PHYSICS XI

UNIT 1

PHYSICS AND MEASURMENTS

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PHYSICS

Physics is the branch of science that studies the nature and behavior of matter, energy, and the interaction between them

BRANCHES OF PHYSICS

MECHANICS: Mechanics is the branch of physics that deals with the studies of motion and its causes. It is considered to be the relationship between force and the object's motion and the relationship between energy and motion. Mechanics is divided into main branches: classical mechanics and quantum mechanics

CLASSICAL MECHANICS

Classical mechanics is concerned with the studies of microscopic objects and their motion under the influence of forces, such as the motion of the planet and stars, the motion of the object on Earth, and the motion of the fluids. It includes the studies of mechanics concepts such as Newton's laws of motion, conservation of energy, Momentum, and the law of thermodynamics

QUANTUM MECHANICS

A branch of physics that deals with the behavior of matter such as atomic particles and energy at the microscopic scale.

It has a wide range of applications, including the development of quantum computers, quantum communication, and quantum cryptography

One of the key concepts in quantum physics is the idea that particles can exist in multiple states at the same time, known as superposition. It is also introducing the concept of entanglement, which describes the behavior of the particles that are connected in such a way that the state of one particle is dependent on the state of the Other particle regardless of the distance between them.

OPTICS

Optics is the branch of physics which is concerned with light and its behavioral patterns and properties. Optics is a branch of physics that deals with the determination of behavior and the properties of light, along with its interactions with matter and also with the instruments which are used to detect it.

THERMODYNAMICS

Thermodynamics deals with the study of heat, energy, and their transformations. It explores concepts like temperature, entropy, energy conservation, and the behavior of gases and fluids.

ELECTROMAGNETISM

The electromagnetic theory explains the behavior of electric and magnetic fields. as well as their interaction with charged particles and currents. It encompasses topics like electric and magnetic forces. Electromagnetic waves, and the principles underlying electricity and magnetism.

HIGH ENERGY PHYSICS

It is the branch of physics that deals with the studies of subatomic particles and their interaction at very high energies. It is concerned with understanding the behavior of matter and energy at the smallest scale. Including the structure and interaction of the particles.

High-energy physics and detectors to study the interaction of electrons, quarks, and neutrinos.

RELATIVITY

Relativity theory, including both special relativity and general relativity, deals with the behavior of objects in extreme conditions, such as those involving high speeds or strong gravitational fields. It explores concepts & like time dilation, length contraction, and the curvature of space-time

Physics: Scope in Science., Technology and Society

Physics plays a significant role in science, technology, and society across various domains. Here are some key aspects highlighting the scope of physics in these areas

SCIENCE

FUNDAMENTAL LAWS

physics provides fundamental laws and principles that form the basis of understanding the natural world. It explores the behavior of matter, energy, forces, and their interactions, enabling scientists to develop theories and models to explain phenomena.

Advancing Knowledge: Physics drives scientific progress by pushing the boundaries of our understanding. It seeks to uncover new insights into the nature of the universe, from the microscopic realm of particles to the vast expanse of the cosmos.

Interdisciplinary Connection: Physics often intersects with other scientific disciplines, such as chemistry, biology, astronomy, and geology. It provides a framework for understanding complex systems and phenomena, facilitating interdisciplinary research and collaboration.

TECHNOLOGY

ENGINEERING APPLICATIONS: Physics principles are employed in various engineering fields. For example, electrical engineers rely on electromagnetism, materials engineers utilize quantum mechanics, and mechanical engineers apply laws of motion to design and optimize technologies.

ENERGY AND POWER: Physics plays a crucial role in the generation, transmission, and utilization of energy. It underpins technologies such as renewable energy systems, nuclear power, electrical grids, and energy storage.

ELECTRONICS AND COMMUNICATIONS: Physics principles are fundamental to the development of electronic devices, telecommunications, and information technology. The study of semiconductor physics, quantum mechanics, and electromagnetism is essential for advancement in these fields

SOCIETY

MEDICAL APPLICATIONS: Physics contributes to medical imaging technologies like X-rays, CT scans, MRI, and ultrasound. It also facilitates advancements in radiation therapy, laser surgery, and medical diagnostics.

MATERIALS SCIENCE: physics research aids in understanding the properties of materials and developing new materials for various applications, including electronics, transportation, construction, and energy technologies.

ENVIRONMENTAL STUDIES: Physics plays a role in studying climate change, atmospheric physics, and environmental monitoring. It helps in developing sustainable technologies and understanding the impact of human activities on the planet.

EDUCATION OD SCIENTIFIC LITERACY: Physics education fosters critical thinking. problem- solving skills, and a scientific mindset. It promotes scientific literacy, enabling individuals to make informed decisions and engage with science-related topics and issues.

PHYSICAL QUANTITIES

A physical quantity is one that can be measured and that consist of a numerical magnitude and a unit. A measurement without a unit is meaningless.

The many physical quantities can be classified into two types; base quantities and derived quantities.

INTERNATIONAL SYSTEM OF UNITS (SI)

The international system of units is called SI units in short, SI units is the short form of the French name "system international d' unites" which means "*international system of units*;. The international system of units is based on seven basic units from which all other units are derived. The seven basic physical quantities, their SI units, and the symbols are given in the following table.

Basic quantity	Symbol of Basic Quantity	Name of the Base SI units	Symbol of SI units
Time	T	Second	s
Length	L	Metre	m
Mass	M	Kilogram	kg
Temperature	T, θ	Kelvin	K
Electric current	I	Ampere	A
Amount of substance	n	Mole	mol
Luminous intensity	l_v	Candela	cd

METER

A meter is defined as the distance between two marks on a platinum–iridium bar kept at 0^oC in the International Bureau of Weights and Measures near Paris.

OR

The meter is the length of the path travelled by light in a vacuum during a time interval of $\frac{1}{299,792,458}$ of a second.

A few of its submultiples are given as below:

1 km = 1000 m = 10^3 m 1 centimeter = 1/100 meter = 10^{-2} m

1m = 100 cm = 10^2 cm 1 millimeter = 1/1000 meter = 10^{-2} m

1m = 1000 mm = 10^3 mm

KILOGRAM

The mass of a cylinder of specific dimensions of platinum – iridium alloy is kept in the International Bureau of Weight and Measures near Paris, France, whose mass is defined as exactly one kilogram. A few of its submultiples are given as below:

1kg = 1000 g = 10^3g

1g = 1000 mg = 10^3 mg

SECOND

For scientific work earlier second was defined as $\frac{1}{86,400}$ of a mean solar day. In october1967 the time standard again redefined in terms of an atomic clock. The atomic clock uses cesium of mass number 133. According to this clock, " a second is defined to be exactly equal to the time interval of 9, 192, 631, 770 vibration of cesium-133 atom.

Some other units of time are commonly used are minute, hour and day

	60 seconds	=	1 minute
	60 minutes	=	1 hour
and	24 hours	=	1 day

the symbol of a second is '**s**', for the minute is '**min**' and for an hour is '**h**'.

AMPERE (A)

The base unit of electrical current; is constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circuit cross-section, and placed 1 meter apart in vacuum, would produce between those conductors a force equal to 2 x 10^{-7} newtons per meter of length.

KELVIN(degrees K)

The base unit of thermodynamic temperature; is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water (the triple point is the point in a phase diagram where three phases coexist in equilibrium).

MOLE (mol)

The base unit of substance; is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilograms of carbon 12. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

CANDELA (Cd)

The base unit of luminous intensity; The luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.

DERIVED UNIT

The units of other physical quantities derived from the fundamental units are known as derived units. These units are obtained by multiplication and division or both of fundamental units.

Quantity	Symbol of Quantity	Units	Symbol and its Equivalent
Speed	**V**	**Meter/second**	**m/s**
Acceleration	**A**	**Meter/second^2**	**m/s^2**
Volume	**V**	**Cubic metre**	**m^3**
Force	**F**	**Newton**	**N or (Kg. m/s^2)**
Pressure	**P**	**Pascal**	**N/m^2**

Work	**W**	**Joules**	**J**
Momentum	**P**	**Newton-second**	**NS (kg.m/s)**
Density	**ρ**	**kilogram/metre^3**	**kg/m^3**
Torque	**τ**	**Newton-metre**	**Nm**
Area	**A**	**Square meter**	**m^2**
frequency	**f**	**hertz**	**Hz**

PREFIXES FOR SI UNITS

The base SI units are sometimes too big or too small for use in measurement, prefixes are used with them to produce smaller or bigger units which are convenient to work with (prefix is a word used before a unit name). some of the prefixes used with SI units are given below.

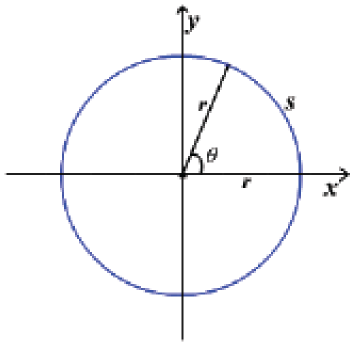
Prefixes for use with SI units

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

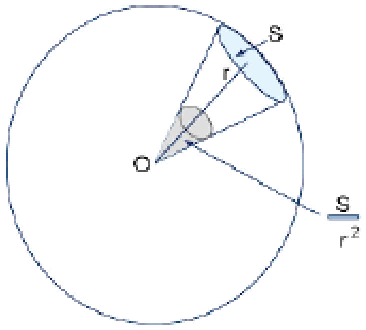
SUPPLEMENTARY UNIT:

Supplementary units, in the context of measurement, are units of measure that are not part of the base units in the International System of Units (SI) but are used to express certain. Physical quantities that are not directly covered. by the base units.

Physical Quantities	Supplementary unit	Symbol	Definition
Plane Angle	Radian	rad	A unit of measurement of angles equal to 57.3°, equivalent to the angle subtended at the center of a circle by an arc equal in length to the radius as shown in figure 1.1 (a).
Solid Angle	Steradian	Sr	The solid angle subtended at the center of a sphere by an area of its surface equal to the square of the radius of that sphere as shown in figure 1.1 (b).



Radian



Steradian

MEASUREMENT TECHNIQUES:

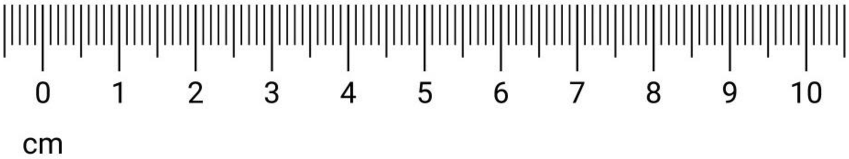
To measure different physical quantities, various techniques and instruments are used. Here are some common measurement techniques for length, mass, time, temperature, and electrical quantities:

LENGTH:

The length of an object can be measured using a ruler, caliper, or tape measure. Moreover, there are certain digital methods to measure the length such as laser rangefinder. digital sliding caliper, odometer, etc.

Digital siding caliper

ODOMETER

MASS:

Physical Balance: A balance or weighing scale can be used to directly measure the mass of an object.

TIME

MECHANICAL CLOCK: This is a traditional method that uses a mechanism, such as a swinging pendulum or a rotating escapement, to keep time. Examples include grandfather clocks, cuckoo clocks, and wristwatches

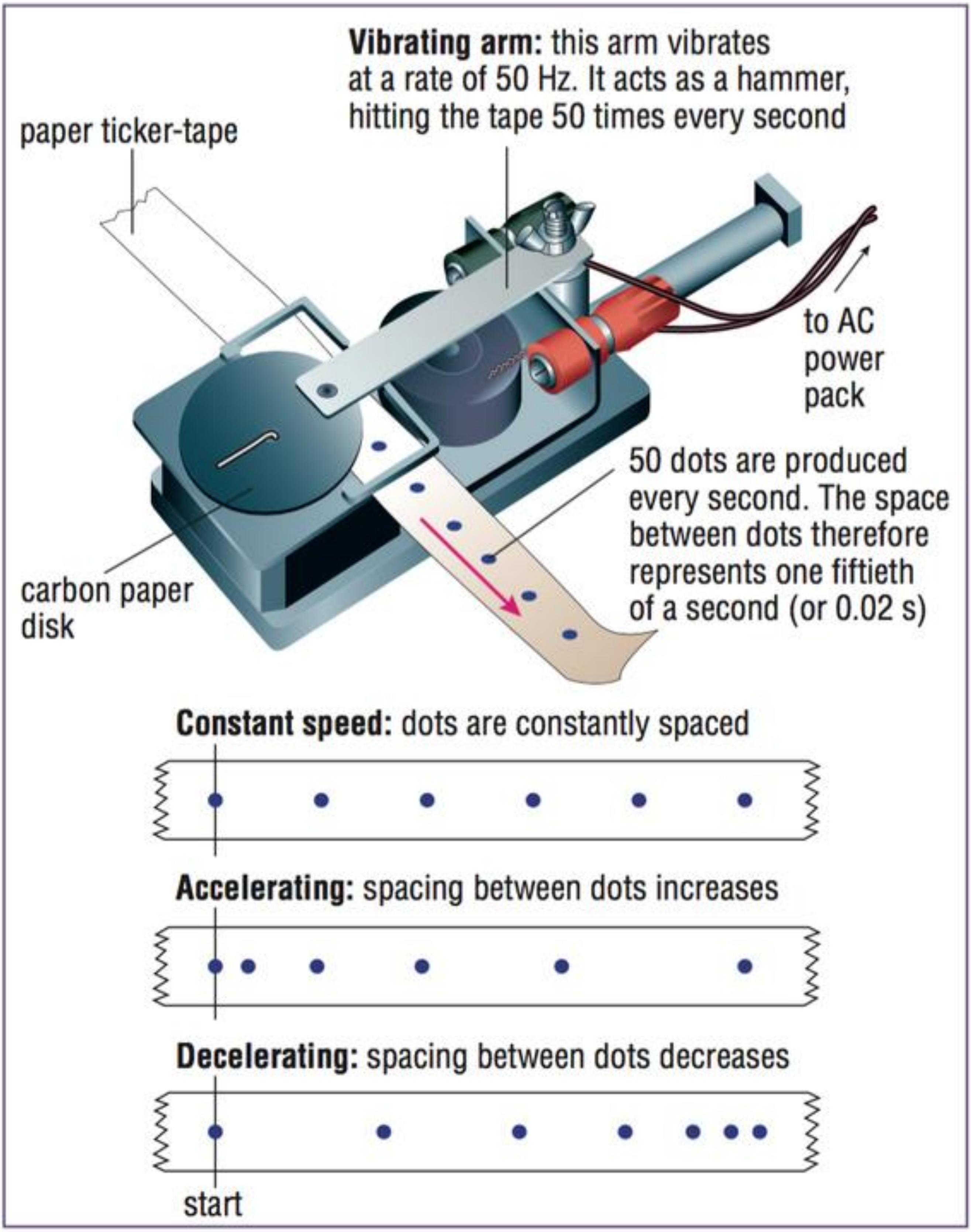
  

ATOMIC CLOCK: For highly accurate and precise time measurements, atomic clocks, such as cesium or rubidium atomic clocks, are used

MEASUREMENT OF SPEED BY THE TICKER TIMER.

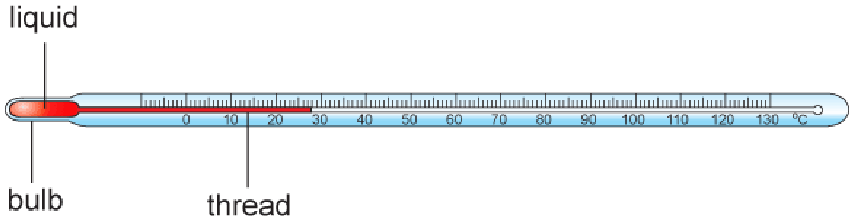
The ticker timer is simply a piece of apparatus that we use to measure time. Most ticker-timers vibrate at 50 Hz and thus make 50 dots per second. For these, the expected mean value of one tick is 1/50 second or 0.02 s.

When you work out the speed of an object you need to know how far it goes in a certain time.



THERMOMETER

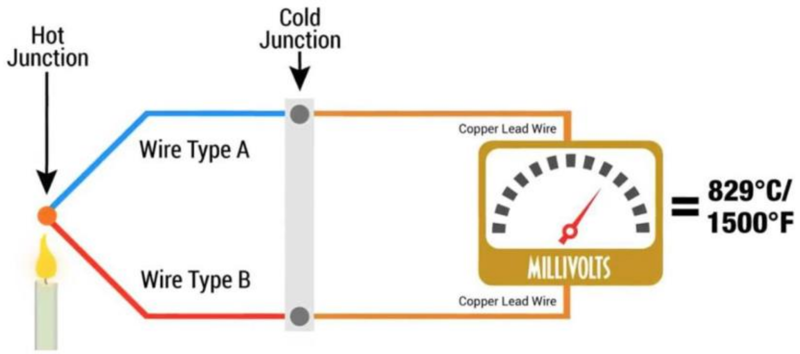
A thermometer is an instrument that measures temperature. It can measure the temperature of a solid such as food, a liquid such as water, or a gas such as air. The three most common units of measurement for temperature are Celsius, Fahrenheit, and Kelvin.



THERMOCOUPLE THERMOMETER

A thermocouple thermometer consists of two wires made up of different materials such as copper and iron. The ends of the wires are joined to each other and to a high–resistance millivoltmeter as shown in the following figure.

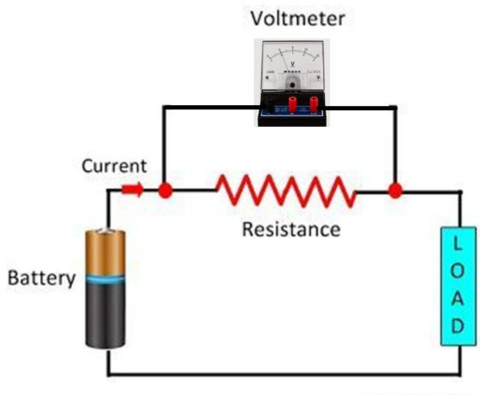
If the two junctions are at different temperatures, that is, one junction is hot and the other is cold, a small electromotive force(emf) is produced.



MEASURING INSTRUMENTS FOR ELECTRICAL QUANTITIES

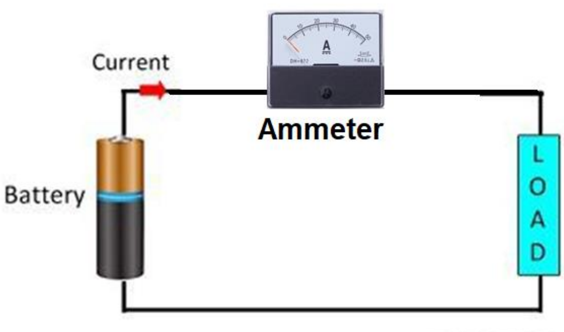
VOLTMETER

A voltmeter measures the electric potential difference between two points in an electric circuit. It is connected in parallel.



AMMETER

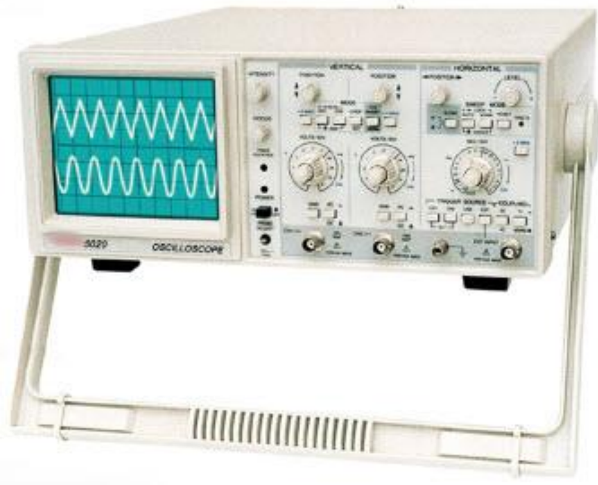
An ammeter measures the electric current in an electric circuit. It is connected in series.



OHM METER: Resistance can be measured using an ohmmeter or a multimeter, which measures the electrical resistance of a component or circuit

CATHODE RAY OSCILLOSCOPE (CRO)

A cathode ray oscilloscope (CRO) is a type of electronic instrument that can be used for a variety of measurement techniques as shown in Figure.



VOLTAGE MEASUREMENT: A CRO can be used to measure the voltage of a signal by displaying its waveform on the screen. The vertical axis of the display represents the voltage, and the horizontal axis represents time. The peak-to-peak voltage of the signal can be measured by using the CRO's vertical and horizontal cursors.

DIMENSION

The dimension of a physical quantity is the power of the fundamental quantities in terms of which it can be represented. Each of the basic quantities is called " dimension" Or

The word dimension has a special meaning in physics. It is used to denote the nature of the physical quantity.

DIMENSION	Symbol
Time	[T]
Length	[L]
Mass	[M]
Temperature	[T], [θ]
Electric current	[A]

Some dimensions of physical quantities are given in the table

Physical Quantities	Expression	Dimensional Formula
Area	Length × Breadth	$[L^2]$
Density	Mass/ volume	$[ML^{-3}]$
Momentum	Mass × velocity	$[MLT^{-1}]$
Work / Energy	Force × displacement	$[ML^2T^{-2}]$
Electric Charge	Current × time	$[AT]$
Gravitational Constant	$[\text{Force} \times (\text{distance})^2] / \text{mass}^2$	$[M^{-1}L^3T^{-2}]$
Moment of Inertia	Mass × (distance)^2	$[ML^2]$
Moment of force	Force × distance	$[ML^2T^{-2}]$
Angular Momentum	Linear Momentum × distance	$[ML^2T^{-1}]$

Q-1 Find the dimensions of the following

PRESSURE

SOLUTION

(i) PRESSURE

SOLUTION

$$[P] = \frac{[F]}{[A]}$$

$$[P] = \frac{[m][a]}{[A]}$$

$$[P] = \frac{[M][L\,T^{-2}]}{[L^2]}$$

$$[P] = [M][L\,T^{-2}][L^{-2}]$$

$$[P] = [M][L^{-1}][T^{-2}]$$

(ii) Gravitation constant (G)

SOLUTION

$$[G] = \frac{[F][r^2]}{[m_1][m_2]}$$

$$[P] = \frac{[ML\,T^{-2}][L^2]}{[M][M]}$$

$$[P] = \frac{[L^3\,T^{-2}]}{[M]}$$

$$[P] = [M^{-1}]\,[L^3]\,[T^{-2}]$$

(iii) POWER

SOLUTION

$$[P] = \frac{[W]}{[t]}$$

$$[P] = \frac{[F][S]}{[t]}$$

$$[P] = \frac{[ML\,T^{-2}][L]}{[T]}$$

$$[P] = [M\,L\,T^{-2}][L][T^{-1}]$$

$$[P] = [M][L^2][T^{-3}]$$

(ii) SURFACE TENSION (T)

SOLUTION

$$[T] = \frac{[F]}{[L]}$$

$$[T] = \frac{[ML\,T^{-2}]}{[L]}$$

$$[PT] = [M][L^0][T^{-2}]$$

HOMOGENEITY PRINCIPLE OF DIMENSIONAL ANALYSIS

The principle of Homogeneity states that the dimensions of each of the terms of a dimensional equation on both sides should be the same. This principle is helpful because it helps us convert the units from one form to another. To better understand the principle, let us consider the following example:

Q-2 Show that the following equations are dimensionally correct

(i) $v = f\,\lambda$

SOLUTION

$L.H.S = [v]$

$L.H.S = [\mathrm{L\,T^{-1}}]$

$R.H.S = [f]\,[\lambda]$

$R.H.S = [T^{-1}]\,[L]$

$R.H.S = [L]\,[T^{-1}]$

we have [L.H.S] = [R.H.S]
Hence, the given equation is dimensionally correct.

(ii) $S = v_i\,t + \frac{1}{2}\,a\,t^2$

SOLUTION

$L.H.S = [S]$

$L.H.S = [\mathrm{L}]$

$R.H.S = [v_i\,][t] + \frac{1}{2}\,[a]\,[t^2]$

$R.H.S = [L\,T^{-1}\,][T] + \frac{1}{2}\,[L\,T^{-2}]\,[T^2]$

$R.H.S = [L\,T^{-1}\,T\,] + \frac{1}{2}\,[L\,T^{-2}\,T^2]$

$\left\{\frac{1}{2}\ \ has\ no\ dimension\right\}$

$R.H.S = [L\,] + \frac{1}{2}\,[L]\ = [L\,] + \ [L]$

$R.H.S = 2\,[L\,]\quad \{2\ has\ no\ dimension\}$

we have [L.H.S] = [R.H.S]
Hence, the given equation is dimensionally correct.

(iii) $x = m\,\frac{\lambda}{2}$ [2024 KB]

SOLUTION

$L.H.S = [x]$

$L.H.S = [\mathrm{L}\,]$

$R.H.S = m\left[\frac{\lambda}{2}\right]$

m and 2 are number, they are dimensional less

$R.H.S = 1 \times \left[\frac{L}{1}\right]$

$R.H.S = [L]$

we have [L.H.S] = [R.H.S]
Hence, the given equation is dimensionally correct.

(iv)) $v_f^2 = v_1^2 + 2\,a\,S$

SOLUTION

$L.H.S = [v_f^2]$

$L.H.S = [\mathrm{L^2\ T^{-2}}]$

$R.H.S = [v_1^2]\ + 2\,[a]\,[S]$

$R.H.S = [L^2T^{-2}] + 2\ \ [LT^{-2}]\,[L]$

$R.H.S = [L^2T^{-2}] + 2\ \ [L^2T^{-2}]$

$2\ has\ no\ dimension$

$R.H.S = [L^2T^{-2}] + \ \ [L^2T^{-2}]$

$R.H.S = [L^2T^{-2}]$

we have [L.H.S] = [R.H.S]
Hence, the given equation is dimensionally correct

Q-3 Show that the following equations are dimensionally correct

(i) $T = 2\pi\sqrt{\frac{L}{g}}$

SOLUTION

$L.H.S = [T]$

$L.H.S = [\mathrm{T}]$

$R.H.S = 2\pi\sqrt{\frac{[L]}{[g]}}$

$R.H.S = 2\pi\sqrt{\frac{[L]}{[L\,T^{-2}]}}$

$R.H.S = 2\pi\sqrt{\frac{1}{[T^{-2}]}}$

$R.H.S = 2\pi\sqrt{[T^2]}$

$R.H.S = 2\pi[T]$

2π *has no dimension*

$R.H.S = [T]$

we have [L.H.S] = [R.H.S]
Hence, the given equation is dimensionally correct.

(i) $\mathrm{T} = 2\pi\sqrt{\frac{\mathrm{m}}{\mathrm{K}}}$

SOLUTION

$L.H.S = [T]$

$L.H.S = [\mathrm{T}]$

$R.H.S = 2\pi\sqrt{\frac{[m]}{[K]}}$

Dimension of K = $[M\,L^{-2}]$

$.R.H.S = 2\pi\sqrt{\frac{[M]}{[M\,T^{-2}]}}$

$R.H.S = 2\pi\sqrt{\frac{1}{[T^{-2}]}}$

$R.H.S = 2\pi\sqrt{[T^2]} = 2\pi[T]$

2π *has no dimension*

$R.H.S = [T]$

we have [L.H.S] = [R.H.S]
Hence, the given equation is dimensionally correct.

(ii) $\mathbf{f} = \frac{1}{2\mathrm{L}}\sqrt{\frac{\mathrm{F}\times\mathrm{L}}{\mathrm{m}}}$

SOLUTION

$L.H.S = [f]$

$L.H.S = [\mathrm{T}^{-1}]$

$R.H.S = \frac{1}{2}\times\frac{1}{[\mathrm{L}]}\sqrt{\frac{[\mathrm{F}]\times[\mathrm{L}]}{[\mathrm{m}]}}$

$\frac{1}{2}$ *has no dimension*

$R.H.S = \frac{1}{[\mathrm{L}]}\sqrt{\frac{[\mathrm{M\,L\,T^{-2}}]\times[\mathrm{L}]}{[\mathrm{M}]}}$

$R.H.S = \frac{1}{[\mathrm{L}]}\sqrt{[\mathrm{L\,T^{-2}}]\times[\mathrm{L}]}$

$R.H.S = \frac{1}{[\mathrm{L}]}\sqrt{[\mathrm{L^2\,T^{-2}}]}$

$R.H.S = \frac{1}{[\mathrm{L}]}\sqrt{[\mathrm{L^2}]}\sqrt{[\mathrm{T^{-2}}]}$

$R.H.S = \frac{1}{[\mathrm{L}]}[\mathrm{L}]\,[\mathrm{T^{-1}}]$

$R.H.S = [\mathrm{T^{-1}}]$

we have [L.H.S] = [R.H.S]
Hence, the given equation is dimensionally correct.

USING DIMENSION TO DERIVE EQUATION

Consider the oscillations of a simple pendulum. We assume that the period of the pendulum [T] depends on the following quantities:

(i) the mass of the pendulum bob [M]

(ii) the length of the string of the pendulum [L], and

(iii) the gravitational acceleration (g) $[LT^{-2}]$

Therefore, the equation can be written as

$$T \; \alpha \; m^x \; l^y \; g^z$$

$$T = K\, m^x \; l^y \; g^z \ldots\ldots\ldots (i)$$

Where x, y, and z are unknown power and k is a dimensionless constant.

The dimensional form is

$$[T] = [M^x] \; [L^y] \; [(L\, T^{-2})^z]$$

$$[T] = [M^x] \; [L^y] \; [L^z\, T^{-2z}]$$

$$[T] = [M^x] \; [L^y] \; [L^z\,][T^{-2z}]$$

$$[T] = [M^x] \; [L^{y+z}] \; [T^{-2z}]$$

$$[M^0][L^0][T^1] = [M^x] \; [L^{y+z}] \; [\, T^{-2z}]$$

Equating the indices for M, L, and T on both sides. we get

$$x = 0$$

$$y + z = 0$$

$$-2z = 1$$

$$z = -\frac{1}{2}$$

$$y - \frac{1}{2} = 0$$

$$y = \frac{1}{2}$$

Substituting these values in expression (i),we get

$$T = K\, m^0 \; l^{\frac{1}{2}}\, g^{-\frac{1}{2}}$$

$$T = K \;\; 1 \times \frac{l^{\frac{1}{2}}}{g^{\frac{1}{2}}}$$

$$T = K \; \frac{\sqrt{l}}{\sqrt{g}}$$

$$T = K \sqrt{\frac{l}{g}} \qquad \therefore \; (K = 2\pi)$$

$$T = 2\,\pi \sqrt{\frac{l}{g}}$$

SIGNIFICANT FIGURES

The number of accurately known digit and first doubtful digit(called least significant) are known as significant figures or significant digit.

RULES OF DETERMINATION SIGNIFICANT FIGURES

1. **ALL non-zero numbers (1,2,3,4,5,6,7,8,9) are ALWAYS significant**

EXAMPLE

(i) 3423
4- significant figure

(ii) 457435
6 -significant figure

(iii) 587
3- significant figure

(iv) 58
2- significant figure

2. **ALL zeroes between non-zero numbers are ALWAYS significant**

EXAMPLE

(i) 3003
4- significant figure

(ii) 40.009
5 -significant figure

(iii) 507
3- significant figure

(iv) 5000097
3- significant figure

3. Zeros locating the position of decimal in numbers of magnitude less than one are not significant

EXAMPLE

(i) 0.0063
2- significant figure

(ii) 0.009
1 -significant figure

(iii) 0.0000307
3- significant figure

(iv) 0.0009078
4 -significant figure

4. Final zeros to the right of the decimal point are significant.

EXAMPLE

(i) 7.0500
5- significant figure

(ii) 0.00900
3 -significant figure

(iii) 9.00300
6- significant figure

(iv) 0.090200
5- significant figure

5. Zeros at the end of the numbers greater than one may are may not be significant

EXAMPLE

(i) 700
1- significant figure

(ii) 980000
2- significant figure

6 For any value written in scientific notation as $A \times 10^{x}$, the number of significant figures is determined by applying the above rules only to the value of A.

EXAMPLE

4.5 × 103 has two significant figures

4.50 × 10-9 has three significant figures

4.500 × 1023 has four significant figures

1.3 Errors and Uncertainty:

Error and uncertainty are two related but distinct concepts in various fields, including statistics, science, and engineering. Here's a distinction between the two:

Error: Error refers to the discrepancy between a measured or observed value and the true or expected value.

Uncertainty: Uncertainty, on the other hand, relates to the lack of precise knowledge or the degree of doubt associated with a measurement, prediction, or estimation. It arises due to limitations in available information or inherent variability in the system being studied.

The main difference between errors and uncertainties is that an ***error is the difference between the actual value and the measured value***, while an **uncertainty is an estimate of the range between them, representing the reliability of the measurement.**

1.4.1 Uncertainty in measurements:

Any experiment will have a number of measurements, and which will be made to a certain degree of accuracy. There is always a degree of uncertainty when measurements are taken; the uncertainty can be thought of as the difference between the ***actual*** reading taken (caused by the equipment or techniques used) and the ***standard value.*** Uncertainties are not the same as errors

- Errors can be because of issues with equipment or methodology that cause a reading to be different from the standard value.
- The uncertainty is a range of values around a measurement within which the true value is expected to lie, and is an **estimate.**

For example: The calculations of velocity require the movement of a time and distance. Using a stop watch to measure time nearest tenth of a second. and using a meter scale to find distance to the nearest of millimeter (for small distances in a laboratory). It is very useful to have a rough idea of the kind of result that you might expect before starting an experiment.

1.4.2 Systematic error and Random Error:

Errors are common occurrences in Physics and there are two specific types of errors that may occur during experiments.

Systematic Errors:

Systematic errors are errors that have a clear cause and can be eliminated for future experiments as shown in fig: 1.5.

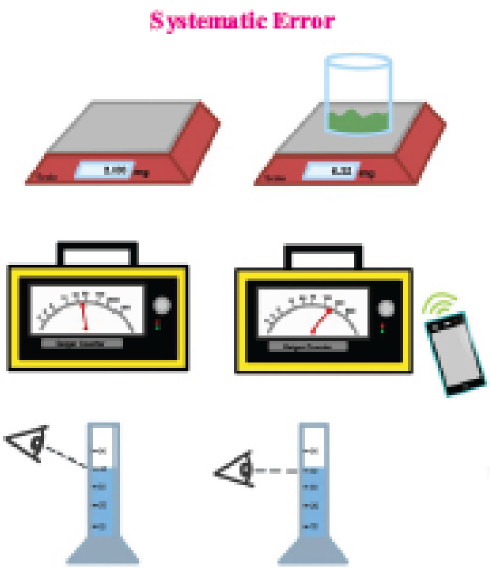


Figure 1.5

There are four different types of systematic errors:

Instrumental: When the instrument being used does not Function properly causing error in the experiment (such as a scale that reads 2g more than the actual weight of the object, causing the measured values to read too high **consistently**)

Environmental: When the surrounding environment (such as a lab) causes errors in the experiment (the scientist cell phone's RF waves cause the geiger counters to incorrectly display the radiation)

Observational: When the scientist inaccurately reads a measurement wrong (such as when not standing straight-on when reading the volume of a flask causing the volume to be incorrectly measured)

Theoretical: When the model system being used causes the results to be inaccurate (such as being told that humidity does not affect the results of an experiment when it actually does)

Random Errors:

Random errors occur randomly, and sometimes have no source/cause as shown in fig:1.6.
There are two types of random errors:

Observational: When the observer makes consistent observational mistakes (such not reading the scale correctly and writing down values that are constantly too low or too high)

Environmental: When unpredictable changes occur in the environment of the experiment (such as students repeatedly opening and closing the door when the pressure is being measured, causing fluctuations in the reading)

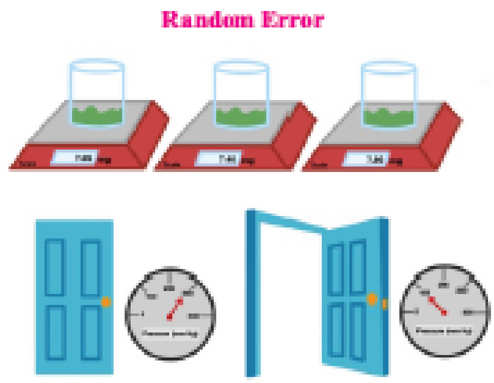


Figure 1.6

Systematic vs. Random Errors:

Systematic errors and random errors are sometimes similar, so here is a way to distinguish between them:

Systematic Errors are errors that occur in the same direction consistently, meaning that if the scale was off by and extra 3lbs, then every measurement for that experiment would contain an extra 3 lbs. This error is identifiable and, once identified, they can be eliminated for future experiments

Random Errors are errors that can occur in any direction and are not consistent, thus they are hard to identify and thus the error is harder to fix for future experiments. An observer might make a mistake when measuring and record a value that's too low, but because no one else was there when it was measured, the mistake went on unnoticed.

COMBINING UNCERTAINTY: ADDING AND SUBTRACTING

Q-4 The length of a copper wire at 30°C is 18.2 ± 0.04 cm and at 60°C is 19.7 ± 0.02 cm. Find the absolute uncertainty and die extension of the wire.

DATA

The length L_1 = 18.2 ± 0.04

The length L_2 = 19.7 ± 0.02

SOLUTIONS

Extension of the wire

$$L = (L_2 - L_1)$$

$$L = (19.7-18.2)$$

$$L = 1.5\text{mm}$$

Absolute uncertainty

$$\Delta L = \Delta L_1 + \Delta L_2$$

$$\Delta L = 0.04 + 0.02$$

$$\Delta L = 0.06$$

Extension of the wire with uncertainty = (L ± ΔL)

Extension of the wire with uncertainty = (1.5 ± 0.06) mm

Q-5 w = (4.52 ± 0.02) cm, x = (2.0 ± 0.2) cm, y = (3.0 ± 0.6) cm. Find z = x + y - w and its uncertainty.

DATA	**So z = x +y -w**
w = (4.52 ± 0.02) cm	**z = 2.0 +3.0 -4.52**
x = (2.0 ± 0.2) cm	**z = 5.0 -4.52**
y = (3.0 ± 0.6) cm	**z = 0.48 cm**
SOLUTIONS	**Answer with uncertainty**
Dz = Dx + Dy + Dw	**Z = (z ± Δz) cm**
Dz = 0.2 + 0.6 + 0.02	**Z = (0.48 ± 0.82) cm**
Dz = 0.82	

Q-6 Three objects have masses of 3 ± 0.1 kg, 7 ± 0.1 kg, and 4 ± 0.05 kg. What is the uncertainty in the total mass of the three objects?

DATA	$\Delta m = \Delta m_1 + \Delta m_2 + \Delta m_3$
$m_1 = (3 \pm 0.1)$ kg	$\Delta m = 0.1 + 0.1 + 0.05$
$m_2 = (7 \pm 0.1)$ kg	$\Delta m = 0.25$
$m_3 = (4 \pm 0.05)$ kg	**Answer with uncertainty**
SOLUTIONS.	$= m \pm \Delta m$
$m = m_1 + m_1 + m_1 =$	$= (14 \pm 0.25)$ kg
$m = 3 + 7 + 4 = 14$ kg	

COMBINING UNCERTAINTY: MULTIPLICATION AND DIVISION

Q-7 **The duration for an athlete to cover a distance of 100 m is recorded as 9.63 seconds. The uncertainty in the distance measurement is 0.2 m, and in the time measurement, it is 0.1 seconds. Determine the percentage and absolute uncertainty in the athlete's speed.**

DATA

S= (100 ± 0.1) kg

t = (9.63 ± 0.1) kg

SOLUTIONS.

$$v = \frac{S}{t}$$

$$v = \frac{100}{9.63}$$

$$v = 10.38\ m/s$$

Percentage uncertainty in the distance S

$$\%\ \text{uncertainty in S} = \frac{\Delta S}{S} \times 100$$

$$\%\ \text{uncertainty in S} = \frac{0.2}{100} \times 100$$

$$\%\ \text{uncertainty in S} = 0.2\ \%$$

Percentage uncertainty in the distance t

$$\%\ \text{uncertainty in t} = \frac{\Delta t}{t} \times 100$$

$$\%\ \text{uncertainty in t} = \frac{0.1}{9.63} \times 100$$

$$\%\ \text{uncertainty in t} = 0.1\ \%$$

Percentage uncertainty in the distance v

$$\%\ \text{uncertainty in } v =$$

$$\%\ \text{uncertainty in S} + \%\ \text{uncertainty in t}$$

$$\%\ \text{uncertainty in } v = 0.2\% + 0.1\%$$

$$\%\ \text{uncertainty in } v = 0.3\%$$

Answer with uncertainty

$$(10.38 \pm 0.2\ \%)$$

Fraction uncertainty in velocity

$$v = 10.38 \pm \left(\frac{0.2}{100} \times 10.38\right)$$

$$v = (10.38 \pm 0.02)$$

Q-8 **The length and width of a rectangular room are measured to be L = (4.05 ± 0.05)m**

And W = (2.95 ± 0.05)m. Calculate the area and its uncertainty

DATA

L = (4.05 ± 0.05) m

W = (2.95 ± 0.05) m

SOLUTIONS.

A = L x W = 4.05 x 2.95 = 11.95 m

Uncertainty in area

$$\frac{\Delta A}{A} = \left(\frac{\Delta L}{L} + \frac{\Delta W}{W}\right)$$

$$\Delta A = \left(\frac{\Delta L}{L} + \frac{\Delta W}{W}\right) \times A$$

$$\Delta A = \left(\frac{0.05}{4.05} + \frac{0.05}{2.95}\right) \times 11.95$$

$$\Delta A = 0.35\ m$$

Answer with uncertainty

$$(A \pm \Delta A) = (11.95 \pm 0.35)m^2$$

UNCERTAINTY IS MULTIPLIED BY POWER

Q-9 **If the radius of sphere is measured a 9.5 cm with an error of 0.02 cm. Find the approximate error in calculating its volume**

DATA

r = (9.5 ± 0.02) cm

V = ?

SOLUTIONS.

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

$$V = \frac{4}{3}\pi (9.5)^3$$

$$V = 1.333\ \pi (857.375)$$

$$V = 3591\ cm^3$$

error in volume

$$\frac{\Delta V}{V} = \left(3 \times \frac{\Delta r}{r}\right)$$

$$\Delta V = \left(3 \times \frac{\Delta r}{r}\right) \times V$$

$$\Delta V = \left(3 \times \frac{0.02}{9.5}\right) \times 3591$$

$$\Delta V = \frac{215.46}{9.5}$$

$$\Delta V = 22.68\ cm^3$$

$$\Delta V = 23\ cm^3$$

Answer with approximate error

(V ± ΔV) = (378 ± 23) cm^3

Q-10

. What is the uncertainty in the calculated area of a circle whose radius is determined to be $r = (14.6 \pm 0.5)cm$?

Area: $A = \pi r^2$ where $r = (14.5 \pm 0.5)cm$

Percentage of uncertainty: $\frac{0.5cm}{14.6cm} \times 100\% = 3.42\%$

The percentage is times 2 when squared = $2 \times 3.42\% = 6.849\%$

Area: $A = \pi(14.6cm)^2 = 669.66189cm^2$

Area uncertainty is about 7%, or in absolute terms, $6.849\% \times 699.6cm^2 = 45.86cm^2 \approx 46cm^2$

Therefore area: $A \pm \Delta A = (670. \pm 46)cm^2 \approx (6.7 \pm 0.5) \times 10^2\ cm^2$

Q-11 **A girl needs to calculate the volume of a pool, so that she knows how much water she will need to fill it. She measures the length, width, and height as under.**

Length = 5.56 ± 0.14 m
Width = 3.12 ± 0.08m
Height = 2.94 ± 0.11m
What will be the pool's volume with percentage uncertainty?

DATA

Length = 5.56 ± 0.14 m

Width = 3.12 ± 0.08m

Height = 2.94 ± 0.11m

V = ?

SOLUTIONS.

$$V = L \times W \times H$$

$$V = 5.56 \times 3.12 \times 2.94$$

$$V = 51\ m^3$$

Percentage uncertainty in the distance S

$$\%\ \text{uncertainty in L} = \frac{\Delta L}{L} \times 100$$

$$\%\ \text{uncertainty in L} = \frac{0.14}{5.56} \times 100$$

$$\%\ \text{uncertainty in S} = 2.51\ \%$$

Percentage uncertainty in the distance w

$$\%\ \text{uncertainty in W} = \frac{\Delta W}{W} \times 100$$

$$\%\ \text{uncertainty in L} = \frac{0.08}{3.12} \times 100$$

$$\%\ \text{uncertainty in S} = 2.56\ \%$$

Percentage uncertainty in the distance H

$$\%\ \text{uncertainty in L} = \frac{\Delta H}{L} \times 100$$

$$\%\ \text{uncertainty in L} = \frac{0.11}{2.94} \times 100$$

$$\%\ \text{uncertainty in S} = 3.74\ \%$$

Percentage uncertainty in the distance v

$$\%\ \text{uncertainty in}\ v = 2.51\% + 2.56\% + 3.74\%$$

$$\%\ \text{uncertainty in}\ v = 8.81\%$$

$$\%\ \text{uncertainty in}\ v = 8.8\%$$

Answer with uncertainty

$$(51 \pm 8.8\ \%)$$

Fraction uncertainty in volume

$$V = 51 \pm \left(\frac{8.8}{100} \times 51\right)$$

$$V = 51 \pm (4.48)$$

$$V = (51 \pm 4.9)$$