System of Units

The principle aspects of the scientific method are accurate measurement, selective analysis, and mathematical formulation. Note that the first and most important is accurate measurements.

Measurement: is the process by which one can convert physical parameters to meaningful number.

1. **Conversion of Physical Parameters**:

Measurement involves capturing the properties of a physical entity—such as length, mass, time, temperature, or electric current—and expressing them in terms of numerical values.

Example: Measuring the temperature of water (physical parameter) and expressing it in degrees Celsius or Fahrenheit (numerical value).

2. **Meaningful Numbers**:

A measurement converts qualitative information into a quantitative form that can be compared, analyzed, or used in calculations. The "meaningful number" reflects the magnitude of the quantity with respect to a standard unit of measurement.

Example: "5 meters" signifies a length five times the standard unit of length, the meter.

3. **Process**:

The measurement process generally involves:

Detection: Using a measuring instrument or sensor to detect the parameter.

Comparison: Comparing the quantity against a defined standard (e.g., meter, kilogram, second).

Representation: Expressing the result as a number with appropriate units.

E-mail: Zainab.kadum.jaber@uomus.edu.iq

Importance of Measurement:

- Facilitates scientific discovery and technological development.
- Ensures uniformity and standardization in trade and industry.
- Enables control and optimization in processes and systems.

Applications:

- Science: Accurate measurements are crucial for experimentation and validation of theories.
- Engineering: Designing and testing require precise measurements to ensure functionality and safety.
- Daily Life: Cooking, construction, and navigation rely on measurement.

Instrument: may be defined as a device for determining the value or magnitude of a quantity or variable.

An instrument is a crucial tool in measurement systems, designed to determine the value or magnitude of a specific quantity or variable. Here's an in-depth exploration of this concept:

1. Definition

An instrument is a device, tool, or system used to:

- Detect a physical phenomenon.
- Measure the corresponding quantity.
- Display, record, or process the measurement for analysis

Key Characteristics of Instruments

1. Purpose:

To measure and quantify physical or non-physical quantities like temperature, pressure, voltage, or flow.
To facilitate accurate and reliable data collection.

2. types of Quantities Measured:

- Physical Quantities: Length, mass, time, temperature, pressure, force, etc.
- Electrical Quantities: Voltage, current, resistance, capacitance, etc.
- Chemical Quantities: pH level, concentration, etc

3. Operation Principle:

Instruments operate on specific principles, such as:

- Mechanical (e.g., spring balance for force).
- Electrical/Electronic (e.g., digital multimeter for electrical parameters).
- Optical (e.g., spectrometer for light wavelengths).

Classification of Instruments

1. Based on Functionality:

Indicating Instruments: Display the measurement in real-time (e.g., speedometer).

Recording Instruments: Keep a permanent record of measurements (e.g., ECG machine).

Integrating Instruments: Measure and totalize over time (e.g., electricity meter).

2. Based on Nature of Output:

Analog Instruments: Provide a continuous output (e.g., analog ammeter).

Digital Instruments: Provide a discrete numeric output (e.g., digital thermometer).

3. Based on Method of Use:

Manual Instruments: Require human interaction (e.g., vernier caliper).

Automatic Instruments: Operate independently (e.g., temperature controllers).

Components of an Instrument

- Sensor/Transducer: Detects the physical quantity and converts it into a readable signal.
- Signal Conditioner: Amplifies, filters, or modifies the signal for processing.
- Display/Output Device: Shows the measured value in a user-friendly format.

Importance of Instruments

1. **Accuracy**: Provide precise measurements essential for experiments, manufacturing, and quality control.
2. **Reliability**: Enable consistent and repeatable results for decision-making.
3. **Efficiency**: Simplify complex measurements, saving time and effort.
4. **Safety**: Monitor critical parameters to ensure safe operation in industrial or medical settings.

Examples of Common Instruments

1. **Ruler/Scale**: Measures length.
2. **Thermometer**: Measures temperature.
3. **Multimeter**: Measures voltage, current, and resistance.
4. **Pressure Gauge**: Measures fluid or gas pressure.
5. **Spectrophotometer**: Measures the intensity of light as a function of wavelength.

The standard measure of each kind of physical quantity is the unit; the number of times the unit occurs in any given amount of the same quantity is the number of measure. Without the unit, the number of measure has no physical meaning

A unit is the standard reference used to express the magnitude of a physical quantity. Without units, measurements lose their context and meaning

Definition of Unit

A unit is a predefined, standardized amount of a physical quantity that serves as a reference for measurement. Examples include meters for length, kilograms for mass, and seconds for time.

Physical Quantity: A characteristic or property of an object that can be quantified (e.g., mass, length, time, temperature).

Unit of Measurement: Provides a standard for comparison, enabling meaningful interpretation of the measurement.

Key Principles

1. Numerical Value and Unit:

Any measurement combines two components:

A numerical value (indicating magnitude).

A unit (providing context).

Example: If the length of a table is measured as 2 meters, "2" is the numerical value, and "meter" is the unit.

2. Physical Meaning:

Without a unit, the numerical value becomes ambiguous. For example, "10" could mean 10 meters, 10 kilograms, or 10 seconds, depending on the context.

3. Standardization:

Units ensure consistency and comparability across different measurements and systems.

Systems of Units

International System of Units (SI):

The most widely used system of units, based on seven fundamental units:

Physical Quantity	SI Unit of Measurement	Symbol
Length	Meter	m
Mass	Kilogram	kg
Temperature	Kelvin	K
Time	Second	s
Capacity/Volume	Litre	L
Current	Ampere	A
Amount of Substance	Mole	mol

E-mail: Zainab.kadum.jaber@uomus.edu.iq

The table above shows the SI units but we use other units as well to measure the given physical quantities. Let us list some of the commonly used to units of measurement below:

Length - kilometer, meter, centimeter, millimeter

Mass - kilogram, gram, milligram

Capacity - kiloliter, liter, milliliter, centiliter

Time - Minute, Hour, Second, Days, Week, Month, Year

Temperature - Kelvin, Celsius, Fahrenheit

All the above units for a specific physical quantity can be expressed in terms of each other using the conversion of the units of measurement.

Other Systems:

Imperial Units of Measurement

Physical Quantity	Imperial Units
Length	foot, inch, yard, mile
Mass	ounce, pound, stone, ton
Capacity	gallon, pint, quart, fluid ounce

Units of Measurement for Length

Length is a physical quantity that gives the measure of how long an object is. There are different aspects of measuring length such as distance covered, height, etc. Units of measurement for all the physical quantities belong to the same category. Each unit of measuring length can be expressed in terms of each other using the conversion method as these units have a standard value. Let us see the commonly used metric and imperial units of measurement of length below along with their relations with one another.

System	Units of Measurement	Conversion
Metric Units	Centimeter (cm)	1 cm = 10 mm
	Meter (m)	1 m = 100 cm
	Kilometer (km)	1 km = 1000 m
	Millimeter (mm)	1 mm = 0.001 m
Imperial Units	Foot (feet)	1 foot = 12 inch
	Inches (inch)	1 inch = 0.83333 feet
	Mile	1 mile = 5280 feet
	Yard	1 yard = 3 feet = 36 inch

Units of Measurement for Mass

Mass is a physical quantity that tells how heavy or light an object is. It is also commonly called the weight of the object. The SI unit of mass is the kilogram (kg). The table below shows the different and commonly used units of measuring mass in the metric and imperial systems along with their conversions:

System	Units of Measurement	Conversion
Metric Units	Milligram (mg)	1 mg = 0.001 g
	Gram (g)	1 g = 1000 mg
	Kilogram (kg)	1 kg = 1000 g
Imperial Units	Ounce (oz)	1 oz = 0.0625 lb
	Pound (lb)	1lb = 16 oz
	Ton	1 ton = 2000 lbs

E-mail: Zainab.kadum.jaber@uomus.edu.iq

Units of Measurement of Time

Time is a measure that tells about the time taken to complete a process, travel from one point to another. It is an ongoing process of continuous events. We measure time in three units, seconds, minutes, hours, days, weeks, months, and years..

Units of Measurement	Conversion
Second (s)	1 s = 1/60 min
Minute (min)	1 min = 60 s
Hour (hr)	1 hr = 60 min = 3600 s
Day	1 day = 24 hr
Week	1 week = 7 days
Month	1 month = 4 weeks
Year	1 year = 12 months

Fundamental and Derived Units

Fundamental Units and Derived Units form the building blocks of the measurement system, essential for defining physical quantities.

Fundamental Units

Fundamental units are the basic, irreducible units of measurement that serve as the foundation for all other units. These cannot be derived from any other units.

Examples of Fundamental Units:

- Length: Meter (m)
- Mass: Kilogram (kg)
- Time: Second (s)
- Electric Current: Ampere (A)
- Thermodynamic Temperature: Kelvin (K)
- Amount of Substance: Mole (mol)
- Luminous Intensity: Candela (cd)

Usage:

- Fundamental units are universally accepted as the building blocks for defining other quantities.
- They are part of the International System of Units (SI).

Auxiliary Fundamental Units:

When specialized fields like thermodynamics, electricity, or illumination are involved, additional fundamental units (e.g., Kelvin, Ampere, Candela) are used.

These units help measure specific properties within those domains.

Derived Units

Derived units are combinations of fundamental units, formed by multiplying or dividing them according to mathematical relationships that define a physical quantity

For

E-mail: Zainab.kadum.jaber@uomus.edu.iq

example, the voltage [volt]:

$$volt = \frac{workdone}{charge} = \frac{Joule}{coulomb} = \frac{J}{C} = \frac{Force \times distance}{current \times time} = \frac{Newton \times meter}{Amper \times second} \Rightarrow$$

$$volt = \frac{mass \times acceleration \times meter}{current \times time} = \frac{mass \times \frac{velocity}{time} \times meter}{current \times time} = \frac{mass \times \frac{distance}{time^2} \times meter}{current \times time}$$

$$volt = \frac{mass \times \frac{meter^2}{time^2}}{current \times time} = \frac{mass \times meter^2}{current \times time^3} = \frac{Kg.m^2}{A.sec^3} = \left[Kg.m^2.A^{-1}.sec^{-3}\right] \text{ basic S.I units}$$

A derived unit is recognized by its ***dimensions***, which can be defined as the complete algebraic formula for the derived unit. The dimensional symbols for the fundamental units of length, mass, and time are **L**, **M**, and **T**, respectively. So the dimensional symbol for the derived unit of voltage is $V = \frac{M.L^2}{I.T^3} = \left[M.L^2.I^{-1}.T^{-3}\right]$

This systematic derivation shows how voltage as a derived unit originates from fundamental units and physical laws, and its dimensions provide a complete representation of its algebraic composition.

Multiples and Submultiples of Units

To measure a wide range of quantities, units often need to be scaled up or down. This is achieved using **multiples** and **submultiples**, which are larger and smaller versions of the base unit, respectively. These are created by multiplying or dividing the unit by powers of ten.

Multiples of Units

Definition: Multiples are used to express quantities larger than the base unit.

They are formed by multiplying the base unit by factors of 10, 100, 1000, etc

E-mail: Zainab.kadum.jaber@uomus.edu.iq

Common Multiples

Prefix	Symbol	Factor	Power of 10
Deca	da	10	10^{1}
Hecto	h	100	10^{2}
Kilo	k	1,000	10^{3}
Mega	M	1,000,000	10^{6}
Giga	G	1,000,000,000	10^{9}
Tera	T	10^{12}	10^{12}
Peta	P	10^{15}	10^{15}

Examples:

1 kilometer (km) = 1,000 meters (m).

1 megawatt (MW) = 1,000,000 watts (W)

Submultiples of Units

Definition: Submultiples are used to express quantities smaller than the base unit.

They are formed by dividing the base unit by factors of 10, 100, 1000, etc.

Common Submultiples

Prefix	Symbol	Factor	Power of 10
Deci	d	0.1	10^{-1}
Centi	c	0.01	10^{-2}
Milli	m	0.001	10^{-3}
Micro	μ	10^{-6}	10^{-6}
Nano	n	10^{-9}	10^{-9}
Pico	p	10^{-12}	10^{-12}
Femto	f	10^{-15}	10^{-15}

E-mail: Zainab.kadum.jaber@uomus.edu.iq

Examples:

1 millimeter (mm) = 0.001 meters (m).

1 microsecond (μs**)** **=** 10^{-6} seconds (s).

Why Multiples and Submultiples Are Useful

1. **Convenience:**

simplifies numerical representation. Example: Instead of saying 10,000,000 , meters, you say 10 mega meters (Mm)

2. **Clarity:**

Prevents excessive zeros in numbers, making them easier to read and interpret.

3. **Scalability:**

Useful for measuring very large or very small quantities without changing the unit system

Basic Definitions:

1. **Speed, Velocity**: The rate of change of distance with respect to time

$$\upsilon = \frac{\partial x}{\partial t} \quad , \quad \chi = \int_0^t \upsilon \partial t = \upsilon . t \quad , \quad \upsilon = \frac{\chi}{t}$$

$$\upsilon = \left[L T^{-1} \right] \text{ basic dimensions, } \upsilon = \left[m \sec^{-1} \right] \text{ basic S.I units}$$

2. **Acceleration**: The rate of change of velocity during the time

$$a = \frac{\partial \upsilon}{\partial t} , \quad \upsilon = \int_0^t a \partial t = a . t \quad , \quad a = \frac{\upsilon}{t}$$

$$a = \left[L T^{-2} \right] \text{ basic dimensions, } a = \left[m \sec^{-2} \right] \text{ basic S.I units}$$

E-mail: Zainab.kadum.jaber@uomus.edu.iq

3. **Momentum**

$$p = mass \times velocity = m \times \upsilon$$
$$p = \left[MLT^{-1}\right] \text{ basic dimensions }, \quad p = \left[kgm\sec^{-1}\right] \text{ basic S.I units}$$

4. **Force (newton), the rate of change of momentum during the time.**

$$F = \frac{\partial p}{\partial t} = \frac{\partial (m\upsilon)}{\partial t}, \quad F = \left[MLT^{-2}\right] \text{basic dimensions}, \quad F = \left[kgm\sec^{-2}\right] \text{basic S.I units}$$

5. **Energy (joule), the distance integral of force**

$$E = \int_0^{\chi} F \partial \chi = F.\chi$$
$$E = \left[ML^2T^{-2}\right] \text{basic dimensions}, \quad E = \left[kgm^2\sec^{-2}\right] = Joule = J$$

6. **Power (watt). The rate of work done**

$$P = \frac{\partial E}{\partial t}$$
$$P = \left[ML^2T^{-3}\right] \text{ basic dimensions}, \quad P = \left[kgm^2\sec^{-3}\right] \text{ S.I units}, \quad P = J.\sec^{-1}$$

7. **Potential of a point (voltage): work done to bring a unit charge from infinity to same point**

$$V = \frac{workdone}{charge} = \frac{Joule}{coulomb}$$
$$V = \left[ML^2I^{-1}T^{-3}\right] \text{basic dimensions}, \quad V = \left[kgm^2A^{-1}\sec^{-3}\right] \text{ basic S.I units}$$

8. **Electrical current: the rate of flow of charge**

$$I = \frac{\partial Q}{\partial t}, \quad Q = \int_0^t I \partial t, \quad Q = I.t$$
$$I = [Amp]$$

9. **Resistance (ohm): the resistance of a load to the current flow when there is voltage difference between its terminals.**

E-mail: Zainab.kadum.jaber@uomus.edu.iq

$$R=\frac{\partial V}{\partial I},\quad R=\left[ML^2I^{-2}T^{-3}\right]\text{ dimensions, } R=\left[kgm^2A^{-2}\sec^{-3}\right]\text{ basic S.I units}$$

10. Capacitance (farad):

$$C=\varepsilon\frac{A}{d},\quad \text{or } C=\frac{Q}{V},\quad C=\left[M^{-1}L^{-2}I^2T^4\right],\quad C=\left[kg^{-1}m^{-2}A^2\sec^4\right]$$

11. Electrical field:

$$E=\frac{\partial V}{\partial x},\quad E=\left[MLI^{-1}T^{-3}\right],\quad E=\left[kgmA^{-1}\sec^{-3}\right]$$

12. ***Permittivity* ϵ:** how much electrical field lines can pass through some medium

$$\epsilon=\frac{farad}{m},\quad \epsilon=\left[M^{-1}L^{-3}I^2T^4\right],\quad \epsilon=\left[kg^{-1}m^{-3}A^2\sec^4\right]$$

13. ***Inductance(henry):***

Induce emf = inductance x rate of change of current

$$e=-L\frac{\partial i}{\partial t},\qquad \int_0^t e\,\partial t=L\int_0^i \partial i,\qquad L=\frac{et}{I}$$

$$Henry=\left[ML^2I^{-2}T^{-2}\right],\quad Henry=\left[kgm^2A^{-2}\sec^{-2}\right]$$

14. ***Reluctance (S):*** the magnetic resistance to magnetic field lines in same material

$$S=\frac{l}{\mu.A},\quad S=\left[M^{-1}L^{-2}I^2T^2\right],\quad S=[kg^{-1}m^{-2}A^2\sec^2]$$

15. ***Magnetic flux(Φ) weber:***

$$\phi=\frac{mmf}{S}=\frac{N.I}{S},\quad \phi=\left[ML^2I^{-1}T^{-2}\right],\quad \phi=\left[kgm^2A^{-1}\sec^{-2}\right]$$

16. ***Frequency(hertz):*** number of cycles in one second

$$f=\frac{cycles}{second}=\frac{1}{\sec},\quad f=\left[T^{-1}\right],\quad f=\left[\sec^{-1}\right]$$

E-mail: Zainab.kadum.jaber@uomus.edu.iq