Chapter 12

Empirical Data Collection and Analysis

Student Learning Outcomes

After studying this chapter, students will be able to:

- Explain that units are standardized for better communication and collaboration. (Some examples may include: In the field of chemistry, the International System of Units (SI) is used to measure physical quantities such as mass, volume, and temperature. This standardized system ensures that chemists worldwide can use the same units to measure and communicate their results, facilitating communication and collaboration in the field. Without standardized units, it would be difficult for chemists to compare their results with one another, and it would be challenging to develop consistent and accurate scientific models. For example, imagine if one chemist measured the mass of a substance in grams while another used ounces. The two measurements would be difficult to compare and combine, potentially leading to inaccurate or inconsistent results.)
- Identify SI units for abstract and physical quantities (some examples include mass, time and amount of matter
- Apply the concept that units can be combined with terms for magnitude, especially kilo, deci, and milli.
- Justify why chemists use cm^3, g and s as more practical units when working with small amounts in lab.
- Explain with examples how different tools and techniques can be used to manage accuracy and precision for inherent errors that arise during measurement.

Introduction

Science is a systematic study of this world through observation and experimentation. It is a method through which we make sense of this world in which we live.

Scientific research is done in all the countries of the world. But the way it is done is not identical everywhere. In order to make sure things are done properly and carefully, we need to share ideas and standardize our approach towards solving the problems.

One of the most usual problem which is faced by the scientific community is the issue of units. If scientists in one country are measuring lengths in metres and in another country in feet, then we will have to face problems in converting them. Comparing quantities in different units is not only confusing but the wastage of time as well.

For the reasons mentioned above scientists have agreed to adopt standard and user-friendly units called SI or System International Units. Things become a lot easier when we use these units.

The adoption of SI units is important in all branches of science because it makes communication easy worldwide. It allows scientists to share data easily.

SI units are preferred because they reduce the number of conversions needed to coordinate information among the scientists.

SI units use base 10, just like our number system. So, it is much easier to learn, remember and convert these units. These units are based on definite and precise standards. SI units are interrelated in such a way that one unit is derived from other units without conversion factors.

Interesting Information!

The following systems of units are commonly used in the world:
1. International System of Units (SI System)
2. Centimetre-gram-second System of Units (CGS System)
3. Metre-kilogram-second System of Units (MKS System)
4. Imperial System of Units

SI units are used almost everywhere in the world. It allows scientists to use a single standard in exchanging scientific data. This fact brings accuracy, consistency and universal understanding in scientific communication. A measurement taken in one part of the world can be easily understood and verified in another part without any confusion.

When scientists belonging to different countries and cultures collaborate on research, they need a common language to share their results. Using SI units enables scientists to compare results, replicate experiments and take benefit of each other work.

In conclusion we can say that SI units allow scientists to work together effectively, advancing the frontiers of our knowledge. All of this ensures safety, reliability, reproducibility and progress.

Exercise

1. What is the difference between reliable and reproducible results?
2. How SI units have brought harmony in the scientific community?

12.1 SI Units in Chemistry

There are seven base units in SI system for physical quantities out of which we use five in Chemistry. These physical quantities are length, time, amount of substance, mass and temperature.

12.1.1 Metre

It is the standard unit of length. Symbol **m** is used for metre. Metre is the distance travelled by light in vacuum in about 300 millionth of a second.

Fig 12.1: Metre rod

12.1.2 Kilogram

Its symbol is **kg** and it is the standard unit of mass. A block is kept in France which is taken as a standard unit of mass. It is also defined as the mass of 1000 cm^3 of water.

Fig 12.2: Different masses

12.1.3 Second

It is the standard unit of time with a symbol **s**. It is the time that elapses during 9,192,631,770 cycles of the radiation produced by the transition between two levels of the cesium-133 atom.

Interesting Information about SI Units

Symbols are not changed in plural forms. For example, 100 millimetres is written as 100 mm and not as 100 mms.

12.1.4 Kelvin

It is represented by **K** and it is the standard unit of temperature. It is $\frac{1}{273^{rd}}$ of the thermodynamic temperature of the triple point of water. It is a point at which all the states of water exist at the same time.

12.1.5 Mole

It is the base unit of the amount of pure substance and it is denoted by **mol**. It is defined as having exactly 6.022 x 10^{23} particles of a substance.

Table (12.1). Base Units of SI system

Quantity	Unit
Length	metre (m)
Time	second (s)
Amount of substance	mole (mol)
Mass	kilogram (kg)
Temperature	kelvin (K)

Derived Units

Apart from these base units, there are other quantities that are mathematically derived from these base units. Examples of the derived units used in chemistry are given in the following Table (12.2).

Table (12.2) Derived Units

Quantity	Unit
Volume	cubic metre (m^3)
Density	kg per cubic metre (kgm^{-3})
Area	square metre (m^2)

In addition to derived units, there are other specific quantities commonly used in chemistry Table (12.3).

Table (12.3) Specific Quantities used in chemistry

Quantity	Unit
Force	newton/N (kgm^{2-})
Pressure	pascal/Pa (Nm^{2-})
Energy	joule/J (Nm)

Since the SI system of units is a metric system, it is based around the number 10 for convenience. A set unit of prefixes has been developed which indicates whether the unit is a multiple or a fraction of the base ten. It allows the reduction of zeros of a very small number or a very large number. These SI prefixes also have a set of symbols that precede the unit symbol, Table (12.4).

Table (12.4) Prefixes used with SI units

Symbol	Prefix	
Mega	M	10^{6}
Kilo	k	10^{3}
Hecto	h	10^{2}
Deca	da	10^{1}
Deci	d	10^{-1}
Centi	c	10^{-2}
Milli	m	10^{-3}
Micro	u	10^{-6}
Nano	n	10^{-9}
Pico	p	10^{-12}

In Chemistry, we measure the masses of the reactants in grams. It is essential because the unit of measurement of molar mass consists of grams per mole. Therefore, given a mass measured in grams as well as a corresponding molar mass, enables us to find the mole of a substance. Moreover, in Chemistry the quantities involved in the laboratory are likely to be small. The choice of gram rather than kg is therefore sensible and normal. Using grams provides more manageable numbers for calculation and prevents the need for excessively large or small values.

Similarly, Celsius scale is most often used to measure temperature in Chemistry rather than Kelvin because it is more convenient to use it. Celsius scale has 100 divisions in total which makes it more compatible with the base ten format of SI system. Another reason is that it is easier to convert temperature on Celsius scale into Kelvin scale. The following equation is used for this conversion.

$$K = °C + 273$$

The unit of measurement of volume in Chemistry is cubic centimetre (cm^3) instead of cubic metre (m^3) because it is easy to measure and calculate with it and it is precise. In laboratory, we usually measure smaller volumes of liquid which are more manageable in cubic centimetre rather than cubic metre.

12.2 Tools and Techniques to Manage Accuracy and Precision

Measurement is the foundation for all experiments in science. Every measurement carries a level of uncertainty which is known as **error**. An error may be defined as the difference between the measured value and the actual value. For example, if two students use the same tool or instrument for measurement, it is not necessary that both of them get similar results. The difference between the measurements is called an error. An error may occur due to two factors: the limitation of the measuring instrument and the skill of the student making the measurement.

When we use tools meant for measurement, we assume that they give correct results. However, these tools may not always be right. In fact, they have errors that naturally occur and these errors are called **systematic errors**. Systematic errors may be removed by adding or subtracting a constant adjustment given to each measurement. Systematic error affect the accuracy of the measurement. All measuring instruments contribute to systematic error e.g. pipette, burette and measuring cylinder may deliver the volume slightly different from the one indicated by their graduation.

Another type of error which a student commits during measurement is called a **random error**. Random error causes one measurement to differ slightly from the next measurement. It comes from unpredictable changes during an experiment. The main reasons for random errors are limitations of instruments, environmental factors and slight variation in procedure. For example, when taking a volume reading from a measuring cylinder, you may read the volume from a different angle each time. Measuring the mass of a sample on a balance may give you different values as the surrounding air affects the balance. A random error often determines the precision of the experiment. The goal of any experiment is to obtain accurate and precise results.

12.3 Accuracy and Precision

Accuracy and precision are both ways to measure the correctness of results. They are used interchangeable in everyday life.

Accuracy measures how close results are to the true or known value. For example, the volume of a liquid is 26 cm^3 . A students measures its volume three times and find the result as 27cm^3. The student is not accurate because he has not calculated the exact result.

The closeness of two or more measurements to each other is called **precision**. For example, if you weigh a given substance five times and every time you get 3.2kg reading, then your measurement is precise but not necessarily accurate.

Precision is independent of accuracy. A student may be accurate but not precise and vice versa.

The exact mass of an object is 20 g. A student measures it and takes three readings as 17.3, 17.4 and 17.2. The student is considered as precise but not accurate. Similarly, another student measures the mass of the same object and gets readings as 19.8, 20.5 and 19.6. The second student is the more accurate but not precise.

Exercise

1. A student weighs a given substance three times, and each time he gets the reading 5.2g. The true weight of the substance is, however, 5.0g. Is the work done by the student **(i)** precise and accurate **(ii)** accurate but not precise **(iii)** precise but not accurate?
2. How will you avoid systematic and random errors?

Key Points

1. The subject of chemistry needs a consistent way to measure and to communicate the quantities like mass, volume, temperature, amount and time. To make sure that all of us can understand each other, scientists all over the world have adopted a common system of units which is based upon the metric system and it is called SI units.
2. There are seven base units and twenty two derived units in SI system but all these units are not used in Chemistry. In Chemistry we generally use five base units and three derived units.

Exercise

1. Tick (✓) the correct answer.

(i) Which of the following pairs of quantities may be measured in the same unit?

(a) Heat and temperature (b) Temperature and area
(c) Heat and work (d) Length and work

(ii) In which unit we usually measure the energy present in the food?

(a) Kilojoules (b Megajoules
(c) Calorie (d) Joule

(iii) What prefix is used for 10^{-12}?

(a) Mega (b) Pico
(c) Giga (d) Tessa

(iv) In SI unit of pressure is expressed in:

(a) Newton per metre (b) Newton per metre square
(c) Joule (d) Pascal

(v) Which symbol is used for kilogram in SI units?

(a) K (b) k
(c) Kgm (d) kg

(vi) What does a mole represent?

(a) Number (b) Mass
(c) Volume (d) Length

(vii) Which unit of volume should usually be used in Chemistry?

(a) Millilitre (b) Litre
(c) Cubic centimetre (d) Cubic metre

(viii) Express 0.000840 in scientific notation:

(a) 8.40×10^{-3} (b) 840×10^{-6}
(c) 8.40×10^{-4} (d) 84.0×10^{-5}

(ix) In SI units prefix nano means:

(a) 10^{-9} (b) 10^{-8}
(c) 10^{-11} (d) 10^{-12}

(x) $65^{o}C$ is equivalent to:

(a) 208 K (b) 338 K
(c) 403 K (d) 300 K

2. Questions for Short Answers

i. What is consistency of results?
ii. Why SI units are user friendly?
iii. Define systematic error and random error.
iv. What is reason behind a random error?
v. Does systematic error affect the accuracy?
vi. Which other systems of measurements are used apart from SI units?
vii. Define metre.
viii. Mention two benefits scientists get by using SI units.

3. Constructed Response Questions

i. Compare the units in SI system with those in MKS system?
ii. What are five basic SI units which are used in Chemistry?
iii. Explain the three units derived for the basic SI units.
iv. Explain why do we prefer to use smaller units of mass and volume in Chemistry?
v. What difficulties we expect to encounter if we use different units of measurement in daily life.

4. Descriptive Questions

i. What are our indigenous units of measurement of mass, volume and length?
ii. Elaborate the difference between precision and accuracy.
iii. How can you avoid systematic errors in your measurements?
iv. How do taking measurements in SI units ensure safety and reliability?
v. Can a student be both inaccurate and imprecise in his measurements?

5. Investigative Question

i. Elaborate the importance of using SI units in space exploration.