cppt} = \frac{3.6 \times 10^6 \text{ pg}}{2.6 \times 10^9 \text{ ng}} = 1.3846 \times 10^{-3} \text{ pg/ng} = 1.3846 \times 10^{-3} \text{ ppt} \approx 1.4 \times 10^{-3} \text{ ppt}$$

b. Concentration in ppm (ppm = μ g/g, mg/kg, ng/mg, or pg/ μ g)

$$\text{Cppm} = \frac{3.6 \mu\text{g}}{2.6 \text{ g}} = 1.384.6 \mu\text{g/g} = 1.384.6 \text{ ppm} \approx 1.4 \text{ ppm, or}$$

$$\text{Cppm} = \frac{3.6 \times 10^{-3} \text{ mg}}{2.6 \times 10^{-3} \text{ kg}} = 1384.6 \text{ mg/kg} = 1.384.6 \text{ ppm} \approx 1.4 \text{ ppm, or}$$

$$\text{Cppm} = \frac{3.6 \times 10^3 \text{ ng}}{2.6 \times 10^3 \text{ mg}} = 1384.6 \text{ ng/mg} = 1.384.6 \text{ ppm} \approx 1.4 \text{ ppm, or}$$

$$\text{Cppm} = \frac{3.6 \times 10^6 \text{ pg}}{2.6 \times 10^6 \mu\text{g}} = 1384.6 \text{ pg}/\mu\text{g} = 1.384.6 \text{ ppm} \approx 1.4 \text{ ppm}$$

c. Concentration in ppb (ppb = ng/g, μ g/kg, or pg/mg)

$$\text{Cppb} = \frac{3.6 \times 10^3 \text{ ng}}{2.6 \text{ g}} = 1384.6 \text{ ng/g} = 1384.6 \text{ ppb} \approx 1.4 \times 10^3 \text{ ppb, or}$$

$$\text{Cppb} = \frac{3.6 \mu\text{g}}{2.6 \times 10^{-3} \text{ kg}} = 1384.6 \mu\text{g/kg} = 1384.6 \text{ ppb} \approx 1.4 \times 10^3 \text{ ppb, or}$$

$$\text{Cppb} = \frac{3.6 \times 10^6 \text{ pg}}{2.6 \times 10^3 \text{ mg}} = 1384.6 \text{ pg/mg} = 1384.6 \text{ ppb} \approx 1.4 \times 10^3 \text{ ppb}$$

d. Concentration in pptr (pptr = ng/kg, or pg/g)

$$\text{Cpptr} = \frac{3.6 \times 10^3 \text{ ng}}{2.6 \times 10^{-3} \text{ kg}} = 1384.6 \text{ ng/kg} = 1384615.4 \text{ pptr} \approx 1.4 \times 10^6 \text{ pptr, or}$$

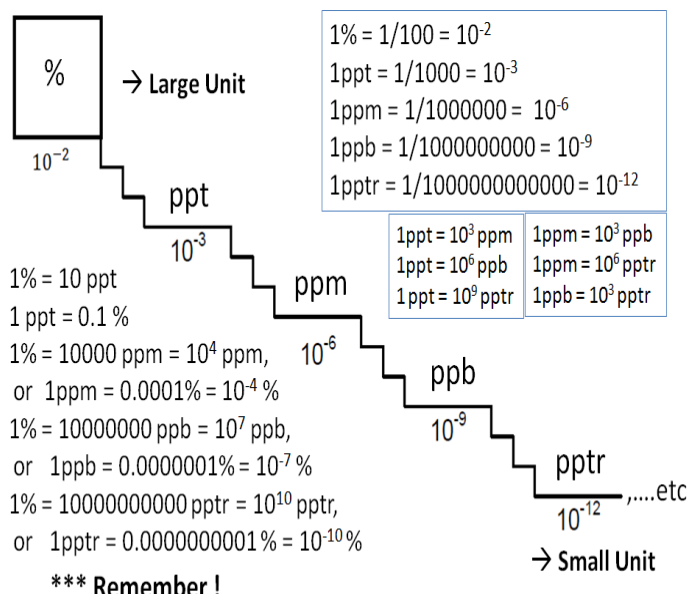
$$\text{Cpptr} = \frac{3.6 \times 10^6 \text{ pg}}{2.6 \text{ g}} = 1384.6 \text{ pg/g} = 1384615.4 \text{ pptr} \approx 1.4 \times 10^6 \text{ pptr}$$

3.1. Approximate conversions between trace concentrations and percent

Fig. 2. shows the relationships among percent composition %, ppt, ppm, ppb, and pptr. Chemists frequently express concentrations in terms of percent (parts per hundred). The percent is the basic unit of concentration and is the unit employed most often in macro analyses which express concentration as units of solute per 100 units of sample in terms of weight percent (% w/w), volume percent (% v/v) and weight-to-volume percent (% w/v). Trace concentrations are usually given in smaller units, such as parts per thousand (ppt, ‰), parts per million (ppm), parts per billion (ppb), or parts per trillion (pptr). These are

calculated in a manner similar to parts per hundred (Christian *et al.*, 2014; Harvey, 2000; Sanagi *et al.*, 2007; Skoog *et al.*, 2014).

In case of dealing with solid dissolved in liquid (usually diluted solutions), Table 2 shows approximate conversions between trace concentrations (ppt, ppm, ppb, pptr) and percent (%). Simple designed equations are used to convert between percent (%) and trace units.



*** Remember !

To convert small units into large units you divide. (÷)

To convert large units to small units you multiply. (×)

Fig. 2. Conversions among common relative concentration units.

Table 2

Approximate conversions between trace concentrations and percent for diluted solutions. (see examples 1, 2 and 3)

Conversion	Designed equation
Converting (%) to (ppt) multiply by 10	$C_{ppt} = C\% \times 10$
Converting (ppt) to (%) divide by 10	$C\% = C_{ppt} / 10$
Converting (%) to (ppm) multiply by 10^4	$C_{ppm} = C\% \times 10^4$
Converting (ppm) to (%) divide by 10^4	$C\% = C_{ppm} / 10^4$
Converting (%) to (ppb) multiply by 10^7	$C_{ppb} = C\% \times 10^7$
Converting (ppb) to (%) divide by 10^7	$C\% = C_{ppb} / 10^7$
Converting (%) to (pptr) multiply by 10^{10}	$C_{pptr} = C\% \times 10^{10}$
Converting (pptr) to (%) divide by 10^{10}	$C\% = C_{pptr} / 10^{10}$

Notes: C represents concentration value, e.g. C_{ppt} means concentration in parts per thousand ...etc. Because the solution is so dilute, it is reasonable to assume that its density (d) is 1.00 g/mL. Therefore, the density is ignored in the above equations.

In case of dealing with **high concentrated** liquid materials such as acids and ammonia the density (d) of liquids must be considered. Table 3 shows approximate conversions between trace concentrations (ppt, ppm, ppb, pptr) and percent (pph). Simple designed equations are used to convert between percent (%) and trace units.

Table 3

Approximate conversions between trace concentrations and percent for concentrated liquids such as acids and ammonia. (see examples 4 and 5)

Conversion	Designed equation
Converting (%) to (ppt) multiply by (d * 10)	$C_{ppt} = C\% \times d \times 10$
Converting (ppt) to (%) divide by (d * 10)	$C\% = C_{ppt} / d \times 10$
Converting (%) to (ppm) multiply by (d * 10^4)	$C_{ppm} = C\% \times d \times 10^4$
Converting (ppm) to (%) divide by (d * 10^4)	$C\% = C_{ppm} / d \times 10^4$
Converting (%) to (ppb) multiply by (d * 10^7)	$C_{ppb} = C\% \times d \times 10^7$
Converting (ppb) to (%) divide by (d * 10^7)	$C\% = C_{ppb} / d \times 10^7$
Converting (%) to (pptr) multiply by (d * 10^{10})	$C_{pptr} = C\% \times d \times 10^{10}$
Converting (pptr) to (%) divide by (d * 10^{10})	$C\% = C_{pptr} / d \times 10^{10}$

Note: Because the solution is so concentrate, the density will vary. Therefore, the density is not ignored.

Practices:

1. A sample of Mollusks was analysed for cadmium (Cd) and found to contain 677 µg/kg. Express this as %?

Converting (ppb) to (%) divide by 10^7

$$C\% = 677 / 10^7 = 6.77 \times 10^{-5}\%$$

2. A sample of Mollusks was analyzed for cadmium (Cd) and found to contain $6.77 \times 10^{-5}\%$. Express this as ppb?

Converting (%) to (ppb) multiply by 10^7

$$C_{ppb} = 6.77 \times 10^{-5} \times 10^7 = 677 \text{ µg/kg (ppb)}$$

3. A solution of NaCl has a concentration of 8.0%. Calculate the concentration in ppt of NaCl solution in which 6.8 g of NaCl has been dissolved making a solution with a volume of 85 mL?

$$C_{ppt} = C\% \times 10 = 8.0\% \times 10 = 80 \text{ g/L, or}$$

$$C_{ppt} = \frac{g}{L} = \frac{6.8g}{0.085L} = 80g/L$$

4. If the following information was written on sulfuric acid bottle: $F_w = 98 \text{ g/mol}$, $d = 1.84 \text{ g/mL}$, 96% H_2SO_4 . Calculate the concentration of sulfuric acid in ppt?

$$C_{ppt} = C\% \times d \times 10 = 96 \times 1.84 \times 10 = 1766 \text{ g/L} \approx 1.8 \times 10^3 \text{ g/L}$$

5. Calculate the percent (%) of sulfuric acid whether the following information was written on sulfuric acid bottle: $F_w = 98 \text{ g/mol}$, $d = 1.84 \text{ g/mL}$, 1766.4 g/L H_2SO_4 ?

$$C\% = \frac{C_{ppt}}{d \times 10} \rightarrow C\% = \frac{1766.4}{1.84 \times 10} = 96\%$$

3.2. Conversions among trace concentrations

The formulated equations are simply designed by using Fig. 2. Table 4 shows simple designed equations that are used to convert among trace concentrations.

Table 4

Conversions among trace units

Conversion	Designed equation
Converting (ppt) to (ppm) multiply by 10^3	$C_{ppm} = C_{ppt} \times 10^3$
Converting (ppm) to (ppt) divide by 10^3	$C_{ppt} = C_{ppm} / 10^3$
Converting (ppt) to (ppb) multiply by 10^6	$C_{ppb} = C_{ppt} \times 10^6$
Converting (ppb) to (ppt) divide by 10^6	$C_{ppt} = C_{ppb} / 10^6$
Converting (ppt) to (pptr) multiply by 10^9	$C_{pptr} = C_{ppt} \times 10^9$
Converting (pptr) to (ppt) divide by 10^9	$C_{ppt} = C_{pptr} / 10^9$
Converting (ppm) to (ppb) multiply by 10^3	$C_{ppb} = C_{ppm} \times 10^3$
Converting (ppb) to (ppm) divide by 10^3	$C_{ppm} = C_{ppb} / 10^3$
Converting (ppb) to (pptr) multiply by 10^3	$C_{pptr} = C_{ppb} \times 10^3$
Converting (pptr) to (ppb) divide by 10^3	$C_{ppb} = C_{pptr} / 10^3$
Converting (ppm) to (pptr) multiply by 10^6	$C_{pptr} = C_{ppm} \times 10^6$
Converting (pptr) to (ppm) divide by 10^6	$C_{ppm} = C_{pptr} / 10^6$

Practices:

1. Find the concentration in ppt, ppm, ppb and pptr of a solution in which 0.1 g of NaCl has been dissolved making a solution with a volume of 2 L?

a. Concentration in ppt $\rightarrow C_{ppt} = \frac{g}{L} = \frac{0.1g}{2L} = 0.05 \frac{g}{L}$ (ppt), or

$$C_{ppt} = \frac{0.1g}{2 \times 10^3} \times 10^3 = 0.05 \text{ mg/mL (ppt)}$$

b. Concentration in ppm $\rightarrow C_{ppm} = C_{ppt} \times 10^3 = 0.05 \times 10^3 \text{ mg/L} = 50 \text{ ppm, or}$

$$C_{ppm} = \frac{0.1g}{2 \times 10^3} \times 10^6 = 50 \text{ µg/mL} = 50 \text{ ppm}$$

c. Concentration in ppb $\rightarrow C_{ppb} = C_{ppt} \times 10^6 = 0.05 \times 10^6 = 50000 \text{ µg/L} = 5 \times 10^4 \text{ ppb, or}$

$$C_{ppb} = \frac{0.1g}{2 \times 10^3} \times 10^9 = 50000 \text{ ng/mL} = 5 \times 10^4 \text{ ppb}$$

d. Concentration in pptr $\rightarrow C_{pptr} = C_{ppt} \times 10^9 = 0.05 \times 10^9 = 50000000 \text{ ng/L} = 5 \times 10^7 \text{ pptr, or}$

$$C_{pptr} = \frac{0.1g}{2 \times 10^3} \times 10^{12} = 50000000 \text{ pg/mL} = 5 \times 10^7 \text{ pptr}$$

2. A sample of canned tuna fish was analysed for mercury (Hg) and found to contain 0.55 mg/kg. Express this as pptr?

Converting (mg/kg = ppm) to (pptr) multiply by 10^6
 Concentration in pptr = $C_{ppm} \times 10^6 = 0.55 \text{ ppm} \times 10^6 = 5.5 \times 10^5 \text{ ng/kg (pptr)}$

3. A sample of kelp was analyzed for arsenic (As) and found to contain 25 $\mu\text{g/g}$. What is the concentration of arsenic (As) in ppt?

Converting (ppm) to (ppt) divide by 10^3
 $C_{ppt} = \frac{C_{ppm}}{10^3} \rightarrow C_{ppt} = \frac{25}{10^3} = 0.025 = 2.5 \times 10^{-2} \frac{\text{mg}}{\text{g}} \text{ (ppt)}$

3.3. Conversion among molarity, normality and percent

The basic concentration units in laboratory are molarity, normality, and percent. Some students are facing little difficulty to convert between them. Here is a solution to that problem.

3.3.1 Converting from molarity (M) to normality (N) and vice versa

The following simple relationship exists between normality and molarity.

(i) Equation to convert from molarity to normality and vice versa; $N = n_{(H^+, OH^-, e^-, \dots \text{etc})} \times M$, where n is the number of reacting units. The number of reacting units denoted by n depends on the chemical reaction. It may vary most often in redox reactions, when different products are obtained. For acids and bases, the number of reacting units is based on the number of protons (i.e., hydrogen ions) an acid will furnish or a base will react with. For oxidation–reduction reactions it is based on the number of electrons an oxidizing or reducing agent will take on or supply (Christian *et al.*, 2014; Harvey, 2000).

Practices: Convert the following Molarities to Normalities.

1. **1.5 M HCl** $\rightarrow N = n_{(H^+)} \times M = 1.0 \times 1.5 = \mathbf{1.5 N}$
2. **0.2 M Ca(OH)₂** $\rightarrow N = n_{(OH^-)} \times M = 2.0 \times 0.2 = \mathbf{0.4 N}$

(ii) Equation to convert from normality to molarity;

$$M = \frac{N}{n_{(H^+, OH^-, e^-, \dots \text{etc})}}$$

Practices: Convert the following Normalities to Molarities.

1. **2.4 N H₂SO₄** $\rightarrow M = \frac{N}{n_{(H^+)}} = \frac{2.4 N}{2.0} = \mathbf{1.2 M}$
2. **1.0 N NaOH** $\rightarrow M = \frac{N}{n_{(OH^-)}} = \frac{1.0 N}{1.0} = \mathbf{1.0 M}$

3.3.2 Conversion between percent and molarity or normality

In order to convert percent to molarity or normality, there are two types of equations to simplify the conversion. One of these types is used when dealing with solid dissolved in liquid (low concentration) and the other one is used when dealing with liquids such as acids and ammonia (high concentration).

In case of dealing with solid dissolved in liquid, which usually prepared in **low concentration**. Because the solution is so dilute, it is reasonable to assume that its density is 1.00 g/mL. Therefore, the density is ignored in the below equations. In order to convert percent to normality or molarity, simple equations are designed to simplify the conversions between them as seen in Table 5.

Table 5

Conversions between percent and normality or molarity in diluted solutions

Conversion	Designed equation
Converting from % to N	$N = C\% \times 10 / Ew$
Converting from N to %	$C\% = N \times Ew / 10$
Converting from % to M	$M = C\% \times 10 / Fw$
Converting from M to %	$C\% = M \times Fw / 10$
General equation for converting from % to N and vice versa	$N \times Ew = C\% \times 10$
General equation for converting from % to M and vice versa	$M \times Fw = C\% \times 10$

Note: Ew represents equivalent weight and Fw represents formula weight, because the solution is so dilute, it is reasonable to assume that its density is 1.00 g/mL. Therefore, the density is ignored in the above equations.

Practices:

1. Find the % percentage, molarity and normality of a solution in which 6.8 g of NaCl has been dissolved making a solution with a volume of 85 mL?

Calculating percent:

$$(w/v)\% = \frac{\text{amount of solute in (g)}}{\text{total volume of solution in (ml)}} \times 100 = \frac{6.8 \text{ g}}{85 \text{ ml}} \times 100 = 8.0\%(w/v) \text{ NaCl}$$

Calculating molarity:

$$M = \frac{C\% \times 10}{Fw} = \frac{8.0 \times 10}{58.44} = 1.37 \text{ M} \approx 1.4 \text{ M, or}$$

$$M = \frac{g}{VL \times Fw} = \frac{6.8 \text{ g}}{0.085 \text{ L} \times 58.44 \text{ g/mol}} = 1.37 \text{ mol/L} \approx 1.4 \text{ M}$$

Calculating normality:

$$N = \frac{C\% \times 10}{Ew} = \frac{8.0 \times 10}{58.44} = 1.37 \text{ N} \approx 1.4 \text{ N, or}$$

$$N = \frac{g}{VL \times Ew} = \frac{6.8 \text{ g}}{0.085 \text{ L} \times 58.44 \text{ g/eq}} = 1.37 \text{ eq/L} \approx 1.4 \text{ N}$$

2. A solution of NaCl has a concentration of 1.37M. What %(w/v) of NaCl solution in which 6.8 g of NaCl has been dissolved making a solution with a volume of 85 mL?

$$C\% = \frac{M \times Fw}{10} = \frac{1.37 \times 58.44}{10} = 8.0\% (w/v) \text{ NaCl}$$

Similarly, when dealing with liquids such as acids and ammonia, which usually purchased in **high concentration**. Because the solution is so concentrate, the density of solution will vary. Therefore, the density is not ignored in the below equations. There is some information written on the bottle of liquid in laboratory such as percent (%), density (d), and formula weight (Fw). This information is used to convert percent to other concentration units. Table 6 shows simple equations that are used to convert percent to molarity or normality and vice versa.

Table 6

Conversions between percent and normality or molarity in concentrated liquids

Conversion	Designed equation
Converting from % to N	$N = C\% \times d \times 10 / Ew$
Converting from N to %	$C\% = N \times Ew / d \times 10$
Converting from % to M	$M = C\% \times d \times 10 / Fw$
Converting from M to %	$C\% = M \times Fw / d \times 10$
General equation for converting from % to N and vice versa	$N \times Ew = C\% \times d \times 10$
General equation for converting from % to M and vice versa	$M \times Fw = C\% \times d \times 10$

Notes: Ew represents equivalent weight, because the solution is so concentrate, the density of solution will vary. Therefore, the density is written in the above equations.

Practices:

1. If the following information was written on the sulfuric acid bottle: Fw = 98 g/mol, d = 1.84 g/ml, 96% H₂SO₄. Calculate the molarity and normality of concentrated sulfuric acid?

Solution:

$$M \times Fw = C\% \times d \times 10$$

$$M = \frac{C\% \times d \times 10}{Fw} = \frac{96 \times 1.84 \times 10}{98} = 18.02 \approx 18 \text{ mol/L (M)}$$

$$N \times Ew = C\% \times d \times 10$$

$$N = \frac{C\% \times d \times 10}{Ew} = \frac{96 \times 1.84 \times 10}{49} = 36.04 \approx 36 \text{ eq/L (N)}$$

2. Calculate the percent (%) of concentrated sulfuric acid? If the following information was written on volumetric flask contained the acid: Fw = 98 g/mol, d = 1.84 g/ml, 18.02M H₂SO₄?

$$C\% = \frac{M \times Fw}{d \times 10} = \frac{18.02 \times 98}{1.84 \times 10} = 96\%$$

3.4. Conversion between trace concentrations and molarity or normality

3.4.1. Conversion between trace concentrations and molarity

In order to convert between trace units (*ppt*, *ppm*, *ppb*, and *pptr*) and molarity (*M*), new equations need to be designed to simplify the conversions between them as shown in Table 7.

Practices:

1. Convert 0.025M of Na_2CO_3 to ppt, ppm, ppb, and pptr?

Concentration in ppt = $M \cdot Fw = 0.025 \text{ M} \cdot 106 \text{ g/mol} = 2.65 \text{ g/L (ppt)}$

Concentration in ppm = $M \cdot Fw \cdot 10^3 = 0.025 \text{ M} \cdot 106 \text{ g/mol} \cdot 10^3 = 2650 \text{ mg/L} \approx 2.65 \cdot 10^3 \text{ ppm}$

Concentration in ppb = $M \cdot Fw \cdot 10^6 = 0.025 \text{ M} \cdot 106 \text{ g/mol} \cdot 10^6 = 2650000 \text{ } \mu\text{g/L} \approx 2.65 \cdot 10^6 \text{ ppb}$

Concentration in pptr = $M \cdot Fw \cdot 10^9 = 0.025 \text{ M} \cdot 106 \text{ g/mol} \cdot 10^9 = 2650000000 \text{ ng/L} \approx 2.65 \cdot 10^9 \text{ pptr}$

Table 7

Conversions between trace units and molarity

Conversion	Designed equation
Converting from M to ppt	$\text{Cppt} = M \cdot Fw$
Converting from ppt to M	$M = \text{Cppt} / Fw$
Converting from M to ppm	$\text{Cppm} = M \cdot Fw \cdot 10^3$
Converting from ppm to M	$M = \text{Cppm} / Fw \cdot 10^3$
Converting from M to ppb	$\text{Cppb} = M \cdot Fw \cdot 10^6$
Converting from ppb to M	$M = \text{Cppb} / Fw \cdot 10^6$
Converting from M to pptr	$\text{Cpptr} = M \cdot Fw \cdot 10^9$
Converting from pptr to M	$M = \text{Cpptr} / Fw \cdot 10^9$

Note: The relationship between any trace concentrations and molarity (*M*) units depends on the formula weight (*Fw*) which represents the atomic or molecular weight of the substance.

2. Calcium ion has a concentration of 0.01 M. What is the concentration of calcium ion in ppm?

Concentration in ppm = $M \cdot Fw \cdot 10^3 = 0.010 \text{ M} \cdot 40.08 \text{ g/mol} \cdot 10^3 = 400.8 \text{ mg/L} \approx 400 \text{ ppm} \approx 4.0 \cdot 10^2 \text{ ppm}$

3. Calculate the molar concentration (molarity) of 1.00 mg/L of Pb^{2+} ?

$$M = \frac{\text{Cppm}}{Fw \cdot 10^3} = \frac{1.00 \text{ ppm}}{207 \cdot 10^3} = 4.83 \cdot 10^{-6} \text{ M}$$

4. Convert 2650 ppm of Na_2CO_3 to M?

$$M = \frac{\text{Cppm}}{Fw \cdot 10^3} = \frac{2650 \text{ ppm}}{106 \cdot 10^3} = 0.0250 \text{ M}$$

5. A solution of NaCl has a concentration of 1.37 M. What is the concentration of NaCl solution in ppt?

Concentration in ppt = $M \cdot Fw = 1.37 \text{ mol/L} \cdot 58.44 \text{ g/mol} = 80.06 \text{ g/L} \approx 80.0 \text{ g/L (ppt)}$

6. A solution of NaCl has a concentration of 80 ppt. What is the molarity of NaCl solution in which 6.8 g of NaCl has been dissolved making a solution with a volume of 85 mL?

$$M = \frac{\text{Cppt}}{Fw} = \frac{\frac{80 \text{ g}}{\text{L}}}{58.44 \frac{\text{g}}{\text{mol}}} = 1.3689 \approx 1.4 \frac{\text{mol}}{\text{L}} \text{ (M), or}$$

$$M = \frac{\text{g}}{Fw \cdot L} = \frac{6.8 \text{ g}}{58.44 \frac{\text{g}}{\text{mol}} \cdot 0.085 \text{ L}} = 1.4 \frac{\text{mol}}{\text{L}} \text{ (M)}$$

3.4.2. Conversion between trace concentrations and normality

Some students and technicians are facing difficulty to correlate between trace units (*ppt*, *ppm*, *ppb*, and *pptr*) and normality (*N*). Table 8 shows simple new equations to simplify the conversions between them. The simple formulated equations will simply work in practice.

Table 8

Conversions between trace units and normality

Conversion	Designed equation
Converting from N to ppt	$\text{Cppt} = N \cdot Ew$
Converting from ppt to N	$N = \text{Cppt} / Ew$
Converting from N to ppm	$\text{Cppm} = N \cdot Ew \cdot 10^3$
Converting from ppm to N	$N = \text{Cppm} / Ew \cdot 10^3$
Converting from N to ppb	$\text{Cppb} = N \cdot Ew \cdot 10^6$
Converting from ppb to N	$N = \text{Cppb} / Ew \cdot 10^6$
Converting from N to pptr	$\text{Cpptr} = N \cdot Ew \cdot 10^9$
Converting from pptr to N	$N = \text{Cpptr} / Ew \cdot 10^9$

Note: The relationship between any trace concentration and normality (*N*) units depends on the equivalent weight (*Ew*) of the substance.

Practices:

1. Convert 0.05N of Na_2CO_3 to ppt, ppm, ppb, and pptr?

a. Concentration in ppt = $N \cdot Ew = 0.05 \text{ N} \cdot 53 \text{ g/eq} = 2.65 \text{ g/L (ppt)}$

b. Concentration in ppm = $N \cdot Ew \cdot 10^3 = 0.05 \text{ N} \cdot 53 \text{ g/eq} \cdot 10^3 = 2650 \text{ mg/L} = 2.65 \cdot 10^3 \text{ ppm}$

c. Concentration in ppb = $N \cdot Ew \cdot 10^6 = 0.05 \text{ N} \cdot 53 \text{ g/eq} \cdot 10^6 = 2.65 \cdot 10^6 \text{ } \mu\text{g/L (ppb)}$

d. Concentration in pptr = $N \cdot Ew \cdot 10^9 = 0.05 \text{ N} \cdot 53 \text{ g/eq} \cdot 10^9 = 2.65 \cdot 10^9 \text{ ng/L (pptr)}$

2. Convert 2650 ppm of Na_2CO_3 to N?

$$N = \frac{\text{Cppm}}{Ew \cdot 10^3} = \frac{2650 \text{ ppm}}{53 \cdot 10^3} = 0.050 \text{ N}$$

3. Calculate the normal concentration (normality) of 1.00 mg/L of Pb^{2+} ?

$$N = \frac{\text{Cppm}}{Ew \cdot 10^3} = \frac{1.00 \text{ ppm}}{103.5 \cdot 10^3} = 9.66 \cdot 10^{-6} \text{ N}$$

4. A solution of NaCl has a concentration of 80 ppt. What is the normality of NaCl solution in which 6.8 g of NaCl has been dissolved making a solution with a volume of 85 mL?

$$N = \frac{\text{Cppt}}{Ew} = \frac{\frac{80 \text{ g}}{\text{L}}}{58.44 \frac{\text{g}}{\text{eq}}} = 1.4 \frac{\text{eq}}{\text{L}} \text{ (N), or}$$

$$N = \frac{\text{g}}{Ew \cdot L} = \frac{6.8 \text{ g}}{58.44 \frac{\text{g}}{\text{eq}} \cdot 0.085 \text{ L}} = 1.4 \frac{\text{eq}}{\text{L}} \text{ (N)}$$

4. Conclusion

We have successfully designed simple equations to fully understand the calculations for common concentration units and conversion between them. This review article is written to be readable by anyone who has an idea in basic principles of general and analytical chemistry. This simple article is a practical training for chemists, technicians, scientists, students, teachers, or engineers for rapid solution of complicated conversion calculations.

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