Chemical Measurements

Unit 1: Some Basic Concepts in Chemistry

Topics: Physical quantities and their measurements in Chemistry; Precision and Accuracy; Significant Figures; SI Units; Dimensional Analysis

Properties of Matter

All substances have various characteristic properties. These properties can be physical or chemical.

Physical properties can be measured/observed without changing the identity of a substance. (*Eg: Color, Mass, Melting and Boiling Point*)

On the other hand, the measurement of **Chemical properties** require the occurence of a chemical change. (*Eg: Acidity, Basicity, Combustibility*)

Measuring Physical Properties

Physical properties such as mass, length, volume, etc. are quantitative in nature, and are expressed by a number followed by units.

47 km

SI Units

By convention, scientists use the **SI System of Units** as a standard for measurement of various physical properties.

In the SI system, units for **seven** base quantities are defined. (See Figure 1.) All the other quantities can be derived by from the base quantities.

Derived Units
SI Units for quantities such as speed, force, energy can be derived from the seven base units.

$$\text{Speed} : \mathrm{m\,s^{-1}}$$

$$\text{Force} : \mathrm{kg\,m\,s^{-2}}$$

$$\text{Energy} : \mathrm{kg\,m^2\,s^{-2}}$$

Common prefixes

These prefixes are used with the SI units to express a large or small quantities.

Multiple	Prefix	Symbol
10^{-15}	femto	f
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T

Physical Properties

Mass

In the SI system, mass is measured in kg. However, in a laboratory, g is used due to small amounts of chemicals used.

Unit	Symbol	Measure of	Definition
second	s	Time	The duration of a given number of oscillations of the caesium-133 atom
metre	m	Distance	The length of the path travelled by light in a vacuum during a certain fraction of a second
mole	mol	Amount	The amount of substance which contains as many elementary particles as there are atoms in 0.012 kg of carbon-12
ampere	A	Current	The current in two parallel conductors of infinite length and placed 1 metre apart in a vacuum, which would produce between them a force of 2×10^{-7} N.m^{-1}
candela	cd	Luminous intensity	Luminous intensity, in a given direction, of a source that emits monochromatic light at a specific frequency
kilogram	kg	Mass	The mass of the international prototype of the kilogram held in Sèvres, France
kelvin	K	Temperature	1/273.16 of the thermodynamic temperature of the triple point of water

Figure 1: Definition of SI Base units

In chemistry, the terms 'weight' and 'mass' are often interchangably used.

Volume

The SI unit of volume is m^3. In a chemical laboratory, cm^3 or dm^3 is often used.

A common unit of volume is l, which is used for measurement of volume of liquids.

$$1\ l\ = 1\,\mathrm{dm}^3 = 1000\,\mathrm{cm}^3$$

The volumes of liquids can be measured using laboratory devices like **burette**, **pipette**, and **graduated cylinder**.

Density

Density refers to the amount of mass of a substance per unit volume. If density is more, it means particles are more closely packed.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\text{SI unit of density} \rightarrow \mathrm{kg\,m^{-3}}$$

In a lab, density is often expressed in $\mathrm{g\,cm^{-3}}$

Temperature

The SI Unit of temperature is Kelvin (K). However, around the world people use °C and °F to measure temperature.

$$^\circ\mathrm{F} = \frac{9}{5}(^\circ\mathrm{C})\ \ 32$$

$$\mathrm{K} = {}^\circ\mathrm{C}\ \ 273.15$$

In the Kelvin scale, the temperature 0 K is referred to as the **absolute zero**, as it is the minimum temperature possible.

Scale	**Water Freezing**	**Water Boiling**	**Room Temperature**
°C	0 °C	100 °C	25 °C
°F	32 °F	212 °F	77 °F
K	273.15 K	373 K	298 K

Scientific Notation

To express very large or very small numbers, we use scientific notation.

Here, the number is expressed as a product of N and 10^n where N is a number from 1 to 10 (not including 10), and n is any integer.

$$N \times 10^n \qquad (0 \leq N < 10;\ n \in \mathbb{Z})$$

$$0.00016 = 1.6 \times 10^{-4}$$
$$232.508 = 2.32508 \times 10^2$$
$$200000 = 2 \times 10^5$$

- The exponent is equal to the number of places the decimal point was shifted.
- If the point is shifted to the right (the number is increased), then the exponent is negative. (and vice versa)

Operations on numbers in Scientific Notation

- **Multiplication and Division**: Numbers can be directly multiplied when in scientific notation. Here, the exponents add/subtract accordingly.

$$(1.6 \times 10^9) \times (6.9 \times 10^{-3})$$

$$= 1.6 \times 6.9 \times 10^6$$
$$= 11.04 \times 10^6$$

- **Addition and Subtraction**: We need to convert both the numbers to have the same exponent in order to add or subtract them.

$$(1.6 \times 10^9)(6.4 \times 10^8)$$

$$(16 \times 10^8)(6.4 \times 10^8)$$
$$22.4 \times 10^8$$

Rounding Off Results

Often, we will need to round off numbers to indicate the amount of precision in the answer. (In this section, all numbers are rounded off to the nearest tenths as an example.)

Steps to round off a number

- If the digit to be removed is more than 5, the preceding number is increased by 1.

$$32.47 \rightarrow 32.5$$

- If the digit to be removed is less than 5, the preceding number is not changed.

$$32.43 \rightarrow 32.4$$

- If the digit to be removed is 5, then:
  - the preceding number is not changed if it is even.
  - the preceding number is increased by 1 if it is odd.

$$32.45 \rightarrow 32.4$$

$$32.75 \rightarrow 32.8$$

Precise and Accurate Measurements
Precision refers to the closeness of two results with each other. (1.93 and 1.95)
Accuracy refers to the agreement of a result with the true value. (1.99 and the true value is 2.00)

Significant Figures

Whenever we make a measurement: say 35.45 g, there is bound to be some error. Errors in measurement can arise due to a variety of reasons, primarily due to the capabalities of the measuring device.

For example, lets say you measure the length of an object to be 10.3 cm using a 30 cm ruler. It is important to note that the least count the ruler is 0.1 cm = 1 mm. Therefore, it is possible that the actual length of the object is not actually 10.3 cm, some value close to (higher or lower than) 10.3 cm which cannot be accurately measured by the ruler. On measuring the object with a vernier calipers, we find that the actual length is 10.3124 cm.

$$\text{Measurement} = 10.3 \text{ cm}$$

$$\text{Actual Value} = 10.3124 \text{ cm}$$

Here, we observe, that last digit of the measurement, 3 uncertain. On accounting for the error in the measurement, we can write the value as 10.3 ± 0.1 cm, meaning the 10 is certain, and the 3 is uncertain.

Significant Figures are *meaningful digits* which include all the digits which are known with certainty, plus one digit which is estimated or uncertain. The uncertainity is indicated by the last significant digit, which is uncertain. Thus, by convention, in the measurement 11.46 L, the uncertainity is ± 1 in the last digit, 6.

Determining Significant Figures

- All non-zero digits are significant.
  - Eg: 13.24 mg has 4 significant figures.
- Zeroes before the first significant digit are insignificant.
  - Eg: 0.057 m has 2 significant figures.
- Zeroes between two non-zero digits are significant.

  - Eg: 1.02 km has 3 significant figures.
- Zeroes at the end of the number are significant, if they are at the right of the decimal point.
  - Eg: 0.400 g has 3 significant figures.[1]
- Zeroes at the end of the number maybe insignificant when there is no decimal point. Otherwise, the uncerainty is ambiguous. (To avoid ambiguity, these numbers are better represented in scientific notation.)
  - Eg: 100 m: Here, it is not clear whether the uncertainty in measurement is 1, 10 or 100. Generally, we assume that the 00 in 100 are estimated and do not represent the actual measurement. Thus, it has only 1 significant digit.
  - Eg: 100. m has 3 significant figures. The decimal point indicates that 100 is the actual measured value.
  - Eg: 100.0 m has 4 significant figures.
- Counting numbers have infinite significant figures. This is because there is no error in the measurement.
  - Eg: The measurement "30 eggs" has ∞ significant figures.
- When numbers are written in scientific notation, all digits are significant.
  - Eg: 6.022×10^{23} has 4 significant figures.
  - Eg: 2.40×10^{-5} has 3 significant figures.

Operations of Significant Figures

Addition and Subtraction

The result cannot have <u>more digits after the decimal point</u>, than the original numbers.

$$\begin{aligned} 12.11 + 18.0 + 1.012 &= 31.122 \\ &= 31.1 \end{aligned}$$

Here, since 18.0 only has one decimal place, the result should be reported with only one digit after the decimal point.

Multiplication and Division

The result cannot have <u>more significant figures</u>, than the original numbers.

$$\begin{aligned} 12.64 \times 0.12 &= 1.5168 \\ &= 1.5 \end{aligned}$$

[1]Here, 4.00 g is different from 4 g, because the two extra zeroes indicate that the measurement is more precise, i.e. 4 ± 0.01 rather than 4 ± 1. Thus, it has more significant figures.

Here, since 0.12 only has two significant figures, the result should be reported with only two significant figures.

Dimensional Analysis

Dimensional Analysis or the **Unit Factor Method** is a method to convert measurements into different units.

Eg: Convert 2 L to m^3.

$$
\begin{aligned}
1\ \text{L} &= 100\ \text{cm}^3 \\
\implies 1 &= \frac{1000\ \text{cm}^3}{1\ \text{L}} \\
1\ \text{m}^3 &= 10^6\ \text{cm}^3 \\
\implies 1 &= \frac{1\ \text{m}^3}{10^6\ \text{cm}^3}
\end{aligned}
$$

$$
\begin{aligned}
2\ \text{L} &= 2\ \text{L} \times \frac{1000\ \text{cm}^3}{1\ \text{L}} \times \frac{1\ \text{m}^3}{10^6\ \text{cm}^3} \\
2\ \text{L} &= 2 \times 10^{-3}\ \text{m}^3
\end{aligned}
$$

Here, fractions such as $\frac{1000\ \text{cm}^3}{1\ \text{L}}$ are known as unit factors, since they are equal to 1. These can be multiplied to a measurement without changing its value.

Questions

1. How many significant figures will be present in the result of this calculation?

$$\frac{2.5 \times 1.25 \times 3.5}{2.01}$$

2. What is the difference between expressing the weight of a solid as 36.5×10^3 g and 36.50×10^3 g?

3. A student performs a titration with different burettes and finds titre values of 25.2 mL, 25.25 mL, and 25.0 mL. The number of significant figures in the average titre value is ____________. **[IIT-JEE 2010]**

4. A measured temperature on Fahrenheit scale is 200 °F. What will this reading be on celsius scale?

5. In which of the following numbers all zeros are significant?

   (A) 0.500
   (B) 30.000
   (C) 0.00030
   (D) 0.0050