UNIT 3

MEASUREMENTS AND INSTRUMENTATION

OUTLINE

- Physical quantities (fundamental and derived quantities) and their units
- Basic Process Skills
- Integrated Process Skills
- Developing Basic Process Skills in Students
- Developing Integrated Process Skills in Students
- Assessment of Science Process Skills

OVERVIEW

- “When you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is meagre and of an unsatisfactory kind.” (Lord Kelvin)
- This unit takes you through Measurements and Instrumentation.
- We hope this is going to be interesting.
- We know you will surely enjoy every bit of it.
- Please take and go through this learning carefully.

PHYSICAL QUANTITIES (FUNDAMENTAL AND DERIVED QUANTITIES) AND THEIR UNITS

- **Measurement**: This refer to as the counting of the number of times a chosen scale is used or the process of determining the magnitude of a quantity in relation to a predetermined standard is known as measurement.
- To explain the natural phenomena, we take help of physics.
- Physics is a science of measurement.
- A measurement is a quantitative description of one or more fundamental properties compared to a standard.
- The measurement of a quantity is mentioned in two parts, the first part gives how many times of the standard unit and the second part gives the name of the unit e.g., 5 metres (5 m).

Why Do We Need to Make a Measurement?

- In science and engineering, we perform experiments. During experiments, we have to take readings. Thus, all these **experiments** require some measurements to be made.
- During the production of mechanical products, we have to measure the parts so as to find whether the part is made as per the specifications. Thus, measurements are necessary for **production and quality control**.
- An accurate measurement is **desirable for both buyer and the seller**. The absence of a suitable measurement may lead to conflicts between them.

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- Have you ever wondered how space scientists make sure that the space shuttle reaches the **desired destination**? Or when the shuttle comes back it comes at a predetermined time and place. This is made possible by accurate measurement of many parameters and extensive calculations.
- The result of measurement of a physical quantity is expressed in terms of a **value**. The value of the physical quantity is equal to the product of the number of times the standard is used for the measurement and the quantity (the standard) defined for making the measurement.
- A **unit** is a measure, device, or a scale in terms of which we make physical measurement.

Characteristics of a Unit

- A unit should be relevant for the quantity being measured.
- The unit used should be convenient.
- A unit should also be well defined i.e.; it should be well understood by other people.
- However, why don’t you assess your understanding of the meaning and need of measurement and about the units and their characteristics.

Self-Assessment Questions

- Define the term measurement by giving two examples.
- What is a unit?
- List the essential characteristics of a unit.

How did our Ancestors make Measurement?

- The need for measurement and measuring devices dates to antiquity.
- When humans became civilised, started cultivating and living in communities, they realised that one cannot do everything, and they need to be interdependent.
- This paved the way for trade and then probably a need of a measure was felt. Various ways of measurements were adopted.
- The system of measurement has evolved a lot since then.
- Let us have a brief account of interesting means of measurement used by our forefathers.

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- The recorded history shows ample evidence that the different parts of the human body were used as a point of reference while making measurements.
- Some of these were, digit: the width of a single finger; foot: the length of a foot; cubit: length of an arm; hand span: the distance between the tip of the thumb and the tip of the little finger when the hand is fully stretched out.
- Similarly, fathom meant the distance between the ends of the hands of an Anglo-Saxon farmer when his arms were fully out stretched.
- It is interesting to note that these are still used sometimes.

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- Certain historical units were based on the things around us, e. g., Romans used a unit called pace which was equal to the stride of their army contingent, and they called the distance travelled by it in 1000 paces to be equal to a mile.
- Similarly, the grain was used as the unit of mass in sixteenth century and was equal to the weight of a wheat grain.
- Use the characteristics of a unit to evaluate the above units; What are the limitations you find in above ancient units of measurement?

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- Can you check the accuracy of the measurements using parts of your body as a unit?
- Take a black board (or a table, a desk, a wall, or any other suitable reasonably long object) with group of 4-5 learners.
- First measure the length of the black/white marker board using hand span and digits as the units of measurement and record your observations in the table given below.

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S/No Name of the learner	S/No Name of the learner Length of the black/white marker board* in Hand span and digits (e.g., 10 Hand spans and 3 digits)
1	1
2	2
3	3
4	4
5	5

Need for a Standard Unit

- As you would have concluded from the activity given above, the units based on parts of human body are arbitrary and inaccurate.
- The results of the measurements vary from person to person because size of the unit is different for different person.
- For example, the units like a cubit or a foot would depend on the person making measurement.
- This created problems in trade between different countries and obviously in the day-to-day transactions.
- To overcome the limitations of body parts as units, and to bring about uniformity in the measurement system, the need for exact measurement was felt.
- For this, a standard of measurements had to be developed which is acceptable to everybody.

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- The problem of measuring lengths accurately was first solved by the Egyptians as far back as in 3000 B.C.
- It was done by defining the standard cubit.
- It was defined to be equal to the distance between the elbow and tip of the middle finger of the Pharaoh ruling Egypt at that time.
- Measuring sticks of length exactly equal to that of standard cubit were made.
- In this way they made sure that the cubit was the same length all over Egypt. Similar efforts were made by other rulers also.
- For example, the British King Henry-I (1100-1137) decreed that a yard would exactly be equal to the distance from the top of his nose to the end of his thumb on outstretched arm.

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- Queen Elizabeth-I declared a mile to be exactly equal to eight furlongs.
- A furlong (furrow long) was the distance a pair of oxen could plough in a field without stopping to rest.
- It was found to be 220 yards.
- These standards proved to be useful but were short lived, as once a given ruler went out of power or died, the system was not followed, and a newer system came into being.
- Further, since different countries and the different provinces in each country were governed by different rulers; they followed different systems of units.
- Consequently, by the eighteenth century many units for mass, length, area and volume came to be in widespread use.

The Modern Measurement Systems

- Immediately after the French Revolution (1790) the French scientists took lead in establishing a new system of weights and measures.
- They advocated the establishment of national standards for the purpose and the use of decimal arithmetic system.
- After detailed deliberations the basic unit of length and mass were defined, and their working standards were prepared.
- The working standard for meter was prepared by marking two lines a metre apart, on a platinum iridium bar.
- Similarly, a platinum-iridium cylinder was constructed, equal to the mass of 1 cubic decimetre of water, as the working standard for mass.

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- During development of units, a number of systems were adopted.
- Two systems which were extensively used were the cgs and mks systems.
- The cgs system was based on centimetre, gram and second as the units for length, mass, and time while mks system used metre, kilogram and second for the same.
- In 1958 it was realised that the units defined as standard needed to be redefined.
- The new exercise of redefining the system of units led to the birth of SI system of units which is currently the system in use.
- Let us learn the SI system in detail.

SI Units

- An international system of units, called SI units, was adopted at the 11th General Conference on Weights and Measures (CGPM) in 1960. SI is an abbreviation of the French name "Le Systemé Internationale de Unite's".
- You know that measurements are concerned with quantities like length, mass, time, density etc.
- Any quantity which can be measured is called a physical quantity.
- The SI system of units is based on seven base units corresponding to seven base physical quantities.
- These are the physical quantities, in terms of which other physical quantities can be measured.
- The names and symbols of the base (fundamental) physical quantities and their corresponding SI units are given in Table 3.1.

Names and symbols of the base physical quantities and the corresponding SI units. data

Fundamental physical quantity	**Symbol of Physical quantity**	**Name of SI Unit**	**Symbol for SI Unit**
Length	l	metre	m
Mass	m	kilogram	kg
Time	t	second	s
Electric current	I	ampere	A
Thermodynamic temperature	T	kelvin	K
Amount of substance	n	mole	mol
Luminous intensity	I	candela	cd

Units and Quantities of Measurement

- **Fundamental quantities, their units and measuring instruments**
- Fundamental quantities are also called basic quantities or units.
- They are the simplest and cannot be derived from other quantities or units.

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Quality	S I Unit	Symbol	Measuring instruments
Length	metre	m	Metre rule, surveyor’s tape, pair of calipers, vernier caliper, micrometer screw gauge
Mass	kilogram	kg	Beam balance, electronic balance
Time	second	s	Stop clock and watches, electronic clock and watches
Electric current	ampere	A	Ammeter
Temperature	kelvin	K	Absolute thermometer, Celsius thermometer and clinical thermometer
Luminous intensity	candela	cd	Photometer
Amount of substance	mole	mol	Carbon-12 scale, mass spectrometer

Derived Units

- The base or fundamental SI units like length, mass, time, etc. are independent of each other.
- The SI units for all other physical quantities such as area, density, velocity can be derived in terms of the base SI units and are called derived units.
- To find the derived unit for a physical quantity we have to find out the relationship between the physical quantity and the base physical quantities.
- Then substitute the units of the base physical quantities to find the desired derived unit.
- Let us take some examples to learn how to derive units for physical quantities in terms of base units.

Example 1. Derive the SI unit for area of a surface.

- To derive the unit, we need to find out the relationship between area and the base physical quantities. As you know that the area of a surface is the product of its length and breadth. So, as the first step we write area as Area = length × breadth
- Since breadth is also a kind of length, we can write,
- Area = length × length
- Then to find the derived unit for area, we substitute the units of the base physical quantities as Unit of area = metre × metre = (metre)2 = m2
- Thus, the SI unit of area is m2 and is pronounced as squared metre. Similarly, you can check that volume would have the SI unit as m3 or cubic metre.

Example 2. Find the derived unit for force.

- You know that force is defined as
- Force = mass × acceleration = mass × (change in velocity/time)
- Since, change in velocity = Length/time
- So, force = mass × (length/time) × (1/time) = mass × (length/time2)
- The SI unit of force can be found by substituting the SI units of the base physical quantities on the right side of the expression.
- Thus, ⇒ SI unit of force = kg m/s2 = kg ms–2

Table 3.2 Some examples of derived SI units of the commonly used physical quantities.

Derived Quantity	Dimensions	Name of Unit	Symbol of the Unit
Area	length × length	square meter	m^2
Volume	length × length × length	cubic metre	m^3
Speed, velocity	length/time	metre per second	$m\ s^{-1}$
Acceleration	(length/time)/time	metre per second squared	$m\ s^{-2}$
Wavenumber	1/length	reciprocal metre	m_{-1}
Density	mass/(length)^3	kilogram per cubic metre	$kg\ m^{-3}$
Work	(mass × length^2)/(time)^2	kilogram square metre per square second	$kg\ m^2/s^2$

Table 3.3 Names and symbols of the derived SI units with Special names

Physical Quantity	Derived SI unit	Special name assigned to the Unit	Symbol assigned to the special name
Frequency	s^{-1}	Hertz	Hz
Force	$kg.m.s^{-2}$	Newton	N
Pressure	$kg.m^{-1}.s^{-2}$	Pascal	Pa
Energy or work	$kg.m^{2}.s^{-2}$	Joule	J
Power	$kg.m^{2}.s^{-3}$	Watt	W

Scientific notation

- In this notation system we represent the numbers as power of ten. In this notation system we can write some examples as;
  - Mass of Earth = 5.97 × 1024 kg
  - Radius of Sun = 6.96 × 108 m
  - Radius of a hydrogen atom = 5 × 10-11 m
  - Mass of an electron (me) = 9.11 × 10-31 kg

Table 3.4: SI Prefixes for multiples and sub multiples of units

Multiple	Prefix	Symbol	Sub multiple	Prefix	Symbol
10^{24}	yotta	Y	10_{-1}	deci	d
10^{21}	zetta	Z	10_{-2}	centi	c
10^{18}	exa	E	10_{-3}	milli	m
10^{15}	peta	P	10_{-6}	micro	µ
10^{12}	tera	T	10_{-9}	nano	n

Cont'd

10^9	giga	G	10_{-12}	pico	p
10^6	mega	M	10_{-15}	femto	f
10^3	kilo	k	10_{-18}	atto	a
10^2	hecto	h	10_{-21}	zepto	z
10^1	deca	da	10_{-24}	yocto	y

ACCURACY AND PRECISION OF MEASURING INSTRUMENTS

- All measurements are made with the help of instruments.
- The accuracy to which a measurement is made depends on several factors.
- For example, if length is measured using a metre scale which has graduations at 1 mm interval, then all readings are good only up to this value.
- All measurements are made with the help of instruments.
- The error in the use of any instrument is normally taken to be half of the smallest division on the scale of the instrument.
- Such an error is called instrumental error. In the case of a metre scale, this error is about 0.5 mm.

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- Physical quantities obtained from experimental observation always have some uncertainity.
- Measurements can never be made with absolute precision.
- Precision of a number is often indicated by following it with symbol and a second number indicating the maximum error likely.
- For example, if the length of a steel rod = 56.473 mm then the true length is unlikely to be less than 56.44 mm or greater than 56.50 mm.
- If the error in the measured value is expressed in fraction, it is called fractional error and if expressed in percentage it is called percentage error.
- For example, a resistor labelled "470 Ω, 10%" probably has a true resistance differing not more than 10% from 470 Ω. So, the true value lies between 423 Ω and 517 Ω.

Precision of Measuring Tools and Significant Figures

- An important factor in the accuracy and precision of measurements is the precision of the measuring tool.
- In general, a precise measuring tool is one that can measure values in very small increments.
- For example, consider measuring the thickness of a coin. A standard ruler can measure thickness to the nearest millimeter, while a micrometer screw gauge can measure the thickness to the nearest 0.005 millimeter.
- The micrometer screw gauge is a more precise measuring tool because it can measure extremely small differences in thickness.
- The more precise the measuring tool, the more precise and accurate the measurements can be.

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- Measurements are said to be consistent when the values of the measurements are close to each other – meaning, the deviation (i.e., the difference) of each measured value from the mean value (of all measured values) is small and the spread (i.e., the difference between the 2 outermost values) is small.
- Therefore, high consistency means small deviation from the mean value, and mall spread between the 2 outmost values.

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- The consistent measuring instrument is one with the ability to register the same or nearly the same readings when a measurement is made repeatedly.
- To improve consistency:
  - Avoid parallax errors;
  - Exercise greater care and consistency in taking readings;
  - Avoid using a defective measuring instrument

Cont'd

- The accuracy of a measurement is the approximation of the measurement to the actual value for a certain quantity.
- The measurement is more accurate if the number of significant figures increases.
- The accuracy of a measurement can be increased by
  - taking several repeat readings
  - to calculate the mean value of the reading
  - avoiding the end errors or zero errors
  - taking into account the zero and parallax errors
  - using more sensitive equipment such as a vernier caliper to replace a ruler.

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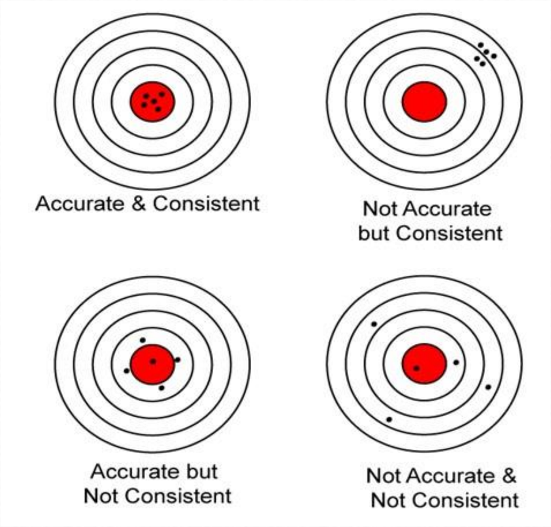
- The difference between precision and accuracy can be shown by the spread of shooting of a target (as shown in the diagram below).



Errors in Measurement

- Any measurement that you make is just an approximation, 100% accuracy is not possible.
- If you measure the same object two different times, the two measurements may not be exactly the same.
- The difference between the two measurements is called a variation in the measurements.
- This variation introduces an unwanted but unavoidable uncertainty in our measurement. This uncertainty is called the Errors in measurement.
- This 'error' should not be confused with a 'mistake'. Error, unlike mistake, does not mean that you got the wrong answer. It just means you didn't get as close to the true value as possible.
- The errors in measurement are a mathematical way to show the uncertainty in the measurement.
- It is the difference between the result of the measurement and the true value of what you were measuring.

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- The uncertainity in the measurement of a physical quantity is called error. It is the difference between the true value and the measured value of the physical quantity. Errors may be classified into many categories.
  - Constant errors
  - Systematic errors
  - Gross errors
  - Random errors

Cont'd

- **Constant errors**: It is the same error repeated every time in a series of observations. Constant error is due to faulty calibration of the scale in the measuring instrument.
- **Systematic errors**: These are errors which occur due to a certain pattern or system. These errors can be minimised by identifying the source of error.
- **Gross errors** arise due to one or more than one of the following reasons:
  - Improper setting of the instrument.
  - Wrong recordings of the observation.
  - Not taking into account sources of error and precautions.
  - Usage of wrong values in the calculation.

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- **Random errors**: It is very common that repeated measurements of a quantity give values which are slightly different from each other. These errors have no set pattern and occur in a random manner. Hence, they are called random errors.

Concept of Absolute Error and Relative Error

- Two important concepts in errors in measurement are absolute error and relative error.
- Absolute error is the actual amount of error of the measurement.
- In other words, it is the difference between the actual or accepted value of measured value and the result of the measurement.
- This brings us to the concept of relative error.
- Relative error gives us the ratio of the absolute error to the accepted measurement.
- It is never possible to measure the true value of a dimension there is always some error.

Sensitivity of an Instrument

- The sensitivity of an instrument is its ability to detect small changes in the quantity that is being measured.
- Thus, a sensitive instrument can quickly detect a small change in measurement.
- Measuring instruments that have smaller-scale parts are more sensitive.
- In order words, sensitivity may be defined as the rate of displacement of the indicating device of an instrument, with respect to the measured quantity.
- That is, sensitivity of an instrument is the ratio of the scale spacing to the scale division value.

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- For example, if on a dial indicator, the scale spacing is 1.0 mm and the scale division value is 0.01 mm, then sensitivity is 100.
- It is also called as amplification factor.
- If we now consider sensitivity over the full range of instrument reading with respect to measured quantities as shown in figure below the sensitivity at any value of y = dx/dy, where dx and dy are increments of x and y, taken over the full instrument scale, the sensitivity is the slope of the curve at any value of y.
- The sensitivity may be constant or variable along the scale.

CLASSIFICATION OF INSTRUMENTS

- The instruments used to measure the physical and electrical quantities are known as measuring instruments. The measuring instruments may be classified as follows:
- Absolute instrument & Secondary instruments:
- Analog and Digital instrument:
- Mechanical, Electrical and Electronics Instruments:

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- **Absolute instrument** measures the process variable directly from the process without the use of conversion. Such instruments do not require comparison with any other standard. The tangent galvanometer is an example for the absolute instrument. These instruments are used as standards in labs and institution.
- **Secondary instrument:** These instruments are so constructed that the deflection of such instruments gives the magnitude of the electrical quantity to be measured directly. These instruments required to be calibrated with respect to the standard instrument. They are direct reading instrument These instruments are usually used in practice. These instruments are used in general for all laboratory purposes. Some of the very widely used secondary instruments are ammeters, voltmeter, wattmeter, energy meter (watt-hour meter), ampere-hour meters, etc.

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- Secondary instruments are further classified as:
- **Indicating instrument**: Those instruments that measure and indicates the magnitude of the electricity. Ordinary ammeters, voltmeters, wattmeters, frequency meters, power factor meters, etc., fall into this category.
- **Integrating instrument**: Integrating instruments are those which measure the total amount of either quantity of electricity (ampere-hours) or electrical energy supplied over a period of time.
- **Recording instrument**: These instruments record continuously the variation of the magnitude of any electric quantity for a definite period of time. Such instruments are generally used in powerhouses where the current, voltage, power, etc., are to be maintained within a certain acceptable limit.

Analog and Digital instrument

- **Analog instrument:** The signals of an analog unit vary in a continuous fashion and can take on an infinite number of values in a given range. Fuel gauge, ammeter and voltmeters, wristwatch, speedometer fall in this category.
- **Digital Instruments**: Signals that vary in discrete steps and that take a finite number of different values in a given range are digital signals and the corresponding instruments are of digital type. Digital instruments have some advantages over analog meters, in that they have high accuracy and high speed of operation. Digital multimeter is an example for the digital instrument.

Mechanical, Electrical and Electronics Instruments

- **Mechanical instrument:** Mechanical instruments are very reliable for static and stable conditions. As they use mechanical parts these instruments cannot faithfully follow the rapid changes which are involved in dynamic instruments.
- **Electrical Instruments**: When the instrument pointer deflection is caused by the action of some electrical methods then it is called an electrical instrument. The time of operation of an electrical instrument is more rapid than that of a mechanical instrument.
- **Electronic Instruments:** Electronic instruments use semiconductor devices. They are very fast in response. For example, a cathode ray oscilloscope (CRO) is capable to follow dynamic and transient changes of the order of few nanoseconds (10-9 sec). In electronic devices, since the only movement involved is that of electrons, the response time is extremely small owing to very small inertia of the electrons.

Methods of Measurement

- **Direct Method of Measurement:** This is a simple method of measurement, in which the value of the quantity to be measured is obtained directly without any calculations.
- When measurements are taken directly using tools, instruments, or other calibrated measuring devices, they are called direct measurements.
- Direct methods of measurement are quite common for the measurement of physical quantities like length, mass, and time. For example, measurement of the length of a table by metre scale.
- With direct measurements, measuring instruments such as Vernier calipers, micrometers, and coordinate measuring machines are used to measure the dimensions of the target directly.
- These measurements are also known as absolute measurements.

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- **Indirect Method Measurement** is the value of quantity to be measured is obtained by measuring other quantities which are functionally related to the required value.
- With indirect measurements, the dimensions are measured using measuring instruments such as dial gauges that look at the difference between targets and reference devices such as gauge blocks and ring gauges (see the figure below).
- These are also known as comparative measurements due to the fact that a comparison is performed using an object with standard dimensions.
- The more predetermined that the shape and dimensions of a reference device are, the easier the measurement becomes.
- However, this method also has the disadvantage of the measurement range being limited.

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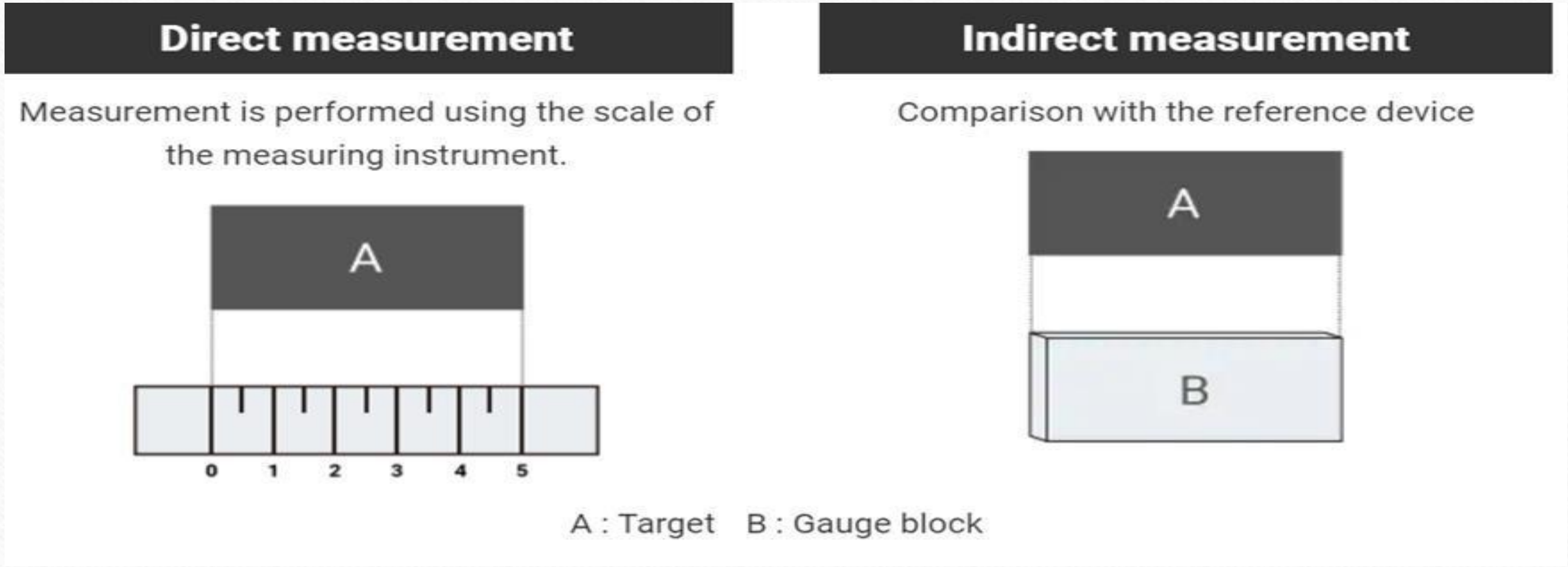
Direct measurement
Measurement is performed using the scale of the measuring instrument.
A
0
1
2
3
4
5
Indirect measurement
Comparison with the reference device
A
B
A : Target
B : Gauge block

Other Methods of Measurement

- **Absolute or Fundamental method:** It is based on the measurement of the base quantities used to define the quantity. For example, measuring a quantity directly in accordance with the definition of that quantity, or measuring a quantity indirectly by direct measurement of the quantities linked with the definition of the quantity to be measured.
- **Comparative method:** In this method the value of the quantity to be measured is compared with known value of the same quantity or other quantity practically related to it. So, in this method only the deviations from a master gauge are determined, e.g., dial indicators, or other comparators.

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- **Transposition method:** It is a method of measurement by direct comparison in which the value of the quantity measured is first balanced by an initial known value A of the same quantity, and then the value of the quantity measured is put in place of this known value and is balanced again by another known value B. If the position of the element indicating equilibrium is the same in both cases, the value of the quantity to be measured is AB. For example, determination of a mass by means of a balance and known weights, using the Gauss double weighing.
- **Coincidence method:** It is a differential method of measurement in which a very small difference between the value of the quantity to be measured and the reference is determined by the observation of the coincidence of certain lines or signals. For example, measurement by vernier calliper and micrometer screw gauge .

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- **Deflection method**: In this method the value of the quantity to be measured is directly indicated by a deflection of a pointer on a calibrated scale.
- **Complementary method**: In this method the value of the quantity to be measured is combined with a known value of the same quantity. The combination is so adjusted that the sum of these two values is equal to predetermined comparison value. For example, determination of the volume of a solid by liquid displacement.

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- **Method of measurement by substitution**: It is a method of direct comparison in which the value of a quantity to be measured is replaced by a known value of the same quantity, so selected that the effects produced in the indicating device by these two values are the same.
- **Method of null measurement**: It is a method of differential measurement. In this method the difference between the value of the quantity to be measured and the known value of the same quantity with which it is compared is brought to zero.

MEASUREMENT OF PHYSICAL QUANTITIES

Quantity	**Measuring Instrument**
Mass	Balances e.g. top pan balance, beam balance, lever arm balance, electronic balance, dial spring balance, top loading balance.
Length	Metre rule, venier calipers, surveyors' tape, measuring tape, micrometer screw gauge, pair of calipers
Volume	Graduated beaker, volumetric flask, measuring cylinder, burette, and pipette. NB: They are for measuring specific volumes of liquids.
Time	Stop watch, stop clock, electronic watch, and electronic clock.
Temperature	Thermometers e.g. absolute thermometer, clinical thermometer, celsius thermometer
Atmospheric pressure	Barometers e.g. Fortins barometer, Aneroid barometer
Electric potential	Voltmeter
Electric current	Ammeter
Luminous intensity	Photometer

Mass and Weight

- The mass of an object is the amount of matter it contains.
- Weight, on the other hand, refers to the downward force produced when an object is in a gravitational field.
- Weight can also be seen as the gravitational force between the earth and an object.
- It is the force a body exerts on its support. In free fall, objects lack weight but retain their mass.
- The kilogram is the SI unit of mass.

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- The mass of an object or body and its weight are related by W = mg, where W is the weight, m is the mass and g the acceleration due to gravity.
- This implies that when the mass of the body is known, the weight can be calculated since g = 9.8 m/s2 or approximated to 10 m/s2.
- An instrument for measuring weight or mass in the laboratory is called a weighing scale or, often, simply a scale.
- A spring scale measures force but not mass, a balance compares masses, but requires a gravitational field to operate.
- The most accurate instrument for measuring weight or mass is the digital scale, but it also requires a gravitational field, and would not work in free fall.

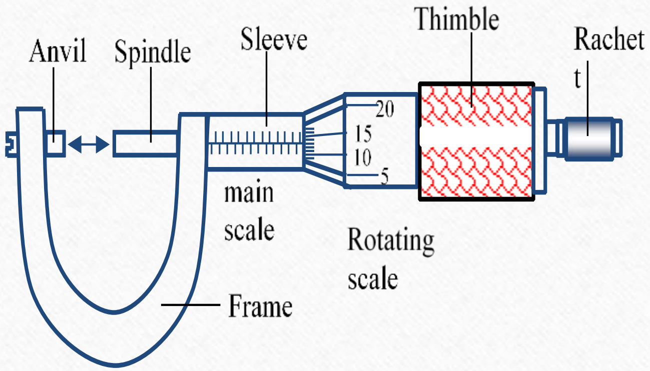
Difference between Mass and Weight

Mass	**Weight**
The mass of an object is a fundamental property of the object; a measure of its inertia; amount of matter in a body	The weight of an object is the force of gravity on the object
The SI unit of mass is kilogram	The SI unit of weight is newton
Is measured using a beam balance.	Is measured using a spring balance.
Is always a constant at any place and time	Depends on gravity at the place.
It is a scalar quantity.	It is a vector quantity.

Measurement of length

- Straight edges and distances are measured with a rule or surveyors' tape.
- The ruler is the instrument used to rule straight lines and the calibrated instrument used for determining length is called a measure.
- The use of the word measure, in the sense of a measuring instrument, only survives in the phrase tape measure, an instrument that can be used to measure but cannot be used to draw straight lines.
- The units used for measurement of length are metres (m), centimetres (cm) and millimetres (mm).
- Other instruments that can be used to measure length are the vernier caliper for measuring both internal and external diameters of objects and the micrometer screw gauge used to measure small, or tiny, lengths such as the diameter of a wire.

Micrometer Screw-Gauge



Using a Micrometer Screw-Gauge

- Place the wire between the anvil and spindle end as indicated in the diagram.
- Rotate the thimble until the wire is firmly held between the anvil and the spindle.
- The rachet is provided to avoid excessive pressure on the wire. It prevents the spindle from further movement – squeezing the wire

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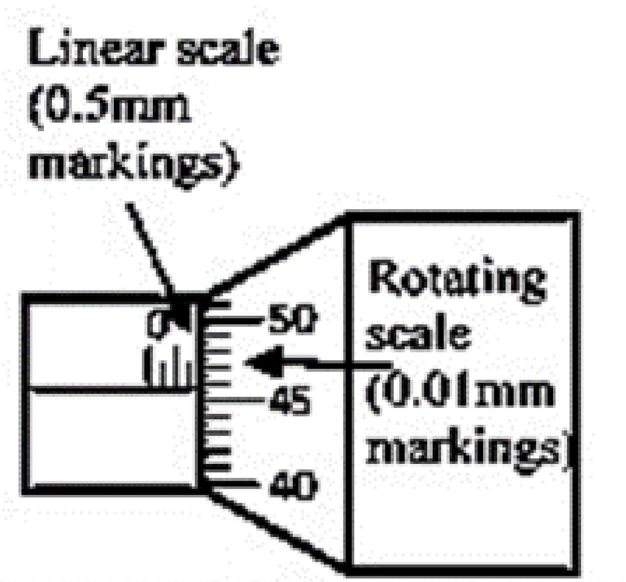
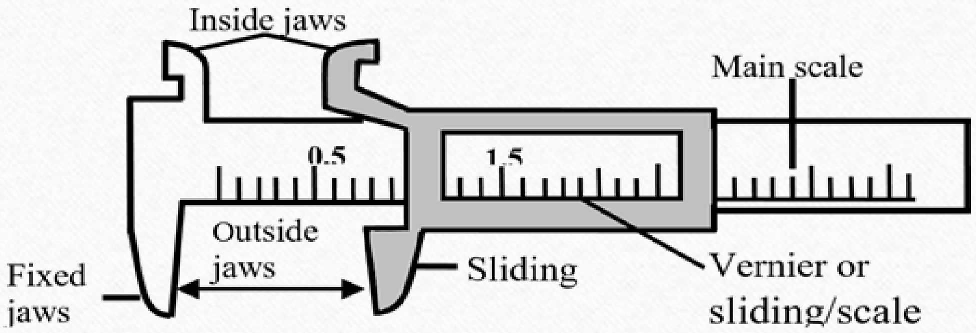
- **To take a reading:**
- First look at the main scale on the sleeve. This has a linear scale reading on it. The long lines are in millimetre and the shorter ones denote half a millimetre.
- On the diagram below this reading is 1.5 mm
- Now look at the rotating scale. That denotes 47 divisions - each division is 0.01mm so we have 0.47mm from this scale.
- The diameter of the wire is the sum of these readings:
- 1.5 + 0.47 = 1.97 mm



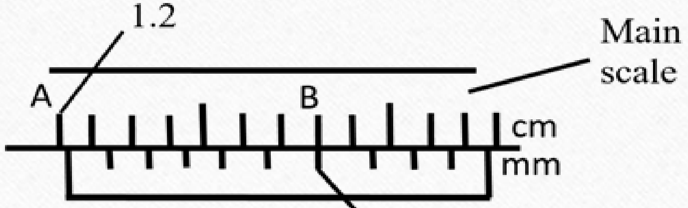
Vernier Calipers

- The vernier caliper is used for measuring both internal and external diameters of objects.
- It consists of main scale in centimetres and a small vernier scale in millimetres and it is precise up to 2 decimal places (e.g. 1.46 cm).
- The vernier caliper has fixed jaw and a movable jaw.
- The object to be measured is placed between the jaws of the calipers, the reading is taken first from the main scale.
- The reading to the second decimal place is obtained by finding the vernier mark which is exactly opposite a mark on the main scale.
- Each division on the vernier equals 0.1 mm or 0.01 cm as shown in the diagram below.

Cont'd



To take a reading:



The reading A on the main scale is 1.2 cm.
The reading B on the main scale coincides with the 6th division mark on the vernier scale.
Therefore, the vernier reading equals 0.6 mm or 0.06 cm.
Total reading = **1.2 +0.06 = 1. 26 cm**

Measurement of Time

- The SI unit of time is the second (s) which is part of the time the earth takes to perform one revolution on its axis.
- The other commonly used units are the minute, hour, day, weeks, month and year.
- In the laboratory, time is normally measured using a stop-clock or stop-watch.
- In some cases where more accuracy is required, as for example, when measuring the acceleration of a trolley moving on a ramp, a millisecond timer clock can also be used.

The other units are:

1 minute = 60 seconds

1 hour = 60 minutes = 3,600 seconds

1 day = 24 hours = 86,400 seconds

1 week = 7 days = 6,04,800 seconds

1 month = 28-31 days = 24,19,200 seconds

1 year = 365.25 days = 3,15,57,600 seconds

Measurement of Temperature

- Temperature is the degree of hotness (or coldness) of a body or substance.
- It is measured in degree Celsius (oC) or kelvin (K) which corresponds to the Celsius and the absolute scale respectively.
- There are two fixed points on the Celsius scale. These are;
  - The lower fixed point which is the temperature of pure melting ice.
  - The upper fixed point which is the temperature of pure boiling water at normal atmospheric pressure

Cont'd

- **Conversion of Temperature Scales**
- The relation between the kelvin and degree Celsius scales is
- $T = 273 + \theta$, or $\theta = T - 273$, where θ is the temperature in degree Celsius and T is the temperature in kelvin.

Worked Examples

- Convert 57 oC to a temperature in Kelvin scale.

  Solution

  T = 273 + θ oC

  T = 273 + 57

  T = 330 K

Cont'd

What is the equivalent of – 112 ^{o}C on the Kelvin scale?

Solution T = 273 + θ ^{o}C

T. = 273 + (-112)

T = 273 – 112

T = 161 K

Fahrenheit and Celsius

- The Fahrenheit temperature scale is named after the German physicist Daniel Gabriel Fahrenheit and is used primarily in the United States.
- The Celsius temperature scale – originally centigrade and later renamed after the Swedish astronomer Anders Celsius – is used almost everywhere else in the world.
- The temperature T in degrees Fahrenheit (°F) is equal to the temperature T in degrees Celsius (°C) times 9/5 plus 32. That is
- $T(°F) = [T(°C) \times 9/5] + 32$
- To convert temperatures in degrees Fahrenheit to Celsius, subtract 32 and multiply by 5/9. That is $T(°C) = [T(°F) - 32] \times (5/9)$

Example

- Convert 20 degrees Celsius to degrees Fahrenheit.

  Solution

  $T(°F) = (20 \times 9/5) + 32 = 68\ °F$

- Convert 50 degrees Fahrenheit to degrees Celsius

  Solution

  $T(°C) = (50 - 32) \text{ x } (5/9) = 10°C$

Measure of Volume

- Volume is a quantity that specifies the space occupied by a three-dimensional shape or object.
- Volume is also termed as capacity, sometimes.
- For example, the amount of water, a cylindrical jar can occupy is measured by its volume. The volume of a cube is equal to the cube of its edge length (side3). For example, if the edge length of the cube is 5 cm, then its volume will be: V = 53 cm3 = 125 cubic cm
- Volume of a solid is measured in cubic units.
- For example, if dimensions are given in meters, then the volume will be in cubic meters.
- This is the standard unit of volume in the International System of Units (SI). Similarly, other units of volume are cubic centimeters, cubic foot, cubic inches, etc.

Example

- If a cuboid has dimensions of 10cm x 3cm x 5cm, then find its volume.

  Sol: Volume of cuboid = length x width x height

  V = 10cm x 3cm x 5cm

  V = 150 cubic centimeters

  Hence, we can see here the unit of volume of cuboid is measured in cubic centimeters.

Volume of liquid

- Basically, the volume of a liquid is measured in liters, where 1 liter is equal to 1000 cubic centimeters.

  1 liter = 1000 cubic centimeters = 0.001 cubic meters

  Hence,

  1 cubic meters = 1000 liters

- **Volume Formulas** Volume = Base Area x Height

Volume of Shapes

Name of geometrical shape	Volume formula
Cube	$V = a^3$, where a is the edge-length of cube
Cuboid	V = length x width x height
Cone	$V = \frac{1}{3} \pi r^2 h$ Where r is the radius and h is the height of cone
Cylinder	$V = \pi r^2 h$, Where r is the radius and h is the height of cylinder
Sphere	$V = 4/3\ \pi r^3$, Where r is the radius of sphere

Volume of other shape

Volume of Frustum	$\pi h/3\ (R^2+r^2+Rr)$ Where 'R' and 'r' are radius of base and top of frustum
Volume of Prism	Base Area x Height
Volume of Pyramid	⅓ (Area of base) (Height)
Volume of Hemisphere	⅔ (πr^3) Where r is the radius

Interesting Facts

- The cube has all its sides equal, therefore, the volume will be equal to the cube of its side-length.
- If the radius and height of a cone and a cylinder are the same, then volume of cone is equal to one-third of volume of cylinder.
- The formula of volume of cuboid and rectangular prism is the same.
- The volume of the prism depends on the shape of its base. For example, if the base is square, then the volume will be (side2 x height).

Measurement of Density

- Matter is made up of particles of different sizes (atoms, molecules, ions).The degree of packing of particles in matter describes its density. Matter in which the particles are large and closely packed together is described to be dense and vice versa.
- Density of a substance is defined as the mass of the substance that occupies a unit volume, i.e.
- $density = \frac{mass}{volume}$ P $= \frac{m}{v}$
- The SI unit of density is kilogram per cubic metre (kg/m3 or kgm-3). A smaller unit of density is g/cm3.

Density of Regular Objects (Regular solid)

- The mass of the solid is found by weighing it on a scale or chemical balance as discussed.
- The volume of the regularly-shaped body is obtained by length measurements using a ruler, vernier calipers or a micrometer screw gauge, depending on the accuracy required.
- This method is applicable to cuboids, spheres, cylinders and cones amongst other regular shapes.
- The formulae discussed under the volume section can be used to calculate for such shapes. The volume of the regular shape is then calculated from the formula;
- $density = \frac{mass}{volume}$

Density of an Irregular Objects (Irregular solid)

- The mass (m_1) of an irregularly-shaped body or solid is found the same way as the regular one.
- In order to find the volume, it is necessary to partly fill a measuring cylinder with water.
- The initial reading (v_1) on the cylinder is taken.
- The solid is then tied to a thin length of a thread and lowered gently into the cylinder with water, until it is completely immersed.
- The new reading (v_2) is taken.
- The difference between the two readings $(v_2 - v_1)$ gives the volume of the irregular solid. The density of the irregular solid is given by; Density $\frac{m_1}{v_2 - v_1}$

Density of a Liquid

- A measuring cylinder is first weighed empty to find its mass say M1 using, for example, a toppan balance.
- Some of the liquid is poured into the cylinder and re-weighed together with the liquid to find the new mass say M2.
- The difference between the two readings (M2 – M1) gives the mass of the liquid. The density of the liquid is calculated from:
- Density $\frac{m_2 - m_1}{v_2 - v_1}$

Worked Examples

- Question 1: A piece of silicon metal has a mass of 144 g and a volume of 24cm3. Find the density of the silicon metal.

  Solution

  = 144 g and volume = $24cm_3$

  $density = \frac{mass}{volume}$

  $density$ = 24144 cm g3−3

  = 6.0gcm

- **Question 2:** If $25cm_3$ of a quantity of wood ash has a mass of 45g, calculate the density of the wood ash in kgm^{-3}.

Solution

Mass of wood ash = 45 g = 45 x $\mathbf{10^{-3}}$ kg

Volume of wood ash = 25 cm3 = 25 x $\mathbf{10^{-6}}m^3$. Therefore, the density of wood ash is given as,

ρ = 4525 ×× 1010−−36 = 1.8 × 103kgm^3

RECORDING AND PRESENTATION OF MEASUREMENT DATA

- **Recording of Measurement Data**
- As well as displaying the current values of measured parameters, there is often a need to make continuous recordings of measurements for later analysis.
- Options for recording data include chart recorders, digital oscilloscopes, digital data recorders, and hard-copy devices such as inkjet and laser printers.
- The various types of recorders used are discussed here.
- Chart Recorders

Chart recorders

- Chart recorders have particular advantages in providing a non-corruptible record that has the merit of instant "viewability."
- Originally, all chart recorders were electromechanical in operation and worked on the same principle as a galvanometric moving coil meter (e.g., analog meters) except that the moving coil to which the measured signal was applied carried a pen rather than carrying a pointer moving against a scale as it would do in a meter.
- The pen drew an ink trace on a strip of ruled chart paper that was moved past the pen at constant speed by an electrical motor.
- The resultant trace on the chart paper showed variations with time in the magnitude of the measured signal.

Cont'd

- All current potentiometric chart recorders contain a microprocessor controller, where the functions vary according to the particular chart recorder.
- Common functions are selection of range and chart speed, along with specification of alarm modes and levels to detect when measured variables go outside acceptable limits.
- Basic recorders can record up to three different signals using three different colored pens.
- However, multipoint recorders can have 24 or more inputs and plot six or more different colored traces simultaneously.
- Another variation is the circular chart recorder, in which the chart paper is circular in shape and is rotated rather than moving translationally.
- Finally, paperless forms of recorder exist where the output display is generated entirely electronically. These various forms are discussed in more detail later.

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- **A pen strip chart recorder** refers to the basic form of the electromechanical potentiometric chart recorder mentioned earlier. It's also called a hybrid chart recorder by some manufacturers.
- **A multipoint strip chart recorder** is a modification of the pen strip chart recorder that uses a dot matrix print head striking against an ink ribbon instead of pens.
- **A heated-stylus chart recorder** is another variant that records the input signal by applying a heated stylus to heat-sensitive chart paper
- **A circular chart recorder** consists of a servo-driven pen assembly that records the measured signal on a rotating circular paper chart.
- **A paperless chart recorder**, sometimes alternatively called a virtual chart recorder or a digital chart recorder, displays the time history of measured signals electronically using a color-matrix liquid crystal display.

Videographic recorder

- **A videographic recorder** provides exactly the same facilities as a paperless chart recorder but has additional display modes, such as bar graphs (histograms) and digital numbers.
- However, it should be noted that the distinction is becoming blurred between the various forms of paperless recorders described earlier and videographic recorders as manufacturers enhance the facilities of their instruments.
- For historical reasons, many manufacturers retain the names that they have traditionally used for their recording instruments but there is now much overlap between their respective capabilities as the functions provided are extended.

Ink-Jet and Laser Printers

- Standard computer output devices in the form of ink-jet and laser printers are now widely used as an alternative means of storing measurement system output in paper form.
- Because a computer is a routine part of many data acquisition and processing operations, it often makes sense to output data in a suitable form to a computer printer rather than a chart recorder.
- This saves the cost of a separate recorder and is facilitated by the ready availability of software that can output measurement data in a graphical format.

Digital Data Recorders

- They provide a further alternative way of recording measurement data in a digital format.
- Data so recorded can then be transferred at a future time to a computer for further analysis, to any of the forms of measurement display devices or to one of the hard-copy output devices.

Presentation of Data

- The two formats available for presenting data on paper are tabular and graphical.
- In some circumstances, it's clearly best to use only one or the other of these two alternatives alone.
- However, in many data collection exercises, part of the measurements and calculations are expressed in tabular form and part graphically, making best use of the merits of each technique.
- Very similar arguments apply to the relative merits of graphical and tabular presentations if a computer screen is used for presentation instead of paper.

Tabular Data Presentation

- A tabular presentation allows data values to be recorded in a precise way that exactly maintains the accuracy to which the data values were measured. In other words, the data values are written down exactly as measured.
- In addition to recording raw data values as measured, tables often also contain further values calculated from raw data.
- A table of measurements and calculations should conform to several rules as illustrated:

Cont'd

- The table should have a title that explains what data are being presented within the table.
- Each column of figures in the table should refer to the measurements or calculations associated with one quantity only.
- Each column of figures should be headed by a title that identifies the data values contained in the column.
- Units in which quantities in each column are measured should be stated at the top of the column.
- All headings and columns should be separated by horizontal (and sometimes vertical) lines.
- Errors associated with each data value quoted in the table should be given.

Graphical Presentation of Data

- Presentation of data in graphical form involves some compromise in the accuracy to which data are recorded, as the exact values of measurements are lost.
- However, graphical presentation has important advantages over tabular presentation.
  - Graphs provide a pictorial representation of results that is comprehended more readily than a set of tabular results.
  - Graphs are particularly useful for expressing the quantitative significance of results and showing whether a linear relationship exists between two variables.

Cont'd

- Like tables, the proper representation of data in graphical form has to conform to certain rules:
  - The graph should have a title or caption that explains what data are being presented in the graph.
  - Both axes of the graph should be labeled to express clearly what variable is associated with each axis and to define the units in which the variables are expressed.
  - The number of points marked along each axis should be kept reasonably small – about five divisions is often a suitable number.
  - No attempt should be made to draw the graph outside the boundaries corresponding to the maximum and minimum data values measured, that is, the graph stops at a point corresponding to the highest measured value.

THANK YOU