Physical Quantities & Measurement

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})

Speed= Distance Time Speed= Distance Time
∴Unit of speed = Unit of DistanceUnit of Time∴Unit of speed = Unit of DistanceUnit of Ti
me
⇒ ms=ms−1⇒ ms=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:

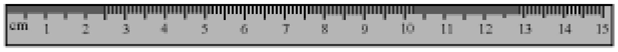
- Symbols of units which are not named after scientists are written in the small letter. For example, m, kg, q and so on.
- The unit which is named after a scientist is written with the first letter of his/her name in the capital. For example, N for Newton, J for joule, W for watt and so on.
- While 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 $10^3\ m^3$

So, you have learned the standard methods of distance measurement. Here are the key points of the lesson for you.

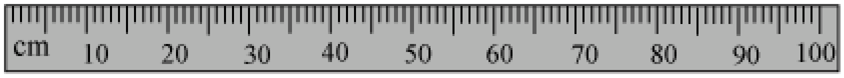
- **Instruments for measuring lengths**

Various types of instruments are used to measure lengths and distances. The use of a measuring instrument depends on the nature of object and the type of surface of object.

- A metre scale is used to measure the lengths of straight objects. For example, the length and width of a table, the length of a book, etc.



15 cm scale



Metre scale

- A measuring tape is primarily used to measure accurate lengths of curved surfaces. For example, to measure the girth of a tree, to measure the size of your chest, etc.

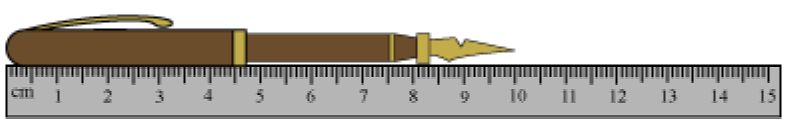
  A tailor uses a measuring tape for accurate measurements.

- **Proper measurement**

- To measure the length of any object, you must follow some steps:

  Step I: First, choose an appropriate instrument for the measurement of the length of the given object.

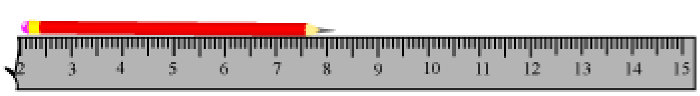
  Step II: Place the chosen scale in contact with the object along its length. Make sure that the zero mark of the scale is in contact with one end of the object.



  Step III: Then, take the reading on the scale that is in contact with the other end of the object. This reading shows the length of the object.

- To measure the length of an object using a broken scale, you should follow these steps:

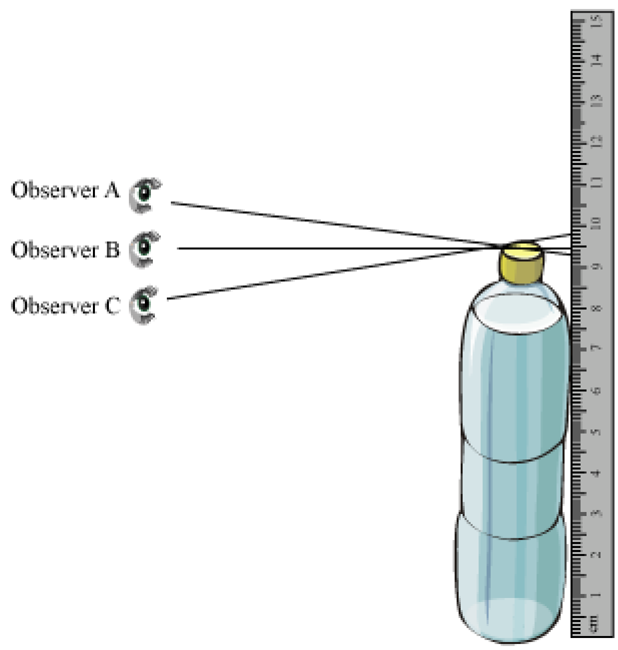
  Step I: Place the broken scale in contact with the object along its length.



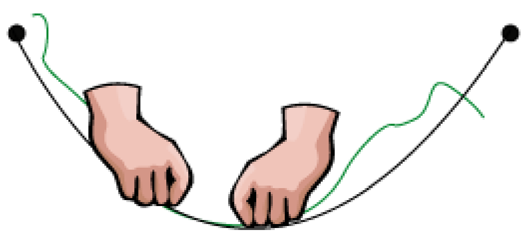
Step II: Then, take the readings on the scale at both the end points of the object and then, subtract both the readings. This gives the length of the object.

- **Precautions while measuring lengths**

- While taking a measurement, your eye should be focussed exactly at the point from where the reading is to be taken as in case of observer B in the given figure.



- **Measurement of curved lines**



You can measure the length of a curved line using a string. For this, draw a curved line on your notebook. Then, fix a string on one end of the curved line. Thereafter, place the string on the drawn line. Using your fingers and thumbs, stretch the string along the curved line tightly until you reach the other end of the line. Then, remove the string and measure its length using a metre scale.

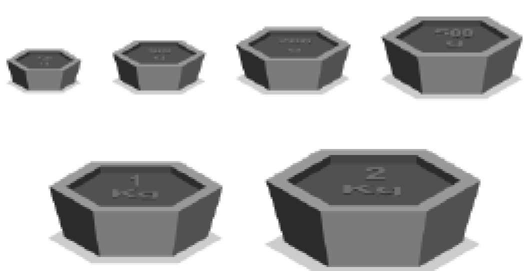
It will give the length of the curved line.

One very important thing is, do not use elastic tape to measure the length because it might stretch and may alter the result.

Standardisation of Weights and Measures

The department of weights and measures run by the government deals with the standardisation of weights and measures to prevent consumers from cheating while buying or selling commodities. This department fixes the weights for 5g, 10g, 100g, 1kg, 10kg, etc. These weights are made up of a mixture of metals.

Officers of the department inspect scales and weights by randomly visiting places.



Some relations:

1000 milligrams (mg) = 1 gram(g)

1000 grams (g) = 1 kilogram (kg)

100 kilograms (kg) = 1 quintal

1000 kilograms (kg) = 10 quintals = 1 tonne

Laws issued by government with respect to weights and measures makes it compulsory for traders to take the following precautions:

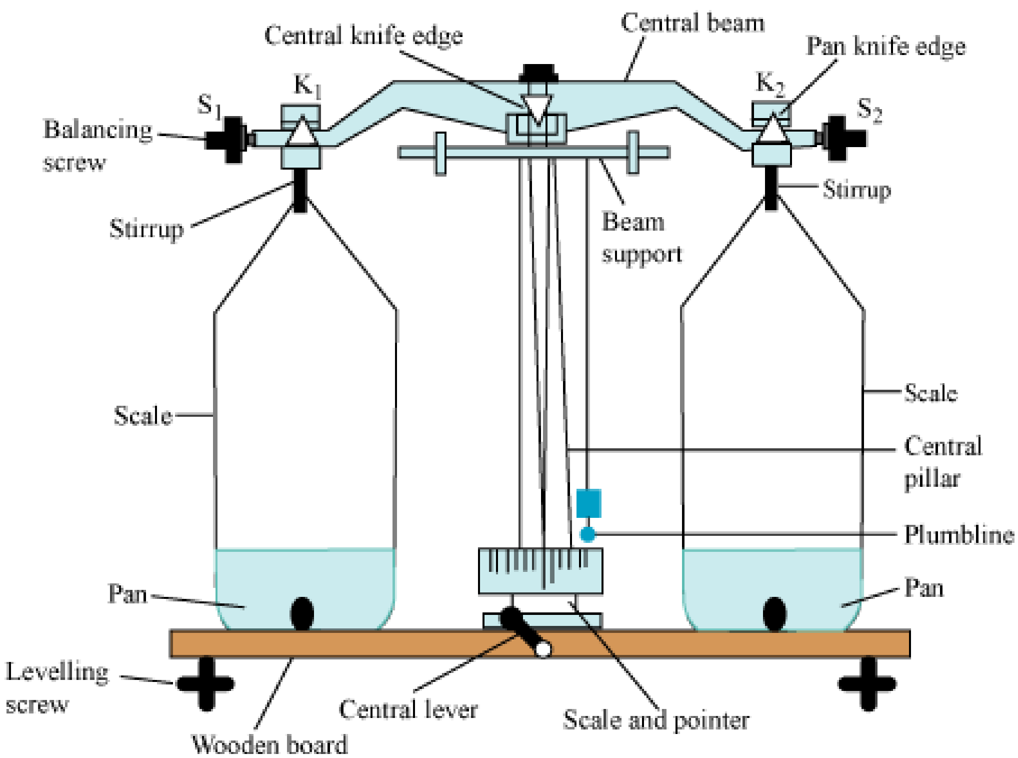
1. A weight is considered as authorised only if it is made up of metal.
2. Each and every weight must contain a hole filled with lead at the centre.
3. The balancing point of the beam should be stable at one place.
4. The beam of the balance should move freely about vertical axis.
5. There should be standardisation mark or stamp of the government on the beam of the balance.

Measurement of Mass

When you go to a grocery market or vegetable market for shopping, you must have seen how the shopkeepers weigh the food items or vegetables. They use beam balance. Some shopkeepers use grocer's balance also. All these instruments are used for general purposes. For the scientific reason, we often need accurate measurement and for that, a simple balance is not adequate. Therefore, in the science laboratory, we use scientific beam balance, which is more complicated than a simple spring balance. Let us study a scientific beam balance.

Scientific beam balance

- **Construction and usage of each part**



Machine Part	Function
Central Beam	Balance beam made up of metal (aluminium or brass)
Balance Screw (S_1 and S_2)	Used for fine adjustment of the balance
Pan knife edges (K_1 and K_2)	The stirrups are kept at rest on these.
Beam Support	In unused condition, the central beam rests on the beam support.
Central knife edge (K)	Pivot point on which the central beam swings
Central Pillar	Supports the whole beam balance system
Pointer	Indicates the balanced position of the beam
Scale	Indicates the amount of unbalance in the beam
Plumbline	Indicates the perfect vertical position of the central pillar
Wooden Base	Supports the whole system
Central Lever	Holds the central pillar up

Base Screws	Used for adjusting horizontal level of the base

- **How to use**
- Bring the central pillar in exact vertical position by adjusting levelling screws. The plumbline indicates the exact vertical position of the pillar.
- Turn the lever very slowly to raise the central rod. Make sure that the pointer points 0 mark or swings evenly on either side of the 0 mark. This indicates that the balance is properly adjusted.
- If the balance on either side is not properly adjusted, then the balancing screws have to be adjusted.
- Bring the central rod down and place the object that has to be weighed on the left pan. On the right pan, place standard weights from the weight box. Raise the central pillar by turning the lever. Repeat this step until the pointer oscillates evenly on either sides of the zero mark in the raised position.
- When the central beam is balanced evenly, note down the total mass on the right-hand side and that is the mass of the object kept on the left pan.

Measurement of Weight

Before further discussion on measurement of weight, we should first know what we mean by weight. When we go to a market and ask the shopkeeper "what is the weight of the vegetables", what we actually want to ask is the mass of the vegetables. Weight of a body is the magnitude of force acting on the body due to gravitation or weight is the force exerted on an object due to gravitation. Mass of an object will remain the same no matter where one goes in the universe, but the weight can change depending upon the gravitational field of the planet. Essentially, weight of an object is commonly denoted by mg, where

$m =$ Mass of the body

g = Acceleration due to gravity

Spring Balance

- A spring balance is used for measuring the weight of an object. It has a spring, one end of which is fixed. The other end of the spring is attached to a hook to hold an object.

The steel spring is enclosed in a metallic case. There is a pointer, which is attached to the spring. The pointer moves over a scale marked on the metallic case.

- One should always check that the pointer points at the zero mark of the scale under no-load condition.

- When a load is attached to the hook, the spring gets elongated because of the weight of the body. Along with the spring, the pointer also moves over the scale. The final position of the pointer gives the weight of the body.

Electronic Balance
Electronic balance is a device used for accurate and precise measurement of mass. They have certain advantages as compared to the traditional beam balance like

- they are portable
- they can measure small mass in the sub-milligram range as well as in large range
- they do not require any prior setting or separate weight box for measurement

It consists of a load-bearing part where the load is placed. The load or the force is converted into the electrical signals by load cells and finally, the signal conditioner displays the mass of the load after processing the load cells signal.

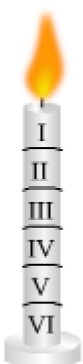
Measurement of Time

Duration of any event is measured in terms of an entity called time. Generally, clocks are used to measure time.

Second is the standard unit for the measurement of time.

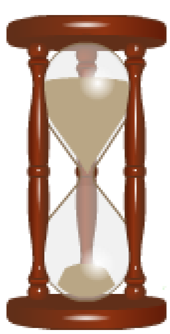
The units of measuring time are seconds, minutes and hours. However, these units of time do not depend on the types of clock, like pendulum clock, big clock , small clock, electric clock, sand glass clock, etc.

Candle Clocks



In the sixth century CE, candle clocks (candle with different markings)were used to measure the period of time for an event to occur. Since the rate of burning of a candle depends upon the quality of wax, it fails to estimate time duration accurately.

Sand glass clock



Sand glass clocks were used in the fourteenth century. Such clocks are more accurate than candle clocks.

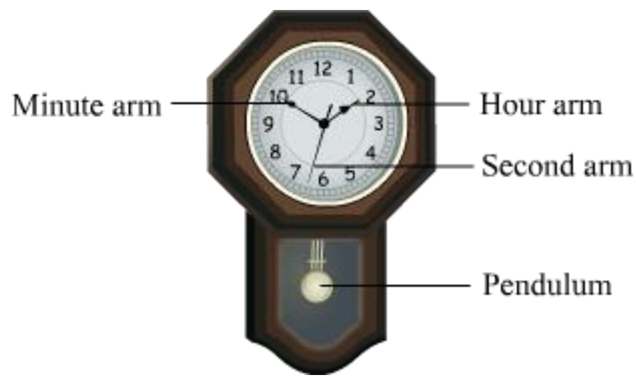
Clock time is expressed in terms of hours, minutes and seconds.

Relations among hours, minutes and seconds are as follows:

1hour = 60 minutes

1minute = 60 seconds.

Pendulum clock



In this clock, time is measured taking use of time taken by the pendulum to complete an oscillation. Depending on the length of the pendulum, it swings back and forth and this gives power to the gear wheels at the centre to move. The centre dial has 12 divisions which are further divided into five small divisions each. So, in total 60 divisions are there at the centre of the dial.

When the pendulum moves from one extreme to the other extreme, the second's arm moves by one small division. When the second's arm completes one round cycle, the minute arm moves by one small division and when it completes one round, the hour's hand moves by 5 small divisions.

Various other types of clocks have been shown below:

Ram says, “I will be 12 years old tomorrow.” That means today Ram’s age is 11 years 11 months and 29 days. So, we can say that a person’s age is expressed easily in terms of years, months and days. Here, the period of time is measured in terms of years, months and days.

Generally, 1 year = 12 months = 365 days

1 month= 30 days

1 day =24 hours.

Stop-watch

Stopwatches are used in laboratories and sports meets (swimming, racing)etc. for the measurement of time intervals.

It can measure the fraction of a second. The minimum time given by it is 0.01s.

Measurement of Temperature

On returning from school, when Ravi touched the iron gate of his house, he found it to be extremely hot. Later, he touched other things made of iron present inside his house and found that they were not hot. Then, he touched other substances (not made of iron) present in his house to determine whether they were hot or cold. He listed the various substances observed in the table given below.

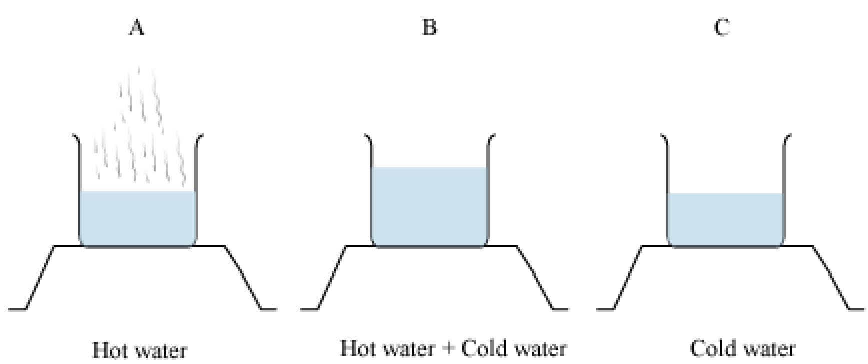
Substance	Hot/ Cold
Tea	Hot
Coffee	Hot
Ice	Cold

Ice cream	Cold
Cooked rice	Hot
Frozen meat	Cold

Try to make a table listing some other substances, which are present in your house and classify them as hot or cold. **However, how do you decide whether a substance is hot or cold? Can you always tell whether a substance is hot or cold simply by touching it?** The following activity will help you understand better.

Activity:

Take three containers and label them as **A, B**, and **C**. Take hot water in container **A**, and cold water in container **C.** In container **B**, mix hot and cold water in equal amounts. Now, place your left hand in container **A** and right hand in container **C** for two minutes. Then, dip both your hands in container **B**.



What can you say about the water present in all three containers? Note your observations in the table given below.

Container	Hot/Cold
A	
B	
C	

What is your observation for container B? Is the water in container B hot or cold?

When you dip your hands in container **B**, your left hand will indicate that the water is cold, while your right hand will indicate that the water is hot. Thus, you will not be able to distinguish whether the water present in container **B** is hot or cold.

From this activity, we can conclude that we cannot decide whether a substance is hot or cold just by touching it. Thus, we require something more reliable than our sense of touch to decide whether a substance is hot or cold.

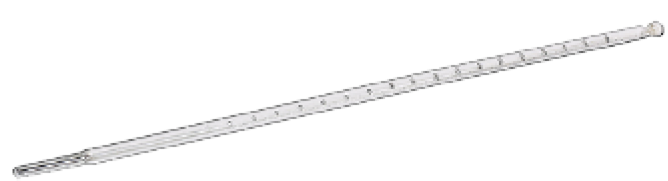
The measure that can be used to detect the degree of hotness of a substance is called temperature. More the temperature of a substance, the hotter it will be. **The device that is used to measure the temperature is called a thermometer.**

The scales used to measure temperature can either be degree Celsius, degree Fahrenheit or Kelvin. The ice point (freezing point of water) and steam point (boiling point of water) in these three scales of temperature are given in the following table.

Scale of temperature	Ice point	Steam point	Number of degrees in between the ice point and steam point
Kelvin	273 K	373 K	100
Celsius	0 °C	100 °C	100
Fahrenheit	32 °F	212 °F	180

There are two types of thermometers: **clinical thermometers and laboratory thermometers**. The table given below lists the difference between them.

Types of Thermometers

Clinical thermometer	**Laboratory thermometer**
This thermometer is used in homes. It is basically used to measure the temperature of humans. It has a temperature range of only 35 °C to 42 °C. **Can you tell the reason why?** This is because our body temperature never goes below 35 °C or above 42 °C. 	This thermometer is used to measure the temperature of all things, except the human body. It is a complex device. It has a temperature range of −10 °C to 110 °C. 

Why can we not use a laboratory thermometer to measure the body temperature of humans? Let us perform a small activity to understand.

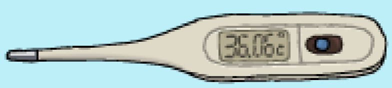
Activity:

Take a beaker full of water. Now, dip a laboratory thermometer in it. Make sure that it touches neither the bottom of the beaker nor the walls of the beaker. You will see that the mercury line rises for some time, but then ceases to rise. Note the reading where the mercury stagnates. This is the temperature of water. Take out the thermometer.

What do you observe? The mercury starts falling rapidly. This means that with a laboratory thermometer, temperature has to be read when placed in water. On the other hand, to measure the body temperature, the thermometer has to taken out of the mouth to note the reading. Thus, it is not convenient to use a laboratory thermometer to measure the body temperature of humans.

Do You Know?

Mercury is a very toxic substance. Hence, now days digital thermometers have become more popular, which do not contain mercury.



The amount of flat surface or region occupied by a closed figure is known as the area of the closed figure. The SI unit of area is square metre (m^2).

Conversion of Units of Area

1 km^2	= 1 km × 1 km	= 1000 m × 1000 m = 10,00,000 m^2
1 hectare	= 1 hm × 1 hm	= 100 m × 100 m = 10,000 m^2
1 are	= 1 dcm × 1 dcm	= 10 m × 10 m = 100 m^2
1 m^2	= 1 m × 1 m	= 100 cm × 100 cm =10,000 cm^2
1 m^2	= 1 m × 1 m	= 1000 mm × 1000 mm

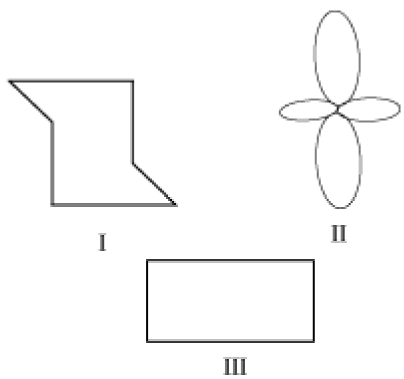
		$=10,00,000 \text{ mm}^2$
1 cm^2	$= 1 \text{ cm} \times 1 \text{ cm}$	$= 10 \text{ mm} \times 10 \text{ mm}$ $= 100 \text{ mm}^2$

Area is represented in square millimetres or mm^2 for small surfaces and the area of slightly bigger surfaces is represented in cm^2 .

Areas of bigger and bigger surfaces are represented in m^2, ares, hectares and km^2.

Measurement of area using graph paper

Look at the following closed figures.



All of the above figures occupy some region or flat surface**.**

Can we tell which one of the above three figures occupy a greater area?

We can answer this question, if we calculate the area of each figure. Now, **how can we do so?**

To calculate the area of each closed figure, we follow the below given steps.

Step 1: Firstly, we place the closed figure on a squared paper or a graph paper where every square measures 1 cm × 1 cm.

Step 2: Then we make an outline of the figure.

Step 3: Now we look at the squares enclosed by the figure. Some of them are completely enclosed, some half, some less than half and some more than half. Note down the number of squares of each category.

Step 4: Calculate the area of the closed figure by considering the following points.

(a) Take the area of 1 full square as 1 square unit.

(b) Ignore portions of the area that are less than half a square.

(c) If some portion enclosed by the figure is more than half a square, then

count its area as one square unit.

(d) If exactly half of the square is counted, take its area as ½ square unit.

Such a convention gives a fair estimate of the desired area.

Let us calculate the area of each figure using the above method and try to find out the figure whose area is more than the other two figures. So go through the given videos to understand the method.

For figure I

For figure II

For Figure III

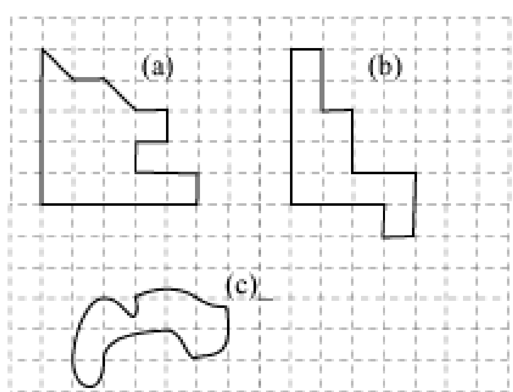
From the above calculations, we can say that figure III has more area than others.

Thus, figure III occupies more space than others.

Let us now discuss one more example based on the area of closed figures.

Example:

Find the areas of the following figures by counting the squares.



Solution:

(a) The number of completely-filled and half-filled squares for the given figure is 14 and 2 respectively.

Therefore, area covered by fully-filled squares = (14 × 1) square units = 14 square units

Area covered by half-filled squares = $\left(2 \times \frac{1}{2}\right)$ square units = 1 square unit

∴ Area of the given figure = (14 + 1) square units = 15 square units

(b) The number of completely-filled squares of the given figure is 11.

∴ Area of the given figure = 11 square units

(c) Observation of the number of completely-filled squares, half-filled squares etc. can be represented by the following table.

Covered Area	**Number**	**Area estimate (square units)**
Completely-filled squares	1	1
Half-filled squares	0	0
More than half-filled squares	7	7
Less than half-filled squares	4	0

∴ Estimated area of the given figure = (1 + 7) square units = 8 square units

Formulae for measuring area of regular bodies

- Area of square = $(\text{side})^2$
- Area of rectangle = length × breadth
- Area of circle = π × (radius)2π × (radius)2
- Surface area of cylinder = 2π × (radius) × length2π × (radius) × length
- Surface area of sphere = 4π × (radius)24π × (radius)2
- Area of triangle = ½ × base × height