CHAPTER 2

Foundations of Measurement in Physics

Precision Measurement with a Vernier Caliper

The Vernier caliper is a precise measuring tool used in physics and engineering to gauge the dimensions of objects with accuracy. It can measure the external size of an object using the top jaws, the internal size using the inner jaws, and the depth using the stem. This tool is crucial for tasks where small size differences matter, such as designing parts to fit together in machines or conducting scientific experiments where exact measurements are required.

Student Learning Outcomes

- Explain with examples that physics is based on physical quantities [Including that these consist of a magnitude and a unit.
- Differentiate between physical and non-physical quantities.
- Differentiate between the base and derived physical quantities and units.
- Apply the seven units of System International (SI) [along with their symbols and physical quantities (standard definitions of SI units are not required)]
- Analyse and express numerical data using scientific notation [In measurements and calculations.]
- Analyse and express numerical data using prefixes [Including use of their symbols to indicate decimal submultiples or multiples of both base and derived units. Specifically: pico (p), nano (n), micro (p), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T). This also includes]
- Interconverting the prefixes and their symbols to indicate multiple and submultiple for both base and derived units.]
- Differentiate between scalar and Vector quantities scalar has magnitude (size) only and that a vector quantity has magnitude and direction. Students should be able to represent vectors graphically]
- Justify that distance, speed, time, mass, energy, and temperature are scalar quantities.
- Justify that displacement, force, weight, velocity, acceleration, momentum, electric field strength and gravitational field strength are vector quantities.
- Determine, by calculation or graphically, the resultant of two vectors at right angles
- *Make reasonable estimates of physical quantities* [Of those that are discussed in the topics of this grade level] Theory of Measurement:
- Justify and illustrate the use of (Common lab instruments to measure length [Including how to measure a variety of lengths with appropriate precision using tapes, rulers, micrometers, and vernier calipers (including reading the scale on analogue calipers and micrometers)]
- Justify and illustrate the use of measuring cylinders to measure volume [Including both measurement of volumes of liquids and determining the volume of a solid by displacement]
- Justify and illustrate how to measure time intervals using lab instruments [Including clocks and digital timers.]
- Determine an average value for an empirical reading[Including small distance and for a short interval of time by measuring multiples (including the period of oscillation of a pendulum)]
- Round off and justify calculational estimates.Based on empirical data to an appropriate number of significant figures]

All the above mentioned SLOs are classified into knowledge and skills for the better understanding of students.

After studying this Unit, the students will be able to understand:

Knowledge

- Physics relies on physical quantities, characterized by a magnitude and unit, exemplified by concepts like length (meters) and force (Newtons), distinguishing them from non-physical quantities, while also understanding the distinction between base and derived physical quantities and units.
- Apply the seven SI units (meter, kilogram, second, ampere, kelvin, mole, and candela) with their respective symbols to represent physical quantities, while also analyzing and expressing numerical data using scientific notation for enhanced clarity and precision.
- Analyze and express numerical data using prefixes (e.g., pico, nano, micro, milli, kilo) and symbols, for both base and derived units. They will also make accurate estimations of relevant physical quantities discussed at this grade level.
- Critique and analyze experiments, identifying error sources and suggesting corrections, and determine average values for empirical readings, including short time intervals like measuring pendulum oscillations.
- Determine the least count of analog data collection instruments from their scales and differentiate between precision and accuracy effectively.
- Justify and demonstrate the utilization of common laboratory instruments such as tapes, rulers, micrometers, and vernier calipers for measuring lengths with appropriate precision. This includes understanding how to read analog calipers and micrometers accurately.
- Justify and demonstrate the utilization of measuring cylinders for measuring volume. This includes understanding how to measure volumes of liquids accurately and determining the volume of a solid by displacement method using a measuring cylinder.
- Justify and illustrate the use of lab instruments such as clocks and digital timers for measuring time intervals accurately. This includes understanding how to operate and interpret readings from both analog and digital timing devices.
- Round off and justify calculational estimates based on empirical data to an appropriate number of significant figures, ensuring accuracy and precision in their calculations.

Skill

- Skills in converting to scientific notation, expressing numerical data using it, and performing arithmetic operations with numbers in scientific notation.
- Skill in interconverting SI prefixes and their symbols in the context of both base and derived units.
- Making close approximations of physical quantities based on known data.
- Ability to identify and correct sources of systematic and random errors in experimental measurements.
- Skills in determining the least count of various analog measurement instruments.
- Ability to accurately measure lengths using various instruments, and identifying potential sources of error.
- Skills in measuring volumes of both liquids and solids using measuring cylinders, with an understanding of potential errors.
- Proficiency in measuring time intervals using lab instruments, and taking precautions to avoid random errors.
- Ability to determine average values for empirical readings, especially for small distances and time intervals, and apply averaging as a tool against random errors.
- Skill in rounding off empirical data to an appropriate number of significant figures.

Knowledge 2.1 | Foundation of Physics

When we observe the universe around us, it becomes evident that everything, from the tiniest particle (atom) to a huge galaxy and also the energy, can be quantified or measured. This essence of measurement is the cornerstone of physics. All measurable things are called physical quantities and the foundation of physics is based on these quantities. By measuring physical quantities, we can get clear answers about the world around us.

Physical Quantities

Physical quantities are measurable properties of matter and energy that comprise two essential components: magnitude and unit. The magnitude refers to the numerical value of the quantity, while the unit is the standard of measurement for the quantity. Together, these components provide a clear and precise description of the physical quantity, which is foundation of physics. For example, If a scientist wants to study the properties of light, they might measure the wavelength of a light wave, such as 500 nanometers. "500" is the magnitude, and "nanometers" is the unit.

So physical Quantities can be defined as Those quantities that we can measure, and laws of physics can be expressed in terms of the relationship among these quantities. They help us to understand and describe the world around us. Some examples of physical quantities are mass, length, time, force, speed, velocity, etc.

(a) Mass (b) Time (c) Temperature

(a)

Happiness Sadness Angry

(b)

Figure 2.1: (a) examples of physical quantities (b) examples of non-physical quantities

Non-Physical Quantities

There are some other quantities around us that can be observed but cannot be measured and, therefore cannot be classified as physical quantities, for example, smell, happiness, feelings, emotions, etc. These are named non-physical quantities

Student Learning Outcome

- *Explain with examples that physics is based on physical quantities [Including that these consist of a magnitude and a unit]*
- *Differentiate between physical and non-physical quantities*
- *Differentiate between the base and derived physical quantities and units.*

Table 2.1: Some time interval

Age of the Universe ≈	4×10^{17}s
Age of the Solar System	1.4×10^{17}s
Age of human species	7.9×10^{12} s
Life span of man (average)	2.2×10^{9}s
Revolution of Earth (1 year)	3.2×10^{7}s
Rotation of Earth (1 day)	8.6×10^{4}s
Travel time for light from Sun	5×10^{2}s
Travel time for light from Moon	1.3 s
Period of heartbeat (hum	≈ 0.9 s

Table 2.2: Relative size of different objects

Length in Meters	
Radius of our galaxy	6×10^{19}
Radius of the Sun	7×10^{8}
Radius of the Earth	6×10^{6}
Height of Mount Everest	9×10^{3}
Height of a typical person	2×10^{0}
Thickness of a page	1×10^{-4}
Size of a typical virus	1×10^{-6}
Radius of a hydrogen atom	5×10^{-11}
Effective radius of a proton	1×10^{-15}

Table 2.3: Masses of Various Objects in kg (Approximate Values)

Objects	Mass
Observable Universe	$\sim 10^{52}$
Milky Way galaxy	$\sim 10^{42}$
Sun	1.99×10^{30}
Earth	5.98×10^{24}
Moon	7.36×10^{22}
Shark	$\sim 10^{3}$
Human	$\sim 10^{2}$
Frog	$\sim 10^{-2}$
Mosquito	$\sim 10^{-5}$
Bacterium	$\sim 1 \times 10^{-15}$
Hydrogen atom	1.67×10^{-27}
Electron	9.11×10^{-31}

Test Yourself

1. If physical quantities can be measured, provide an example of a measuring instrument for one of the physical quantities you have studied.
2. Imagine a friend says that the "Intensity of a smell" should be a physical quantity because some smells are stronger than others. How would you respond to your friend's statement?

Multiple Choice Questions

1. What is a physical quantity?
   a) A quantity that can only be described
   b) A quantity that can be measured and expressed with units
   c) A feeling or emotion
   d) A type of food
2. If a scientist wants to study the quality of a painting, is this a study of a physical or non-physical quantity?
   a) Physical quantity, as it can be measured with units
   b) Non-physical quantity, as it cannot be measured with units
   c) Both physical and non-physical quantities
   d) Neither physical nor non-physical quantities

Table 2.4: Seven base quantities along with their units

Quantity	Unit	Symbol
mass	kilogram	kg
length	metre	m
time	second	s
electric current	ampere(amp)	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	Candela	cd

Base and Derived Quantities

Physical quantities are either fundamental or derived, measured directly, or derived, calculated from other quantities. For instance, we measure distance using a ruler and time with a stopwatch, while average speed is calculated by dividing distance by time. This leads us to two categories: base and derived quantities.

Base quantities are the foundational elements in physics, like length, mass, and time, essential for defining other quantities. The International System of Units recognizes seven such base quantities, including thermodynamic temperature, electric current, luminous intensity, and amount of substance. These base quantities are measured directly and form the cornerstone for more complex measurements. So, we define base quantities are the minimum number of quantities that shall be measured directly without the help of other physical quantities. The seven base quantities in the International System of Units, are listed in the table 2.4.

Derived quantities, on the other hand, are formed by combining base quantities. For example, speed is derived from length and time. So, physical quantities those that are not independent and are measured by following a procedure of calculation in which other physical quantities are involved. These quantities, such as area, volume, and force, help us describe and measure our world in more detail. They are crucial for understanding various aspects like the size of a surface (area) or the space an object occupies (volume).

The relationship between base and derived quantities is key to comprehending the physical world and its phenomena. Some derived Quantities are listed in the table 2.5

Table 2.5 Examples of derived quantities

Derived quantity		Formula
Name	Symbol	
Area	A	Length × Breadth
Volume	V	Length × Breadth × Height
Velocity	v	$\frac{\text{Displacement}}{\text{Time taken}}$
Acceleration	a	$\frac{\text{Change in velocity}}{\text{Time taken}}$
Momentum	P	Mass × Velocity
Density	ρ	$\frac{\text{Mass}}{\text{Volume}}$
Force	F	Mass × Acceleration
Pressure	P	$\frac{\text{Force}}{\text{Area}}$
Frequency	f	$\frac{1}{\text{Time period}}$
Work	W	Force × Displacement
Power	P	$\frac{\text{Work}}{\text{Time taken}}$

Test Yourself

1. If you were to measure the space inside a box, which derived quantity would you be finding?
2. Suppose you are measuring how much light a bulb emits. Which base quantity are you working with?

Multiple Choice Questions

1. Which of the following sets includes only base quantities?
   a) Time, Mass, Temperature
   b) Speed, Force, Energy
   c) Velocity, Acceleration, Power
   d) Work, Momentum, Torque
2. If the density is a derived quantity, what could be the base quantities used to express it?
   a) Mass and Length
   b) Time and Length
   c) Force and Speed
   d) Energy and Work

Do You Know?

MASS

SI unit: kilogram (kg)

- One kilogram is the mass of one liter of water, or about the mass of an average sized pineapple.

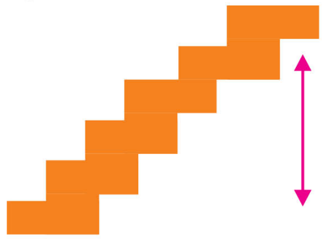
Do you Know?

LENGTH

SI unit: meter (m)

One meter is about the average height of a 32-year-old person, or five steps up a typical staircase.

- Micrometer (μm): A millionth of a meter is equal to the length of a bacterium.
- Millimeter (mm): A thousandth of a meter is equal to the diameter of a pinhead.



Skill 2.1

"Understand the core of physics through the exploration of physical quantities, distinguishing between base and derived units. Learn to differentiate physical from non-physical quantities, using examples to deepen your comprehension."

Knowledge 2.2 | Mastering SI Units and Scientific Notation

Student Learning Outcome

- *Apply the seven units of System International (SI) [along with their symbols and physical quantities (standard definitions of SI units are not required)]*
- *Analyze and Express Numerical Data using Scientific Notation*

Before a measurement can be made, a standard or unit must be chosen. The size of the quantity to be measured is then found with an instrument having a scale marked in the unit. In 1971, scientists from all over the world agreed on a set of standard units for measuring things. These units are called the International System of Units, or SI. Scientists adopted an International System of units at a General Conference on Weight and Measurement in 1960 and finally refined it in 1970. It is considered to be a complete and coherent system of units for all physical quantities. The SI is a set of metric units now used in many countries. It is a decimal system in which units are divided or multiplied by 10 to give smaller or larger units

Base Units and Derived Units

The SI is based on seven units, which are the meter, kilogram, second, ampere, kelvin, mole, and candela. These are units of seven base quantities called base units. Base units, along with their symbols, are listed in the table 2.4.

These are the units of derived quantities. For example, a unit of force is newton, and that of speed is a meter per second. The units of all the derived physical quantities are a combination of fundamental units without introducing any numerical value, as presented in the table 2.5.With derived units, any measurable quantity can be communicated. Some derived units have special names, and some are expressed simply in terms of other units.

Do you Know?

TIME

SI unit: second (s)

One second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between two hyperne levels of the ground state of the cesium-133 atom.

- a minute is 60 seconds
- an hour is 3,600 seconds
- a day is 86,400 seconds
- a week is 604,800 seconds
- a year (other than leap
- years) is 31,536,000 seconds
- and a (Gregorian) century
- averages 3,155,695,200 seconds

Do you Know?

TEMPERATURE SI unit: kelvin (K)

Just one degree rise in temperature can make you feel hot and feverish.

Temperature scales

In the USA, an everyday temperature scale uses degree Fahrenheit (°F). where the freezing point of water is 32°F. Kelvin measures all the way down to absolute zero where heat energy does not exist.

- 0 kelvin = absolute zero, when all objects and their particles are still.
- 1 kelvin = the coldest known object in the universe, the Boomerang Nebula.
- 1,000 kelvin = the temperature inside a charcoal fire.

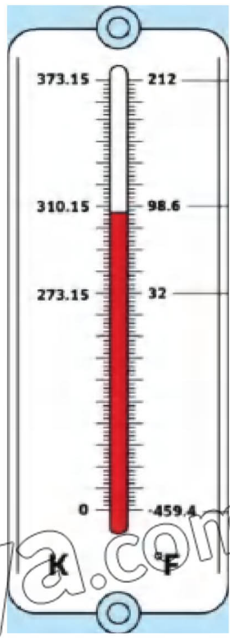


Table 2.6: Derived units of physical quantities

Derived quantity		S.I unit	
Name	**Formula**	**Fundamental units**	**Special name**
Area	l x w	$m \times m = m^2$	-
Volume	l x w x h	$m \times m \times m = m^3$	-
Velocity	d / t	$\frac{m}{s} = ms^{-1}$	-
Acceleration	$\frac{v_f - v_i}{t}$	$\frac{ms^{-1}}{s} = ms^{-2}$	-
Momentum	mv	$kg \times ms^{-1} = kg\ ms^{-1}$	-
Density	$\frac{m}{V}$	$\frac{kg}{m^3} = kgm^{-3}$	-
Force	ma	$kg \times ms^{-2} = kg\ ms^{-2}$	newton, N
Pressure	$\frac{F}{A}$	$\frac{kg\ ms^{-2}}{m^2} = kgm^{-1}s^{-2}$ or $\frac{N}{m^2} = Nm^{-2}$	pascal, Pa
Frequency	$\frac{1}{T}$	$\frac{1}{s} = s^{-1}$	hertz, Hz
Work	Fd	$kg\ ms^{-2} \times m = kgm^2s^{-2}$ or $N \times m = Nm$	joule, J
Power	$\frac{w}{t}$	$\frac{kg\ m^2 s^{-2}}{s} = kg\ m^2 s^{-3}$ or $\frac{J}{s} = Js^{-1}$	watt, W
Electric charge	$I \times t$	$A \times s = As$	coulomb, C

Test Yourself

1. What are derived units, and can you name one example?
2. Why is the unit symbol for ampere capitalized?
3. How would you represent the unit of force in terms of base units?

Multiple Choice Questions

1. Which of the following is NOT a derived unit in the SI system?
   a) newton b) pascal c) ampere d) joule
2. A scientist is measuring the amount of substance in a chemical reaction. Which SI base unit will be appropriate for this measurement?
   a) kelvin b) mole c) candela d) ampere
3. Which of the following options correctly matches the SI base unit with its symbol?
   a) ampere - A, candela - C, mole - M
   b) meter - m, kilogram - kg, second - s
   c) kelvin - K, ampere - A, Second - s
   d) Both b and c

Do you Know?

Light Intensity

SI unit: candela (cd)
One candle is the light intensity given off by a candle Fame.

A millionth of a candela = the lowest light intensity perceived by human vision.
A thousandth of a candela = a typical night sky away from city lights.
1 billion candelas = the intensity of the sun when viewed from Earth.

Do you Know?

Amount Of A Substance

SI unit: mole (mol) One mole is a set number of atoms, molecules, or other particles. Because substances all have different atomic structures, one mole of one substance may be very different to that of another.

A mole of gold atoms is about six gold coins.

A mole of sugar molecules is about two small cups.

- A tenth of a mole of iron atoms = the amount of iron in the human body.
- 1,000 moles of carbon atoms = the amount of carbon in the human body.
- 10 million trillion moles of oxygen molecules the amount of oxygen in Earth's atmosphere.

Power of Ten

When we measure a physical quantity, it may have very small or very large value. To write very large or very small numerical value in a neat way, we write them in terms of the power of 10. The example below shows how it works.

$2000 = 2 \times 10 \times 10 \times 10 \qquad = 2 \times 10^3$

$200 = 2 \times 10 \times 10 \qquad = 2 \times 10^2$

$20 = 2 \times 10 \qquad = 2 \times 10^1$

$2 \ = 2 \times 1 \qquad = 2 \times 10^0$

$0.3 = 3/\ 10 = 3/10^1 \qquad = 3 \times 10^{-1}$

$0.03 = 3/100 = 3/\ 10^2 \qquad = 3 \times 10^{-2}$

$0.003 = 3/1000 = 3/10^3 \qquad = 3 \times 10^{-3}$

The above numbers are written in the power of ten. The power shows how many times the number has to be multiplied by 10 if the power is greater than 0 or divided by 10 if the power is less than 0. Note that 1 is written as 100.

Scientific Notation: This way of writing numbers is called scientific or standard notation, which we will discuss in the next topic in detail.

Scientific notation, or standard form, is a concise way of expressing very large or very small numbers using powers of 10. It is based on two rules:

1. A number in standard form is written as $A \times 10^n$, where:

- A is a digit between 1 and 10 (integer or decimal).
- n is a positive integer for numbers greater than one or a negative integer for numbers less than one.

2. In standard form, only one non-zero digit appears before the decimal point, and the value is adjusted by multiplying by an appropriate power of 10.

Conversion to Scientific Notation:

- For large numbers, move the decimal point after the first non-zero digit, and the number of places shifted becomes the exponent of 10. e.g., 300 becomes 3×10^2.
- For numbers less than 1 , place a decimal after the first non-zero digit and count the places to determine the negative exponent of 10 . e.g., 0.0023 becomes 2.3×10^{-3}.

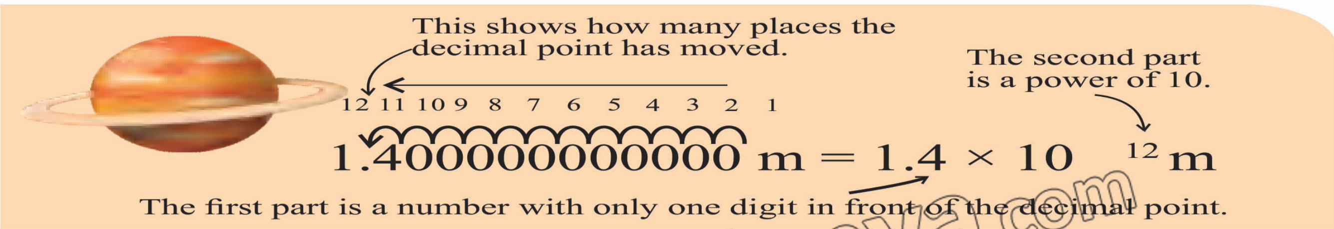


Figure 2.2(a): Writing distance of Saturn from Sun in scientific notation

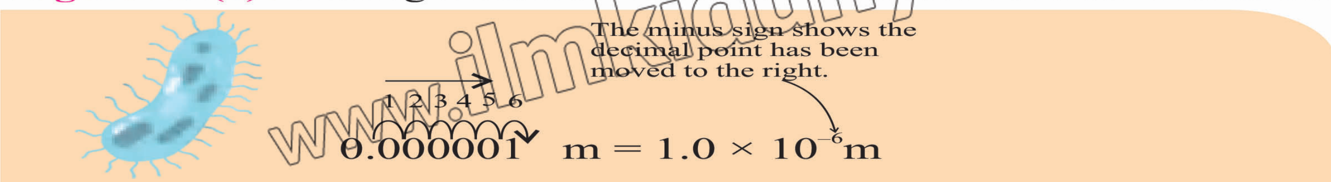


Figure 2.2(b): Writing size of bacteria in scientific notation

In scientific measurements and calculations, scientific notation is used to maintain the precision of data, ensuring the number of significant figures is clear. When performing operations with numbers in scientific notation, the laws of exponents are followed as

Multiplication with Scientific Notation

Multiplying two numbers in scientific notation, you multiply the coefficients and add the exponents

For example, let us multiply (2×10^3) and (3×10^4).

- Multiply the coefficients: $2 \times 3 = 6$
- Add the exponents: $3 + 4 = 7$

So, $(2 \times 10^3) \times (3 \times 10^4) = 6 \times 10^7$.

Division with Scientific Notation

When dividing numbers in scientific notation, you divide the coefficients and subtract the exponents.

For example, let us divide (6×10^8) by (3×10^4).

- Divide the coefficients: $6 / 3 = 2$
- Subtract the exponents: $8 - 4 = 4$

So, $(6 \times 10^8) / (3 \times 10^4) = 2 \times 10^4$.

Addition and Subtraction with Scientific Notation

When adding or subtracting numbers in scientific notation, they must first be expressed with the same exponent.

For example, to add 5.67×10^3 and 3.4×10^4,

Rewrite the first number to match the exponent of the second number.

So 5.67×10^3 becomes 0.567×10^4,

Add the Coefficient: $0.567 + 3.4 = 3.967$

So, the result is 3.967×10^4.

Knowledge 2.3 | SI Prefixes and Estimation

As we encounter a vast range of physical quantities in our world, from the immense scale of radius of earth at about 6,400 kilometers to the incredibly minute size of an atom at approximately 0.1 nanometers, the need to manage and communicate these values effectively becomes evident. To bridge the gap between these extremes and handle very large or very small values, we employ prefixes. Additionally, the ability to make reasonable estimates of physical quantities, aids us in problem solving, decision making, experiment planning, and understanding the order of magnitude of a result, especially in complex and dynamic systems where exact measurements can be challenging or time-consuming.

Prefixes

A **prefix** is a **letter** placed at the **beginning** of a SI base unit. The SI allows other units to be created from standard or base units by using prefixes, which act as **multipliers.** The SI units, used with prefixes, indicate **multiples** or **sub-multiples** of a base unit. For example, 2000 meters (meter as the base unit) written in standard form as

Test Yourself

1. List the rules for converting large and small numbers to scientific notation.
2. How do you multiply two numbers in scientific notation?

Multiple Choice Questions

1. Which of the following represents 0.0009 in scientific notation?
   a) 9×10^{-4} b) 0.9×10^{-4}
   c) 90×10^{-3} d) 9×10^{-3}
2. What is the value of 4.2×10^3 divided by 2×10^2 ?
   a) 21×10 b) 2.1×10^2
   c) 2.1×10 d) 2.1×10^1

Skill 2.2

Master the system international units (SI), and also develop skills in analyzing and expressing numerical data through the precision of scientific notation. Learn to simplify complex numbers for clearer understanding and effective communication in physics.

Student Learning Outcome

- Analyse and express numerical data using prefixes [Including use of their symbols to indicate decimal submultiples or multiples of both base and derived units. Specifically: pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T). This also includes] Interconverting the prefixes and their symbols to indicate multiple and sub-multiple for both base and derived units.]
- Make reasonable estimates of physical quantities [Of those that are discussed in the topics of this grade level]

2.0×10^3 meters, can also be written as 2.0 kilometers where the prefix kilo (k) means 1000..

Example 2.1

Express the following measurement

(i) 5,000,000 meters into kilometers.
(ii) 300 milligrams in grams.
(iii) 0.0045 kilometers to meters.
(iv) 1500 microseconds in milliseconds.

Solution

(i) $5{,}000{,}000\ \text{m} = 5{,}000 \times 10^3\ \text{m} = 5{,}000\ \text{km}$

(ii) $300\ \text{mg} = 3 \times 10^2\ \text{mg}$

As in the table of Prefixes, milli $= \times 10^{-3}$

So, $300\ \text{mg} = 3 \times 10^2\ \text{mg} = 3 \times 10^2 \times 10^{-3}\ \text{g} = 3 \times 10^{2-3}$

$$3 \times 10^{-1} = \frac{3}{10}\ \text{g} = 0.3\text{g}$$

(iii) $0.0045\ \text{km} = 4.5 \times 10^{-3}\ \text{km}$

As the prefix "kilo" is equal to 10^3

So, $0.0045\ \text{km} = 4.5 \times 10^{-3} \times 10^3\ \text{m} = 4.5 \times 10^{-3+3}\text{m}$

$= 4.5 \times 10^0\ \text{m} = 4.5 \times 1 = 4.5\ \text{m}$

(iv) (After writing in standard form, use "micro (μ)" = 10^{-6},

$1500\ \mu\text{s} = 1.5 \times 10^3\ \mu\text{s} = 1.5 \times 10^3 \times 10^{-6}\ \text{s} = 1.5 \times 10^{3-6}\ \text{s}$

$= 1.5 \times 10^{-3}\ \text{s} = 1.5\ \text{ms}.$

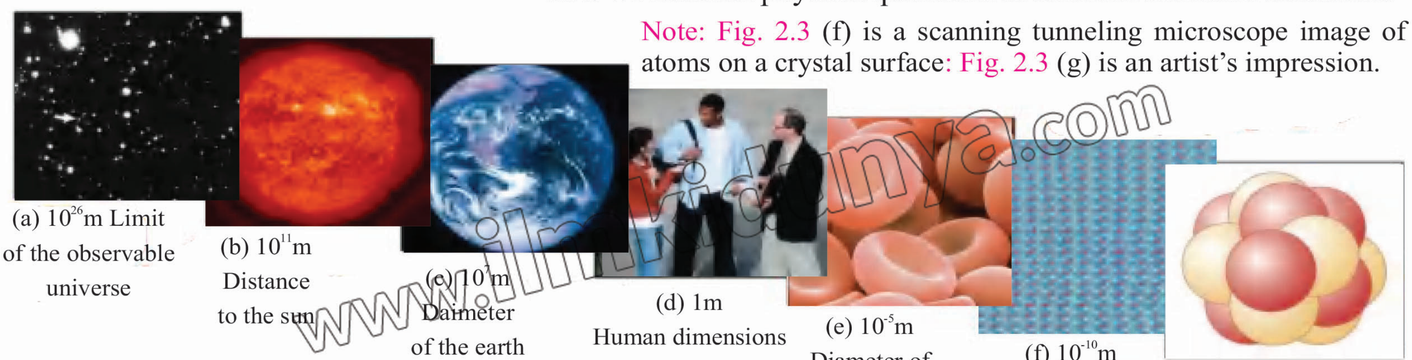
Order of Magnitude

The term order of magnitude refers to the scale of a value expressed in the metric system. Each power of 10 in the metric system represents a different order of magnitude. For example, 10^1, 10^2, 10^3 are different orders of magnitude.

Quantities that share the same specific power of 10 are considered to be in the same order of magnitude group. For example, both 800 (expressed as 8×10^2) and 450 (expressed as 4.5×10^2) belong to the same order of magnitude because they use the same power of 10.

Understanding order of magnitude, which helps quickly assess the size of values, like the tiny atom with a 10^{-9}meter diameter or the massive Sun with a 10^9meter diameter, leads us to explore why and how we estimate physical quantities in different scientific situations."

Note: Fig. 2.3 (f) is a scanning tunneling microscope image of atoms on a crystal surface: Fig. 2.3 (g) is an artist's impression.



(a) 10^{26}m Limit of the observable universe
(b) 10^{11}m Distance to the sun
(c) 10^7m Daimeter of the earth
(d) 1m Human dimensions
(e) 10^{-5}m Diameter of a red blood cell
(f) 10^{-10}m Radius of an atom
(g) 10^{-14}m Radius of an atomic nucleus

Figure 2.3: Some typical lengths in the universe

- Treat unit names like regular words, with lowercase letters unless they start a sentence.
- Always leave a space between the number and the unit, like "25kg."
- Break up big numbers with spaces, not commas. Like "15 739."
- Only use one prefix at a time. "10 ns" is correct, not "10 m μs". Similarly, "5 pm" is correct not "5 μμm".

Knowledge 2.4 Analyzing and Correcting Measurement Errors

In the scientific process, conducting experiments is essential for exploring physical quantities such as mass, length, and time. Accurate measurement of these quantities is essential for obtaining reliable data. Before we delve into using measurement tools like rulers for length and stopwatches for time, it is important to address potential measurement errors. Recognizing and understanding these errors enables us to refine our experiments and enhance the credibility of our findings.

Understanding the least count is vital as it allows us to estimate the precision of measurements obtained from the instrument, aligning with the goal of determining an average value for an empirical reading. This is particularly relevant when measuring small distances or short intervals of time, including the period of oscillation of a pendulum.

Errors

Error represents the difference between the measured value and the true value of a quantity. It indicates how far off the measurement is from the actual value.

In scientific experiments, perfect accuracy in measurements is unattainable; all measurements come with some degree of error. Historically, it was believed errors could be eliminated, but modern science accepts that error is an inherent part of any measurement.

There are two main sources of error in a measurement

a. Limitation in the sensitivity of the instrument

b. Imperfection in the technique used to make the measurement or in the negligence or inexperience of the person.

Using a ruler that only marks millimeters, you might not accurately measure a length of 5.6 mm, since it can not show the fraction of millimeters, demonstrating a limitation in the sensitivity of ruler.

Similarly, if someone uses a Vernier caliper but fails to align the scale properly due to inexperience, they might read 2.05 cm as 2.00 cm due to a parallax error, showcasing an imperfection in measurement technique.

Above two sources of error can lead to two types of errors that add uncertainty to our results.

Skill 2.3

"Enhance your measurement skills by learning to use prefixes for expressing numerical data in both base and derived units. Practice making reasonable estimates of physical quantities."

Student Learning Outcome

- *Critique and analyze experiments for sources of error [Including identifying sources of systematic and random error in measurements and suggesting steps to correct them]*
- *Determine an average value for an empirical reading [Including small distance and for a short interval of time by measuring multiples (including the period of oscillation of a pendulum)]*

Potential source of error

A power outage can lead to a lack of light in a laboratory setting as electrical lighting systems fail to operate. This absence of light makes it difficult to observe and measure experimental outcomes accurately, potentially affecting the reliability of scientific observations.

Do you Know?

1. TRUE VALUE:

The "true value" is the exact and ideal number we had get in a perfect experiment with no mistakes. For example, the true value of gravitational acceleration (g) of earth at sea level is about 9.80665 m/s^2. In a physics experiment using a pendulum to measure g, the calculated value might differ slightly from this true value because of errors like incorrect timing or measurement inaccuracies. To get closer to the true value, students can repeat the experiment, use better timing methods, and reduce other errors. By averaging these improved results, they can estimate g more accurately.

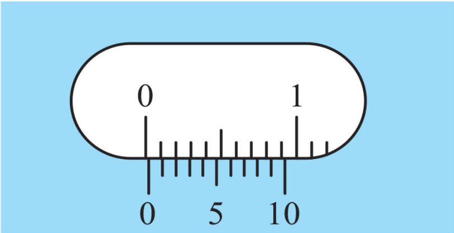


Figure 2.4 Zero error in the vernier caliper

Systematic error

Systematic errors occur consistently and predictably. These errors are often caused by faulty equipment or mistakes made by the individual during the measurement process.

For example, a bent ruler may have unsymmetrical divisions i.e., inaccurate markings, leading to systematic error. Similarly, if an instrument's zero setting shifts over time, causing it not to read zero when it should, this "zero error" is another type of systematic error shown in figure 2.4.

Systematic error can be reduced by following the process

- Eliminate any zero error present in the instrument
- Calibrate the instrument by comparing it with a standard one,
- Ensure that the eye of observer is correctly positioned in line with the measurement mark.

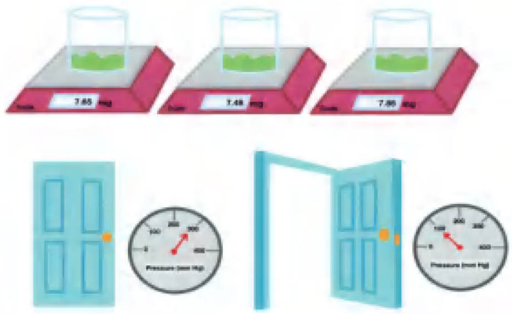
But sometimes, we just have to accept that these errors are part of the experiment. When these systematic errors are small, we say that our measurement is accurate.

Random Error

Random error" refers to unpredictable fluctuations and inconsistencies that occur in all experimental results. Such an error may arise when a single quantity is measured multiple times, but different values are obtained even though conditions remain the same.

These errors often stem from limitations inherent in the tools and techniques used for measurement. Environmental changes like temperature or voltage variations may also cause random errors.

Random Error



Observational Error
A student repeatedly weights a beaker with solution and gets different measurements every time

Environmental Error
When getting a pressure reading, students were entering and exiting the lab, causing the pressure to be lower

Figure 2.5 Random error in measurements of time and mass.

More precise and reliable measuring instruments can help to decrease random error. For example, if you are measuring the thickness of a book with a meter rod, you might encounter a random error of approximately ±1mm. However, if you use a more precise tool like a Vernier Caliper for the same measurement, the random error could reduce to around ±0.01mm.

Furthermore, to reduce random errors, taking several measurements of the same quantity and maintaining consistent laboratory conditions and then averaging these measurements allows the positive and negative random errors to offset each other, leading to a final value that more closely approximates the true value.

Important information

Parallax Error (Systematic Error):
It is a measurement discrepancy that occurs when the apparent position of an object shifts due to the change in the observer's viewing angle, leading to inaccurate readings in various instruments like telescopes or measuring devices.

Do you Know?

To reduce random error, averaging multiple readings is effective because positive and negative errors cancel each other out, bringing the average closer to the true value.

Averaging: A tool Against Random Error

Empirical data is information we gather directly from observations and measurements, not from theories. When we want to find the average value of this data, we add up all the measurements and then divide by how many measurements we took. But when we measure something using tools, there are tiny, unpredictable ups and downs in our measurements, which we call random errors. These errors can be positive or negative.

Now, here is the cool part: when we take lots of measurements, these random errors start to balance each other out. The positive ones cancel out the negative ones, and the result becomes more accurate. So, averaging our measurements helps make our data more precise and reliable. Here we will discuss averaging in measuring small distances and small time intervals

a. Measuring small distance

Imagine you are measuring the thickness of a thin piece of aluminum using a micrometer. You take five measurements in millimeters:

Average = (0.35 + 0.37 + 0.36 + 0.38 + 0.37)/5 = 0.366 mm, which is about 0.37mm.

By averaging like this, we reduce the impact of random errors.

b. Measuring small time intervals (The time period of simple Pendulum)

To discuss concept of average in measuring small time intervals, we take example of measuring time period of simple pendulum shown in figure 2.6 . When you pull the bob to one side and release it, it swings back and forth. Time taken to complete one swing is called time period. To measure the time period, you can use a stopwatch, but keep in mind that your reaction time when starting and stopping the stopwatch may affect accuracy. To minimize this effect, measure longer time intervals compared to your reaction time.

For instance, if the pendulum takes 2 seconds for one swing, count the time for multiple swings, like 30 swings taking 54.5 seconds. Calculate the time period by dividing the total time by the number of swings, for example, 1.82 seconds. To reduce random errors, repeat this process at least three times and calculate an average for more accurate results.

Skill 2.4

Enhance measurement proficiency by critically analyzing experiments to identify systematic and random errors, and suggest corrective steps to improve accuracy and reliability. Master the calculation of average values from empirical readings, particularly in measurements of small distances and short time intervals, to combat random error and refine experimental precision."

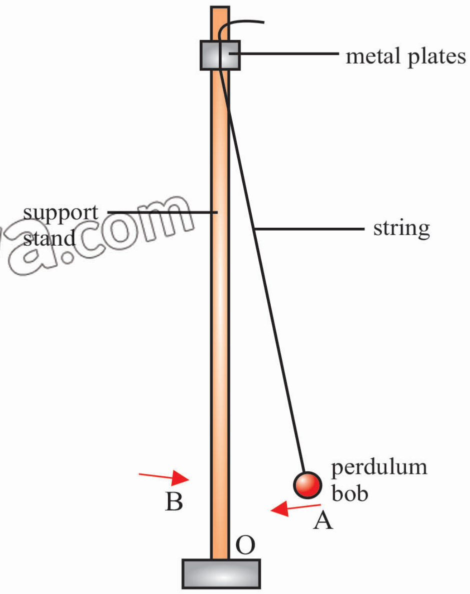


Figure 2.6 Oscillating simple pendulum

Multiple Choice Questions

1. What can cause a random error?
   a) A bent ruler b) Estimating a measurement value
   c) A scale that does not start at zero d) Consistently slow stopwatch
2. What does the least count of an instrument represent?
   a) Maximum value it can measure b) Average value it can measure
   c) Smallest value it can measure accurately
   d) Estimated value it can measure
3. Which of the following is NOT a reason to measure an empirical reading multiple times?
   a) To make the experiment more complicated.
   b) To get a more accurate average value.
   c) To minimize the impact of random errors. d) To ensure reliability.

Test Yourself

1. In which scenario is random error more likely: measuring the length of a table with a ruler or estimating the weight of a fruit by hand?
2. How can taking multiple readings help in reducing the impact of random errors?
3. When an instrument consistently provides measurements that are higher than the true value, which type of error is most likely present?

Student Learning Outcome

- *Determine the least count of a data collection instrument (analog) from its scale.*
- *Differentiate between precision and accuracy.*

Important information

Measuring small lengths with instruments having a small least count reduces percentage error by providing more precise and accurate readings. Conversely, for large lengths, using instruments with a larger least count is suitable, as the relative error decreases with the increase in length, balancing precision with practicality in measurements.

Do you Know?

Human reaction times can exceed 0.1 seconds, affecting the precision of manual stopwatch measurements. Automatic stopwatches, triggered by events such as breaking a light beam, offer significantly greater accuracy for time measurements.

(a)

(b)

Figure 2.7 (a) Analog stopwatch
(b) Digital stopwatch

Knowledge 2.5 Understanding Measurement Concepts

After learning about errors in measurements, it is important to delve into the concept of the least count of a measuring instrument. Understanding the least count is essential for achieving accurate measurements. It gives us insight into the precision of our measurements. Also minimizing systematic errors and reducing random errors contribute to improving measurement precision and accuracy. Therefore, grasping these concepts is critical for obtaining reliable measurements in experiments.

Least Count of Data Collection Instruments (analog) from its Scale

Grasping the precision of our measuring instruments is key in scientific studies. So, we are about to dive into the idea of the least count.

The least count (L.C) of an instrument is the smallest difference in a reading that the instrument can measure or the smallest measurement that can be taken accurately with the instrument. It can be regarded as a resolution of the instrument. The least count helps to minimize errors in measurement. For example, if a ruler has markings at each millimeter, its least count is 1mm, indicating that you can reliably measure and differentiate lengths as small as 1 millimeter apart.

Figure 2.6 A meter ruler with smallest division of 1 mm on its scale

$$\textbf{least count of meter ruler} = \frac{1\,\text{cm}}{100} = 0.1\,\text{cm} = 1\,\text{mm}$$

For time measurements, the least count of a stopwatch can vary. Digital stopwatches commonly have a least count of 0.01 seconds, while analog stopwatches might have a least count of 0.1 seconds. To measure the least count of a stopwatch, you need to look at the divisions on the stopwatch. If you are using a digital stopwatch, it might display time up to milliseconds, tenths of a second, hundredths of a second, etc. If it is an analog stopwatch, the divisions will be represented on the dial.

For an analog stopwatch, observe the smallest division or interval between consecutive markings on the dial of stopwatch . For a digital stopwatch, note the last decimal place displayed on the stopwatch when timing. For example, if your stopwatch displays time up to two decimal places, its least count will be a hundredth of a second i-e. 0.01s.

Limitations in Using Measuring Instruments

Selecting the right measuring tool is crucial for accuracy. For large objects like bookshelves, a meter rod that measures to the nearest millimeter works well. For precise measurements, like the diameter of a wire, use a screw gauge with a 0.01mm minimum value. Using the incorrect tool can result in significant measurement errors. Refer to the table 2.7 for the best instrument choices for different measurement needs and their limitations.

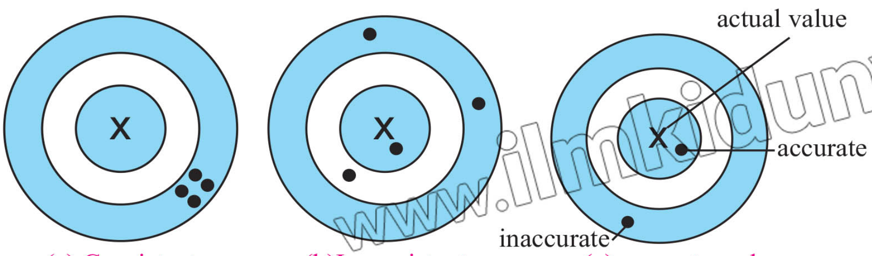
Table 2.7: Limitation of Measuring Instruments

Instrument	Length to be measured	Smallest unit of measurement
Measurement Tape	Several meters	1 cm or 1 mm
Meter rule or half-meter rule	Several centimetres to 1 meter	0.1 cm or 1 mm
Vernier Calliper	Several millimetres to centimetres	0.01 cm or 0.1 mm
Micrometer Screw Gauge	Less than 1 millimeter to about 2 centimeters+	0.001 cm or 0.01 mm

The least count of a measuring instrument is crucial for understanding its precision and accuracy. It determines the smallest measurement that can be taken accurately with the instrument, allowing scientists to assess the level of detail they can achieve in their measurements. A smaller least count indicates higher precision and the ability to make finer distinctions, contributing to more accurate scientific experiments and observations.

Precision and Accuracy

Precision in measuring instruments refers to their ability to provide highly exact and detailed measurements, allowing for discrimination between small differences in the quantity being measured. Instruments with high precision offer measurements with numerous significant digits, and their smallest measurement is defined by their precision, known as the least count. For example, a micrometer screw gauge (0.01 mm precision) is more precise than vernier calipers (0.1 mm precision). Consistency is a crucial aspect of precision, ensuring that repeated measurements of the same quantity under identical conditions yield consistent results, reflecting the instrument's reproducibility and reliability. This is indicated in figure 2.8(a),(b) and (c).



(a) Consistent measurements (b)Inconsistent measurements (c) accurate and inaccurate measurements.

Figure 2.8 Precision and Accuracy

Do you Know?

3. Repeatability: Repeatability in measurements means obtaining consistent results when an experiment is repeated under the same conditions with the same method and equipment. It is essential for ensuring the reliability of experimental results.

Example: In a physics lab, measuring the period of a pendulum multiple times under identical conditions (same pendulum length, initial displacement, and environment) demonstrates repeatability. If the periods recorded are very close (e.g., 2.00s, 2.01s, 2.00s, 2.02s), it indicates that the measurements are repeatable, showing that the method is reliable and the results accurately reflect the behavior of pendulum .

4. Reproducibility: Reproducibility in physics refers to the ability to achieve consistent results when an experiment is repeated under different conditions, such as with different equipment or by different researchers.

Example: Consider an experiment to measure the electrical resistivity of a semiconductor. A team measures the resistivity using their equipment and methodology. Another team in a different lab repeats the experiment with their own equipment. If both teams obtain similar results despite the differences in equipment and setting, the experiment is considered reproducible.

Information about Electronic Instrument

Electronic instruments are often more accurate than manual versions. However, this does not always make them the best choice. They are more expensive and easier to damage, so they should only be used in experiments where greater accuracy is necessary.

Figure 2.9 digital multimeter

Do you Know?

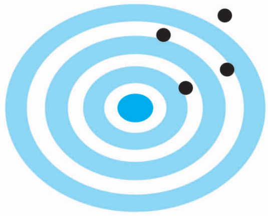
5. Anamoly: In physics, an "Anomaly" is a data point in experimental results that significantly deviates from the general pattern. These are extreme values, either much higher or lower than the rest.

Example: In an experiment measuring gravitational acceleration with a pendulum, most values might cluster around 9.8 m/s^2. If one measurement is unexpectedly at 15 m/s^2, this is an anomaly. It suggests a potential measurement error or an unusual occurrence during the experiment. Anomalies are crucial for identifying experimental errors or, in rare cases, new phenomena.

Accuracy is about how close measurements are to the true value or accepted value of the quantity being measured, irrespective of the number of significant figures used in the measurement. It is affected by both random and systematic errors, which cause measurements to deviate from the true value.

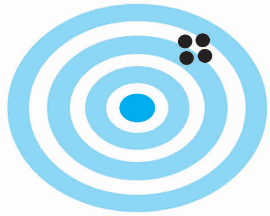
By eliminating systematic and random errors, we can ensure that the measurements closely reflect the true value, increasing the overall accuracy of the results.

Produces values that are the same or very close to each other. To understand the difference, it helps to think of measurements as trying to hit a target.



Inaccurate and imprecise

The measurements are inaccurate, as they are not near the center of the target, and imprecise, as they are not close to each other.



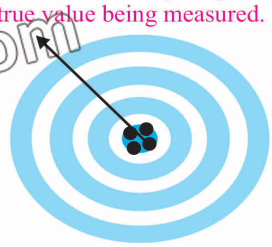
Precise but inaccurate

These measurements are precise because they are all nearly the same value, but they are inaccurate because they are not close to the center.

Accurate but imprecise

These are close to the center but not to each other, so they are accurate but imprecise.

The center of the target represents the true value being measured.



Accurate and precise

These measurements are both accurate and precise.

Do you Know?

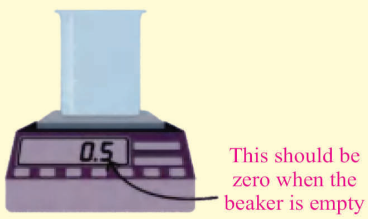
Validity of Experimental Design: The "Validity of Experimental Design" refers to how accurately an experiment tests its stated hypothesis. It involves:

Independent Variable: The factor manipulated by the researcher.

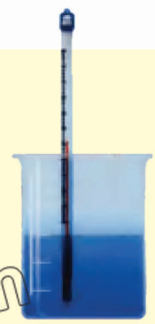
Dependent Variable: The outcome measured in response to changes in the independent variable.

Controlled Variables: Factors kept constant to ensure that changes in the dependent variable are solely due to the independent variable. A valid experiment is a fair test where only the independent and dependent variables are allowed to change, ensuring that the results are due to the manipulated variable and not other factors. This validity is crucial for credible, reliable research findings.

Interesting Information



The accuracy of some instruments depends on how they are used. Balances should be set to zero with a container on them so you only measure the mass of the contents. If a balance is not zeroed properly, all the measurements will be incorrect by the same amount. This is a systematic error and reduces the accuracy of the



Random errors are different for every reading. For example, if you take the temperature of water in a beaker, the thermometer might return at slightly different reading each time it dips into a different part of the water. This reduces the precision of your measurements.

Test Yourself

1. What does a consistent 5 grams more reading on a laboratory scale tell you about the precision and accuracy of scale?
2. Describe a situation where a measurement can be both precise and accurate.

Multiple Choice Questions

1. Which of the following indicates a higher level of precision in measurements?
   a) Larger random error b) Larger systematic error
   c) Smaller random error d) Zero error
2. What does the least count of an instrument represent?
   a) Maximum value it can measure
   b) Average value it can measure
   c) Smallest value it can measure accurately
   d) Estimated value it can measure
3. Which of the following statements about precision and accuracy is FALSE?
   (a). High precision means that the measurements are consistent with one another.
   (b). High accuracy means that the measurements are close to the true value.
   (c) . High precision always guarantees high accuracy.
   (d). Itis possible for a measurement to be precise but not accurate.

Skill 2.5

Develop a nuanced understanding of precision and accuracy in measurements, discerning their unique definitions and implications in scientific experiments. Gain proficiency in evaluating the least count of measuring instruments to enhance precision and ensure accurate data collection."

Knowledge 2.6 | Techniques of Measuring Length

In the fascinating world of scientific exploration, mastering the art of measurement is a foundational skill. This section will guide you through the practical use of common laboratory instruments to accurately measure length, volume, and time. Alongside, we will also explore the method of deriving average values from the data we gather, ensuring a well rounded approach to understanding and applying these essential techniques in various scientific inquiries.

Length Measuring Instrument

(a) Tape

A measuring tape is used for measuring long distances without perfect accuracy shown in figure 2.10. It is commonly used in sports events like long jump, shot-put, and javelin. The tape is not highly accurate, with 1 cm or 1 mm being the smallest unit it can measure. It can measure a length of several meters. But it is flexible and handy for measuring curved or non straight distances.

Measuring the circumference of round objects, like trees in a forest, is another practical use of the measuring tape.

Precaution

When evaluating an experimental procedure, assess its reliability by considering if the results can be consistently reproduced under the same conditions. If inconsistencies arise, suggest adjustments such as increasing sample size, refining measurement techniques, or standardizing environmental factors to ensure reliable outcomes. By implementing these changes, you enhance the procedure's repeatability and bolster confidence in the obtained results.

Important information

Validity of an Experimental Procedure

To determine the validity of an experimental procedure, assess whether the results accurately reflect the hypothesis being tested. If doubts arise regarding validity, consider adjustments such as controlling for confounding variables, ensuring proper randomization and blinding techniques, or refining the experimental design to better align with the intended hypothesis. These changes can enhance the validity of procedure, ensuring that the results genuinely represent what they are intended to measure.

Student Learning Outcome

- *Justify and illustrate the use of common lab instruments to measure length [Including how to measure a variety of lengths with appropriate precision using tapes, rulers, micrometers, and vernier calipers (including reading the scale on analog calipers and micrometers)]*

Figure 2.10 Length measuring tap

(b) Meter Rule

The meter rule is a tool commonly used for measuring lengths in laboratories, such as the length of an object or the distance between two points. It has a total length of one meter, which is equivalent to 100 centimeters. Each centimeter on the rule is further divided into 10 smaller units known as millimeters (mm). Consequently, the smallest unit of measurement achievable with a meter rule is one millimeter, which constitutes its least count as discussed in previous topic. A 12cm meter rule is shown in figure 2.11. In measuring length of the object from meter ruler, following errors may occur.

Systematic and Random Error

1. To accurately measure an length of object, align it along a ruler, not starting from the zero mark, but from a point where both ends of the object can be read directly. This method, as illustrated in the figure 2.11, helps avoid systematic errors like zero error by subtracting the two readings. Remember, an instrument's zero mark itself may not be error-free.

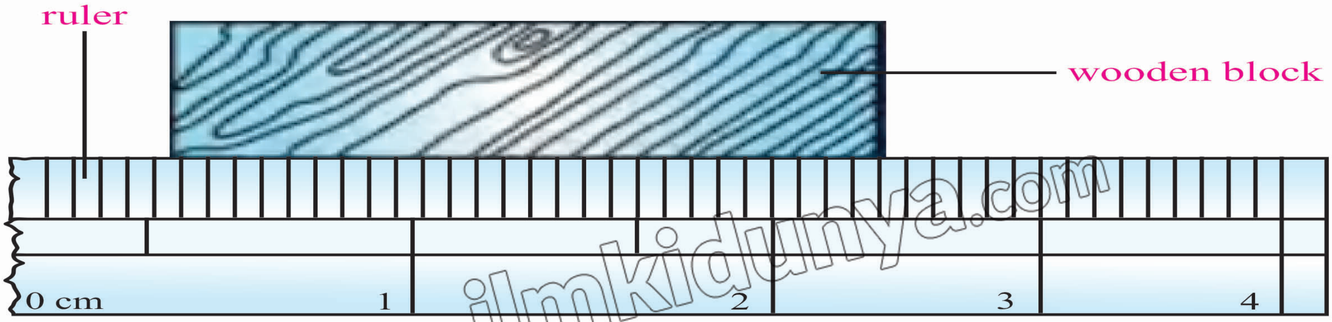


Figure 2.11 Method of taking Reading from meter rule to avoid zero error

2. To avoid parallax error when measuring with a meter rule, keep your eye directly over the measurement point. Parallax error, caused by viewing from an angle, can make readings seem misaligned. For accurate measurements, ensure your line of sight is perpendicular to the scale, reducing errors from incorrect angles as shown in figure 2.12.

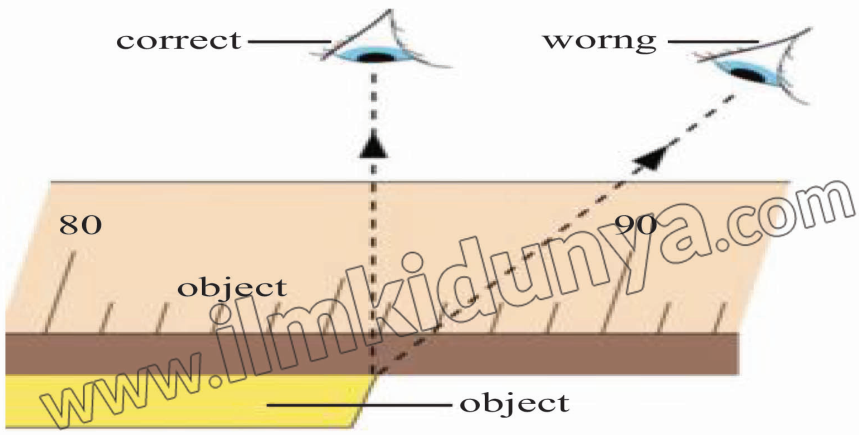


Figure 2.12: Wrong position of eye causes systematic error

3. Random error can arise during the reading of the last digit on a meter ruler, stemming from the ruler's limitations which is shown in below figure 2.13. To minimize this type of error, a more precise instrument, such as vernier calipers with a smaller least count, can be used for greater accuracy.

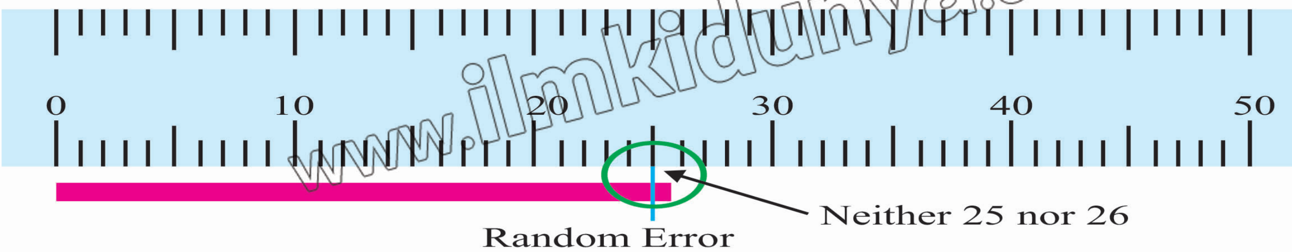


Figure 2.13 End of the object is not coinciding with any mark of the meter ruler but lies between 25 cm and 26 cm leading to a doubt in measurement.

(c) Vernier Calipers

Using a meter rule, measurements can be accurate up to 1mm, but for greater precision, instruments like Vernier Calipers are used.

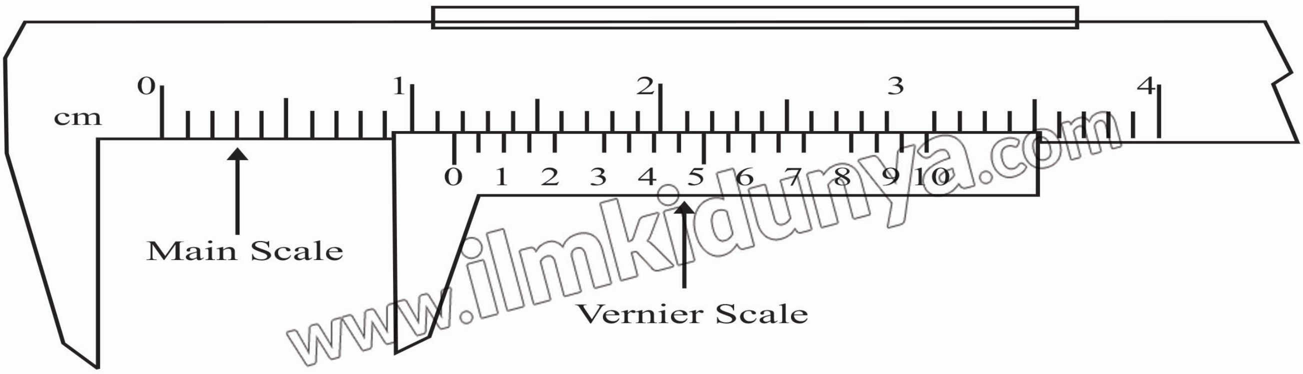


Figure 2.14 A vernier calipers with open jaws

Vernier Calipers feature two jaws, as seen in figure 2.14. One jaw is fixed and attached to the main scale, marked in centimeters and millimeters. The other jaw is movable and equipped with a vernier scale, which has 10 divisions, each measuring measuring 0.9mm. The least count (L.C) of the Vernier Calipers, or the smallest measurement it can accurately determine, is the difference between one division on the main scale and one on the vernier scale, which is 0.1mm. This allows for more precise measurements than what is possible with a standard meter rule. Least count of the Vernier Callipers can also be found as given below:

$$\text{least count of Verner Caliper} = \frac{\text{smallest division on main scale}}{\text{no of divisions on vernier scale}}$$

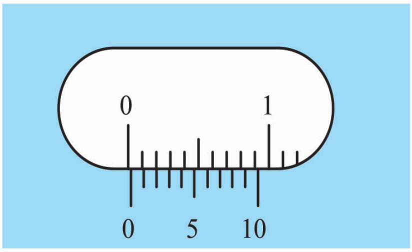
$$\text{So, L.C} = \frac{1\text{mm}}{10} = 0.1 \text{ mm}$$

Procedure To Take Reading

Read the mark on the main scale preceding the ' 0 ' mark on the vernier scale. The ' 0 ' mark on the vernier scale acts as a pointer for the main scale reading. The ' 0 ' mark on the vernier scale in figure 2.15 lies between 3.2cm and 3.3cm. Therefore, the reading on the main scale is 3.2cm. Read the mark on the vernier scale that is exactly in line or coincides with any mark on the main scale. In the figure 2.18 given below, the fourth mark on the vernier scale is exactly in line with a mark on the main scale. Therefore, the vernier scale reading = $4 \times 0.01\text{cm} = 0.04\text{cm}$.

Challenge

Find the zero error from the given figure.



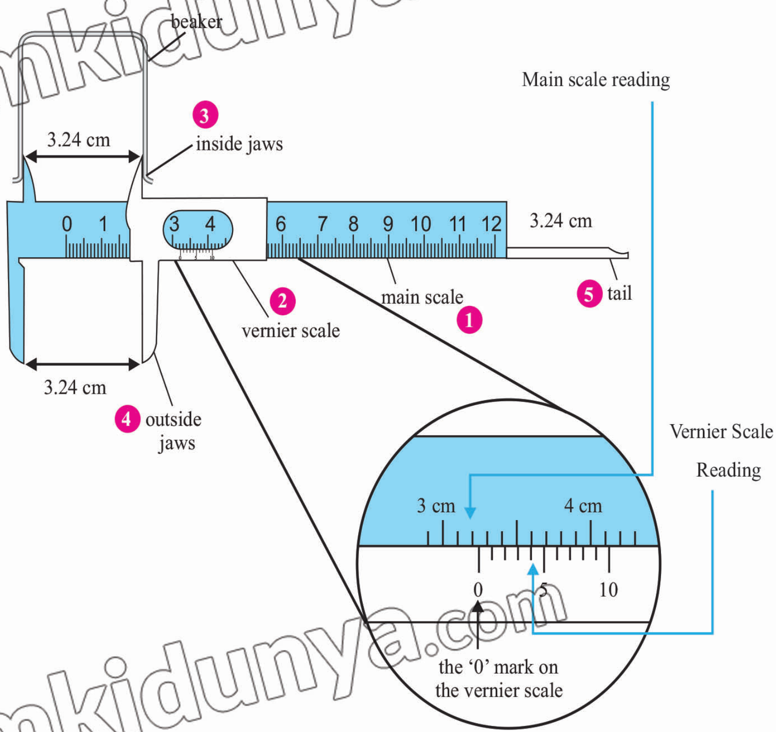


Figure 2.15 Measuring length by vernier calipers

Caliper's reading = Main scale reading + Vernier scale reading
= 3.2cm + 0.04cm = 3.24 cm

Example 2.2

Figure 2.16 shows the use of a pair of vernier callipers to measure the diameter of a steel ball.

Solution

Main scale reading = 3.0cm
Vernier scale reading = $4 \times 0.01 = 0.04$cm
Diameter of the steel ball = 3.0cm + 0.04cm
= 3.04cm

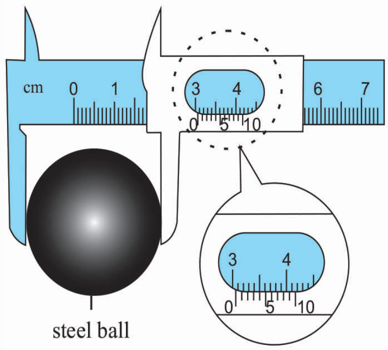


Figure 2.16 dieameter is measured by vernier callipers

Systematic Error

- Vernier calipers may exhibit zero error if the '0' mark on the main scale does not align with the '0' mark on the vernier scale when the caliper jaws are fully closed. This zero error can be positive (if the vernier scale's zero is on the right of the main scale's zero) or negative (if on the left). It affects all measurements taken with the caliper and can lead to incorrect readings. This is indicated in figure 2.17. To correct for zero error, note which vernier scale mark aligns with the main scale and multiply it by the least count. This value should be subtracted from the reading of caliper to get the accurate measurement.

Hence
Corrected reading of vernier Calipers = Callipers reading – Zero error

- Efforts should be made to avoid parallax in vernier calipers by ensuring the observer's eye is at the same level as the scales.

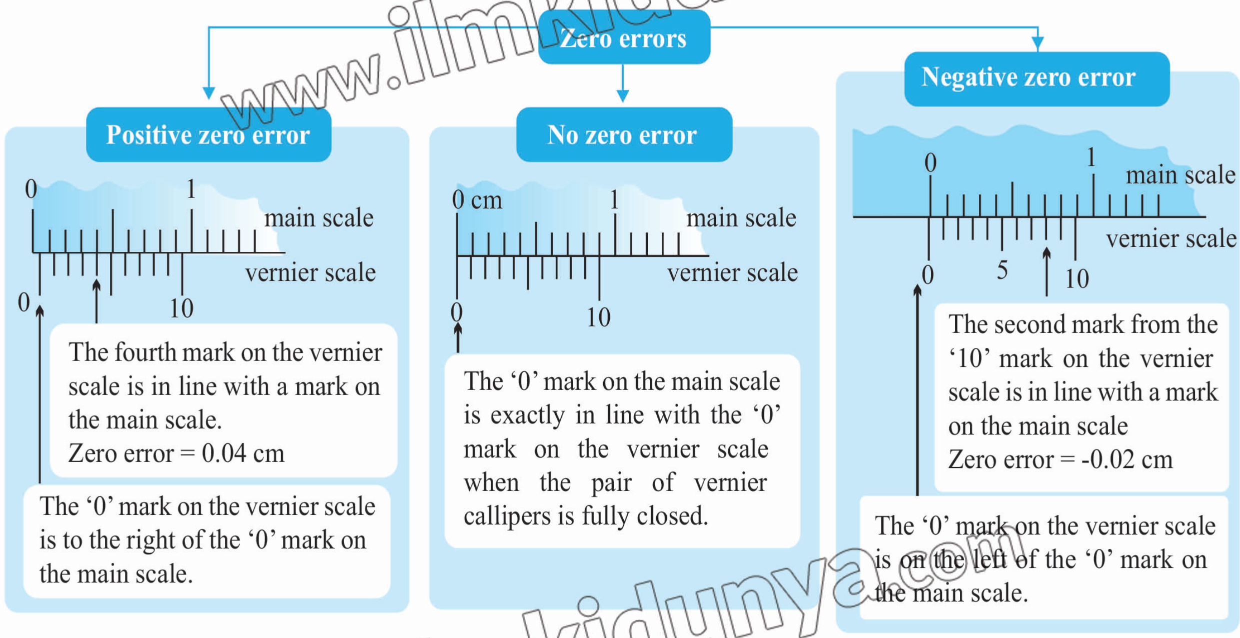


Figure 2.17 Zero error determination in vernier calipers. It may have positive or negative value

Random Error:

Random errors in Vernier calipers are generally related to the variability in aligning the Vernier scale with the main scale during measurements.

To minimize random errors when using Vernier calipers or similar measuring instrument, several strategies can be employed. Firstly, taking multiple readings of the same quantity and averaging them helps reduce the impact of random variations. Secondly, maintaining consistent laboratory conditions, such as temperature and lighting, throughout the measurements is crucial to prevent environmental factors from introducing errors.

Example 2.3

Determine the correct size of the object. As shown in figure 2.18(a) (Hint: There is a zero error in this vernier calipers figure 2.18(b)

Solution

First, determine the zero error.

Zero error = +0.02 cm

Then, find the reading from the pair of vernier callipers.

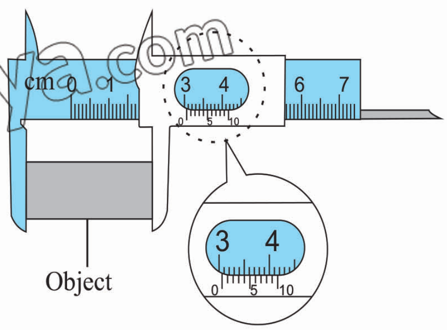


Figure 2.18 (a) Vernier callipers to measure the size of an object.

Main scale reading = 3.2 cm
Vernier scale reading = 0.04 cm
Vernier calliper reading = 3.2 +0.04 = 3.24 cm
Correct size of object = Vernier calliper reading – Zero error
So,
Correct size of object = 3.24 − (+0.02)
= 3.24 – 0.02 = 3.22 cm

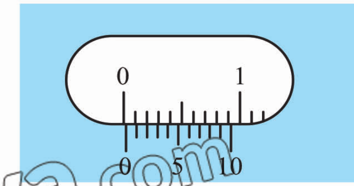


Figure 2.18 (b) Reading when the jaws of vernier callipers are closed.

Vernier Calipers is the tool for measuring lengths or sizes of objects with an accuracy of 0.01 cm. Let us explore another more precise measuring instrument than vernier calipers known as the micrometer screw gauge. While both instruments serve similar purposes, the micrometer screw gauge offers even higher levels of precision.

Micrometer Screw gauge:

The screw gauge, also known as the micrometer screw gauge, is a tool designed for measuring small lengths with more precise than a Vernier Caliper. As illustrated in figure 2.19, it typically consists of a U-shaped metal frame with a solid metal stud on one end. On the opposite end, there is a hollow cylinder (or sleeve) marked with a millimeter scale along an index line parallel to its axis. This cylinder is fixed and acts as a nut. Inside the thimble, there's a threaded spindle. Each complete rotation of the thimble moves the spindle 1mm along the index line. This movement is called pitch of the screw on the spindle, which is the distance between consecutive threads, measuring 1mm.

The thimble has 100 divisions around its one end. It is the circular scale of the screw gauge. As thimble completes one rotation, 100 divisions pass the index line and the thimble moves 1mm along the main scale. Thus, each division of circular scale crossing the index line moves the thimble through 1/100mm or 0.01mm on the main scale called least count of screw gauge which can also be found as given below:

$$\text{Least count of screw gauge} = \frac{\text{pitch of the screw guage}}{\text{no. of divisions on circular scale}} = \frac{1\text{mm}}{100} = 0.01\text{mm or } 0.001\text{cm}$$

Thus, least count of the screw gauge is 0.01mm or 0.001cm.

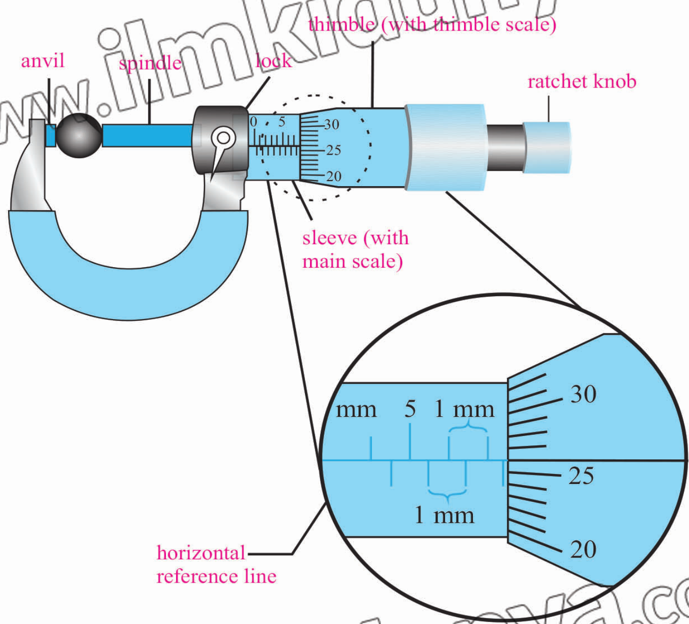


Figure 2.19 A Micrometer screw guage

Procedure to Take Reading

To measure an object with a vernier caliper, gently secure it between the anvil and spindle by turning the thimble. The main scale provides measurements in millimeters (mm), and if the line below the index line is visible, add 0.5 mm to the reading. For instance, if the main scale reads 7.5 mm shown in figure 2.19, move to the thimble scale for more precision. Align the thimble scale with the main scale's index line, like the 26th division in the figure. Multiply this aligned value by the least count (0.01 mm) to get the thimble scale reading, i.e., 26 x 0.01 mm = 0.26 mm. Finally, add the main and thimble scale readings together to obtain the final measurement, e.g.
7.5 mm + 0.26 mm = 7.76 mm.

Precaution !

In conducting experiments, it is crucial to mitigate systematic errors by taking specific steps, such as verifying the levelness of the table used for setup, to ensure the integrity and accuracy of experimental results.

Systematic Error

To determine zero error (systematic Error), adjust the spindle and stud gap of the screw gauge by rotating the ratchet clockwise. If the circular scale's zero aligns with the index line (as in figure 2.20 (a), the zero error is zero. When the circular scale's zero is below the index line, it results in a positive zero error. Multiply the number of divisions on the circular scale that have not crossed the index line by the least count of screw gauge to calculate the positive zero error (as depicted in figure 2.20 (b). Conversely, if the circular scale's zero has up from the index line, it leads to a negative zero error. In this case, multiply the number of divisions on the circular scale that crossed the index line by the screw gauge's least count to find the negative zero error (as shown in figure 2.20 (c).

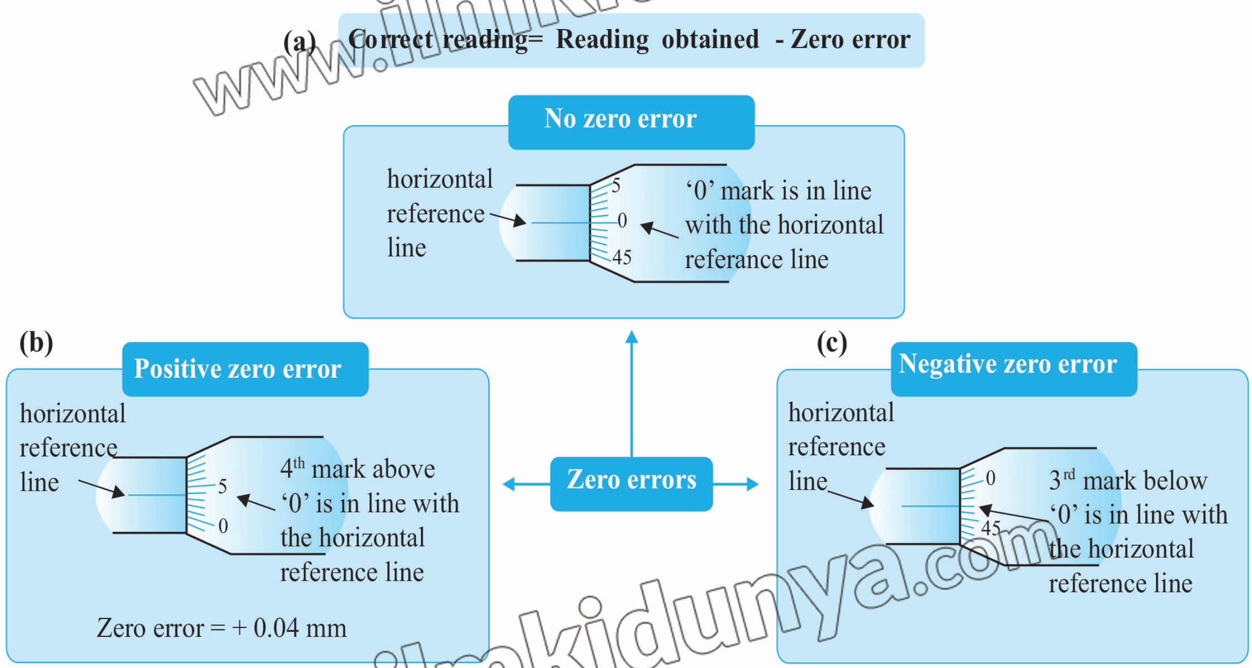


Figure 2.20 (a) Zero of circular scale coincide with index line representing no zero error (b) shows positive zero error of + 0.04 mm (c) indicates negative zero error of –0.03 mm

Precaution !

Make sure to use measuring tools as precisely as possible. This means paying close attention to the smallest details the tool can show you, like the tiny lines on a ruler, to get the most accurate measurements.

So, Correct reading of screw gauge = reading obtained – zero error

Also, to avoid parallax, ensure the eye of observer should be at the same level as the thimble scale. Observers may also use magnification tools to enhance the visibility of scales.

Random Error

Pressure variations, caused by different users or changes in the same grip of user, can result in random reading fluctuations. When using the micrometer, the observer carefully rotates the thimble to lightly secure the object between the spindle and the anvil. It is crucial not to exert excessive pressure on the object. The ratchet knob serves as a guide, producing a clicking sound when appropriately applied, ensuring that the pressure remains consistent and does not affect the measurement.

Example 2.4

Figures 2.21 (a,b) show the readings on a micrometer screw gauge before and after being used to measure the size of an object. What is the correct size of the object?

Solution

The reading of the gauge

= 16.00 mm + 0.41 mm = 16.41 mm

Zero error = –0.02 mm

= 16.41 (–0.02) = 16.41+0.02 = 16.43 mm

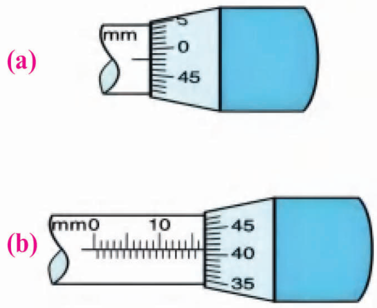


Figure 2.21 Main scale and circular scale of screw guage

Challenge

What are the readings on the micrometer screw gauges in the below figure?

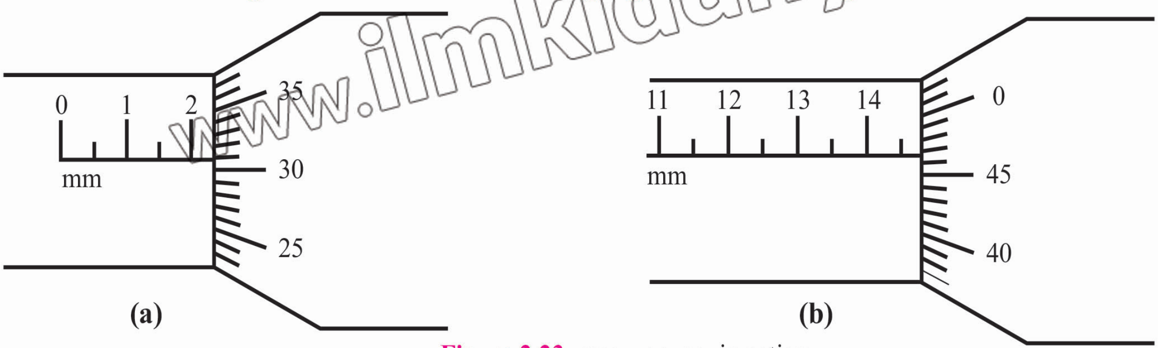


Figure 2.23 screw gauge in action

Use of Protractor for Determining Angle

To measure ∠AOB, place the protractor zero at the angle of vertex, aligning the base arm with the protractor's zero degrees line. Read the angle in an anticlockwise direction using the inner calibration. The measure of ∠AOB is found to be 60°.

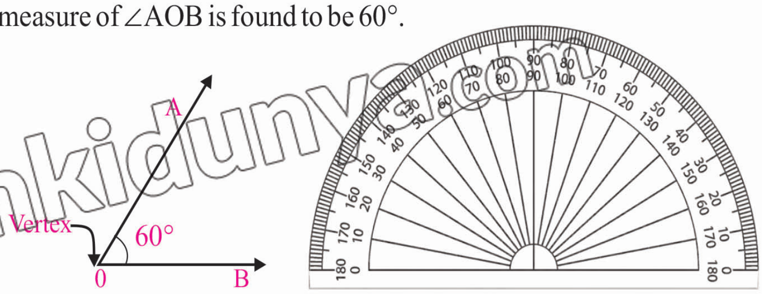


Figure 2.24 use of protector to measure the angle

Test Yourself

1. Which instrument would be most appropriate for measuring the thickness of a thin wire?
2. How can you identify a zero error on a vernier caliper?
3. What is the advantage of using a tape measure over a ruler?
4. Why might you choose a vernier caliper over a micrometer for a specific measurement?

Multiple Choice Questions

1. When measuring the length of a football field, which tool would be most suitable?
   a) Micrometer b) Vernier caliper c) Ruler d) Tape measure
2. The main advantage of using a vernier caliper is?
   a) It can measure very large objects.
   b) It can measure internal and external dimensions.
   c) It is always digital.
   d) It is the most basic measuring tool.
3. For which of the following would a micrometer be most suitable?
   a) Measuring the thickness of a book
   b) Measuring the diameter of a hair strand
   c) Measuring the width of a table d) Measuring the length of a rope

Important information

When encountering unfamiliar methods in an experiment, leveraging basic equipment creatively can lead to profound insights. For instance, using a simple pendulum to study motion offers a hands-on approach to understanding complex principles, encouraging innovative thinking and application of foundational knowledge.

Knowledge 2.7 | Measurement of Volume of liquid and solid

Volume is the quantity of space occupied by an object, and it is typically measured in cubic units. The SI unit of volume is the cubic meter (m^3), but this unit is often too large for everyday use. As a result, smaller units of cubic centimeters (cm^3) and cubic decimeters (dm^3) are commonly used for convenience. These are indicated in figure 2.25 below.

Student Learning Outcome

- *Justify and illustrate the use of measuring cylinders to measure the volume [Including both measurement of volumes of liquids and determining the volume of a solid by displacement]*

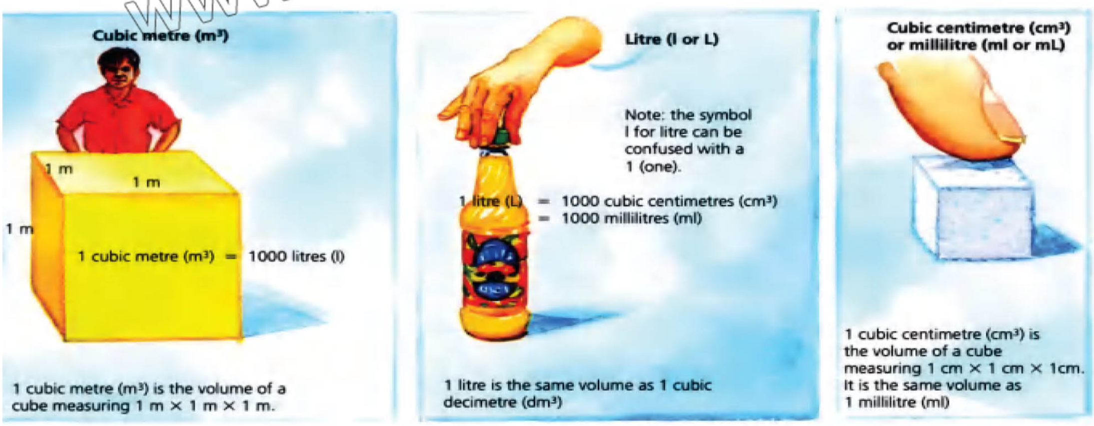


Figure 2.25: understanding of different unit of volume

Liquid and solids have definite volume. Now we discuss how volume of liquid and solids are calculated.

(a) Measurement of Volume of Liquid: To measure the volume of a liquid, a common tool used is a measuring cylinder. This cylindrical container has a scale marked on its side, typically in milliliters (ml) or cubic centimeters (cm^3). When a liquid is poured into the measuring cylinder, the level of the liquid on the scale directly indicates its volume as indicated in figure 2.26

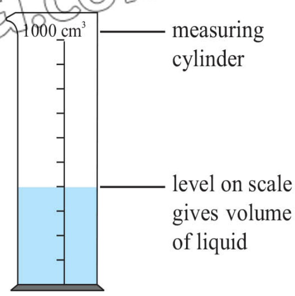


Figure 2.26 measuring cylinder to measure the volume

Setting Up an Experiment

When doing experiments, it is really important to stay safe and get things right. Setting up the equipment with the help of the teacher is super important. It helps us avoid mistakes and makes sure everything goes smoothly. Plus, it is a great way to learn how to use the equipment correctly and understand the experiments better. So, always ask your teacher for help when setting up experiments!

Appropriate apparatus for collecting data

When deciding which tools to use for collecting data, it is important to choose the right apparatus. For example, if you need to measure the length of an object, you would use a ruler or a measuring tape. For liquids, a graduated cylinder or a beaker would be suitable. When measuring small distances or thicknesses, tools like vernier calipers or micrometers are handy. Additionally, if you are timing events, a stopwatch or a timer would be the right choice. By selecting the appropriate apparatus, you ensure accurate and reliable data collection in your experiments.

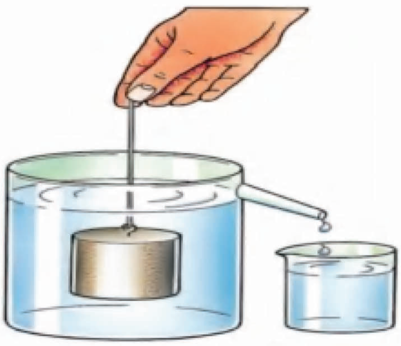


Figure 2.28: Displacement can to measure volume of large solids

(b) Measurement of Volume of Solid

(i) Regular shaped Solids

For objects with simple (regular) shapes like rectangular blocks or cylinders, their volumes can be calculated using mathematical formulas. For example, the volume of a cube is calculated by using the formula Volume = $(\text{length})^3$. Similarly, the volume of a sphere is calculated by using:

Volume of sphere $= \frac{4}{3}\pi \times (\text{radius})^3$

(ii) Irregular shaped solids:

Irregularly shaped objects cannot have their volume calculated directly with formulas. Instead, the volume of these solids can be determined through displacement methods shown in figure 2.27. One way is to submerge the irregular solid in a measuring cylinder partially filled with water. The rise in the water level indicates the volume of the solid that has displaced the water. If the solid floats, it can be weighed down with a known mass, and the total volume is found. The volume of the added mass is measured separately and then subtracted from the total volume to find the volume of the irregular solid.

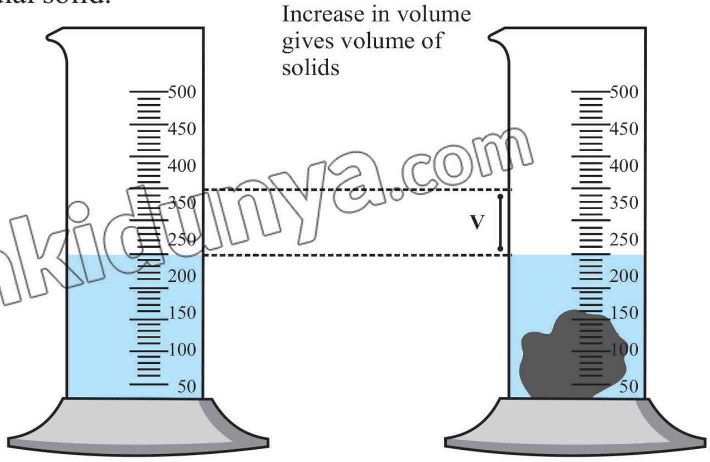


Figure 2.27: measuring the volume of small irregular shaped solid

Large size irregularly shaped solids Using Displacement can

For even larger irregular solids that cannot fit into a measuring cylinder, a displacement can is used. The displacement can is filled with water up to the level of the spout by overfilling and allowing the excess water to run out as shown in figure 2.28. The irregular solid is then carefully lowered into the water, displacing an amount of water equal to its own volume. The displaced water is collected in a beaker and then transferred to a measuring cylinder to determine the volume of the irregular solid.

Precautions in Measuring volume of solid

When taking readings of the volume of a liquid using a graduated cylinder, it is essential to follow certain precautions to ensure accuracy:

Position your eye at the same level as the liquid surface (meniscus) to avoid parallax errors.
Identify the correct type of meniscus, whether it is concave or convex shown in figure 2.29.
For a concave meniscus, read the volume at the bottom of the curve where it
intersects with the graduated markings.
For a convex meniscus, read the volume from the top of the curve where it intersects with the markings.
Avoid reading the volume from any other point in the meniscus. These precautions are crucial to obtaining accurate measurements when using a graduated cylinder.

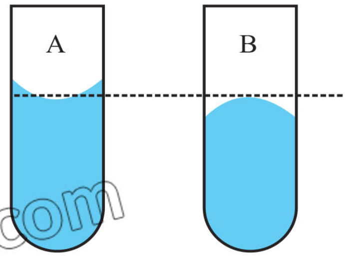


Figure 2.29 a: dotted line indicates the correct reading of level of liquid

Challenge: Use the information bellow to calculate:

a) the mass, volume, and density of the liquid
b) the mass, volume, and density of the stone.

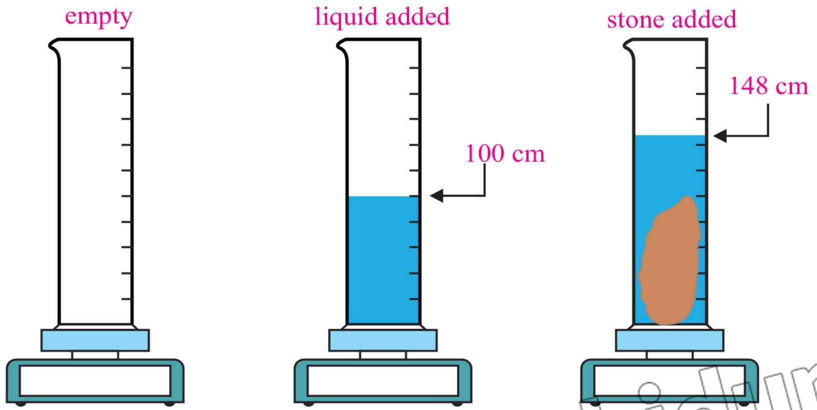


Figure 2.29 b: Finding the volume of irregular shape of object.

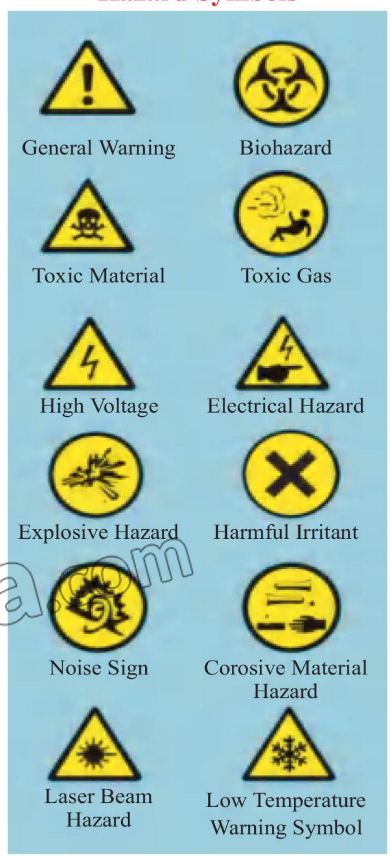
Types of Hazards

Physical Hazards: These hazards are related to physical processes that could cause harm. They include conditions where there is a risk of injury from physical processes like radiation, pressure, noise, or temperature extremes. Examples: *Radiation*: Exposure to ultraviolet, infrared, or microwave radiation from laboratory equipment. *Extreme Temperatures:* Burns from hot surfaces or frostbite from handling liquid nitrogen. *Sharp Objects:* Cuts or punctures from needles, glass slides, or broken glassware.

Chemical Hazards: These hazards are associated with the use of chemicals. They can include risks of fire, explosion, poisoning, or health issues from chemical exposure. Examples: *Toxic Chemicals*: Inhalation or skin contact with toxic substances like mercury, benzene, or formaldehyde. *Corrosive Substances*: Burns or skin irritation from acids or bases like hydrochloric acid or sodium hydroxide.
Flammable Materials: Fire hazards from solvents like ethanol or acetone.

Biological Hazards: These hazards involve exposure to biological materials that could cause infections, allergies, or other health issues. Examples: *Pathogenic Microorganisms*: Exposure to bacteria,

Hazard Symbols



Precaution !

When examining an experimental design, look for steps that could be dangerous, such as handling chemicals without gloves or using glassware on an unstable surface. To reduce these risks, you can wear appropriate safety equipment, ensure all equipment is securely placed, and follow proper handling procedures for all materials. Always prioritize safety to prevent accidents and injuries during experiments.

viruses, or fungi that can cause diseases. *Allergens*: Reactions to biological materials like latex, animal dander, or certain plants. *Biomedical Waste:* Risk of infection from contaminated needles or other sharp instruments.

Safety Hazards: These encompass a range of conditions that pose a risk to personal safety. This category is broad and includes anything that could cause trips, falls, electric shocks, or other physical injuries. *Examples: Slippery Floors:* Falls due to wet or oily surfaces. *Electrical Hazards:* Electric shocks from faulty equipment or improper handling of electrical devices.

Obstructed Safety Equipment: Inaccessibility to safety showers, eyewash stations, or fire extinguishers due to clutter. Each of these hazards requires specific safety protocols and equipment to minimize the risk of injury or health issues in the laboratory.

Most appropriate personal protective equipments

Experiments which involve the handling of chemicals, pathogenic biological materials, risks of physical injury, high temperature, fire or radiations, high pressure systems or explosive materials should require the following personal protective equipments for safety measure:

Precaution !

In assessing an experimental setup, identify any unsafe practices, such as inadequate ventilation when working with chemicals or improper handling of hot surfaces. To mitigate these hazards, ensure proper ventilation or use fume hoods when dealing with chemicals, and always wear appropriate protective gear, such as gloves and goggles, when handling hot surfaces or hazardous materials. Additionally, follow established safety protocols and procedures to minimize the risk of accidents or injuries.

PERSONAL PROTECTIVE EQUIPMENTS


Lab coat

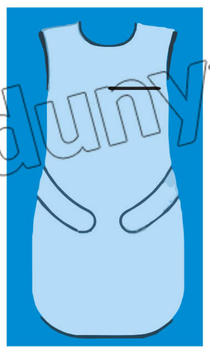

Safety goggles


Safety gloves


Closed-toe shoes


Face shield and mask


Respirators


Lead apron

Knowledge 2.8 | Measurement of time Interval

Measuring time intervals is fundamental in understanding and quantifying the dynamics of processes, events, and phenomena in both our daily lives and in scientific research. It allows us to track progress, coordinate activities, and analyze the duration and rate of change within systems without delving into the specific methodologies used for its measurement.

Measuring Time Interval in Laboratory

In your physics course, you will learn to measure time intervals using stopclocks or stopwatches. These instruments have levers or buttons to start, stop, and reset them. Before using them in experiments, get familiar with their operation.

Two common types are mechanical stopclocks (analog) and digital stopwatches. Mechanical stopclocks measure to the nearest one-fifth of a second, while digital stopwatches can measure to the nearest one hundredth of a second. It is crucial to understand how to use the controls, especially in digital stopwatches with features like the 'lap' function.

To use a stopclock (or stopwatch) effectively, follow these steps:

- Get familiar with the controls of timer for starting, stopping, and resetting before starting your experiment.
- For mechanical stopclocks, ensure it is reset to zero. Digital stopwatches often reset automatically when you press reset.
- Start the timer when your event or process begins.
- Stop the timer when the event or process ends to see the elapsed time.
- Note the time displayed for an accurate measurement.
- Reset the timer to zero for the next measurement.
- For better accuracy, repeat the timing process and calculate the average time interval.

Multiple Choice Questions

1. Which of the following instruments provides the most precision when measuring short time intervals?
   a) Wall clock b) Sundial
   c) Hourglass d) Digital timer
2. If you are measuring the time it takes for a pendulum to complete 10 oscillations, which tool would be best suited?
   a) Grandfather clock b) Digital timer with a stopwatch feature
   c) Hourglass d) Calendar
3. If a digital timer displays times in hundreds of a second (e.g., 12.34 seconds), what does this indicate about its precision?
   a) It can measure time intervals as small as 1 second
   b) It can measure time intervals as small as 1/10th of a second
   c) It can measure time intervals as small as 1/100th of a second
   d) It can measure time intervals as small as 1/1000th of a second

Student Learning Outcome

- *Justify and illustrate how to measure time intervals using lab instruments [Including clocks and digital timers.*

Figure 2.30 a Analogue stopclock

Figure 2.30 b Digital stopwatch

Test Yourself

1. Why might digital timers be preferred over traditional clocks in some laboratory settings?
2. What is the significance of the "zero" or "reset" button on a digital timer?

Precaution !

Consider your reaction time when using a stopwatch it can impact accuracy. Measure longer time intervals for more reliable results. Analog stopclocks work well for manual timing experiments, avoiding precision issues due to reaction time.

Skill 2.5

"Gain proficiency in using measuring instruments by learning to determine the least count of analog tools and effectively using common lab devices for precise measurements. Explore techniques for measuring lengths, volumes, and time intervals, including the application of rulers, micrometers, vernier calipers, measuring cylinders, and digital timers."

Knowledge 2.9 | Data Interpretation and Rounding Off Calculations

Student Learning Outcome

- *Round off and justify calculational estimates [Based on empirical data to an appropriate number of significant figures]*

After discussing various measuring instruments such as rulers, vernier calipers, screw gauges, and volume measuring cylinders, and use of stopwatch, it is crucial to understand how to round off and justify calculational estimates based on empirical data. These skills ensure that measurements are expressed with the appropriate number of significant figures, contributing to the precision and accuracy of scientific experiments.

Rounding Off Numbers

Rounding off numbers is a way we simplify them, but it is important to do it correctly to keep our values as accurate as possible. This process is particularly useful when dealing with measurement results where some digits might not be very important. This is where the concept of "significant figures" comes in. But first, let us look at the rules for rounding off:

- If the digit you are dropping is less than 5, you keep the last digit as it is. For example, 25.73 becomes 25.7 when rounded to one decimal place.
- If the digit you are dropping is more than 5, add 1 to the last digit you are keeping. For instance, 1.87 becomes 1.9 when rounded to one decimal place.
- When the digit you are dropping is 5, then we will proceed as
  - If there is no non-zero digit after the 5 (like in 63.21500), and you are rounding to two decimal places, look at the last digit you are keeping. If it is odd (like the 1 in 63.21500), you add 1 to it. So, 63.21500 becomes 63.22.
  - If the last digit you are keeping is even (like the 6 in 53.76500), you do not add anything to it. So, 53.76500 just becomes 53.76.

These rules for rounding off are closely related to our next topic. Significant figures are the digits in a number that carry meaningful information about its precision. When we round off numbers, we are essentially choosing the number of significant figures we want to keep while ensuring that our number stays as close to the original value as possible. The topic of significant figures will help us understand why and how to keep certain digits while getting rid of others.

Significant Figures

Measuring quantities is fundamental in scientific investigations, but it is important to recognize that every measurement carries some degree of error due to instrument limitations and human factors. Significant figures play a crucial role in indicating the accuracy of measurements.

For instance, the measurement '4.5' has two significant figures: '4' and '5'. In contrast, '0.0385' has three significant figures, with '3' being the most significant and '5' being the least, as it may vary slightly. Significant figures can be defined as the known digits plus the first uncertain digit.

Consider measuring the length of a sidewalk in different units - meters, decimeters, and centimeters. When measured in meters, a 50-meter sidewalk has two significant figures ('5' and '0'). Switching to decimeters, it becomes '500' decimeters with three significant figures. Finally, in centimeters, it's '5000' centimeters with four significant figures, indicating increased precision with smaller units. It means that smaller the least count of measuring instrument, larger the number of significant figures and higher the accuracy of the measurement.

Rules for Deciding the Significant Figures

1. Non-zero Digits: All non-zero digits (1-9) are always significant. For instance, in the measurement 112.6 mm, there are four significant figures.

2. Zeros: The significance of zeros depends on their position:

- Zeros between two non-zero digits are always significant. For example, in numbers like 402 and 7.05, the zeros are significant.
- Zeros to the left of a non-zero digit are not significant, as in 0.00387 and 08.39.
- Zeros to the right of a non-zero digit may or may not be significant:

In decimal numbers, zeros to the right of a non-zero digit are significant, like in 1.320 and 3.6000.

In non-decimal numbers, zeros to the right of a non-zero digit may or may not be significant, depending on the least count of the measuring device. For instance, for the measurement of 3,000 kg:

If the least count of scale is 1 kg, there are four significant digits (3.000×10^3 kg).

If the least count is 10 kg, there are three significant digits (3.00×10^3kg).

If it is 100 kg, there are two significant digits (3.0×10^3 kg).

3. When a measurement is recorded in scientific notation, as shown above, a figure other than the power of ten is a significant figure.

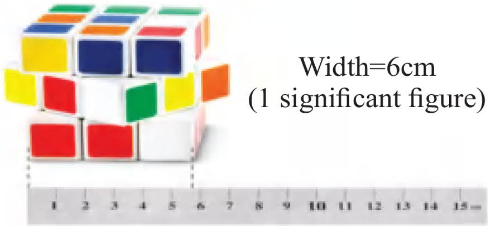
Significant Figures in Calculations

- In addition or subtraction, the result should have no more decimal places than the least accurate measurement. For example, when adding 203.4 and 105.214, the result would be 308.6 because the least accurate measurement 203.4 has only one decimal place
- When measurements are multiplied or divided, the result can contain no more significant figures than the least precise measurement. For example, when multiplying 6.7 cm and 3.42 cm, the result is rounded off to two significant figures, resulting in 23 cm^2.

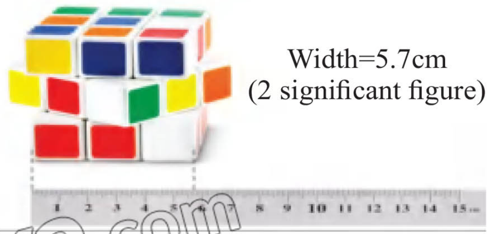
Important information

Recording Data

The number of significant figures in your measurements depends on the measuring tools you use. If you use a ruler with centimeter markings, you'll have fewer significant figures compared to using a ruler with millimeter markings. Digital tools usually provide more significant figures than older ones, but that doesn't always mean they are more accurate.



Width=6cm
(1 significant figure)



Width=5.7cm
(2 significant figure)

Figure 2.31 significant figures in width measurement

Important information

Using calculators

Sums done on calculators may give you more significant figures than you need. Suppose you calculate the resistance of a light bulb using the formula below. You use readings from a voltmeter and an ammeter that each show values to three significant figures.

$$\mathbf{R} = \frac{\mathbf{8.12\,V}}{\mathbf{1.04\,A}}$$

The answer on a calculator is 7.8076923.

Writing your answer like this implies you know the resistance to 8 significant figures, but the measuring instruments were only accurate to 3 significant figures, so your answer should be too:

$$\mathbf{R = 7.81\ \Omega\ \ (3\ S.F.)}$$

When multiplying or dividing, round your answer to the same number of significant figures as the least accurate starting value.

When adding or subtracting, round your answer to the same number of decimal places as the least accurate starting value.

Example 2.5

Add the following lengths and write the result in appropriate significant figures.
Length A = 12.56cm
Length B = 8.4cm

Solution

Length A + Length B = 12.56cm + 8.4cm = 20.96cm
As the length B = 8.4cm has the least number of decimal places (only one decimal place),
So the final answer should also be rounded to one decimal place which is 21.0cm.

Example 2.6

Find the area of a rectangle whose length and width are 5.2m and 3.78m.

Solution

Area of rectangle = length × width = 5.2m × 3.78m = $19.6176\ m^2$
Since the value with the least number of significant figures (5.2 m) has two significant figures, your final answer should also have two significant figures. So, the result is rounded off to $20m^2$.

Test Yourself

1. What are significant figures, and why are they important in rounding off calculational estimates in empirical data?
2. You have a measured value of 12.345 and you want to round it to three significant figures. What will the value be, and how do you justify this rounding?

Multiple Choice Questions

1. When performing the subtraction 45.678 - 12.34, to how many decimal places should the result be rounded off?
   a) One decimal place
   b) Two decimal places
   c) Three decimal places
   d) Four decimal places
2. Which of the following is NOT a rule for determining significant figures?
   a) Any non-zero number is significant.
   b) Any zeros between two significant figures are significant.
   c) Leading zeros are significant.
   d) Trailing zeros in a decimal number are significant.
3. If a measurement in an experiment is 123.456789 and the instrument used can measure up to three decimal places, to what value should the measurement be rounded?
   a). 123 b). 123.5
   c). 123.46 d). 123.458

Key Points

- Base physical quantities, such as length, time, and mass, are fundamental and do not depend on other quantities. Derived physical quantities, like speed (m/s) or volume (cubic meters), are derived from combinations of base quantities.
- Physical quantities pertain to measurable aspects of the physical world, while non-physical quantities lack measurable attributes. For example, temperature (physical) vs. happiness (non-physical).
- The System International (SI) units are the standard units of measurement for physical quantities. They include the meter (m), second (s), kilogram (kg), ampere (A), kelvin (K), mole (mol), and candela (cd), each with its respective symbol.
- In experiments, it is essential to identify sources of systematic and random errors in measurements. Correcting errors and improving precision is crucial for obtaining reliable results.
  Calculating the average value of empirical readings, such as distances or time intervals, involves measuring multiples to reduce errors. For example, determining the period of oscillation of a pendulum.
- The least count of an instrument is the smallest measurement that can be read or recorded. It determines the precision of the instrument and is essential for accurate data collection.
  Precision refers to the consistency of measurements, while accuracy refers to how close measurements are to the true value. Both are important for reliable results.
- Lab instruments like rulers, tapes, micrometers, and vernier calipers are used to measure length with precision.
- Measuring cylinders are used to measure the volume of liquids and solids through displacement. This technique is valuable for accurate volume measurements.
- Lab instruments like clocks and digital timers are used to measure time intervals with precision, a critical aspect of experiments and data collection.
- The process of adjusting numbers to a desired level of precision by changing them to the nearest value based on a predetermined rounding digit. This technique simplifies numbers for ease of understanding and use in calculations.
- The digits within a number that contribute to its measurement accuracy, including all non-zero digits, zeros between significant digits, and any final zeros in the decimal part. They indicate the precision of a measurement, with the count of significant figures reflecting the degree of accuracy.

Exercise

A Multiple Choice Questions

1. Identify the base quantity in the following:
a) volume b) density c) force d) current

2. When expressing 5000 in scientific notation, it becomes:
a) 5×10^3 b) 5×10^4 c) 50×10^3 d) 0.5×10^4

3. What is the prefix for 10^6 ?
a) milli b) kilo c) mega d) giga

4. Which is a systematic error?
a) A misread scale
b) An unpredictable fluctuation in readings
c) Random disturbances in the lab
d) Different readings due to human reaction times

5. When estimating the size of a large crowd, you are working with:
a) Scientific Notation b) Precision c) Order of Magnitude d) SI units

6. To ensure accuracy in an experiment, one should:
a) Take multiple readings and find the average
b) Only use digital instruments
c) Use the largest instrument available
d) Always measure at night

7. After performing a calculation, rounding off numbers is important for:
a) Accuracy b) Precision
c) Clarity in presentation d) Making calculations harder

8. Which of the following numbers has three significant figures?
a) 100.5 b) 1000 c) 0.00105 d) 1050

9. If an error leads to unpredictable fluctuations in readings, this error can best be categorized as:
a) Human error. b) Instrumental error. c) Systematic error. d) Random error

10. What is measured using a micrometer?
a) Area b) Current c) Length d) Mass

11. A student determines the circumference of a football. Which instrument gives a reading that is the circumference of the football?
a) caliper b) micrometer c) ruler d) tape

12. A length of copper wire is labeled: length 0.50 m and diameter 0.50 mm. Which instruments are most suitable to measure accurately the length and the diameter of the wire?

	Length	Diameter
a)	metre rule	metre rule
b)	metre rule	micrometer
c)	callipers	metre rule
d)	callipers	micrometer

13. In an experiment, a ball is rolled down a curved track that is about half a metre long. 0.5 m, Which measuring device is used to measure the length accurately?
a) metre rule b) micrometer
c) stop-watch d) tape measure

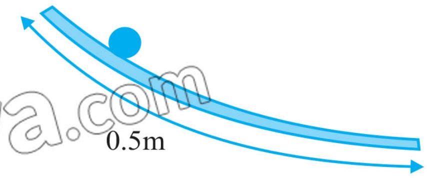


Figure 2.32 A ball is rolled on a curved track

14. The diagrams show four balances, W, X, Y and Z.

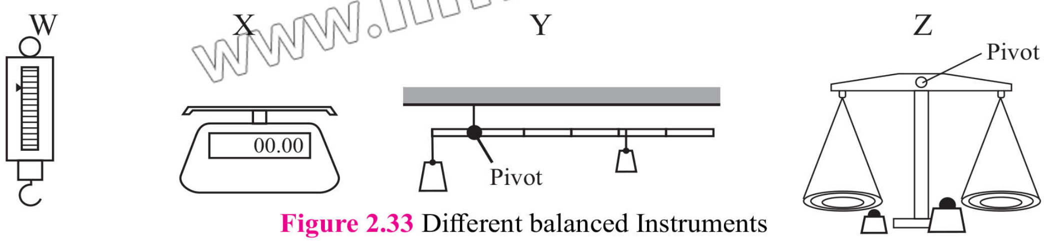


Figure 2.33 Different balanced Instruments

The scales of all the balances are calibrated on the Earth to measure mass. Which balances also measure mass correctly when used on the Moon?
a) W and X b) W and Z c) X and Y d) Y and Z

15. A small cylinder is rolled along a ruler and completes two full turns as shown in the diagram.

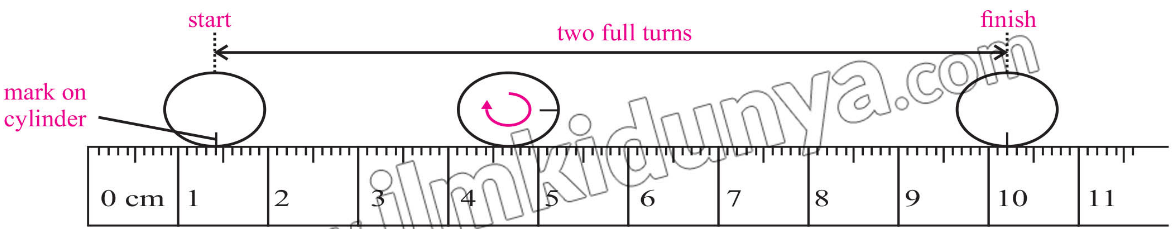


Figure 2.34 A small cylinder is rolled along a ruler.

What is the circumference of the cylinder?

a) 4.4cm b) 5.1cm c) 8.8cm d) 10.2cm

16. Micrometers, metre rules, tapes and calipers are used for measuring lengths. Which row identifies the most suitable device for accurately measuring the stated length?

	Length	**measuring device**
a)	0.15 mm	micrometer
b)	0.50 mm	metre rule
c)	0.15 m	tape
d)	0.50 m	calipers

17. What is the correct unit for the quantity shown?

	Quantity	**Unit**
a)	electromotive force (e.m.f.)	N
b)	latent heat	J
c)	pressure	kg/m^3
d)	weight	kg

18. Stop-watches are used to time the runners in a race. The stop-watches show the times recorded for the winner and another runner.

What is the difference in time between the winner and the other runner?

a) 0.4608 s b) 6.08 s c) 46.08 s d) 608 s

Winner Other runner

Figure 2.35 Times recorded for winner and another runner by the stopwatch.

B Short Questions

1. Which base quantity are you working with? Why are base quantities considered the foundation of all other physical quantities?

2. What happens to the exponent when you divide two numbers in scientific notation?

3. How would you correctly write a measurement of 20 megawatts per second?

4. Express 5 square kilometers in square meters.

5. If the diameter of a planet is on the order of 10^6 m, what would be the rough estimate of its diameter in kilometers?

6. Using orders of magnitude, estimate how many times larger the diameter of Sun (on the order of 10^9m) is compared to an diameter of atom (on the order of 10^{-9}m).

7. What is a parallax error, and how can it be corrected?

8. In which scenario is random error more likely: measuring the length of a table with a ruler or estimating the weight of a fruit by hand?

9. How do you determine the least count of a micrometer screw gauge?

10. If a vernier caliper's main scale has a division of 1mm and there are 10 divisions on the vernier scale, what is the least count of the vernier calipers?

11. What is the advantage of using a tape measure over a ruler?

12. Why might you choose a vernier caliper over a micrometer for a specific measurement?

13. What is the reading on the Vernier scales below? The scale is in metric units.

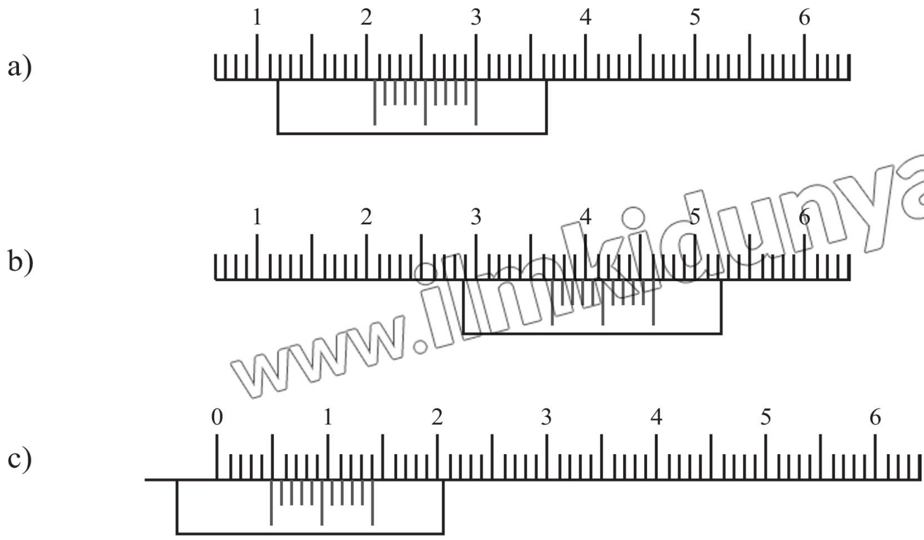
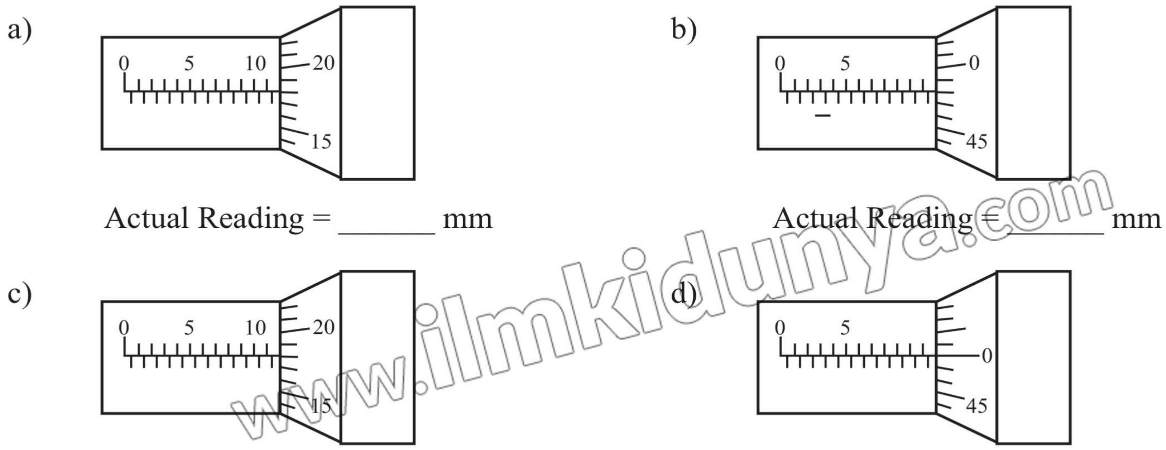


Figure 2.36 Reading on vernier scale.

14. Micrometer Screw Gauge

The following micrometer screw gauges have no zero errors. Determine the actual readings or each gauge:



a) Actual Reading = ______ mm

b) Actual Reading = ______ mm

c) Actual Reading = ______ mm

d) Actual Reading = ______ mm

Figure 2.37 Determine the actual reading by screw guage .

15. Indicate how many significant figures there are in each of the following measured values.

246.32	107.854	100.3	0.678
1.008	0.00340	14.600	0.0001
700000	350.670	1.0000	320001

16. Calculate the answers to the appropriate number of significant figures.

32.567	246.24	658.0
135.0	238.278	23.5478
+ 1.4567	+ 98.3	+1345.29

17. Calculate the answers to the appropriate number of significant figures.

a) 23.7 x 3.8 = b) 45.76 x 0.25 = c) 81.04 x 0.010 =

d) 6.47 x 64.5= e) 43.678 x 64.1 = f) 1.678 / 0.42 =

g) 28.367 / 3.74 = h) 4278 / 1.006 =

18. A student records the mass and volume of two irregular objects, one made of iron and the other of copper. The student uses the equipment shown in Figure.

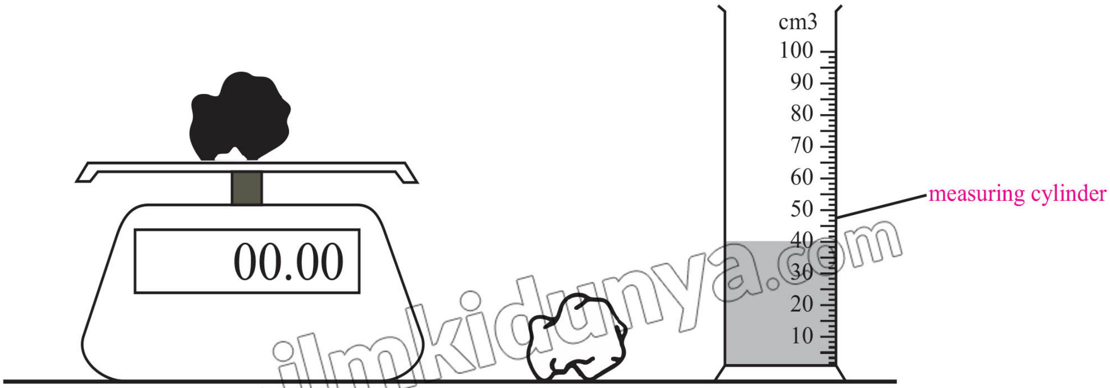


Table given below shows the results obtained.

Figure 2.38 Recorded the mass and volume of two irregular objects.

irregular objects	mass/g	volume/cm^3
iron	400	51
copper	350	39

Describe how to determine the volume of an irregular object with the measuring cylinder.

C Long Questions

1. Describe the concept of the order of magnitude. How does it differ from precise measurements? Estimate the order of magnitude of the distance between the Earth and the Moon.
2. Differentiate between systematic and random errors with examples. Why is it important to recognize and account for these errors in experiments?
3. Describe how you would accurately measure the volume of a stone of regular and irregular shape using the displacement method, what steps would you follow?
4. Differentiate between precision and accuracy using a dartboard analogy. If you were to take multiple readings of a pendulum's period of oscillation, how would these terms apply?
5. Justify the use of the ruler, micrometer, and vernier calipers in the lab. Also, discuss the importance of understanding the least count and limitations of each instrument.
6. Describe the procedure for accurately measuring the length of an object using a meter ruler. Include the steps you would take from the moment you place the object alongside the ruler to when you read off the measurement. Additionally, discuss common sources of error when using a meter ruler for measurements and suggest strategies to minimize these errors, ensuring more precise results.
7. Outline the procedure for measuring the thickness or diameter of a small object using a micrometer screw gauge. Your explanation should cover the process of positioning the object, turning the screw, and accurately reading the scale, including the thimble and sleeve. Discuss the common mistakes that can lead to measurement errors with the micrometer screw gauge and recommend practices to avoid these mistakes, thereby enhancing the reliability of measurements.

D Numerical Problems

1. Convert 5 kilometers to meters and 3 milligrams to grams.
2. Express 0.000067 in scientific notation.
3. During an experiment, a student measured the length of a rod five times and got the following readings: 5.2cm, 5.3cm, 5.1cm, 5.3cm, and 5.2cm. Calculate the average length and the random error (difference between the highest and lowest reading).
4. A student uses vernier calipers and notes the main scale reading as 2.5cm and the vernier scale reading as 7 divisions. If one division on the vernier scale is equivalent to 0.01cm, what is the total length measured?
5. A stone was dropped into a measuring cylinder containing 50ml of water. The water level rose to 85ml. Calculate the volume of the stone.
6. A student measures the thickness of a metal sheet using a micrometer The main scale reading is 4mm and the circular scale reading is 25 divisions. If one division on the circular scale represents 0.01mm, what is the thickness of the sheet?
7. If a bacteria cell has a typical length of 0.000002 meters, estimate its order of magnitude.
8. A student measures the time taken for a small toy car to travel 10 meters. The five trials gave readings of 5.2s, 5.5s, 5.1s, 5.3s, and 5.4s. Calculate the average time taken.
9. A star is approximately 9.461×10^{12}km away from Earth. If another star is 100 times less distant than the first star express the distance of the second star in scientific notation.

PHYSICS

9

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