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Introduction

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1.1. Definition

The subject **Theory of Machines** may be defined as that branch of Engineering-science, which deals with the study of relative motion between the various parts of a machine, and forces which act on them. The knowledge of this subject is very essential for an engineer in designing the various parts of a machine.

Note: A machine is a device which receives energy in some available form and utilises it to do some particular type of work.

1.2. Sub-divisions of Theory of Machines

The Theory of Machines may be sub-divided into the following four branches :

1. *Kinematics.* It is that branch of Theory of Machines which deals with the relative motion between the various parts of the machines.

2. *Dynamics.* It is that branch of Theory of Machines which deals with the forces and their effects, while acting upon the machine parts in motion.

3. *Kinetics.* It is that branch of Theory of Machines which deals with the inertia forces which arise from the combined effect of the mass and motion of the machine parts.

4. *Statics.* It is that branch of Theory of Machines which deals with the forces and their effects while the machine parts are at rest. The mass of the parts is assumed to be negligible.

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1.3. Fundamental Units

The measurement of physical quantities is one of the most important operations in engineering. Every quantity is measured in terms of some arbitrary, but internationally accepted units, called ***fundamental units***. All physical quantities, met within this subject, are expressed in terms of the following three fundamental quantities :

Stopwatch

Simple balance

1. Length (*L* or *l*),

2. Mass (*M* or *m*), and

3. Time (*t*).

1.4. Derived Units

Some units are expressed in terms of fundamental units known as derived units, *e.g.*, the units of area, velocity, acceleration, pressure, etc.

1.5. Systems of Units

There are only four systems of units, which are commonly used and universally recognised. These are known as :

1. C.G.S. units, **2.** F.P.S. units, **3.** M.K.S. units, and **4.** S.I. units.

1.6. C.G.S. Units

In this system, the fundamental units of length, mass and time are ***centimetre, gram*** and ***second*** respectively. The C.G.S. units are known as absolute units or physicist's units.

1.7. F.P.S. Units

In this system, the fundamental units of length, mass and time are ***foot, pound*** and ***second*** respectively.

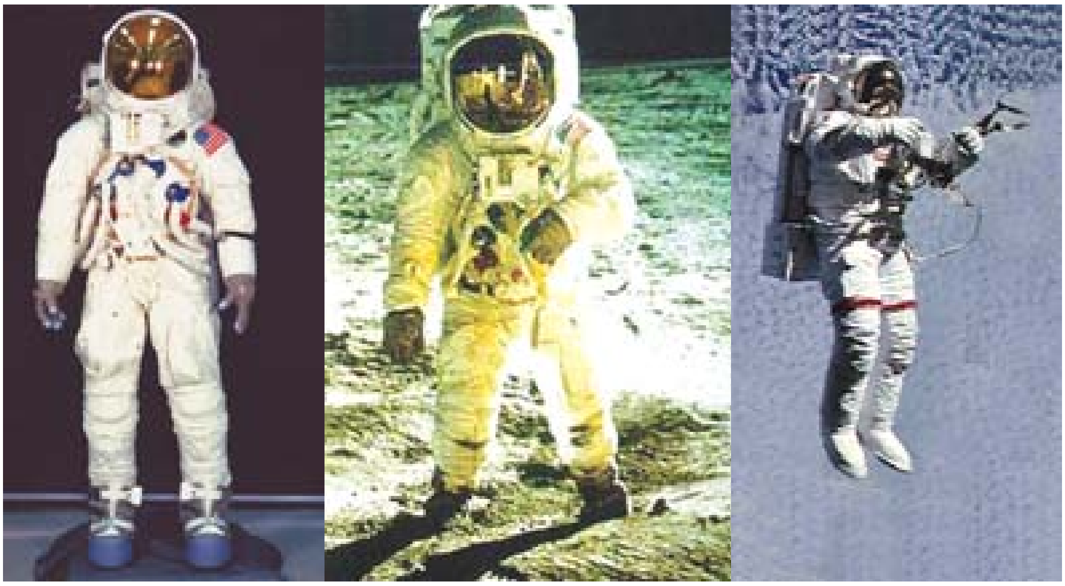
1.8. M.K.S. Units

In this system, the fundamental units of length, mass and time are ***metre, kilogram*** and ***second*** respectively. The M.K.S. units are known as gravitational units or engineer's units.

1.9. International System of Units (S.I. Units)

The 11th general conference* of weights and measures have recommended a unified and systematically constituted system of fundamental and derived units for international use. This system is now being used in many countries. In India, the standards of Weights and Measures Act, 1956 (vide which we switched over to M.K.S. units) has been revised to recognise all the S.I. units in industry and commerce.

* It is known as General Conference of Weights and Measures (G.C.W.M.). It is an international organisation, of which most of the advanced and developing countries (including India) are members. The conference has been entrusted with the task of prescribing definitions for various units of weights and measures, which are the very basic of science and technology today.



A man whose mass is 60 kg weighs 588.6 N (60 × 9.81 m/s^2) on earth, approximately 96 N (60 × 1.6 m/s^2) on moon and zero in space. But mass remains the same everywhere.

In this system of units, the fundamental units are metre (m), kilogram (kg) and second (s) respectively. ***But there is a slight variation in their derived units.*** The derived units, which will be used in this book are given below :

Density (mass density)	kg/m^3
Force	N (Newton)
Pressure	Pa (Pascal) or N/m^2 (1 Pa = 1 N/m^2)
Work, energy (in Joules)	1 J = 1 N-m
Power (in watts)	1 W = 1 J/s
Absolute viscosity	kg/m-s
Kinematic viscosity	m^2/s
Velocity	m/s
Acceleration	m/s^2
Angular acceleration	rad/s^2
Frequency (in Hertz)	Hz

The international metre, kilogram and second are discussed below :

1.10. Metre

The international metre may be defined as the shortest distance (at 0°C) between the two parallel lines, engraved upon the polished surface of a platinum-iridium bar, kept at the International Bureau of Weights and Measures at Sevres near Paris.

1.11. Kilogram

The international kilogram may be defined as the mass of the platinum-iridium cylinder, which is also kept at the International Bureau of Weights and Measures at Sevres near Paris.

1.12. Second

The fundamental unit of time for all the three systems, is second, which is 1/24 × 60 × 60 = 1/86 400th of the mean solar day. A solar day may be defined as the interval of time, between the instants, at which the sun crosses a meridian on two consecutive days. This value varies slightly throughout the year. The average of all the solar days, during one year, is called the mean solar day.

1.13. Presentation of Units and their Values

The frequent changes in the present day life are facilitated by an international body known as International Standard Organisation (ISO) which makes recommendations regarding international standard procedures. The implementation of ISO recommendations, in a country, is assisted by its organisation appointed for the purpose. In India, Bureau of Indian Standards (BIS) previously known as Indian Standards Institution (ISI) has been created for this purpose. We have already discussed that the fundamental units in M.K.S. and S.I. units for length, mass and time is metre, kilogram and second respectively. But in actual practice, it is not necessary to express all lengths in metres, all masses in kilograms and all times in seconds. We shall, sometimes, use the convenient units, which are multiples or divisions of our basic units in tens. As a typical example, although the metre is the unit of length, yet a smaller length of one-thousandth of a metre proves to be more convenient unit, especially in the dimensioning of drawings. Such convenient units are formed by using a prefix in front of the basic units to indicate the multiplier. The full list of these prefixes is given in the following table.

With rapid development of Information Technology, computers are playing a major role in analysis, synthesis and design of machines.

Table 1.1. Prefixes used in basic units

Factor by which the unit is multiplied	*Standard form*	*Prefix*	*Abbreviation*
1 000 000 000 000	10^{12}	tera	T
1 000 000 000	10^{9}	giga	G
1 000 000	10^{6}	mega	M
1 000	10^{3}	kilo	k
100	10^{2}	hecto*	h
10	10^{1}	deca*	da
0.1	10^{-1}	deci*	d
0.01	10^{-2}	centi*	c
0.001	10^{-3}	milli	m
0. 000 001	10^{-6}	micro	μ
0. 000 000 001	10^{-9}	nano	n
0. 000 000 000 001	10^{-12}	pico	p

* These prefixes are generally becoming obsolete probably due to possible confusion. Moreover, it is becoming a conventional practice to use only those powers of ten which conform to 10^{3x}, where x is a positive or negative whole number.

1.14. Rules for S.I. Units

The eleventh General Conference of Weights and Measures recommended only the fundamental and derived units of S.I. units. But it did not elaborate the rules for the usage of the units. Later on many scientists and engineers held a number of meetings for the style and usage of S.I. units. Some of the decisions of the meetings are as follows :

1. For numbers having five or more digits, the digits should be placed in groups of three separated by spaces* (instead of commas) counting both to the left and right to the decimal point.
2. In a four digit number,** the space is not required unless the four digit number is used in a column of numbers with five or more digits.
3. A dash is to be used to separate units that are multiplied together. For example, newton metre is written as N-m. It should not be confused with mN, which stands for millinewton.
4. Plurals are never used with symbols. For example, metre or metres are written as m.
5. All symbols are written in small letters except the symbols derived from the proper names. For example, N for newton and W for watt.
6. The units with names of scientists should not start with capital letter when written in full. For example, 90 newton and not 90 Newton.

At the time of writing this book, the authors sought the advice of various international authorities, regarding the use of units and their values. Keeping in view the international reputation of the authors, as well as international popularity of their books, it was decided to present units*** and their values as per recommendations of ISO and BIS. It was decided to use :

4500	not	4 500	or	4,500
75 890 000	not	75890000	or	7,58,90,000
0.012 55	not	0.01255	or	.01255
30×10^6	not	3,00,00,000	or	3×10^7

The above mentioned figures are meant for numerical values only. Now let us discuss about the units. We know that the fundamental units in S.I. system of units for length, mass and time are metre, kilogram and second respectively. While expressing these quantities we find it time consuming to write the units such as metres, kilograms and seconds, in full, every time we use them. As a result of this, we find it quite convenient to use some standard abbreviations.

We shall use :

m	for metre or metres
km	for kilometre or kilometres
kg	for kilogram or kilograms
t	for tonne or tonnes
s	for second or seconds
min	for minute or minutes
N-m	for newton × metres (*e.g.* work done)
kN-m	for kilonewton × metres
rev	for revolution or revolutions
rad	for radian or radians

* In certain countries, comma is still used as the decimal mark.

** In certain countries, a space is used even in a four digit number.

*** In some of the question papers of the universities and other examining bodies, standard values are not used. The authors have tried to avoid such questions in the text of the book. However, at certain places, the questions with sub-standard values have to be included, keeping in view the merits of the question from the reader's angle.

1.15. Force

It is an important factor in the field of Engineering science, which may be defined as an agent, which produces or tends to produce, destroy or tends to destroy motion.

1.16. Resultant Force

If a number of forces *P*,*Q*,*R* etc. are acting simultaneously on a particle, then a single force, which will produce the same effect as that of all the given forces, is known as a ***resultant force.*** The forces *P*,*Q*,*R* etc. are called ***component forces.*** The process of finding out the resultant force of the given component forces, is known as ***composition of forces.***

A resultant force may be found out analytically, graphically or by the following three laws:

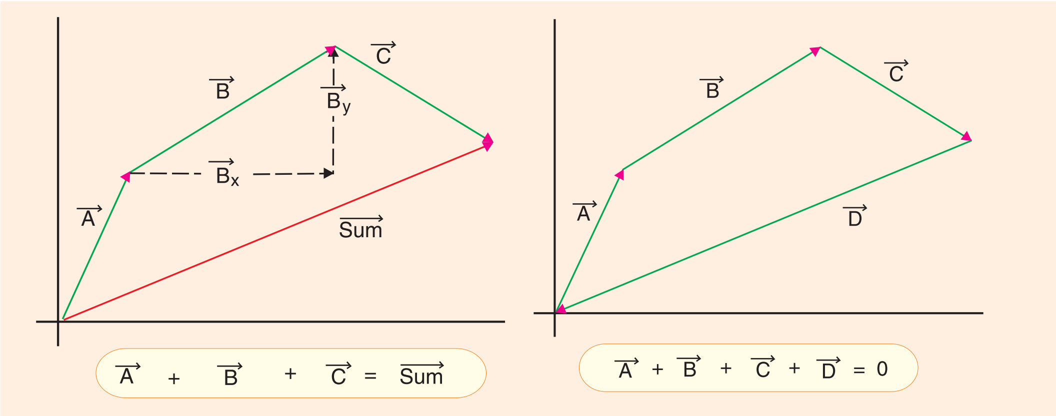
1. ***Parallelogram law of forces.*** It states, "If two forces acting simultaneously on a particle be represented in magnitude and direction by the two adjacent sides of a parallelogram taken in order, their resultant may be represented in magnitude and direction by the diagonal of the parallelogram passing through the point."

2. ***Triangle law of forces.*** It states, "If two forces acting simultaneously on a particle be represented in magnitude and direction by the two sides of a triangle taken in order, their resultant may be represented in magnitude and direction by the third side of the triangle taken in opposite order."

3. ***Polygon law of forces.*** It states, "If a number of forces acting simultaneously on a particle be represented in magnitude and direction by the sides of a polygon taken in order, their resultant may be represented in magnitude and direction by the closing side of the polygon taken in opposite order."

1.17. Scalars and Vectors

1. Scalar quantities are those quantities, which have magnitude only, *e.g.* mass, time, volume, density etc.



2. Vector quantities are those quantities which have magnitude as well as direction *e.g.* velocity, acceleration, force etc.

3. Since the vector quantities have both magnitude and direction, therefore, while adding or subtracting vector quantities, their directions are also taken into account.

1.18. Representation of Vector Quantities

The vector quantities are represented by vectors. A vector is a straight line of a certain length possessing a starting point and a terminal point at which it carries an arrow head. This vector is cut off along the vector quantity or drawn parallel to the line of action of the vector quantity, so that the length of the vector represents the magnitude to some scale. The arrow head of the vector represents the direction of the vector quantity.

1.19. Addition of Vectors

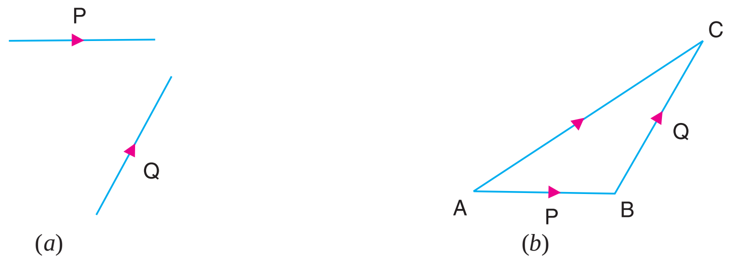


Fig. 1.1. Addition of vectors.

Consider two vector quantities *P* and *Q*, which are required to be added, as shown in Fig.1.1(*a*).

Take a point *A* and draw a line *AB* parallel and equal in magnitude to the vector *P*. Through *B*, draw *BC* parallel and equal in magnitude to the vector *Q*. Join *AC*, which will give the required sum of the two vectors *P* and *Q*, as shown in Fig. 1.1 (*b*).

1.20. Subtraction of Vector Quantities

Consider two vector quantities *P* and *Q* whose difference is required to be found out as shown in Fig. 1.2 (*a*).

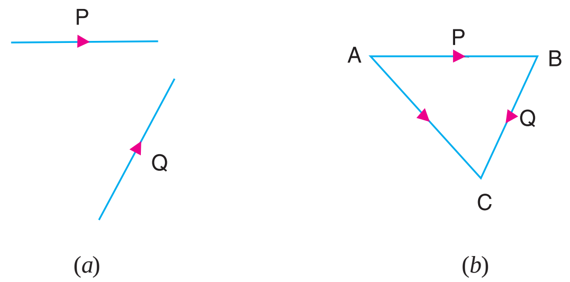


Fig. 1.2. Subtraction of vectors.

Take a point *A* and draw a line *AB* parallel and equal in magnitude to the vector *P*. Through *B*, draw *BC* parallel and equal in magnitude to the vector *Q*, ***but in opposite direction.*** Join *AC*, which gives the required difference of the vectors *P* and *Q*, as shown in Fig. 1.2 (*b*).

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