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OPEN AND DISTANCE LEARNING (ODL) PROGRAMMES

(FOR THOSE WHO JOINED THE PROGRAMMES FROM THE ACADEMIC YEAR 2023–2024)

B.Sc. Physics

Course Material

INTRODUCTORY PHYSICS

JFPH11

Prepared

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Tirunelveli - 12

B.Sc. Physics I Year

JFPH11 - INTRODUCTORY PHYSICS

Syllabus

UNIT	CONTENTS
I	Vectors, scalars –examples for scalars and vectors from physical quantities–addition, subtraction of vectors – resolution and resultant of vectors – units and dimensions– standard physics constants.
II	Different types of forces–gravitational, electrostatic, magnetic, electromagnetic, nuclear –mechanical forces like, centripetal, centrifugal, friction, tension, cohesive, adhesive forces.
III	Different form soft energy – conservation laws of momentum, energy–types of collisions – angular momentum– alternate energy sources– real life examples.
IV	Types of motion – linear, projectile, circular, angular, simple harmonic motions – satellite motion – banking of a curved roads – stream line and turbulent motions – wave motion – comparison of light and sound waves – free, forced, damped oscillations.
V	Surface tension – shape of liquid drop – angle of contact – viscosity – lubricants – capillary flow – diffusion – real life examples– properties and types of materials in daily use - conductors, insulators – thermal and electric.
RecommendedText	
1	D. S. Mathur, 2010, Elements of Properties of Matter, S.Chand and Co
2	BrijLal and N. Subrahmanyam, 2003, Properties of Matter, S.Chand and Co.

Unit - I

A scalar quantity is defined as the physical quantity with only magnitude and no direction. The physical quantities which are specified with the magnitude or size alone are scalar quantities.

Examples of Scalar Quantities

Some examples of scalar include:

- Mass
- Speed
- Distance
- Time
- Volume
- Density
- Temperature

What Is a Vector Quantity?

Vector quantities refer to the physical quantities characterized by the presence of both magnitude as well as direction.

Characteristics of Vectors

- They possess both magnitudes as well as direction.
- They do not obey the ordinary laws of Algebra.
- These change if either the magnitude or direction change or both change.

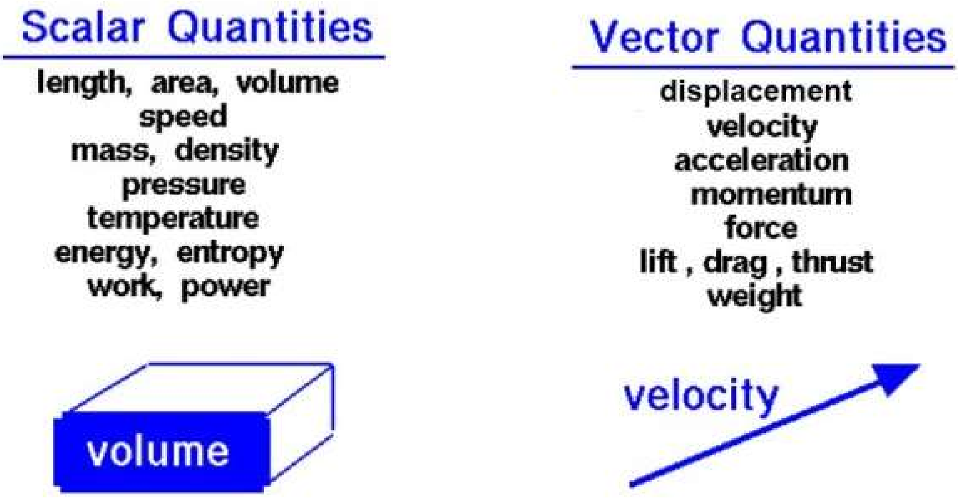
Examples of Vector Quantities

Examples of vector quantity include:

- Linear momentum
- Acceleration
- Displacement
- Momentum
- Angular velocity
- Force
- Electric field
- Polarization

Difference between Scalars and Vectors

The difference between Scalars and Vectors is crucial to understand in physics learning.



Vector algebra is one of the essential topics of algebra. It studies the algebra of vector quantities. As we know, there are two types of physical quantities, **scalars and vectors**. The scalar quantity has only magnitude, whereas the vector quantity has both magnitude and direction.

Vectors algebra is the branch of algebra that involves operations on vectors.

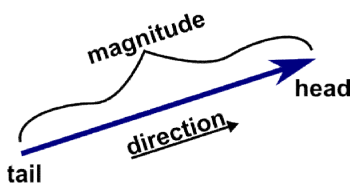
	Vector	Scalar
Definition	A physical quantity with both the magnitude and direction.	A physical quantity with only magnitude.
Representation	A number (magnitude), direction using unit cap or arrow at the top and unit.	A number (magnitude) and unit
Symbol	Quantity symbol in bold and an arrow sign above	Quantity symbol
Direction	Yes	No
Example	Velocity and Acceleration	Mass and Temperature

Vector Addition and Subtraction

We can add, subtract, and multiply vector quantities using special vector algebra rules.

Vector algebra is the type of Algebra that is used to perform various algebraic operations on vectors. As we know vectors are quantities that have both magnitude and direction whereas scalar quantities only have magnitude and no direction.

As these quantities have directions operations on these quantities are not easily applied and the concept of vector algebra is used to perform operations on these quantities.



In the above figure, the length of the line shows the magnitude of the vector, and the arrowhead points to its direction. It is basically a directed line segment. Its starting point A is called the initial point (tail) and point B where it ends is called the terminal point (head).

Representation of Vectors

Vectors are represented by taking an arrow above the quantity, i.e. velocity vector is represented as $\vec{v}$ where the arrow above 'v' represents that it is a vector quantity. Vectors can also be represented by taking their respective magnitude in x, y, and z-directions respectively.

Magnitude of Vectors

The magnitude of a vector represents the strength of the vector. We can calculate the magnitude of the vector by taking the square root of the sum of the squares of each component in the x, y, and z directions.

The magnitude of a vector is calculated by taking the square root of the sum of the square of the components of the vector in the x, y, and z directions.

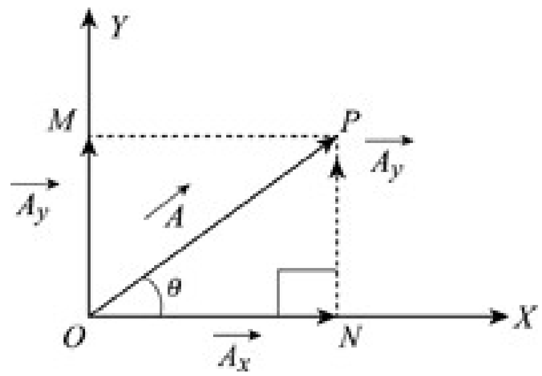
For any vector $\vec{A} = a\hat{\imath} + b\hat{\jmath} + c\hat{k}$, the magnitude of the vector is represented as |A| and its value is $|\vec{A}| = \sqrt{(a^2 + b^2 + c^2)}$

The magnitude of a vector is a scalar value.

Resolution of a vector in two Dimensions

The resolution of a vector into two mutually perpendicular vectors is called the rectangular resolution of vector in a plane or two dimensions.

Consider that a vector $\overrightarrow{OP} = \vec{A}$ has to be resolved into two component vector along the direction of two mutually perpendicular directions of X-axis and Y-axis. Let $\hat{\imath}$ and $\hat{\jmath}$ be the unit vectors along X-axis and Y-axis respectively figure.



From point P, drop PM and PN perpendicular to X-axis and Y-axis respectively. From the parallelogram law of vector addition, it follows that

$$\overrightarrow{OP} = \overrightarrow{OM} + \overrightarrow{MP}$$

If $OM = A_x$ and $ON = MP = A_y$, then

$$\overrightarrow{OB} = A_x\,\hat{i} \text{ and } \overrightarrow{ON} = \overrightarrow{MP} = A_y\,\hat{j}$$

Therefore, the above, equation becomes

$$\overrightarrow{OP} = A_x\,\hat{i} + A_y\,\hat{j}$$

$$\text{or} \qquad \vec{A} = A_x\,\hat{i} + A_y\,\hat{j} \qquad \ldots\text{(i)}$$

The equation (i) describes vector, $\vec{A}$ into the component vector $A_x\,\hat{i}$ and $A_y\,\hat{i}$. In practice $A_x\,\hat{i}$ and $A_y\,\hat{j}$ are called respectively x-component and y-component of vectors $\vec{A}$. Further A_x and A_y are called magnitude of the two-component vectors.

If A is the magnitude of the vector $\vec{A}$ and θ is its inclination with X-axis, then from the right-angled triangle OMP,

$$\cos\theta = \frac{OM}{OP} = \frac{A_x}{A}$$

$$\text{or} \qquad A_x = A\cos\theta \qquad \ldots\text{(ii)}$$

$$\text{Also} \qquad \sin\theta = \frac{MP}{OA} = \frac{A_y}{A}$$

$$A_y = A\sin\theta \qquad \ldots\text{(iii)}$$

Adding the squares of A_x and A_y, we get

$$A_x^2 + A_y^2 = (A\cos\theta)^2 + (A\sin\theta)^2$$

$$\text{or,} \qquad A_x^2 + A_y^2 = A^2\cos^2\theta + A^2\sin^2\theta$$

$$\Rightarrow \qquad A_x^2 + A_y^2 = A^2(\cos^2\theta + \sin^2\theta)$$

$$\text{or,} \qquad A_x^2 + A_y^2 = A^2 \quad (\because \sin^2\theta + \cos^2\theta = 1)$$

$$\text{or,} \qquad A^2 = A_x^2 + A_y^2$$

$$\Rightarrow \qquad A = \sqrt{A_x^2 + A_y^2} \qquad \ldots\text{(iv)}$$

Dividing A_y by A_x, we get

$$\frac{A_y}{A_x} = \frac{A\sin\theta}{A\cos\theta}$$

$$\Rightarrow \qquad \frac{A_y}{A_x} = \tan\theta$$

$$\text{or,} \quad \tan\theta = \frac{A_y}{A_x}$$

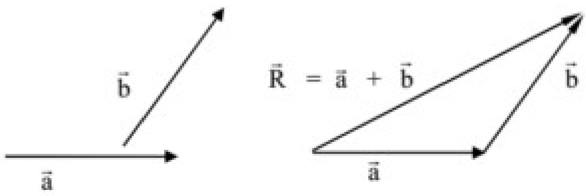
$$\text{or,} \quad \theta = \tan^{-1}\left(\frac{A_y}{A_x}\right) \qquad \ldots(v)$$

A resultant vector is defined as a single vector whose effect is the same as the combined effect of two or more vectors.

Triangle Law of Vector Addition:

When two vectors which are to be added taken in order are represented in direction and magnitude by two sides of a triangle then the third side taken in opposite order represents the resultant completely i.e. in direction and magnitude.

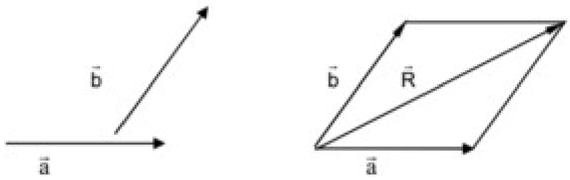
- Consider two vectors which are to be added as shown. There resultant is found as follows.
- The first vector is drawn with a suitable scale and in the given direction
- Then from the head of the first vector, the second vector is drawn with the same scale and in the same direction of the second vector. Thus the tail of the second vector lies at the head of the first vector.
- Then the vector joining the tail of the first vector and the head of the second vector represents the resultant completely i.e. in the direction and magnitude.



Parallelogram Law of Vector Addition:

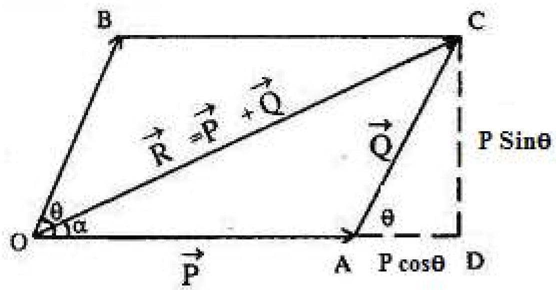
If two vectors are represented in direction and magnitude by two adjacent sides of parallelogram then the resultant vector is given in magnitude and direction by the diagonal of the parallelogram starting from the common point of the adjacent sides.

- Consider two vectors which are to be added as shown. There resultant is found as follows.
- The first vector is drawn with a suitable scale and in the given direction
- Then from the tail of the first vector, the second vector is drawn with the same scale and in the same direction of the second vector. Thus, the tail of the second vector lies at the tail of the first vector.
- A parallelogram is completed by drawing lines parallel to vectors and through the heads of vectors   and
- Then the diagonal passing through common tail represents the resultant completely, i e. in the direction and the magnitude.



Analytical Method to Find the Resultant of Two Vectors:

Let P and Q be the two vectors which are combined into a single resultant. Draw OA and OB to represent the vectors P and Q respectively to a suitable scale. The parallelogram OACB is constructed and the diagonal OC is drawn.



To find the magnitude of R

OA is produced and CD perpendicular to produced OA is drawn. In the Δ OCD

$OC^2 = OD^2 + CD^2$

$\therefore OC^2 = (OA + AD)^2 + CD^2$

$\therefore \quad OC^2 = OA^2 + 2\,OA.AD + AD^2 + CD^2$ ———(1)

In the Δ ACD, $AD^2 + CD^2 = AC^2$

Substituting this in equation (1)

$\therefore OC^2 = OA^2 + 2\,OA.AD + AC^2$ ————(2)

If θ is the angle between the two vectors , then ∠ AOB = θ,

But ∠ DAC = ∠ AOB = θ

In the ΔACD, AD = AC cos θ

Substituting this value in equation (2)

$OC^2 = OA^2 + 2\,OA.AC\cos\theta + AC^2$

But OC = R, OA = P, and AC = OB = Q

$R^2 = P^2 + 2\,P.Q\cos\theta + Q^2$

$$R = \sqrt{P^2 + Q^2 + 2PQ\cos\theta}$$

Using this relation the magnitude of the resultant can be determined.

To find the direction of R :

Let α be the angle made by the resultant with vector P

$$\text{In } \Delta \text{ OCD}, \quad \tan\alpha = \frac{CD}{OD}$$

$$\therefore \tan\alpha = \frac{CD}{OA + AD}$$

$$\therefore \tan\alpha = \frac{CD}{OA + AC\cos\theta}$$

$$\text{In } \Delta \text{ ACD}, \quad \sin\theta = \frac{CD}{AC}$$

$$\therefore CD = AC\sin\theta$$

$$\therefore \tan\alpha = \frac{AC\sin\theta}{OA + AC\cos\theta}$$

$$\text{But } AC = OB$$

$$\therefore \tan\alpha = \frac{OB\sin\theta}{OA + OB\cos\theta}$$

$$\therefore \tan\alpha = \frac{Q\sin\theta}{P + Q\cos\theta}$$

Using this relation the direction of the resultant can be determined.

Special cases:

Case – I: When the two vectors are in the same direction, then $\theta = 0^o$ and $\cos 0^o = 1$, we have

$$R = \sqrt{P^2 + Q^2 + 2P.Q\cos 0}$$

$$\therefore R = \sqrt{P^2 + Q^2 + 2P.Q(1)}$$

$$\therefore R = \sqrt{P^2 + 2P.Q + Q^2}$$

$$\therefore R = \sqrt{(P + Q)^2}$$

$$\therefore R = P + Q$$

Thus when the two vectors are in the same direction the magnitude of the resultant is the sum of the magnitudes of the two vectors. The direction of the resultant is the same as the two vectors.

Case – II: When the two vectors are in the opposite direction then $\theta = 180^o$ and $\cos 180^o = -1$, we have

$$R = \sqrt{P^2 + Q^2 + 2P.Q\cos 180^o}$$

$$\therefore R = \sqrt{P^2 + Q^2 + 2P.Q(-1)}$$

$$\therefore R = \sqrt{P^2 - 2P.Q + Q^2}$$

$$\therefore R = \sqrt{(P - Q)^2}$$

$$\therefore R = P - Q$$

Thus when the two vectors are in the opposite direction the magnitude of the resultant is the difference of magnitude of the two vectors. The direction of the resultant is the same as the vector having a larger magnitude.

Case – III: When the two vectors are perpendicular to each other then $\theta = 90^o$ and cos $90^o = -1$, we have

$$R = \sqrt{P^2 + Q^2 + 2P.Q\cos 90^o}$$

$$\therefore R = \sqrt{P^2 + Q^2 + 2P.Q(0)}$$

$$\therefore R = \sqrt{P^2 + Q^2}$$

Thus when the two vectors are perpendicular to each other, then the magnitude of the resultant of the two vectors is given by the above expression. The direction of the resultant is obtained usingthe relation.

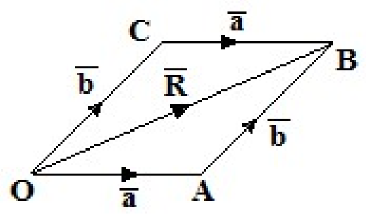
$$\tan\alpha = \frac{Q}{P}$$

Characteristics of Vector Addition:

- Vector addition is commutative. i.e. **A + B = B + A**
- Vector addition is associative. i.e. **(A + B) + C = A + (B + C)**
- Their exists an additive identity of the vector. i.e. Zero vector is additive identity. If is any vector and is a zero vector, then $\bar{A} + \bar{o} = \bar{o} + \bar{A} = \bar{A}$ **.**
- There exists an additive inverse of a vector i.e. if $\bar{A}$ is any vector then there exists a vector $-\bar{A}$ such that $\bar{A} + (-\bar{A}) = 0$.

Vector Addition Obeys Commutative Law:

Consider two vectors a and b which are to be added together,



Let us represent vector a and vector b by sides OA and AB of parallelogram OABC respectively.

In Triangle OAB, by the triangle law of vector addition

a + b = R ………… (1)

In Triangle OCB, by the triangle law of vector addition

b + a = R ………… (2)

From equations (1) and (2)

a + b = b + a

Thus vector addition is commutative. This law is known as the commutative law of vector addition.

Vector Addition Obeys Associative Law:

Consider three vectors a, b and c which are to be added together,

Vectors a, b and c are represented by sides OA, AB, and BC of the polygon

Applying polygon law of vector addition the resultant R is found

Applying triangle law of vector addition to the Δ OAB, we have

a + b = P ………… (1)

Applying triangle law of vector addition to the Δ OBC, we have

P + c = R ………… (2)

From (1) and (2) we have

R = (a + b) + c ……….. (3)

Now, Applying triangle law of vector addition to the Δ ABC, we have

b + c = Q ………… (4)

Now, Applying the triangle law of vector addition to the Δ OAC, we have

a + Q = R ………… (5)

From (4) and (5) we have

R = a + (b + c) ……….. (3)

From (3) and (6)

(a + b) + c = a + (b + c)

Thus vector addition is associative. This law is known as the associative law of vector addition.

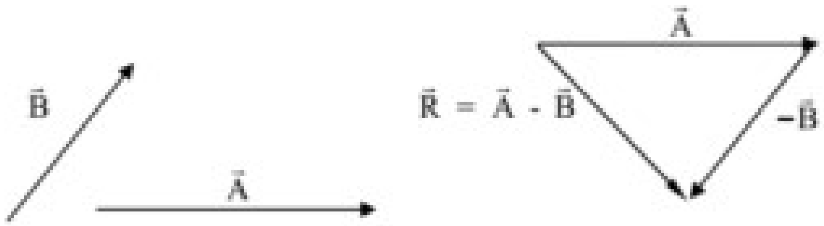
Notes:

- When two vectors having the same magnitude are acting on a body in opposite directions, then their resultant vector is zero.
- Two vectors of different magnitudes cannot give zero resultant vector.
- Three vectors of different or same magnitudes can give zero resultant vector if they are collinear. In such case, if they are represented in direction and magnitude taken in order (one after another) then, they form a closed triangle.

Subtraction of vectors:

Subtraction of vectors can be treated as the addition of a vector and a negative vector.

- Consider two vectors which are to be subtracted as shown. There resultant is found as follows.
- The first vector is drawn with proper scale and in a given direction
- Then from the head of the first vector, a vector is drawn with the same scale and in the opposite direction of the second vector.
- Then the vector joining the tail of the first vector and head of the second vector represents the resultant completely i.e. in direction and magnitude.



Units

There are as many units as there are independent quantities. We consider length, mass, and time three quantities which are independent of each other. Hence, they have three separate units for their measurements. Hence it is required to define systems of units.

Notes:

- The two vectors to be added should have the same nature. i.e. force can be added to force and velocity can be added to velocity, but the force cannot be added to the velocity.
- The two scalars to be added should have the same nature. i.e. mass can be added to mass and time can be added to time, but the mass cannot be added to the time.
- Scalar and vectors can never be added.

System of Units:

A system of units is a collection of units in which certain units are chosen as fundamental and all others are derived from them. This system is also called an absolute system of units. In most systems, the mass, length, and time are considered to be fundamental quantities, and their units are called fundamental units. The following are some systems of units which are in common use.

c.g.s. system of units: The unit of length is centimetre (cm). The unit of mass is gram (g). The unit of time is second (s)

m.k.s. system of units: The unit of length is the metre (m). The unit of mass is the kilogram (kg). The unit of time is second (s)

f.p.s. system of units: The unit of length is a foot (ft). The unit of mass is a pound (Lb). The unit of time is second (s). This system is no more in use. This system is also known as Imperial system or the British Imperial system. Temperature is measured in Fahrenheit.

S.I. System of Units:

In the year 1960, the Eleventh General Conference of Weights and Measures introduced the International System of Units. The International Standard Organization (ISO) and the International Electrochemical Commission endorsed the system in 1962. In October 1971 a replacement of the metric system of units was done with a new system called SystemeInternationale d' Unites. The International System of Units, commonly known as the SI system, is the modern form of the metric system and is the most widely used system of measurement in the world. It provides a standard and coherent set of units for expressing physical quantities.

Fundamental Units:

	Fundamental Quantity	S.I. Unit	Symbol
1	Length	Metre	m
2	Mass	Kilogram	kg

3	Time	Second	s
4	Temperature	Kelvin	K
5	Electric current	Ampere	A
6	Luminous intensity	Candela	cd
7	Amount of substance	mple	mol

Besides these seven basic units, there are two supplementary units. S.I. unit for the plane angle is radian (rad) and that of solid angle is steradian (sd).

Supplementary Units:

	Quantity	S.I. Unit	Symbol
1	Plane angle	radian	rad
2	Solid angle	steradian	sr

This system of units is an improvement and extension of the traditional metric system. Now, this system of units has replaced all other systems of units in all branches of science, engineering, industry, and technology.

Dimensions of Physical Quantity:

The power to which fundamental units are raised in order to obtain the unit of a physical quantity is called the dimensions of that physical quantity. Dimensions of physical quantity do not depend on the system of units.

If 'A' is any physical quantity, then the dimensions of A are represented by [A]. Mass, length and time are represented by M, L, T respectively. Therefore, the dimensions of fundamental quantities are as follows:

[Mass] = [M]

[Length] = [L]

[Time] = [T]

Now electric current (I) and temperature (K) are also considered as fundamental quantities and using them the dimensions of electrical quantities are found. An expression, which gives the relation between the derived units and fundamental units in terms of dimensions is called a dimensional equation. Thus the dimensional equation of speed is$[L^1M^0T^{-1}]$ and 1, 0, -1 are called dimensions.

Dimensions of Some Physical Quantities:

Sr.No.	Derived Quantity	Dimensions	S.I. Unit	Symbol

1	Area	$[L^2M^0T^0]$	square metre	m^2
2	Volume	$[L^3M^0T^0]$	cubic metre	m^3
3	Density	$[L^{-3}M^1T^0]$	kilogram per cubic metre	Kg/m^3
4	Velocity	$[L^1M^0T^{-1}]$	metre per second	m/s
5	Acceleration	$[L^1M^0T^{-2}]$	metre per square second	m/s^2
6	Momentum	$[L^1M^1T^{-1}]$	kilogram metre per second	Kg m/s
7	Force	$[L^1M^1T^{-2}]$	newton	N
8	Impulse	$[L^1M^1T^{-1}]$	newton second	Ns
9	Work	$[L^2M^1T^{-2}]$	joule	J
10	Kinetic energy	$[L^2M^1T^{-2}]$	joule	J
11	Potential energy	$[L^2M^1T^{-2}]$	joule	J
12	Power	$[L^2M^1T^{-3}]$	watt	W
13	Pressure	$[L^{-1}M^1T^{-2}]$	newton per square metre	N/m^2
14	Electric charge	$[L^0M^0T^1I^1]$	coulomb	C
15	Electric current	$[L^2M^1T^{-3}I^{-1}]$	ohm	Ω
16	Electric potential	$[L^2M^1T^{-3}I^{-2}]$	volt	V

Derivation of Dimensions of Some Physical Quantity:

We should know following facts before finding dimensions of other physical quantities.

The dimensions of length (l), breadth (b), height (h), depth (d), thickness (t), width (w), circumference (c), perimeter (p), distance (S), displacement (S), radius (r), diameter (D) are $[L^1M^0T^0]$

Dimensions of mass are $[L^0M^1T^0]$ and that of time are $[L^0M^0T^1]$.

Dimensions and Unit of Volume (V):

Volume = Length × Breadth × Height

$\therefore\ V = l \times b \times h$

$\therefore$ [V] = [l] × [b] × [h]

$\therefore [V] = [L^1M^0T^0][L^1M^0T^0][L^1M^0T^0]$

$\therefore [V] = [L^3M^0T^0]$

Dimensions of volume are $[L^3M^0T^0]$

S.I. Unit of volume is cubic metre (m^3). c.g.s. unit of volume is cubic centimetre3 (cm^3).

Dimensions and Unit of Density (ρ or d):

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\rho = \frac{m}{V}$$

$$\therefore [\rho] = \frac{[m]}{[V]}$$

$$\therefore [\rho] = \frac{[L^0M^1T^0]}{[L^3M^0T^0]}$$

$$\therefore [\rho] = [L^{-3}M^1T^0]$$

Dimensions of density are $[L^{-3}M^1T^0]$

S.I. Unit of density is kilogram per cubic metre (kg m3 or kg m^{-3}). c.g.s. unit of density is gram per cubic centimetre (g cm^{-3})

Dimensions and Unit of Velocity or Speed (v):

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time}}$$

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

$$\therefore [v] = \frac{[S]}{[t]}$$

$$\therefore [v] = \frac{[L^1M^0T^0]}{[L^0M^0T^1]}$$

$$\therefore [v] = [L^1M^0T^{-1}]$$

Dimensions of velocity or speed are $[L^1M^0T^{-1}]$

S.I. Unit of velocity or speed is metre per second (m s^{-1}). c.g.s. unit of velocity or speed is centimetre per second (cm s^{-1}).

Dimensions and Unit of Acceleration (a or f):

$$\text{Acceleration} = \frac{\text{Change in Velocity}}{\text{Time}}$$

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

$$\therefore [a] = \frac{[v]}{[t]}$$

$$\therefore [a] = \frac{[L^1M^0T^{-1}]}{[L^0M^0T^1]}$$

$$\therefore [a] = [L^1M^0T^{-2}]$$

Dimensions of acceleration are $[L^1M^0T^{-2}]$

S.I. Unit of acceleration is metre per square second (m s^{-2}).

c.g.s. unit of acceleration is centimetre per square second (cm s^{-2}).

Dimensions and Unit of Force (F):

Force = Mass × Acceleration

$\therefore$ F = m× a

$\therefore$ [F] = [m] × [a]

$\therefore$ $[F] = [L^0M^1T^0][L^1M^0T^{-2}]$

$\therefore$ $[F] = [L^1M^1T^{-2}]$

Dimensions of force are $[L^1M^1T^{-2}]$

S.I. Unit of force is kilogram metre per square second (kg m s^{-2}), This unit is known as newton (N).

c.g.s. unit of acceleration is gram centimetre per square second (g cm s^{-2}). This unit is known as dyne.

Dimensions and Unit of Momentum (p):

Momentum = Mass × Velocity

$\therefore$ p = m× v

$\therefore$ [p] = [m] × [v]

$\therefore$ $[p] = [L^0M^1T^0][L^1M^0T^{-1}]$

$\therefore$ $[p] = [L^1M^1T^{-1}]$

Dimensions of momentum are $[L^1M^1T^{-1}]$

S.I. Unit of momentum is kilogram meter per second (kg m s^{-1}).

c.g.s. unit of momentum is gram centimeter per second (g cm s^{-1})

Dimensions and Unit of Impulse of Force (J):

Impulse of Force = Force × Time

∴ $J = F \times t$

∴ $[J] = [F] \times [t]$

∴ $[J] = [L^1M^1T^{-2}][L^0M^0T^1]$

∴ $[J] = [L^1M^1T^{-1}]$

Dimensions of impulse of force are $[L^1M^1T^{-1}]$

S.I. Unit of impulse of force is kilogram meter per second (kg m s^{-1}). Common S.I. unit used is newton second (N s)..c.g.s. unit of impulse of force is gram centimeter per second (g cm s^{-1}). Common c.g.s. unit is dyne second.

Dimensions and Unit of Work (W):

Work Done = Force × Displacement

∴ $W = F \times s$

∴ $[W] = [F] \times [s]$

∴ $[W] = [L^1M^1T^{-2}][L^1M^0T^0]$

∴ $[W] = [L^2M^1T^{-2}]$

Dimensions of work are $[L^2M^1T^{-2}]$

S.I. Unit of work is kg square metre per square second. Commonly this unit is known as joule (J).

c.g.s. Unit of work is gram square centimetre per square second. Commonly this unit is known as erg.

Dimensions and Unit of Potential Energy (E or U):

Potential Energy = Mass × Acceleration due to gravity × Height

∴ $E = m \times g \times h$

∴ $[E] = [m] \times [g] \times [h]$

∴ $[E] = [L^0M^1T^0][L^1M^0T^{-2}][L^1M^0T^0]$

∴ $[E] = [L^2M^1T^{-2}]$

Dimensions of potential energy are $[L^2M^1T^{-2}]$

S.I. Unit of potential energy is kg square metre per square second. Commonly this unit is known as joule (J).

c.g.s. Unit of potential energy is gram square centimetre per square second. Commonly this unit is known as erg.

Dimensions and Unit of Kinetic Energy (E):

Kinetic Energy = 1/2 Mass × Velocity²

$\therefore E = 1/2 \times m \times v^2$

$\therefore [E] = [m] \times [v]^2$

$\therefore [E] = [L^0M^1T^0][L^1M^0T^{-1}]^2$

$\therefore [E] = [L^0M^1T^0][L^2M^0T^{-2}]$

$\therefore [E] = [L^2M^1T^{-2}]$

Dimensions of kinetic energy are $[L^2M^1T^{-2}]$

S.I. Unit of kinetic energy is kg square metre per square second. Commonly this unit is known as joule (J).

c.g.s. Unit of kinetic energy is gram square centimetre per square second. Commonly this unit is known as erg.

Dimensions and Unit of Pressure (P):

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

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

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

$$\therefore [P] = \frac{[L^1M^1T^{-2}]}{[L^2M^0T^0]}$$

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

Dimensions of Pressure are $[L^{-1}M^1T^{-2}]$ S.I. Unit of pressure is

S.I. Unit of pressure is newton per square metre or pascal (N m^{-2} or Pa).

c.g.s. unit of pressure is dyne per square centimetre (dyne cm^{-2})

Dimensions and Unit of Power (P):

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

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

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

$$\therefore [P] = \frac{[L^2M^1T^{-2}]}{[L^0M^0T^1]}$$

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

Dimensions of Power are $[L^2M^1T^{-3}]$

S.I. Unit of Power is watt (W). c.g.s. unit of power is erg per second (erg s^{-1})

Dimensions and Unit of Electric Charge:

Electric Charge = Electric Current × Time

$\therefore$ Q =I× t

$\therefore$ [Q] = [I] × [t]

$\therefore$ $[Q] = [L^0M^0T^0I^1][L^0M^0T^1]$

$\therefore$ $[Q] = [L^0M^0T^1I^1]$

Dimensions of electric charge are $[L^0M^0T^1I^1]$

S.I. Unit of electric charge is coulomb (C)

Dimensions and Unit of Electric Potential:

$$\text{Electric Potential} = \frac{\text{Work}}{\text{Electric Charge}}$$

$$V = \frac{W}{Q}$$

$$\therefore [V] = \frac{[W]}{[t]}$$

$$\therefore [V] = \frac{[L^2M^1T^{-2}]}{[I^1T^1]}$$

$$\therefore [V] = [L^2M^1T^{-3}I^{-1}]$$

Dimensions of electric potential are $[L^2M^1T^{-3}I^{-1}]$

S.I. Unit of electric potential is volt (V)

Dimensions and Unit of Electric Resistance:

$$\text{Electric Resistance} = \frac{\text{Electric Potential}}{\text{Electric Current}}$$

$$R = \frac{V}{I}$$

$$\therefore [R] = \frac{[V]}{[I]}$$

$$\therefore [R] = \frac{[L^2M^1T^{-3}I^{-1}]}{[I^1]}$$

$$\therefore [R] = [L^2M^1T^{-3}I^{-2}]$$

Dimensions of electric resistance are $[L^2M^1T^{-3}I^{-2}]$

S.I. Unit of electric resistance is ohm (Ω)

Writing SI Units and their Symbols:

- All units and their symbols should be written in small case letters e.g. centimetres (cm), metre (m), kilogram per metre cube (kg m^{-3}).
- The units named after scientists are not written with a capital initial letter but its symbol is written in capital letter. Thus the unit of force is written as 'newton' or' N' and not as 'Newton'. Similarly unit of work and energy is joule (J), S.I. unit of electric current is ampere (A). The S.I. nit of pressure is pascal (Pa) and that of temperature is kelvin (K).
- No full stop should be placed after the symbol.
- The denominators in a compound unit should be written with negative powers. Thus an index notation should be used to write a derived unit. for example unit of velocity should be written as ms^{-1} instead of m/s. The unit of density is kilogram per metre cube (kg m^{-3} and not kg/m^3)
- No plural form of a unit or its symbol should be used. example 5 newtons should be written as 5 N and not as 5 Ns.
- A compound unit obtained from units of two or more physical quantities is written either by putting a dot or leaving a space between symbols of two units. Example unit of torque is newton metre is written as Nm ot N.m. Unit of impulse is newton second is written as N s or N.s.
- Some space should be maintained between the number and its unit.

Advantages of S.I. System of Units:

- Units are simple to express
- This system uses only one unit for one physical quantity. Hence it is a rational system of units.
- Units of many physical quantities are related to each other through simple and elementary relationships For example 1 ampere = 1 volt / 1 ohm.
- It is a metric system of units. There is a decimal relationship between the units of the same quantity and hence it is possible to express any small or large quantity as a power of 10. i.e. inter-conversion is very easy. For e.g. 1kg = 1000 gm = 10^3 gm

- The physical quantities can be expressed in terms of suitable prefixes.
- a joule is a unit of all forms of energy and it is a unit of work. Hence it forms a link between mechanical and electrical units. Hence S.I. the system is a rational system because it uses only one unit for one physical quantity.
- This system forms a logical and interconnected framework for all measurements in science, technology, and commerce.
- All derived units can be obtained by dividing and multiplying the basic and supplementary units and no numerical factors are introduced as in another system of units. Hence S.I. system of units is a coherent system. Hence S.I. system of units is used worldwide.

General Steps to Find Derived Unit:

- Step -1 Write the formula for the quantity whose unit is to be derived.
- Step -2 Substitute units of all the quantities in one system of units in their fundamental or standard form.
- Step -3 Simplify and obtain derive unit of the quantity.

Example: To find the unit of velocity.

- Velocity is a derived quantity. Hence its unit is a derived unit.
- The velocity is given by, velocity = displacement/time
- S.I. unit of velocity = S.I. unit of displacement/ S.I. unit of time = m/s
- Thus S.I. unit of velocity is m/s

Applications of Dimensional Analysis:

- To check the correctness of physical equation:
- To Find Dimensions of New Physical Quantity:
- To derive the form of a physical equation:
- To derive the relation between different units of different systems of a physical quantity:

Example – 01:

To check the correctness of physical equation, v = u + at, Where 'u' is the initial velocity, 'v' is the final velocity, 'a' is the acceleration and 't' is the time in which the change occurs.

Solution:

Given equation is v = u + at

L.H.S. = v, hence [L.H.S.] = [v] = $[L^1M^0T^{-1}]$ ………………. (1)

R.H.S = u + at, hence [R.H.S] = [u] + [a][t]

[R.H.S] = $[L^1M^0T^{-1}] + [L^1M^0T^{-2}][L^0M^0T^1]$

$[R.H.S] = [L^1M^0T^{-1}] + [L^1M^0T^{-1}]$

$[R.H.S] = [L^1M^0T^{-1}]$ ……………. (2)

From (1) and (2) we have [L.H.S.] = [R.H.S.]

Hence by principle of homogeneity the given equation is dimensionally correct.

Example – 02:

To check the correctness of physical equation, $a = v^2/r^2$, Where 'a' is the centripetal acceleration of a body performing uniform circular motion along a circle of radius 'r' with linear speed 'v'.

Solution:

Given equation is $a = v^2/r^2$

L.H.S. = a, hence $[L.H.S.] = [a] = [L^1M^0T^{-2}]$ ………………. (1)

R.H.S = v^2/r^2 , hence $[R.H.S] = [v]^2/[r]^2$

$[R.H.S] = [L^1M^0T^{-1}]^2 / [L^1M^0T^0]^2$

$[R.H.S] = [L^2M^0T^{-2}] / [L^2M^0T^0]$

$[R.H.S] = [L^0M^0T^{-2}]$ ……………. (2)

From (1) and (2) we have [L.H.S.] ≠ [R.H.S.]

Hence by the principle of homogeneity, the given equation is dimensionally not correct.

Example – 03:

Find dimensions of universal gravitation constant (G).

Solution:

If m_1 and m_2 are two masses separated by a distance r from each other then the force of gravitation acting between them is given by Newton's law of gravitation

$$F = \frac{Gm_1m_2}{r^2}$$

$$\therefore G = \frac{Fr^2}{m_1m_2}$$

$$\therefore [G] = \frac{[F][r]^2}{[m_1][m_2]} = \frac{[L^1M^1T^{-2}][L^1]^2}{[M^1][M^1]}$$

$$\therefore [G] = \frac{[L^1M^1T^{-2}][L^2]}{[M^2]} = \frac{[L^3M^1T^{-2}]}{[M^2]}$$

$$\therefore [G] = [L^3M^{-1}T^{-2}]$$

Hence dimensions of universal gravitation constant are $[L^3M^{-1}T^{-2}]$

Example – 04:

Find dimensions of the coefficient of viscosity (η).

Solution:

Le F be the viscous force acting between two layers of liquid area A having velocity difference of dv between them. Let dx be the separation between the two layers and η is coefficient of viscosity, then by Newton's law of viscosity

$$F = \eta A \frac{dv}{dx}$$

$$\therefore \eta = \frac{F.dx}{A.dv}$$

$$\therefore [\eta] = \frac{[F][dx]}{[A][dv]} = \frac{[L^1M^1T^{-2}][L^1]}{[L^2][L^1T^{-1}]}$$

$$\therefore [\eta] = \frac{[L^2M^1T^{-2}]}{[L^3T^{-1}]} = [L^{-1}M^1T^{-1}]$$

Hence dimensions of the coefficient of viscosity are $[L^{-1}M^1T^{-1}]$

Example – 05:

The period (T) of a simple pendulum is assumed to depend on length (l) of the pendulum, acceleration due to gravity (g) and mass (m) of the bob of the pendulum. If the constant of proportionality is 2π, then find the equation for the time period of the simple pendulum.

Solution:

let $T \propto l^x$, $T \propto g^y$, $T \propto m^z$,

Combining above relations we have $T \propto l^x g^y m^z$,

$T = k\, l^x g^y m^z$ ………….. (1)

By principle of homogeneity of dimensions we have

$[T] = [l]^x [g]^y [m]^z$

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

$\therefore [L^0M^0T^1] = [L^xM^0T^0][L^yM^0T^{-2y}][L^0M^zT^0]$

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

Considering equality of two sides we have

$x + y = 0$, $z = 0$, $-2y = 1$

$\therefore y = -1/2$

$x + y = 0$

$\therefore x - 1/2 = 0$

$\therefore x = 1/2$

Substituting $x = 1/2$, $y = -1/2$ and $z = 0$ in equation (1) we get

$T = k\, l^{1/2} g^{-1/2} m^{0}$

The value of constant in this case is 2π , i.e. $k = 2\pi$

$$T = k\frac{l^{1/2}}{g^{1/2}} = k\sqrt{\frac{l}{g}}$$

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

This is the formula for time period of the simple pendulum.

Standard physics constants

Speed of light	c	3×10^8 m/s
Planck constant	h	6.63×10^{-34} J s
	hc	1242 eV-nm
Gravitation constant	G	6.67×10^{-11} m^3 kg^{-1} s^{-2}
Boltzmann constant	k	1.38×10^{-23} J/K
Molar gas constant	R	8.314 J/(mol K)
Avogadro's number	N_A	6.023×10^{23} mol^{-1}
Charge of electron	e	1.602×10^{-19} C
Permeability of vacuum	μ_0	$4\pi \times 10^{-7}$ N/A^2
Permitivity of vacuum	ϵ_0	8.85×10^{-12} F/m
Coulomb constant	$\frac{1}{4\pi\epsilon_0}$	9×10^9 N m^2/C^2
Faraday constant	F	96485 C/mol
Mass of electron	m_e	9.1×10^{-31} kg
Mass of proton	m_p	1.6726×10^{-27} kg
Mass of neutron	m_n	1.6749×10^{-27} kg
Atomic mass unit	u	1.66×10^{-27} kg
Atomic mass unit	u	931.49 MeV/c^2
Stefan-Boltzmann constant	σ	5.67×10^{-8} W/(m^2 K^4)
Rydberg constant	R_∞	1.097×10^7 m^{-1}
Bohr magneton	μ_B	9.27×10^{-24} J/T
Bohr radius	a_0	0.529×10^{-10} m
Standard atmosphere	atm	1.01325×10^5 Pa
Wien displacement constant	b	2.9×10^{-3} m K

Unit -2

Force

A force describes, quantitatively, the interaction between two objects. A force is a vector quantity: it has a magnitude and a direction. The interaction may be at a distance or through contact. Forces are used to push or pull stationary objects, to stop moving objects, to change direction of moving objects.

Forces always exist in pairs: a force of action and a force of reaction (third law of Newton). Action and reaction forces acts on different objects and have equal magnitudes.

A force is represented mathematically by a vector because both magnitude and direction are important to describe the force.

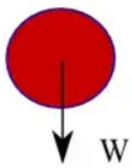
The SI unit of a force is the Newton. 1 Newton = 1 Kg × 1 m/s

Force is an important concept as it influences motion. It can be defined as an interaction that changes the motion of an object if unopposed. But the simple definition of force is that it is the push or pull experienced by any object. Force is a vector quantity, thus it has both magnitude and direction. Therefore, one has to specify both the direction and the magnitude to describe the force acting on an object.

Types of forces

Gravitational force:

Gravitational force is a fundamental force of nature that exists between all objects with mass. It is the force responsible for the attraction between two masses. The concept of gravitational force was first described by Sir Isaac Newton in the late 17th century.



The magnitude of the gravitational force between two objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers. The mathematical expression for the gravitational force between two masses, M_1 and M_2, separated by a distance r, is given by Newton's law of universal gravitation:

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

where:

F is the magnitude of the gravitational force between the two masses.

G is the gravitational constant (approximately 6.67×10^{-11} Nm^2/kg^2), which is a universal constant.

M_1 and M_2 are the masses of the two objects.

r is the distance between the centers of the two masses.

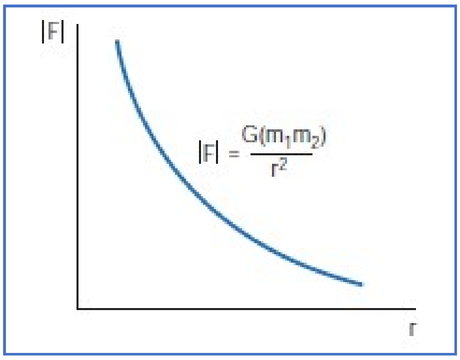
The direction of the gravitational force is attractive and acts along the line connecting the centers of the two masses. This means that objects with mass are always pulling each other towards one another.

Gravitational force is responsible for various phenomena in the universe, ranging from the motion of celestial bodies like planets, stars, and galaxies to the everyday force of gravity that keeps us anchored to the surface of the Earth. It is a crucial force that governs the structure and dynamics of the cosmos.

Important features of gravitational force:

The gravitational force between two masses is independent of the medium.

As the distance between two masses increases, the strength of the force tends to decrease because of inverse dependence on r^2. Physically it implies that the planet Uranus experiences less gravitational force from the Sun than the Earth since Uranus is at larger distance from the Sun compared to the Earth.



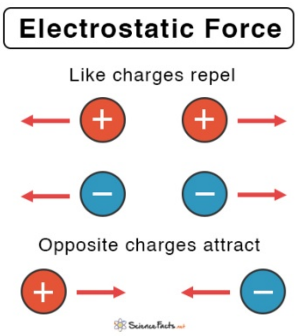
The gravitational forces between two particles always constitute an action- reaction pair. It implies that the gravitational force exerted by the Sun on the Earth is always towards the Sun. The reaction-force is exerted by the Earth on the Sun. The direction of this reaction force is towards Earth.

The torque experienced by the Earth due to the gravitational force of the Sun is zero.It implies that angular momentum $\vec{L}$ is a constant vector. The angular momentum of the Earth about the Sun is constant throughout the motion. It is true for all the planets. In fact, this constancy of angular momentum leads to the Kepler's second law.

Both M_1 and M_2 are treated as point masses. When it is said that Earth orbits around the Sun due to Sun's gravitational force, we assumed Earth and Sun to be point masses. This assumption is a good approximation because the distance between the two bodies is very much larger than their diameters. For some irregular and extended objects separated by a small distance, we cannot directly use the above equation.

This assumption about point masses holds even for small distance for one special case. To calculate force of attraction between a hollow sphere of mass M with uniform density and point mass m kept outside the hollow sphere, we can replace the hollow sphere of mass M as equivalent to a point mass M located at the center of the hollow sphere. The force of attraction between the hollow sphere of mass M and point mass m can be calculated by treating the hollow sphere also as another point mass. Essentially the entire mass of the hollow sphere appears to be concentrated at the center of the hollow sphere.

Electrostatic force:



Electrostatic force is a fundamental force in physics that arises from the interaction between electric charges. It is responsible for the attraction or repulsion between charged particles, such as electrons and protons, due to their electric fields. This force plays a crucial role in the behavior of atoms, molecules, and macroscopic objects.

Coulomb's law states that the electrostatic force is directly proportional to the product of the magnitude of the two point charges and is inversely proportional to the square of the distance between the two point charges.

$$\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$$

where:

F is the magnitude of the electrostatic force,

k is Coulomb's constant (≈8.99×10^9 N m2/C^2k≈8.99×10^9 Nm^2/C^2),

q_1 and q_2 are the magnitudes of the charges of the two particles (measured in Coulombs, C),

r is the distance between the centers of the two charges (measured in meters, m).

The force on the charge q_2 exerted by the charge q_1 always lies along the line joining the two charges. $\hat{r}_{12}$ is the unit vector pointing from charge q_1 to q_2. Likewise, the force on the charge q_1 exerted by q_2 is along $\hat{r}_{21}$ (i.e., in the direction opposite to $\hat{r}_{12}$. Hence, the electrostatic force obeys Newton's third law.

In SI units, $k = \frac{1}{4\pi\varepsilon_0}$and its value is 9×10^9 Nm^2C^{-2}. Here ε_0 is the permittivity of free space or vacuum and its value is 8.85 x 10^{12} $C^2N^{-1}m^{-2}$

In a medium of permittivity ε, the force between two point charges is given by $\vec{F} = \frac{1}{4\pi\varepsilon}\frac{q_1q_2}{r^2}\hat{r}$. Since ε>ε_0, the force between two point charges in a medium other than vacuum is always less than that in vacuum. We define the relative permittivity for a given medium as ε_r. For vacuum or air, ε_r = 1 and for all other media ε_r> 1.

Coulomb's law has same structure as Newton's law of gravitation. Both are inversely proportional to the square of the distance between the particles. The electrostatic force is directly proportional to the product of the magnitude of two point charges and gravitational force is directly proportional to the product of two masses. But there are some important differences between these two laws.

The gravitational force between two masses is always attractive but Coulomb force between two charges can be attractive or repulsive, depending on the nature of charges.

• Since the value of the constant *k* is much greater than the value of the gravitational constant *G*, the electrostatic force is always greater in magnitude than gravitational force for smaller size objects.

• The gravitational force between two masses is independent of the medium. For example, if 1 kg of two masses are kept in air or inside water, the gravitational force between two masses remains the same. But the electrostatic force between the two charges depends on nature of the medium in which the two charges are kept at rest.

The expression for Coulomb force is true only for point charges. But the point charge is an ideal concept. However we can apply Coulomb's law for two charged objects whose sizes are very much smaller than the distance between them.

Key points about electrostatic force:

Like charges (e.g., two positive or two negative charges) repel each other, resulting in a repulsive force.

Opposite charges (e.g., positive and negative charges) attract each other, leading to an attractive force.

The electrostatic force is a long-range force, meaning it acts over a distance without direct contact between the charged particles.

Electrostatic forces are extremely strong at the atomic and subatomic levels but tend to cancel out in macroscopic objects due to the presence of both positive and negative charges in equal amounts.

The force of attraction between an electron and a proton in an atom is what keeps the electrons in orbit around the nucleus.

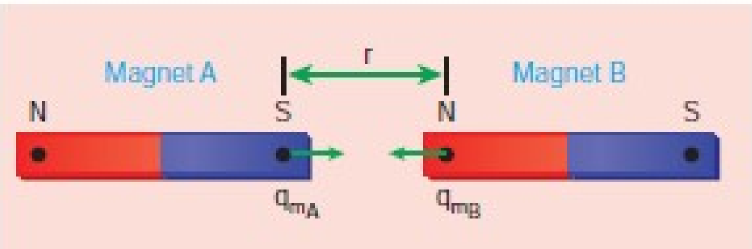
Electrostatic forces play a vital role in various everyday phenomena, including static electricity, lightning, and the functioning of electrical devices.

Understanding the electrostatic force is crucial in fields such as electromagnetism, electronics, and atomic physics, as it forms the basis for the behavior of charged particles and the interactions between them.

Magnetic force

The force of attraction or repulsion between two magnetic poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them.

where k is a proportionality constant whose value depends on the surrounding medium. In SI unit, the value of k for free space is $k = \frac{\mu_0}{4\pi} = 10^{-7} Hm^{-1}$ where μo is the absolute permeability of free space (air or vacuum) and H stands for 'Henry'.



$$F \propto \frac{m_1 m_2}{\mu r^2}$$

Magnetic force is a fundamental force in physics that arises due to the interaction between moving electric charges and magnetic fields. It plays a crucial role in a wide range of phenomena and technologies, from generating electricity in power plants to the operation of magnets and electric motors.

The magnetic force experienced by a charged particle moving through a magnetic field is perpendicular to both the velocity of the particle and the magnetic field lines. It follows the right-hand rule, where if you point your thumb in the direction of the velocity of the charged particle, and your fingers in the direction of the magnetic field, then the direction in which your palm faces represents the direction of the magnetic force acting on the particle.

Key points about magnetic force:

Magnetic force cannot alter the speed of the charged particle, only its direction.

The force is maximum when the charged particle moves perpendicular to the magnetic field (θ = 90 degrees) and is zero when it moves parallel (θ = 0 degrees) to the field lines.

Magnetic forces play a critical role in the operation of electric motors, generators, and transformers, which are crucial components in modern electrical systems.

Magnetic fields also influence the behavior of charged particles in particle accelerators and can be used for particle confinement in devices like magnetic traps used in research.

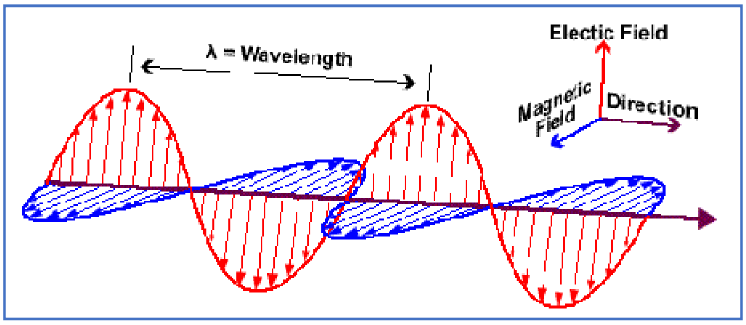
Understanding the magnetic force is essential for various scientific and engineering applications, from designing and optimizing magnetic devices to explaining the behavior of charged particles in the presence of magnetic fields.

Electromagnetic force:

The electromagnetic force is one of the four fundamental forces of nature, along with the strong nuclear force, the weak nuclear force, and gravity. It is responsible for the interaction between electrically charged particles, such as protons, electrons, and ions.

The importance of the electromagnetic force in physics can't be understated because it plays a role in virtually all of the phenomena that we observe in the world around us. It is responsible for the behavior of electric and magnetic fields, which are present in everything from lightning strikes to the operation of motors and generators.

Additionally, the electromagnetic force is responsible for the behavior of light and other forms of electromagnetic radiation, such as radio waves, microwaves, and X-rays.



At the subatomic level, the electromagnetic force is responsible for the behavior of charged particles within atoms and molecules. This force determines the structure of atoms and the chemical properties of elements, allowing for the formation of chemical bonds that hold molecules together.

Without the electromagnetic force, it would be impossible for molecules to form, and the complex chemistry that is necessary for life as we know it would not be possible.

One of the most significant applications of the electromagnetic force is in electronics and communications technology. From cell phones to satellites, the electromagnetic force plays a vital role in our modern technological infrastructure. The electromagnetic force also plays a crucial role in many other areas of physics, including particle physics, astrophysics, and cosmology. It is responsible for the behavior of charged particles in the presence of magnetic fields, which is important for understanding phenomena such as the aurora borealis, and for the study of high-energy particles in particle accelerators.

The electromagnetic force is transmitted by particles called photons.

Photons are elementary particles that have no electric charge, no rest mass, and travel at the speed of light in a vacuum.

Photons are produced when an electrically charged particle, such as an electron, undergoes a transition from a higher energy level to a lower energy level. This process is called photon emission.

Electric motors and generators rely on the electromagnetic force as well.

In medicine, magnetic resonance imaging (MRI) uses the electromagnetic force to create detailed images of the human body. It works by using a very strong magnetic field and radio waves to manipulate the spin of protons in the body's tissues, which are then detected by sensors to create an image.

The magnetic force experienced by a charged particle moving through a magnetic field is perpendicular to both the velocity of the particle and the magnetic field lines. It follows the right-hand rule, where if you point your thumb in the direction of the velocity of the charged particle, and your fingers in the direction of the magnetic field, then the direction in which your palm faces represents the direction of the magnetic force acting on the particle.

The force on a charged particle can be calculated using the following formula:

$$\vec{F} = q\vec{E} + q(\vec{v} \times \vec{B}) = q\vec{E} + qvB\sin\theta$$

where:

F is the magnetic force in Newtons (N).

q is the charge of the particle in Coulombs (C).

v is the velocity of the particle in meters per second (m/s).

B is the magnetic field strength in Tesla (T).

θ is the angle between the velocity vector and the magnetic field vector.

Nuclear forces:

Nuclear forces, strong nuclear force, and weak nuclear force are two of the four fundamental forces of nature other than electromagnetic and gravitational forces. Unlike Coulomb’s Law or Newton’s Law of Gravitation, there is no simple mathematical way to describe nuclear forces. Nuclear forces are one of the strongest forces of nature.

According to the standard model nuclear forces arise due to the exchange of gluons. Since nucleons are made up of quarks, i.e., neutron (udd) and proton (uud), where u and d denote up and down quarks, respectively. The exchange of quarks between the neutron and proton keeps them intact inside the nucleus.

The nuclear forces exist inside the nucleus, i.e., the nuclear force exists between protons and neutrons and holds them together inside the nucleus.

Nuclear force exists between neutrons-neutrons, neutrons-protons, and protons-protons. As we know according to Coulomb's Law same charges repel each other and protons are made of similar charges but still inside a nucleus protons are held together even though they repel each other, this is because of nuclear force. The nuclear force is one of the strongest forces in nature hence it overcomes the electrostatic force inside the nucleus and keeps it intact.

The nuclear forces are further classified into two categories. On the basis of intensity, nuclear force is further classified as,

- Strong Nuclear Force
- Weak Nuclear Force

Strong Nuclear Force

Strong nuclear force is the force that acts between particles such as quarks, and other. It is the strongest force out of the four fundamental forces of interaction. Two similar charges repel each other because of the Coulomb's force, but in a nucleus, strong nuclear force overcomes the Colombian forces and keeps protons and protons together inside the nucleus. If the strong nuclear forces that bind protons and neutrons in an atom break, high-energy photons are released. Some of the properties of this force are,

- Strong nuclear forces are responsible for holding the nuclei of atoms stable.
- They are about 10^6 times greater than the weak nuclear force.
- They work at a distance of less than 10^{-15} m.

The magnitude of Strong Nuclear Force is far greater than the electromagnetic and gravitational force.

Weak Nuclear Force

Weak nuclear force is involved in the particle where radioactive decay occurs. They change neutrons into protons in the process of nuclear decay. Some of the properties of this force are

- They exist between subatomic particles involving radioactive decay.
- They are neither attractive nor repulsive.

Properties of Nuclear Forces

Various properties of nuclear forces are discussed below,

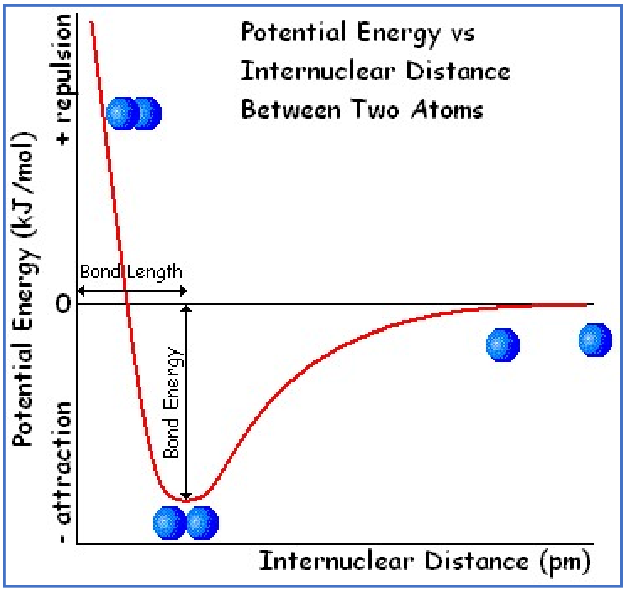
1. **Nuclear Force is the strongest Fundamental Force**

The magnitude of the nuclear force between two protons is 100 times Coulomb's electrostatic repulsive force and 10^{36} times the gravitational attractive force. The nuclear force is stronger than Coulomb's repulsive force and is able to keep the protons bound in a very small nucleus.

2. **Nuclear force is Attractive Force**

Nuclear force is attractive in nature and the variation of the potential energy of the nucleus with the distance (r) between the nucleons is shown in the figure below.

The graph in the figure reveals Potential energy is released at a distance of r_o ($\approx$ 0.8 fm). When the distance between two nucleons is greater than r_o, the nuclear forces are attractive. As the distance between them decreases and is smaller than r_o this force becomes repulsive and becomes minimum ($\approx$ 0.8 fm) and increases rapidly which avoids the collapsing of the nucleus.



3. **Nuclear Force is Charge Independent**

The interaction between two nucleons is independent of whether one or both nucleons have a charge on them. In other words, the nuclear force between Proton-Proton (p-p)proton-neutron (p-n), and neutron-neutron (n-n)is the same, so these forces are charge independent.

4. **Nuclear Force is Short-Range Force**

The nuclear forces between two nucleons exist only when the distance between nucleons is comparable to the size of the nucleus i.e. of the order of 10^{-15}. These forces cease to act as the distance between two nucleons exceeds 10^{-15}. Moreover, a nucleon can interact with only its neighboring nucleons just as an atom in solid form bonds only with the surrounding atoms. Thus, these forces are short-range forces.

5. **Nuclear Force is Exchange Force**

Nuclear forces are due to the exchange of π mesons between the nucleons, so they are called exchange forces. The force between two nucleons does not act along the line joining their centers and is therefore called non-Central force.

6. **Nuclear force is Spin-Dependent**

It has been observed that the nuclear force between nucleons having parallel spins is greater than the force between nucleons having anti-parallel spins. Thus, they are spin-dependent.

Examples of Nuclear Forces

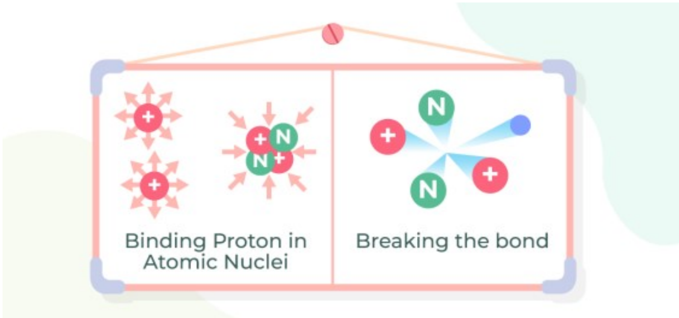
As previously mentioned, the most obvious example of Nuclear Force is the binding of protons, which are naturally repulsive due to their positive charge.

- Nuclear Force is responsible for the working of the nuclear reactor and nuclear weapons.
- Strong nuclear force is responsible for the stability of the nucleus of an atom.
- Weak nuclear force is responsible for radioactive decay.

Nuclear Stability

Nuclear Stability can be explained, by three forces interacting with each other inside a nucleus.

The main force responsible for the stability of the nucleus is the **Strong Nuclear Force**, which is responsible for nucleus cohesiveness by pushing the different nucleons together and is also responsible for the generation of alpha radiation.



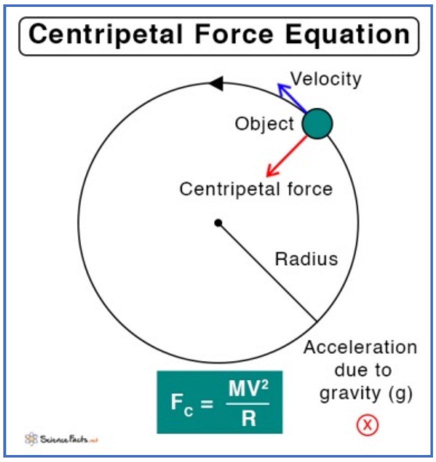
Electromagnetic Repulsion force acts between protons, but its magnitude is far less than the strong nuclear force.

The third of these is the '**weak**' force, which works inside individual nucleons and can occasionally result in the change of a neutron into a proton (or vice versa), accompanied by the production of beta radiation.

The image shows the nuclear stability and its bond breakage.

Mechanical forces:

Centripetal force is defined as the force acting on a body that is moving in a circular path that is directed toward the center around which the body moves. The term comes from the Latin words centrum for "center" and petere, meaning "to seek."



Centripetal force may be considered the center-seeking force. Its direction is orthogonal (at a right angle) to the motion of the body in the direction toward the center of curvature of the body's path. Centripetal force alters the direction of an object's motion without changing its speed.

Centripetal force is the force that keeps an object moving in a circular path. It is directed towards the center of the circle and acts perpendicular to the object's velocity. Centripetal force is required to counteract the tendency of an object to move in a straight line, according to Newton's first law of motion (inertia). Without centripetal force, an object moving in a circular path would continue in a straight line due to its inertia.

The formula for centripetal force can be expressed as:

$$F = \frac{mv^2}{r}$$

Where: F is the centripetal force in Newtons (N) m is the mass of the object in kilograms (kg) v is the velocity of the object in meters per second (m/s) r is the radius of the circular path in meters (m)

It's important to note that centripetal force is not a distinct force itself but rather a name given to the net force acting on an object that results in circular motion. This force can be provided by various sources, such as tension in a string, gravitational attraction, or friction, depending on the specific situation.

For instance, when an object is tied to a string and spun around in a circle, the tension in the string provides the necessary centripetal force to keep the object in circular motion. In the case of planetary motion, the gravitational force between the planet and the sun provides the centripetal force that keeps the planet in its orbit.

Practical Applications of Centripetal Force

The classic example of centripetal force is the case of an object being swung on a rope. Here, the tension on the rope supplies the centripetal "pull" force.

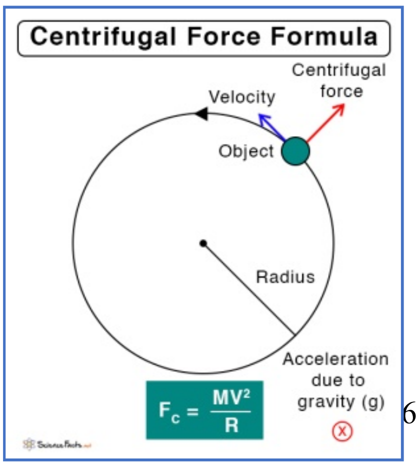
Centripetal force is the "push" force in the case of a Wall of Death motorcycle rider.

Centripetal force is used for laboratory centrifuges. Here, particles that are suspended in a liquid are separated from the liquid by accelerating tubes oriented so the heavier particles (i.e., objects of higher mass) are pulled toward the bottom of the tubes. While centrifuges commonly separate solids from liquids, they may also fractionate liquids, as in blood samples, or separate components of gases.

Gas centrifuges are used to separate the heavier isotope uranium-238 from the lighter isotope uranium-235. The heavier isotope is drawn toward the outside of a spinning cylinder.

A liquid mirror telescope (LMT) may be made by rotating a reflective liquid metal, such as mercury. The mirror surface assumes a paraboloid shape because the centripetal force depends on the square of the velocity. Because of this, the height of the spinning liquid metal is proportional to the square of its distance from the center. The interesting shape assumed by spinning liquids may be observed by spinning a bucket of water at a constant rate.

Centrifugal force:



Centrifugal force is a fictitious or apparent force that appears to act on a body moving in a curved path and accelerating toward the center of that curve. It is an outward force that arises due to the body's inertia as it tries to move in a straight line, according to Newton's first law of motion.

In reality, the concept of centrifugal force is a result of an observer's perspective in a non-inertial reference frame.

When an object moves in a circular path or undergoes a curved motion, an observer in the rotating or accelerating reference frame sees the object appear to be pushed outward from the center of the circle. This apparent force is referred to as the centrifugal force.

However, from an inertial reference frame (a frame that is not accelerating or rotating), there is no need to introduce the concept of centrifugal force to explain the object's motion. Instead, we can describe the motion using the concept of centripetal force, which is a real force acting toward the center of the circular path, responsible for keeping the object in its curved trajectory.

To summarize, centrifugal force is an apparent force that arises in a non-inertial reference frame when an object is subjected to circular or curved motion, but it is not an actual force experienced by the object itself. The actual force responsible for the object's curved path is the centripetal force, which acts inward toward the center of the curve.

Difference between Centripetal and Centrifugal Force

While centripetal force acts to draw a body toward the center of the point of rotation, the centrifugal force ("center-fleeing" force) pushes away from the center.

According to Newton's First Law, "a body at rest will remain at rest, while a body in motion will remain in motion unless acted upon by an external force." In other words, if the forces acting upon an object are balanced, the object will continue to move at a steady pace without acceleration.

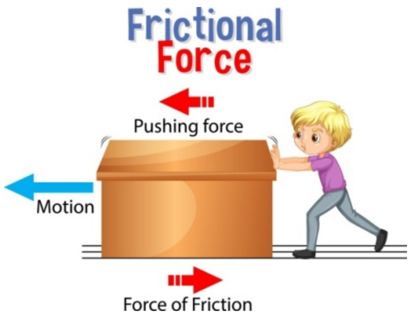
The centripetal force allows a body to follow a circular path without flying off at a tangent by continuously acting at a right angle to its path. In this way, it is acting upon the object as one of the forces in Newton's First Law, thus keeping the object's inertia.

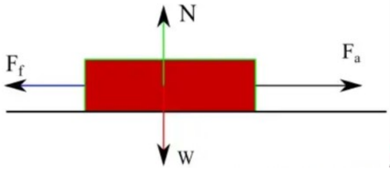
Newton's Second Law also applies in the case of the centripetal force requirement, which says that if an object is to move in a circle, the net force acting upon it must be inward. Newton's Second Law says that an object being accelerated undergoes a net force, with the direction of the net force the same as the direction of the acceleration. For an object moving in a circle, the centripetal force (the net force) must be present to counter the centrifugal force.

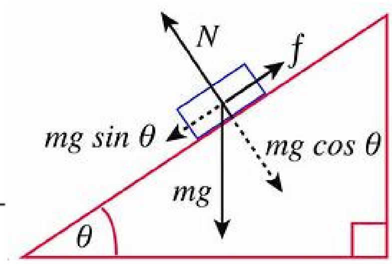
From the standpoint of a stationary object on the rotating frame of reference (e.g., a seat on a swing), the centripetal and centrifugal are equal in magnitude, but opposite in direction. The centripetal force acts on the body in motion, while the centrifugal force does not. For this reason, centrifugal force is sometimes called a "virtual" force.

Frictional force:

Frictional force is a fundamental concept in physics that describes the resistance encountered when two surfaces slide or attempt to slide past each other. It opposes the relative motion between two objects in contact and acts parallel to the surface of contact. Friction is a result of interactions between the atoms and molecules at the interface of the two surfaces.







There are two main types of friction:

Static Friction: This type of friction prevents the relative motion between two objects at rest. When you try to push an object across a surface, static friction opposes your force until the force exceeds the maximum static friction force. Once the force reaches this threshold, the object will start moving, and the friction becomes kinetic.

$$F_s \leq \mu_s N$$

Kinetic Friction: Also known as dynamic friction, kinetic friction acts between two surfaces in relative motion. It opposes the motion and acts in the direction opposite to the velocity of the moving object. Once an object starts sliding, the kinetic friction is generally lower than the maximum static friction force.

$$F_k = \mu_k N$$

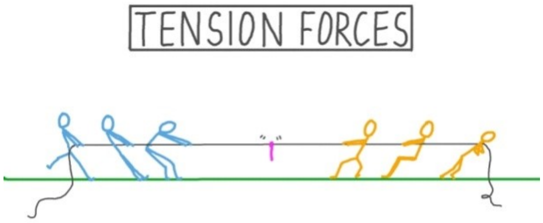
The amount of frictional force depends on several factors, including the nature of the surfaces in contact, the roughness of the surfaces, and the force pressing the surfaces together. The coefficient of friction is a dimensionless quantity that represents the ratio of the frictional force to the normal force (force perpendicular to the surface). It is denoted by the symbol "μ" and varies between 0 and 1. The coefficient of friction is different for static and kinetic friction, denoted as μ_s and μ_k, respectively.

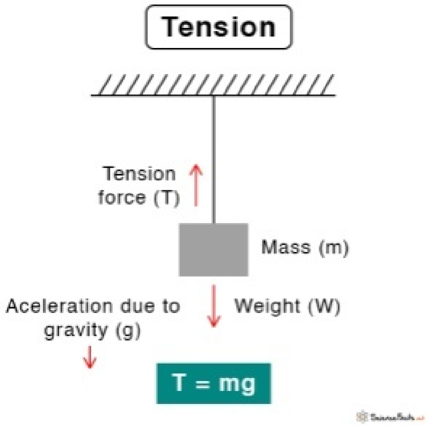
For inclined plane, $\mu_s = \tan\theta$

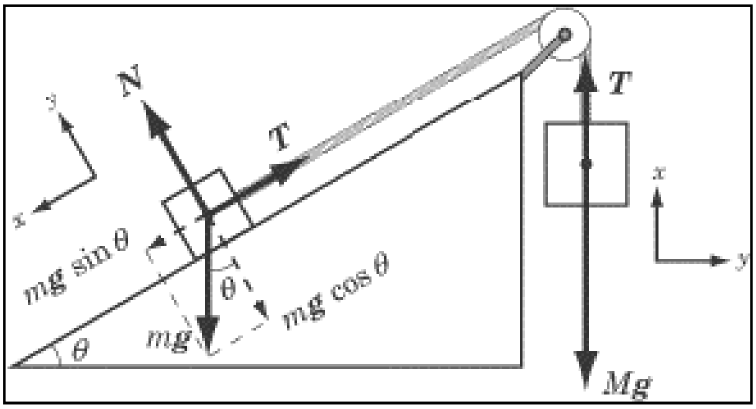
Frictional force plays a crucial role in various real-life situations, such as walking, driving vehicles, and the functioning of machines. While friction can sometimes be undesirable (e.g., causing energy loss and wear), it is also essential in many applications, such as providing traction and stability. Engineers and scientists study friction to optimize designs, reduce energy losses, and improve overall efficiency in mechanical systems.

Tension force:

Tension force refers to the force that is transmitted through a string, rope, cable, or any other flexible connector when it is pulled taut by opposing forces. It is a common concept in physics and engineering and plays a crucial role in many everyday situations and various technical applications.







When an object is subjected to two or more opposing forces along its length, the tension force develops in the connector that holds the object together. The tension force acts in the direction of the string or cable and is equal in magnitude at all points along the connector, assuming it is massless and has no internal friction. If the connector is not massless, its weight can be considered and may affect the overall tension distribution.

In practical scenarios, tension forces can be found in numerous situations, such as:

Tension in a hanging rope: When an object is suspended from a rope or cable, the tension force in the rope supports the object's weight and prevents it from falling.

Tension in a bridge cable: In a suspension bridge, the main cables experience tension forces that support the weight of the bridge deck and the vehicles crossing it.

Tension in a pulley system: When a load is lifted using a system of pulleys and ropes, the tension force in the ropes allows for the transmission of force from the input side to the output side of the pulley system.

Tension in a string instrument: In string instruments like guitars or violins, tension in the strings generates sound when they vibrate.

Understanding tension forces is essential in many engineering fields, such as civil engineering, mechanical engineering, and aerospace engineering, as they affect the stability, strength, and performance of structures and systems.

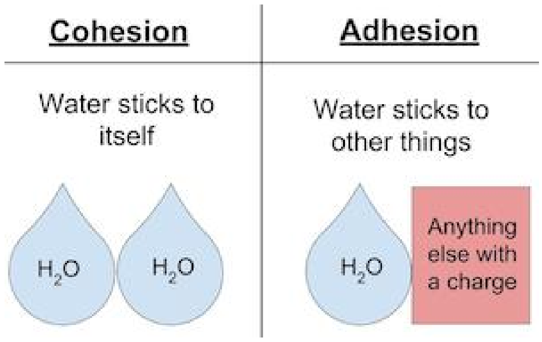
The magnitude of the tension force in a string or cable can be calculated using Newton's second law of motion and the equilibrium conditions for the connected objects.

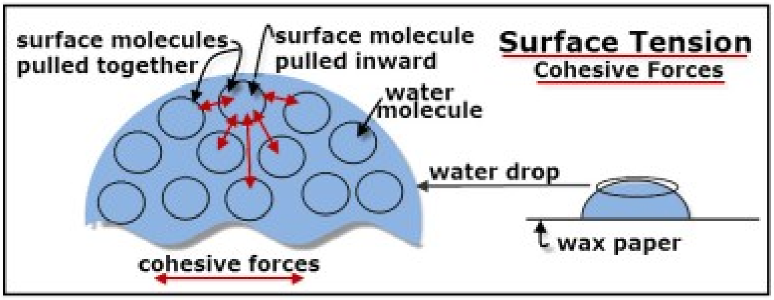
Cohesive force:

Cohesive force refers to the attractive force that holds particles or molecules of the same substance together. It is a phenomenon that allows the particles to stick or adhere to one another, creating a cohesive bond within the substance. Cohesive forces are responsible for the formation of drops in liquids, the ability of some materials to resist being pulled apart, and the surface tension of liquids, among other effects.

The strength of cohesive forces depends on the type of substance and the intermolecular forces present. In liquids, cohesive forces are generally stronger than in gases because the particles are closer together. For example, water exhibits strong cohesive forces due to hydrogen bonding between its molecules, which contributes to its high surface tension and the formation of water droplets.

Cohesive forces are essential in many natural phenomena and industrial processes, such as capillary action, adhesion, and the functioning of certain adhesives. They play a crucial role in the properties and behavior of materials and substances in various states (solid, liquid, and gas).

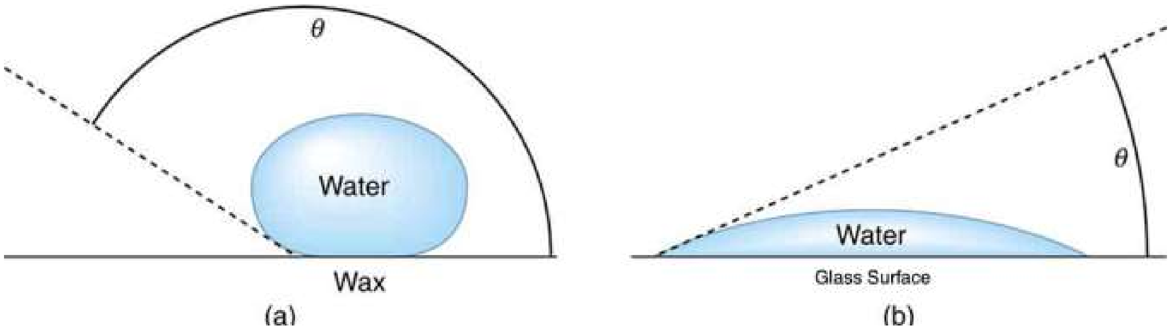


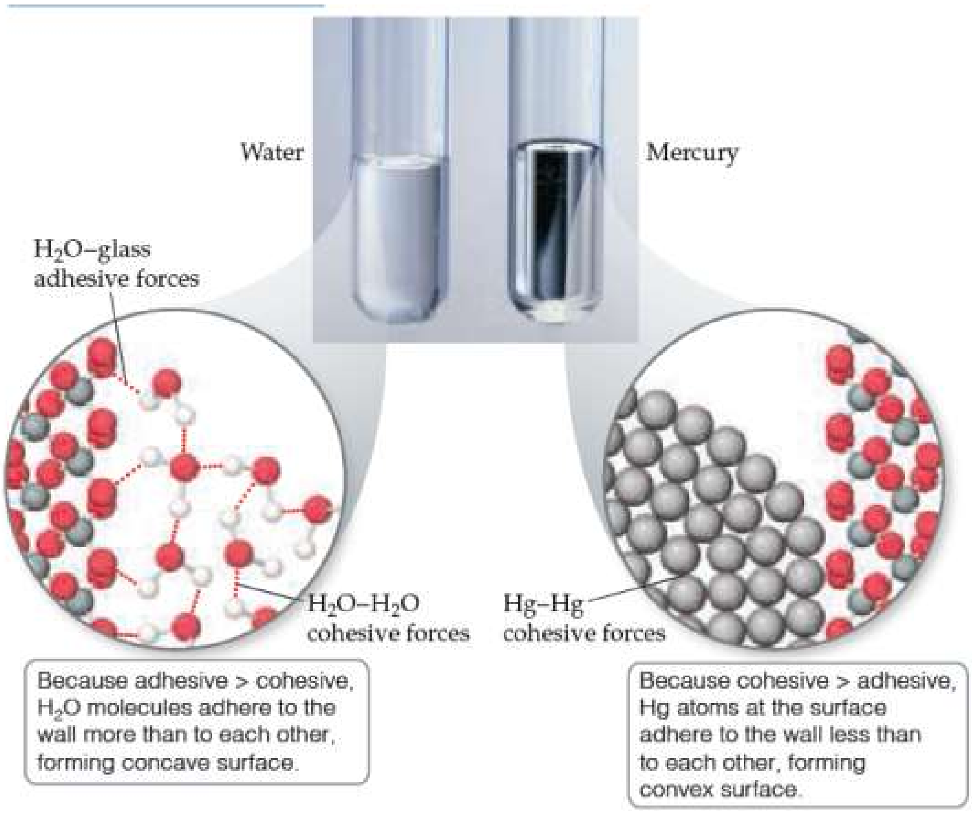


Adhesive force:

Adhesive force, also known as adhesion, refers to the attractive force between molecules of different substances. It is the force that causes two dissimilar materials to stick or adhere to each other when they come into contact. Adhesive forces are essential in many aspects of everyday life and various industries, including physics, chemistry, engineering, and biology.

The strength of the adhesive force depends on the nature of the materials involved and the interactions between their molecules. Some materials have strong adhesive properties and can adhere firmly to other surfaces, while others may have weak adhesive forces and not stick as well.





Adhesive forces are crucial in adhesion phenomena, such as gluing objects together, using tape or stickers, applying bandages to skin, or even the adhesion of water to the inner surfaces of a narrow glass tube, which is known as capillary action.

Adhesive and cohesive forces

The opposite of adhesive forces is cohesive forces, which refer to the attractive forces between molecules of the same substance. For example, water molecules exhibit cohesive forces, causing them to form droplets due to their strong mutual attraction. Cohesive and adhesive forces often work together to determine the behavior of liquids and solids when they come into contact with each other or with other surfaces.

Understanding adhesive forces is vital for developing adhesives and bonding materials in various industries, such as construction, automotive, aerospace, and medical fields. Proper adhesion can lead to improved product performance, durability, and overall functionality.

Unit -3

Energy is the fundamental form of living for all living beings. The Sun in this universe is considered as the elemental form of energy on the planet of Earth. Energy refers to the ability of any object to do work. Energy is required to perform work. It is a qualitative property of a body. The law of conservation of energy states that energy can't be created nor destroyed. It can just be transferred from one medium to another.

The S.I unit of energy is **Joule (J)**. It is a **scalar** quantity, which has magnitude only and no direction. Its dimensional formula is **[ML^2T^{-2}]**.

Different forms of Energy

Mechanical Energy

Mechanical energy is energy that results from movement or the location of an object. Mechanical energy is the sum of kinetic energy and potential energy.

Examples: An object possessing mechanical energy has both kinetic and potential energy, although the energy of one of the forms may be equal to zero. A moving car has kinetic energy. If you move the car up a mountain, it has kinetic and potential energy. A book sitting on a table has potential energy.

Thermal Energy

Thermal energy or heat energy reflects the temperature difference between two systems.

Example: A cup of hot coffee has thermal energy. You generate heat and have thermal energy with respect to your environment.

Nuclear Energy

Nuclear energy is energy resulting from changes in the atomic nuclei or from nuclear reactions.

Example: Nuclear fission, nuclear fusion, and nuclear decay are examples of nuclear energy. An atomic detonation or power from a nuclear plant are specific examples of this type of energy.

Chemical Energy

Chemical energy results from chemical reactions between atoms or molecules. There are different types of chemical energy, such as electrochemical energy and chemiluminescence.

Example: A good example of chemical energy is an electrochemical cell or battery.

Electromagnetic Energy

Electromagnetic energy (or radiant energy) is energy from light or electromagnetic waves.

Example: Any form of light has electromagnetic energy, including parts of the spectrum we can't see. Radio, gamma rays, x-rays, microwaves, and ultraviolet light are some examples of electromagnetic energy.

Sonic Energy

Sonic energy is the energy of sound waves. Sound waves travel through the air or another medium.

Example: A sonic boom, a song played on a stereo, your voice.

Gravitational Energy

Energy associated with gravity involves the attraction between two objects based on their mass. It can serve as a basis for mechanical energy, such as the potential energy of an object placed on a shelf or the kinetic energy of the Moon in orbit around the Earth.

Example: Gravitational energy holds the atmosphere to the Earth.

Kinetic Energy

Kinetic energy is the energy of motion of a body. It ranges from 0 to a positive value.

Example: An example is a child swinging on a swing. No matter whether the swing is moving forward or backward, the value of the kinetic energy is never negative.

Potential Energy

Potential energy is the energy of an object's position.

Example: When a child swinging on a swing reaches the top of the arc, she has maximum potential energy. When she is closest to the ground, her potential energy is at its minimum (0). Another example is throwing a ball into the air. At the highest point, the potential energy is greatest. As the ball rises or falls it has a combination of potential and kinetic energy.

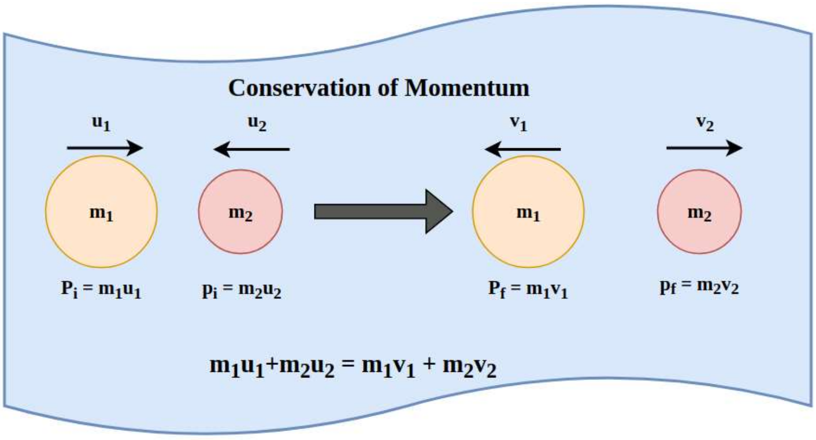
Ionization Energy

Ionization energy is the form of energy that binds electrons to the nucleus of its atom, ion, or molecule.

Example: The first ionization energy of an atom is the energy needed to remove one electron completely. The second ionization energy is energy to remove a second electron and is greater than that required to remove the first electron.

Conservation of Momentum

It is important we realize that momentum is conserved during collisions, explosions, and other events involving objects in motion. To say that a quantity is conserved means that it is constant throughout the event. In the case of conservation of momentum, the total momentum in the system remains the same before and after the collision.



Using the impulse-momentum theorem, the change in momentum of object 1 is given by

$\Delta p_1 = F_1 \Delta t,$

where F_1 is the force on object 1 due to object 2, and Δt is the time the force acts, or the duration of the collision.

Similarly, the change in momentum of object 2 is $\Delta p_2 = F_2 \Delta t$ where F_2 is the force on object 2 due to object 1, and we assume the duration of the collision Δt is the same for both objects. We know from Newton's third law of motion that $F_2 = -F_1$, and so $\Delta p_2 = -F_1 \Delta t = -\Delta p_1$.

Therefore, the changes in momentum are equal and opposite, and $\Delta p_1 + \Delta p_2 = 0$.

Because the changes in momentum add to zero, the total momentum of the two-object system is constant. That is,

$$p_1 + p_2 = constant$$

$$p_1 + p_2 = \acute{p}_1 + \acute{p}_2$$

where $\mathbf{p}'_1$ and $\mathbf{p}'_2$ are the momenta of objects 1 and 2 after the collision.

This result that momentum is conserved is true not only for this example involving the two objects, but for any system where the net external force is zero, which is known as an **isolated system**. The **law of conservation of momentum** states that for an isolated system with any number of objects in it, the total momentum is conserved. In equation form, the law of conservation of momentum for an isolated system is written as

$p_{tot} = constan$ or $p_{tot} = \acute{p}_{tot}$

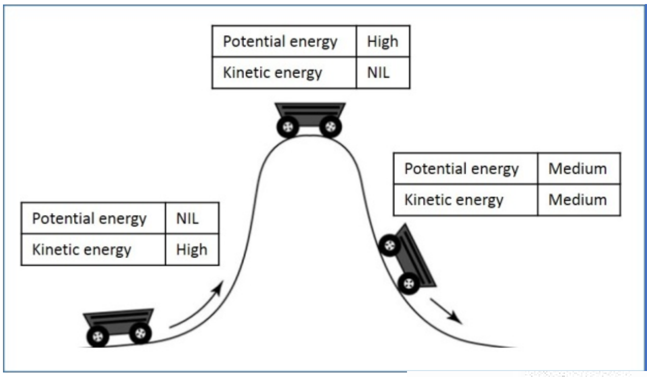
where $\mathbf{p}_{tot}$ is the total momentum, or the sum of the momenta of the individual objects in the system at a given time, and $\mathbf{p}'_{tot}$ is the total momentum sometime later.

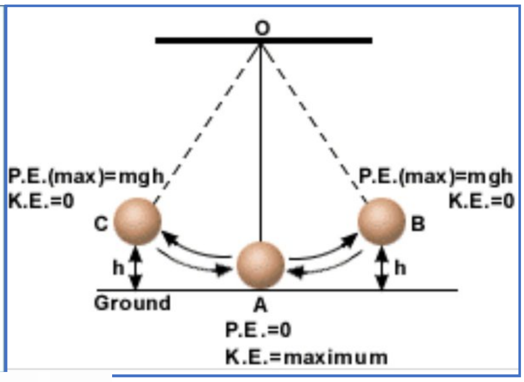
The conservation of momentum principle can be applied to systems as diverse as a comet striking the Earth or a gas containing huge numbers of atoms and molecules.

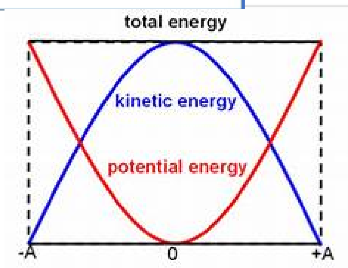
The conservation of energy

Energy can be transferred usefully, stored or dissipated, but it cannot be created or destroyed.

In all cases, energy comes from one store and is transferred to another store. This means that all the energy in the Universe was present at the Big Bang and will still be around at the very end of time.







Energy can be defined as the ability to perform work in physics. **Law of Conservation of Energy** states that energy cannot be made or destructed in any process. It may, however, be changed from one form to another. The overall energy contained in the isolated system remains constant when all kinds of energy are considered. This law applies to all kinds of energy. To sum it up:

A single system, shut down from all its surroundings, retains its complete energy. This is illustrated through the following diagram of a swinging pendulum:

$U_t = U_i + W + Q$

where,

- *U_i denotes the initial energy of a system*
- *W denotes the work done*
- *Q denotes the heat added or removed*

Derivation

Assuming that the gravitational potential at the earth's surface is zero. Consider the case of a fruit falling to the ground.

Assume A to be a point on the tree at a height of ‘h’ from the ground; the fruit’s velocity is zero, hence energy is highest there.

E = mass × gravitation constant × height …(1)

Along the path of its descent, its potential energy diminishes but its kinetic energy grows.

The fruit is falling freely under gravity towards the bottom of the tree at point B, and it is at a height ‘a’ from the ground, and it has speed as it reaches point B. As a result, it will have simultaneously kinetic and potential energy at this moment.

Potential energy = $m \times g \times x$ …(2)

Third equation of motion states that: $v^2 = 2g \times (h - a)$

or, Kinetic energy of the fruit = $mg \times (h - a)$ …(3)

From the above equations, we have:

$E = mg \times (h - a) + m \times g \times x$

$= mgh$

Similarly the result can be proved for different value of height of the falling fruit.

Question 1. An object of 2 kg is dropped from a 30 m building. Find its velocity when it is 10 m above the ground.

Solution:

The object’s potential energy decreases as it falls, but its kinetic energy increases.

Change in potential energy = *Final mgf – Initial mgf*

$= 2\ kg \times 10\ m/s \times 10\ m - 2\ kg \times 10\ m/s \times 30\ m$

$= -400\ J$

Now, $mv^2/2 = 400$

or, $\mathbf{v = 20\ m/s}$

Examples of conservation of energy

The skydiver

When a skydiver jumps out of a plane, he begins to lose gravitational potential energy as his height decreases and he gains kinetic energy as his speed increases.

However, not all of the gravitational potential energy is transferred into kinetic energy as some work is done pushing against the air particles. Some of the gravitational potential energy is transferred to the air particles and is stored as internal energy.

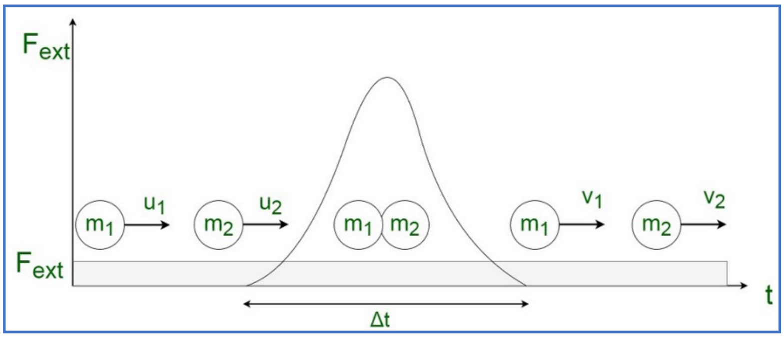
Smartphones

All smartphones contain a battery that stores chemical energy. When a smartphone is in use, electrical work is done and a current flows - the battery’s chemical energy is transferred in a number of ways to light the screen and produce sound.

The light that comes from a smartphone is emitted as light radiation, and the sound waves are produced by a speaker that vibrates back and forth.

In addition to this, many smartphones also heat up when used, so chemical energy is also transferred into internal energy. This energy is stored in the atoms of the smartphone's conductors and it is these atoms that emit infrared radiation.

Collision



A collision is an event where a strong force acts for a very short span of time between two or more bodies. A collision is an isolated event. The energy and momentum of the interacting particles undergo a change as a result of the collision. The collision may occur by actual physical contact of the involved bodies, for instance, the collision between two billiard balls or a ball and bat. There may be collisions where there is no actual physical contact, for instance, the collision of the alpha particles by a nucleus.

Any collision is guided by three distinct identifiable stages, that is, before, during, and after. Before the collision, the interacting forces between the particles are zero, since the particles are independent. Also, after the collision, the force again becomes zero. During the collision, the particles come in contact with each other, therefore, the force of interaction becomes very large. The motion of the bodies is guided by the dominating forces. Since, in most of the practical cases, the magnitude of the interacting force is unknown, therefore, Newton's second law of motion can't be used in such cases. The initial and final velocities can be computed using the law of conservation of momentum.

For instance, consider two bodies with masses m_1 and m_2, moving with velocities u_1 and u_2. They undergo a collision due to the application of an external force F_{ext} for a small interval of time, and then the final velocities become v_1 and v_2.

Conservation of Momentum and Energy conservation during a Collision

According to the fundamental laws of physics, certain attributes are applicable for any types of collision:

- **Momentum conservation:** The collision takes place for a very small interval of time, and during this period the average impulsive force causing the collision is significantly larger than the external force acting on the system. Therefore, during a collision, the application of external forces, such as frictional or gravitational forces are not considered into account. This impulsive force is internal in nature, therefore, the total momentum of the system remains constant for all practical purposes. Therefore, it remains conserved throughout the system.

- **Energy conservation:** According to the law of conservation of energy, energy can neither be destroyed nor created. It can only be transferred from one medium to another. Therefore, the total energy during a collision always remains conserved. Total energy includes all the plausible forms of energy created and destroyed during a collision, such as mechanical energy, internal energy, excitation energy as well as mass-energy.

Types of collision

During the collision, the interacting bodies come in immediate contact with each other due to which they exert forces. This activity takes place for a very short period of time. There are two types of collisions, namely :

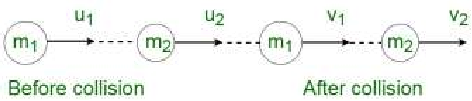
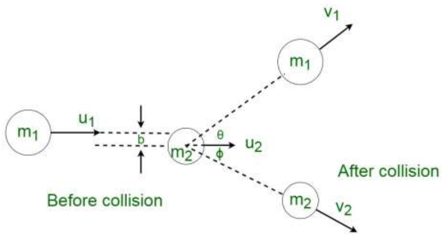
On the basis of conservation of kinetic energy

1. Perfectly elastic collision
2. Inelastic collision
3. Perfectly inelastic collision

Parameter	Perfectly elastic collision	Inelastic collision	Perfectly inelastic collision
Definition	The kinetic energy after the collision is equal to kinetic energy before the collision.	The kinetic energy after the collision is not equal to kinetic energy before the collision.	In this collision, two bodies stick together or move with the same velocity after the collision.
Coefficient of restitution	$e = 1$	$0 < e < 1$	$e = 0$
Kinetic Energies	$(KE)_{final} = (KE)_{initial}$	• When the initial KE is converted into internal energy of the product (as heat, elastic, or excitation), then $(KE)_{final} < (KE)_{initial}$ • When internal energy stored in the colliding particles is released, then $(KE)_{final} > (KE)_{initial}$	There is a large loss in kinetic energy.
Example	The collision between atomic particles.	The collision between two vehicles on a road.	Firing of a bullet that remains embedded in a wooden block.

On the basis of the direction of colliding bodies

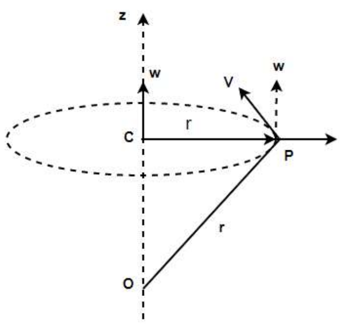
1. Head-on or one-dimensional collision
2. Oblique collision

Parameter	Head-on or one-dimensional collision	Oblique collision
Definition	The motion of the colliding or interacting particles before and after the collision acts along the same line the collision.	The motion of the colliding or interacting particles before and after the collision does not act along the same line the collision. If the interacting particles before and after collision remain in the same plane, then the oblique collision is referred to as the 2-dimensional otherwise, referred to as the 3-dimensional collision.
Impact Parameter	Impact parameter b is zero for this type of collision 	Impact parameter b lies between 0 and ($r_1 + r_2$) i.e. $0 < b < (r_1 + r_2)$ where r_1 and r_2 are radii of colliding bodies. 
Example	Collision of two gliders on an air track.	Collision of the billiard balls.

Angular momentum

For a rigid body, motion is generally both rotational and translation. If the body is fixed at one point, the motion is usually rotational. It is known that force is needed to change the translatory state of the body and to provide it with linear acceleration. Torque and angular momentum are rotational equivalents of force and momentum. These entities help us change the rotational state of the body.

It has been mentioned that torque is analogous to force. In the same way, angular momentum is analogous to linear momentum. This is also a vector product similar to its counterpart torque. Consider a particle P with the linear momentum "p" and a position vector with respect to the origin O. The angular momentum of the particle is denoted by "L",



$$\vec{L} = \vec{r} \times \vec{p}$$

The magnitude of angular momentum will be given by,

$$L = rp\sin\theta$$

Where r and p are the magnitudes of the position vector and linear momentum respectively. The angle θ is the angle between the position vector and the linear momentum. Here also "rsin(θ)" is the perpendicular angle between the momentum and the position vector.

The relation between the torque and force can also be derived from these equations.

$$\vec{L} = \vec{r} \times \vec{p}$$

Differentiating the above equation,

$$\frac{d\vec{L}}{dt} = \frac{d}{dt}(\vec{r} \times \vec{p})$$

$$\vec{\tau} = \frac{d\vec{L}}{dt} = \vec{r} \times \frac{d\vec{p}}{dt} = \vec{r} \times \vec{F}$$

Angular Momentum of a System of Particles

Often, bodies are not point masses. They contain more than one particle. Let us assume that the body consists of n particles each of which has a position vector r_i and momentum denoted by p_i. In that case, the angular momentum of the system is given by the vector sum of the individual momentum of the particles.

$L = l_1 + l_2 + l_3 + .. l_n$

Each particle has an angular momentum which is given by,

$l_i = r_i \text{ x } p_i$

$L = r_1 \text{ x } p_1 + r_2 \text{ x } p_2 + r_3 \text{ x } p_3 \ldots . r_n \text{ x } p_n$

Example: A body is revolving around an axis in a circular motion with a radius of 0.1m, the momentum of the body is given by 50 Kgm/s. Find the angular momentum of the body.

Answer:

Angular momentum of a body is given by,

$$\vec{L} = \vec{r} \times \vec{p}$$

Where r is the perpendicular distance of the force from the rotational axis and p is the linear momentum.

Given: r = 0.3m and p = 50Kgm/s.

Plugging the values in the equation,

$$\vec{L} = \vec{r} \times \vec{p}$$

$\Rightarrow l = 0.3 \times 50$

$\Rightarrow l = 15$

Alternate Energy Sources

We all need energy for our daily activities. We obtain energy from natural resources like fossil fuels. Some of these natural resources are non-renewable and cannot replenish faster as we need them. The burning of fossil fuels causes many environmental issues like global warming and pollution. Nowadays, these resources are replaced by alternative sources of energy that replenish quickly and are eco-friendly.

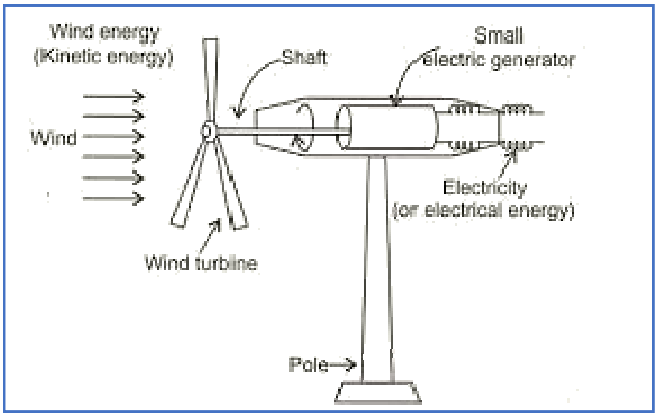
Alternative sources of energy are present in nature and can be replenished quickly. These are also known as non-conventional sources of energy. Alternative sources of energy do not use fossil fuels. They do not cause pollution and can be consumed over a long period without being exhausted.

Many renewable sources of energy come under the category of alternative sources or non-conventional sources of energy. For example, solar energy, wind energy, wave energy, and geothermal energy.

Types of Alternative Sources of Energy

The types of alternative sources of energy are explained below:

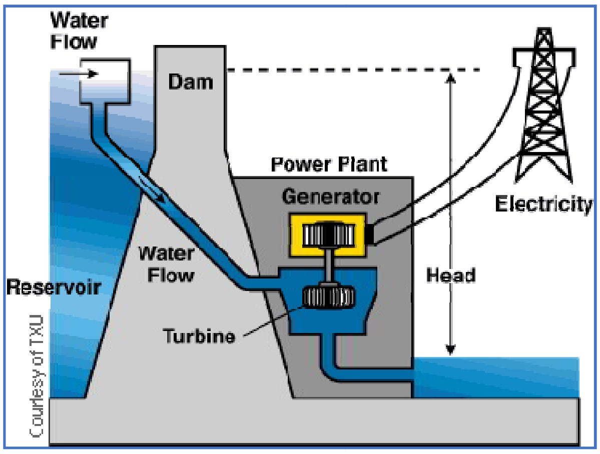
Wind Energy



The kinetic energy of high-speed winds is used to generate electricity by wind-powered generators. Windmills harness wind energy. A windmill consists of a tall pole on the top of which a fan-like structure is attached. This fan-like structure is called a wind turbine.

The force of high-speed winds makes the blades of the fan attached to the windmill rotate. The blades of the windmill are connected to the shaft of a generator, which also rotates with the movement of blades. This makes the generator produce electricity. A windmill is also used to lift water from a well. Wind energy is a renewable source of energy.

Hydroelectric Energy

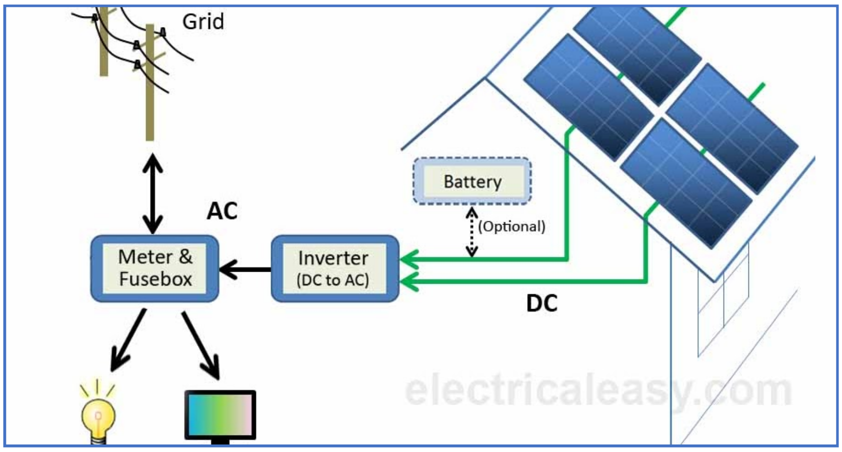


In a hydroelectric power plant, the potential of stored water in a reservoir is converted into the kinetic energy of water. This kinetic energy of water is used to rotate the blades of the turbine connected to a generator. The rotating turbine drives the generator's shaft, thereby converting the mechanical energy of the rotating shaft into electrical energy. It is also a renewable source of energy.

Solar Energy

Sun is the primary source of heat and light on the earth. The energy received by the earth from the sun is about 1.4 kilojoules per second per square meter, also known as the solar constant. Solar energy can be harnessed with the help of a solar cooker and solar cell. A solar cell is usually made of silicon that directly converts sunlight into electricity.

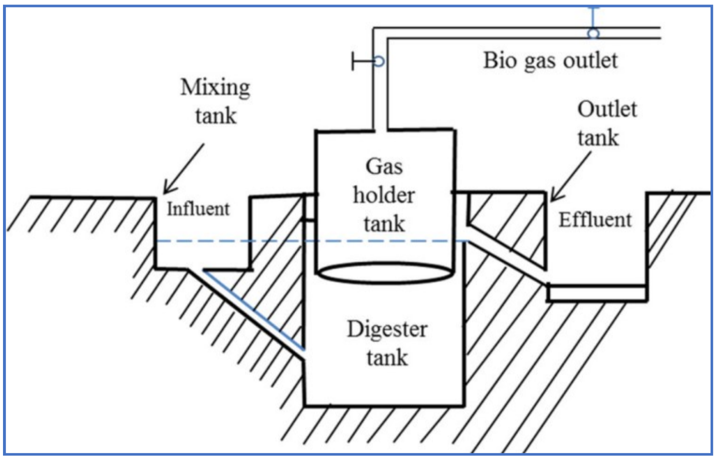
A typical solar cell produces a voltage of 0.5 to 1V and can produce about 0.7W of electricity. A solar panel consists of many solar cells. The electricity requirements of many households in remote areas are fulfilled by using solar panels. Street lights and traffic lights are also powered by solar energy. Solar cells are used in calculators.



A solar cooker is a device used to cook food. It consists of a box-like structure whose outer surface is painted black to absorb more heat, a thick sheet of glass to cover the food kept inside it, and a plane mirror reflector. The food tobe heated is kept inside the box, and this box is kept in sunlight so that its reflector faces the sun. The mirror reflector reflects the sun rays to the glass sheet cover. The food absorbs the heat from the sun. Also, the thick glass sheet does not allow the loss of heat from the solar cooker to the surroundings.

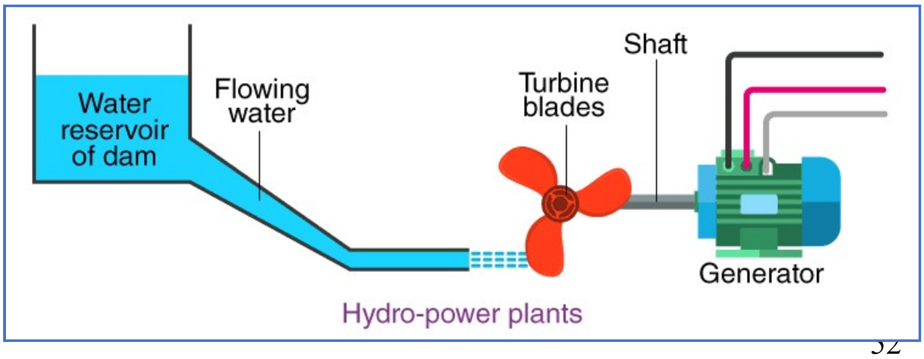
Biomass Energy

Biomass refers to organic material from plants or animals. This includes wood, sewage, and ethanol (which come from corn or other plants). Biomass can be used as a source of energy because this organic material has absorbed energy from the Sun. This energy is, in turn, released as heat energy when burned.



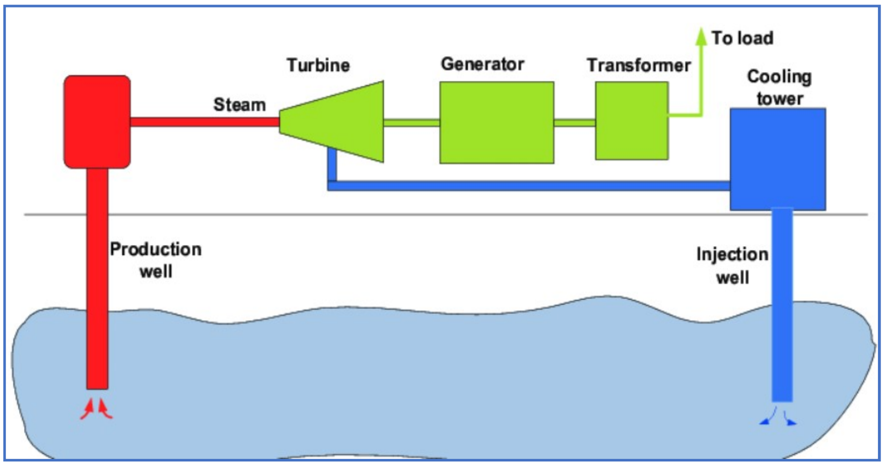
Hydroelectric Energy

Hydropower is one of the oldest renewable resources and has been used for thousands of years. Today, every U.S. state uses some amount of hydroelectricity. With hydropower, the mechanical energy from flowing water is used to generate electricity. Hydroelectric power plants use the flow of rivers and streams to turn a turbine to power a generator, releasing electricity.



Geothermal Energy

Geothermal energy comes from the heat generated deep within Earth's core. Geothermal reservoirs can be found at tectonic plate boundaries near volcanic activity or deep underground.

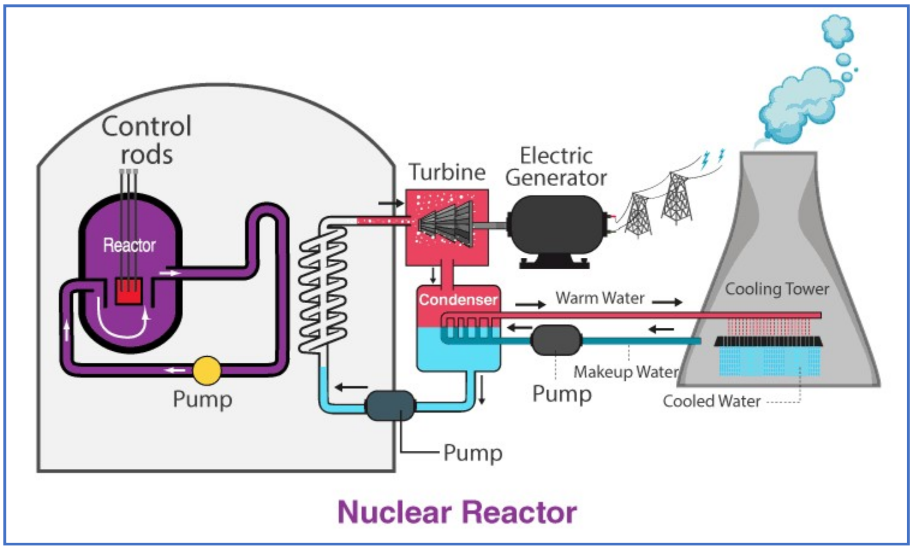


Geothermal energy can be harnessed by drilling wells to pump hot water or steam to a power plant. This energy is then used for heating and electricity.

The heat energy of the earth's interiors is known as geothermal energy. This energy is used to generate electricity. The trapped molten rocks in the region under the earth's surface called hot spots heats the underground water. The steam produced by the hot water is allowed to rotate the blades of the turbines, which rotate the shafts of the generators connected to them.

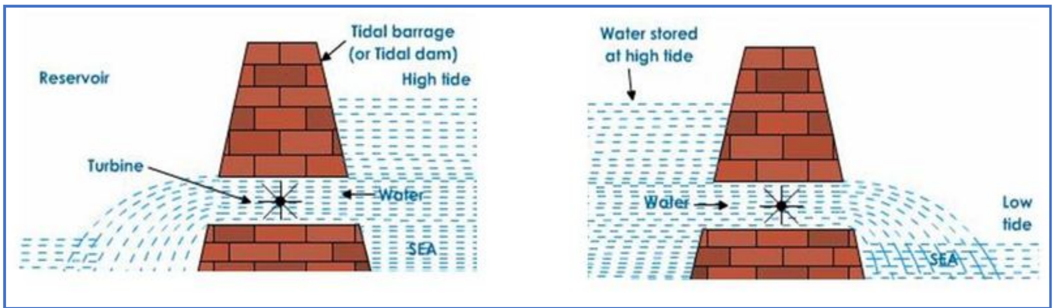
Nuclear Energy

Nuclear energy is the most reliable source of energy. The fission of one uranium atom produces million times the energy produced by burning one atom of carbon from coal. Nuclear energy is produced by splitting the nucleus of a heavy atom into lighter nuclei. This process is called nuclear fission. It generates a large amount of energy that can be used to rotate generator turbines to produce electrical energy. In nuclear fission, the nucleus of uranium or plutonium is bombarded with low-energy neutrons.



Tidal Energy

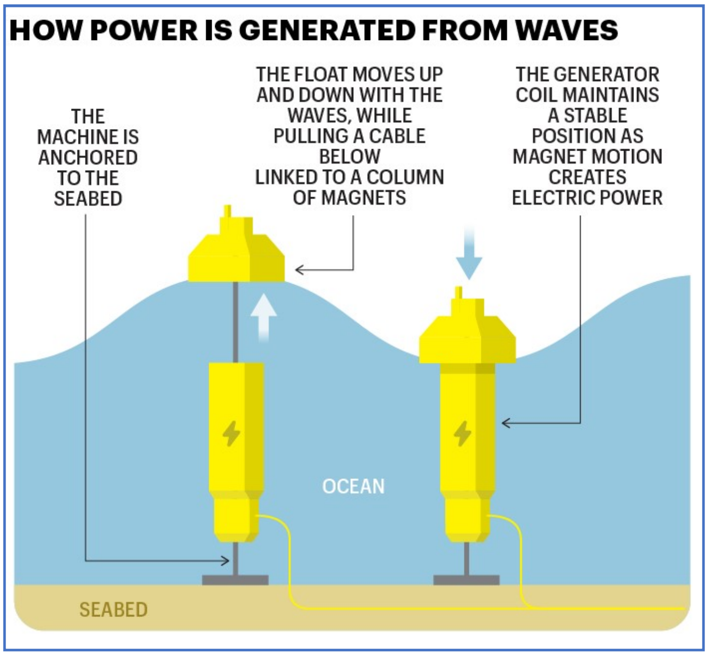
Oceanic tides are the source of energy. Oceanic tides refer to the rise and fall of the water



level of an ocean relative to coastal lines. Tides result from the gravitational force of the sun and moon on the earth. Energy can be harnessed from tides by constructing a dam across a delta. Turbines of generators are attached at the openings of these dams whose blades are rotated with the rise and fall in the ocean level, producing electricity.

Wave Energy

The kinetic energy of oceanic waves is used to produce electricity. These waves are caused by winds that blow across the sea. At a wave power station, chambers are constructed that trap seawater. These chambers have an opening at the top from which air is forced in and out when the water level rises or falls in the chamber. A generator turbine is fixed at these openings, which rotate with air movement, and the generator produces electricity.



Benefits of Using Alternative Sources of Energy

1. Alternative sources of energy do not use fossil fuels, so they do not produce greenhouse gas.
2. They are renewable. Therefore, they do not get exhausted by increasing their consumption.
3. The construction of dams for hydroelectricity helps in controlling floods.
4. The use of solar cookers and solar water heaters helps in saving fossil fuels.
5. They save money because once their power plants are set up, they only require maintenance.

Limitations of Renewable Sources of Energy

- The initial installation of power plants is expensive. A large area of land is needed to set up wind energy farms (about 22 hectares area is required to set a wind energy farm for producing 1MW1MW power). It can only be set up in areas where the minimum wind speed is about 15km/h.15km/h.
- Many lands are submerged underwater while setting up a hydroelectric power plant and building a dam. It drastically affects aquatic life and wildlife.

Methane gas is released when this submerged vegetation rots under anaerobic condition.

- There are limited sites for setting up geothermal energy and tidal energy power plants.
- Nuclear power plants produce radioactive wastes and radiation that can be a dangerous hazard if leaked accidentally.
- The efficiency of renewable sources of energy like solar energy is low on a cloudy day.

UNIT - 4

Motion

Motion of a body can be referred to as its change in position depending on its surroundings in a given time interval. Motion, in physics, for any object which has some mass can be measured in distance, displacement, speed, velocity, acceleration, and time.

Types of motion

There are also different other types of motion as per directions or as per state of motion.

Types of motion as per state

- Uniform Motion
- Non-Uniform Motion

Types of motion as per direction

- One Dimensional Motion
- Two Dimensional Motion
- Three Dimensional Motion

Other types of motion

- Translational Motion
- Periodic Motion
- Circular Motion

Linear, projectile, circular, angular, simple harmonic motions

Linear

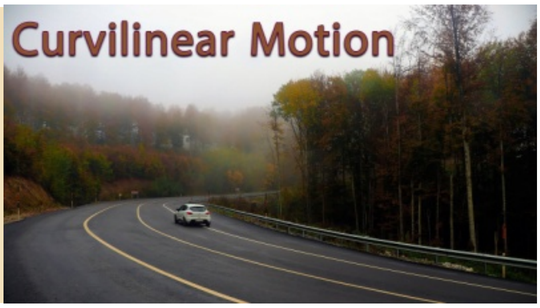
We can describe the motion of an object whose *velocity vector does not continuously change direction* as "linear" motion. For example, an object that moves along a straight line in a particular direction, then abruptly changes direction and continues to move in a straight line can be modeled as undergoing linear motion over two different segments.

When an object undergoes linear motion, we always model the motion of the object over straight segments separately. Over one such segment, the acceleration vector will be co-linear with the displacement vector of the object.

Particles move from one point to another in a straight line or a curved path in linear motion. On the basis of the path, the motion can be classified as follows –

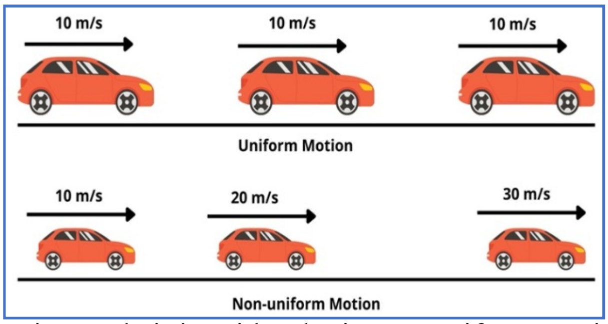
- Rectilinear Motion – Motion in a straight line.
- Curvilinear Motion – Motion in a curved path.

Examples of linear motion are the motion of the train, the motion of a car on the road, etc.



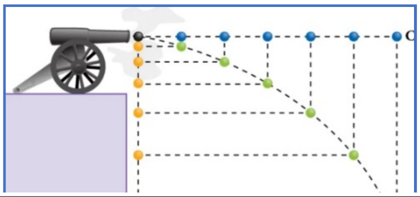
Types of Linear Motion:

- **Uniform Motion** - a body said to be in uniform motion when it moves in a straight line at a constant speed. For example a car moving at a steady speed on a straight road. In a graphical representation uniform motion can be represented by a straight line.

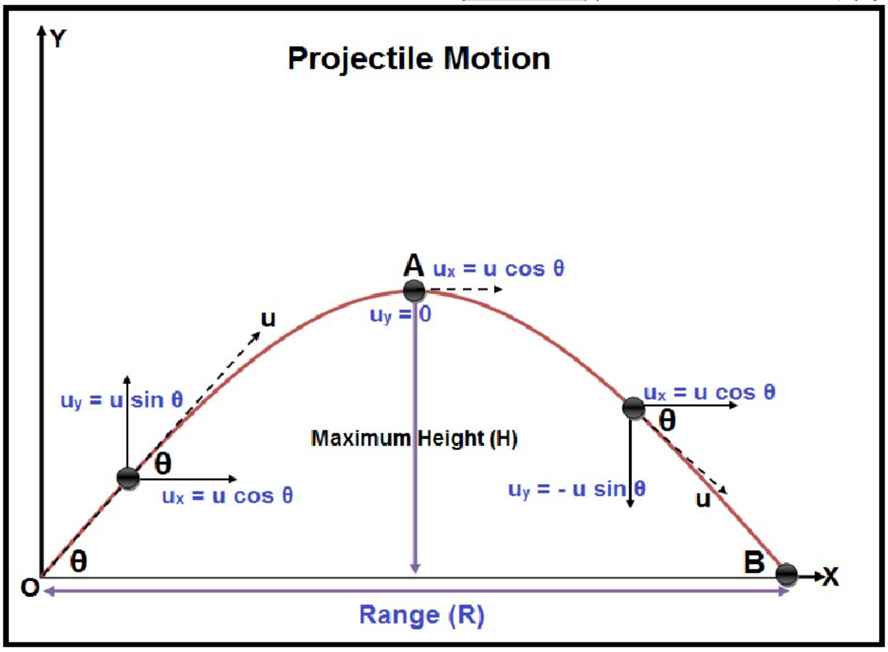


- **Non-Uniform Motion** - a body covers and equal distances in a set and given time intervals it is said to be in non uniform motion. In the graphical representation this motion can be represented as a curved line.

Projectile



Projectile motion is the motion of an object thrown (projected) into the air when, after the initial force that launches the object, air resistance is negligible and the only other force that object experiences is the force of gravity. The object is called a projectile, and its path is called its trajectory. Air resistance is a frictional force that slows its motion and can significantly alter the trajectory of the motion. Due to the difficulty in calculation, only situations in which the deviation from projectile motion is negligible and air resistance can be ignored are considered in introductory physics. That approximation is often quite accurate.



The most important concept in projectile motion is that when air resistance is ignored, *horizontal and vertical motions are independent*, meaning that they don't influence one another.

Initial Velocity

The initial velocity can be expressed as x components and y components:

$$u_x = u.cos\theta \quad ; \qquad u_y = u.sin\theta$$

In this equation, u stands for initial velocity magnitude and θ refers to projectile angle.

Time of Flight

The time of flight of a projectile motion is the time from when the object is projected to the time it reaches the surface. T depends on the initial velocity magnitude and the angle of the projectile:

$$T = \frac{2.u_y}{g} = \frac{2.u\sin\theta}{g}$$

Acceleration

In projectile motion, there is no acceleration in the horizontal direction. The acceleration, a, in the vertical direction is just due to gravity, also known as free fall:

$$a_x = 0 \qquad ; \qquad a_y = -g$$

Velocity

The horizontal velocity remains constant, but the vertical velocity varies linearly, because the acceleration is constant. At any time, t, the velocity is:

$$u_x = u.cos\theta$$

$$u_y = u.sin\theta - gt$$

Then the velocity will be:

$$u = \sqrt{u_x^2 + u_y^2}$$

Displacement

At time, t, the displacement components are:

$$x = u.t.cos\theta$$

$$y = u.t.si \quad -\frac{1}{2}gt^2$$

The equation for the magnitude of the displacement is

$$\Delta r = \sqrt{x^2 + y^2}$$

Maximum Height

The maximum height is reached when v_y=0. Using this we can rearrange the velocity equation to find the time it will take for the object to reach maximum height

$$t_h = \frac{u \sin\theta}{g}$$

where t_h stands for the time, it takes to reach maximum height. From the displacement equation we can find the maximum height

$$h = \frac{u^2 . \sin^2\theta}{2g}$$

Range

The range of the motion is fixed by the condition y=0. Using this we can rearrange the parabolic motion equation to find the range of the motion:

$$R = \frac{u^2 . \sin 2\theta}{2g}$$

Parabolic Trajectory

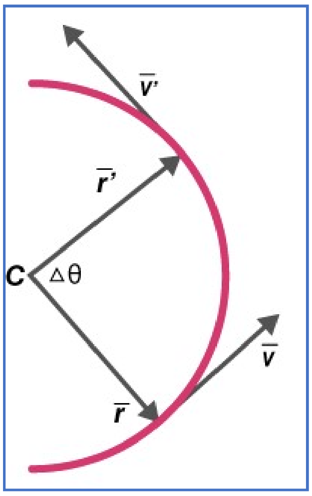
We can use the displacement equations in the x and y direction to obtain an equation for the parabolic form of a projectile motion:

$$y = \tan\theta . x - \frac{g}{2 . u^2 . \cos^2\theta} . x^2$$

Circular motion

Circular motion is described as a movement of an object while rotating along a circular path. Circular motion can be either uniform or non-uniform. During uniform circular motion, the angular rate of rotation and speed will be constant, while during non-uniform motion the rate of rotation keeps changing.

Some of the most common examples of circular motion include man-made satellite that revolves around the earth, a rotating ceiling fan, a moving car's wheel, the blades in a windmill, and gears in gas turbines.



A particle is said to execute circular motion when it moves along the circumference of a circular path. An important aspect of circular motion is that the direction of motion is changing continuously unlike in the case of linear motion.

Angular Motion

Angular Displacement

It is defined as the angle turned by a rotating particle per unit time. It is represented by Δθ and measured in radians. In the figure, angular displacement is measured between the position vectors rand r'.

Angular Velocity

It is defined as the rate of change in angular displacement of a particle in a circular motion. It is denoted by

$\boldsymbol{\omega} = \lim_{\Delta t \to 0} (\Delta\theta/\Delta t) = d\theta/dt$

Angular velocity is measured in rad/s. Apart from angular velocity and angular speed, a particle in circular motion also possesses linear velocity and corresponding linear speed.

$\mathbf{v} = d\mathbf{s}/dt$

$v = |d\mathbf{s}/dt|$; **s** is the displacement of the particle

Relation between Linear Speed(V) and Angular Speed(Ω)

In vector form

$v = \omega \times r$

Where **r** is the position vector of the particle measured with respect to the centre of the circle.

(Or)

$v = r\omega$

The acceleration of a particle in circular motion has two components:

- Tangential acceleration a_t: This is the component of acceleration in the direction of the velocity of the particle.

$a_t = d|\mathbf{v}|/dt$

- Radial acceleration a_r: This is the component of acceleration directed towards the centre of the circle. This component causes a change in the direction of the velocity of a particle in a circular motion.

$a_r = v^2/r = r\omega^2$

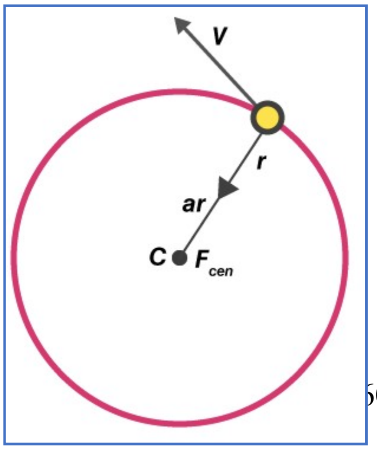
Angular Acceleration

It is defined as the rate of change of angular velocity of the rotating particle. It is measured in rad/s^2

$\alpha = d\omega/dt = d^2\theta/dt^2$

Circular motion can be uniform and non-uniform depending on the nature of acceleration of the particle. The motion is called uniform circular motion when the particle is moving along a circular path possessing a constant speed.

During circular motion, the velocity vector changes its direction at each point on the circle. This implies that the radial component of acceleration is always non-zero. The tangential component can take a positive or negative value in the case of non-uniform circular motion and a zero value in the case of uniform circular motion.



We understand that the acceleration of a particle in a circular motion is always directed towards the centre and is given by v^2/r. Applying Newton's second law of motion in this situation;

$F_c = mv^2/r$

Where m is the mass of the particle

F_c is the centripetal force directed towards the centre of the circular path as illustrated in

Examples of centripetal forces include gravitational force, the tension in a string and friction.

Simple harmonic motions

Periodic Motion

Periodic motion is defined as the motion of any object that repeats its motion after a fixed interval of time. Ex.: motion of the Moon around the Earth.

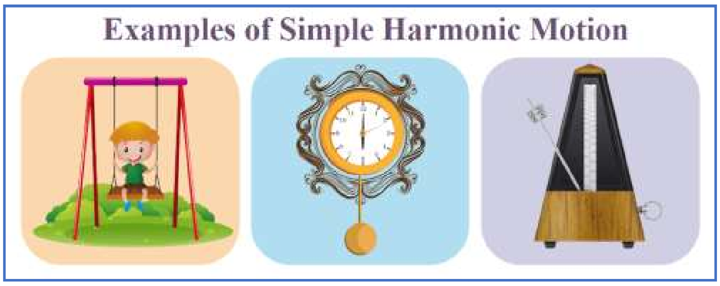
Oscillation Motion

Oscillatory motion is the to-and-fro motion of an object from its mean position. SHM is an example of Oscillatory motion.

Simple Harmonic Motion

Simple harmonic motion is an oscillatory motion in which the acceleration of particle at any position is directly proportional to its displacement from the mean position.

Such as the motion of a cantilever. We can say that all Simple Harmonic Motions are oscillatory and periodic, but the converse is not true.



As SHM is an example of Oscillatory Motion. Simple Harmonic Motions (SHM) are all oscillatory and periodic, but not all Oscillatory or Periodic motions are SHM. Oscillatory motion is also referred to as Harmonic Motion and out of all Harmonic Motions, the most important one to study is Simple Harmonic Motion (SHM). Some characteristics of SHM are as follows:

- SHM is a type of Periodic and Oscillatory Motion.
- There is always a restoring force acting on an object in SHM, which always acts in the opposite direction to the displacement of the object from the mean position.
- The amplitude in the SHM remains constant throughout the motion of the object.
- The acceleration of the object is directly proportional to the displacement of the object from its mean position.

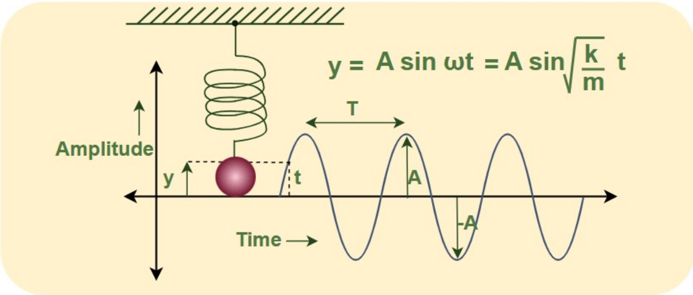
- The velocity of the object is maximum at the equilibrium position.
- The total energy in SHM remains conserved, as there is always a conversion of kinetic and potential energy happening throughout the motion.

Examples of Simple Harmonic Motion (SHM)

There are a lot of examples of Simple Harmonic Motion around us, we just need to see them from the perspective of SHM. From swings in the park to the motion of the cantilever, all are examples of SHM.

Mean Position

In Simple Harmonic Motion, the position of the object where there is no restoring force acting on it is the mean position. In other words, the point about which the object moves between its extreme position is called the mean position of the object. The mean position is sometimes referred to as Equilibrium Position as well.



Amplitude

The amplitude of a particle in SHM is its maximum displacement from its equilibrium or mean position, and as displacement is a vector quantity, its direction is always away from the mean or equilibrium position. The SI unit of amplitude is the meter and all the other units of length can also be used for this.

Frequency

The frequency of SHM is the number of oscillations performed by a particle per unit of time. SI unit of frequency is Hertz or r.p.s. (rotations per second), and is given by:

- *Frequency*

$f = 1/T$

- *Angular Frequency*

$\omega = 2\pi f = 2\pi/T$

Time Period

For a particle performing SHM, the time period is the amount of time it takes to complete one complete oscillation. As a result, the time period or simply period of SHM is the shortest time before the motion repeats itself.

$T = 2\pi/\omega$

where ω is the Angular frequency and T is the Time period.

Phase

The phase of SHM represents the magnitude and direction of particle displacement at any instant of the motion which is its state of oscillation.

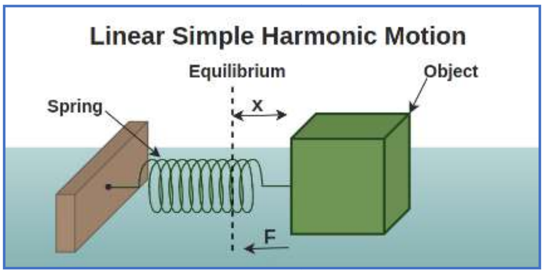
The expression for a particle's position as a function of time and angular frequency is as follows:

$x = A \sin(\omega t + \phi)$

where **$(\omega t + \phi)$** is the phase of particle.

Linear Simple Harmonic Motion

When a particle moves back and forth along a straight line around a fixed point (called the equilibrium position), this is referred to as **Linear Simple Harmonic Motion.** Some examples of Linear SHM include the oscillation of a liquid column U-tube, the motion of a simple pendulum with very small displacements, and the vertical small vibration of a mass carried by elastic string.



Conditions for Linear Simple Harmonic Motion

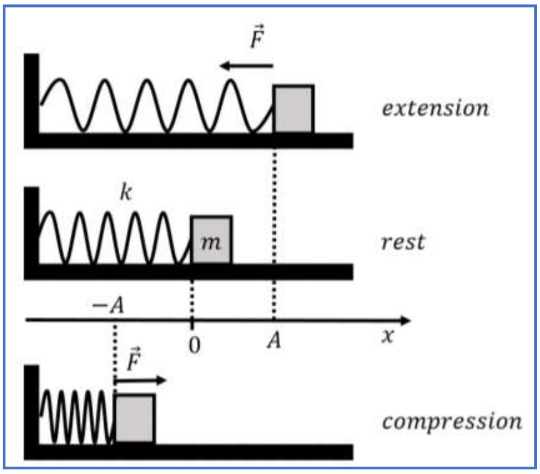
The restoring force or acceleration acting on the particle must always be proportional to the particle's displacement and directed toward the equilibrium position.

$F \propto -X$

$a \propto -x$

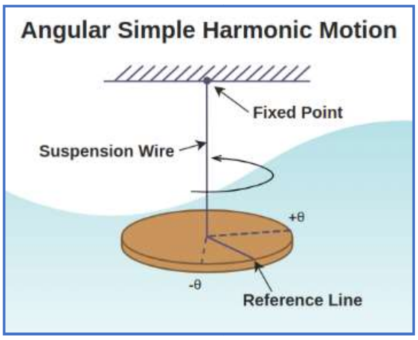
where

- **F** is the Restoring Force
- **X** is the Displacement of Particle from Equilibrium Position
- **a** is the Acceleration



Angular Simple Harmonic Motion

An angular simple harmonic motion occurs when a system oscillates angularly with respect to a fixed axis. The displacement of the particle in angular simple harmonic motion is measured in terms of angular displacement. The torsional pendulum is one example of Angular SHM.



Conditions for Angular Simple Harmonic Motion

The restoring torque (or) angular acceleration acting on the particle should always be proportional to the particle's angular displacement and oriented towards the equilibrium position.

T ∝ -θ

α∝ -θ

where

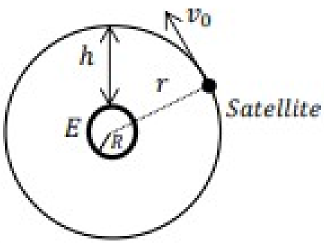
- **T** is Torque
- **θ** is the Angular Displacement
- **α** is the Angular Acceleration

Satellite motion

Objects that move around a planet is called a satellite. Moon is a natural satellite of earth. Man made satellite that revolve around the planets are called artificial satellites.

Orbital velocity of the satellite

It is the velocity with which a satellite orbits the earth. Consider a satellite of mass m revoving around earth of mass M. Let the radius of the orbit be r and v_0 be the orbital velocity of the satellite. Let R be the radius of the earth and the distance of the satellite from the surface of earth be h such that $= R + h$.



For the satellite to remain in orbit the necessary centripetal force is provided by the gravitational force of attraction between the earth and the satellite. Thus the centripetal force is given by $F_c = \frac{mv_0^2}{r}$ and gravitational force is $F_g = \frac{GMm}{r^2}$.

The condition for the satellite to remain in orbit is $F_c = F_g$.

or $\frac{mv_0^2}{r} = \frac{GMm}{r^2}$ or $v_0^2 = \frac{GM}{r}$ or $\boldsymbol{v_0} = \sqrt{\frac{\boldsymbol{GM}}{\boldsymbol{r}}} = \sqrt{\frac{\boldsymbol{GM}}{\boldsymbol{R+h}}}$

If g is the acceleration due to gravity at the surface of the earth, then $mg = \frac{GMm}{R^2}$ or $g = \frac{GM}{R^2}$. Thus $GM = gR^2$. Now the expression for orbital velocity becomes

$\boldsymbol{v_0} = \sqrt{\frac{\boldsymbol{gR^2}}{\boldsymbol{R+h}}}$. If the satellite is very close to the earth, then $R + h \approx R$.

Thus $\boldsymbol{v_0} = \sqrt{\boldsymbol{gR}}$ As $= 9.81\ ms^{-1}$ $and\ R = 6400\ km$, we have the orbital velocity of the satellite close to surface of earth as approximately $8\ kms^{-1}$.

Time period of the satellite

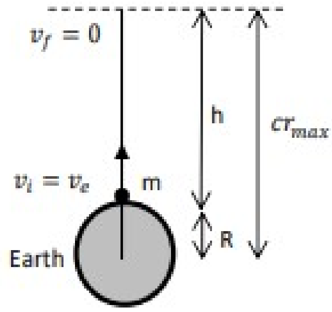
The orbital velocity of a satellite is $v_0 = \sqrt{\frac{GM}{r}}$, But $v_0 = r\omega$ where ω is the angular velocity of the satellite and $\omega = \frac{2\pi}{T}$ where T is the time period of the satellite.

Thus $v_0 = r\frac{2\pi}{T}$ or $T = \frac{2\pi r}{v_0} = 2\pi r\sqrt{\frac{r}{GM}} = 2\pi\sqrt{\frac{r^3}{GM}}$

As $r = R + h$ and $GM = gR^2$, the time period of the satellite , which is the time taken for the satellite to once round its orbit is $\boldsymbol{T = 2\pi\sqrt{\frac{(R+h)^3}{gR^2}}}$

If the satellite is very close to earth, then $+h \approx R$. Thus $\boldsymbol{T = 2\pi\sqrt{\frac{R}{g}}}$. Substituting the values of R and g in this equation we get $T = 5075\ s = 84\ minute$.

Escape velocity



It is defined as the minimum velocity with which an obje t has to be projected from the surface of the earth so that it escapes the earth's gravitational force of attraction. It is denoted by v_e .

Consider an object of mass m projected with n initial velocity v_i upwards against gravitational pull of the earth of mass M and radius R.

The initial kinetic energy of the object at the surface of earth is $K = \frac{1}{2}mv_i^2$

The potential energy of the object is $U = -\frac{GMm}{R}$

Thus the initial total energy of the object is $K + U = \frac{1}{2}mv_i^2 - \frac{GMm}{R}$ ....(1)

When the object reaches its maximum height when there is no influence of the gravitational pull, its velocity gradually decreases to zero and thus kinetic energy is zero and the potential energy is $-\frac{GMm}{r_{max}}$. Thus total energy is $K' + U' = 0 - \frac{GMm}{r_{max}}$ ...(2)

The total energy of the system remains constant. Thus equating (1) and (2), we get

$$\frac{1}{2}mv_i^2 - \frac{GMm}{R} = -\frac{GMm}{r_{max}}$$

Solving for v_i , we get $v_i^2 = 2GM\left(\frac{1}{R} - \frac{1}{r_{max}}\right)$

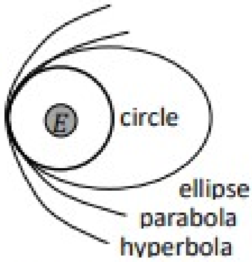
As the escape velocity is the minimum velocity with which the object is projected such that $v_f = 0$ when $r = r_{max} = \infty$. Thus $v_i = v_e$, the above equation becomes

$$v_e^2 = 2GM\left(\frac{1}{R} - \frac{1}{\infty}\right) \quad \text{or} \quad v_e^2 = 2GM\left(\frac{1}{R}\right) \quad \text{or} \quad \boldsymbol{v_e = \sqrt{\frac{2GM}{R}}}.$$

As $GM = gR^2$, thus $v_e = \sqrt{\frac{2gR^2}{R}}$ or $\boldsymbol{v_e = \sqrt{2gR}}$

It is independent of the mass of the object and it depends on the acceleration due to gravity. Its value is found to be 11.2 kms^{-1}.

Condition for launching artificial satellites



The path of a satellite around earth depends on the following conditions

1. For a satellite to be in circular orbit, the condition is $v = v_0 = \sqrt{\frac{GM}{r}}$
2. For the planet to be in elliptical orbit, $v > v_0 < v_e$ i.e. the velocity of the satellite must be greater than the orbital velocity but less than the escape velocity.
3. The path becomes parabola if $v_e = \sqrt{\frac{2GM}{R}}$ and the satellite escapes to infinity
4. The path will be a hyperbola if, $v_e > \sqrt{\frac{2GM}{R}}$ and the satellite escapes to infinity.

Geosynchronous and geostationary orbits

Geosynchronous orbit is an orbit of a satellite around the earth with an orbital period of one sidereal day, and geostationary orbit is a special case of geosynchronous orbit where they are placed right above the equator. One sidereal day is the time during which earth completes on rotation about its own axis. This time is approximately equal to 23 hr, 56 min, 4.09 sec.

The basic difference between geosynchronous and geostationary satellites is that in case of geosynchronous orbit, a person at a point on Earth, will see a satellite in this orbit in the same place in the sky at the same time of the day, everyday.

In case of geostationary orbit, a person at any point on Earth, will see a satellite in this orbit stationary with respect to his position, just like a star in the sky. Thus a geostationary orbit is a *geosynchronous* orbit around Earth at 35,786 km above the equator, so that it remains stationary as seen from Earth. Usually geosynchronous orbit can be elliptical or circular in nature and the satellite may have any inclination about the equator but the geostationary orbit is circular in nature. Most of the communication satellites are geostationary satellites.

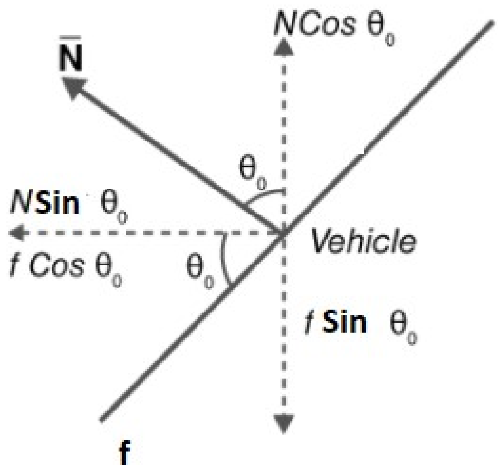
Applications of satellites includes the following fields

- Astronomy
- Communication
- Atmospheric studies
- Navigation
- Remote sensing
- Search and rescue
- Space exploration

Banking of a curved roads

At Banked Roads

The effect of friction on the motion of a vehicle on a circular road can be minimized if the road is slightly raised on the outer end. This is called banking. Let the road be banked at an angle θ_0 as illustrated in the figure.



Net force along the vertical direction is zero since there is no acceleration along this direction.

Therefore,

$N \cos \theta_0 = f \sin \theta_0 + mg$ …..(1)

The centripetal force is provided by the horizontal component of N and f

$mv^2/r = N \sin \theta_0 + f \cos \theta_0$….(2)

Substituting $f= \mu N$ in equations (1) and (2) gives v_{max}

$N \cos \theta_0 = \mu N \sin \theta_0 + mg$

$mv^2/r = N \sin \theta_0 + \mu N \cos \theta_0$

Solving the above equations gives us,

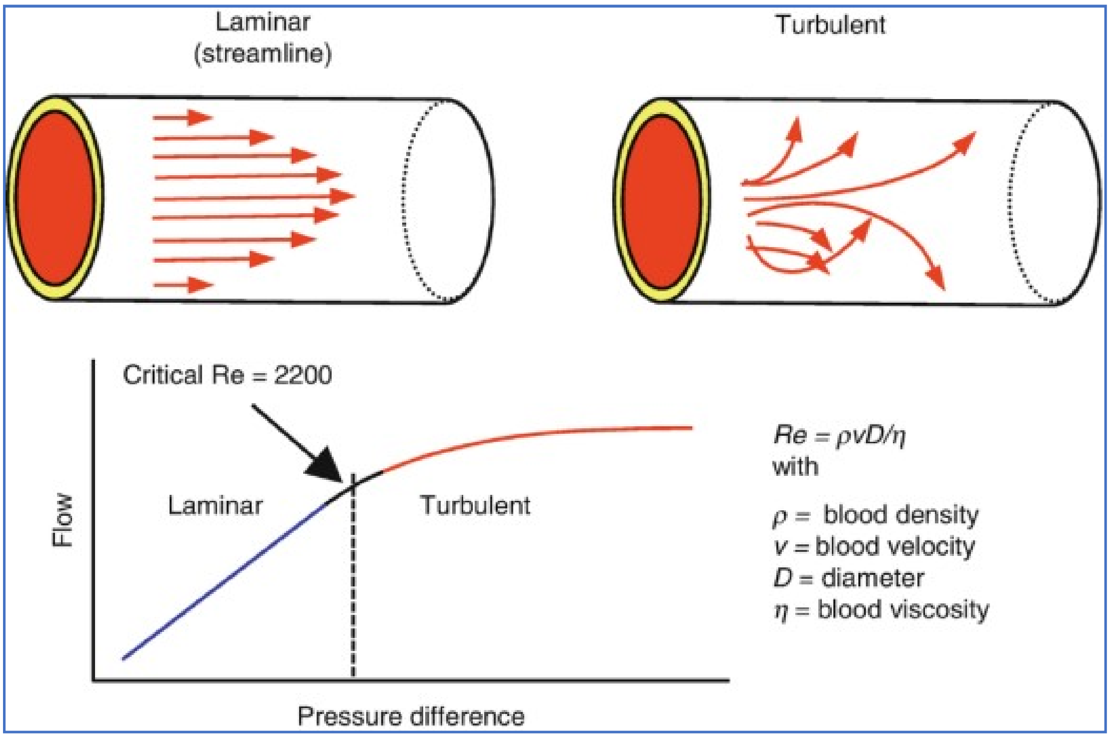
$$v_{max} = \sqrt{rg \tan \theta_0}$$

$\tan \theta_0 = v_{max}^2/rg$

Stream-line and turbulent motions

A fluid flowing through a closed channel such as pipe or between two flat plates is either laminar flow or turbulent flow, depending on the velocity, pipe size (or on the Reynolds number), and fluid viscosity.

When a fluid (such as blood) flows past a solid surface (such as the vascular wall), a thin layer develops adjacent to the surface where frictional forces retard the motion of the fluid. There is a gradient of frictional resistance (and thus velocity) between fluid in contact with the solid surface and fluid in the center of the stream. If the fluid elements travel along well-ordered, nonintersecting layers, this is termed laminar flow. The flow resistance in laminar flow is due entirely to viscous resistance of the fluid and the interactions between the fluid and the stationary wall. In laminar flow, the average velocity of a fluid is one half of the maximum velocity observed in the center of the stream.



The type of flow is determined by a non-dimensional number called the Reynolds number for a pipe flow.

Re = (VD/v)

Where,
D = Diameter of pipe
V = Mean velocity of the flow in pipe
v = Kinematic viscosity of fluid

Conditions

1. If the Reynolds number is less than 2000, then the flow is called laminar flow.
2. If the Reynolds number is more than 4000, then the flow is called turbulent flow.
3. If the Reynolds number is between 2000 and 4000, the flow may be laminar or turbulent flow.

The common examples of turbulent flow are blood flow in arteries, oil transport in pipelines, lava flow, atmosphere and ocean currents, the flow through pumps and turbines, the flow in boat wakes and around aircraft wingtips.

In contrast, turbulent flow occurs when fluid elements from adjacent layers become mixed. Turbulent flow is chaotic and less efficient because of energy losses (these losses are termed inertial resistance). In turbulent flow, the relationship between pressure difference and flow is no longer linear, since the amount of resistance in the tube increases with flow. Thus, larger pressure differences are required to maintain flow. Turbulence, and associated loss of energy along with the narrowed radius, are two of the primary causes of the drop in pressure that occurs distal to a severe stenosis.

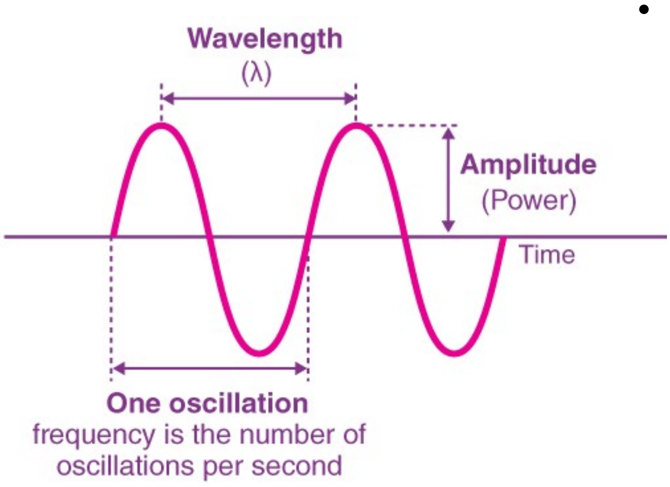
Turbulence is important for several reasons, one of which is that it creates noise (e.g., in a pipe when flow velocity is high), which is the cause of some cardiac murmurs and the Korotkoff sounds (used when measuring blood pressure.

	Streamline flow	Turbulent flow
i.	The smooth flow of a fluid, with velocity smaller than certain critical velocity (limiting value of velocity), is called streamline flow or laminar flow of a fluid.	The irregular and unsteady flow of a fluid when its velocity increases beyond critical velocity are called turbulent flow.
ii.	In a streamlined flow, the velocity of a fluid at a given point is always constant.	In a turbulent flow, the velocity of a fluid at any point does not remain constant.
iii.	Two streamlines can never intersect, i.e., they are always parallel and hence can never form eddies.	In a turbulent flow, at some points, the fluid may have a rotational motion which gives rise to eddies.
iv.	Streamline flow over a plane surface can be assumed to be divided into a number of plane layers. In a flow of liquid through a pipe of uniform cross-sectional area, all the streamlines will be parallel to the axis of the tube.	A flow tube loses its order and particles move in a random direction.

Wave motion

A wave is a disturbance in a medium that carries energy without a net movement of particles. It may take the form of elastic deformation, a variation of pressure, electric or magnetic intensity, electric potential, or temperature.

- Transfers energy.
- Usually involves a periodic, repetitive movement.
- Does not result in a net movement of the medium or particles in the medium (mechanical wave).



There are some basic descriptors of a wave. Wavelength is the distance between two successive identical parts of the wave. Amplitude is the maximum displacement from the neutral position. This represents the energy of the wave. Greater amplitude carries greater energy. Displacement is the position of a particular point in the medium as it moves as the wave passes. Maximum displacement is the amplitude of the wave

Frequency (f) is the number of repetitions per second in Hz, Period (T) is the time for one wavelength to pass a point.

The velocity (v) of the wave is the speed at which a specific part of the wave passes a point. The speed of a light wave is c.

Types of Waves:

The types of waves are given below.

Transverse Waves

Waves in which the medium moves at right angles to the direction of the wave.

Examples of transverse waves:

- Water waves (ripples of gravity waves, not sound through water)
- Light waves
- S-wave earthquake waves
- Stringed instruments
- Torsion wave

The high point of a transverse wave is a crest. The low part is a trough.

Longitudinal Wave:

A longitudinal wave has the movement of the particles in the medium in the same dimension as the direction of movement of the wave.

Examples of longitudinal waves:

- Sound waves
- P-type earthquake waves
- Compression wave

Parts of longitudinal waves:

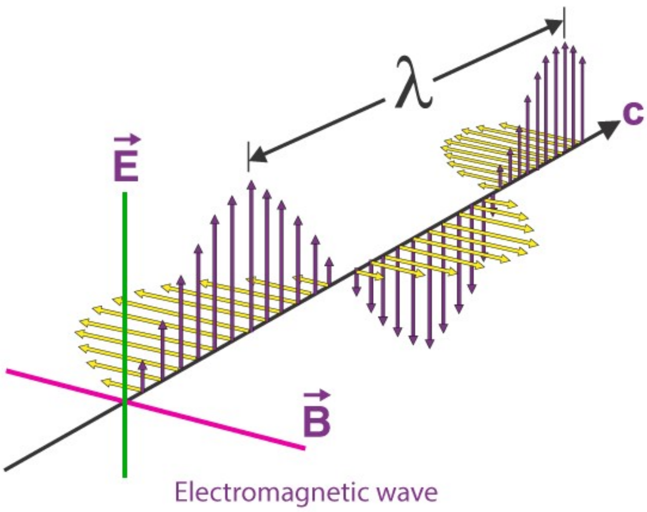
Compression: where the particles are close together.
Rarefaction: where the particles are spread apart.

Mechanical waves:

It is a wave which needs a medium in order to propagate itself. Sound waves, waves in a slinky, and water waves are all examples of this.

Matter Waves:

Any moving object can be described as a wave When a stone is dropped into a pond, the water is disturbed from its equilibrium positions as the wave passes; it returns to its equilibrium position after the wave has passed.



Electromagnetic Waves:

These waves are disturbance that does not need any object medium for propagation and can easily travel through the vacuum. They are produced due to various magnetic and electric fields. The periodic changes that take place in magnetic and electric fields and therefore known as electromagnetic waves.

Electromagnetic wave

Wave Speed Formula

It is the total distance covered by the wave in a given time period. The formula for wave speed is given as,

Wave Speed = Distance Covered/Time taken

Properties of Waves

The prime properties of waves are as follows:

Amplitude – Wave is an energy transport phenomenon. Amplitude is the height of the wave, usually measured in metres. It is directly related to the amount of energy carried by a wave.

Wavelength – The distance between identical points in the adjacent cycles of crests of a wave is called a wavelength. It is also measured in metres.

Period – The period of a wave is the time for a particle on a medium to make one complete vibrational cycle. As the period is time, hence is measured in units of time such as seconds or minutes.

Frequency – Frequency of a wave is the number of waves passing a point in a certain time. The unit of frequency is hertz (Hz) which is equal to one wave per second.

The period is the reciprocal of the frequency and vice versa.

$$Period = \frac{1}{Frequency}. \qquad \textbf{OR} \qquad Frequency = \frac{1}{Period}$$

Speed – The speed of an object means how fast an object moves and is usually expressed as the distance travelled per time of travel. The speed of a wave refers to the distance travelled by a given point on the wave (crest) in a given interval of time. Speed of a wave is thus measured in meter/second i.e. m/s.

$$Speed = \frac{Distance}{Time}$$

Comparison of light and sound waves

BASIS OF COMPARISON	LIGHT WAVES	SOUND WAVES
Description	Light wave can be considered to be made of waves as well as particles.	Sound is only a wave. It does not show particular nature.
Nature	Light waves are electromagnetic or transverse waves consisting of varying electric and magnetic fields.	Sound waves are longitudinal waves consisting of compressions and rarefactions.
Medium	Light waves do not require a material medium for propagation. The waves can travel in a vacuum.	Sound waves require a material medium for propagation.
Effect	Light waves are of different frequencies, resulting in different colors.	Sound waves are of different frequencies giving notes of different pitches.
Propagation	Light propagates by a chain reaction of electric and magnetic fields recreating each other.	Sound propagates by a chain reaction of density and pressure disturbances recreating each other.
Distance Of Travel	Light waves can travel through a much greater distance.	Sound waves do not travel far as their energy is dissipated easily.
Velocity	Light waves travels at much higher velocity as compared to sound waves. The velocity of light waves through a vacuum is 2.998 x 10^8 m/s.	Sound waves moves relatively at low velocity when compared to light waves. The velocity of sound waves is about 343 m/s at room temperature and atmospheric pressure.
Wavelength	Visible light has a wavelength of range from 400-700nm, Violet light has a wavelength of 400nm whereas red light has a wavelength of 700nm.	The wavelength of sound frequencies audible to the human ear is approximately 17 m and 17 mm.
Frequency	Violet light has a frequency of 7.5 x 10^{14} Hz whereas red light has a frequency of 4.3 x 10^{14}Hz.	Frequency of sound waves varies between 20Hz and 20000Hz. Sounds with frequencies below 20Hz are referred to as infrasound.
Change In	The speed of light in a medium is	The velocity of sound wave can

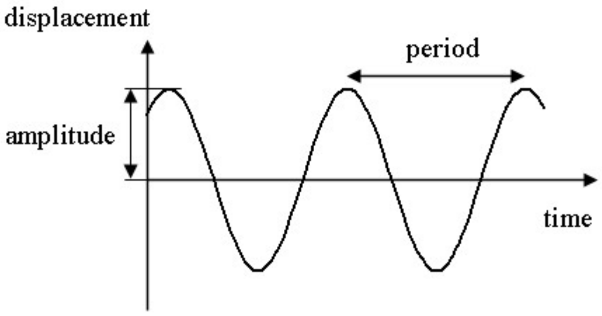
Velocity	constant.	change.
Polarization	Light waves can be polarized.	Sound waves cannot be polarized.
Oscillation of Matter	In a light wave, the electric and magnetic vectors oscillate.	In sound waves, the particles of the medium actually oscillate.

Free, damped and forced oscillations

1. Free Oscillation

When a body vibrates with its own frequency, it is called a free oscillation. The free oscillation has a constant amplitude and period without any external force to set the oscillation. An example would be the vibrations in a tuning fork.

Free oscillation contains a consistent period and amplitude without needing any outside force to set it. Generally, free oscillation does not go through damping. But in the region of all-natural systems, the process of damping is observed till the time any consistent outside force emerges to overcome it. In this system, every property remains constant, including frequency, amplitude, and energy.



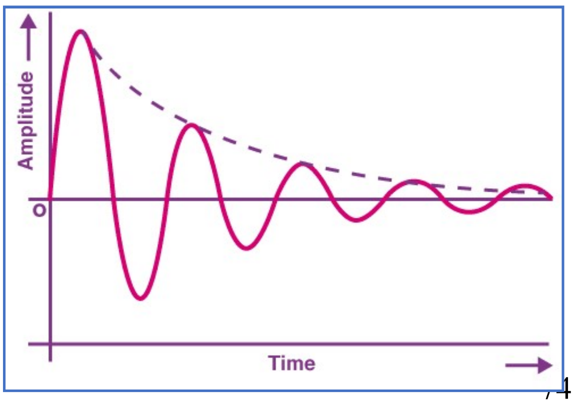
Example of free oscillation-

Oscillations of a simple pendulum, oscillations of objects connected to a horizontal spring, sound produced by tuning a fork in short distance etc.

2. Damped Oscillation

Most free oscillations eventually die out due to the ever-present damping forces in our surrounding. The oscillation that decreases with time is called damped oscillation. Due to external factors such as friction or air resistance that results in damping, the amplitude of oscillation reduces with time, and this will result in energy loss from the system. An example would be the decaying oscillations of a pendulum.

Damping refers to a type of friction to oscillation. And damped oscillation refers to the kind of oscillation that gets dull over time. Due to the presence of damping, the oscillation's amplitude decreases over time. Due to the system's energy loss, the amplitude is lessening. Therefore, the system loses energy when it attempts to overcome outside forces,



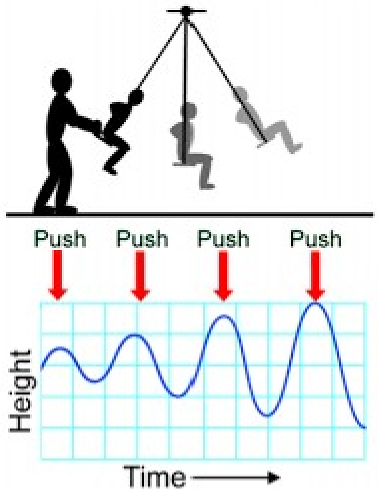
including resistance, friction and many other resistive forces. Thus, when there is a reduction in amplitude, the system's energy also reduces. Damping is classified into two categories: natural and artificial damping.

Example of damped oscillation-

In practical situations all the oscillation is having some type of friction or air resistance, like oscillations of a simple pendulum with damping force due to air drag.

3. Forced Oscillation

When something oscillated by being influenced by an external periodic force, it is called a forced oscillation. Here, the amplitude of oscillation experiences damping but remains constant due to the other external energy supplied to it. For example, when you play with a toy that involves an object being supported by an elastic band suspended on your finger. In the beginning, if you hold your finger still, the object bounces up and down with a small amount of damping. If you move your finger up and down, the object will follow along. The object responds by oscillating with the increasing amplitude as you increase the frequency at which you move your fingers.



The phenomenon of driving a system with a frequency equal to its natural frequency is called resonance. The less damping a system has, the higher the amplitude of the forced oscillations near resonance. The more damping there is, the broader reaction it has to various driving frequencies.

Forced oscillation is when any external periodic force causes the body to oscillate. In this scenario, oscillation amplitude goes through a damping process. However, there are no changes in amplitude, and it remains constant. It is because the system has an external energy supply.

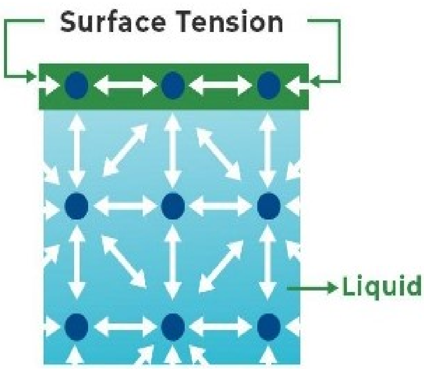
Example: A bird flapping its wings periodically and repeatedly to achieve a consistent flight is an example of forced oscillation. Its wings move a certain distance from its initial position, then reach the equilibrium position, again flap in the opposite direction to move the similar direction, then again coming to its initial position.

UNIT - 5

Surface tension

Surface tension is the ability of fluid surfaces to contract into the smallest possible surface area. We can add a few more drops even after filling a glass full of water before it spills, which is caused by the surface tension of the surface. Its isolated surface behaves like a strong rubber membrane due to the suppressive force in the fluid molecules. As a result, the individual surface of the fluid is still in a state of stress and tends to have the smallest field. Thus, Surface Tension refers to the tension on the fluid's individual surface.

***Surface tension** is described as the phenomenon that occurs when the surface of a liquid comes into contact with another phase (it can be a liquid as well). Liquids appear to have the smallest possible surface area. The liquid's surface looks like an elastic sheet.*



Imagine a line XY on the independent surface of the fluid in the equilibrium, then at every point on this line, the same force acts in its exact opposite direction. Every point stretched with the same force in both directions.

Thus, in the equilibrium, force acting on any other per unit length of an imaginary line on an independent surface of the fluid, which is perpendicular to the line and in the direction of the tangent line of the surface, is called Surface Tension.

Surface tension is denoted by σ or T symbol.

Cohesion and Surface Tension

Surface Tension at liquid molecules is generated by the cohesion force among the atoms of the liquid. The cohesion force is the attractive force between two particles of Solid and Liquid. Cohesion force is the force required to hold the solid and liquid particles together.

Surface Tension is the property of the substance because of the cohesion forces. The surface tension resists the change in the structure of the surface.

Surface Tension at Molecular Level

Due to the Cohesion force the water molecule tends to stick together. The water molecule at the bottom layer has various molecules above them to stick but the molecule at the top layer does not have various other molecules to cling together. Thus, they attach to each other with a larger force and resist any change in their structure.

The molecule inside the body of the liquid experiences the forces from all directions and thus, the net force cancels out each other, whereas the particle at the top layer experiences a strong inward force resulting in the surface tension of the water. Because of this water has one of the highest surface tension among liquids.

Mathematically, the surface tension is defined as the force (F) acting on the surface and the length (l) of the surface, so is given as:

$$T = F / l$$

Also, the ratio of the work done (W) and the change in the area of the surface (A) is termed surface tension.

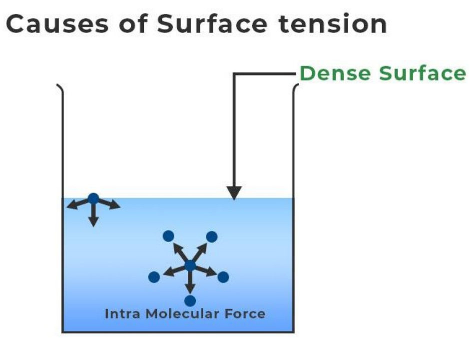
$$T = W / A$$

Surface tension is the ratio of the dragging force to the length and thus its SI unit is N/m as force is measured in N and length is measured in m. In the CGS system, its unit is Dyne/cm.

The dimension formula of Force is $[MLT^{-2}]$ whereas the dimension of length is [L] thus, the dimensional formula of Surface Tension is $[M L^0 T^{-2}]$.

What is the Cause of Surface Tension?

The effect known as surface tension is caused by the cohesive forces between liquid molecules. Since the molecules at the surface lack like molecules in both directions, they cohere more closely to those specifically aligned with them on the surface. This creates a surface "film" that



makes moving an object across the surface more difficult than moving it while fully submerged.

Assume a jar is filled with water; the water molecules can be found in two positions in this jar: First, beneath the water, and second, on the surface of the water. Since there are no molecules above these molecules, the molecules at the water's surface are unbalanced. As a result, only the molecules below will be attracted. As a result, a thin crust will form on the liquid's upper surface. Because of this thick layer, a form of stress is generated, which is known as Surface Tension. These phenomena can also be explained in terms of energy.

Example: Find the surface tension of the liquid with a dragging force of 12 N when the length at which the force acts is 4 m.

Solution:

Given,

F = 12 N ; L = 4 m

According to the Surface Tension formula, T = F/L

T = 12/4 = 3 N/m

Methods of Measurement

Some methods which are used to measure the surface tension of any liquid are,

- Capillary Rise Method
- Bubble Pressure Method
- Spinning Drop Method

Other than these there are various other methods that are used for measuring the surface tension of the liquids.

Examples of Surface Tension

Various examples which are explained with the help of Surface tension are,

Walking on Water

Various insects can easily walk on the surface of the water because the force of their weight is not enough to penetrate the surface of the water.

Floating Needle

A needle made of steel can easily be made to float on the surface of the water even though it is many times denser than water because of the surface tension of the water.

Spherical Shape of Water Droplets

Small droplets of fluid are spherical due to surface tension. The molecules of water tend to stick together due to intra-molecular force, and the energy of molecules that are located on the surface of droplets contains higher energy and tries to push the other molecule to the centre of the droplet.

Fire Polishing of Glass

When we heat a glass material in flames, the glass surface starts melting. But due to surface tension, it starts to become soft and smooth which makes the glass very flat and smooth. This method is most applicable to flat external surfaces.

Soaps and Detergents

Soaps and Detergents can easily clean clothes because they lower the surface tension of the water and thus allowing it to easily soak the grease and soil particles and then remove them.

Rise of Liquids in Capillary Tubes

A tube whose radius is very short and uniform is called a capillary tube. When an open capillary is dipped in water, the water rises to some height in the capillary tube.

Factors affecting Surface Tension

Various factors which affect the Surface Tension of any liquid are,

- If the solute is highly soluble in the fluid, the surface tension of the fluid would increase. And if the solute is less soluble in the fluid, then the surface tension of the fluid would decrease.
- If there are dust particles or any lubricant present on the surface of the fluid, the surface tension of the fluid decreases.
- Increasing the temperature reduces the surface tension of the fluid. And decreasing the temperature increases the surface tension.

Applications of Surface Tension

Surface tension has a huge role in daily life, health and many industrial processes. There are so many techniques that have been developed to modify surface tension.

1. Daily life Example:

a) Small insects such as the water strider can walk on the surface of the water because their weight is very less so they can't penetrate the water.

b) Disinfectants are mainly the solution of low surface tension so that when we use them in the field they can float on the water and spread out on the cells to destroy them.

c) Soaps and detergents also work on the basis of surface tension. They lower the surface tension of the water so that the soaps and detergents easily soak into the pores and holes.

d) The water bubbles are round because the surface tension of water provides the tension to form the bubble with the water and the surface tension minimizes the bubble into spherical shapes.

e) A small needle can be floated on the surface of the water.

2. Role of surface tension on human health:

Surface tension changes in biological phenomena can determine various diseases in the human body.

3. Industrial applications:

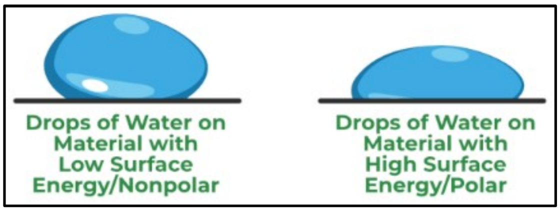
Surface tension is an important factor in industrial processes. In all the industrial plants the R&D departments use the surface tension phenomena to improve the quality of the products. Many operations are used to improve the quality of the product such as detergent formulations. By the use of detergent formulations, we can improve the cleaning properties with more biological surfactants at a lower temperature.

4. Surface tension is also important for characterization for food, pharmaceutical and packaging products.

Shape of liquid drop

What is Surface Energy?

Surface energy measures the breakdown of intermolecular bonds caused by the formation of a surface. Surface-free energy and interfacial-free energy are other names for it. Surface energy is defined as the work done per unit area by the force that forms the new surface.



The image given below shows the surface of the water molecules.

When the free surface area of a liquid is increased, effort must be done against the force of surface tension. This work is stored as potential energy on the liquid surface. This increased potential energy per unit area of the free surface of the liquid is referred to as surface energy.

Mathematically, the surface energy is defined as:

Surface energy = Surface tension × Change in the surface area

or

$$E_S = T \times \Delta A$$

where T denotes surface tension and ΔA denotes an increase in surface area.

Therefore, the SI unit of surface energy is Nm^{-2} *and the dimensional formula is* $[MT^{-2}]$.

Pressure inside a soap bubble

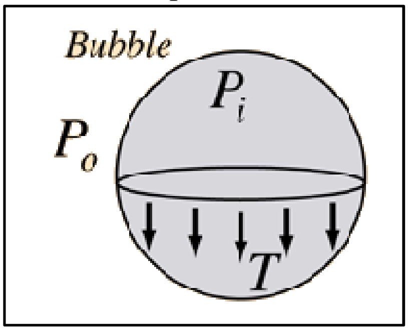
The surface tension of water provides the necessary wall tension for the formation of bubbles with water. The tendency to minimize that wall tension pulls the bubbles into spherical shapes.

The interference colors indicate that the thickness of the soap film is on the order of a few wavelengths of visible light. Even though the soap film has less surface tension than pure water, which would pull itself into tiny droplets, it is nevertheless strong to be able to maintain the bubble with such a small thickness.

The pressure difference between the inside and outside of a bubble depends upon the surface tension and the radius of the bubble. The relationship can be obtained by visualizing the bubble as two hemispheres and noting that the internal pressure which tends to push the hemispheres apart is counteracted by the surface tension acting around the circumference of the circle.

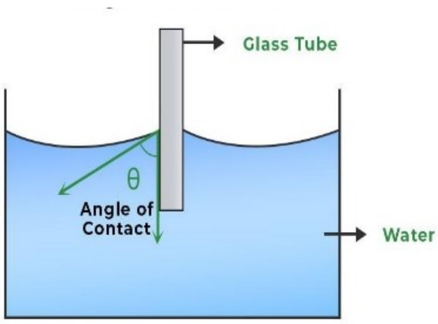
For a bubble with two surfaces providing tension, the pressure relationship is:

$$P_i - P_o = \frac{4T}{r}$$



Angle of contact

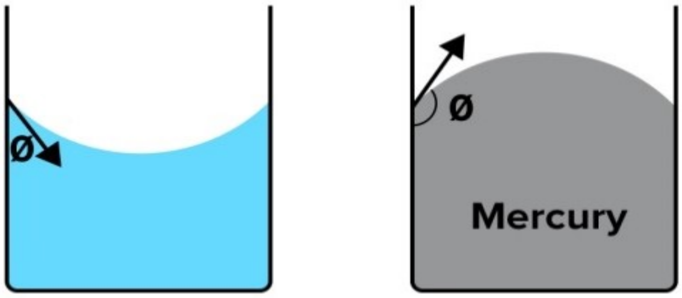
The angle of contact is defined as the angle subtended between the tangents drawn at the liquid surface and the solid surface within the liquid at the point of contact, or it is defined as the angle subtended between the tangents



drawn at the liquid surface and the solid surface within the liquid at the **angle of contact (θ).**
The angle of contact depends on the following factors:

- The nature of the liquid, the solid with which it comes into contact.
- The medium that exists above the free surface of the liquid.
- As the temperature of the liquid rises, so does the angle of contact.
- When soluble impurities are added to a liquid, the angle of contact drops.

The **angle of contact**, also known as the ***contact angle***, refers to the angle formed at the interface between a liquid and a solid surface. It is the angle between the tangent line at the point of contact and the solid surface, as measured through the liquid phase. The angle of contact provides information about the wetting behaviour of the liquid on the solid surface.



(A) Acute angle (B) Obtuse angle

The angle of contact is influenced by intermolecular forces between the liquid, solid, and surrounding medium. It can be classified into three categories:

Wetting

If the liquid spreads over the solid surface and wets it effectively, forming a relatively flat contact area, the angle of contact is less than 90 degrees. This is referred to as a small or acute angle of contact. The liquid is said to be wetting the solid surface.

Non-wetting

If the liquid forms a droplet on the solid surface and does not spread, resulting in a large angle of contact greater than 90 degrees, it is referred to as a non-wetting or a large angle of contact. The liquid does not effectively wet the solid surface.

Partial Wetting

In some cases, the liquid wets the solid surface to a certain extent, but not completely. The angle of contact falls between 0 and 90 degrees, indicating partial wetting.

The angle of contact plays a significant role in various scientific and practical applications. It affects phenomena such as adhesion, surface tension, capillary action, and the behavior of droplets on surfaces.

Angle of Contact Definition

"The angle of contact, also known as the contact angle, is the angle formed at the interface between a liquid and a solid surface. It is the angle between the tangent line at the point of contact and the solid surface, as measured through the liquid phase."

Characteristics of Angle of Contact

The angle of contact is a crucial parameter that governs the wetting behavior of a liquid on a solid surface. It influences adhesion, surface tension, and capillary phenomena, with wetting angles less than 90 degrees indicating good wetting, angles greater than 90 degrees indicating poor wetting, and angles between 0 and 90 degrees representing partial wetting. Understanding and controlling the angle of contact is essential in various scientific and practical applications involving liquids and solid surfaces.

Wetting	Angle of Contact	Characteristics

Behavior		
Wetting	Less than 90°	The liquid spreads over the solid surface, forming a relatively flat contact area. It indicates good adhesion and surface wetting.
Non-Wetting	Greater than 90°	The liquid forms a droplet on the solid surface, not spreading effectively. It shows poor adhesion and surface repelling.
Partial Wetting	Between 0° and 90°	The liquid wets the solid surface to some extent but not completely. It exhibits a combination of wetting and non-wetting characteristics.

Importance of Angle of Contact

The angle of contact plays a significant role in several important aspects and applications. Here are some key reasons highlighting the importance of the angle of contact:

Wetting and Adhesion: The angle of contact determines the wetting behavior of a liquid on a solid surface. It indicates the degree of contact and adhesion between the liquid and the surface. Understanding the wetting properties is crucial in processes such as coating, printing, painting, and surface treatment, where the adhesion and spreading of liquids on solid substrates are essential for desired performance and quality.

Surface Energy and Surface Tension: Measurements and control of the angle of contact are valuable in studying surface properties, surface modification techniques, and the behavior of liquids in confined spaces or porous materials.

Surface Roughness and Topography: The angle of contact is affected by the surface roughness and topography of the solid surface. It influences the contact area and the resulting wetting behavior.

Capillary Action and Fluid Flow: The angle of contact is involved in capillary action and fluid flow in narrow channels or porous materials. It determines the rise or fall of liquids in capillary tubes and affects the flow rates and dynamics of fluids.

Viscosity

Dynamic viscosity (or simply viscosity) is defined as the relationship between the shear stress and the strain rate of a fluid.

Viscosity is produced due to the internal frictional forces between adjacent layers of fluid that resist the relative motion of the fluid layers. These frictional forces arise due to intermolecular interactions within the liquid and determine the fluid's resistance to flow.

The viscosity is considered zero in ideal fluids, also known as perfect fluids. This means that there is no internal resistance to deformation, and the fluid flows without friction. In some cases, this assumption is valid for simplifying mathematical calculations, but in reality, no fluid is entirely ideal.

Viscosity is measured in units such as the Pascal second (Pa·s) in the SI units or the centipoise (cP). It can be determined by different techniques, such as capillary viscometry or rotating a cylinder in a fluid bath.

The formula for the dynamic viscosity is:

$\mu = \tau / (dv/dy)$

Where:

- μ is the dynamic viscosity

- τ is the shear stress
- dv/dy is the velocity gradient in the direction of flow.

This formula calculates a liquid's viscosity based on the flow conditions and applied force.

Applications

Viscosity has many applications in various fields, some examples of which are:

- Industrial processes: In many industrial processes, such as chemical production, polymer processing, and oil and gas refining, it is a critical issue that affects product quality and efficiency.
- Transportation of fluids: it is a key factor in their ability to be transported through pipelines and other channels. Oil viscosity, for example, can impact the efficiency of pipelines and must be monitored to avoid costly and dangerous pipeline failures.
- Biomedical engineering: In this field, it is a critical parameter in blood flow, which can impact the risk of many diseases in case of too much low or high viscosity. Controlling and measuring blood viscosity is vital for diagnosing and managing these conditions.
- Food processing: Viscosity is a crucial factor in many food processing applications. The viscosity of food products can also impact their shelf life and stability.
- Lubrication: The viscosity of lubricants is critical for protecting the moving parts of engines and machinery, by reducing friction and wear. Controlling the viscosity of lubricants is essential for ensuring these systems' long-lasting and efficient performance.
- Ink and paint manufacturing: Viscosity is a critical parameter in the manufacturing of inks and paints, where it can affect the flow and spreading properties of the products.

Lubricants

Machine parts are jammed in winter. The viscosity of the lubricants used in machine parts increase due to low temperature. When two objects come in contact with each other, friction is produced. In the case of machines, friction is produced due to continuous movements of its parts. The friction so produced causes wear and tear of the machine parts. This wear and tear can result in an untimely breakdown of the machine. To reduce this we use lubricants.

Lubricants are fluids with low viscosity which reduces the friction among the machine parts and thus help to increase the machine longevity.
The value for viscosity of any fluid can be given by the given formulae.

$$\eta = \frac{2ga^2(\Delta\rho)}{9v}$$

Where η is the viscosity of the fluid, g is acceleration due to gravity, a is the radius of the sphere which was used to measure the viscosity of the fluid, Δρ is the difference in density of the fluid and the sphere which was used to measure the viscosity of the fluid and and v is the velocity of the sphere in the fluid.
In winters, the temperature decreases. The decrease in temperature causes increase in density having more effect on fluids then solids. Hence the density of the fluid increases. This causes an increase in Δρ, which increases η and thus the ease of movement between machine parts decreases causing jamming.
We can also use the concept of velocity. When temperature increases, the kinetic energy of the particles also increases and thus easy flow of the particles but when temperature decreases the movement becomes slow due to less kinetic energy.

Capillary flow

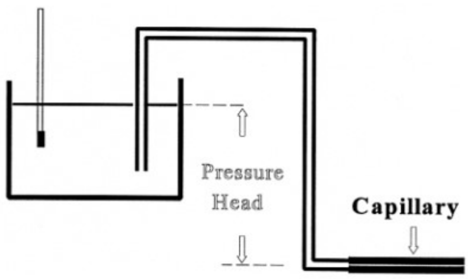
The coefficient of viscosity of a fluid can be found from measurements of the volume rate of flow through small tubes. For simple analysis to be possible laminar or streamlined flow must prevail. Conditions of flow can be described by a dimensionless quantity, Reynolds Number, N_R. N_R is defined as:

$$N_R = \rho \frac{vD}{\eta}$$

where ρ is the density, v is the average velocity of flow, D is the linear dimension for the system, and the η is the coefficient of viscosity. In the case of fluid flow in a tube D is the diameter of the tube, and for laminar flow N_R must be less than about 2000, i.e., the velocity of flow in the tube must be limited. At higher velocities the flow becomes turbulent. For streamlined flow of a liquid through a tube the volume rate of flow, Q, is given by Poiseuille's formula: Q

$$Q = \frac{\pi a^4}{8\eta\ell} p \text{ , or, transposing, } p = \frac{8\eta\ell}{\pi a^4} Q$$

Where, ‘a’ is the radius of the tube, ‘l’ its length, and ‘p’ the pressure difference across its length. Note that this formula reflects the physical equilibrium situation of a force on the fluid due to a pressure difference p being balanced by a viscous force (i.e., one due to a frictional effect), with no other forces acting.



EXPERIMENT: The flow of water, Q, is to be measured at several values of p and for two or three different capillary tubes. The pressure p depends on the head of water, i.e., the height of the water in the reservoir above the level of the tube. The length of the tube can be readily found. The radius is more difficult to find. It has been measured for you by introducing a thread of mercury into the tube, determining its length and then its mass (and hence volume). The resulting values of the radii of the tubes are provided. The viscosity of water changes rapidly with temperature. Measure the temperature of the water at the beginning and end of the lab period. If there is a difference, estimate the error this introduces into your determination of the viscosity.

Diffusion

Diffusion, process resulting from random motion of molecules by which there is a net flow of matter from a region of high concentration to a region of low concentration. A familiar example is the perfume of a flower that quickly permeates the still air of a room.
The rate of flow of the diffusing substance is found to be proportional to the concentration gradient. If j is the amount of substance passing through a reference surface of unit area per unit time, if the coordinate x is perpendicular to this reference area, if c is the concentration of the substance, and if the constant of proportionality is D, then $j = -D(dc/dx)$; dc/dx is the rate of change of concentration in the direction x, and the minus sign indicates the flow is from higher to lower concentration. D is called the diffusivity and governs the rate of diffusion.

Real life examples

1. **Surface Tension:**
   - **Water Striders:** These insects can "walk" on the surface of water due to the high surface tension of water. The cohesive forces between water molecules create a "skin" that supports the insect's weight.

2. **Shape of Liquid Drop:**
   - **Raindrops:** Raindrops tend to be spherical due to surface tension, which minimizes their surface area, and gravity, which pulls them into a spherical shape as they fall.
3. **Angle of Contact:**
   - **Water in a Glass:** The angle at which water meets the edge of a glass is an example of the angle of contact. If the angle is small, the water wets the glass, and if it's large, the water forms droplets.
4. **Viscosity:**
   - **Honey Pouring:** Honey is more viscous than water, and you can observe this by noticing how slowly it flows when poured. The higher the viscosity, the slower a liquid flows.
5. **Lubricants:**

- **Engine Oil:** Engine oil is used as a lubricant in car engines. It reduces friction between moving parts, allowing them to function smoothly and prevent overheating.

6. **Capillary Flow:**
   - **Paper Towels:** When you place a paper towel in water, you can see the liquid being drawn up into the paper towel due to capillary action. The tiny spaces in the paper act as capillaries.
7. **Diffusion:**
   - **Perfume Spreading:** When you spray perfume in one area of a room, it slowly spreads throughout the room due to diffusion. The perfume molecules move from areas of high concentration to low concentration until they are evenly distributed.

Properties and types of materials in daily use

1. **State of Matter:** Matter can exist in one of three primary states: solid, liquid, or gas. The state is determined by the arrangement and motion of particles within the material.
2. **Melting Point:** The melting point is the temperature at which a solid substance transforms into a liquid.
3. **Boiling Point:** The boiling point is the temperature at which a liquid substance transforms into a gas.
4. **Specific Heat Capacity:** Specific heat capacity is the amount of heat energy required to raise the temperature of a unit mass of a substance by a certain amount. It varies between different materials.
5. **Thermal Conductivity:** Thermal conductivity measures a material's ability to conduct heat, with good conductors (e.g., metals) having high thermal conductivity, while insulators have low thermal conductivity.
6. **Electrical Conductivity:** Electrical conductivity indicates a material's ability to conduct electric current and is classified as conductors (e.g., metals), insulators (e.g., rubber), and semiconductors (e.g., silicon).
7. **Magnetic Properties:** Materials can exhibit various magnetic properties, including ferromagnetism, paramagnetism, and diamagnetism, based on their response to magnetic fields.

8. **Optical Properties:** Optical properties include transparency, reflectivity, and refractivity, and materials can be transparent, translucent, or opaque to light.
9. **Chemical Composition:** The chemical composition of a material is determined by the types and quantities of atoms or molecules it contains. It plays a crucial role in the material's chemical behavior.
10. **Solubility:** Solubility is the ability of a substance to dissolve in a solvent. Some substances are highly soluble in certain solvents, while others are not.
11. **Reactivity:** Reactivity refers to how readily a substance reacts with other substances, such as acids, bases, or other chemicals.
12. **Crystal Structure:** Some materials have a regular, repeating atomic arrangement called a crystal lattice. The arrangement of atoms in the lattice determines many of a material's properties, such as its mechanical behavior.
13. **Elasticity:** Elasticity describes a material's ability to return to its original shape after deformation. Materials can be classified as elastic, plastic, or brittle based on their response to deformation.
14. **Strength:** Strength represents the maximum stress a material can withstand before it undergoes permanent deformation or failure.

Classification

Based on specific properties of the materials, materials can be classified in the following manner.

1. **Mechanical Properties:**
    - **Metals:** Known for their strength and durability, metals like steel and aluminum are used in construction, tools, and vehicles.
    - **Plastics:** These materials can be rigid or flexible, and they are used in a wide range of products, from packaging to toys.
    - **Elastomers:** Rubber and other elastomers are known for their elasticity and are used in tires, seals, and shock absorbers.
    - **Ceramics:** Ceramic materials are used for their hardness and heat resistance in applications such as tiles and pottery.
2. **Electrical Conductivity:**

- **Metals:** Copper and aluminum are excellent conductors of electricity, making them essential for electrical wiring and components.
- **Semiconductors:** Materials like silicon are used in electronic devices, as their conductivity can be controlled.

3. **Thermal Conductivity:**
   - **Metals:** Metals like copper and aluminum are excellent heat conductors, used in cooking utensils and heat sinks.
   - **Insulators:** Materials like wood and fiberglass are poor conductors of heat and are used for insulation.
4. **Optical Properties:**
   - **Glass:** Transparent materials like glass are used in windows and lenses.
   - **Polymers:** Plastics can be transparent, translucent, or opaque, making them suitable for various optical applications.
5. **Magnetic Properties:**
   - **Ferromagnetic Materials:** Iron, nickel, and cobalt are used in magnets and magnetic storage devices.
   - **Non-Magnetic Materials:** Materials like aluminum and copper are used in non-magnetic applications.
6. **Chemical Resistance:**
   - **Stainless Steel:** Resistant to corrosion, stainless steel is used in kitchen utensils, cutlery, and chemical processing equipment.
   - **Plastics:** Certain plastics are resistant to chemical corrosion and are used in chemical storage containers.
7. **Biological Compatibility:**
   - **Biocompatible Materials:** Medical implants and devices often use materials like titanium, medical-grade plastics, and ceramics that are compatible with the human body.
8. **Density:**
   - **Wood:** Low-density materials like wood are used in construction and furniture.
   - **Lead:** High-density materials like lead are used in radiation shielding.
9. **Durability:**
   - **Concrete:** Known for its durability, concrete is used in building structures.

- **High-Strength Alloys:** These materials are used in aerospace and automotive applications for their durability and strength.

Conductors and Insulators

Conductors and insulators are two categories of materials that describe how well or poorly they conduct electric current. These properties are crucial in understanding and using materials in electrical and electronic applications.

Conductors:

1. **Definition:** Conductors are materials that allow electric current to flow through them with ease. They have a high electrical conductivity, which means that their atoms or molecules permit the movement of electrons, the charge carriers.
2. **Examples:** Common examples of conductors include metals like copper, aluminum, silver, and gold. These materials have a high density of free electrons, which can move through the material when a voltage is applied.
3. **Characteristics:**
    - Low resistance to the flow of electric current.
    - Good heat and electrical conductivity.
    - Electrons in the outermost energy level of their atoms are loosely bound and can move freely.
4. **Applications:** Conductors are widely used in electrical wiring, power transmission lines, electronic circuits, and various electrical devices. They are essential for efficiently conducting and transmitting electricity.

Insulators:

1. **Definition:** Insulators are materials that do not permit the easy flow of electric current. They have low electrical conductivity because their atoms or molecules do not allow the movement of electrons.

2. **Examples:** Insulators include materials like rubber, glass, plastic, and wood. These materials have tightly bound electrons and do not readily allow the flow of electric charge.
3. **Characteristics:**
    - High resistance to the flow of electric current.
    - Poor heat and electrical conductivity.
    - Electrons in the outermost energy level of their atoms are tightly bound and do not move easily.
4. **Applications:** Insulators are used to prevent the flow of electricity and protect against electrical hazards. They are commonly used as electrical insulation in cables, wires, and electronic devices, as well as in the construction of electrical and electronic systems.

It's important to note that there is also a category of materials known as semiconductors. Semiconductors have electrical conductivity between that of conductors and insulators. They can be controlled to carry or block electric current, making them essential in electronics, as they can be used to create transistors, diodes, and integrated circuits.

The choice of conductor, insulator, or semiconductor for a specific application depends on the electrical properties and requirements of the device or system in which they are used.

Thermal and electric conduction

Thermal and electric conductivities are two different, but related properties of materials, describing their ability to conduct heat and electricity, respectively.

Thermal Conductivity:

Thermal conductivity is a measure of how well a material conducts heat. It quantifies the rate at which heat energy is transferred through a substance. The unit of thermal conductivity is typically watts per meter per degree Celsius (W/m·°C) in the International System of Units (SI). Some key points about thermal conductivity include:

- High thermal conductivity: Materials with high thermal conductivity, such as metals (e.g., copper and aluminum), conduct heat very efficiently. Heat flows quickly through these materials.

- Low thermal conductivity: Insulators, like wood, plastics, and some ceramics, have low thermal conductivity. They are poor conductors of heat, and heat transfer occurs slowly through them.
- Thermal conductivity is essential in various applications, including building insulation, the design of cooking utensils, and in the construction of heat exchangers and cooling systems in engineering.

Electrical Conductivity:

Electrical conductivity refers to a material's ability to conduct an electric current. It is a measure of how well a substance allows the movement of electrons when a voltage is applied across it. Electrical conductivity is measured in units of siemens per meter (S/m) in SI. Some key points about electrical conductivity include:

- High electrical conductivity: Materials with high electrical conductivity are good conductors of electricity. Metals, like copper, aluminum, and silver, are excellent electrical conductors.
- Low electrical conductivity: Materials that are poor conductors or insulators, such as rubber, glass, and plastic, have low electrical conductivity. They do not readily allow the flow of electric charge.
- Electrical conductivity is crucial in electrical and electronic applications, such as wiring and the construction of electrical circuits. Good conductors are used for transmitting electrical power efficiently.