UNITS AND MEASUREMENT

UNIT ONE

OBJECTIVES

1. WHAT IS PHYSICS ?
2. SCIENTIFIC METHOD
3. PHYSICS IN RELATION TO SOCIETY
4. BRANCHES IN PHYSICS
5. Physical Quantity – Fundamental & Derived Quantities
6. Unit – Fundamental & Derived Units
7. Characteristics of Standard Unit
8. fps, cgs, mks & SI System of Units
9. Definition of Fundamental SI units
10. Measurement of Length – Large Distances and Small Distances
11. Measurement of Mass and Measurement of Time
12. Significant Figures, Scientific Notation
13. Dimensions, Dimensional Formulae and Dimensional Equations
14. Dimensional Analysis – Applications- and Demerits

Introduction
WHAT IS PHYSICS?

- Physics (from a Greek term meaning nature) is historically the term to designate the study of natural phenomena (also natural philosophy till early in the 19th century)
- Goal of physics: to understand and predict how nature works
- Everything in nature obeys the laws of physics
- Everything we build also obeys the laws of physics

WHAT IS PHYSICS ?

- A way of describing the **physical world**

-Physics comes from the Greek "physis" meaning "nature" and the Latin "physica" meaning **natural things**

- Physics is understanding the behavior and structure of matter
  - It deals with how and why **matter** and **energy** act as they do
  - Energy is the conceptual system for explaining how the universe works and accounting for changes in matter

- Although energy is not a “thing” three ideas about energy are important

1. It is changed from one form to another (transformed) by physical events
2. It cannot be created nor destroyed (conservation)
3. When it is transformed some of it usually goes into heat

PHYSICS & MATHS

* The laws of physics can be expressed in terms of mathematical equations

MOTION WITH CONSTANT VELOCITY

$$x = vt$$

space velocity time

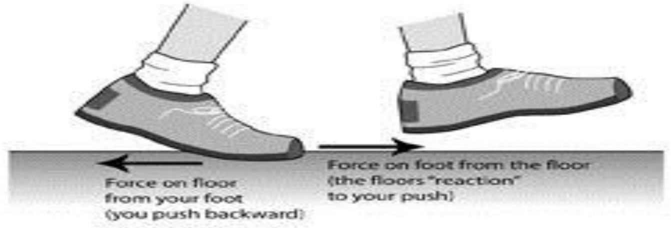
Prediction from theory

Observation from experiments

How do you walk?

Newton's third law states that every action has an equal and opposite reaction.

This is relevant to walking because when you put your foot on the ground, you are applying a force to it. In doing this, the ground also actually applies an equal force onto your foot, in the opposite direction, pushing you forward.



Balancing a see-saw:

If you have two people with different weights it is impossible to maintain the board balanced if they are both sited the same distance from the axis of rotation since for a system to be balanced there needs to be equal torques. To make the board balanced with different weights you need to increase the lever arm (lever arm = smallest distance from the axis of rotation, always perpendicular to force) of the person with the least weight so that the torques equal. In practice the heaviest person of a see-saw needs to sit close to the center while the lightest one sits away from it.

The Effect of Collision Time Upon the Force

Force	Time	Impulse
100	1	100
50	2	100
1	100	100

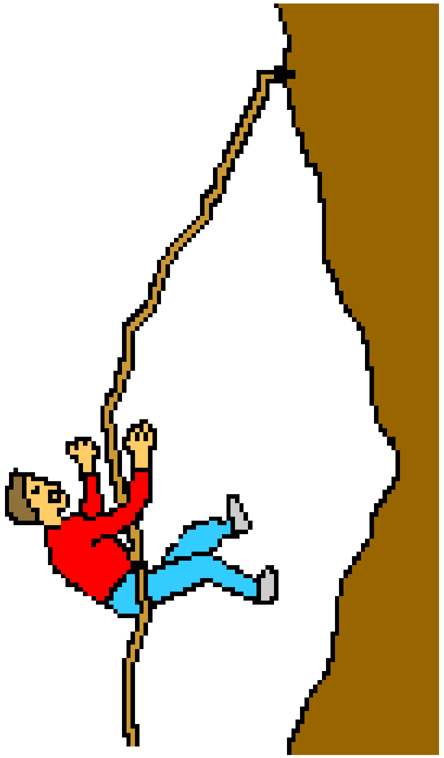
Observe that the greater the time over which the collision occurs, the smaller the force acting upon the object. Thus, to minimize the effect of the force on an object involved in a collision, the time must be increased. And to maximize the effect of the force on an object involved in a collision, the time must be decreased.

Air bags

- Air bags are used in automobiles because they are able to minimize the effect of the force on an object involved in a collision. Air bags accomplish this by extending the time required to stop the momentum of the driver and passenger. When encountering a car collision, the driver and passenger tend to keep moving in accord with Newton's first law. Their motion carries them towards a windshield that results in a large force exerted over a short time in order to stop their momentum. If instead of hitting the windshield, the driver and passenger hit an air bag, then the time duration of the impact is increased.

MOUNTAIN CLIMBERS

- Nylon ropes are used in the sport of rock-climbing for the same reason. Rock climbers attach themselves to the steep cliffs by means of nylon ropes. If a rock climber should lose her grip on the rock, she will begin to fall. In such a situation, her momentum will ultimately be halted by means of the rope, thus preventing a disastrous fall to the ground below. The ropes are made of nylon or similar material because of its ability to stretch. If the rope is capable of stretching upon being pulled taut by the falling climber's mass, then it will apply a force upon the climber over a longer time period. Extending the time over which the climber's momentum is broken results in reducing the force exerted on the falling climber.



Mountain climbers use nylon ropes to increase the stopping time and decrease the stopping force.

Throwing an egg into a bed sheet

- Another common physics demonstration involves throwing an egg into a bed sheet. The bed sheet is typically held by two trustworthy students and a volunteer is used to toss the egg at full speed into the bed sheet. The collision between the egg and the bed sheet lasts over an extended period of time since the bed sheet has *some give* in it. By extending the time of the collision, the effect of the force is minimized. The egg has never broken when hitting the bed sheet.

How a credit card works?

A credit card works because it contains magnets placed in a specific pattern. The credit card machine has coil of wires that cause a change in magnetic field when the card is swiped. This process is called electromagnetic induction. The change in magnetic field induces a voltage that creates a current that is used to signal your account

information to the machine.

Pretty much anything in this world, having to do with electricity and magnetism ?

- Electric generators,
- Light bulbs,
- Computers,
- Smart phones,
- Microwaves, etc................ were all a result of Physics.

PHYSICS IN RELATION TO SOCIETY

- Physics - the study of matter, energy and their interactions - is an international enterprise, which plays a key role in the future progress of humankind. The support of physics education and research in all countries is important because:

1) Physics is an exciting intellectual adventure that inspires young people and expands the frontiers(boundaries)of our knowledge about Nature.
2) Physics generates fundamental knowledge needed for the future technological advances that will continue to drive the economic engines of the world.
3) Physics contributes to the technological infrastructure and provides trained personnel needed to take advantage of scientific advances and discoveries.

4) Physics is an important element in the education of chemists, engineers and computer scientists, as well as practitioners of the other physical and biomedical sciences.

5) Physics extends and enhances our understanding of other disciplines, such as the earth, agricultural, chemical, biological, and environmental sciences, plus astrophysics and cosmology - subjects of substantial importance to all peoples of the world.

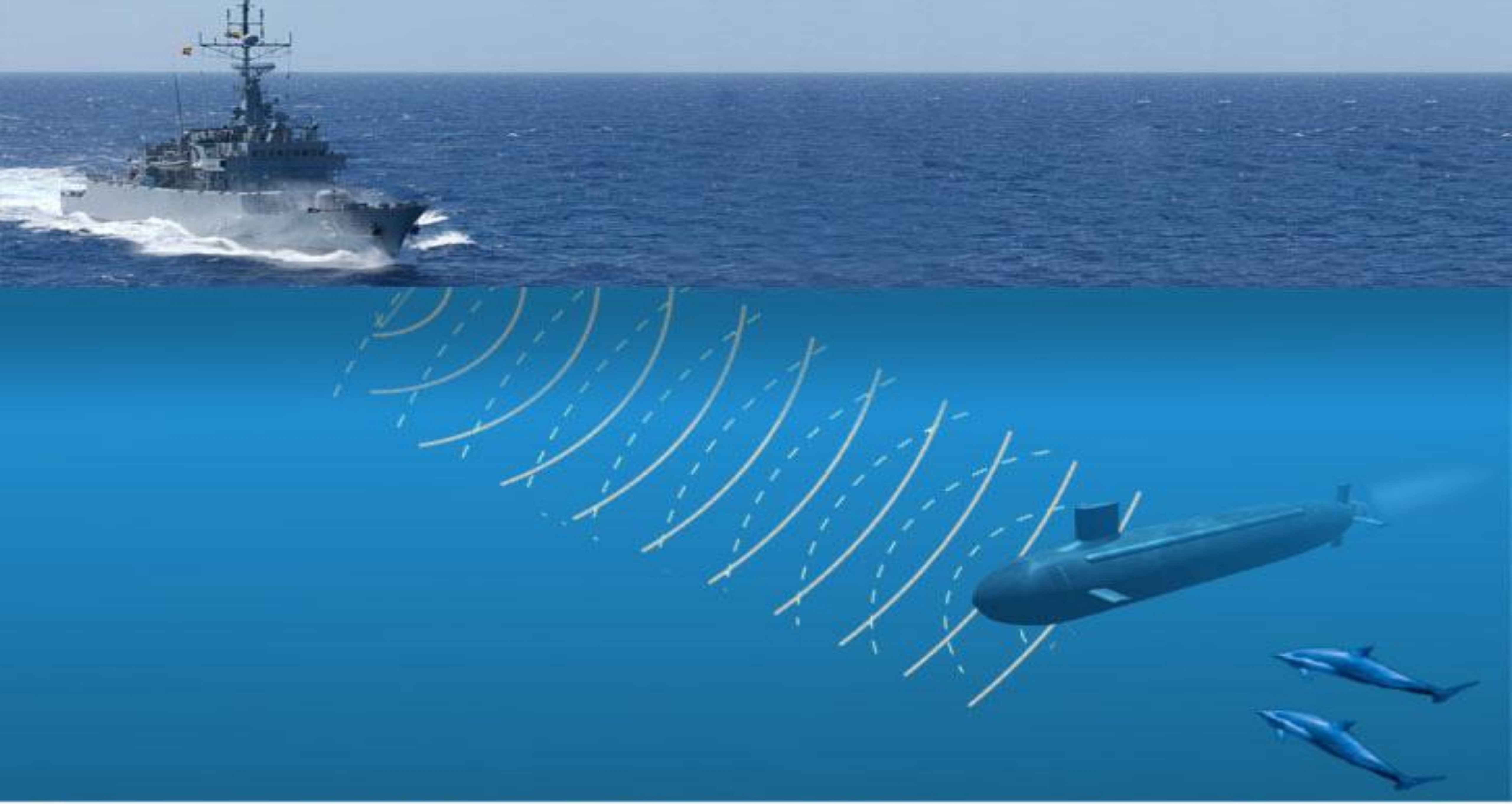
6) Physics improves our quality of life by providing the basic understanding necessary for developing new instrumentation and techniques for medical applications, such as computer tomography, magnetic resonance imaging, positron emission tomography, ultrasonic imaging, and laser surgery.

To Measure the Distance of a Submarine (Echo Method)

- Ultrasonic waves are transmitted through the ocean and if on its path any submerged objects are encountered, then as per law, the waves are reflected back to the origin. The time of sending the wave and the time of receiving the reflected wave are worked out and the distance of the submerged object (submarine in this case) is worked out by the formula

$$S = \frac{v \times t}{2}$$

- where s is the distance between the point of transmission, v is the velocity of sound waves sent and t is the total time taken by the waves to travel to and fro.



Warships using sonar to find submarines. It's thought the war ships sonar disrupts dolphins ultrasound system.

Branches in PHYSICS

Thermodynamics – Heat and temperature

Mechanics –Motion and its causes

Vibrations and Waves – Periodic motion

Atomic – Structure of the atom, energy associated with atomic changes

Nuclear – Structure of the nucleus, energy associated with nuclear changes

Electromagnetism – Electricity, magnetism and EM waves

Optics – Behavior of light

SCIENTIFIC METHOD

The steps of scientific method

- Observation
- Hypothesis
- Experiment
- Theory or law
- Prediction

- ## Observation

The first step in scientific method is to make careful observations to collect data. The data may be drawn from a simple observation, or they may be obtained from experiments.

- ## Hypothesis

From an analysis of these observations and experimental data, a model of nature is hypothesized. The hypothesis is an assumption that is made in order to draw out and test its logical or empirical consequences. We should be able to confirm it by testing. Testing of the hypothesis is called the experiment.

- Experiment

An experiment is a controlled procedure carried out to discover, test, or demonstrate something. An experiment is performed to confirm that the hypothesis is valid. If the results of the experiment do not support the hypothesis, the experimental procedure must be checked. If the procedure is alternate and results still contradict the hypothesis, then the original hypothesis must be modified. Another experiment is then design to test the modified hypothesis.

- Theory

If the experimental results confirm the hypothesis, the hypothesis becomes a new theory about some specific aspect of nature, a scientifically acceptable general principle based on observed facts.

- Prediction

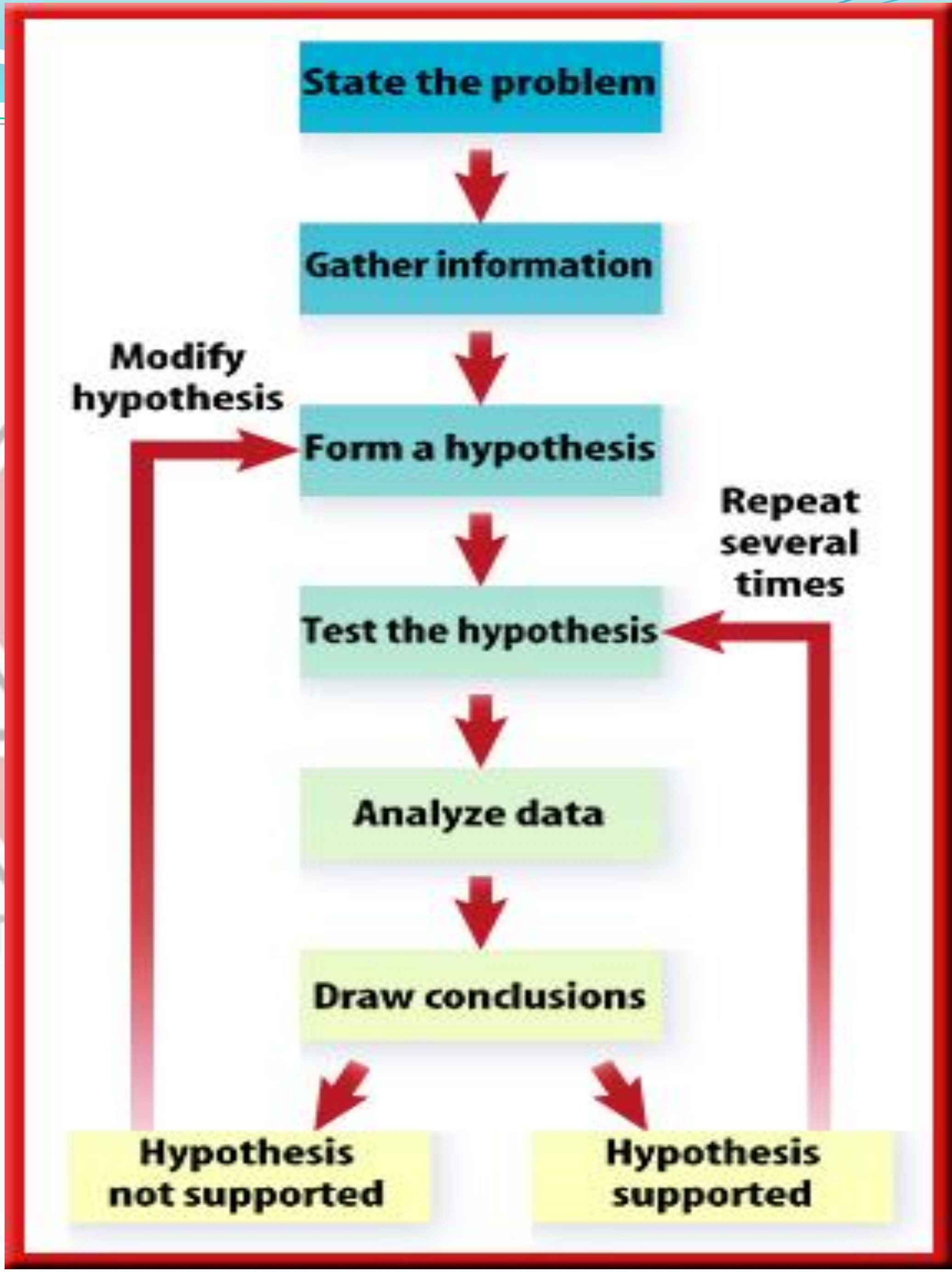
After a careful analysis of the new theory, a prediction about some unknown aspect of nature can be made.

- Investigations in physics generally follow the scientific method

-Observations + initial data collection leading to a question, hypothesis formulation and testing, interpret results + revise hypothesis if necessary, state conclusions

-Some hypotheses can be tested by making observations.

-Others can be tested by building a model and relating it to real-life situations.

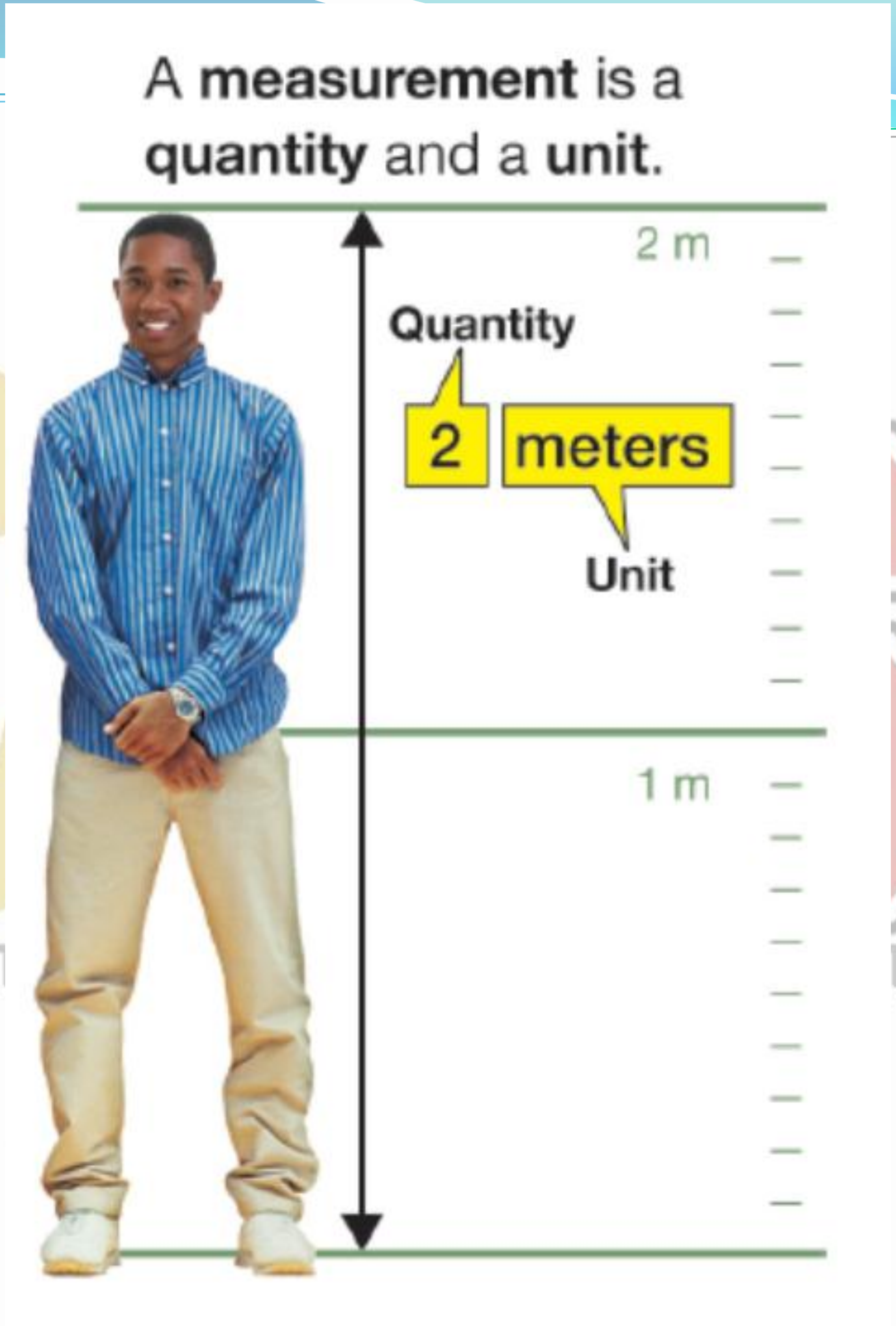


UNITS AND MEASURMENT

MEASUREMENTS

* allow us to make quantitative comparisons between the laws of physics and the natural world
* Common measured quantities: length, mass, time, temperature…
* A measurement requires a system of units

  Measurement = number x unit



A **measurement** is a **quantity** and a **unit**.
2 m
Quantity
2
meters
Unit
1 m

Physical Quantity A quantity which is measurable is called ‘physical quantity’.

Fundamental Quantity

A physical quantity which is the base and can not be derived from any other quantity is called ‘fundamental quantity’.

Examples: Length, Mass, Time, etc.

Derived Quantity

A physical quantity which can be derived or expressed from base or fundamental quantity / quantities is called ‘derived quantity’.

Examples: Speed, velocity, acceleration, force, momentum, torque, energy, pressure, density, thermal conductivity, resistance, magnetic moment, etc.

Unit

Measurement of any physical quantity involves comparison with a certain basic, arbitrarily chosen, internationally accepted reference standard called unit.

Fundamental Units

The units of the fundamental or base quantities are called fundamental or base units.

Examples: metre, kilogramme, second, etc.

Derived Units

The units of the derived quantities which can be expressed from the base or fundamental quantities are called derived units.

Examples: metre/sec, kg/m^3, $kg\ m/s^2$, $kg\ m^2/s^2$, etc.

System of Units

A complete set of both fundamental and derived units is known as the system of units.

Characteristics of Standard Units

A unit must fulfill the following requirements:

i) It should be well defined.

ii) It should be of suitable size i.e. it should neither be too large nor too small in comparison to the quantity to be measured.

iii)It should be reproducible at all places.

iv)It should not change from place to place or time to time.

v) It should not change with the physical conditions such as T,P, etc.

vi)It should be easily accessible.

SYSTEM OF UNITS

In earlier time, various systems like 'fps', 'cgs' and 'mks' system of units were used for measurement. They were named so from the fundamental units in their respective systems as given below:

I. **cgs system-** Set up in France. It is based on centimeter, gram and second as the fundamental units of length, mass and time respectively.

II. **fps system-** It is a British system based on foot, pound and second as the fundamental units of length, mass and time respectively.

III. **mks system-** It is also a French system based on meter, kilogram and second as the fundamental units of length, mass and time respectively.

IV. **SI: The international system of units-**

Quantity	Dimension	System of units		
		fps	cgs	mks
Length	L	foot	centi meter	meter
Mass	M	pound	gram	kilogram
Time	T	second	second	second

THE INTERNATIONAL SYSTEM OF UNITS (SI)*

- The 11th Conférence Générale des Poids et Mesures (CGPM) (1960) adopted the name *Système International d'Unités* (International System of Units, SI), for the recommended practical system of units of measurement.
- The 11th CGPM laid down rules for the base units, the derived units, prefixes and other matters.
- The SI is not static but evolves to match the world's increasingly demanding requirements for

Fundamental units

The physical quantities which can be treated as independent of other physical and are not usually defined in terms of other physical quantities are called physical quantities. Such as-

STANDARD MEASURES

SI FUNDAMENTAL UNITS

* There are seven well-defined units which by convention are regarded as dimensionally independent

Physical quantity	unit	symbol
LENGTH	metre	m
MASS	kilogram	kg
TIME	second	s
ELECTRIC CURRENT	ampere	A
THERMODYNAMIC TEMPERATURE	kelvin	K
AMOUNT OF SUBSTANCE	mole	mol
LUMINOUS INTENSITY	candela	cd

Quantity	Unit	Symbol
Length	....	m
Mass	kilogram	...
.....................Temperature	kelvin	...
Time	second	s
Amount of	mole	mol
Luminous Intensity	....	cd
Electric Current	ampere	...

Base Units

Base units are considered so because they are not derived from any pre-existing number or formula. We need to be able to discuss things like distance, temperature and time, and we do so by agreeing to a reliable definition of some basic (base!) facts.

Base Units

- Length

  Meter

  (m)

Base Units

- Mass

  Kilogram

  (kg)

Base Units

- Time

Seconds

(s)

Base Units

- Temperature

Kelvin

(K)

Base Units

- Amount of Substance

mole

(mol)

Base Units

- Electric Current

Ampere

(A)

Base Units

- Luminous Intensity

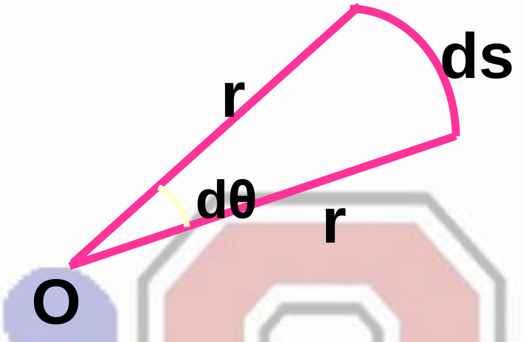
  candela

  (cd)

	Quantity	Symbol	SI unit	Symbol
Supplementary units	Plane angle	$d\theta$	radian	rad
	Solid angle	$d\Omega$	steradian	sr

Plane angle

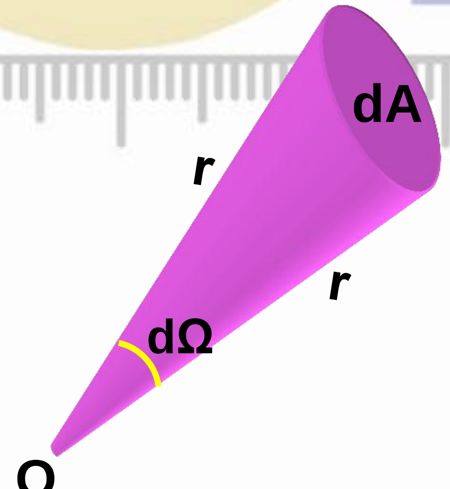
Plane angle ‘dθ’ is the ratio of arc ‘ds’ to the radius ‘r’. Its SI unit is ‘radian’.



$$d\theta = \frac{ds}{r}$$

Solid angle

Solid angle ‘dΩ’ is the ratio of the intercepted area ‘dA’ of the spherical surface described at the apex ‘O’ as the centre, to the square of its radius ‘r’. Its SI unit is ‘steradian’.



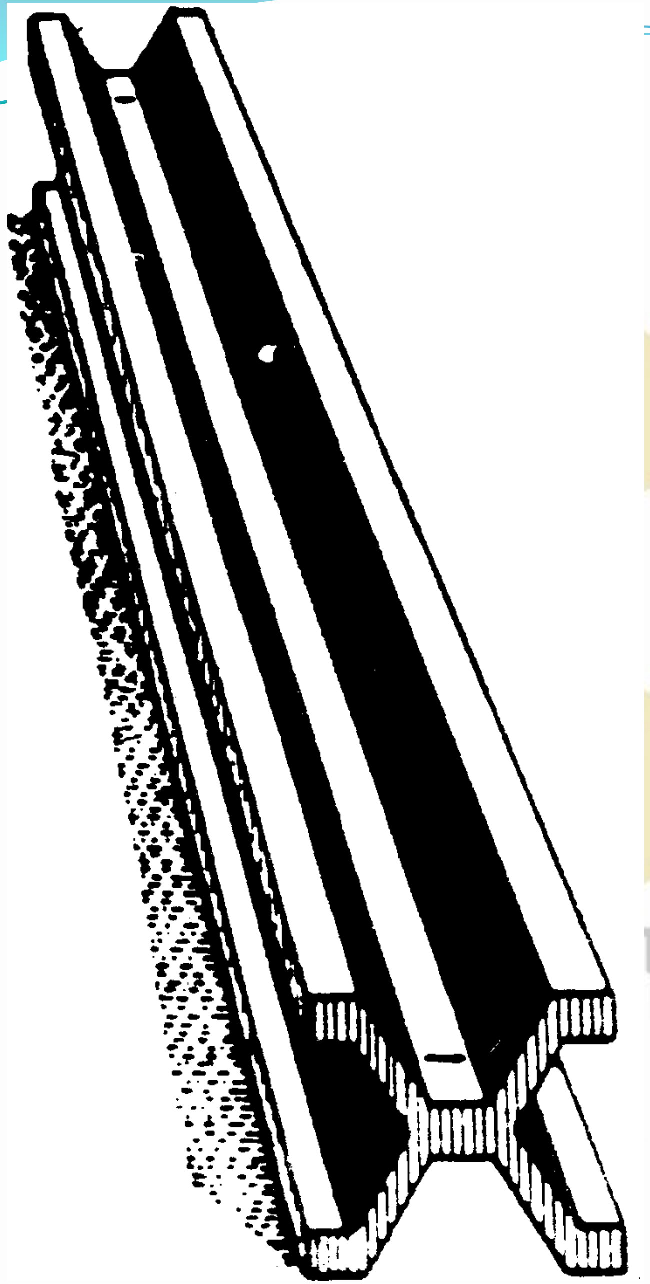
$$d\Omega = \frac{dA}{r^2}$$

SI FUNDAMENTAL UNIT OF LENGTH

* Previously: 1 metre (from the Greek metron=measure)= one ten-millionth of the distance from the North Pole to the equator; standard metre (platinum-iridium alloy rod with two marks one metre apart) produced in 1799

* The metre is the length of the path travelled by light in vacuum during a time interval of 1/299,792,458 of a second

The standard meter(previous)



It is a bar of Platinum-Iridium kept at a constant temperature The meter is defined as the distance between the two scratch marks

TYPICAL DISTANCES

Diameter of the Milky Way	$2x10^{20}$ m
One light year	$4x10^{16}$ m
Distance from Earth to Sun	$1.5x10^{11}$ m
Radius of Earth	$6.37x10^{6}$ m
Length of a football field	10^{2} m
Height of a person	$2x10^{0}$ m
Diameter of a CD	$1.2x10^{-1}$ m
Diameter of the aorta	$1.8x10^{-2}$ m
Diameter of a red blood cell	$8x10^{-6}$ m
Diameter of the hydrogen atom	10^{-10} m
Diameter of the proton	$2x10^{-15}$m

The Milky Way is the galaxy that contains our Solar System. The descriptive "milky" is derived from the appearance from Earth of the galaxy – a band of light seen in the night sky formed from stars
Age: 13.21 billion years
Number of stars: 100–400 billion

Range and Order of Lengths

S.No	Size of the object or distance	Length (m)
1	Size of proton	10^{-15}
2	Size of atomic nucleus	10^{-14}
3	Size of the Hydrogen atom	10^{-10}
4	Length of a typical virus	10^{-8}
5	Wavelength of a light	10^{-7}
6	Size of the red blood corpuscle	10^{-5}
7	Thickness of a paper	10^{-4}
8	Height of the Mount Everest from sea level	10^{4}
9	Radius of the Earth	10^{7}
10	Distance of the moon from the earth	10^{8}
11	Distance of the Sun from the earth	10^{11}
12	Distance of the Pluto from the Sun	10^{13}
13	Size of our Galaxy	10^{21}
14	Distance of the Andromeda galaxy	10^{22}
15	Distance of the boundary of observable universe	10^{26}

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Some Units are retained for general use (Though outside SI)

Name	Symbol	Value in SI Unit
minute	min	60 s
hour	h	60 min = 3600 s
day	d	24 h = 86400 s
year	y	365.25 d = 3.156 x 10^7 s
degree	o	10 = (π / 180) rad
litre	l	1 dm^3 = 10^{-3} m^3
tonne	t	10^3 kg
carat	c	200 mg
bar	bar	0.1 MPa = 10^5 Pa
curie	ci	3.7 x 10^{10} s^{-1}
roentgen	r	2.58 x 10^{-4} C/kg
quintal	q	100 kg
barn	b	100 fm^2 = 10^{-28} m^2
are	a	1 dam^2 = 10^2 m^2
hectare	ha	1 hm^2 = 10^4 m^2
standard atmosphere pressure	atm	101325 Pa = 1.013 x 10^5 Pa

Units to Know About

- Length
    - Angstrom (Å) = 10^{-10}m

MEASUREMENT OF LENGTH

The order of distances varies from 10^{-14} m (radius of nucleus) to 10^{25} m (radius of the Universe)

The distances ranging from 10^{-5} m to 10^{2} m can be measured by direct methods which involves comparison of the distance or length to be measured with the chosen standard length.

Example:

i) A metre rod can be used to measure distance as small as 10^{-3} m.
ii) A vernier callipers can be used to measure as small as 10^{-4} m.
iii) A screw gauge is used to measure as small as 10^{-5} m.

For very small distances or very large distances indirect methods are used.

Range of Lengths

The size of the objects we come across in the Universe varies over a very wide range. These may vary from the size of the order of 10^{-14} m of the tiny nucleus of an atom to the size of the order of 10^{26} m of the extent of the observable Universe.
We also use certain special length units for short and large lengths which are given below:

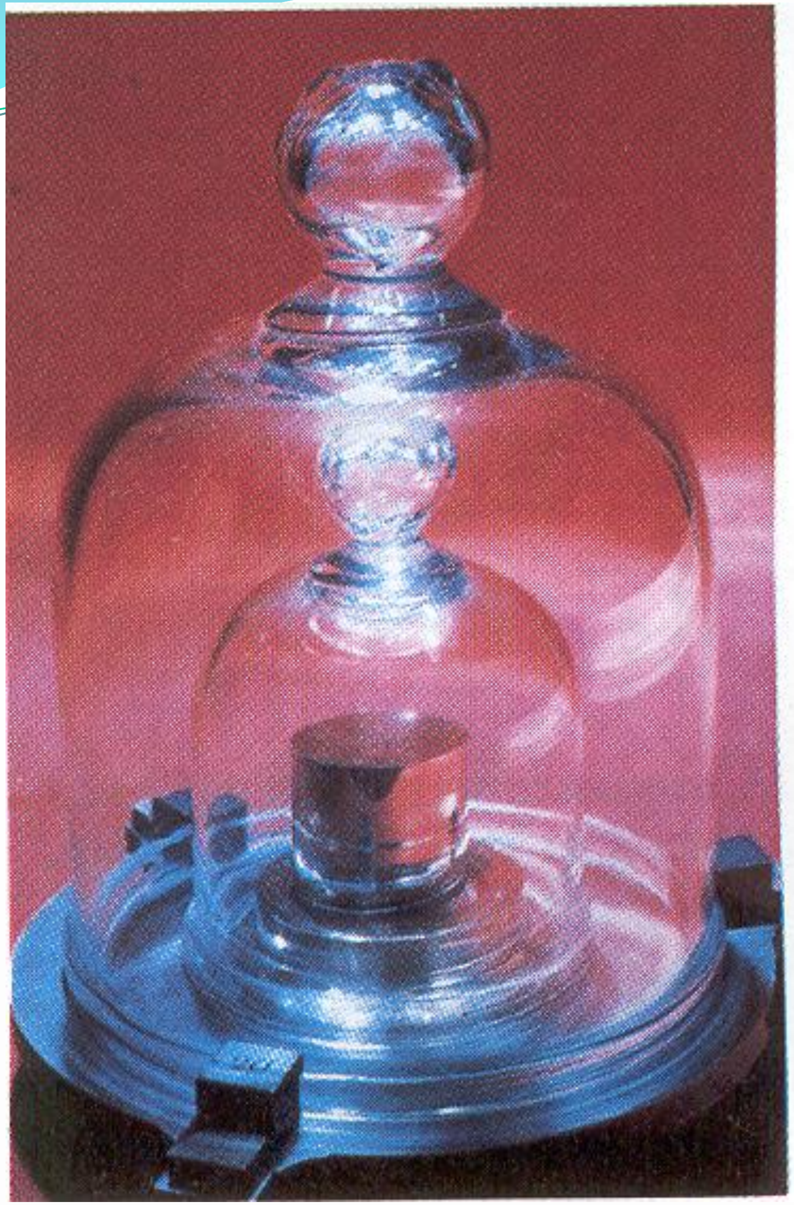
Unit	Symbol	Value	Definition
1 fermi	1 f	10^{-15} m	
1 angstrom	1 Å	10^{-10} m	
1 Astronomical Unit	1 AU	1.496×10^{11} m	Average distance of the Sun from the Earth
1 light year	1 ly	9.46×10^{15} m	The distance that light travels with speed of 3×10^8 m s^{-1} in 1 year
1 parsec		3.08×10^{16} m (3.26 ly)	The distance at which average radius of Earth's orbit subtends an angle of 1 arc second

SI FUNDAMENTAL UNIT OF MASS

The kilogram is equal to the mass of the international prototype of the kilogram.

Cylinder of platinum and iridium 0.039 m in height and diameter

The mass is not the weight (=measure of the gravitational force)



The kilogram (kg)

It is defined as the mass equal to the mass of a cylinder made of platinum-iridium made by the International Bureau of Weights and Measures. All other standards are made as copies of this cylinder

TYPICAL MASSES

• Galaxy (Milky Way)	4×10^{41} kg
• Sun	2×10^{30} kg
• Earth	5.97×10^{24} kg
• Elephant	5400 kg
• Automobile	1200 kg
• Human	70 kg
• Honeybee	1.5×10^{-4} kg
• Red blood cell	10^{-13} kg
• Bacterium	10^{-15} kg
• Hydrogen atom	1.67×10^{-27} kg
• Electron	9.11×10^{-31} kg

SI FUNDAMENTAL UNIT OF TIME

- Previously: the revolving Earth was considered a fairly accurate timekeeper.

  Mean solar day = 24 h = 24 x 60 min = 24x60x60 s = 84,400 s

  Today the most accurate timekeeper are atomic clock

  (accuracy 1 second in 300,000 years)

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

TYPICAL TIMES

• Age of the universe	5×10^{17} s
• Age of the Earth	1.3×10^{17} s
• Existence of human species	6×10^{13} s
• Human lifetime	2×10^{9} s
• One year	3×10^{7} s
• One day	8.6×10^{4} s
• Time between heartbeat	0.8 s
• Human reaction time	0.1 s
• One cycle of a high-pitched sound wave	5×10^{-5} s
• One cycle of an AM radio wave	10^{-6} s
• One cycle of a visible light wave	2×10^{-15} s

SI FUNDAMENTAL UNIT OF TEMPERATURE

* The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

The triple point of any substance is that temperature and pressure at which the material can coexist in all three phases (solid, liquid and gas) at equilibrium.

Other Units to Know About

- Temperature

  3 common scales

    Fahrenheit

    Celsius

    Kelvin

Temperature

Freezing Pt	Boiling Pt
32 °F	212 °F
0 °C	100 °C
273.15 K	373.15 K

Temperature

- Formulas for converting scales

$$°C + 273.15 = K$$

$$1.8(°C) + 32 = °F$$

Unit of electric current (ampere)

- The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to $2 \times 10{-}7$ newton per meter of length.

Unit of amount of substance (mole)

1. The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12; its symbol is "mol."
2. 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.

Unit of luminous intensity (candela)

- The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 × 1012 hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.
- It follows that the spectral luminous efficacy for monochromatic radiation of frequency of 540 × 1012 hertz is exactly 683 lumens per watt, K(ʎ555) = 683 lm/W = 683 cd sr/W (the wavelength ʎ of radiation of this frequency is about 555 nm).

Derived Units

- Area

Derived Units

- Area

length squared

(m^2)

Second Derivative

- Volume

Second Derivative

- Volume

  length cubed

  (m^3)

Other units to know about

- Volume

  Liter (l) = 1 dm^3

  1 l = 1.06 qt

  1 ml = 1 cm^3

Derived Units

- Density

Derived Units

- Density

mass per unit volume

(kg/m^3)

First Derivative

- Speed (velocity)

Second Derivative

- Speed (velocity)

distance traveled (displacement) per unit time

(m/s)

Third Derivative

- Acceleration

Derived Units

- Acceleration

speed (velocity) changed per unit time

(m/s^2)

Derived Units

- Force

Derived Units

- Force

  mass times acceleration of an object

  (kg m/s^2)

Derived Units

- Force
- Note:

$$(kg\ m/s^2) = \text{Newton (N)}$$

Derived Units

- Pressure

Derived Units

- Pressure

  Force per unit area

  (kg /m s^2) or N/m^2

Derived Units

- Pressure

Note:

$(kg\ /m\ s^2) = N/m^2 = \text{Pascal (Pa)}$

Other Units to Know About

- Pressure

  Atmosphere (atm) def.- the pressure exerted by the earth's armosphere at sea level on an average day.

  torr or mm of Mercury (mmHg) def.-the pressure exerted by a column of mercury (Hg) 1 mm high.

Derived Units

- Energy

Derived Units

- Energy

  Force times distance traveled

  $$(kg\ m^2 /s^2)$$

Derived Units

- Energy

Note:

$(kg\ m^2/s^2)$ = Joule (J)

SI DERIVED UNITS

Formed by combining fundamental units according to the algebraic relations linking the corresponding quantities

Physical quantity	unit	equivalent
FREQUENCY	Hertz	$Hz = 1/s = s^{-1}$
FORCE	Newton	$N = kg.m.s^{-2}$
PRESSURE	Pascal	$Pa = N.m^{-2}$ $= kg.\ m^{-1}\ s^{-2}$
ENERGY, WORK	Joule	$J = N.m$ $= kg.m^2.s^{-2}$
POWER	Watt	$W = J.s^{-1}$ $= kg.m^2.s^{-3}$

Derived units

The physical quantities whose defining operations are based on other physical quantities are called as derived units. Such as-

- speed (v) = distance / time * unit: m/s
- acceleration (a) = velocity / time * unit: m/s/s = m/s^2
- force (F) = mass x acceleration *unit: kgm/s^2
- energy (E) = force x distance *unit: kgm^2/s^2 = Nm=J
- charge (Q) = current x time *unit: As = C

COMMON SI PREFIXES

Power	Prefix	Abbreviation
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}	deka	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

SIGNIFICANT DIGITS

- The result of a measurement is known only within a certain degree of accuracy

- significant digits are the number of digits reliably known (excluding digits that indicate the decimal place)

- 3.72 and 0.0000372 have both 3 significant digits

SIGNIFICANT DIGITS

power of ten

Scientific notation

3.50×10^{-3}

number of
Sig digits

SIGNIFICANT DIGITS

How many significant digits are in

* 35.00 — 4
* 35 — 2
* $3.5x10^{-2}$ — 2
* $3.50x10^{-3}$ — 3

?

CONVERTING UNITS

- You will need to be able to convert from one unit to another for the same quantity.

Example:

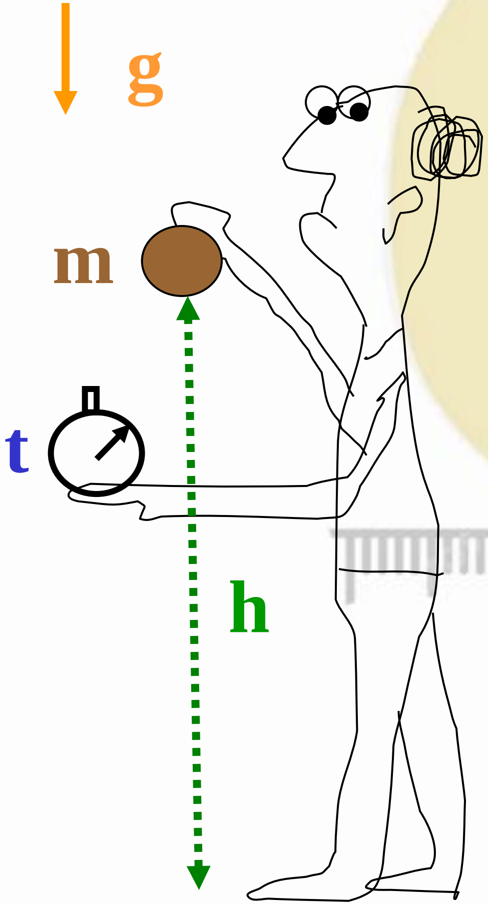
Convert 72 km.h^{-1} to m.s^{-1}

$$72km.h^{-1} = 72\frac{\cancel{km}}{\cancel{h}} \times \frac{1000m}{1\cancel{km}} \times \frac{1\cancel{h}}{3600s}$$

$$= \frac{72}{3.6} m.s^{-1} = 20 m.s^{-1}$$

Question: How do we define all other units?

Answer: Using an equation that connects the parameter whose units we wish to define with other parameters whose units are known.



Example 1: Find the units of acceleration

$h = gt^2/2$ Solve this equation for g

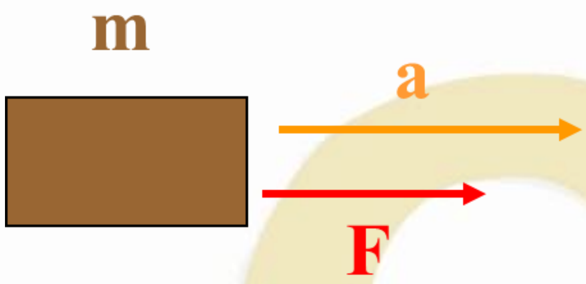
$g = 2h/t^2$

Units of left hand side = Units of right hand side

Units (g) = units $(2h/t^2)$ = m/s^2

Note: The number 2 has no units

Example 2: Find the units of force



Newton's second law

$$F = ma$$

Units(F) = units(m) × units(a) = $kg.m/s^2$

Note: We call the SI unit of force the "Newton" in honor of Isaac Newton who formulated the three laws of motion in mechanics. Symbol: N

Conversions

* You will need to be able to convert from one unit to another for the same quantity
  * J to kWh
  * J to eV
  * Years to seconds
  * And between other systems and SI

KWh to J and J to eV

* $1\ kWh = 1kW \times 1\ h$
  $= 1000W \times 60 \times 60\ s$
  $= 1000\ Js^{-1} \times 3600\ s$
  $= 3600000\ J$
  $= 3.6 \times 10^6\ J$

* $1\ eV = 1.6 \times 10^{-19}\ J$

SI Format

The accepted SI format is

- $m\ s^{-1}$ not m/s
- $m\ s^{-2}$ not m/s/s

* i.e. we use the suffix not dashes

ORDER OF MAGNITUDES

* An order of magnitude calculation is a rough estimate designed to be accurate to within a factor of about 10

* To get ideas and feeling for what size of numbers are involved in situation where a precise count is not possible or important

ORDER OF MAGNITUDE

TYPICAL DISTANCES

Diameter of the Milky Way	2×10^{20} m
One light year	4×10^{16} m
Distance from Earth to Sun	1.5×10^{11} m
Radius of Earth	6.37×10^{6} m
Length of a soccer pitch	10^{2} m
Height of a person	2×10^{0} m
Diameter of a CD	1.2×10^{-1} m
Diameter of the aorta	1.8×10^{-2} m
Diameter of a red blood cell	8×10^{-6} m
Diameter of the hydrogen atom	10^{-10} m
Diameter of the proton	2×10^{-15} m

ORDER OF MAGNITUDE

EXAMPLE

Estimate the number of seconds in a human "lifetime."
You can choose the definition of "lifetime."
Do all reasonable choices of "lifetime" give answers that have the same order of magnitude?

The order of magnitude estimate: 10^9 seconds

- 70 yr = 2.2×10^9 s
- 100 yr = 3.1×10^9 s
- 50 yr = 1.6×10^9 s

Summary for Range of Magnitudes

* You will need to be able to state (express) quantities to the nearest order of magnitude, that is to say to the nearest 10^x

Range of magnitudes of quantities in our universe

* Sizes
  * From 10^{-15} m (subnuclear particles)
  * To 10^{+25} m (extent of the visible universe)
* masses
  * From 10^{-30} kg (electron mass)
  * To 10^{+50} kg (mass of the universe)
* Times
  * From 10^{-23} s (passage of light across a nucleus)
  * To 10^{+18} s (age of the universe)

Ratios

* You will also be required to state (express) ratios of quantities as differences of order of magnitude.

Example:

* the hydrogen atom has a diameter of 10^{-10} m
* whereas the nucleus is 10^{-15} m
* The difference is 10^{5}
* A difference of 5 orders of magnitude

Now try these ratios

* Mass of electron to your mass
* Radius of atom to your height
* Mass of electron to mass of uranium atom
* Radius of Earth to size of universe

Solutions

* Mass of electron to your mass

$10^{-30} / 10^{2} = 10^{-32}$ so 32 orders of mag.

* Radius of atom to your height

$10^{-10} / 10^{0} = 10^{-10}$ so 10 orders of mag.

* Mass of electron to mass of uranium atom

$10^{-30} / 10^{-25} = 10^{-5}$ so 5 orders of mag.

* Radius of Earth to size of universe

$10^{7} / 10^{26} = 10^{-19}$ so 19 orders of mag.

IMPORTANT

The following conventions are adopted while writing a unit:

(1) Even if a unit is named after a person the unit is not written in capital letters. i.e. we write joules not Joules.

(2) For a unit named after a person the symbol is a capital letter e.g. for joules we write 'J' and the rest of them are in lowercase letters e.g. second is written as 's'.

(3) The symbols of units do not have plural form i.e. 70 m not 70 ms or 10 N not 10 Ns.

(4) Punctuation marks are not written after the unit e.g. 1 litre = 1000 cc not 1000 c.c.

Advantages of SI

1. SI is a coherent system of units i.e system based on a certain set of fundamental units, from which all derived units are obtained by multiplication or division without introducing numerical factors.
2. SI is a rational system of units as it assigns only one unit to be a particular physical quantity. For example, joule is the unit for all types of energy. This is not so in other systems of units.

3. SI is an absolute system of units. There are no gravitational units on the system. This use factor 'g' is thus eliminated.
4. SI is a metric system i.e the multiples and sub multiples of units are expressed as power of 10.
5. In current electricity, the absolute units on the SI, like ampere for current, volt for potential difference, ohm for resistance, Henry for inductance, farad for capacity and so on.

16 MCQ'S

1 . 1KWH is unit of

1. Time
2. Power
3. Energy
4. Stress

2. Unit of Intensity of magnetic induction field is

1. N/Am
2. Tesla
3. Wb/m^2
4. All above

3. Which of the following has no units?

1. Thermal capacity
2. Magnetic susceptibility
3. Angular acceleration
4. Moment of a magnet

4. Which one of the following units is a fundamental unit?

1. watt
2. joule/sec
3. ampere
4. newton

5. kg m/sec is the unit of

1. Impulse
2. Angular acceleration
3 . Capacity of condenser
4. Acceleration.

6. Which of the following is a common unit of a physical quantity in M.K.S & S.I systems.

1. ampere
2.kelvin
3. mole
4. joule/sec

7. Which of the following is Unit of length?

1. Lunar Month
2. Kelvin
3. candela
4. Light year

8. rad/sec^2 is the unit of

1. Angular displacement
2. Angular velocity
3. Angular acceleration
4. Angular momentum

9. Which of the following is not a unit of power .

1. Watt
2. joule/hr
3. Nm/sec
4. N/sec

10. If the unit of force were 20N, that of power were 1MW and that of time were 1 millisecond then the unit of length would be

a) 20m
b) 50m
c) 100m
d) 1000m

11. The physical quantity having units of mass is

1. Density
2. Momentum
3. Inertia
4. Moment of force

12. A force 100N acts on a body. If the units of mass and length are doubled and unit of time is halved, then the force in the new system changes to

a) 160N
b) 1.6 N
c) 16N
d) 1600N

13. The electric resistance of a conductor is 54 ohm. If the unit of mass and length are tripled, units of time and electric current are doubled .Then the value of new electric resistance.

a)540 ohm

b) 1080 ohm

c) 1620 ohm

d)1944 ohm

14.Which of the following is a derived unit ?

1. ampere
2. mole
3. candela
4. newton

15) The power of a motor is 150W.If the unit of force is doubled, unit of velocity is tripled what will be the new unit of power.

a) 600W b)750W

c) 900W d) 300w

16. The fundamental unit which is common in F.P.S and M.K.S systems is

1. foot 2. sec

3.kilo gram 4. pound

DIMENSIONAL ANALYSIS

Dimensional Analysis

The dimensional analysis of a physical parameter such as velocity v, acceleration a , etc expresses the parameter as an algebraic combination of length [L], mass [M], and time [T]. This is because **all** measurements in mechanics can be ultimately be reduced to the measurement of length, mass , and time. [L], [M], and [T] are known as **primary dimensions**

How do we derive the dimensions of a parameter?

- The dimensions of a physical quantity are the powers to which the fundamental quantities are raised to represent that physical quantity.
- The equation which expresses a physical quantity in terms of the fundamental units of mass, length and time, is called dimensional equation.
- According to this principle of homogeneity a physical equation will be dimensionally correct if the dimensions of all the terms in the all the terms occurring on both sides of the equation are the same.

DIMENSIONS OF PHYSICAL QUANTITIES

The nature of a physical quantity is described by its dimensions.

All the physical quantities can be expressed in terms of the seven base or fundamental quantities viz. mass, length, time, electric current, thermodynamic temperature, intensity of light and amount of substance, raised to some power.

The dimensions of a physical quantity are the powers (or exponents) to which the fundamental or base quantities are raised to represent that quantity.

Note:

Using the square brackets [ ] around a quantity means that we are dealing with 'the dimensions of' the quantity.

Example:

i) The dimensions of volume of an object are $[L^3]$

ii) The dimensions of force are $[MLT^{-2}]$

iii)The dimensions of energy are $[ML^2T^{-2}]$

Dimensional Quantity

Dimensional quantity is a physical quantity which has dimensions.

For example: Speed, acceleration, momentum, torque, etc.

Dimensionless Quantity

Dimensionless quantity is a physical quantity which has no dimensions.

For example: Relative density, refractive index, strain, etc.

Dimensional Constant

Dimensional constant is a constant which has dimensions.

For example: Universal Gravitational constant, Planck's constant, Hubble constant, Stefan constant, Wien constant, Boltzmann constant, Universal Gas constant, Faraday constant, etc.

Dimensionless Constant

Dimensionless constant is a constant which has no dimensions.

For example: 5, -.0.38, e, π, etc.

DIMENSIONAL ANALYSIS

Notation: L length; M mass; T time

QUANTITY	DIMENSION
Distance	[L]
Area	[L^2]
Volume	[L^3]
Velocity	[L] . [T^{-1}]
Acceleration	[L] . [T^{-2}]
Energy	[M] [L^2] . [T^{-2}]

DIMENSIONAL FORMULAE AND DIMENSIONAL EQUATIONS

The expression which shows how and which of the base quantities represent the dimensions of a physical quantity is called the *dimensional formula* of the given physical quantity.

Example:

(i) The dimensional formula of the volume is $[M^{\circ} L^{3} T^{\circ}]$,
(ii)The dimensional formula of speed or velocity is $[M^{\circ} L T^{-1}]$
(iii) The dimensional formula of acceleration is $[M^{\circ} L T^{-2}]$

An equation obtained by equating a physical quantity with its dimensional formula is called the dimensional equation of the physical quantity.

Example:

(i) $[V] = [M^{\circ} L^{3} T^{\circ}]$
(ii) $[v] = [M^{\circ} L T^{-1}]$
(iii) $[a] = [M^{\circ} L T^{-2}]$

Quantities having the same dimensional formulae

1. Impulse and momentum
2. Work, energy, torque, moment of force
3. Angular momentum, Planck's constant, rotational impulse
4. Stress, pressure, modulus of elasticity, energy density
5. Force constant, surface tension, surface energy
6. Angular velocity, frequency, velocity gradient
7. Gravitational potential, latent heat
8. Thermal capacity, entropy, universal gas constant and Boltzmann's const.
9. Force, thrust
10. Power, luminous flux

Dimensional formulae for physical quantities often used in Physics are given at the end. (From Slide 26)

DIMENSIONAL ANALYSIS AND ITS APPLICATIONS

Dimensional analysis is a tool to find or check relations among physical quantities by using their dimensions.

When magnitudes of two or more physical quantities are multiplied, their units should be treated in the same manner as ordinary algebraic symbols.

We can cancel identical units in the numerator and denominator.

Similarly, physical quantities represented by symbols on both sides of a mathematical equation must have the same dimensions.

Main uses of the dimensional analysis

- There are three main uses of the dimensional analysis-
- (a) To convert a unit of given physical quantities from one system of units to another system for which we use

  $$n_2 = n_1[M_1/M_2]^a[L_1/L_2]^b[T_1/T_2]^c$$

- (b) To check the correctness of a given physical relation.
- (c) To derive a relationship between different physical quantities.

I. Checking the Dimensional Consistency of Equations

The principle of homogeneity of dimensions:

The magnitudes of physical quantities may be added together or subtracted from one another only if they have the same dimensions.

For example, initial velocity can be added to or subtracted from final velocity because they have same dimensional formula $[M^0LT^{-1}]$.

But, force and momentum can not be added because their dimensional formulae are different and are $[MLT^{-2}]$ and $[MLT^{-1}]$ respectively.

1. To check the dimensional consistency of $v^2 = u^2 + 2as$

The dimensions of the quantities involved in the equation are:

$[u] = [M^0LT^{-1}]$

$[v] = [M^0LT^{-1}]$

$[a] = [M^0LT^{-2}]$

$[s] = [M^0LT^0]$

Substituting the dimensions in the given equation,

(Note that the constant 2 in the term '2as' does not have dimensions)

$$[M^0LT^{-1}]^2 = [M^0LT^{-1}]^2 + [M^0LT^{-2}]\,[M^0LT^0]$$

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

Each term of the above equation is having same dimensions. Therefore, the given equation is dimensionally correct or dimensionally consistent.

DIMENSIONAL ANALYSIS

Dimensional consistency

distance velocity time distance

$$x = vt + x_o$$

$$[\boldsymbol{L}] = \frac{[\boldsymbol{L}]}{\cancel{[\boldsymbol{T}]}}\cancel{[\boldsymbol{T}]} + [\boldsymbol{L}] = [\boldsymbol{L}] + [\boldsymbol{L}] = [\boldsymbol{L}]$$

Note:

If an equation fails the consistency test, it is proved wrong;
But if it passes, it is not proved right.

Thus, a dimensionally correct equation need not be actually an exact (correct) equation, but a dimensionally wrong (incorrect) or inconsistent equation must be wrong.

Example: Equations $v^2 = u^2 - 2as$ or $v^2 = u^2 + \frac{1}{2}as$ are dimensionally consistent but are incorrect equations in mechanics.

Albert Einstein tried his famous mass-energy equation as

$$E = m / c^2,\ E = m^2 / c,\ E = m^2 c, \text{ etc.}$$

Finally he settled with $E = m c^2$ using dimensions and then proved it with the help of Calculus.

2. To check the dimensional consistency of ½ $mv^2 = mgh$

The dimensions of the quantities involved in the equation are:

$[m] = [ML^0T^0]$
$[v] = [M^0LT^{-1}]$
$[g] = [M^0LT^{-2}]$
$[h] = [M^0LT^0]$

Substituting the dimensions in the given equation,

$[ML^0T^0]\,[M^0LT^{-1}]^2 = [ML^0T^0]\,[M^0LT^{-2}]\,[M^0LT^0]$

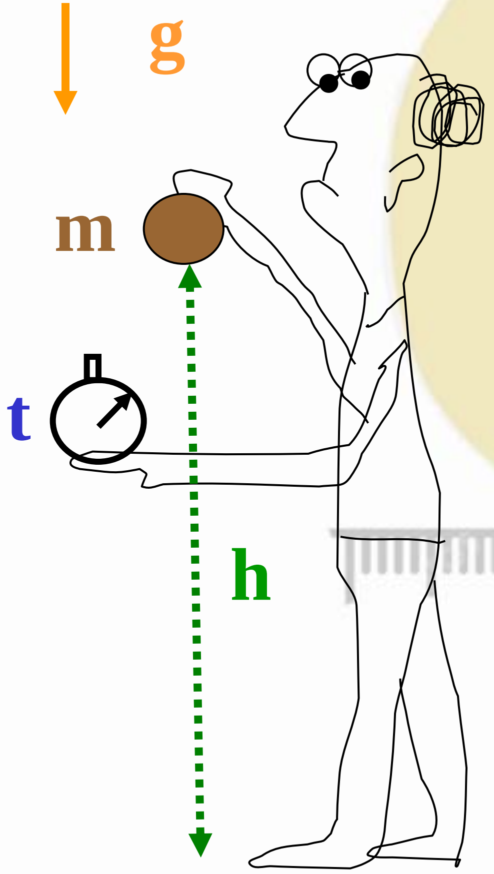
(Note that the constant ½ in the term '½ mv^2' does not have dimensions)

$[ML^2T^{-2}] = [ML^2T^{-2}]$

Each term of the above equation is having same dimensions.Therefore, the given equation is dimensionally correct or dimensionally consistent.

Dimensional analysis can be used to detect errors in equations

Example:



$h = gt^2/2$ [LHS] = [RHS]

[LHS] = [h] = [L]

$[RHS] = [gt^2/2] = [g][t^2] = [L][T]^{-2}[T]^2 = [L]$

Indeed [LHS] = [RHS] = [L] as might be expected from the equation $h = gt^2/2$ which we know to be true.

Note 1: If an equation is found to be dimensionally incorrect then it is incorrect

Note 2: If an equation is dimensionally correct it does not necessarily means that the equation is correct.

Example: Lets try the (incorrect) equation

$h = gt^2/3$ $[LHS] = [L]$

$[RHS] = [g][t^2] = [L]$

Even though $[LHS] = [RHS]$ equation

$h = gt^2/3$ is wrong!

II. Conversion of units in one system into another system

Units are derived from the dimensions and the dimensions are derived from the actual formulae of physical quantities.

If the dimensions are known for a physical quantity, then it is easy to express it in fps, cgs, mks, SI systems or any other arbitrary chosen system.

$$n_1[M_1^a L_1^b T_1^c] = n_2[M_2^a L_2^b T_2^c] \qquad \frac{n_2}{n_1} = \left(\frac{M_1}{M_2}\right)^a \left(\frac{L_1}{L_2}\right)^b \left(\frac{T_1}{T_2}\right)^c$$

n_1 and n_2 are the magnitudes in the respective systems of units.

Smaller the unit bigger the magnitude of a physical quantity and vice versa.

For example, 1 m = 100 cm (m is the bigger unit and cm is the smaller one)

1 N = 10^5 dynes (Newton is bigger and dyne is smaller)

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Example:

1. To convert 1 joule in erg.

‘joule’ is unit of energy or work in SI system and ‘erg’ is the unit in cgs system.
The dimensional formula of energy or work is $[ML^2T^{-2}]$.
The units from dimensions in SI and cgs systems are kg m^2 s^{-2} and g cm^2 s^{-2} respectively.

Let n_1 joule = n_2 erg

	SI System	cgs System
Magnitude	$n_1 = 1$	$n_2 = ?$
Mass (M)	1 kg (=1000 g)	1 g
Length (L)	1 m (= 100 cm)	1 cm
Time (T)	1 s	1 s
$[M^aL^bT^c] = [ML^2T^{-2}]$ Therefore, a=1, b=2, c=-2		

$$n_2 = n_1 \left(\frac{M_1}{M_2}\right)^a \left(\frac{L_1}{L_2}\right)^b \left(\frac{T_1}{T_2}\right)^c$$

$$n_2 = 1 \left(\frac{1000\text{ g}}{1\text{ g}}\right)^1 \left(\frac{100\text{ cm}}{1\text{ cm}}\right)^2 \left(\frac{1\text{ s}}{1\text{ s}}\right)^{-2}$$

$$n_2 = 1\,(1000)^1\,(100)^2\,(1)^{-2}$$

$$n_2 = 10^7$$

$\therefore$ $\boxed{1 \text{ joule} = 10^7 \text{ erg}}$

2.To convert 1 newton into a system where mass is measured in mg, length in km and time in minute

'newton or kg m s^{-2}' is unit of force in SI system and 'mg km min^{-2}' is the unit in the new system. The dimensional formula of force is $[MLT^{-2}]$.

Let n_1 newton = n_2 mg km min^{-2}

	SI System	New System
Magnitude	$n_1 = 1$	$n_2 = ?$
Mass (M)	1 kg (=10^6 mg)	1 mg
Length (L)	1 m (= 1/1000 km)	1 km
Time (T)	1 s (= 1/60)	1 min
$[M^aL^bT^c] = [MLT^{-2}]$ Therefore, a=1, b=1, c=-2		

$$n_2 = n_1 \left(\frac{M_1}{M_2}\right)^a \left(\frac{L_1}{L_2}\right)^b \left(\frac{T_1}{T_2}\right)^c$$

$$n_2 = 1 \left(\frac{10^6 \text{ mg}}{1 \text{ mg}}\right)^1 \left(\frac{1/1000 \text{ km}}{1 \text{ km}}\right)^1 \left(\frac{1/60 \text{ m}}{1\text{m}}\right)^{-2}$$

$$n_2 = 1\,(10^6)^1\,(10^{-3})^1\,(60)^2$$

$$n_2 = 3.6 \times 10^6$$

$\therefore$ 1 newton = 3.6×10^6 mg km min^{-2}

III. Deducing Relation among the Physical Quantities

$$T = k\sqrt{\frac{l}{g}}$$

The method of dimensions can sometimes be used to deduce relation among the physical quantities.

For this we should know the dependence of the physical quantity on other quantities (upto three physical quantities or linearly independent variables) and consider it as a product type of the dependence.

Example:

1. Consider a simple pendulum, having a bob attached to a string that oscillates under the action of the force of gravity. Suppose that the period of oscillation of the simple pendulum depends on its length (l), mass of the bob (m) and acceleration due to gravity (g). Derive the expression for its time period using method of dimensions.

The dependence of time period T on the quantities l, g and m as a product may be written as:

$$T = k\, l^x m^y g^z$$

where k is dimensionless constant and x, y and z are the exponents.

The dimensions of the quantities involved in the equation are:

$[m] = [ML^0T^0]$

$[l] = [M^0LT^0]$

$[g] = [M^0LT^{-2}]$

$[T] = [M^0L^0T]$

By substituting dimensions on both sides of $T = k\, l^x m^y g^z$, we have

$[M^0L^0T] = [M^0LT^0]^x [ML^0T^0]^y [M^0LT^{-2}]^z$

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

On equating the dimensions on both sides, we have

$y = 0$

$x + z = 0$

$-2z = 1$

So that $x = ½$, $y = 0$, $z = -½$

Then, $T = k\, l^{½} g^{-½}$

Or $T = k\sqrt{\dfrac{l}{g}}$

The value of k is 2π and determined from other methods.

$\therefore\ \boxed{T = 2\pi\sqrt{\dfrac{l}{g}}}$

Demerits of Dimensional Analysis

The dimensional analysis can not be used in the following cases:

1. The value of constants in an equation can not be determined as the constants do not have dimensions.
2. Only dimensional consistency and not the physical consistency can be tested.
3. Dimensions can be found from the physical quantity, but physical quantity can not be always guessed from dimensions because two or more quantities may have same dimensions.
4. The equation containing the dependency on more than 3 quantities can not be determined using only M, L and T.
   (Note that if 4 independent quantities are involved, then 4 variables and hence 4 simultaneous equations are required; hence there must be 4 fundamental dimensions)
5. The equation containing exponential, trigonometric, logarithmic functions, etc. can not be derived as they do not have dimensions.
6. The equations having the relations other than products / quotients can not be derived

Limitations of Dimensional Analysis

- Dimensional analysis has no information on dimensionless constants.
- If a quantity is dependent on trigonometric or exponential functions, this method cannot be used.
- In some cases, it is difficult to guess the factors while deriving the relation connecting two or more physical quantities.
- This method cannot be used in an equation containing two or more variables with same dimensions.
- It cannot be used if the physical quantity is dependent on more than three unknown variables.
- This method cannot be used if the physical quantity contains more than one term, say sum or difference of two terms.

Dimensional formulae for some physical quantities

	Physical quantity	Symbol	Formula	Dimensional formula	Unit
General	Length	L	Fundamental	$[M^0LT^0]$	m
	Mass	M	Fundamental	$[ML^0T^0]$	kg
	Time	T	Fundamental	$[M^0L^0T]$	s
	Area	A	Length x breadth	$[M^0L^2T^0]$	m^2
	Volume	V	Length x breadth x height	$[M^0L^3T^0]$	m^3
	Linear density		Mass / length	$[ML^{-1}T^0]$	kg m^{-1}
	Mass Density	ρ	Mass / volume	$[ML^{-3}T^0]$	Kg m^{-3}
	Specific gravity or relative density	RD	Density of the substance / density of water	$[M^0L^0T^0]$	--
	Specific volume		1 / density	$[M^{-1}L^3T^0]$	kg^{-1} m^3
	Time period	T	Time taken for 1 oscillation	$[M^0L^0T]$	s
	Frequency	ν	1 / time period	$[M^0L^0T^{-1}]$	Hz or s^{-1}

Mechanics	Distance, displacement, wavelength, focal length	s, λ, f		$[M^0LT^0]$	m
	Speed	v	Distance / time	$[M^0LT^{-1}]$	$m\ s^{-1}$
	Velocity	v	Displacement / time	$[M^0LT^{-1}]$	$m\ s^{-1}$
	Velocity gradient		dv / dx	$[M^0L^0T^{-1}]$	s^{-1}
	Acceleration or acceleration due to gravity	a or g	Velocity / time	$[M^0LT^{-2}]$	$m\ s^{-2}$
	Momentum	p	Mass x velocity	$[MLT^{-1}]$	$kg\ m\ s^{-1}$
	Force	F	Mass x acceleration	$[MLT^{-2}]$	$kg\ m\ s^{-2}$ or newton (N)
	Force constant or spring constant	K	Force / extension	$[ML^0T^{-2}]$	$N\ m^{-1}$
	Impulse	j	Force x time	$[MLT^{-1}]$	N s or $kg\ m\ s^{-1}$

Mechanics	Work	W	Force x Displacement	$[ML^2T^{-2}]$	$kg\ m^2s^{-2}$ or joule (J)
	Energy	E	Capacity to do work	$[ML^2T^{-2}]$	joule (J)
	Energy density		Energy / volume	$[ML^{-1}T^{-2}]$	$J\ m^{-3}$
	Power	P	(Work or energy) / time	$[ML^2T^{-3}]$	$J\ s^{-1}$ or Watt (W)
	Pressure	P	Force / area	$[ML^{-1}T^{-2}]$	$N\ m^{-2}$ or Pascal (Pa)
	Pressure head			$[M^0LT^0]$	m

Gravitation	Gravitational potential		G P E / mass	$[M^0L^2T^{-2}]$	$J\ kg^{-1}$
	Universal gravitational constant	G	$G = F\ d^2/(m_1m_2)$	$[M^{-1}L^3T^{-2}]$	$N\ m^2\ kg^{-2}$
	Intensity of gravitational field		F / m	$[M^0L^1T^{-2}]$	$N\ kg^{-1}$

Rotational Motion	Angle	θ	Arc/radius	$[M^oL^oT^o]$	rad
	Angular displacement	θ		$[M^oL^oT^o]$	rad
	Angular impulse		Torque x time	$[ML^2T^{-1}]$	N m s
	Angular velocity	ω	Angular displacement / time	$[M^oL^oT^{-1}]$	rad s^{-1}
	Angular frequency	ω	Angular displacement / time	$[M^oL^oT^{-1}]$	rad s^{-1}
	Angular momentum	L	Moment arm x linear momentum	$[ML^2T^{-1}]$	kg m^2 s^{-1}
	Torque or moment of force	τ	Force x moment arm	$[ML^2T^{-2}]$	N m
	Moment of inertia	I	Mass x radius²	$[ML^2T^o]$	kg m^2

Properties of matter					
	Stress		Restoring force / area	$[ML^{-1}T^{-2}]$	N m^{-2} or Pa
	Strain		Change in dimension / original dimension	$[M^0L^0T^0]$	--
	Modulus of elasticity	E	Stress / strain	$[ML^{-1}T^{-2}]$	N m^{-2} or Pa
	Bulk modulus	K	$\Delta P.\frac{V}{\Delta V}$	$[ML^{-1}T^{-2}]$	N m^{-2} or Pa
	Compressibility		1 / bulk modulus	$[M^{-1}LT^2]$	Pa^{-1} or N^{-2} m^2
	Poisson's ratio		Lateral strain / longitudinal strain	$[M^0L^0T^0]$	--
	Surface tension	σ	Force / length	$[ML^0T^{-2}]$	N m^{-1} or J m^{-2}
	Surface energy		Energy / area	$[ML^0T^{-2}]$	J m^{-2}
	Coefficient of viscosity	η	$F = \eta A \frac{dv}{dx}$	$[ML^{-1}T^{-1}]$	Poise

Heat	Heat	Q or H	Energy	$[ML^2T^{-2}]$	J
	Temperature	θ	Fundamental	$[M^oL^oT^o\theta]$	kelvin (K)
	Temperature gradient		$\frac{\text{changeintemperature}}{\text{distance}}$	$[M^oL^{-1}T^o\theta]$	m^{-1} K
	Thermal capacity		Mass x specific heat or heat energy / temp.	$[ML^2T^{-2}\theta^{-1}]$	J K^{-1}
	Water equivalent	w		$[ML^oT^o]$	kg
	Specific heat Capacity	s or c	c = Q / (m θ)	$[M^oL^2T^{-2}\theta^{-1}]$	J kg^{-1} K^{-1}
	Ratio of specific Heats	γ	c_p / c_v	$[M^oL^oT^o]$	--
	Latent heat	L	L = Q/m	$[M^oL^2T^{-2}]$	J kg^{-1}
	Entropy		$\Delta S = \Delta Q / T$	$[ML^2T^{-2}\theta^{-1}]$	J $^{-1}$
	Specific entropy		1/entropy	$[M^{-1}L^{-2}T^2\theta]$	K J^{-1}
	Joule's constant or mechanical equivalent of heat	J	J = W / H	$[M^oL^oT^o]$	J cal^{-1}

Heat	Calorific value			$[M^0L^2T^{-2}]$	$J\ kg^{-1}$
	Coefficient of linear or areal or volume expansion	α, β, γ	Change in dimension/(original dimension x temp.)	$[M^0L^0T^0\theta^{-1}]$	K^{-1}
	Coefficient of thermal conductivity	K	K = (H.E. x thickness)/(area x temp. x time)	$[MLT^{-3}\theta^{-1}]$	$W\ m^{-1}\ K^{-1}$
	Pressure coefficient or volume coefficient			$[M^0L^0T^0\theta^{-1}]$	K^{-1}
	Boltzmann's Constant	K		$[ML^2T^{-2}\theta^{-1}]$	$J\ K^{-1}$
	Stefan's constant	σ	$\left(\frac{\text{heat energy}}{\text{area x time x temperature}^4}\right)$	$[ML^0T^{-3}\theta^{-4}]$	$W\ m^{-2}\ K^{-4}$
	Universal gas constant	R	Work / temperature	$[ML^2T^{-2}\theta^{-1}]$	$J\ mol^{-1}K^{-1}$

Electricity	Electric current	I	Fundamental	$[M^oL^oT^oI]$	Ampere (A)
	Electric charge or quantity of electric charge	Q	Current x time	$[M^oL^oTI]$	Coulomb or A s
	Electric dipole moment	p	Charge x dipole Length	$[M^oLTI]$	C m
	Electric field strength or Intensity of electric field	E	Force / charge	$[MLT^{-3}I^{-1}]$	N C^{-1}, or V m^{-1}
	Emf (or) electric potential Difference	E	Work / charge	$[ML^2T^{-3}I^{-1}]$	volt (V)
	Electric resistance	R	$\frac{\text{potential difference}}{\text{current}}$	$[ML^2T^{-3}I^{-2}]$	Ohm(Ω)
	Electric conductance		1 / resistance	$[M^{-1}L^{-2}T^3I^2]$	Ohm^{-1} or mho or siemen
	Resistivity or specific Resistance	ρ	ρ = RA/l	$[ML^3T^{-3}I^{-2}]$	m
	Specific conductance or Conductivity		1 / specific Resistance	$[M^{-1}L^{-3}T^3I^2]$	siemen/ metre or S m^{-1}
	Electric capacitance	C	Charge / potential	$[M^{-1}L^{-2}T^4I^2]$	C V^{-1} or farad
	Permittivity of free space	ε_o	$\varepsilon_o = \frac{Q_1Q_2}{4\pi Fd^2}$	$[M^{-1}L^{-3}T^4I^2]$	$C^2 N^{-1}m^{-2}$

Magnetism	Magnetic pole strength	m	m = M / l	$[M^oLT^oI]$	A m
	Magnetic dipole moment	M	Pole strength x dipole length	$[M^oL^2T^oI]$	A m^2
	Permeability of free space	μ_o	$\mu_o = \frac{4\pi F d^2}{m_1 m_2}$	$[MLT^{-2}I^{-2}]$	H m^{-1} or N A^{-2}
	Intensity of magnetization, magnetic field strength, magnetic intensity, magnetic moment density	I	Magnetic moment / Volume	$M^oL^{-1}T^oI]$	A m^{-1}
	Magnetic flux	Φ_b	Magnetic induction x area	$[ML^2T^{-2}I^{-1}]$	weber (Wb)
	Magnetic induction, magnetic flux density, magnetic field	B	Force/(current x length)	$[ML^oT^{-2}I^{-1}]$	N A^{-1} m^{-1} or tesla (T)
	Inductance or coefficient of self induction	L	$L = 2E/(LI^2)$	$[ML^2T^{-2}I^{-2}]$	henry (H)

Optics	Luminous flux			$[ML^2T^{-3}]$	lumen or $J\ s^{-1}$
	Refractive index	μ	c_{air} / c_{med}	$[M^0L^0T^0]$	--
	Illumination (Illuminance)			$[ML^0T^{-3}]$	lux or lumen/metre²
	Decay constant	λ	$\lambda = 0.693$ / half life	$[M^0L^0T^{-1}]$	disintegrations per second
	Planck's constant	h	Energy / frequency	$[ML^2T^{-1}]$	J s
	Wien's constant	b	Wavelength x temp.	$[M^0LT^0\theta]$	m K