UNIT 16

EMPIRICAL DATA COLLECTION AND ANALYSIS

Student Learning Outcomes (SLOs)

After completing this lesson, the student will be able to:

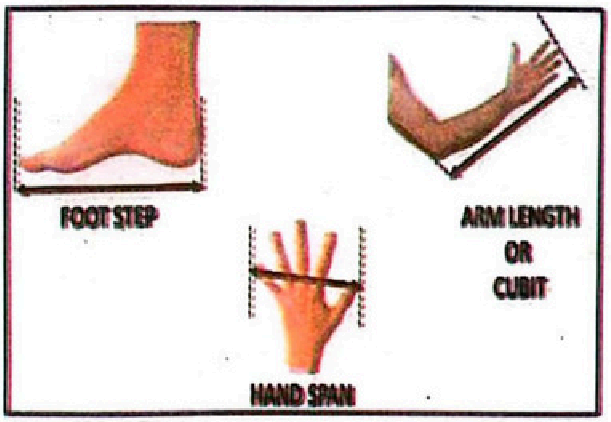
- Explain that units are standardized for better communication and collaboration
- Identify SI for abstract and physical quantities
- Apply the concept that units can be combined with terms for magnitudes, especially for kilo, Deci, and Milli.
- Justify why chemists use cm^3, g, and s as more practical units when working with small amounts in the lab.
- Explain with examples how different tools and techniques can be used to manage accuracy and precision for inherent errors that arise during measurement.

- Scientific narration standard form
- Use the standard form $A\times10^n$ where n is a positive or negative integer and is $1 < A < 10$"
- Convert quantitative values into and out of the scientific notation form.
- Identify appropriate apparatus for measurement of time, temperature, mass, and volume, including
    1. Stopwatch
    2. Thermometer
    3. Balances
    4. Burrettes
    5. Volumetric pippetes
    6. Measuring cylinders
    7. Gas syringes
- Suggest advantages and disadvantages of experimental methods and apparatus

16.1 STANDARD UNITS

Measurement is an essential requirement to keep accuracy in our daily life. ***Measurement is a comparison of an unknown quantity with a known fixed quantity.*** For example, when you feel sick, your mother measures your body temperature with the help of a thermometer. The thermometer shows a 102°F temperature. So, do you have a fever? Yes, since our normal body temperature is 98.6°F, any value above it confirms that you are suffering from fever. It means that by measuring your body temperature, she will know exactly if you have a fever or not. So, Accurate, precise measurement is a fundamental component of chemistry.

In the past, people didn't have accurate measuring methods to calculate standard measurements. People used **abstract units** to measure with. For example, when an object was measured with a cubit or hand span, its length varied from person to person. The simple reason for the variation was the difference in the size of the cubit or hand-span of each person. Thus, this system of measurement was inconvenient as well as inaccurate. So, to maintain uniformity in measurement, scientists from all over the world accepted some of the units as standard units. This set of units is generally referred to as Standard International or SI system of units.



In 1960, scientists from different parts of the world gathered and agreed to adopt a single system of units called **the International System of Units or SI units.**

In the field of chemistry, the international system of units (SI) is used to measure physical quantities such as mass, volume, and temperature. This standard system ensures that chemists around the world can use the same units to measure and communicate their results, facilitating communication and collaboration in the field. Without standard units, it would be difficult for chemists to compare the results with one another, and it would be challenging to develop consistent and accurate scientific models.

During measurement, we compare the unknown quantity of things or substances with a known fixed quantity. This fixed quantity with which we compare unknown quantities is called a **unit of measurement.** The **standard unit** of measurement is a value that is fixed and cannot be changed.

Physical quantity:

A quantity that can be measured is called physical quantity. For instance, mass, amount of substance, length, time, temperature, etc.

16.1.1 SI UNITS

The entire metric system is composed of two different types of units, namely, fundamental units and derived units. The units are standard used to measure physical quantities, such as mass or length. There are seven units called Fundamental Units (or Base Units). These are used to measure different physical quantities. The kilogram, meter, and second are the fundamental base units. Whereas all other units that are derived from fundamental units are called **Derived Units.** So derived units are not independent; they are composed of two or more fundamental units.

Table 16.1: Fundamental units

S.no.	Physical Quantity	Unit	Symbol
1	Mass(m)	Kilogram	kg
2	Length (L)	Meter	m
3	Time (t)	Second	s
4	Temperature	Kelvin	K
5	Quantity of substance	Mole	mol
6	Electric current	Ampere	A
7	Luminous intensity	Candela	cd

16.1.2 SI Prefixes

The SI system develops a standard system of prefixes to the basic units, Prefixes are used to identify the original unit's multiples or fractions.

Table 16.2: Prefixes for measurements

Prefix	Unit abbreviation	Meaning	Example	Abbreviation
Kilo	k	1000	1 kilometer (km) = 1000 m	10^3m
hector	h	100	1 hectometer (hm) = 100 m	10^2m
Deca	da	10	1 decameter (dam) = 10m	10^1 m
			1 meter	10^0
Deci	d	1/10	1 decimeter (dm) = 0.1 m	10^{-1}m
Centi	c	1/100	1 centimeter (cm) = 0.01 m	10^{-2}m
Milli	m	1/1,000	1 millimeter (mm) = 0.001 m	10^{-3} m

Prefixes are also used to specify the number of atoms of each element in a molecule of the compound. When naming a binary molecular compound, the subscript for each element determines what prefix should be used.

The prefixes are written at the beginning of the name of each element. The following are the prefixes used for naming binary molecular compounds.

Greek Prefixes Used in Naming Molecular Compounds

Prefix	Meaning
Mono-	1
Di-	2
Tri-	3
Tetra-	4
Penta-	5
Hexa-	6
Hepta-	7
Octa-	8
Nona-	9
Deca-	10

Binary Molecular Compounds

Formula	Name
CO	carbon monoxide
CO_2	carbon dioxide
SO_2	sulfur dioxide
NO	nitrogen monoxide
S_2Cl_2	disulfur dichloride
N_2O	dinitrogen monoxide
CCl_4	carbon tetrachloride
PCl_5	phosphorus pentachloride

16.2 CONVERSION AND THE IMPORTANCE OF UNITS:

The ability to convert from one unit to another is essential in scientific methods.

For example, a nurse has a tablet of 50 mg She has to give 0.2 g of tablet to a patient. She needs to know that 0.2 g equals 200 mg so 4 tablets are needed. There is a simple way to convert from one unit to another.:

LENGTH CONVERSION (Converting smaller units into larger units)					
10 millimeters	=	1 centimeter	10 mm	=	1 cm
10 centimeters	=	1 decimeter	10 cm	=	1 dm
100 centimeters	=	1 meter	100 cm	=	1 m
1000 meters	=	1 kilometer	1000 m	=	1 km

TIME CONVERSION (Converting smaller units into larger units)		
60 seconds	=	1 minute
60 minutes	=	1 hour
24 hours	=	1 day
7 days	=	1 week
365 days	=	1 year

MASS CONVERSION (Converting smaller units into larger units)		
100 miligrams	=	1 gram
1000 grams	=	1 kilogram

In the laboratory, chemists use cm^3 (cubic centimeters), g (grams), and s (seconds) as more practical units when working with small amounts in the lab for several reasons

- **Appropriateness:** The use of cm^3 allows chemists to easily measure and calculate the volume of liquids and solids. It is a smaller unit than liters and is more suitable for measuring small volumes accurately.
- **Precision:** To have precise measurements the use of grams as a unit of mass provides a more accurate and consistent measurement compared to larger units like kilograms.
- **Compatibility:** The use of these units ensures compatibility with a wide range of laboratory equipment and instruments. The use of smaller units makes it easier to perform experiments and obtain accurate results.
- **Time-sensitive reactions:** In chemistry, time plays a significant role in various reactions. Using seconds as a unit of time allows chemists to accurately measure reaction rates, reaction times, and other time-dependent parameters.
- **International Standards:** The International System of Units (SI) recommends the use of these units for scientific measurements. This standardization ensures uniformity and helps communication between scientists worldwide.

DO YOU KNOW?

The SI unit for volume is the cubic meter (m^3). The cubic centimeter (m^3), the liter (l), and the milliliter (ml) are also used.

1 liter(l) = 1000 milliliters (ml)

1 liter(l) = 1 decimeter cube (dm^3)

1 decimeter cube(dm^3) = 1000 cubic centimeters (cm^3)

1000 cubic centimeters (cm^3) = 1 liter (l)

16.3 SCIENTIFIC NOTATION:

Scientific notation or Standard form is used to represent very large or very small numbers in the form of multiplication of single-digit numbers and exponent raised to the power of 10. Scientific notation simplifies calculations, comparisons, and communication of measurement involving very large or very small numbers. It is a powerful tool for expressing the magnitudes of quantities used in everyday life.

For example, 650,000,000 can be written in scientific notation as 6.5×10^8.

The magnitude of any physical quantity can be expressed as:

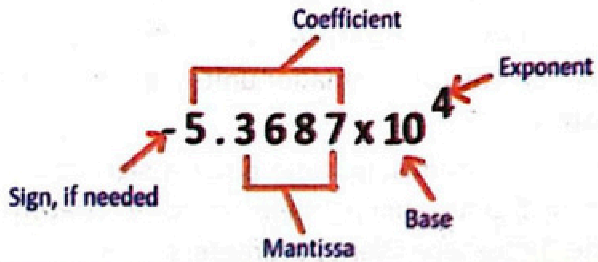
$$a \times 10^n$$

$1 \le a < 10$ n is an integer

$$A \times 10^n$$

Where A is any number greater than or equal to 1 and less than 10 and n is any integer (whole number), negative or positive.

The exponent of base 10 determines how big or small the number. The exponent is positive if the number is very large, and it is negative if the number is very small. Numbers in **scientific notation or standard form** are expressed as a multiple of a power of ten.



Example 16.1:

Is the following number written in standard form?

$$14 \times 10^5$$

Solution:

A number is not written in standard form as A must be a number less than 10 and greater than or equal to 1. A is given as 14 which is greater than 10. This number is standard form would be:

$$1.4 \times 10^6$$

16.3.1 Scientific Notation Rules

To determine the power or exponent of 10, we must follow the rule listed below:

- The base should always be 10.
- The exponent must be a non-zero integer, which means it can be either positive or negative.
- The absolute value of the coefficient is greater than or equal to 1 but it should be less than 10.
- Coefficients can be positive or negative numbers including whole and decimal numbers.
- The mantissa carries the rest of the significant digits of the number.

Let us understand how many places we need to move the decimal point after the single-digit number with the help of the below representation.

- If the given number is greater than 10 then the decimal point has to move to the left, and the power of 10 will be positive.

  Example: $6000 = 6 \times 10^3$ is in scientific notation.

- If the given number is smaller than 1, then the decimal point has to move to the right, so the power of 10 will be negative.

  Example: $0.006 = 6 \times 0.001 = 6 \times 10^{-3}$ is in scientific notation.

Scientific Notation Examples

$$490000000 = 4.9 \times 10^{8}$$
$$1230000000 = 1.23 \times 10^{9}$$
$$50500000 = 5.05 \times 10^{7}$$
$$0.000000097 = 9.7 \times 10^{-8}$$
$$0.0000212 = 2.12 \times 10^{-5}$$

Example 16.2:

Convert 0.00000046 into scientific notation.

- **Solution:** Move the decimal point to the right of 0.00000046 up to 7 places.
- The decimal point was moved 7 places to the right to form the number 4.6.
- Since the numbers are less than 1d the decimal is moved to the right. Hence, we use a negative exponent here.

$$\Rightarrow 0.00000046 = 4.6 \times 10^{-7}$$

This is the scientific notation.

EXAMPLE 16.3: Convert 12 kilograms to milligrams.

Solution:

To convert from a larger unit to a smaller unit, we need to multiply.

There are 1000 grams in 1 kilogram.

Therefore, 12 kilograms will have

12 ×× 1,000 = 12,000 grams

So there are 12,000 grams in 12 kilograms

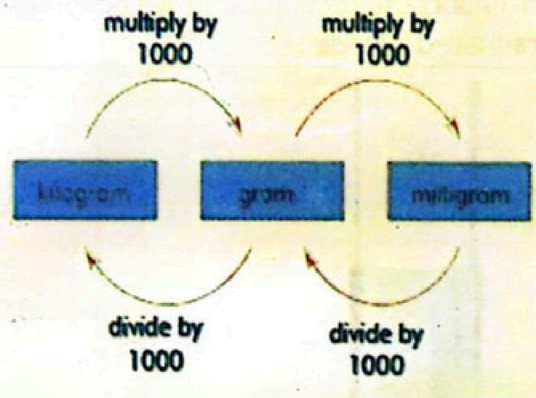
Now, there are 1000 milligrams in 1 gram.

Therefore 12 kilograms will have,

12,000 ×× 1,000 = 12,000,000 milligrams

So, there are 12,000,000 milligrams in 12,000 grams.

Hence, there are 12,000,000 milligrams in 12 kilograms.



16.3.2 Converting Ordinary Form to Standard Form:

EXAMPLE	ORDINARY NOTATION	STANDARD NOTATION
Diameter of Earth	12 700 000 m	1.27×10^{7} m
Length of the great wall of china	6 400 000 m	6.4×10^{6} m
Height of a soldier	1.7 m	1.7×10^{0} m
Length of mosquito	0.01 m	1×10^{-2} m
Length of red blood cell	0.0 000 075 m	7.5×10^{-6} m

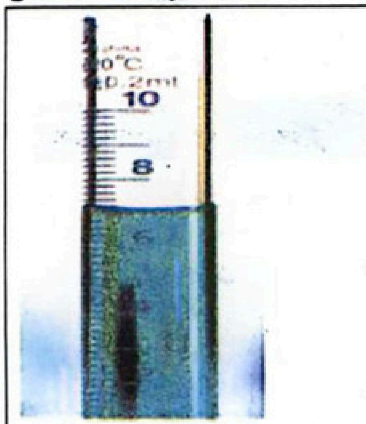
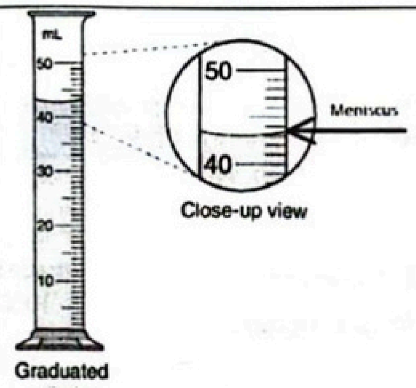
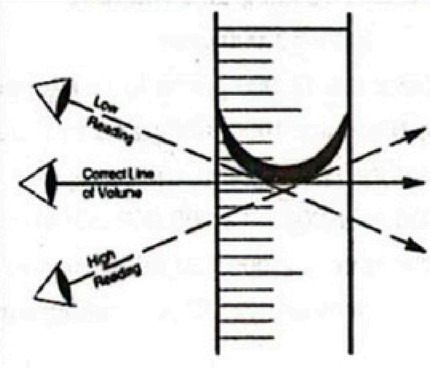
16.4 TOOLS AND TECHNIQUES USED IN EXPERIMENTAL METHODS FOR ACCURACY AND PRECISION OF RESULTS

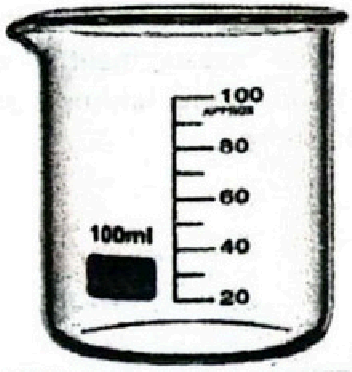
Inaccurate and Imprecise | **Inaccurate but Precise** | **Accurate and Precise**

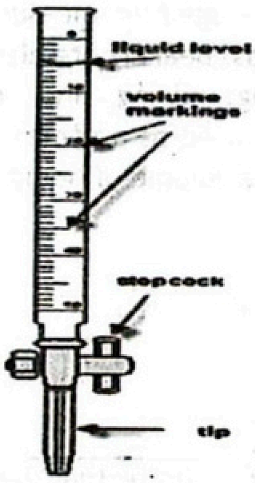
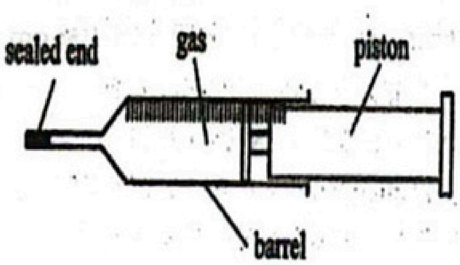
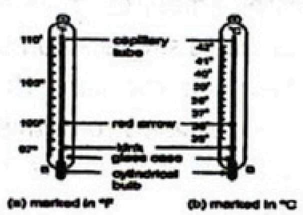
When making measurements, it is important to be as accurate and precise as possible. Accuracy is a measure of how close an experimental measurement is to the true value. Precision refers to how close repeated measurements (using the same device) are to each other. In general, within the laboratory, accuracy is a measure of how well your equipment is adjusted. For example, if your balance is not adjusted correctly, you can make very precise, repeated measurements, but the measurements will not represent the true value. Precision, on the other hand, is usually determined by how careful the scientist is in making measurements. If you are careless and spill part of your sample on the way, your measurements in repeated experiments will not be precise even if your balance is accurate. Different tools and techniques can be used to manage accuracy and precision for inherent errors that arise during measurement

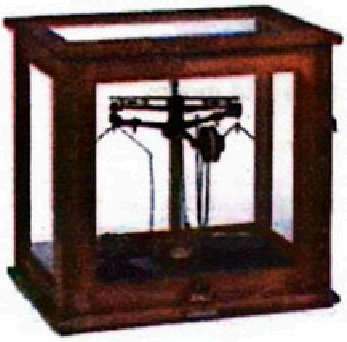
16.5 TECHNIQUE AND TOOLS FOR ACCURATE MEASUREMENT IN LABORATORY:

An important technique in a chemistry lab is the ability to accurately measure a liquid in a graduated cylinder.

		 The right way to take reading
When a solution is in the graduated cylinder the liquid sticks to the sides making a 'U' shape called a meniscus. This makes it difficult to read a measuring cylinder accurately	If you are too high, you will read a smaller volume If you are too low, you will read a larger volume	When you get to 'eye level' you will read an accurate volume of water.

Beaker 	Measuring Beakers are tools used to measure the approximate volume of liquids. Beakers are also used for holding samples, stirring, mixing, and heating liquids. Beakers can also be used as a container for reactions and to estimate the volume of liquid.
Measuring Cylinder 	Measuring cylinders is more accurate than beakers. They should only be used when an approximate volume measurement is required. They are mostly found in sizes of 10 cm^3 , 25 cm^3 , 50 cm^3 and 100 cm^3
Volumetric pipettes 	Most pipettes are used to transfer amounts of up to 1-100 ml of liquids. can only measure a single volume, usually 25 cm^3 . However, they can measure this volume very accurately. They are designed to deliver the measured volume when emptied under gravity, so they hold a slightly greater volume than this. They should only be used with a pipette filler

Burette  	Burettes are designed to deliver any volume up to 50 cm^3. They are more accurate than measuring cylinders but less accurate than pipettes. The volume delivered can be deduced by subtracting the initial measurement from the final measurement. They need to be used with a stand, clamp and boss and they are mainly used in titrations.
Gas syringes  	Gas syringes are used to collect and measure the volume of gas. They have a similar accuracy to measuring cylinders.
Laboratory Thermometer  	The thermometer is used to is used for measuring temperatures other than the human body temperature. It ranges from -10˚C to 110˚C.The laboratory thermometers are used for laboratory purposes such as checking the boiling point and freezing points or temperature of other substances.
Analytical balance 	Analytical balances are precision measuring instruments used in quantitative chemical analysis. It is used to determine the mass of solid objects, liquids, powders, and granular substances.

Beam balance 	It is a valuable tool when an accurate measurement of mass is required. Doesn't require any kind of electricity for its operation.
Electronic balance 	Electronic balance is an instrument used in the accurate measurement of the weight of materials. Electronic balance is a significant instrument for laboratories for precise measurement of chemicals that are used in various experiments. Laboratory electroni c balance provides digital results of measurement.
Stopwatch 	Stopwatches and timers are instruments used to measure time intervals, which is defined as the elapsed time between two events. Stopwatches show time reading up to 2 decimal places. So, the precision of most stopwatches is 0.01 seconds.

16.6 ADVANTAGES AND DISADVANTAGES OF EXPERIMENTAL METHODS

Experimental methods have become a valuable part of human life to learn about the world around them. Chemists used different tools and techniques to perform experimental procedures. Marie Curie, Robert Boyle, Linus Pauling, Ernest Rutherford, and Antoine Lavoisier, for instance, did various experiments to uncover key concepts of chemistry. The same goes for modern experts, who utilize this scientific method to see if new drugs are effective, discover treatments for illnesses, and discover new gadgets.

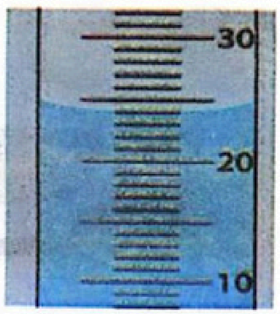
ADVANTAGES	DISADVANTAGES
It gives researchers a high level of control.	It can lead to artificial situations.
It allows researchers to utilize many variations.	It can take a lot of time and money.
It can lead to excellent results.	It can be affected by errors.
It can be used in different fields.	It might not be feasible in some situations.

KEY POINTS

- Physical quantities are measurable quantities.
- Scientific notation is an internationally accepted way of writing numbers in which numbers are recorded using the power of 10 and there is only one non-zero digit before the decimal.
- Scientific measurements use units to quantify and describe the magnitude of something. For example, scientists quantify length in meters.
- Accuracy represents how close a measurement comes to its true value.
- Precision is how close a series of measurements of the same thing are to each other.

REVIEW QUESTIONS

1. Encircle the correct answer.



(i) What is the volume of the liquid in this graduated cylinder?

(a) 23 (b) 24

(c) 25 (d) 22

(ii) How many cubic centimeters (cm^3) are there in 1 decimeter cube (1 dm^3):

(a) 100 cm^3 (b) 1000 cm^3

(c) 10 cm^3 (d) 1 cm^3

(iii) To change SI units by factors of ten into smaller or bigger units they use :

(a) Prefixes (b) symbols

(c) abbreviation (d) ratio

(iv) A distance of 1 kilometer means?

(a) 100 m (b) 1000 cm

(c) 1000 cm (d) 1000 m

(v) One nanometer is equal to:

(a) 10^{-10} m (b) 10^{-9} m

(c) 10^{-8} m (d) 10^{-7} m

(vi) The standard form of 38000000000 is:

(a) 3.8×10^{8} (b) 3.8×10^{9}

(c) 3.8×10^{10} (d) 3.8×10^{11}

(vii) The property of a measuring instrument to give the output very close to the actual value is termed as:

(a) Sensitivity (b) Accuracy

(c) Precision (d) Repeatability

(viii) The standard form of 0.0000000034 is:

(a) 3.4×10^{-8} (b) 3.4×10^{-9}

(c) 3.4×10^{-10} (d) 3.4×10^{-11}

(ix) In SI, the unit of mass is:

(a) kilogram (b) centimetre

(c) kelvin (d) millimetre

(x) In the measuring instruments, the degree of conformity and closeness to the true value is known as:

(a) precision (b) accuracy

(c) sensitivity (d) compatibility

2. Give short answer.

(I) What is system international? Why SI units are standardized for better communication and collaboration.

(ii) In a race, why it is essential to use seconds or minutes as the unit for measurement for recording the time instead of hours?

(iii) Differentiate between accuracy and precision.

(iv) A chemist has a sample of mass 0.003 kilograms. How will he convert this mass to milligrams?

(v) What is the use of prefixes in measurements?

(vi) What are the advantages of using scientific tools like measuring cylinders, stopwatch and thermometers in measurements?

3. How to Calculate the accuracy of measurements?

4. Evaluate how tools for measurements are helpful in performing scientific techniques.

5. How does scientific notation enhance the ability to communicate about extremely large and small numbers? Convince.

6. Why do scientists realize the need for a standardized system of measurement?

PROJECT

Design an experiment to determine density of a liquid.