CHAPTER

1 MEASUREMENTS

STUDENT LEARNING OBJECTIVES

After studying this chapter, students will be able to:

- Make reasonable estimates of values of physical quantities for those quantities that are discussed in the topics of this grade.
- Use the correct prefixes for expressing units and their symbols.
- Differentiate between base and derived physical quantities.
- Analyse the homogeneity of physical equations through dimensional analysis.
- Derive formulae in simple cases through using dimensional analysis.
- Analyse and critique the accuracy and precision of data collected by measuring instruments.
- Justify why measurement is a crucial part of scientific investigation.
- Assess the uncertainty in a derived quantity by simple addition of absolute, fractional or percentage uncertainties.
- Quote answers with correct scientific notation, number of significant figures and units in all experimental and numerical work.

For Your Information
Science is the knowledge of [illegible]

Q. What is Physics?

Physics is the most fundamental branch of physical sciences. It provides the basic principles and laws which help in understanding the mysteries of other branches of science such as astronomy, chemistry, geology, biology and health sciences.

Q. Why are accurate measurements important in Physics?

Physics is an experimental science and the scientific method emphasises the need of accurate measurement of various measurable physical quantities. This chapter stresses understanding the concept of measuring techniques and recording results.

- **Importance of Measurement:** Physics relies heavily on accurate measurement for scientific investigation.
- **Physical Quantities:** These are measurable quantities. They can be base (fundamental) or derived.
- **Units and Prefixes:** Correct prefixes and symbols are essential for expressing units of physical quantities.
- **Physics as a fundamental Science:** Physics provides the foundation for other sciences.
- **Impact of Physics:** Physics has significantly impacted our lives through technology and engineering.

Do You Know?
Computer chips are made from wafers of the [illegible]

Interdisciplinary nature of Physics
Astrophysics
Biophysics
Chemical Physics
Engineering Physics
Geophysics
Medical physics
Physical oceanography
Physics of music

Q. Think over! Computer chips are made from silicon, which is obtained from sand. It is up to us whether we make a sand castle or a computer out of it.

Ans: This "Think over" prompt highlights how raw materials, like sand, can be transformed into incredibly advanced technologies, like computer chips, through human ingenuity and scientific application. It emphasises the power of innovation rooted in physics.

Areas of Physics

Mechanics	Heat & Thermodynamics	Optics	Sound
Hydrodynamics	Special relativity	General relativity	Quantum
Mechanics	Atomic physics	Molecular physics	Nuclear physics
Solid-state physics	Particle physics	Superconductivity	Super fluidity
Plasma physics	Magneto Hydrodynamics	Space physics	

1.1 PHYSICAL QUANTITIES AND THEIR UNITS

Q. Physical quantities are measureable quantities, what do you know about their characteristics and classification. Differentiate between fundamental (base) and derived quantities. Also explain how derived quantities can be derived from base or fundamental quantities?

Definition: Physical quantities are those that can be measured directly or indirectly. Physics laws are expressed in terms of physical quantities.

Characteristics:

- They have magnitude.
- They may or may not have direction.
- They can be expressed in terms of units.
- They follow the laws of physics.

Examples:

- Length
- Mass
- Time
- Temperature
- Force
- Energy
- Velocity
- Electric current

Table 1.1

Physical Quantity	SI Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Intensity of light	candela	cd
Amount of substance	mole	mol

Classification of Physical Quantities

Physical quantities can be further classified based on various criteria:

Fundamental and Derived Quantities:

- Fundamental quantities are independent and cannot be expressed in terms of other quantities (e.g., mass, length, time).
- Derived quantities are expressed in terms of fundamental quantities (e.g., velocity, acceleration, force).

Scalar and Vector Quantities:

- Scalar quantities have only magnitude (e.g., mass, temperature, speed).
- Vector quantities have both magnitude and direction (e.g., velocity, force, displacement).

Importance of Physical Quantities in Physics

Physical quantities are the foundation of physics. They allow us to:

- Describe natural phenomena precisely.
- Formulate laws and theories.
- Perform experiments and make predictions.
- Develop technology and solve real-world problems.

Do You Know?

Mass can be thought of as a form of energy. In fact the mass is highly concentrated form of energy. Einstein's famous equation.
$E = mc^2$ means
Energy = mass x speed of Light² According to this equation 1kg mass is actually 9×10^{16} J energy
Explanation:
If m = 1kg, then
Energy $= mc^2 = 1kg \times (3 \times 10^8\, ms^{-1})^2 = 9 \times 10^{16}$ J

Fundamental and Derived Quantities

In physics, quantities are classified as either fundamental or derived, depending on their relationship with other quantities.

Fundamental Quantities

Fundamental quantities are the basic quantities that are independent of each other and cannot be defined in terms of other physical quantities. They form the foundation upon which other physical quantities are built. The International System of Units (SI) recognizes seven fundamental quantities:

1. **Length** (meter, m)
2. **Mass** (kilogram, kg)
3. **Time** (second, s)
4. **Electric Current** (ampere, A)
5. **Thermodynamic Temperature** (kelvin, K)
6. **Amount of Substance** (mole, mol)
7. **Luminous Intensity** (candela, cd)

For Your Information

	Interval (s)
Age of the universe	5 x 10[illegible]
Age of the Earth	1.4 x 10[illegible]
One year	3.2 x 10[illegible]
One day	8.6 x 10[illegible]
Time between normal heartbeats	8 x 10[illegible]
Period of audible sound waves	1 x 10[illegible]
Period of typical radiowaves	1 x 10[illegible]
Period of vibration of an atom in a solid	1 x 10[illegible]
Period of visible light waves	2 x 10[illegible]

Approximate Values of Some Time Intervals

Q. How derived quantities can be derived from base or fundamental quantities?

Ans

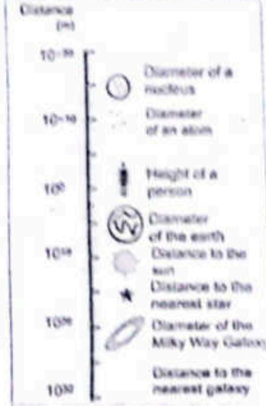
Derived Quantities

Derived quantities, on the other hand, are defined in terms of fundamental quantities. They are obtained by combining fundamental quantities through multiplication, division, or both.

Examples of Derived Quantities:

1. **Area:** Area is derived from the fundamental quantity of length. For example, the area of a rectangle is calculated by multiplying its length and width (length × length). The SI unit of area is square meter (m^2).
2. **Volume:** Volume is also derived from length. The volume of a cube is found by cubing its side length (length × length × length). The SI unit of volume is cubic meter (m^3).
3. **Velocity (Speed):** Speed is derived from the fundamental quantities of length and time. It is defined as the distance (length) traveled per unit of time (length/time). The SI unit of speed is meters per second (m/s).
4. **Density:** Density is derived from the fundamental quantities of mass and volume. It is defined as mass per unit volume (mass/volume). The SI unit of density is kilograms per cubic meter (kg/m^3).
5. **Force:** Force is derived from the fundamental quantities of mass, length, and time. According to Newton's second law of motion, force is equal to mass times acceleration. Acceleration, in turn, is derived from length and time ($length/time^2$). So, force can be expressed as mass × ($length/time^2$). The SI unit of force is the newton ($N = kg\, m\, s^{-2}$).
6. **Energy/Work**, measured in joules (J), is another derived unit, defined as the product of force (newtons) and distance (meters), giving us the unit $kg\, m^2/s^2$.

For Your Information



Order of magnitude of some distances

Table 1.2

Physical quantity	Unit	Symbol	In terms of base units
Plane angle	radian	rad	dimensionless
Solid angle	steradian	sr	dimensionless
Force	newton	N	$kg\, m\, s^{-2}$
Work	joule	J	$N\, m = kg\, m^2\, s^{-2}$
Power	watt	W	$J\, s^{-1} = kg\, m^2\, s^{-3}$
Electric charge	coulomb	C	A s
Pressure	pascal	Pa	$N\, m^{-2} = kg\, m^{-1}\, s^{-2}$

7. **Pressure:** The Pascal (Pa), the unit of pressure, is obtained from the equation: Pressure = force ÷ area So, Pa = N ÷ m² = (kg m s⁻²) ÷ m² = kg m⁻¹ s⁻² Therefore, the Pascal (Pa) in SI base units is kg m⁻¹ s⁻².
8. **Electric Charge:** It is the product of current and time, Q = It. Since SI unit of current is ampere and that of time is second, so derived unit of charge is coulomb = ampere x second.
9. **Electric Potential (Volt):** It is the potential energy per unit charge (V=W/q) which is defined as joule per coulomb (J/C). Which further breaks down to kg m² s⁻² divided by (A s) and we get kg m² s⁻³ A⁻¹.

Measurement of Base Quantities: It involves choosing a standard and comparing the quantity to the standard.

Reliable and Accurate Measurements: is essential for effective use.

MULTIPLE CHOICE QUESTIONS

- **Which of the following is a base physical quantity?**
  (a) Velocity (b) Area (c) Time (d) Density

Answer: c) Time
Explanation: Time is a fundamental quantity and is not derived from other physical quantities listed. Velocity (length/time), area (length * length), and density (mass/volume) are derived quantities.

- **Physics is considered the most fundamental branch of:**
  (a) Biological sciences (b) Chemical sciences (c) Physical sciences (d) Geological sciences

Answer: c) Physical sciences
Explanation: The text states that "Physics is the most fundamental branch of physical sciences."

- **Which of the following is a base physical quantity?**
  (a) Velocity (b) Area (c) Time (d) Density

Answer: (c) Time
Explanation: Time is a fundamental quantity and is not derived from other physical quantities listed. Velocity (length/time), area (length * length), and density (mass/volume) are derived quantities.

- **The diameter of milky way galaxy is: SGD 2023 GII**
  (a) 10[illegible] m (b) 10[illegible] m (c) 10[illegible] m (d) 10[illegible] m
- **Time taken by light to reach form sun to earth is: DGK 2023 GII**
  (a) 1min, 20 sec (b) 4 min, 20 sec (c) 8 min, 20 sec (d) 10 min, 20 sec

SLO BASED SHORT QUESTIONS & ANSWERS

Q: Why is accurate measurement considered an important part of scientific investigation in Physics?
Ans: Accurate measurement is important because Physics is an experimental science. Reliable data obtained through precise measurements forms the basis for testing hypotheses, developing theories, and making predictions about the physical world.

Q: How has physics influenced our daily lives?
Ans: Physics has led to the development of tools, techniques, and technologies that have greatly improved communication, transportation, medicine, and countless other aspects of modern life.

Q: Differentiate between base and derived physical quantities, giving one example of each.
Ans: Base physical quantities are fundamental and cannot be expressed in terms of other physical quantities (e.g., length, mass, time). Derived physical quantities are expressed as combinations of base quantities (e.g., velocity, which is derived from length and time).

1.2 INTERNATIONAL SYSTEM OF UNITS (SI)

Q. How you will define it stating types of units, prefixes, scientific notation and conventions for using units?

Ans

INTERNATIONAL SYSTEM OF UNITS (SI)

The International System of Units, abbreviated as SI, is the modern form of the metric system and is the most widely used system of measurement in the world. It provides a standardized framework for measurements, ensuring consistency and comparability across various fields, including science, technology, industry, and commerce.

It was established in 1960 and was refined in 1971 to include a comprehensive set of base units that serve as the foundation for all other measurements in science.

Base Units

The SI system is founded on seven base units, each representing a fundamental physical quantity:

1. **Meter (m):** Length
2. **Kilogram (kg):** Mass
3. **Second (s):** Time
4. **Ampere (A):** Electric current
5. **Kelvin (K):** Thermodynamic temperature
6. **Mole (mol):** Amount of substance
7. **Candela (cd):** Luminous intensity

Derived Units

Derived units are formed by combining base units to express other physical quantities. For example:

- **Velocity:** m s⁻¹ (meter per second)
- **Acceleration:** m s⁻² (meter per second squared)
- **Force:** kg m s⁻² (kilogram meter per second squared), also known as the Newton (N)
- **Energy:** kg m² s⁻² (kilogram meter squared per second squared), also known as the Joule (J)

Prefix	Symbol	Factor
yocto	y	10^{-24}
zepto	z	10^{-21}
atto	a	10^{-18}
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
deca	da	10^{1}
hecto	h	10^{2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}
peta	P	10^{15}
exa	E	10^{18}
zetta	Z	10^{21}
yotta	Y	10^{24}

SI Prefixes

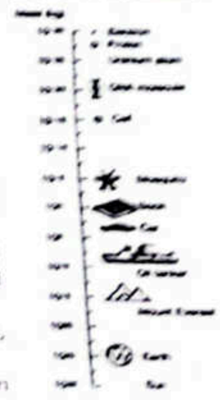
SI prefixes are used to denote multiples and submultiples of the base units, providing a convenient way to express very large or very small quantities.

What is the importance of SI Units?

- **Universality:** SI units provide a common language for measurement, facilitating global communication and collaboration in science, technology, and trade.
- **Coherence:** SI units are coherent, meaning that derived units are expressed as simple products or ratios of base units, simplifying calculations and reducing errors.
- **Consistency:** The SI system is based on fundamental physical constants, ensuring the stability and consistency of measurements over time.
- **Decimal-based:** The decimal nature of SI units makes conversions between different magnitudes straightforward, using powers of 10.

In short, the International System of Units is an important tool in physics.

Interesting Information



Order of magnitude of some masses

and many other disciplines, providing a standardized, coherent, and universally accepted system for quantifying the world around us.

Some other derived quantities with their derived units which are expressed in terms of base units are listed in the table.

Derived Quantity	Description	Derived Unit (SI)	Expressed as Product/Quotient of SI Base Units	Expressed in Base Units
Area	Measure of a surface	square meter (m^2)	Length × Width	m^2
Volume	Measure of space occupied	cubic meter (m^3)	Length × Width × Height	m^3
Power	Rate of doing work	watt (W)	Energy / Time	$kg\ m^2\ s^{-3}$
Electric Potential	Electric potential energy per charge	volt (V)	Power / Electric Current	$kg\ m^2\ s^{-3}\ A^{-1}$
Electric Resistance	Opposition to the flow of electric current	ohm (Ω)	Electric Potential / Electric Current	$kg\ m^2\ s^{-3}\ A^{-2}$
Magnetic Flux	Measure of the amount of magnetic field	weber (Wb)	Magnetic Field × Area	$kg\ m^2\ s^{-2}\ A^{-1}$
Magnetic Flux Density	Measure of magnetic field strength	tesla (T)	Magnetic Flux / Area	$kg\ s^{-2}\ A^{-1}$
Frequency	Number of occurrences per unit time	hertz (Hz)	1/s	s^{-1}

What are the Additional Units Permitted in SI?

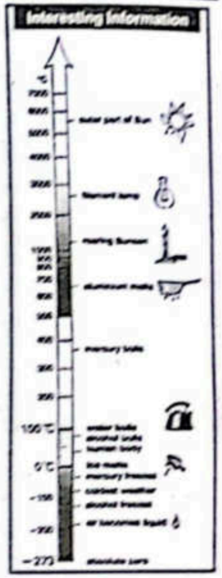
- Traditional angle units (degree, arcminute, arcsecond).
- Traditional time units (minute, hour, day, year).
- Logarithmic units (bel, decibel).
- Common metric units (litre, tonne).
- Non-metric scientific units (atomic mass unit, electron volt).
- Nautical mile and knot.
- Metric units of land area (acre, hectare).
- Units of pressure (bar, millibar, kilobar).
- Units in physics and astronomy (angstrom, barn).

What is Scientific Notation?

- It is a method of expressing numbers in standard form using powers of ten.
- In practice there should be one non-zero digit to the left of the decimal point (e.g., 1.347×10^{3}).

What are the conventions for Using SI Units?

1. Symbols, not abbreviations, are used (e.g., A, s).
2. Unit names are lowercase (except Celsius).
3. Symbols are lowercase (except L for litre).
4. Symbols for scientists are capitalized (e.g., N, Pa, W).
5. Symbols and prefixes are in roman style.
6. Symbols are singular (e.g., 1 kg, not 1 kgs).



7. No full stop after symbols (except at sentence end).
8. Prefixes are written without space before the base unit (e.g., mL).
9. Space between number and symbol (e.g., 1 kg, 10 ms).
10. No compound prefixes (e.g., pF, not μμF).
11. Powers apply to the whole multiple (e.g., $1\ km^2 = 1 \times 10^6\ m^2$).
12. Use negative index notation (e.g., $m\ s^{-1}$, not m/s).
13. Use scientific notation (e.g., 1.437×10^{3}).
14. Do not mix symbols and names (e.g., ms^{-1}, not metre/sec).
15. Record practical work in convenient units, but report final results in base units.
16. Do not use CGS units (dyne, erg, gauss, etc.).

For your information

Travel time of light

Moon to Earth	1 min 20 s
Sun to Earth	8 min 20 s
Pluto to Earth	5 h 20 s

Some Specific Temperatures

Atomic Clock

The caesium atomic frequency standard at the National Institute of Standards and Technology in Colorado (USA). It is the primary standard for the unit of time.

For your information

Colour printing uses just four colours—cyan, magenta, yellow and black to produce the entire range of colours. All the colours in this book have been made from just these four colours.

MULTIPLE CHOICE QUESTIONS

- **Which of the following is a derived quantity?**
  (a) Time (b) Mass (c) Force (d) Length

Answer: c) Force

Explanation: Force is derived from base quantities (mass, length, and time), while the others are base quantities.

- **How many base units are there in the SI system?**
  (a) Five (b) Six (c) Seven (d) Eight

Answer: c) Seven

Explanation: The SI system defines seven base units.

- **The measurement of a base quantity involves:**
  (a) Only choosing a standard (b) Only comparing with a standard
  (c) Choosing a standard and comparing with it (d) Calculating using a formula

Answer: c) Choosing a standard and comparing with it

Explanation: Measuring a base quantity requires both selecting a standard and having a comparison procedure.

- **The SI system was established in:**
  (a) 1860 (b) 1960 (c) 2000 (d) 1900

Answer: b) 1960

Explanation: The International System of Units was established in 1960.

- **Which of the following is a derived unit?**
  a) Kilogram (kg) b) Second (s) c) Newton (N) d) Mole (mol)

Answer: c) Newton (N)

Explanation: The Newton is the unit of force, derived from $kg\ m\ s^{-2}$. The others are base units.

- **The prefix "kilo" in "kilometer" represents:**
  a) 10^{-3} b) 10^{3} c) 10^{-6} d) 10^{6}

Answer: b) 10^{3}

Explanation: 'Kilo' represents 1000 or 10^3.

- **The correct scientific notation for 0.000056 is:**
  (a) 56×10^{-6} (b) 5.6×10^{-5} (c) 5.6×10^{0} (d) 56×10^{6}

Answer: (b) 5.6×10^{-5}

Explanation: In scientific notation, there should be one non-zero digit to the left of the decimal point

- **Which unit is used to measure pressure?**
  (a) Angstrom (b) Watt (c) Bar (d) Nautical Mile

Answer: c) Bar

Explanation: Bar is a unit of pressure.

- **The prefix 'milli' represents:**
  (a) 10^3 (b) 10^{-3} (c) 1 (d) 10^{-6}

Answer: b) 10^{-3}

Explanation: The prefix 'milli' (m) stands for one-thousandth, which is mathematically represented as 10^{-3}.

SLO BASED SHORT QUESTIONS & ANSWERS

Q: Why are physical quantities important in Physics?

Ans: Physical quantities are fundamental because the laws of Physics are expressed in terms of them. Therefore, accurate measurement of these quantities is important for understanding and quantifying physical phenomena.

Q: Differentiate between base and derived quantities. Give two examples of each.

Ans:
- Base quantities are fundamental and not defined in terms of other quantities (e.g., length, time).
- Derived quantities are defined in terms of base quantities (e.g., velocity, force)

Q: What are the two steps involved in measuring a base quantity?

Ans: The two steps are:
1. Choosing a standard.
2. Establishing a procedure to compare the quantity with the standard.

Q: What is the importance of having reliable and accurate measurements?

Answer: Reliable and accurate measurements are essential for the data to be used effectively in scientific investigations, engineering applications, and other fields.

Q: What is the International System of Units (SI)?

Answer: The SI is a system of definitions and standards for physical quantities, agreed upon internationally in 1960. It consists of base units and derived units and is used by the global scientific community.

Q: What are derived units? Give three examples.

Answer: Derived units are units that are defined in terms of base units. Examples include:
- Newton (N) for force ($kg\ m\ s^{-2}$)
- Pascal (Pa) for pressure ($N\ m^{-2}$)
- Watt (W) for power ($J\ s^{-1}$)

Q: Why is scientific notation used in physics? Explain with an example.

Answer: Scientific notation is used to express very large or very small numbers in a concise and standardized way. For example, the speed of light is approximately 300,000,000 $m\ s^{-1}$, which in scientific notation is $3.0 \times 10^8\ m\ s^{-1}$. This makes it easier to write, read, and perform calculations with such numbers.

Q: Besides base and derived units, what other types of units are permitted within the SI system? Give two examples.

Ans: The SI system allows for the use of some additional units, including:
- Traditional units for time, such as minute, hour, day, and year
- Units commonly used in specific fields, such as the nautical mile (used at sea) and the electron volt (used in atomic physics)

Q. Why are prefixes important in the SI system? Give two examples of prefixes and their corresponding powers of ten.

Ans: Prefixes simplify the representation of very large or very small quantities, making them easier to work

with Examples
- Kilo (k) represents 10^3 (e.g., kilometer = 1000 meters)
- Milli (m) represents 10^{-3} (e.g., millimeter = 0.001 meter)

Q. State four conventions for writing SI units and symbols correctly.

Answer:
1. Use symbols, not abbreviations (e.g., A for ampere).
2. Unit names are lowercase (newton, metre)
3. Symbols are lowercase (m for metre, s for second).
4. Symbols for scientists are capitalized (N for newton).

Q. Explain why it is important to follow conventions when using SI units.

Ans: Consistent use of SI unit conventions ensures clear communication and avoids confusion in scientific and technical contexts. It promotes uniformity and facilitates the exchange of information globally.

For Your Information

Standard definitions of seven base units are given below.

(i) **Meter:** In 1960, meter was redefined as 1,650,763.73 wavelengths of the orange red light emitted by the atoms of krypton-86 lamp. In 1983, the meter was redefined as
The distance traveled by light in vacuum during a time of 1/299,792,458 second.
The latest definition establishes that the speed of light in vacuum is **299,792,458** $m\ s^{-1}$.

(ii) **Kilogram:** In 1901, mass standard was setup as kilogram and defined as,
The mass of platinum (90%) and iridium (10%) alloy cylinder, 3.9 cm in diameter and 3.9 cm in height, kept at the International Bureau of Weights and Measures in France.

(iii) **Second:** It is defined as, 1/86400 part of an average day of the year 1900 A.D.
However, since 1967, one second is redefined as,
*The time during which Cesium-133 atom completes **9,192,631,770** vibrations.*

(iv) **Kelvin:** One Kelvin is defined as, *The fraction **1/273.16** of the thermodynamic temperature of the triple point of water.*
It should be noted that the triple point of a substance means the temperature at which solid, liquid and vapor phases are in equilibrium. The temperature of triple point of water is taken as 273.16 K. This standard was adopted in 1967.

(v) **Ampere:** One ampere is that current which if maintained in two straight parallel conductors of infinite length, of negligible circular cross section and placed a meter apart in vacuum, would produce between these conductors a force equal to **2×10^{-7} newton per meter** of length.
This unit was setup in 1971.

(vi) **Candela:** The luminous intensity in the perpendicular direction of a surface of **1/600000** square meter of a black body radiator at the solidification temperature of platinum under standard atmospheric pressure.
The definition was established in1967.

(vii) **Mole:** It is defined as, The mole is the amount of substance of a system, which contains as many elementary entities as there are atoms in 0.012 kg of Carbon-12. This unit was adopted in 1971.

1.3 UNCERTAINTY IN MEASUREMENT

Q: What is error and uncertainty? Also state types of error. Why do all measurements contain some uncertainty? What is absolute uncertainty? How is fractional uncertainty calculated? How is percentage uncertainty calculated?

Error and Uncertainty

Error and uncertainty are related but distinct concepts in the light of measurement and data analysis.

Error

Error is the difference between a measured value and the true or accepted value. It represents the inaccuracy of a measurement.

Uncertainty

Uncertainty, on the other hand, is a doubt associated with a measurement. It provides a range of values within which the true value is likely to lie.

Types of Errors and Their Causes

Errors can be broadly classified into two types:

1. **Systematic Errors:**

- o **Causes:**
- Calibration errors in instruments
- Zero errors (instrument not reading zero when it should)
- Faulty equipment or experimental design
- Consistently incorrect methodology
- o **Characteristics:**
- Affect accuracy
- Lead to measurements that consistently deviate from the true value
- Cannot be reduced by taking multiple measurements
- Can be eliminated by applying zero correction

2. **Random Errors:**

- o **Causes:**
- Fluctuations in environmental conditions (e.g., temperature, pressure)
- Limitations of the measuring instrument
- Variations in the observer's judgment
- Statistical fluctuations in the measured quantity
- Due to unknown reasons when large number of readings are taken
- o **Characteristics:**
- Affect precision
- Cause measurements to vary randomly around the true value
- Can be reduced by taking multiple measurements and calculating the average
- Cannot be eliminated completely

Do you know?

Mass can be thought of as a form of energy. In effect, the mass is highly concentrated form of energy. Einstein's famous equation, $E=mc^2$ means:

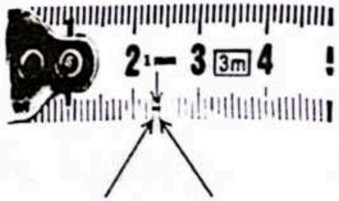
Energy = mass x (speed of light)^2

According to this equation 1 kg mass is actually 9×10^{16} J of energy.

What is Absolute uncertainty?

- It Indicates measurement consistency.
- Depends on the least count of the measuring instrument.

In simpler terms, it tells us how precise a measurement is, and this precision is limited by the smallest division on the measuring tool.



What is Resolution or Least count? It refers to the smallest increment that can be measured accurately by an instrument. It signifies the precision of the instrument and indicates the minimum value of a physical quantity that can be reliably determined. For instance, consider the commonly used meter rod and tape measure with a resolution of 1 mm. This means that any length measurement made using these tools cannot be accurate to a value smaller than 1 mm.

For example, if one edge of the book coincides with 10.0 cm mark and the other with 33.5 cm, then the length with uncertainty is given by

(33.5 ± 0.05) cm - (10.0 ± 0.05) cm = (23.5 ± 0.1) cm

It means that the true length of the book is in between 23.4 cm and 23.6 cm. Hence, the maximum uncertainty is ± 0.05 cm, which is equivalent to an uncertainty of 0.1 cm. In fact, it is equal to least count of the metre rule.

Do You Know?

Mass can be thought of as a form of energy. In effect, the mass is highly concentrated form of energy. Einstein's famous equation, $E=mc^2$ means:

Energy = mass x speed of Light^2

According to this equation 1 kg mass is actually 9×10^{16} J energy.

Q: Why do all measurements contain some uncertainty?

Ans: You can count the number of pages in a book exactly, but measuring its length requires an instrument. Every instrument is calibrated to a smallest division mark, which limits its accuracy. When a reading is taken, it's to the nearest graduation, meaning there's always some uncertainty.

Q. If least count of stop watch is 0.01s and time for 25 vibrations is 37.5s, then calculate uncertainty in the time period. What you conclude from the result?

Ans:

- The period T is calculated as: T = 37.5 s/25 = 1.50 s, with an uncertainty of 0.01 s/25 = 0.0004 s.
- Therefore, the period T is written as T = 1.50 ± 0.004 s.
- **Conclusion:** This illustrates the importance of counting a large number of observations to reduce timing uncertainty.

Q. How do you calculate fractional uncertainty and percentage uncertainty?

Ans:

- Fractional uncertainty = Absolute uncertainty / Measured value
- Percentage uncertainty = (Absolute uncertainty / Measured value) x 100

Q. Why all measurements contain some degree of uncertainty?

Ans: Measurements have uncertainty because of limitations in instruments, environmental factors, human error, the nature of what's being measured, and sampling issues. This uncertainty is classified as either systematic (consistent deviations) or random (varying deviations). Uncertainty is quantified to show the reliability of a measurement.

Q. Why measurements in physics have errors and define uncertainty?

Ans: Measurements are never perfect due to limitations in the instruments used or human error. These errors can be categorized as either random or systematic. While error can be removed from a result, it leads to *uncertainty*, which is essentially a *doubt* in the final measurement.

Uncertainty in Digital Instruments

Q. How is uncertainty indicated in digital instruments?

Ans: With a digital scale, fluctuations in the last digit reflect uncertainty. If the last digit fluctuates by 1 or 2, that digit is written down. Larger fluctuations (more than 2) may indicate external influences (like air currents) or that the displayed digit is not truly significant.

Q: How do significant figures simplify the indication of uncertainty?

Ans: If a measurement is recorded using significant figures, its last digit (which is an estimation) indicates the accuracy of the recorded value.

MULTIPLE CHOICE QUESTIONS

- **Which of the following is NOT allowed in the SI system?**

(a) km^2 (b) ms^{-1} (c) μμF (d) 1.4×10^3 m

Answer: c) μμF

Explanation: Compound prefixes are not allowed, μμF should be expressed as pF.

- **If the length of an object is measured as 25.5 cm using a ruler with a least count of 0.1 cm, the absolute uncertainty is:**

(a) 0.05 cm (b) 0.1 cm (c) 0.2 cm (d) 25.5 cm

Answer: b) 0.1 cm

Explanation: The absolute uncertainty is equal to the least count of the measuring instrument.

- **The correct way to represent "metre per second" is:**

(a) m/second (b) metre/sec (c) ms^{-1} (d) $m\ s^{-1}$

Answer: c) ms^{-1}

Explanation: Negative index notation is preferred, and there should be a space between units.

- **If a measurement is given as 10.0 ± 0.2 cm, the percentage uncertainty is:**

(a) 0.2% (b) 2% (c) 20% (d) 0.02%

Answer: c) 2%

Explanation: Percentage uncertainty = (0.2 cm / 10.0 cm) × 100% = 2%.

- The smallest division mark on a measuring instrument limits its:
  (a) Accuracy (b) Precision (c) Both accuracy and precision (d) Neither accuracy nor precision
  - **Answer:** (b) Precision
  - **Explanation:** The smallest division, or least count, directly determines the precision of the instrument, as it defines the smallest measurable increment.
- What is "absolute uncertainty" in a measurement?
  (a) The true value of the quantity. (b) The average of multiple readings. (c) The maximum uncertainty, estimated as one smallest division of the instrument. (d) The percentage error in the measurement.

Answer: (c) The maximum uncertainty, estimated as one smallest division of the instrument.

Explanation: Absolute uncertainty is defined as the smallest division on the instrument's scale, indicating the maximum possible error in a single reading.

- If a metre rule is graduated in millimetres, what is its absolute uncertainty?
  (a) ± 1 cm (b) ± 0.1 cm (c) ± 0.01 cm (d) ± 1 m

Answer: (b) ± 0.1 cm

Explanation: 1 millimetre (mm) is equal to 0.1 centimetre (cm). The absolute uncertainty is typically taken as one smallest division.

- How is percentage uncertainty calculated?
  (a) (Measured value / Absolute uncertainty) × 100% (b) (Absolute uncertainty / Measured value) × 100% (c) Absolute uncertainty × Measured value (d) Measured value - Absolute uncertainty

Answer: (b) (Absolute uncertainty / Measured value) × 100%

Explanation: This is the standard formula for percentage uncertainty, showing the relative error.

- In digital instruments, what does a fluctuation of 1 or 2 in the last digit usually indicate?
  (a) The instrument is broken. (b) The reading is completely unreliable. (c) The reading is being influenced by external factors significantly. (d) The last digit is within the expected uncertainty and can be written down.

Answer: (d) The last digit is within the expected uncertainty and can be written down.

Explanation: Small fluctuations (1 or 2 digits) in a digital display are considered normal and indicate that the last digit is still significant and part of the measurement's uncertainty range.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Why do all measurements contain some uncertainty?**

Ans: All measurements contain uncertainty because every measuring instrument has a finite limit to its accuracy, determined by its smallest division, meaning a reading is always an estimation to the nearest graduation.

- **How is absolute uncertainty determined for an analog instrument?**

Ans: For an analog instrument, the absolute uncertainty is typically estimated as one smallest division or graduation mark on its scale.

- **What is fractional uncertainty, and how is it calculated?**

Ans: Fractional uncertainty is the ratio of the absolute uncertainty to the measured value. It is calculated as Absolute uncertainty / Measured value.

- **What might a large fluctuation (more than 2 digits) in the last digit of a digital instrument reading suggest?**

Ans: A large fluctuation might suggest that the reading is being influenced by external factors (like air currents) or that the displayed digit is not truly significant.

- **How does the concept of significant figures simplify the indication of uncertainty?**

Ans: Significant figures simplify uncertainty indication by implying that the last digit recorded in a measurement is an estimated or doubtful digit, thereby communicating the accuracy of the recorded value.

1.4 USE OF SIGNIFICANT FIGURES

Q. What are significant figures? How we can estimate the number of significant figure in the physical measurement and explain the way to rounding off data.

SIGNIFICANT FIGURES:

The number of digits of a measurement about which we are sure are called significant figures. In any measurement, the accurately known digits and the first estimated or doubtful digit are called significant figures.

- Significant figures are digits in a measurement about which we are reasonably sure.
- It reflects the precision of the measuring instrument.
- Calculators often show many digits, but these should be rounded off.
- Rounding is done based on the instrument's uncertainty or least count.
- Scientific notation helps avoid ambiguity in significant figures.

Beware!

Calculators are designed to yield as many digits as the memory of the calculator chip permits. Hence, be sure to round off the final answers of calculations down to correct number of significant figures.

Example: For example, weighing the same object with different balances:

- Electronic balance: mass = 3.145 ± 0.001 g (more precise)
- Lever balance: mass = 3.1 ± 0.1 g
- The uncertainty is often implied (e.g., 3.145 g means uncertainty of at least ± 0.001 g).
- Significant figures include all accurately known digits plus the first estimated digit.
- Proper use of significant figures represents measurement uncertainty.
- More significant figures indicate a more precise measurement.

For your information

These are not decoration pieces of glass but are the earliest known exquisite and sensitive thermometers, built by the Accademia del Cimento (1657-1667) in Florence. They contained alcohol some times coloured red to easier reading.

Counting Significant Digits:

All non-zero digits (1-9) are significant.

(a) **Zero between two significant figures:** It is significant (e.g., 305 has 3 significant figures).

(b) **Zeros to the left of the most significant figure:** Not significant (e.g., 0.00467 and 02.59 have 3 significant figures each).

(c) **Zeros to the right of a significant figure:**

- In decimal fractions, zeros to the right of a significant figure are significant (e.g., 3.570 has 4 significant figures, 7.4000 has 5 significant figures).
- In integers (e.g., 8,000 kg), the number of significant zeros depends on the measuring instrument's precision. If the least count is 1 kg, it's 8.000×10^3 kg (4 significant figures). If the least count is 10 kg, it's 8.00×10^3 kg (3 significant figures).

(d) **Scientific notation:** Figures other than the powers of ten are significant (e.g., 8.70×10^4 kg has 3 significant figures).

In Multiplying/Dividing Numbers:

- Result should have no more significant figures than the least accurate factor (the one with the fewest significant figures).

Example: In computation of following:

$$\frac{5.348\times10^{-2}\times3.64\times10^{4}}{1.336}=1.45708982\times10^{3}=1.46\times10^{3}$$

- Calculation result 1.45708982×10^3 should be rounded to three significant figures because 3.64×10^4 has three sig figs.

In Addition and Subtraction: When adding and subtracting numbers, the result should be rounded to the same number of decimal places as the number with the fewest decimal places.

- **Rule:** The answer should have the same number of decimal places as the quantity with the *least* number of decimal places.
- **Focus:** Decimal places are important, not the total number of significant figures.

Examples:

- 72.1 m + 3.45 m = 75.55 m
  - 72.1 m has the fewest decimal places (one).
  - Rounded answer: 75.6 m
- 12.234 m - 4.10 m = 8.134 m
  - 4.10 m has the fewest decimal places (two).
  - Rounded answer: 8.13 m

It is important to distinguish this rule from the rule for multiplication and division, where significant figures are considered.

Q: What are the rounding-off rules for deleting insignificant figures?

Ans:

(a) If the first digit dropped is less than 5: The last digit retained remains unchanged.

(b) If the first digit dropped is more than 5: The digit to be retained is increased by one.

(c) If the digit to be dropped is exactly 5: The previous digit to be retained is increased by one if it is odd, and retained as such if it is even.

Examples of rounding to three significant figures:

- 43.75 is rounded off as 43.8
- 56.8546 is rounded off as 56.9
- 73.650 is rounded off as 73.6
- 64.350 is rounded off as 64.4

Limitations of Significant Figures:

- Significant figures only deals with one source of uncertainty that arise in reading the scale.
- Total experimental uncertainty includes personal and systematic errors, which can be larger than suggested by significant figures alone.

SLO BASED SHORT QUESTIONS & ANSWERS

- **State the rules for determining whether zeros are significant in a given measurement.**

Ans:

- Zeros between significant figures are significant.
- Zeros to the left of significant figures are not significant.
- Zeros to the right of significant figures in a decimal fraction are significant.
- The significance of zeros to the right of significant figures in an integer depends on the precision of the measuring instrument.

- **Explain why the result of a multiplication or division should not have more significant figures than the least accurate factor.**

Ans: The result of a calculation cannot be more precise than the least precise measurement used in the

calculation. Retaining more significant figures would imply a higher degree of accuracy that is not justified by the data.

- **Describe the rules for rounding off numbers to a specific number of significant figures.**

Ans:

- If the first digit dropped is less than 5, the last retained digit remains unchanged.
- If the first digit dropped is more than 5, the last retained digit is increased by one.
- If the digit dropped is 5, the preceding retained digit is increased if odd, and remains the same if even.

- **What are significant figures, and why are they important in measurements?**

Ans: Significant figures are the digits in a measurement about which we are reasonably sure. They are important because they reflect the precision of the measuring instrument and indicate the uncertainty of the measurement.

- **Explain why it is necessary to round off calculator results when dealing with experimental data.**

Ans: Calculators often display many digits, but these can mislead someone into thinking the result is more precise than the original measurements. Rounding off to the correct number of significant figures ensures that the result accurately reflects the precision of the measurements used in the calculation.

- **How does the number of significant figures in a measurement reflect the precision of the measuring instrument?**

Ans: A measurement with more significant figures implies that it was made with a more precise instrument. For example, 3.145 g indicates a more precise measurement than 3.1 g.

SOLUTION TO QUICK QUIZ

1. Give the correct number of significant figures for 0.0054 m, 0.03030 m, 40.0 m, 0.5 m, 8.20×10^3 m.

- 0.0054 m: 2 significant figures (leading zeros don't count)
- 0.03030 m: 4 significant figures (leading zeros don't count, trailing zeros after the decimal count)
- 40.0 m: 3 significant figures (trailing zeros after the decimal count)
- 0.5 m: 1 significant figure
- 8.20×10^3 m : 3 significant figures

2. Give the answer to the appropriate number of significant figures: 2602 kg + 36.02 kg + 54.1 kg =

When adding, the result should have the same number of decimal places as the measurement with the fewest decimal places.

2602 kg + 36.02 kg + 54.1 kg = 2692.12 kg

- The measurement with the fewest decimal places is 54.1 kg (one decimal place). So, the answer should be rounded to one decimal place:

Answer: 2692.1 kg

Quick Quiz

1. Give the correct number of significant figures for 0.0054 m, 0.03030 m, 40.0 m, 0.5 m, 8.20×10^3 m.
2. Give the answer to the appropriate number of significant figures. 2602 kg + 36.02 kg + 54.1 kg = ?
3. Give the answer to the appropriate number of significant figures. 3.54 kg - 2.4 kg = ?
4. Give the answer to the appropriate number of significant figures. 2.45×10^3 m x 2.46 m / 3.6 m = ?

3. Give the answer to the appropriate number of significant figures: 3.54 kg - 2.4 kg = ?

Similar to addition, when subtracting, the result should have the same number of decimal places as the measurement with the fewest decimal places.

3.54 kg - 2.4 kg = 1.14 kg

The measurement with the fewest decimal places is 2.4 kg (one decimal place). So, the answer should be rounded to one decimal place:

Answer: 1.1 kg

4. Give the answer to the appropriate number of significant figures: 2.45×10^3 m x 2.46 m / 3.6 m = ?

When multiplying and dividing, the result should have the same number of significant figures as the measurement with the fewest significant figures.

2.45×10^3 m x 2.46 m / 3.6 m = 1674.16666667 m^2

- 2.45×10^3 m has 3 significant figures.
- 2.46 m has 3 significant figures.
- 3.6 m has 2 significant figures.

The measurement with the fewest significant figures is 3.6 m (2 significant figures). So, the answer should be rounded to two significant figures.

Answer: 1.7×10^3 m^2

MULTIPLE CHOICE QUESTIONS

- **In a digital instrument reading, a large fluctuation in the last digit suggests that:**
  (a) The reading is very precise (b) The reading has low uncertainty
  (c) The displayed digit may not be significant (d) The instrument is faulty

Answer: (c) The displayed digit may not be significant.
Explanation: Large fluctuations indicate that the reading might be affected by external factors, making the last digit unreliable.

- **Significant figures in a measurement:**
  (a) Are only the accurately known digits (b) Include all digits shown on a calculator
  (c) Are the digits about which we are reasonably sure
  (d) Are only relevant in theoretical calculations

Answer: (c) Are the digits about which we are reasonably sure.
Explanation: Significant figures include all accurately known digits plus the first estimated digit.

  (a) Calculators always show incorrect digits
  (b) Extra digits can mislead about the precision of the result
  (c) It simplifies calculations (d) It is a convention in mathematics

Answer: b) Extra digits can mislead about the precision of the result.
Explanation: Rounding ensures that the result reflects the precision of the original measurements.

- **A measurement of 4.567 g is more precise than a measurement of 4.6 g because it has:**
  (a) Fewer decimal places (b) More significant figures.
  (c) A smaller magnitude (d) A larger uncertainty

Answer: b) More significant figures.
Explanation: More significant figures indicate a more precise measurement.

- **How many significant figures are in the number 0.005020?**
  (a) 3 (b) 4 (c) 6 (d) 7

Answer: b) 4
Explanation: The zeros to the left of the 5 are not significant, but the zero between the 5 and 2, and the zero to the right of the 2 are significant.

- **How many significant figures are in 1200 kg if the least count of the scale is 10 kg?**
  (a) 2 (b) 3 (c) 4 d) 1

Answer: b) 3
Explanation: If the least count is 10 kg, then the number should be written as 1.20×10^3 kg, which has three significant figures.

- **When multiplying 2.5 cm and 3.25 cm, the answer should be rounded to:**
  (a) 8.125 cm^2 (b) 8.13 cm2 (c) 8.1 cm^2 (d) 8 cm^2

Answer: c) 8.1 cm^2
Explanation: 2.5 cm has the fewest significant figures (two). Therefore, the answer (8.125 cm^2) should be rounded to two significant figures, which is 8.1 cm^2

- **Round off 12.65 to three significant figures.**
  (a) 12.6 (b) 12.7 (c) 12.65 (d) 13.0

Answer: a) 12.6
Explanation: The digit to be dropped is 5, and the preceding digit (6) is even, so it remains unchanged.

1.5 PRECISION AND ACCURACY

Q. Differentiate between the terms precision and accuracy with reference to measurement of Physical Quantities.

Precision and Accuracy

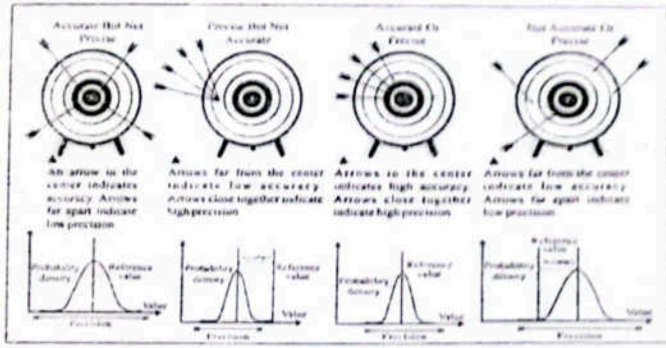
Precision and accuracy are two important concepts in measurement and data analysis. They describe how close measurements are to each other and to the true value.

- **Precision** of a measurement is determined by the instrument used. A smaller least count means more precise measurement. It refers to the reproducibility of a measurement.
- **Accuracy** is the closeness of a measurement to the exact or accepted value of a physical quantity. It is expressed by fractional or percentage uncertainty. A smaller fractional or percentage uncertainty means a more accurate measurement.

Examples

A common analogy to illustrate the difference between accuracy and precision is using a target.

- **High accuracy, low precision:** The darts are scattered around the center of the target.
- **Low accuracy, high precision:** The darts are clustered close together but are far from the center of the target.
- **High accuracy, high precision:** The darts are clustered close together and hit the center of the target.
- **Low accuracy, low precision:** The darts are scattered far from the center of the target and are not close together.



- **Relationship between Uncertainty and Accuracy:** The smaller the fractional or percentage uncertainty, the more accurate the measurement.

Example 1:

When the length of an object is recorded as 25.5cm by using a meter rod having smallest division in millimeter. Then it is the difference of initial and final positions. The uncertainty in the single reading is taken as $\pm$ 0.5mm = $\pm$0.05cm, which is now double (due to initial and final readings) and it is called absolute uncertainty equal to the least count of the measuring instrument. Thus,

- Metre rule measurement: 25.5 cm, Least count = 0.1 cm
- Fractional uncertainty = 0.1 / 25.5 = 0.004

Remember Thumb Rule
- Precision: Less absolute uncertainty
- Accuracy: Less % age uncertainty

- Percentage uncertainty = 0.004 x x100% = 0.4%

Example 2:

Now consider another length is recorded as 0.45cm by using Vernier Caliper having least count as 0.01 cm. Thus;

- Vernier Callipers measurement: 0.45 cm, Least count = 0.01 cm
- Fractional uncertainty = 0.01/0.45 = 0.02
- Percentage uncertainty = 0.02 x 100% = 2%

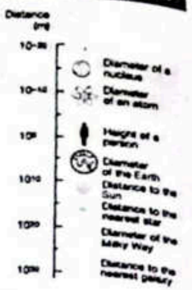
- **Comparison:** The 25.5 cm measurement (metre rule) is less precise but more accurate than the 0.45 cm measurement (Vernier Callipers).
- **Relative Measurement:** For smaller physical quantities, more precise instruments are needed.
- **Conclusions:**
  - Precise measurement: less absolute uncertainty.
  - Accurate measurement: less fractional or percentage uncertainty.
- **Note:** Smaller the physical quantity more precise instrument should be used.
- **Limitations:** Exact measurements are impossible; we aim to get as close as possible within instrument limitations.
- **Assessment of Total Uncertainty:** Knowing uncertainties in factors allows calculation of maximum possible error in the final result.
- **Relationship with Uncertainty:** Uncertainty is a quantification of the doubt associated with a measurement. Both precision and accuracy are related to uncertainty.
- **Precision and Uncertainty:** High precision implies low random uncertainty. Random uncertainty affects the spread of measurements and is reflected in the standard deviation.

For Your Information

Travel Time of light		
Moon to Earth	1min	80s
Sun to Earth	8 min	50s
Pluto to Earth	5 hrs	20s

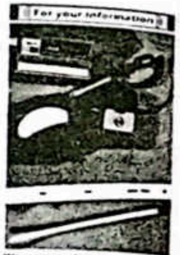
- **Accuracy and Uncertainty:** High accuracy implies low systematic uncertainty. Systematic uncertainty causes measurements to deviate consistently from the true value.

For Your Information



Order of magnitude of some distances

For your information



We use many devices to measure physical quantities, such as length, time and temperature. They all have some limit of precision.

MULTIPLE CHOICE QUESTIONS

- **Which statement correctly defines the precision of a measurement?**
  (a) How close the measurement is to the true value. (b) How reproducible the measurement is, determined by the instrument's least count. (c) The percentage error in the measurement. (d) The total number of significant figures.

Answer: (b) How reproducible the measurement is, determined by the instrument's least count.

Explanation: Precision refers to the consistency of repeated measurements and is directly linked to the smallest division an instrument can measure.

- **Accuracy in a measurement is best expressed by:**
  (a) The number of significant figures. (b) The absolute uncertainty.
  (c) The least count of the instrument. (d) The fractional or percentage uncertainty.

Answer: (d) The fractional or percentage uncertainty.

Explanation: Accuracy indicates closeness to the true value, and a smaller fractional or percentage uncertainty implies higher accuracy.

- **A measurement of 25.5 cm (least count 0.1 cm) has a percentage uncertainty of 0.4%. A measurement of 0.45 cm (least count 0.01 cm) has a percentage uncertainty of 2%. Which measurement is more accurate?**
  (a) 25.5 cm (b) 0.45 cm
  (c) Both are equally accurate

  (d) Cannot be determined from the given information

Answer: (a) 25.5 cm

Explanation: The measurement with the smaller percentage uncertainty (0.4%) is more accurate.

- **A highly precise measurement always implies:**
  (a) High accuracy.
  (b) A small least count of the measuring instrument.
  (c) The absence of all errors.
  (d) That the measurement is exactly the true value.

Answer: (b) A small least count of the measuring instrument.

Explanation: Precision is directly related to the instrument's least count; a smaller least count allows for more precise readings. High precision does not guarantee high accuracy (e.g., if there's a systematic error).

- **What is the "Thumb Rule" for accuracy in terms of uncertainty?**
  (a) Less absolute uncertainty. (b) Less fractional uncertainty.
  (c) More absolute uncertainty. (d) More fractional uncertainty.

Answer: (b) Less fractional uncertainty.

Explanation: The thumb rule states that accuracy is associated with less fractional or percentage uncertainty.

SLO BASED SHORT QUESTIONS & ANSWERS

- **How does the smallest measurement an instrument can resolve (e.g., 0.1 cm on a ruler) affect the precision of your measurements?**

Ans: An instrument's resolution (smallest measurable value) limits our precision. A ruler with 0.1 cm markings can't measure further than that.

- **How is the precision of a measurement primarily determined?**

Ans: The precision of a measurement is primarily determined by the instrument or device being used, specifically its least count (the smallest division it can measure).

- **What does a smaller fractional or percentage uncertainty imply about a measurement?**

Ans: A smaller fractional or percentage uncertainty implies that the measurement is more accurate, meaning it is closer to the true or accepted value of the physical quantity.

- **Can a measurement be precise but not accurate? Explain with an example.**

Ans: Yes, a measurement can be precise but not accurate. For example, if a faulty scale consistently gives readings that are 2 kg higher than the actual mass, the readings would be precise (reproducible and close to each other) but not accurate (not close to the true value).

- **What is the "Thumb Rule" for precision in terms of uncertainty?**

Ans: The "Thumb Rule" for precision is "Less absolute uncertainty." This means an instrument with a smaller least count will provide more precise measurements.

Q: **Why do smaller physical quantities often demand more precise instruments for accurate measurement?**

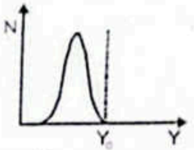
Ans: Smaller physical quantities demand more precise instruments because the absolute uncertainty (least count) remains constant, but for a smaller measured value, it results in a larger fractional or percentage uncertainty, thus reducing accuracy. A more precise instrument can minimize this relative error.

- **Difference between Accuracy and Precision**

A table summarizing the key differences is given below:

Feature	Accuracy	Precision
Meaning	Closeness to the true value	Closeness of repeated measurements with each other
Analogy	Hitting the bullseye	Tightly clustered throws (even if not on bullseye)
Requires	Single measurement compared to true value	Multiple measurements of the same thing
Independence	Can be accurate even if not precise (lucky guess)	Can be precise but not accurate (consistently wrong)

- What we conclude about the precision and accuracy if a quantity "y" is measured many times during an experiment say "N" times and then each value is plotted against "N" but true value is y. The plotted graph is as shown below



- What is the best analysis about this graph?

Ans: Precision means closeness of data with each other whereas accuracy means closeness of data with true value. In the above figure since the plotted graph is away from true value so data is not accurate but it may be precise because spreading of data is not too much as shown by width of graph on horizontal-axis. All values are away from their mean value so being closes to each other they are precise but not accurate.

1.6 ASSESSMENT OF TOTAL UNCERTAINTY IN THE FINAL RESULT

Q. Describe Assessment of Total Uncertainty in the Final Result.

Ans

ASSESSMENT OF TOTAL UNCERTAINTY IN THE FINAL RESULT:

To assess the total uncertainty or error, it is necessary to evaluate the likely uncertainties in all the factors involved in that calculation. The maximum possible uncertainty or error in the final result can be found as follows:

i. **For Addition and Subtraction:**

Absolute uncertainties are **added**. For example, the distance 'x' is found by difference between two separate position measurements

$x_1 = 10.5 \pm 0.1cm$

And $x_2 = 26.8 \pm 0.1cm$

Then $x = x_2 - x_1$

Or $x = (26.8 \pm 0.1) - (10.5 \pm 0.1) = 16.3 \pm 0.2cm$

ii. **For Multiplication and Division:**

Percentage uncertainties are **added.**

The maximum uncertainty in the value of resistance R of a conductor is determined by using $R = V/I$ as follows:

% age of uncertainty in V = 2%

% age uncertainty in I = 6%

% age uncertainty in R = % age uncertainty in V + % age uncertainty in I.

= 2% + 6% = 8%

Explanation: The maximum possible uncertainty in the value of resistance R of a conductor determined from the measurement of potential difference V and resulting current flow I by using $R = \frac{V}{I}$ is found as follows:

$V = 5.2 \pm 0.1V$

$I = 0.84 \pm 0.05A$

The percentage uncertainty for $V = \frac{0.1}{5.2} \times 100\% = 2\%$

The percentage uncertainty for $I = \frac{0.05}{0.84} \times 100\% = 6\%$

Hence total uncertainty in the value of $R(= \frac{V}{I}) = 2\% + 6\% = 8\%$ Thus

result is given as; $R = \frac{5.2}{0.84} = 6.19\ VA^{-1} = 6.2$ ohms with a percentage uncertainty

of 8% (6.2 $\pm$ 8% of 6.2) $= 6.2 \pm \frac{8}{100} \times 6.2$

$R = 6.2 \pm 0.5$ohms

The result is rounded off to two digits because both V and R have two significant figures.

iii. **For Power Factor :**

Multiply** the **percentage** uncertainty by the **power

For Example:

In the calculation of the volume of sphere using formula

$V = \frac{4}{3}\pi r^3$

% age uncertainty in V = power factor × (% age uncertainty in r)

Let % age uncertainty in r = 0.4 %

Total % age uncertainty in V = 3 × 0.4 %

= 1.2 %

Explanation, *volume of the sphere is calculated by using the formula,*

$$V = \frac{4\pi}{3} r^3$$

Where r is radius of the sphere. If radius of a small sphere is measured by Vernier Caliper with least count 0.01 cm, then,

$r = 2.25 \pm 0.01cm$

Absolute uncertainty = least count = ± 0.01cm

Percentage uncertainty is

$r = \frac{0.01}{2.25} \times 100\% = 0.4\%$

Total percentage uncertainty in volume is

$V = 0.4\% \times 3 = 1.2\%$

Thus volume, $V = \frac{4\pi}{3} r^3 \Rightarrow V = \frac{4 \times 3.14}{3} \times (2.25\ cm)^3$

$V = 47.689\ cm^3$ with 1.2% uncertainty

Thus result should be recorded as;

$V = 47.689 \pm (\frac{1.2}{100} \times 47.689) \Rightarrow V = 47.689 \pm 0.6\ (cm)^3$

iv. **For uncertainty in the Average Value of Many Measurements:**

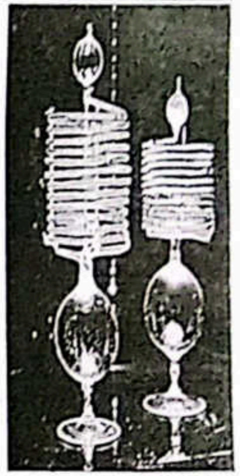
a) Find the average value of measured values.

b) Find deviation of each measured value from the average value.

c) The **mean deviation** is the absolute uncertainty in the **average value**.

d) For example, six readings of measured diameter of a wire, as measured by micrometer screw gauge in mm are

For Your Information



These are not decoration pieces of glass but are the earliest known exquisite and sensitive thermometers, built by the Accademia del Cimento (1657-1667), in Florence. They contained alcohol, sometimes coloured red for easier reading.

For Your Information

Colour printing uses just four colours cyan, magenta, yellow and black to produce the entire range of colours. All the colours in this book have been made from just these four colours.

Remember Thumb Rule

For calculation of end result:

- Addition / Subtraction: same precision
- Multiplication / Division: same accuracy (Same number of significant figures).

1.20, 1.22, 1.23, 1.19, 1.22, 1.21

Then, Average value

$$= \frac{1.20 + 1.22 + 1.23 + 1.19 + 1.22 + 1.21}{6} = 1.21\ mm$$

The deviations of the readings, which are the difference between reading and average value are 0.01, 0.01, 0.02, 0.02, 0.01 and 0

$$\text{Mean of deviation} = \frac{0.01 + 0.01 + 0.02 + 0.02 + 0.01 + 0}{6} = 0.01mm$$

Thus uncertainty in the mean diameter (1.21mm) is 0.01 mm recorded as, **Average=1.21 ± 0.01mm**

v. **For the Uncertainty in a Timing Experiment:**

The uncertainty in the **time period** of a vibrating body is found by **dividing** the **least count** of timing device with the **number of vibrations** i.e.

$$\text{Uncertainty in time period} = \frac{\text{least count}}{\text{No. of vibration}}$$

For example:

The time of 30 vibrations of a simple pendulum recorded by stopwatch accurate up to one tenth of a second is 54.6s. Thus the time period is,

$$T = \frac{54.6S}{30} = 1.82\ s$$

$$\text{Uncertainty in time period} = \frac{0.1s}{30} = 0.003s$$

Thus the time period is written as,

$$T = 1.82 \pm 0.003\ s$$

Hence, it is advisable to count large number of swings to reduce uncertainty

For Your Information

Atomic Clock

ATOMIC CLOCK

The cesium atomic frequency standard at the nations' Institute of Standard and Technology in Colorado (U.S.A), it is the primary standard for the unit of time.

EXPLANATION

To meet the need for a better standard of time, atomic clock has been developed. In this device the frequencies associated with certain atomic transactions can be measured precisely. In 1967, the SI unit of time, the second, was redefined by 13th General Conference on Weights and Measures. Using characteristic frequency of cesium-133 atom According to this standard

TALENT INFORMATION FOR YOU

Summary of Rules for Combining Uncertainties

- **Addition and Subtraction Rule:**
  - Add absolute uncertainties
  - If Q = x + y or Q = x - y, then ΔQ = Δx + Δy
- **Multiplication and Division (Product and quotient rule):**
  - Add relative or percentage uncertainties.
  - If Q = x × y or Q = x / y, then (ΔQ / Q) = (Δx / x) + (Δy / y)
- **Powers of a quantity:**
  - Multiply the relative uncertainty by the power.
  - If $Q = x^n$, then (ΔQ / Q) = n × (Δx / x)
- **Uncertainty in Average Value:**
  - Calculate the average value: Sum all the measured values and divide by the number of measurements.
  - Calculate the deviation for each measurement: Subtract the average from each measured value.
  - The deviation can be taken as the absolute value to ignore the sign.
  - Determine the mean deviation: This is the average of all the absolute deviations and represents the uncertainty in the average measurement.
- **Uncertainty in Timing Experiment**
  - In determining the uncertainty in a timing experiment for the period of a vibrating body, the least count of the timing device is divided by the number of vibrations
  - Uncertainty in time period = L.C of stopwatch/no. of vibrations

Thumb Rule for Total Uncertainty

- **For addition and subtraction:** Absolute uncertainties are added.
- **For multiplication and division:** Percentage uncertainties are added.
- **For power factor:** Power factor x Percentage uncertainty

MULTIPLE CHOICE QUESTIONS

- **In an experiment, we measure quantities a, b and c then x is calculated from the formula $x = \frac{ab^2}{c^3}$ the percentage errors in a, b and c are ± 1%, ± 3% and ± 2% respectively. The percentage error in x can be:**

  (a) ± 1% (b) ± 4% (c) ± 7% (d) ± 13%

Answer: d

Explanation: We know that in case of multiplication and division percentage uncertainties are added to find percentage error in the final result. So percentage error in $x = \frac{ab^2}{c^3}$ is calculated as

Percentage error in x = (% uncertainty in a) + 2(% uncertainty in b) + (% uncertainty in c) = ± 1% + 2(± 3%) + 3(± 2%) = ± 13%

- **If the percentage error of A, B and C as *l*, m and n respectively, then the total percentage error in the product of ABC is:**

  (a) *lmn* (b) *l* + m + n (c) $\frac{1}{l} + \frac{1}{m} + \frac{1}{n}$ (d) *lm* + mn + n*l*

Solution: (Answer: b) Since in case of Multiplication and Division Percentage uncertainties are added. So l,m,n will be added as

Percentage error in ABC = (% uncertainty in A) + (% uncertainty in B) + (% uncertainty in C) = l + m + n

- **The percentage errors in the measurement of mass and speed are 2% and 3% respectively. How much will be maximum error in the estimate of kinetic energy obtained by measuring mass and speed?**

  (a) 11% (b) 8% (c) 5% (d) 1%

Solution: (Answer: b) Since For Multiplication and Division Percentage uncertainties are added and for Power Factor ***Multiply** the **percentage** uncertainty by the **power**. So percentage uncertainty(maximum error) in K.E (K.E= $\frac{1}{2}mv^2$) will be calculated as*

Percentage error in K.E = (% uncertainty in m) + 2(% uncertainty in v) = 2% + 2(3%) = 8%

- **A cyclist moving with initial velocity having a percentage error of 2 % moves with an acceleration of error -3% for a time "t" which has an error of 2%. What must be the error in distance "s" covered by it?**

  (a) 14.5% (b) 8.5% (c) 11% (d) 10.5%

Solution:

Since percentage errors in velocity, time and acceleration are Δv_i = 2 %, Δa = -3%, Δt = 2%. Now the relation for the measurement of distance by 2nd equation of motion is : $s = v_it + \frac{1}{2}at^2$

Now for Addition and Subtraction Absolute uncertainties are added. **For Multiplication and Division: Percentage uncertainties are added. For Power Factor:** ***Multiply** the **percentage** uncertainty by the **power***. so

Δs = 2% + 2% + 3% + 2 × 2%=11% is the maximum error in the measurement of distance

SLO BASED SHORT QUESTIONS & ANSWERS

Q: The time of 30 vibrations of simple pendulum recorded by to watch accurate upto one tenth of a second is 54.6 seconds. Find its uncertainty. (LHR 2021) (BWP 2021 GI) (GRW 2021 GII) (LHR 2022 GI) (SWL 2023 GII)

Ans: The uncertainty in the time period of a vibrating body is found by dividing the least count of timing device with the number of vibrations i.e.

$$\text{Uncertainty in time period} = \frac{\text{least count}}{\text{No. of vibration}} = \frac{0.1}{30} = 0.003$$

Q: Find the percentage uncertainty in the volume of a cylinder, if the percentage uncertainties in length and diameter of cylinder are 0.3% and 0.6% respectively. (GRW 2021 GII) (FSD 2023 GII)

Ans: The volume (V) of a cylinder is defined as $V = \pi r^2 l$, where r is the radius (diameter/2) and l is the length of cylinder. So uncertainty in the measurement of volume of cylinder is

= 2(% uncertainty in d) + (% uncertainty in l)

= 2(0.6)% + (0.3)%= (1.2 + 0.3)% = 1.5%

Q: The volume of sphere $V = 47.689\ cm^3$ with 1.2% uncertainty. What is the correct range of volume measurement? (SWL 2018) (DGK 2021) (SWL 2021 G1)

Ans: Volume of sphere is $= \frac{4}{3}\pi r^3$ So correct range of volume measurement is

Volume = 47.689 ± 1.2% of 47.689 = 47.689 ± 0.572 = 48.261 to 47.117

1.7 DIMENSION OF PHYSICAL QUANTITIES

Q. What is meant by Dimension of Physical Quantities? Explain with examples. Also write its uses and limitations.

DIMENSIONS OF PHYSICAL QUANTITIES:

How many times a physical quantity occurs in a given formula is called its dimension. Each basic measurable physical property represented by a specific symbol written within square brackets is called a dimension.

All other physical quantities can be derived as combinations of the basic dimensions. In physics, dimension describes the physical nature of a quantity.

If a physical quantity is expressed in terms of symbols of base units, then dimension for that physical quantity is obtained. The base units of length, mass, and time, denoted by [L], [M] and [T] respectively, are used to indicate the dimensions of a physical quantity. They only indicate their nature and not their magnitudes.

Dimensions of base quantities		
1	Mass	[M]
2	Length	[L]
3	Time	[T]
4	Current	[I]
5	Temp	[θ] or [K]
6	Amount of substance	[N]
7	Luminous intensity	[J]

For example

i. **Dimension of Speed:**

Speed is measured in $m\ s^{-1}$

$$\text{Dimension of speed} = \frac{\text{Dimension of length}}{\text{Dimension of time}}$$

$$[v] = \frac{[L]}{[T]} = [L][T^{-1}] = [LT^{-1}]$$

ii. **Dimension of Acceleration:**

Acceleration is expressed in $m\ s^{-2}$. Thus it has dimensions of length divided by time square i.e.

$$\text{Dimension of acceleration} = \frac{\text{Dimension of length}}{(\text{Dimension of time})^2}$$

$$[a] = \frac{[L]}{[T^2]} = [L][T^{-2}] = [LT^{-2}]$$

iii **Dimension of Force:**

The dimensions of force are:

$$[F] = [m][a] = [M][LT^{-2}] = [MLT^{-2}]$$

iv. **Dimension of Momentum and impulse:**

The dimensions of momentum are

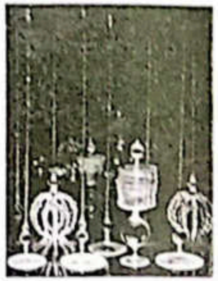
$$[P] = [m][v] = [M][LT^{-1}] = [MLT^{-1}]$$

v. **Dimension of Work and Energy:**

The dimensions of work are:

Work = Force × distance

$$[W] = [ma][d] = [MLT^{-2}][L] = [ML^2T^{-2}]$$



Early thermometers built by Accademia del Cimento (1657-1667) in France, Italy

vi. **Dimension of Power:**

The dimensions of power are:

$$\text{Power} = \frac{\text{work}}{\text{time}}$$

$$\text{Power} = \frac{[ML^2T^{-2}]}{[T]}$$

$$\text{Power} = [ML^2T^{-2}][T^{-1}]$$

$$\text{Power} = [ML^2T^{-3}]$$

For Your Information

The pair of quantities which have same dimensions.

- work, torque, energy
- impulse, momentum
- angular momentum, Planck's constant
- Pressure, stress, elastic modulus
- Decay constant λ, frequency f

USES OF DIMENSIONS:

i. **Checking the Homogeneity of Physical Equation:**

To check the correctness of an equation we show that the dimensions of the quantities on both sides of the equation are the same, regardless of the formula. This is called the principle of homogeneity of dimensions.

ii. **Deriving a Possible Formula:**

The success of this method for deriving a relation for a physical quantity depends on the correct guessing of various factors on which the physical quantity depends.

Note: It does not give any information about constant of proportionality.

Limitation of Dimensional Analysis

- Doesn't give dimensionless constants.
- Limited to power relationships.
- Can't distinguish between scalars and vectors.
- Difficult with complex relationships.
- Doesn't guarantee correctness.

TABLE CONTAINING THE DIMENSIONAL FORMULAS FOR SOME DERIVED QUANTITIES:		
Quantity	**Formula**	**Dimensional Formula**
Area	Length x Width	$[L^2]$
Volume	Length x Width x Height	$[L^3]$
Velocity	Distance / Time	$[LT^{-1}]$
Acceleration	Change in Velocity / Time	$[LT^{-2}]$
Force	Mass x Acceleration	$[MLT^{-2}]$
Momentum	Mass x Velocity	$[MLT^{-1}]$
Torque	Force x Distance	$[ML^2T^{-2}]$
Work	Force x Distance	$[ML^2T^{-2}]$
Energy	Force x Distance	$[ML^2T^{-2}]$
Angular Momentum	Mass x Velocity x Radius	$[ML^2T^{-1}]$
Volt	Work / Charge	$[ML^2T^{-3}A^{-1}]$

Electric Intensity	Force / Charge	$[MLT^{-3}A^{-1}]$
Magnetic Induction	Force / (Current x Length)	$[MT^{-2}A^{-1}]$
Magnetic Permeability	Magnetic Induction x Length / Current	$[MLT^{-2}A^{-2}]$
Charge	Current x Time	[AT]
Permittivity of Free Space	Charge / (Electric Intensity x Area)	$[A^2T^4M^{-1}L^{-3}]$

MULTIPLE CHOICE QUESTIONS

- **Dimensional analysis can be used to:**
  (a) Find the numerical value of constants in an equation.
  (b) Determine the accuracy of measuring instruments.
  (c) Check the correctness (homogeneity) of a physical equation.
  (d) Calculate the percentage error in a measurement.

Answer: (c) Check the correctness (homogeneity) of a physical equation.

Explanation: Dimensional analysis is primarily used to verify if the dimensions on both sides of a physical equation are consistent.

The relation for the measurement of change in speed of sound when temperature increases by $t^{\circ}C$ is written as:

$v_t = v_o + 0.61 \times t$

- **The dimensions of "0.61" in above relation must be:**
  (a) $[M^{1}LT^{-1}K^{-1}]$ (b) $[MLT^{-1}K^{-1}]$ (c) $[M^{0}LT^{-1}K]$ (d) $[MLT^{-1}K]$

Solution:

$V_t = V_o + 0.61 \times t$

↓↓↓

$ms^{-1}\ ms^{-1}\ ms^{-1}$ must have units of ms^{-1}

So

$0.61 \times t = ms^{-1}$

↓

K (Kelvin)

$0.61 = \frac{ms^{-1}}{K} = [M^{0}LT^{-1}K^{-1}]$

- **For a diffraction grating the relation for diffraction element "d" is $\frac{L}{N}$, what must be the dimensions of "N".**
  (a) $[M^{0}L^{-1}T^{0}]$ (b) $[M^{0}LT^{0}]$ (c) $[M^{0}L^{-1}T^{0}]$ (d) $[M^{0}L^{0}T^{0}]$

Solution:

Diffraction element is a distance so "N" must be unit less.

- **The dimensions of "$\frac{gT^2}{4\pi^2 r}$" are same as that of:**
  (a) distance (b) frequency **(c) Angular displacement** (d) Time period

Solution: Let $x = \frac{gT^2}{4\pi^2 r}$ Now putting units in above equation: $= \frac{ms^{-2} \times s^2}{m}$ = No units mean $[M^{0}L^{0}T^{0}]$

Which may be considered as dimensional formula for either plane or solid angle which makes angular displacement as best option?

SLO BASED SHORT QUESTIONS & ANSWERS

Q: Find the dimensions and S.I. units of coefficient of viscosity in $F = 6\pi\eta rv$. (MTN 2018 GII) (AJK, FSD 2021) (MTN, RWP 2021 GI) (DGK 2021 GII) (FSD, SWL, LHR 2023 GI) (DGK 2023 GII)

$F = 6\pi\eta rv \Rightarrow \eta = \frac{F}{6\pi rv}$

since 6π is a constant so it had no dimension, hence

$[\eta] = \frac{[F]}{[rv]} = \frac{[MLT^{-2}]}{[LLT^{-1}]} = [ML^{-1}T^{-1}]$

Calculate the dimension of physical quantities, if possible, 2π and rupees hundred. (GRW 2021 GI)

Ans: 2π is dimensionless. It is a mathematical constant that represents the ratio of a circle's circumference to its diameter. So is has no dimension. -

The dimension of "rupees hundred" is M (money). It represents an amount of money and doesn't have a physical dimension.

Show that formula $T = 2\pi\sqrt{\frac{l}{g}}$ is dimensionally correct. (FSD, MTN 2021 GII)

L.H.S Dimension of $T = [T]$ and R.H.S Dimension of $\sqrt{\frac{\ell}{g}} = \left[\frac{\ell}{g}\right]^{\frac{1}{2}} = \left[\frac{L}{LT^{-2}}\right]^{\frac{1}{2}} = [T^2]^{\frac{1}{2}} = [T]$ it shows that above formula is dimensionally correct.

Q: Show that $S = v_i t + \frac{1}{2} at^2$ is dimensionally correct. ((Lhr 2016 Group I, Lhr 2013 Group II)RWP, LHR 2023 GII)

Ans: L.H.S. = [S] = [L]

R.H.S = $[v_i t] + [\frac{1}{2}at^2] = [LT^{-1}][T] + [LT^{-2}][T^2]$

$= [L] + [L] = [L]$

So, L.H.S. = R.H.S.

Q: How does the principle of homogeneity help in checking a physical equation?

A: The principle of homogeneity helps by stating that for an equation to be correct, the dimensions of all terms on both sides of the equation must be identical. If they are not, the equation is dimensionally incorrect.

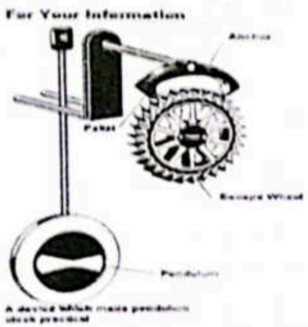
Q: Why cannot dimensional analysis determine numerical factors or constants in a derived formula?

A: Dimensional analysis cannot determine numerical factors or constants because these factors are dimensionless and do not contribute to the overall dimensions of the physical quantity. Their values can only be found through experiments or by plotting graphs.

Q: Can dimensional analysis prove that an equation is fundamentally correct? Explain.

A: No, dimensional analysis cannot prove that an equation is fundamentally correct. It can only confirm dimensional consistency. Even if an equation is dimensionally correct, it might still be incorrect if it contains wrong numerical factors or other physical inaccuracies that dimensional analysis cannot detect.

For Your Information



A device which made pendulum clock practical

For Your Information

Colour printing uses just four colours cyan, magenta, yellow and black to produce the entire range of colours. All the colours in this book have been made from just these four colours.

Explanation:

Any colour can be produced by a suitable combination of red, green, and blur colours. Two colours which produce white light, when mixed are termed as complementary colours. The appearance of colours is a process of subtractive nature. Thus colours obtained with paints and inks result from subtractive process.

DO YOU KNOW? FOR YOUR INFORMATION

Student Learning Outcome

- Make reasonable estimates of physical quantities [Of those quantities that are discussed in the topics of this grade] *The SLO is included in curriculum but detail is missing in text book so given here for your information*

Estimation in Physics:

1. **What is Estimation?**

   Estimation is the process of finding an approximate value for a quantity. It involves making reasonable assumptions and using available information to arrive at a result that is "close enough" to the actual value, without needing precise measurements or complex calculations.

- Estimation does not mean guessing the value of a quantity but it involves determining a rough estimate of the quantity through reasoning and scientific understanding.
- It is not just guessing. Rather applying scientific understanding and reasoning and predicting approximate values.

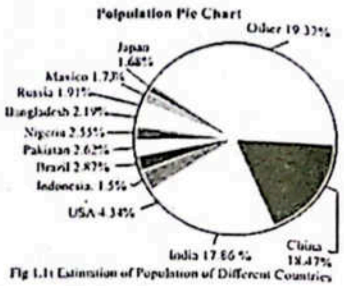


Fig 1.1: Estimation of Population of Different Countries

2. **Why is Estimation Important?**

- It is important in real-life applications (e.g., buying curtains, gauging distances).
- Quick, smart decisions when exact numbers are unavailable.
- Develops a sense of scale (big vs. small).
- Checks if physics problem answers are reasonable.

3. **How to Make Good Estimates:** Following steps are taken into account

- **Define the Measurement:**
  - Clearly identify what needs to be measured (length, volume, time, etc.).
- **Use Reference Points:**
  - Relate estimates to familiar objects (e.g., doorway height).
- **Break Down Complex Problems:**
  - Divide into smaller, manageable parts.
- **Apply Physics Principles:**
  - Incorporate relevant physics concepts (e.g., gravity).
- **Provide a Range:**
  - Give a range of values to account for uncertainty.

- **Cross-Validate:**
  - Use multiple methods to verify estimates (e.g., measuring dimensions and water capacity of a pool).

4. **Example: Filling a Pool**

- **Problem: Estimate time to fill a pool with a hose.**
- **Steps:**
  - Estimate pool volume (length x width x depth).
  - Estimate hose flow rate (e.g., time to fill a bucket).
  - Calculate filling time (total volume / flow rate).
- (Let pool is 10 meters long, 5 meters wide, and 2 meters deep, giving 100 cubic meters) and the flow rate of the hose (for example, 10 liters per minute, which you can gauge by timing how long it takes to fill a 10-liter bucket). Then, use these estimates to calculate the filling time: 100,000 liters divided by 10 liters/minute equals 10,000 minutes, or about 6-9 days.

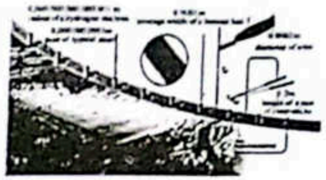


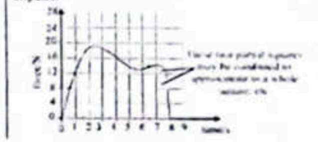
Fig 1.2: It's necessary to have methods for measuring a vast spectrum of sizes since the objects in our surroundings vary from extremely large to incredibly tiny.

Note: Measurement Scales:

- Physics deals with a wide range of sizes (very large to very small).
- It requires diverse measurement methods.

Example 1.1

The figure illustrates the method of estimating the area under a non-uniform force-time curve to determine impulse.



Example-1.1: Area under a Curve

- Method: Divide the area into squares.
- Technique: Combine partial squares for approximation.
- Purpose: To determine impulse.
- Highlighted are approximately 26 full yellow squares and additional partial squares under the curve, which collectively approximate 4 full squares. With each square representing an impulse of 4 Ns, the estimated total impulse is about 120 Ns, with an expected examination tolerance, for instance, of ±4 Ns.

CHALLENGE TASK

How we can Estimate the Height of a Building without Direct Measurement?

Answer: Building Height Estimation via Human Comparison

To roughly estimate height of a building, compare it to a person standing nearby. Visually stack the person's height against the building, counting how many "people heights" it appears to be. Multiply this number by an assumed average human height (1.7-1.8 meters) to get an approximation. This method is simple but provides only a rough estimate.

TEST YOURSELF

1. **Estimate the amount of water in liters that would fill a standard bathtub. Explain your reasoning.**

   We can estimate the height of a building using a man's height as:

- **Assume you know the average height of a man.** Let's say the average height of a man is 1.8 meters.
- **Count how many "man-heights" tall the building is.** You might visually estimate that the building is about 10 times the height of a man.
- **Multiply the man's height by the number of "man-heights."**
  - Estimated building height = 1.8 meters/man-height * 10 man-heights = 18 meters.

  Therefore, we would estimate the building to be approximately 18 meters tall.

2. **Express the heaviest and lightest of an object, in terms of the SI base units.**

   We can express "heaviest" and "lightest" in terms of SI base units as:

   The terms "heaviest" and "lightest" refer to the weight of an object, which is the force exerted on the object due to gravity. Therefore, we need to express the unit of force in SI base units.

- **Weight:**
  - Weight is a force, and the SI unit of force is the newton (N).
  - Newton is derived from the base units of kilogram (kg), meter (m), and second (s).
  - $1\ N = 1\ kg\ m\ s^{-2}$

  So, both the "heaviest" and "lightest" objects are measured in the same SI base units: **$kg\ m\ s^{-2}$**