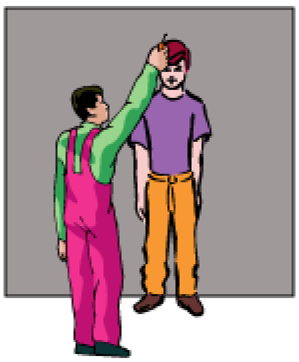
Measurements and Experimentation

Non Standard Method of Measurement

Go to a cricket ground with your friends. Measure the length of the cricket pitch using your foot span as the unit of measurement. Tell your friends to do the same and record the length of the pitch measured by each person. **Is the measurement the same for everyone?**

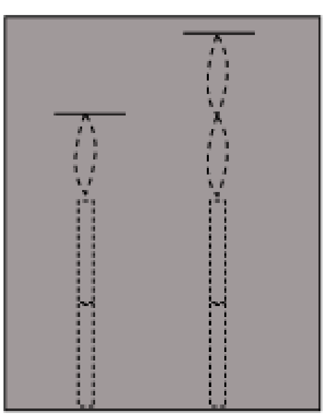
Measurement without standard scales:



Raju and Ravi fight frequently over who is taller. They decide to measure their heights by standing next to a wall and marking their heights.

They measure the height of each mark by using a *gilli-danda* to measure the distance between the foot of the wall and their respective marks.

It is found that Raju's height is equal to two *dandas* and one *gilli*, whereas that of Ravi is equal to two *dandas* and two *gillis*. Hence, Ravi is taller than Raju. **However, can you rely on such measurement? Does this type of measurement accurately determine their heights?**



Measuring height by *gilli-danda*

Measuring the length of a cricket pitch with the help of your foot span or measuring a person's height with a *gilli-danda* are non-standard methods of measuring distances.

Measure your own height first by using a *gilli-danda* and then by using a stump and a bail. Will you get the same result in both cases? If not, then can you explain the reason for this?

Your height in terms of a *gilli* and a *danda* will not be equal to your height in terms of a stump and a bail because the lengths of a *gilli* and a *danda* are not equal to lengths of a stump and a bail.

Thread levelling:

In the activities, you found that it is difficult to measure the exact length or height using foot span, *gilli-danda*, or other unconventional methods of measurements. However, you can measure the exact height or length using thread.

Take a section of thread. This will be your **one thread length**. Now, fold and mark the thread as $\frac{1}{2}$ in the middle. Fold the thread again and mark $\frac{1}{4}$, $\frac{1}{8}$ … at the folding points respectively. These points will indicate $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$ … thread lengths. Now, you will be able to measure your exact height in units of thread length.

Try to measure the exact length and breadth of your bed in units of thread length.

Tailors, carpenters, and farmers need a uniform system of measurement to measure respectively the length of a cloth; the length, height, and width of a block of wood; and the area of a cultivated land.

Non Standard Units of Measurement:

In earlier days the length was measured by using units that were based on hands and feet.
These units include:

- Cubit- It is measured as the distance between the tip of the outstretched middle finger and the elbow.

- Hand span- It is measured as the distance between the tip of the thumb and the tip of the little finger of fully stretched palm of a hand.

- Fathom- it is the distance between the tips of the outstretched arms.
- Pace- It is the distance between two walking steps.

These units were considered unreliable because they can vary from person to person as the length of hands and feet are different in different people.

Difficulties with non-standard measurement systems:

Measuring lengths using labelled thread is also a non-standard system of distance measurement. Some difficulties naturally arise in measuring distances. Suppose your teacher asks you about the length of your desk. You can easily find the length in units of hand span or thread length.

However, if he asks you to measure the distance between the school and your home or between the sun and the earth, then you will face difficulties. You cannot measure these distances using your hand span, *gilli- danda,* thread length, etc. Such quantities required a standard scale of measurement.

Systems of Units

Measurement

It is the process of assigning a number to an attribute (or phenomenon) according to a rule or set of rules.

Units

- A unit is the chosen standard of measurement of quantity, which has the same nature as the quantity.
- To express any physical quantity completely, we need the numerical value and the unit (u).

Physical quantity = nu

Fundamental Units: Units for fundamental or base quantities (length, mass and time)

Derived Units: Units obtained from fundamental units

Example:

Unit of speed (ms^{-1})

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

$$\therefore \text{Unit of speed} = \frac{\text{Unit of Distance}}{\text{Unit of Time}}$$

$$\Rightarrow \frac{\text{m}}{\text{s}} = \text{ms}^{-1}$$

Systems of Units

- CGS System: Base units for length, mass and time in this system are centimeter, gram and second respectively.
- FPS System: Base units for length, mass and time in this system are the foot, pound and second respectively.
- MKS System: Base units in this system are metre, kilogram and second.
- International System (SI) of Units: Based on seven base units; at present the internationally accepted system

SI Base Quantities and Units

- Length − metre (m)
- Mass − kilogram (kg)
- Time − second (s)
- Electric current − ampere (A)
- Thermodynamic temperature − kelvin (K)
- Amount of substance − mole (mol)
- Luminous intensity − candela (cd)

Derived Units

- The units of different physical quantities can be derived from the seven basic fundamental units. These are called derived units.
- Some common derived units are mentioned in the given table.

S.No.	Physical Quantity	Relationship with Fundamental Unit	Symbol
1.	Volume	Length cube	m^3
2.	Density	Mass per unit volume	kg m^{-3}
3.	Velocity	Distance covered in unit time	ms^{-1}
4.	Acceleration	Velocity changes per unit time	ms^{-2}
5.	Force	Mass × Acceleration	kg ms^{-2}
6.	Work	Force × Distance traveled	kg m^2s^{-2}

7.	Pressure	Force per unit area	kg $m^{-1}s^{-2}$

We have seen various objects as large as a mountain to as small as a speck. Therefore, to measure such large and small quantities, we have to use a simple method.

Example:

Diameter of the sun = 1,391,000,000 m

Diameter of a hydrogen atom = 0.000,000,000,106 m

Thus, when we are using metre, we find that the content is either quiet bulky or very small. At the same time, it is very inconvenient. Therefore, to counter this, we use a standard form of expression as:

Diameter of the sun = 1,391,000,000 m = 1.39×10^9 m

Diameter of a hydrogen atom = 0.000,000,000,106 m = 1.06×10^{-10} m

The exponential part of a particular measurement is called the order of magnitude of a quantity.

The prefixes and symbols for such order of magnitude are listed in the given table.

Multiple	**Prefix**	**Symbol**
10^{-15}	femto	f
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m
10^{-2}	centi	c
10^{-1}	deci	d
10^{3}	kilo	k
10^{6}	mega	M

10^9	giga	G

Bigger Units:

To know the distance between two or more heavenly bodies, for measuring heavy materials used in daily life and to count the large span of time we require bigger units.

- For length, the bigger units used are:

  (i) Astronomical unit (A.U.): It is the mean distance between Earth and Sun. 1 A.U. = 1.496×10^{11} m

  (ii) Light year (ly): It is the distance travelled by light in vacuum, in one year. 1 ly =9.46×10^{12} km

  (iii) Parsec: 1 Parsec = 3.26 ly

- For mass, the bigger units use are:

  (i) quintal: 1 quintal = 100 kg
  (ii) metric tonne: 1 metric tonne = 1000 kg = 10 quintal

- For time:

  (i) lunar month: 1 lunar month =29.5 days
  (ii) Leap year
  (iii) Decade
  (iv) Century
  (v) Millennium

Directions for writing units:

The following rules have been observed while writing the physical quantity:

- Symbols of units which are not named after scientists are written in the small letter. For example, m, kg, q and so on.

- The unit which is named after a scientist is written with the first letter of his/her name in the capital. For example, N for Newton, J for joule, W for watt and so on.

- While writing the full name of a unit we do not consider if the unit is named after scientist or not, it is always written with lower initial letter. For example, the unit of length as meter, mass as kilogram, force as Newton and so on.

- Compound units, formed by the product of two or more units are written after placing a dot, cross or leaving a space between the two symbols. For example, the unit of electric dipole C.m or C××m or C m.

- The compound unit uses negative powers when one unit is divided by another. For example, unit of power = joule/second = J s−1s-1.
- Shorter forms of units are never written in the plural. For example, 10 kilograms cannot be written as 10 kgs.
- Units cannot be written with more than one prefix. In spite of writing kMW, we must write GW.
- The prefix and symbol combined together become a new symbol for the unit. For example, km^3 means $(10^3\ m)^3 = 10^9\ m^3$. It does not mean $10^3\ m^3$

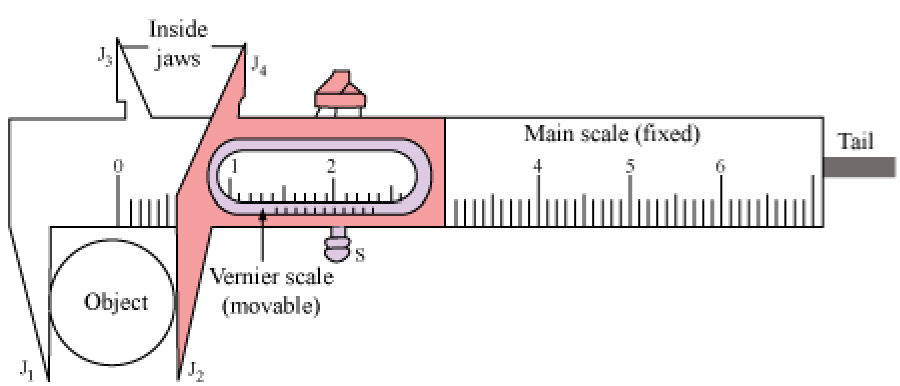
Measurement of Length- Lab Method

Vernier Calliper

For measuring length of a rod, diameter of a sphere, depth of small bottle, etc., vernier calliper is used. Vernier calliper was invented by Pierre Vernier. It has an accuracy up to 0.01 cm.

Principle: The vernier calliper consists of two scales: main scale with jaw J_1 and vernier scale with jaw J_2. The main scale is graduated with division of 1 mm each. The vernier scale graduation is such that the length of *n* division on it is equal to the (*n*-1) divisions of the main scale. The vernier scale can slide over the fixed main scale such tha the vernier scale can be fixed at any position on the main scale with the help of a screw S.

Essential Parts:



1. **Main Scale**

It is a thin long strip of steel on which a scale in engraved in mm. The main scale is generally 15 cm long.

2. **Vernier Scale**

   It is a small movable scale, which slides along the main scale. It has 10 divisions adding up to 9 mm length.

3. **External jaws**

   J_1 and J_2 are called external jaws because they are used for measuring external dimensions.

4. **Internal jaws**

   J_3 and J_4 are collectively called internal jaws and are used for measuring internal dimensions of a hollow object.

5. **Tail**

   It is at the end of main scale and slides along with the Vernier scale.

   When jaws J_1 and J_2 are closed, the zero mark of the main scale coincides with that of the Vernier scale and 19^{th} main scale divisions coincide with 20^{th} Vernier scale divisions.

Terms and Definitions:

Pitch

The smallest value of length, which can be acquired directly from the main scale accurately, is called pitch.

Least Count

The magnitude of the smallest measurement, which can be measured by an instrument accurately, is called its least count.

Formula for measuring a length

Length of an object is found by using the formula,

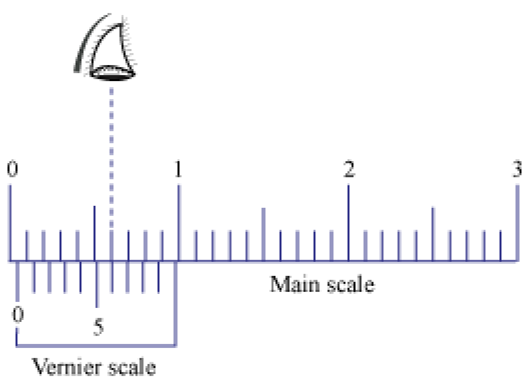
Length = (Pitch × Main Scale Division) + (Least Count × Vernier Scale Division)

Zero Error of Vernier Calliper

If the zeroes of M.S. and V.S. do not coincide, then the instrument is said to have a zero error.

1. **Positive Zero Error**

   If the zero mark of the Vernier scale lies on right hand side of zero mark of the main scale, then the error is said to be positive and correction is said to be negative.

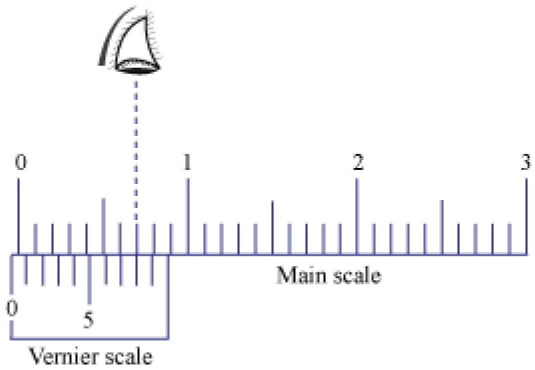


Correction = −Coinciding division of V.S. × L.C.

This correction has to be added to the measured length.

2. **Negative Zero Error**

   If the zero mark of the Vernier scale lies on left hand side of zero mark of the main scale, then the error is said to be negative and correction is said to be positive.



Correction = (n − Coinciding division of V.S.) × L.C.

Where, n is the total number of Vernier scale divisions

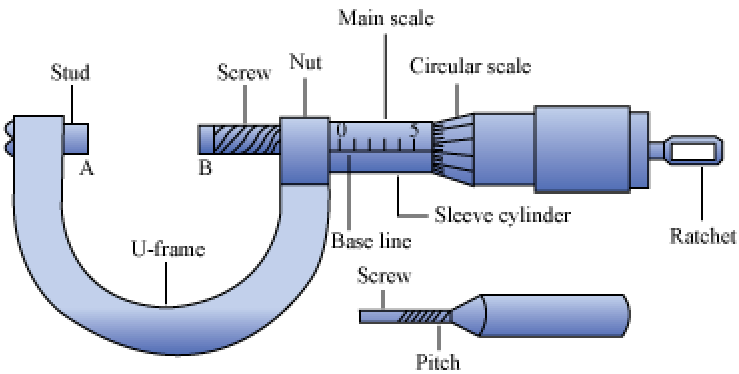
Screw gauge

A micrometer screw gauge is used for measuring much smaller lengths than what a vernier calliper can measure. It works with an accuracy of 0.001 cm. It is mainly used for measuring the diameter of thin wires.

Principle of a Screw gauge

It works on the principle of a screw. This device can measure the thickness of a sheet, diameter of wire, etc.

Construction



1. **U-frame**

It is a U-shaped steel frame with stud (fixed jaw) at one end and a nut at the other end.

2. **Nut and screw**

   The nut is threaded from inside and the screw from outside.

3. **Thimble and circular cylinder**

   The screw is connected to a hollow circular cylinder (S), which rotates along with nut on turning.

4. **Sleeve cylinder**

   It is a hollow cylinder attached to the nut.

5. **Base line**

   Commonly called main scale or sleeve scale, it is the graduated line parallel to the axis of the nut.

6. **Circular scale or thimble scale**

   It is the hollow half cone moving over the sleeve cylinder.

7. **Ratchet**

   It is attached to screw by means of a spring.

Terms and Definitions:

Pitch of Screw: It is the distance between two consecutive threads of the screw, measured along the axis of the screw.

$$\boxed{\text{Pitch} = \frac{\text{Distance moved by thimble on main scale}}{\text{Number of rotations of thimble}}}$$

Least count of Screw: It is the smallest distance moved by its tip when the screw turns through 1 division marked on it.

$$\boxed{\text{L.C.} = \frac{\text{Pitch}}{\text{Number of C.S. division}}}$$

Formula for measuring a diameter

The diameter of a wire is measured by using the formula,

Observed diameter = Main scale reading + Circular scale reading × L.C.

Of course the zero error, if any, has to be added or subtracted accordingly.

Zero Error:

When stud A and screw end B are joined and zero of main scale does not coincide with that of the circular scale, the screw gauge is said to have a zero error.

1. **Positive zero error**

When zero line on circular scale is below the reference line, there is a positive zero error and correction is negative.

Correction = −Coinciding division of C.S. × L.C.

2. **Negative zero error**

When zero line on circular scale is above the reference line, there is a negative zero error and correction is positive.

Correction = (*n* − Coinciding division of C.S.) × L.C.

Where, n is the total number of circular scale divisions

3. Backlash error

A type of error known as backlash error occurs when the tip of the screw does not start moving in the opposite direction on reversing the direction of rotation of the thimble at once, but remains stationary for a part of rotation. This happens due to the wear and tear of threads of a screw.

Measurement of Time

Before going into the subject, let us look at this animation.

So, you have learned the importance of measuring time. You also have learned about some time-measuring instruments, some from ancient and medieval ages and some from modern times.

Let us learn about the units of time in detail.

Units of Time

In ancient times, people used large units for measuring time. For example, the time interval between two consecutive sunrises was considered **a day**. However, they were not able to accurately measure the time taken by relatively shorter events such as lightning, rain, or time taken to cover a distance.

Period	Method of measuring time in ancient times
Day	Time between two consecutive sunrises
Month	Time between two consecutive new or full moons
Year	Time taken by the Earth to complete one revolution around the sun

Take a rubber ball and drop it from a height on to a hard surface. The ball will bounce repeatedly and stop after some time. Which device would you require to measure the time taken by the ball to stop?

We require some convenient units that can be used for measuring short as well as long intervals of time.

- The internationally accepted unit of time is **second**. Its symbolic representation is **s**. However, this unit is used for representing shorter durations of time only. Minutes (min) and hours (h) are used for representing longer durations of time.

- We use different units of time depending on the requirement and convenience. For example, it is easy to express the pulse rate using minutes as units of time. However, while expressing the time taken to travel from Delhi to Jaipur, we use hours as the unit of time.

Modern Technology

Scientists use modern technology for scientific research to determine shorter intervals of time such as millisecond (ms), microsecond (μs), and nanosecond (ns); and larger intervals of time such as million years (MY), billion years (BY), etc.

Discuss with your teacher how the larger units of time are used in astronomy.

<table>
<tr><td rowspan="7">The given table shows the respective amount of time taken by all the participants to cross the finish line in a cycling race.

The time displayed at the start of the race was 10:45:00

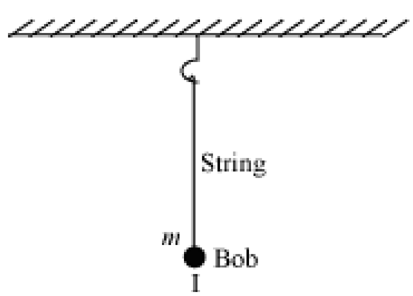
Who took the least amount of time to finish the race?</td><td>Participant</td><td>Display on digital clock</td></tr>
<tr><td>Ram</td><td>10:46:45</td></tr>
<tr><td>Shyam</td><td>10:46:35</td></tr>
<tr><td>Ajit</td><td>10:46:57</td></tr>
<tr><td>Aditya</td><td>10:46:13</td></tr>
<tr><td>Jay</td><td>10:47:01</td></tr>
<tr><td>Ramesh</td><td>10:46:41</td></tr>
</table>

Till now, we were discussing the different types of clocks that are used by people today to measure time. **Now, the question that arises is – how is a clock able to measure time?**

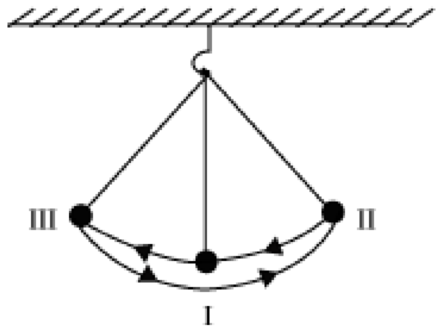
The answer lies in the fact that a clock uses some kind of periodic motion in its working. One such object that exhibits periodic motions is a **simple pendulum.** In this section, we will discuss some common characteristics of a simple pendulum.

Characteristics of a simple pendulum

- A simple pendulum consists of a mass *m* that is suspended by a piece of string. The mass is known asthe **bob** of the pendulum. A simple pendulum is shown in the given figure. Here, point **I** represents the **mean position** of the bob.



- The bob begins to move to and fro when it is released from the extreme position **II** i.e., it will go up to another extreme position **III** via mean position **I**, and then go up to position **II** again via mean position **I**. It will continue to move in the same way. This back and forth motion of the bob via mean position **I** is called the **periodic or the oscillatory motion of the bob.**

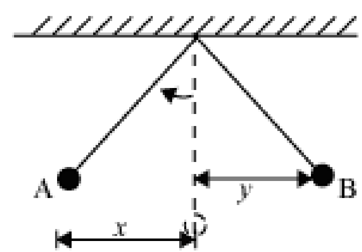


- The bob completes one **oscillation** when it moves from extreme position **II** to extreme position **III** via mean position **I** and then returns to extreme position **II**, following the same path.

- The time taken to complete one oscillation is termed as the **time period** of the pendulum. If a simple pendulum completes 15 oscillations in 5 seconds, then the time period of the pendulum is 1/3 seconds to complete one oscillation.

- Consider *T* is the time period of a simple pendulum which means that in *T* seconds the pendulum completes 1 oscillation. This implies that in 1 second, the number of oscillations will be 1/*T* which is equal to the frequency of the pendulum i.e. *f*.

$$\boxed{f = \frac{1}{T} \text{ or } T = \frac{1}{f}}$$

Take a stone and attach it to the ceiling by a thread. Now, move it to one side up to a distance *x* (point A) and release it. It will go up to point B on the other side. Measure the horizontal distance *y* with the help of a ruler. Is *y* = *x*?	

You will find that the distance *y* < *x*. This is because air particles present in the medium oppose the motion of the pendulum. Hence, its distance decreases continuously until the bob comes to rest.

What will happen to the motion of the pendulum if it is allowed to oscillate in space?

Suspend a bob in a vertical stand and allow it to oscillate. Measure the time required by it to complete 10 oscillations. Wait until the bob comes to rest at the mean position. Now, move the bob to a distance greater than the first distance and release it.

Measure the time taken by the bob to complete 10 oscillations again. Repeat the same steps for different distances and record the time period in the following table. **Is the time period dependent on displacement *x*?** Discuss this with your teacher.

S. No	Value of x (in cm)	Time taken to complete 10 oscillations	Time period
1.	-	-	-
2.	-	-	-
3.	-	-	-
4.	-	-	-

After performing this activity, you will find that the time periods for all distances are nearly equal to each other. This activity shows that the time period of a pendulum does not depend on the distance through which it is displaced.

Repeat the same activity by changing the mass of the bob and find out whether the **time period of a pendulum depends on the mass of the bob**.

Modern quartz clocks and watches lose or gain one second once in 2 to 10 years!

Galileo and the swinging lamp Galileo was one of the greatest scientists of his time. He was a physicist, astronomer, and mathematician. Once when he was sitting in a cathedral, he noticed that the lamp, suspended by a long chain from the ceiling, swung back and forth because of wind currents. He measured the time taken by the lamp to complete one oscillation using his pulse rate. He was surprised to find that each oscillation took an equal amount of time. He set up his own pendulum and obtained the same result as that obtained with the swinging lamp. He concluded from his findings that a pendulum takes equal time to complete each oscillation.	

Measurement of Time

- Atomic standard of time → Periodic vibrations produced in a cesium atom
- 1 second → time required for 9, 192, 631, 770 vibrations of the radiation of cesium 133 atom
- In our country, the National Physical Laboratory (NPL) has the responsibility of maintaining Indian standard time.