

SLO 1: Measurement

1.1 Physical Quantities

1.1.1 Differentiate Between Physical And Non-Physical Quantities

ASPECT	PHYSICAL QUANTITIES	NON-PHYSICAL QUANTITIES
Definition	Quantities that can be measured and observed directly.	Quantities that cannot be measured directly using instruments.
Examples	Length, mass, time, temperature, speed, force, current, etc.	Happiness, anger, beauty, intelligence, thoughts, emotions, etc.
Measurement	Can be measured using tools (e.g., ruler, thermometer).	Cannot be measured with scientific instruments.
Units	Have defined units	No standard units.
Scientific Use	Used in physics and other sciences for calculations.	Not used in physical sciences for measurement.
Objectivity	Objective — same for all observers.	Subjective — varies from person to person.

1.1.2 Exemplify That Physics Is Based On Physical Quantities Only

A physical quantity is a physical property of a phenomenon, body, or substance that can be quantified by measurement. Physical quantities can be measured directly or indirectly using some tools and instruments such as length of an object using a ruler, time duration of an event using a clock, the temperature (the degree of hotness) of somebody using a thermometer. The foundation of physics rests upon physical quantities through which the laws and principles of physics are expressed.

1.1.3 Identify Various Physical Quantities As Base And Derive Quantities

Physics is much concerned with matter and energy and the interaction between them which is explained with the help of describing the mathematical relations between various physical quantities. All physical quantities are important for describing the nature around us.

A physical quantity can be expressed as the combination of a magnitude expressed by a number –usually a real number – and a unit. Physical quantities are classified into two categories:

1. Fundamental quantities: Physical quantities which cannot be explained by other physical quantities are called fundamental physical quantities. There are seven fundamental physical quantities.
2. Derived physical quantities: Physical quantities which are explained on the basis of fundamental physical quantities are called derived physical quantities. Some examples include

DERIVED QUANTITIES	S.I UNIT	SYMBOL OF UNIT
Volume	cubic meter	m^3
Velocity	meter per second	$m s^{-1}$
Force	Newton	N
Density	kilogram per cubic meter	kg/m^3
Acceleration	meter per second square	m/s^2

1.2 The International System (SI) of Units

1.2.1 List The Seven Base Quantities Of International System

FUNDAMENTAL QUANTITIES	S.I UNIT	SYMBOL OF UNIT
Length	meter	m
Mass	Kilogram	kg
Time	second	s
Electric current	Ampere	A
Temperature	Kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

1.2.2 Differentiate Between Base And Derived Physical Quantities And Units

Aspect	Base Physical Quantities and Units	Derived Physical Quantities and Units
Definition	Fundamental quantities that are independently defined.	Quantities derived from base quantities through multiplication or division.
Quantities	Length, mass, time, electric current, temperature, amount of substance, luminous intensity	Speed, area, volume, force, pressure, acceleration, energy, etc.
SI Units	Meter (m), kilogram (kg), second (s), ampere (A), kelvin (K), mole (mol), candela (cd)	Meter per second (m/s), newton (N), joule (J), pascal (Pa), etc.
Dependence	Independent — cannot be broken down into other physical quantities.	Dependent — formed by combining two or more base quantities.
Number in SI System	7 base quantities and units.	Unlimited number of derived quantities and units.
Usage	Serve as the foundation for all other physical measurements.	Used to express more complex physical concepts.

1.3 Scientific Notation

1.3.1 Convert Prefixes And Their Symbols To Indicate Multiples And Sub-Multiples

PREFIX	SYMBOL	FACTOR	PREFIX	SYMBOL	FACTOR
yotta	Y	10^{24}	centi	c	10^{-2}
zetta	Z	10^{21}	milli	m	10^{-3}
Exa	E	10^{18}	micro	μ	10^{-6}
Peta	P	10^{15}	nano	n	10^{-9}
tera	T	10^{12}	Pico	p	10^{-12}
giga	G	10^9	femto	f	10^{-15}
mega	M	10^6	Atto	a	10^{-18}
kilo	k	10^3	zepto	z	10^{-21}
Deci	d	10^{-1}	yocto	y	10^{-24}

1.3.2 Convert Numerical Values Of Measurement In Scientific Notation

Find the value of each of the following quantities:

(a) $(4 \times 10^3 \text{ kg})(6 \times 10^6 \text{ m})$

(b) $\frac{6 \times 10^6 \text{ m}^3}{2 \times 10^{-2} \text{ m}^2}$

Solution

(a) $(4 \times 10^3 \text{ kg})(6 \times 10^6 \text{ m}) = (4 \times 6) \times 10^{3+6} \text{ kg m}$
 $= 24 \times 10^9 \text{ kg m}$
 $= 2.4 \times 10^{10} \text{ kg m}$

(b) $\frac{6 \times 10^6 \text{ m}^3}{2 \times 10^{-2} \text{ m}^2} = \frac{6}{2} \times 10^{6-(-2)} \text{ m}^{3-2}$
 $= 3 \times 10^8 \text{ m}$

Solve the following:

(a) $5.123 \times 10^4 \text{ m} + 3.28 \times 10^5 \text{ m}$

(b) $2.57 \times 10^{-2} \text{ mm} - 3.43 \times 10^{-3} \text{ mm}$

Solution

(a) $5.123 \times 10^4 \text{ m} + 3.28 \times 10^5 \text{ m}$
 $= 5.123 \times 10^4 \text{ m} + 32.8 \times 10^4 \text{ m}$
 $= (5.123 + 32.8) 10^4 \text{ m}$
 $= 37.923 \times 10^4 \text{ m}$
 $= 3.7923 \times 10^5 \text{ m}$

(b) $2.57 \times 10^{-2} \text{ mm} - 3.43 \times 10^{-3} \text{ mm}$
 $= 2.57 \times 10^{-2} \text{ mm} - 0.343 \times 10^{-2} \text{ mm}$
 $= (2.57 - 0.343) 10^{-2} \text{ mm}$
 $= 2.227 \times 10^{-2} \text{ mm}$
 $= 2.227 \times 10^{-2} \times 10^{-3} \text{ m}$
 $= 2.227 \times 10^{-5} \text{ m}$

1.4 Scalars and Vectors

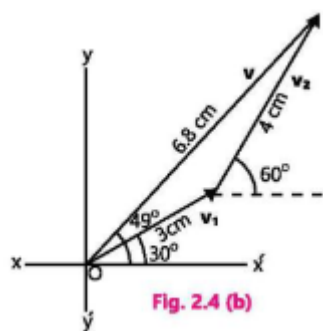
1.4.1 Differentiate Between Scalar And Vector Quantities

FEATURE	SCALAR	VECTOR
Definition	Quantities that have magnitude only.	have both magnitude and direction.
Direction	No direction involved.	Direction is essential.
Representation	Represented by a number and unit (e.g., 5 m, 20°C).	Represented with magnitude, unit, and direction (e.g., 5 m north, 20 N left).
Addition Rule	Added using simple arithmetic.	Added using vector rules (e.g., tip-to-tail method or parallelogram method).

1.4.2 List Out Various Physical Quantities As Scalar Or Vector

SCALAR		VECTOR	
Quantity	Unit	Quantity	Unit
Distance	meter (m)	Displacement	meter (m)
Speed	meter/second (m/s)	Velocity	meter/second (m/s)
Time	second (s)	Acceleration	meter/second ² (m/s ²)
Mass	kilogram (kg)	Force	newton (N)
Temperature	Kelvin (K)	Weight	newton (N)
Energy	joule (J)	Momentum	kg·m/s
Work	joule (J)	Electric Field	N/C or V/m
Power	watt (W)	Magnetic Field	tesla (T)
Volume	cubic meter (m ³)	Torque	newton-meter (N·m)
Density	kg/m ³		
Pressure	pascal (Pa)		

1.4.3 Describe The 'Head To Tail' Rule Of Vector Addition



Let us add two vectors v_1 and v_2 having magnitudes of 300 N and 400 N acting at angles of 30° and 60° with x-axis. By selecting a suitable scale 100 N = 1cm, we can draw the vectors. To add these vectors, we apply a rule called head-to-tail rule, which states that:

“To add a number of vectors, redraw their representative lines such that the head of one line coincides with the tail of the other. The resultant vector is given by a single vector which is directed from the tail of the first vector to the head of the last vector”

Measured length of resultant vector is 6.8 cm. According to selected scale, magnitude of the resultant vector v is 680 N and direction is angle 49 deg with x-axis. We can find the resultant vector of more than two vectors by adding them with the same way applying head-to-tail rule.

1.4.4 Determine, Using Pythagoras Theorem And Graphs, The Resultant Of Two Vectors At Right Angle

Identify the base, hypotenuse, and altitude of graph.

Use Pythagoras Theorem to find magnitude of resultant vector

$$R = \sqrt{A^2 + B^2}$$

Use trigonometric identity of Tangent to find the angel between Vector and resultant.

$$\theta = \tan^{-1} \frac{\text{perpendicular}}{\text{base}}$$

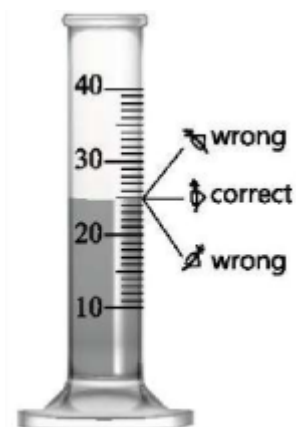
1.5 Measuring Instruments

Measuring Cylinder

It is a cylinder made of glass or transparent plastic with a scale divided in cubic centimeters (cm^3 or cc) or milliliters (mL) marked on it. It is used to find the volume of liquids and non-dissolvable solids. The cylinder can also be used to find the volume of solids.

Working:

The level of liquids in the cylinder is marked to find the volume. In order to read the volume correctly, the cylinder must be placed on a horizontal surface and the eye shall be kept in level with meniscus of water surface. The meniscus is the top level of the liquid surface. Water in the cylinder curves downward and its surface is called concave surface. The reading is taken corresponding to the bottom edge of the surface. The mercury in the cylinder curves upward. Its surface is convex and the reading is taken corresponding to the top edge.



Least Count:

The least count of a measuring cylinder is the smallest volume it can accurately measure, which corresponds to the smallest division marked on the scale of the cylinder. How to find the least count:

1. Check the volume range of the measuring cylinder (e.g., 100 mL).

- Count the number of divisions between two major markings (e.g., between 10 mL and 20 mL).
- Divide the difference in volume by the number of divisions. (1mL)

Measuring tape

A measuring tape is a flexible ruler used to measure length, width, height, or circumference. It is commonly used in construction, tailoring, carpentry, and by students in labs. Measuring tapes are usually made of cloth, plastic, or metal and are marked with units like millimeters (mm), centimeters (cm), inches, or feet.



Working:

A measuring tape works on a simple principle of direct length comparison. You pull the tape out of its case and place it along the object or distance you want to measure. The measurement is read at the point where the object ends on the scale of the tape. In rigid tapes, like metal ones used in construction, the tape remains straight when extended. In soft tapes, like tailor's tapes, the tape easily bends around curves and body parts.

Least Count:

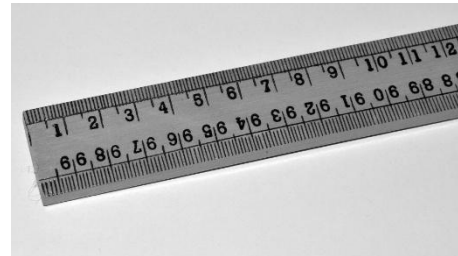
The least count is the smallest length it can accurately measure, equal to the smallest division on the scale. Most commonly, the least count is 1 mm (0.1 cm) in metric tapes. In tapes with only centimeter markings, the least count is 1 cm.

Meter rule

Length is measured using a meter rule in the laboratory. The smallest division on a meter scale is 1 mm.

Working:

To measure the length of an object, the meter rule is placed in such a way that its zero coincides one edge of the object and then the reading in front of the other edge is the length of the object. One common source of error comes from the angle at which an instrument is read. Meter ruler should either be tipped on its edge or read when the person's eye is directly above the ruler. If the meter ruler is read from an angle, such as from point A or C, the object will appear to be of different length. This is known as parallax.



Least Count:

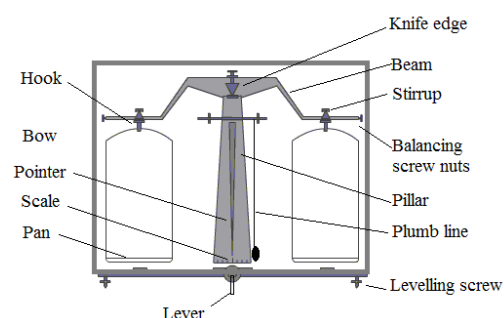
The smallest measurement that can be taken with a meter rule is 1 mm. One millimeter is known as least count of the meter rule.

Physical Balance

There are many kinds of balances used for measuring mass of an object. Mass is the measure of quantity of matter in a body whereas the weight is the force by which the body is attracted towards the Earth. The mass of an object is found by comparing it with known standard masses. This process is called weighing. In laboratories, we use physical balance which is based on the principle of levers.

Working:

Level base of the balance using levelling screws until the plumb line is exactly above the pointed mark. Turn the knob so that the



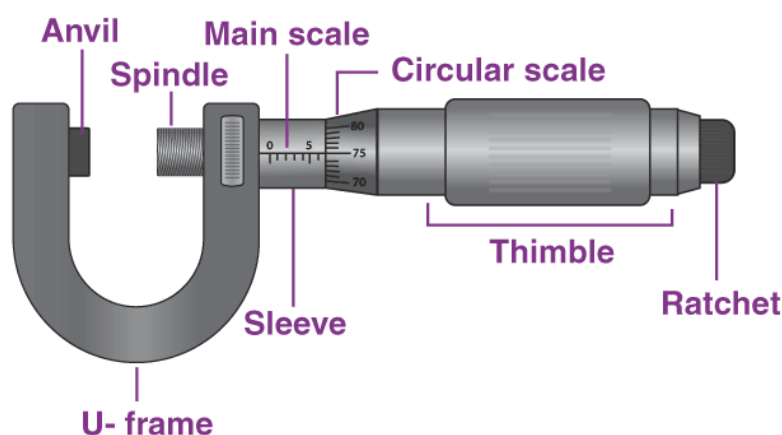
pans of the balance are raised up. The beam should be horizontal and pointer at the center of the scale. If not, turn the balancing screws on the beam so that it becomes horizontal. Place the object to be weighed on the left pan. Place the known weight from the weight box in the right pan using forceps. Adjust the weight so that pointer remains on zero or oscillates equally on both sides of the zero of the scale. The total of standard masses (weights) is a measure of the mass of the object in the left pan.

Least Count:

The least count is the smallest mass that can be measured accurately with the instrument. For a standard physical (beam) balance, the least count is usually 0.01 grams (10 milligrams). Least Count = 0.01 g

Screw gauge

It is used to measure very small lengths such as diameter of a wire or thickness of a metal sheet.



Working:

1. The main scale on the sleeve which has markings of 0.5 mm each.
2. The circular scale on the thimble which has 50 divisions.

Some instruments may have main scale marking of 1 mm and 100 divisions on the thimble. When the thimble makes one complete turn, the spindle moves 0.5 mm (1 scale division) on the main scale which is called pitch of the screw gauge.

Least Count:

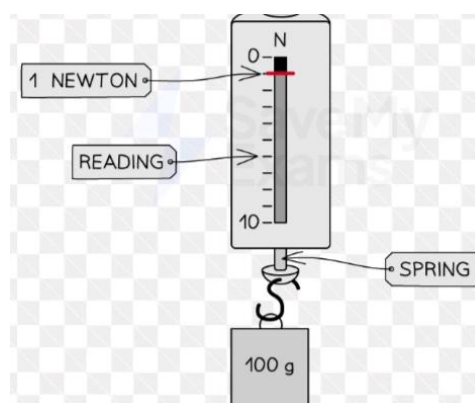
$$\text{Least Count of Screw Gauge} = \frac{\text{Pitch of Screw Gauge}}{\text{Number of divisions on circular scale}} = \frac{0.5 \text{ mm}}{50} = 0.01 \text{ mm}$$

Spring Balance

A spring balance is a device used to measure force or weight. It consists of a spring fixed at one end with a hook to attach objects at the other. The object's weight stretches the spring, and the amount of stretch is proportional to the force applied.

Working:

A spring balance works based on Hooke's Law, which states that "the extension of a spring is directly proportional to the force applied, provided the elastic limit is not exceeded" $F = kx$



Least Count:

The least count is the smallest force or weight the spring balance can measure accurately, which equals the smallest division marked on the scale. $\text{Least Count} = \text{Total Range} \div \text{Number of Divisions} = 10 \text{ N} \div 100 = 0.1 \text{ N}$

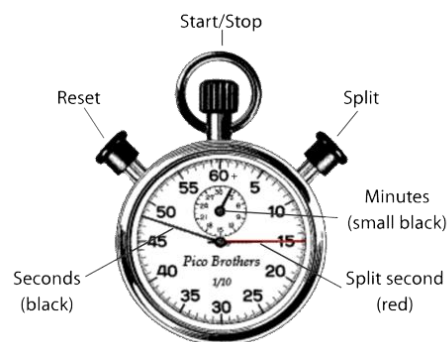
Typical Least Count: 0.1 N (can vary depending on the balance)

Stopwatch

The duration of time of an event is measured by a stopwatch.

Working:

It contains two needles, one for seconds and other for minutes. The dial is divided usually into 30 big divisions each being further divided into 10 small divisions. Each small division represents one tenth (1/10) of a second. While using, a knob present on the top of the device is pressed. This results in the starting of the watch. The same knob is again pushed to stop it. After noting the reading, the same knob is again pressed to bring back the needles to the zero position.



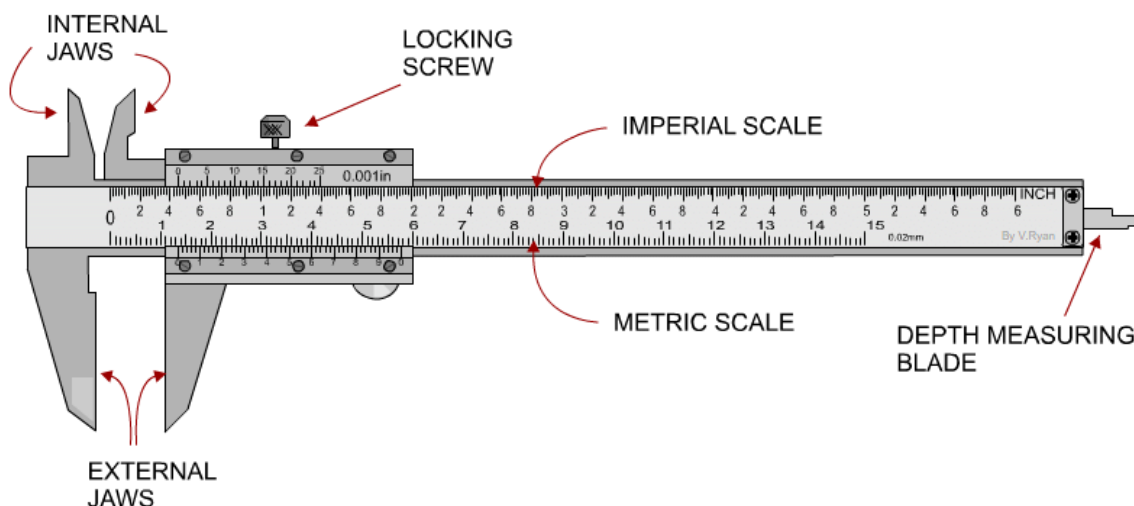
Least Count:

Electronic/digital watches can measure one hundredth part of a second. $\text{Least Count} = 0.01\text{s}$

One tenth of a second is the least count of this stopwatch. $\text{Least Count} = 0.1\text{s}$

Vernier Calipers

Vernier Calipers was Invented by a French Scientist Pierre Vernier in 1631. It is an instrument used for small lengths down to 1/10th of a millimeter.



Working:

It can be used to measure the thickness, diameter, width or depth of an object. The two scales on it are:

1. A main scale which has marking of 1mm each.
2. A Vernier (sliding) scale of length 9 mm and it is divided into 10 equal parts

Least Count:

Least count of a Vernier Calipers is the difference between one main scale division (M.S) and one Vernier scale (VS) division. Hence, $\text{Least count} = 1 \text{ M.S div} - 1 \text{ V.S div}$

$$= 1 \text{ mm} - 0.9 \text{ mm} = 0.1 \text{ mm}$$

1.6 Error and Accuracy

1.6.1 Identify Sources Of Errors In The Measurement

Measurements using tools and Instruments are never perfect. They inherit some errors and differ from their true values. The best we can do is to ensure that the errors are as small as reasonably possible. A scientific measurement should indicate the estimated error in the measured values. Usually, there are four types of experimental errors affecting the measurements.

Human Error:

They occur due to personal performance. The limitation of the human perception such as the inability to perfectly estimate the position of the pointer on a scale. Personal errors can also arise due to faulty procedure to read the scale. In timing experiments, the reaction time of an individual to start or stop clock also affects the measured value. Human error can be reduced by ensuring proper training, techniques and procedure to handle the instruments and avoiding environmental distraction or disturbance for proper focusing: The best way is to use automated or digital instruments to reduce the impact of human errors.

Systematic Error:

They refer to an effect that influences all measurements of particular measurements equally. It produces a consistence difference in reading. It occurs due to some definite rule. It may occur due to zero error of instrument, poor calibration of instrument or incorrect marking. The effect of this kind of error can be reduced by comparing the Instrument with another which is known to be more accurate. Thus, a correction factor is applied.

Random Error:

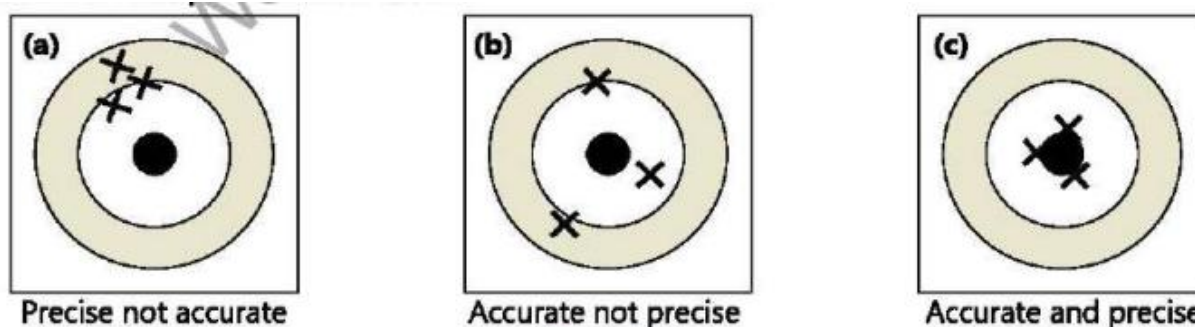
It is said to occur when repeated measurements of a quantity give different values under the same conditions. It is due to some unknown causes which are unpredictable. The experimenter has a little or no control over it. Random error arises due to sudden fluctuation or variation in the environmental conditions. For example, changes in temperature, pressure, humidity, voltage, etc. The effect of random errors can be reduced using several or multiple readings and then taking their average or mean value.

Parallax Error:

Parallax error is due to Incorrect position of eyes when taking measurements. It can be avoided by keeping eye perpendicular to the scale reading.

1.6.2 Differentiate Between Precision And Accuracy

TYPE	ACCURACY	PRECISION
Definition	How close a measurement is to the true or actual value.	How consistent repeated measurements are, even if they are not correct.
Focus	Correctness of the result	Repeatability of the result
Example	If the actual weight is 100g and you measure 99.9g, it's accurate.	If you measure 98g, 98g, 98g repeatedly, it's precise but not accurate.
Target Analogy	Arrows close to the bullseye (center) = accurate	Arrows close to each other, even if not near the center = precise



1.7 Significant Figures

1.7.1 Describe Significant Figures

The significant figures or digits are the digits of a measurement which are reliably known.

Significant figures are the digits in a number that carry meaning and contribute to its accuracy.

Example: In 34.76, all four digits are significant. But in 0.00053 only 5 and 3 are significant.

1.7.2 Apply The Rules For Rounding A Number To The Appropriate Number Of Significant Figures.

1. Identify how many significant figures you need.
2. Count significant digits from left to right, starting with the first non-zero digit.
3. Look at the digit after the last significant figure you want:
 - a. If it's 5 or more, round up the last significant digit.
 - b. If it's 4 or less, leave it as it is.
4. Replace digits after that with zeros (for whole numbers) or remove them (for decimals).
5. Zeros before the first non-zero digit are not significant (e.g., in 0.0034, only 3 and 4 are significant).
6. Zeros between digits are significant (e.g., in 103, all 3 digits are significant).

Example 1: Round 456.78 to 3 significant figures

First 3 significant digits: 456

Next digit = 7 → round up

Answer = 457

Example 2: Round 0.004562 to 2 significant figures

First 2 significant digits: 4 and 5

Next digit = 6 → round up

Answer = 0.0046

Example 3: Round 78900 to 2 significant figures

First 2 significant digits: 7 and 8

Next digit = 9 → round up

Answer: 79000