

Training module # WQ I-2

Basic chemistry concepts

New Delhi, May 1999

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1 Module context

This module introduces basic concepts of chemistry required by chemists at all levels in their daily work in the laboratory. No prior training in other module is needed to complete this module successfully.

2 *Module profile*

| | | |
|---------------------------------------|---|--|
| Title | : | Basic chemistry concepts |
| Target group | : | As per training need |
| Duration | : | One session of 90 min |
| Objectives | : | After the training the participants will be able to: <ul style="list-style-type: none">• Convert units from one to another• Discuss the basic concepts of quantitative chemistry• Report analytical results with the correct number of significant digits. |
| Key concepts | : | <ul style="list-style-type: none">• SI units and symbols• Elements compounds and radicals• Equivalent weights• Principles of titration• Significant figures |
| Training methods | : | Lecture, exercises |
| Training tools required | : | Board, flipchart, OHS |
| Handouts | : | As provided in this module |
| Further reading and references | : | <ul style="list-style-type: none">• Analytical Chemistry: An introduction, D.A. Skoog and D. M. West/1986. Saunders College Publishing• Chemistry of Environment Engineering, C. N. Sawyer, P. L. McCarty and C.F. Parkin. McGraw-Hill, 1994 |

3 Session plan

| No | Activities | Time | Tools |
|----|---|--------|--------------------------------------|
| 1 | Preparations | | |
| 2 | Introduction: <ul style="list-style-type: none"> Basic chemistry concepts | 5 min | OHS |
| 3 | Units of measurement <ul style="list-style-type: none"> Introduce the subject of units of measurement and the importance of standardisation of units. Demonstrate how to calculate the concentration of substances in liquids and how to convert units. Explain and emphasise use of factor label method. | 15 min | Main text Tables 1 & 2 OHS |
| 4 | Ions, molecules and molecular weights <ul style="list-style-type: none"> Describe the concept of ion charge, neutrality of molecules and molecular weights. | 10 min | Main text Tables 3 & 4 OHS |
| 5 | Equivalent weights <ul style="list-style-type: none"> Explain the concept, determination and use of equivalent weights emphasising factor label method. | 15 min | Main text Tables 3 & 4 OHS |
| 6 | Standard solutions and titrimetric methods <ul style="list-style-type: none"> Define standard solutions and describe titrimetric method of analysis. <i>Emphasise again the use of factor label method in all calculations.</i> | 15 min | OHS |
| 7 | Significant figures <ul style="list-style-type: none"> Explain importance of reporting data in significant figures. | 10 min | OHS |
| 8 | Exercise <ul style="list-style-type: none"> Ask participants to answer the questions in the handout Distribute exercise sheets as additional handouts | 10 min | Exercise sheet Solution sheet |
| 9 | Wrap up <ul style="list-style-type: none"> Distribute & discuss answers. Refer to additional questions for homework | 10 min | |

4 Overhead/flipchart masters

OHS format guidelines

| Type of text | Style | Setting |
|------------------------|-------------------------------|---|
| Headings: | OHS-Title | Arial 30-36, Bold with bottom border line (not: underline) |
| Text: | OHS-lev1 OHS-lev2 | Arial 26, Arial 24, with indent maximum two levels only |
| Case: | | Sentence case. Avoid full text in UPPERCASE. |
| Italics: | | Use occasionally and in a consistent way |
| Listings: | OHS-lev1 OHS-lev1-Numbered | Big bullets. Numbers for definite series of steps. Avoid roman numbers and letters. |
| Colours: | | None, as these get lost in photocopying and some colours do not reproduce at all. |
| Formulas/ Equations | OHS-Equation | Use of a table will ease alignment over more lines (rows and columns) Use equation editor for advanced formatting only |

Basic chemistry concepts

1. Units of measurement
2. Elements, compounds and molecular weights
3. Equivalent weights and chemical reactions
4. Titrimetric calculations
5. Significant figures

1. Units of measurement

See table 1 & 2 in Handout

1. Units of measurement: concentration units

Example:

Four kg common salt is thrown in a tank containing 800 m³ of water. What is the resulting concentration of salt in mg / L?

$$\begin{aligned}
 &= \frac{4 \text{ kg}}{800 \text{ m}^3} \times \frac{10^6 \text{ mg}}{1 \text{ kg}} \times \frac{1 \text{ m}^3}{10^3 \text{ L}} = \frac{4}{800} \times \frac{10^6}{10^3} \times \frac{\text{mg}}{\text{L}} \\
 &= 5 \frac{\text{mg}}{\text{L}}
 \end{aligned}$$

1. Units of measurement: conversion of units

Example (Factor - label method):

Convert 5mg/L into $\mu\text{g/L}$

$$5 \frac{\text{mg}}{\text{L}} = 5 \frac{\text{mg}}{\text{L}} \times \frac{1000 \mu\text{g}}{1 \text{ mg}}$$
$$= 5000 \frac{\mu\text{g}}{\text{L}}$$

2. Elements, compounds & molecular weights

- Elements combine to make compounds which do not have any net charge
- Compounds dissolved in water dissociate into charged ions
- Radicals are groupings of elements acting together as charged ions

See Table 3 & 4 in handout

2. Elements, compounds & molecular weights

Example:

Write the molecular formula for aluminium sulphate (alum) if each molecule has 18 molecules of water of crystallisation.

No. of +ive charges on $2\text{Al}^{3+} = 6$

No. of -ive charges on $3\text{SO}_4^{2-} = 6$

The formula is $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$

2. Elements, compounds & molecular weights

Example:

Calculate the molecular weight of alum $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ and its sulphur content.

$$\begin{array}{rclclcl} 2\text{Al}^{+++} & = & 2 & \times & 27 & = & 54 \\ 3\text{SO}_4^{--} & = & 3 & \times & 96 & = & 288 \\ 18\text{H}_2\text{O} & = & 18 & \times & 18 & = & 324 \\ & & & & \text{Total} & = & \mathbf{666} \end{array}$$

$$\text{Sulphur content: } 3 \times \frac{32}{666} = \mathbf{14.4\%}$$

3. Equivalent weight

- Molecular weight / Valency
- Valency is equal to:
 - absolute number of ion charge
 - number of H^+ or OH^- ions that can combine with the ion
 - absolute number of change in charge of ion in a reaction
- Quantity of chemicals equivalent to each other
- One chemical expressed as another
- Same number of equivalents of reactants in a chemical reaction

3. Equivalent weight

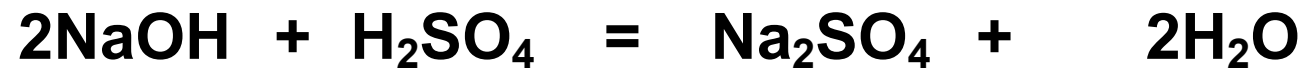
Example: Express 120 mg Ca⁺⁺ / L as mg CaCO₃/L

- Equivalent weight of Ca⁺⁺ = 20
- Equivalent weight of CaCO₃ = 50

$$\begin{array}{ccccccc}
 & \text{mg Ca}^{++} & & \text{mg Ca}^{++} & & \text{1 meq} & & \text{50mg CaCO}_3 \\
 120 & \frac{\text{-----}}{\text{L}} & = & 120 & \frac{\text{-----}}{\text{L}} & \times & \frac{\text{-----}}{\text{20mg Ca}^{++}} & \times & \frac{\text{-----}}{\text{1meq}} \\
 & & & & & & & & \\
 & & & = & 300 & & \frac{\text{mg CaCO}_3}{\text{-----}} & & \\
 & & & & & & \text{L} & &
 \end{array}$$

3. Equivalent weight

Example: for the balanced reaction



- 2 moles NaOH react with 1 mole H₂SO₄
- 80g NaOH react with 98g H₂SO₄
- 2eq NaOH react with 2 eq H₂SO₄

4. Titrimetric method

- Standard solutions contain known concentration of one reactant
- 1 *N* solution contains 1 eq wt/L
- React standard solution against unknown concentration in sample
- End point is determined using indicator
- Eq of reactant in standard = Eq of reactant in sample

4. Titrimetric method

Example:

Calculate the alkalinity of a sample if 50 mL aliquot consumed 12.4 mL of 0.1N standard H₂SO₄.

Standard acid consumed

$$\frac{0.1\text{meq}}{\text{mL}} \times 12.4\text{mL} = 1.24 \text{ meq}$$

$$\text{Therefore alkalinity} = \frac{1.24\text{meq}}{50\text{mL}}$$

4. Titrimetric method

Example (Contd.):

Expressed as CaCO₃

$$\begin{aligned}
 &= \frac{1.24 \text{ meq}}{50 \text{ mL}} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{50 \text{ mg CaCO}_3}{1 \text{ meq}} \\
 &= 1240 \frac{\text{mg CaCO}_3}{\text{L}}
 \end{aligned}$$

5. Significant figures

- Significant figures in a number comprise
 - digits about which there is no uncertainty
 - one last digit which has uncertainty
- Round off by dropping digits that are not significant
 - if a digit > 5 is dropped, increase preceding digit by 1
 - if a digit < 5 is dropped, leave preceding digit unchanged
 - if digit 5 is dropped, round off preceding digit to nearest even number

5. Significant figures

- Addition/Subtraction: results have the same decimal places as the number added/ subtracted with the least decimal places

Example

$$\begin{array}{r} 0.0072 \\ 12.02 \\ + 488 \\ \hline 500.0272 \end{array} \rightarrow \mathbf{500}$$

5. Significant figures

- Multiplication/Division: results have the same number of significant places as the number multiplying/dividing with the least significant places.

Example

$$\frac{56 \times 0.003462 \times 43.22}{1.684} = 4.975740998 \rightarrow 5.0$$

Exercise

1. *Express 0.1 m/s velocity in km/d*
2. *Calculate the normality of a $\text{Ba}(\text{OH})_2$ solution if 31.76 mL were needed to neutralise 46.25 mL of 0.1280 N HCl.*
3. *How many significant figures are there in 41.94, 0.0075, 7500, $7.5 \times 10^{+3}$, 7.5×10^{-3} , 4.029*

Basic chemistry concepts

1. Units of measurement
2. Elements, compounds and molecular weights
3. Equivalent weights and chemical reactions
4. Titrimetric calculations
5. Significant figures

5 *Evaluation*

Additional questions

- Write chemical formulas for: (a) magnesium hydroxide, (b) trihydrogen orthophosphate, (c) calcium hypochlorite, (d) barium sulphate, (e) ammonium carbonate.
- Calculate the quantities of chemicals needed to prepare the following solutions: (a) one L of 0.5N CaSO_4 , (b) 250 mL of 0.5M MgCO_3 , (c) 2.5 L of 4M $(\text{NH}_4)_2\text{CO}_3$.
- Express: (a) 272 mg/L CaSO_4 as CaCO_3 , (b) 280 g/L as g/m^3 , (c) 40 kg/m^3 as mg/L.
- Calculate quantity of sulphuric acid present in: (a) 12 mL of 0.02N solution, (b) 10 L of 1.0M solution.
- Chloride in water is determined by precipitating it with standard silver nitrate solution. Calculate the concentration of chloride in a sample of water if 12 mL of 0.01N AgNO_3 was required to react with 50 mL of water sample.
- How many significant figures are there in 21.22, 0.07, 4.0×10 , 4×10 , 3.050.
- Express the result in correct number of significant digits: (a) $124/1.2$, (b) $23 + 1.2 - 2.90 + 1.72$

6 *Handouts*

Basic chemistry concepts

1. Units of measurement
2. Elements, compounds and molecular weights
3. Equivalent weights and chemical reactions
4. Titrimetric calculations
5. Significant figures

1. Units of measurement

See table 1 & 2 in Handout

1. Units of measurement: Concentration units

Example:

Four kg common salt is thrown in a tank containing 800 m³ of water. What is the resulting concentration of salt in mg / L?

$$\begin{aligned} &= \frac{4 \text{ kg}}{800 \text{ m}^3} \times \frac{10^6 \text{ mg}}{1 \text{ kg}} \times \frac{1 \text{ m}^3}{10^3 \text{ L}} = \frac{4}{800} \times \frac{10^6}{10^3} \times \frac{\text{mg}}{\text{L}} \\ &= 5 \frac{\text{mg}}{\text{L}} \end{aligned}$$

Example (Factor - label method):

Convert 5mg/L into $\mu\text{g/L}$

$$\begin{aligned} 5 \frac{\text{mg}}{\text{L}} &= 5 \frac{\text{mg}}{\text{L}} \times \frac{1000 \mu\text{g}}{1 \text{ mg}} \\ &= 5000 \frac{\mu\text{g}}{\text{L}} \end{aligned}$$

2. Elements, compounds & molecular weights

- Elements combine to make compounds which do not have any net charge
- Compounds dissolved in water dissociate into charged ions
- Radicals are groupings of elements acting together as charged ions

See Table 3 & 4 in handout

2. Elements, compounds & molecular weights

Example:

Write the molecular formula for aluminium sulphate (alum) if each molecule has 18 molecules of water of crystallisation.

- No. of +ive charges on 3SO_4^{2-} = 6
- No. of -ive charges on 3SO_4^{2-} = 6

The formula is $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$

Example:

Calculate the molecular weight of alum $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ and its sulphur content.

| | | | | | | |
|------------------------|---|--------------|---|----|---|------------|
| 2Al^{+++} | = | 2 | x | 27 | = | 54 |
| 3SO_4^{--} | = | 3 | x | 96 | = | 288 |
| $18\text{H}_2\text{O}$ | = | 18 | x | 18 | = | 324 |
| | | Total | | | = | 666 |

$$\text{Sulphur content} : 3 \times \frac{32}{666} = 14.4\%$$

3. Equivalent weight

- Molecular weight / Valency
- Valency is equal to:
 - absolute number of ion charge
 - number of H^+ or OH^- ions that can combine with the ion
 - absolute number of change in charge of ion in a reaction
- Quantity of chemicals equivalent to each other
- One chemical expressed as another
- Same number of equivalents of reactants in a chemical reaction

Example: Express 120 mg Ca^{++} / L as mg CaCO_3 /L

Equivalent weight of Ca^{++} = 20

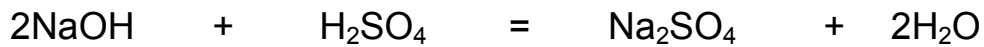
Equivalent weight of CaCO_3 = 50

$$120 \frac{\text{mg Ca}^{++}}{\text{L}} = 120 \frac{\text{mg Ca}^{++}}{\text{L}} \times \frac{1 \text{ meq}}{20 \text{ mg Ca}^{++}} \times \frac{50 \text{ mg CaCO}_3}{1 \text{ meq}}$$

$$= 300 \frac{\text{mg CaCO}_3}{\text{L}}$$

3. Equivalent weight

Example: for the balanced reaction



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Calculate the alkalinity of a sample if 50 mL aliquot consumed 12.4 mL of 0.1N standard H₂SO₄.

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$$\text{Therefore alkalinity} = \frac{1.24\text{meq}}{50\text{mL}}$$

Expressed as CaCO₃

$$\begin{aligned} &= \frac{1.24\text{meq}}{50\text{mL}} \times \frac{1000\text{mL}}{1\text{L}} \times \frac{50\text{mg CaCO}_3}{1\text{meq}} \\ &= 1240 \frac{\text{mg CaCO}_3}{\text{L}} \end{aligned}$$

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- Addition/Subtraction: results have the same decimal places as the number added/ subtracted with the least decimal places

Example

$$\begin{array}{r} 0.0072 \\ 12.02 \\ + 488 \\ \hline 500.0272 \end{array} \rightarrow 500$$

- Multiplication/Division: result has the same number of significant places as the number multiplying/dividing with the least significant places.

Example

$$\begin{array}{r} 56 \\ \hline 1.684 \end{array} \times 0.003462 \times 43.22 = 4.975740998 \rightarrow 5.0$$

Exercise

1. Express 0.1 m/s velocity in km/d

2. Calculate the normality of a $\text{Ba}(\text{OH})_2$ solution if 31.76 mL were needed to neutralise 46.25 mL of 0.1280 N HCl.

Exercise

3. How many significant figures are there in 41.94, 0.0075, 7500, $7.5 \times 10^{+3}$, 7.5×10^{-3} , 4.029, 1.0075?

Add copy of Main text in chapter 8, for all participants.

7 Additional handouts

These handouts are distributed during delivery and contain test questions, answers to questions, special worksheets, optional information, and other matters you would not like to be seen in the regular handouts.

It is a good practice to pre-punch these additional handouts, so the participants can easily insert them in the main handout folder.

Questions and Answers

Exercise 1

Question:

Express 0.1 m/s velocity in km/d.

Answer:

$$\begin{aligned}
 0.1 \frac{\text{m}}{\text{s}} &= 0.1 \frac{\text{m}}{\text{s}} \times \frac{1 \text{ km}}{1000\text{m}} \times \frac{86400 \text{ s}}{\text{d}} \\
 &= 0.1 \frac{\cancel{\text{m}}}{\cancel{\text{s}}} \times \frac{1\text{km}}{1000\cancel{\text{m}}} \times \frac{86400 \cancel{\text{s}}}{\text{d}} \\
 &= 8.64 \frac{\text{km}}{\text{d}}
 \end{aligned}$$

Exercise 2

Question

Calculate the normality of a Ba(OH)₂ solution if 31.76 mL were needed to neutralise 46.25 mL of 0.1280 N HCl.

Answer

No. of equivalents in 31.76mL barium hydroxide is equal to no of equivalents in HCl solution. Assume normality of Ba(OH)₂ equal to 'a' N.

$$\begin{aligned}
 a \frac{\text{meq}}{\text{mL}} \times 31.76 \text{ mL} &= 0.1280 \frac{\text{meq}}{\text{mL}} \times 46.25 \text{ mL} \\
 \text{or } a \frac{\text{meq}}{\text{mL}} \times 31.76 \text{ mL} &= 0.1280 \frac{\text{meq}}{\text{mL}} \times 46.25 \text{ mL} \\
 \text{or } a \frac{\text{meq}}{\text{mL}} &= \frac{1}{31.76 \text{ mL}} \times 0.1280 \times 46.25 \text{ meq} \\
 \text{or } a \frac{\text{meq}}{\text{mL}} &= 0.186397 \frac{\text{meq}}{\text{mL}}
 \end{aligned}$$

Round off to

$$a = 0.1864$$

Therefore the strength of the Ba(OH)₂ solution is 0.1864 N.

Exercise 3

Question

How many significant figures are there in 41.94, 0.0075, 7500, $7.5 \times 10^{+3}$, 7.5×10^{-3} , 4.029, 1.0075

Answer

| Number | Significant figures | Hint |
|-----------------------------|---------------------|---|
| <u>41.94</u> | 4 | Count number of digits |
| <u>7.5</u> $\times 10^{+3}$ | 2 | Zeros bounded by other digits on the right side only, do not count |
| 7500 | ? | Unknown since zero might have been used to indicate order of magnitude only |
| <u>7.5</u> $\times 10^{+3}$ | 2 | 7.5 contains two significant figures, 10^3 is used for magnitude |
| <u>7.5</u> $\times 10^{-3}$ | 2 | Rewrite as 0.0075, again zeros bounded by other digits on right side only, do not count |
| <u>4.029</u> | 4 | Enclosed zeros always count |
| <u>1.0075</u> | 5 | |

8 Main text

| | Page |
|---|-------------|
| 1. Units of measurements | 1 |
| 2. Elements, compounds and molecular weights | 3 |
| 3. Equivalent weights and chemical reactions | 6 |
| 4. Titrimetric methods of analysis | 7 |
| 5. Significant figures | 8 |

Basic chemistry concepts

Laboratory analysts are required to communicate the results of analyses accurately and without any ambiguity. For this purpose, a specified system of units and symbols should be used consistently. Learning basic calculations and concepts helps in appreciating the various steps involved in the analytical procedures and understand the need to follow these steps precisely. This text attempts at providing the necessary foundation.

1. Units of measurements

To develop a uniform method of reporting, the International System of Units (SI) is commonly used in most countries. Table 1 gives some of the common units used in chemical calculations and environment monitoring.

Table 1 Common SI units and symbols

| Quantity | SI unit | SI symbol |
|---------------------|--------------------------|-------------------|
| Length | meter | m |
| Mass | kilogram | kg |
| Time | second | s |
| Temperature | Celsius | °C |
| Area | square meter | m ² |
| Volume | cubic meter | m ³ |
| Velocity | meter per second | m/s |
| Flow rate | cubic meter per second | m ³ /s |
| Concentration (w/v) | kilogram per cubic meter | kg/m ³ |

In the environmental field it is quite common to encounter both extremely large quantities and extremely small ones. To describe such extreme values a system of prefixes is used. Commonly used prefixes and their meaning are given Table 2

Table 2 Common prefixes used with unit symbols

| Prefix | Symbol | Meaning |
|--------|--------|------------------|
| micro | μ | 10 ⁻⁶ |
| milli | m | 10 ⁻³ |
| centi | c | 10 ⁻² |
| deci | d | 10 ⁻¹ |
| deca | da | 10 |
| hecta | h | 10 ⁺² |
| kilo | k | 10 ⁺³ |
| mega | M | 10 ⁺⁶ |

Example 1

4 kg of common salt is thrown in a tank containing 800 m³ of water. What is the resulting concentration of salt in mg/l ? μg/L? (1m³ = 1000 l)

$$4 \text{ kg}/800 \text{ m}^3 \times 10^6 \text{ mg}/1 \text{ kg} \times 1 \text{ m}^3/1,000 \text{ L} = 5 \text{ mg/L}$$

$$5 \text{ mg/L} \times 1,000 \text{ μg}/1 \text{ mg} = 5,000 \text{ μg/L}$$

Units of a quantity can be converted by multiplying the quantity by an appropriate “factor-label”. In Example 1, to convert kg it is multiplied by a factor 10⁶/1 having a label mg/kg. Note that the value of factor-label fraction is one and that the label is chosen in such a way that it cancels the unit to be converted and replaces it by the desired unit. Concentrations of substances in water are expressed as a ratio, mass or volume of the substance in a given mass or volume of water.

Concentrations of substances in liquids are also expressed as a ratio of the mass of the substance to a specified mass of mixture or solution, usually as parts per million (ppm by weight).

If 1 L of solution weighs 1 kg, for 1 mg/L we can write 1 mg/L × 1 L / 1,000 g × 1 g/ 1,000 mg = 1 mg/ 10⁶ mg = 1 ppm. Therefore mg/L and ppm can be used interchangeably as long as the density of the solution can be assumed to be 1,000 g/L.

2. Elements, compounds and molecular weights

Table 3 lists some basic information regarding elements that an environmental chemist may encounter. Certain groupings of atoms act together as a unit in a large number of compounds. These are referred to as radicals and are given special names. The most common radicals are listed in Table 4. The information regarding the valence and ionic charge given in the tables can be used to write formulas of compounds by balancing +ive and -ive charges. For example, sodium chloride will be written as NaCl, but sodium sulphate will be Na_2SO_4 .

Most inorganic compounds when dissolved in water ionise into their constituent ionic species. Na_2SO_4 when dissolved in water will dissociate in two positively charged sodium ions and one negatively charged sulphate ion. Note that the number of +ive and -ive charges balance and the water remains electrically neutral.

The gram molecular weight of a compound is the summation of atomic weights in grams of all atoms in the chemical formula. This quantity of substance is also called a mole (mol). Some reagent grade compounds have a fixed number of water molecules as water of crystallisation associated with their molecules. This should also be accounted for in the calculation of the molecular weight.

Example 2

Write the molecular formula for aluminium sulphate (alum) given that the aluminium ion is Al^{3+} , the sulphate ion is SO_4^{2-} and that each molecule has 18 molecules of water of crystallisation. Calculate its molecular weight. What is the percentage of sulphur in the compound?

As the total number of +ive and -ive charges must be the same within a molecule, the lowest number of Al^{3+} and SO_4^{2-} ions which can combine together is 2 and 3 respectively so that:

Number of +ive charges on $2\text{Al}^{3+} = 6$
Number of -ive charges on $3\text{SO}_4^{2-} = 6$
Therefore the formula is $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$

The molecular weight is
 $2\text{Al}^{3+} = 2 \times 27 = 54$
 $3\text{SO}_4^{2-} = 3 \times 96 = 288$
 $18\text{H}_2\text{O} = 18 \times 18 = 324$
Total = 666

Percent sulphur = $(3 \times 32/666) \times 100 = 14.4$

Table 3 Basic Information on common elements

| Name | Symbol | Atomic Weight | Common Valence | Equivalent Weight |
|------------|--------|---------------|----------------|-------------------|
| Aluminium | Al | 27.0 | 3+ | 9.0 |
| Arsenic | As | 74.9 | 3+ | 25.0 |
| Barium | Ba | 137.3 | 2+ | 68.7 |
| Boron | B | 10.8 | 3+ | 3.6 |
| Bromine | Br | 79.9 | 1 - | 79.9 |
| Cadmium | Cd | 112.4 | 2+ | 56.2 |
| Calcium | Ca | 40.1 | 2+ | 20.0 |
| Carbon | C | 12.0 | 4- | |
| Chlorine | Cl | 35.5 | 1- | 35.5 |
| Chromium | Cr | 52.0 | 3+ | 17.3 |
| | | | 6+ | |
| Copper | Cu | 63.5 | 2+ | 31.8 |
| Fluorine | F | 19.0 | 1- | 19.0 |
| Hydrogen | H | 1.0 | 1+ | 1.0 |
| Iodine | I | 126.9 | 1- | 126.9 |
| Iron | Fe | 55.8 | 2+ | 27.9 |
| | | | 3+ | |
| Lead | Pb | 207.2 | 2+ | 103.6 |
| Magnesium | Mg | 24.3 | 2+ | 12.2 |
| Manganese | Mn | 54.9 | 2+ | 27.5 |
| | | | 4+ | |
| | | | 7+ | |
| Mercury | Hg | 200.6 | 2+ | 100.3 |
| Nickel | Ni | 58.7 | 2+ | 29.4 |
| Nitrogen | N | 14.0 | 3- | |
| | | | 5+ | |
| Oxygen | O | 16.0 | 2- | 8.0 |
| Phosphorus | P | 31.0 | 5+ | 6.0 |
| Potassium | K | 39.1 | 1+ | 39.1 |
| Selenium | Se | 79.0 | 6+ | 13.1 |
| Silicon | Si | 28.1 | 4+ | 6.5 |
| Silver | Ag | 107.9 | 1+ | 107.9 |
| Sodium | Na | 23.0 | 1+ | 23.0 |
| Sulphur | S | 32.1 | 2- | 16.0 |
| Zinc | Zn | 65.4 | 2+ | 32.7 |

Table 4 Common radicals in water

| Name | Formula | Molecular Weight | Electrical Charge | Equivalent Weight |
|-------------------------------|---------------------------|------------------|-------------------|-------------------|
| Ammonium | NH_4^+ | 18.0 | 1+ | 18.0 |
| Hydroxyl | OH^- | 17.0 | 1- | 17.0 |
| Bicarbonate | HCO_3^- | 61.0 | 1- | 61.0 |
| Carbonate | CO_3^{2-} | 60.0 | 2- | 30.0 |
| Orthophosphate | PO_4^{3-} | 95.0 | 3- | 31.7 |
| Orthophosphate, mono-hydrogen | HPO_4^{2-} | 96.0 | 2- | 48.0 |
| Orthophosphate, di-hydrogen | H_2PO_4^- | 97.0 | 1- | 97.0 |
| Bisulphate | HSO_4^- | 97.0 | 1- | 97.0 |
| Sulphate | SO_4^{2-} | 96.0 | 2- | 48.0 |
| Bisulphite | HSO_3^- | 81.0 | 1- | 81.0 |
| Sulphite | SO_3^- | 80.0 | 2- | 40.0 |
| Nitrite | NO_2^- | 46.0 | 1- | 46.0 |
| Nitrate | NO_3^- | 62.0 | 1- | 62.0 |
| Hypochlorite | OCl^- | 51.5 | 1 - | 51.5 |

3. Equivalent weights and chemical reactions

Table 3 and Table 4 also give the valence and equivalent weights of the listed substances. Valence is determined as (1) the absolute value of ion charge, (2) the number of H⁺ or OH⁻ a specie can react with, or (3) the absolute value of change in charge on a specie when undergoing a chemical reaction. The equivalent weight is determined by dividing the atomic or molecular weight by the valence. A major use of the concept of equivalents is that one equivalent of an ion or molecule is chemically equivalent to one equivalent of a different ion or molecule.

Example 3

Express 120 mg/L Ca²⁺ concentration as CaCO₃.

$$\begin{aligned} 120 \text{ mg Ca}^{2+}/\text{L} &= 120 \text{ mg Ca}^{2+}/\text{L} \times 1 \text{ meq}/20 \text{ mg Ca}^{2+} \times 50 \text{ mg CaCO}_3/1 \text{ meq} \\ &= 300 \text{ mg CaCO}_3/\text{L} \end{aligned}$$

A balanced chemical equation is a statement of combining ratios that exist between reacting substances. Consider the reaction between NaOH and H₂SO₄:



It is seen that 2 moles (80g) of NaOH react with 1 mole (98g) of H₂SO₄. In terms of equivalents, the number of equivalents of NaOH (80 {molecular weight} divided by 40 {equivalent weight} = 2) is the same as that of H₂SO₄ (98 {molecular weight} divided by 49 {equivalent weight} = 2). Stated differently, in a balanced chemical reaction the number of equivalents of combining reactants is the same. This concept is utilised in determination of unknown quantities in titrimetric analyses described in the following section.

4. Titrimetric methods of analysis

Titrimetric or volumetric method makes use of standard solutions, which are reagents of exactly known strength. It involves determining the exact volume of the standard required to react completely with the unknown substance contained in a known weight or volume of the sample. The standard can be of highest known purity and stable under conditions of storage, called a primary standard. If it is unstable, it is necessary to determine the purity of the standard periodically. Such a standard is called a secondary standard.

The strength of standard solutions is defined in terms of either normality (N) or molarity (M). A 1.0N solution contains one equivalent weight of the substance in 1L of the solution. For a given reaction, if one is fixed the other is also known. A 0.05M H₂SO₄ will be 0.1N (2 equivalents/ mole), since one mole of sulphuric acid combines with two moles of hydroxyl ion, Equation (1).

Example 4

Calculate the number of meq of H₂SO₄ present in 35 mL of 0.1N standard solution.

The strength of 0.1N solution = 0.1eq/L = 0.1meq/mL

Therefore number of meq present in 35 mL = 0.1meq/ml x 35 mL = 3.5 meq.

One of the requirements of titrimetric analyses is that it should be possible to know the exact volume of the standard consumed by the unknown substance in the sample. This is achieved by using an indicator in the reaction mixture. The indicator causes a visual change in the appearance of the mixture as soon as the reaction is complete.

Example 5

Calculate the concentration of alkali present in a sample when 50 mL aliquot of the sample consumed 12.4 mL of 0.1N standard H₂SO₄. Express your result in meq/L, mg NaOH/L, mg CaCO₃/L.

Standard acid consumed = 0.1 meq/mL x 12.4 mL = 1.24 meq

Therefore, the concentration of alkali in the sample

= 1.24 meq/50 ml x 1000 mL/1 L

= 24.8 meq/L

= 24.8 meq/L x 40 mg NaOH/meq

= 992 mg/L as NaOH

= 24.8 meq/L x 50 mg CaCO₃/meq

= 1240 mg/L as CaCO₃

5. Significant figures

If individuals in a group are asked to measure a line exactly 6 cm and 4 mm long using a scale marked in cm graduations only, they may report the result as 6.3, 6.2, 6.5, 6.4, 6.6 cm, etc. To avoid ambiguity in reporting results or in presenting directions for a procedure, it is the custom to use significant figures only. In a significant figure all digits are expected to be known definitely, except the last digit, which may be in doubt. Thus in the above example there are only two significant figures (the figure before the decimal point is certain, after the decimal point the figure is based on an estimation between two graduations of the scale). If more than a single doubtful digit is carried, the extra digit or digits are not significant.

Round off by dropping digits that are not significant. If digits greater than 5 are dropped increase the preceding digit by one unit; if the digit is less than 5, do not alter preceding digit. If the digit 5 is dropped, round off the preceding digit to the nearest even number: thus 2.25 becomes 2.2 and 2.35 becomes 2.4.

The digit 0 may at times introduce ambiguity. If an analyst calculates total residue of 1146 mg/L, but realises that 4 is somewhat doubtful and therefore 6 has no significance, he may round off the result and report it as 1150 mg/L. Obviously he can not drop the digit 0, although it has no significance. The recipient of the result will not know if the digit 0 is significant or not.

Zeros bounded by other digits only on the right side only are never significant. Thus, a mass of 21.5 mg has three significant figures. Reported in g, the value will be 0.0215, which will again have 3 significant digits.

In most other cases, there will be no doubt as to the sense in which the digit 0 is used. It is obvious that the zeros are significant in such numbers as 104 5.000 and 40.08.

A certain amount of care is needed in determining the number of significant figures to carry in the result of an arithmetic operation. When numbers are added or subtracted, the number that has fewest decimal places, not necessarily the fewest significant figures, puts the limit on the number of places that justifiably may be carried in the sum or difference. The sum $0.0072 + 12.02 + 488 = 500.0272$, must be rounded off to 500, because one of the numbers, 488, has no decimal places.

For multiplication or division, round off the result of the calculation to as few significant figures as are present in the factor with the fewest significant figures. For example, for the calculation $(56 \times 0.003462 \times 43.22) / 1.684$, the result 4.975740998, may be rounded off to 5.0, because one of the components, 56, has only two significant figures.