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PINNACLE

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PHYSICS

Units and Measurements

Physical Quantities

Physical quantities are the characteristics or properties of matter that can be measured using numerical values.

Examples - Length, mass, temperature, time, force, speed, distance, acceleration, velocity, momentum, current.

Types of Physical Quantities

On the basis of unit and measurement, the physical quantities are divided into three parts -

Fundamental Quantities

The physical quantities which do not require another physical quantity to be expressed.

Examples - Distance, time, mass, electric current, temperature, amount of substance and luminous intensity.

Derived Quantities

The derived quantities that require two or more principal quantities to be expressed.

Examples - Force, area, volume, speed.

Supplementary Quantities

Quantity that requires neither a base quantity nor a derived quantity to express it.

Examples - Plane angle (radian - rad) and Solid Angle (Steradian - sr).

On the basis of magnitude and direction, the physical quantity is divided into two parts -

Vector Quantities

A physical quantity which has magnitude as well as direction.

Examples - Displacement, velocity, torque, acceleration, force, weight, momentum, impulse, electric field, magnetic field, current density, angular velocity.

Scalar Quantities

A physical quantity which has only its magnitude but no direction.

Examples - Distance, energy, power, time, speed, volume, density, pressure, work, charge, electric current, temperature, specific heat, frequency, mass.

Unit

The standard that is needed to express any physical quantity is called a unit.

Units are also divided into the following parts -

Fundamental Units or Base Units

The units of fundamental physical quantities are called fundamental units. There are seven fundamental units i.e., metre, kilogram, second, ampere, kelvin, candela and mole.

Derived Units

The units of all other physical quantities which are obtained with the help of fundamental units are called derived units.

Examples - Units of area, volume, density, speed, power, work, force, energy, acceleration, momentum.

Supplementary Units

The units used for the supplementary quantities are known as supplementary units.

Examples: Units of plane angle and solid angle.

System of Units

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

The common systems of units are -

(i) MKS System (Metre Kilogram Second) : In this system, the units of length, mass and time are

metre,
kilogram and second respectively.

(ii) CGS System or Gaussian System (Centimetre Gram Second) : In this system, the units of length, mass and time are centimetre, gram and second respectively.

The MKS and CGS systems are called metric or decimal systems.

(iii) FPS System or British System (Foot Pound Second) : In this system, the units of length, mass and time are respectively foot, pound and second.

(iv) SI System (International System of Units) : SI was adopted and accepted in the International Conference of Weights and Measures held at Geneva in 1960, on the basis of comprehensive consensus. SI system is an extended and modified form of the MKS system.

International System (SI Unit)

In 1960, the original units were six, but in 1971 it became seven units by adding Mole.

Base Quantity	Name	Symbol
Mass	kilogram	kg
Length	metre	m
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Luminous Intensity	candela	cd
Amount of Substance	mole	mol

Supplementary Units and their Symbols in SI System

Name of quantity	Name of unit	Symbol
Plane angle	radian	rad
Solid angle	steradian	sr

Radian and Steradian are dimensionless quantities, because angle can be expressed as the ratio of the length of an arc to the radius of that circular object.

Derived Unit

It is a SI unit of measurement composed of a combination of the seven base units.

Name	Formula	SI unit	Dimension
Area	Length × Breadth	m^2	$[M^0L^2T^0]$
Density	$\frac{Mass}{Volume}$	$kg\ m^{-3}$	$[M^1L^{-3}T^0]$
Velocity	$\frac{Displacement}{Time}$	ms^{-1}	$[M^0L^1T^{-1}]$
Acceleration	$\frac{Change\ in\ velocity}{Time}$	ms^{-2}	$[M^0L^1T^{-2}]$
Force	Mass × acceleration	N	$[M^1L^1T^{-2}]$
Linear momentum	Mass x Velocity	$kg\ ms^{-1}$	$[M^1L^1T^{-1}]$
Impulse	Force × Time	Ns	
Work	Force × displacement	joule	$[M^1L^2T^{-2}]$
Power	$\frac{Work}{Time}$	watt	$[M^1L^2T^{-3}]$
Pressure	$\frac{Force}{Area}$	Nm^{-2}	$[M^1L^{-1}T^{-2}]$
Angular velocity	$\frac{Angle}{Time}$	rad/s	$[M^0L^0T^{-1}]$
Torque	Moment of inertia × Angular acceleration	Nm	$[M^1L^2T^{-2}]$
Angular acceleration	$\frac{Angular\ velocity}{Time}$	$rad\ s^{-2}$	$[M^0L^0T^{-2}]$
Angular frequency	2π × frequency	$rad\ s^{-1}$	$[M^0L^0T^{-1}]$
Moment of inertia	Mass × (radius of gyration)^2	kgm^2	$[M^1L^2T^0]$
Surface tension	$\frac{Force}{Length}$	Nm^{-1}	$[M^1L^0T^{-2}]$
Surface energy	$\frac{Energy}{Area}$	joule/ m^2	$[M^1L^0T^{-2}]$
Universal Gravitational constant	$\frac{Force \times (radius)^2}{mass1 \times mass2}$	$Nm^2\ kg^{-2}$	$[M^{-1}L^3T^{-2}]$
Coefficient of viscosity	$\frac{force \times distance}{area \times velocity}$	$Ns.m^{-2}$	$[M^1L^{-1}T^{-1}]$
Planck's constant	$\frac{Energy}{Frequency}$	Js	$[M^1L^2T^{-1}]$
Modulus of Elasticity (E)	$\frac{Stress}{strain}$	Nm^{-2}	$[M^1L^{-1}T^{-2}]$
Power of lens	$\frac{1}{focal\ length}$	D	$[M^0L^{-1}T^0]$
Charge (q)	Current × time	C	$[M^0L^0T^1A]$
Strain	$\frac{Change\ in\ dimension}{Original\ dimension}$	No units	$[M^0L^0T^0]$
Specific gravity	$\frac{Density\ of\ body}{density\ of\ water\ at\ 4°C}$	No units	$[M^0L^0T^0]$
Efficiency	$\frac{output\ work\ or\ energy}{input\ work\ or\ energy}$	No units	$[M^0L^0T^0]$

Refractive index	$\frac{speed\ of\ light\ in\ vacuum}{speed\ of\ light\ in\ medium}$	No units	$[M^0L^0T^0]$

Dimensions of Physical Quantities

Dimension of physical quantities is defined as the power to which the fundamental units are raised to represent it.

For example : kilogram is expressed in dimensions as [M], length [L], time [T], Temperature [K], Electric current [A], Luminous intensity [cd], Amount of substance [mol].

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

Dimensional Formula

Q = $[M^aL^bT^c]$ where M, L, T are base dimensions of mass, length, and time respectively and a, b and c are their respective exponents.

Some Physical Quantities and their Dimensional Formulae

Area = Length × Breadth

$\Rightarrow [L \times L] = [L^2] = [M^0L^2T^0]$

Velocity = Displacement/Time

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

Acceleration = Change in velocity/Time

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

Force = Mass × Acceleration

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

Kinetic energy = $\frac{1}{2}\,Mass \times (Velocity)^2$

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

Dimensionless Quantities

The physical quantities which have zero dimensions and the same numeric value in all systems of units such as angle, solid angle, relative density, specific gravity, Poisson's ratio etc are called dimensionless quantities.

Practical Units of Length, Mass and Time

Practical Units of Length	Practical Units of Mass	Practical Units of Time
1 Parsec = 3.26 light year = 3.083 × 10^{16} m	Chandra Shekhar unit: 1 CSU = 1.4 times the mass of sun = 2.8 x 10^{30} kg	1 Solar year = 366.25 Sidereal day = 365.25 average solar day
1 Light year = 9.46 × 10^{15} m	Atomic mass unit (amu) = 1.67 x 10^{-27} kg	1 Solar month = 30 or 31 days
1 Astronomical unit (1AU) = 1.496×10^{11}m	1 Slug = 14.59 kg	1 Lunar month = 29.5 days
1 angstrom = 1Å = 10^{-10} m	1 Metric tonne = 10^3 kg	1 Leap year = 366 day (29 days in feb of leap year)
1 X-ray unit = 1XU = 10^{-13} m	1 Quintal = 10^2 kg	1 Shake = 10^{-8} s (now obsolete)
1 fermi = 1 fm = 10^{-15} m	1 Pound = 0.4535 kg	1 Day = 24 hours = 1440 min = 86400 s
1 micron = μm = 10^{-6} m	1 Gram (g) = 10^{-3}kg	1 Nanosecond (ns) = 10^{-9} s
1 Nanometre (nm) =10^{-9} m	1 Milligram (mg) = 10^{-6} kg	1 Millisecond (ms) = 10^{-3}s
1 Terameter =10^{+12} m	1 Microgram (μg) = 10^{-9}kg	1 Picosecond (ps) = 10^{-12} s
1 Picometre = 10^{-12} m		1 Microsecond (μs) = 10^{-6} s

Measurement of Large Distances

Light-year - It is the distance a light photon travels in the vacuum in one Julian year. 1 light Year = 9.467 × 10^{15} metre.

Astronomical Unit - It measures the average distance between the center of the Earth and the center of the Sun. Astronomical Unit = 1.496 × 10^{11} metre.

Parsec - It is a unit of distance used in astronomy. 1 Parsec = 3.086 × 10^{16} metre = 3.26 light years.

Prefix And Symbol for Various Power of 10

Prefix	Multiple	Symbol
yotta	10^{24}	Y
zetta	10^{21}	Z

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

Range and Order of Lengths

Object	Length (m)
Size of proton	10^{-15}
Size of atomic nucleus	10^{-14}
Size of hydrogen atom	10^{-10}
Size of red blood corpuscle	10^{-5}
Thickness of paper	10^{-4}
Radius of the Earth	10^{7}
Distance of Moon to Earth	10^{8}
Distance of Sun to Earth	10^{11}
Size of galaxy	10^{21}
Distance to the boundary of observable universe	10^{26}

Range and Order of Masses

Object	Mass (kg)
Electron	10^{-30}
Proton	10^{-27}
Red blood cell	10^{-13}
Dust Particle	10^{-9}
Rain Drop	10^{-6}
Mosquito	10^{-5}
Grape	10^{-3}
Human	10^{2}
Moon	10^{23}
Earth	10^{25}
Sun	10^{30}
Milky Way galaxy	10^{41}

Range and Order of Time Intervals

Event	Time interval(s)
Life-span of most unstable particle	10^{-24}
Period of X-rays	10^{-19}
Period of light wave	10^{-15}
Life of an excited state of an atom	10^{-8}
Period of sound wave	10^{-3}
Wink of eye	10^{-1}
Time between successive human heart beats	10^{0}
Travel time for light from moon to the earth	10^{0}
Travel time for light from the sun to the earth	10^{2}
Rotation period of the Earth	10^{5}
Rotation and revolution periods of the moon	10^{6}
Revolution period of the Earth	10^{7}
Travel time for light from nearest star	10^{8}
Age of the universe	10^{17}

Error in Measurement

The difference between true value and measured value of a quantity is called error of measurement.

Accuracy - The accuracy of a measurement is a measure of how close the measured value is to the true value of the quantity.

Precision - It quantifies the level of detail or fineness in measurements, indicating the extent to which a quantity is measured with accuracy within its resolution or limit.

Example - Suppose the true value of a certain length is near 5.678 cm. In one experiment, using a measuring instrument of resolution 0.1 cm, the measured value is found to be 5.5 cm, while in another experiment using a measuring device of greater resolution, say 0.01 cm, the length is determined to be 5.38 cm. The first measurement has more accuracy (because it is closer to the true value) but less precision (its resolution is only 0.1 cm), while the second measurement is less accurate but more precise.

Types of Errors

In general, the errors in measurement can be broadly classified are as follows:

Systematic Errors - These are the errors that tend to be in one direction, either positive or negative. Some sources of systematic errors are as follows:

(a) Instrument Errors - Errors due to calibration or imperfect design in measuring instruments.

(b) Personal Errors - Errors that arise due to personal bias, lack of proper setting of equipment or carelessness of the individual in making observations without following proper precautions.

(c) Imperfection in experimental technique or procedure - To determine the temperature of a human body, a thermometer placed under the armpit will always give a temperature lower than the actual value of the body temperature.

Random Errors - The random errors are those errors, which occur irregularly and hence are random with respect to sign and size. They are typically caused by various factors such as random fluctuations in experimental conditions (e.g.,temperature, voltage supply, mechanical vibrations), as well as inherent limitations in the observer's ability to make precise measurements.

Least Count Error - The smallest value that can be measured by the measuring instrument is called its least count. The least count error is the error associated with the resolution of the instrument.

Absolute Error - The magnitude of the difference between the individual measurement and the true value of the quantity is called the absolute error of the measurement.

Relative error - The ratio of mean absolute error to the mean value of the quantity is called relative error or fractional error. If this ratio is expressed as percentage, then the error is called percentage error.

Significant Figures

The digits that are known reliably plus the first uncertain digit are known as significant digits or significant figures.
If we say the period of oscillation of a simple pendulum is 1.62 s, the digits 1 and 6 are reliable and certain, while the digit 2 is uncertain. Thus, the measured value has three significant figures.

Rules for Counting Significant Figures

Non-zero digits - All non-zero digits in a number are significant.
Example - The number 123.45 has five significant figures.

If the number is less than 1, the zero(s) on the right of the decimal point but to the left of the first non-zero digit are not significant. (In <u>0.00</u> 5408, the underlined zeroes are not significant).

Captive Zeros - Zeros between non -zero digits are counted.
Example - The number 10.05 has four significant figures.

Trailing Zeros without a Decimal Point - Trailing zeros without a decimal point at the end of a number are ambiguous and not significant. The notation may be used to indicate the number of digits to remove ambiguity.
Example - The number 1200 can be written as 1.20×10^3 to represent three significant figures.

Trailing Zeros With Decimal Point - For a number with a decimal, the trailing zero(s) are significant. The zeros coming after the decimal point are significant and are counted.
Example - The number 3.500 has four significant digits.

Exact numbers - Integers obtained from counting objects or defined values are considered to be infinite numbers.
Example - If you have 5 apples, the number 5 is considered to have an infinite number of significant digits.

Arithmetic Operation with Significant Numbers

(i) Addition and Subtraction - In both addition and subtraction, the final result should retain as many decimal places as are there in the number with the least decimal places.

(ii) Multiplication and Division - In multiplication and division, the final result should retain as many significant figures as are there in the original number with least significant figures.

Scientific Instruments and their Use

Ammeter - It measures the strength of electric current (in ampere).

Altimeter - It is used in aeroplanes to measure altitude.

Anemometer - It is used for measuring wind speed.

Audiometer - It measures intensity of sound.

Barometer - It measures atmospheric pressure.

Bolometer - It is used to measure infrared radiations.

Binocular - It is used to view distant objects.

Calorimeter - It measures the quantity of heat.

Cardiogram - It traces movements of the heart, recorded on a cardiograph.

Dynamo - It converts mechanical energy into electrical energy.

Dynamometer - It measures electrical power.

Electroscope - It detects the presence of electric charge .

Endoscope - It examines internal parts of the body.

Fathometer - It is used to measure the depth of oceans.

Galvanometer - It measures the electric current of low magnitude.

Hydrometer - It is used for measuring specific gravity (or relative density) of liquids.

Hygrometer - It is used to measure relative humidity.

Lactometer - It determines the purity of milk.

Manometer - It measures the pressures of gases.

Microscope - It is used to view small objects or organisms.

Odometer - It measures the distance traveled by a vehicle.

Periscope - It is used to view objects above sea level.

Photometer - It is used to determine the intensity of light.

Potentiometer - It is used to measure the electromotive force (emf) of cells.

Pyrometer - It is a remote - sensing radiation thermometer used to measure the high temperature of the surface.

Radiometer - It measures the emission of radiant energy.

Salinometer - It determines the salinity of the solution.

Seismograph - It used to measure the intensity of earthquake shocks.

Speedometer - It is an instrument placed in a vehicle to record its speed.

Spherometer - It is used to measure the radius of curvature of an object such as lenses and curved mirrors which are spherical in shape.

Stroboscope - It is used to measure periodic motion.

Tachometer - An instrument used in measuring speeds of aeroplanes and motor boats.

Telescope - It is used to view distant objects in space.

Thermometer - It is used to measure temperature.

Thermostat - It regulates the temperature at a particular point.

Viscometer - It measures the viscosity of liquids.

Voltmeter - It measures the electric potential difference between two points.

Practice Questions :-

Q.1. Which of the following is the correct match of the column-A with column-B ?

Column-A (PhysicalProperty)	Column-B (Unit)
i. Electric current	a. Tesla
ii. Voltage	b. Farad
iii. Capacitance	c. Ampere
iv. Magnetic field	d. Volt

SSC CGL 24/07/2023 (1st shift)
(a) i-c, ii-d, iii-b, iv-a (b) i-c, ii-a, iii-b, iv-d
(c) i-d, ii-c, iii-b, iv-a (d) i-c, ii-d, iii-a, iv-b

Q.2. Match the points under List I with those under List II.

List I (Instrument)	List II (Use)
1. Sextant	a. Measures the angle between two visible objects
2. Udometer	b. Measures small quantities of radiant heat
3. Thermopile	c. Measures the temperature of a surface
4. Pyrometer	d. Measures the amount of rainfall

SSC CHSL Tier II (26/06/2023)
(a) 1-b, 2-d, 3-c, 4-a (b) 1-a, 2-d, 3-b, 4-c
(c) 1-c, 2-d, 3-b, 4-a (d) 1-c, 2-b, 3-d, 4-a

Q.3. The Wind Vane instrument measures the ______.
SSC MTS 15/05/2023 (Morning)
(a) relative humidity (b) temperature
(c) wind velocity (d) wind - direction

Q.4. Which among the following is a unit of measurement that describes the rate at which the universe is expanding?
SSC CHSL 21/03/2023 (1st Shift)
(a) Faraday constant (b) Planck's constant
(c) Electric constant (d) Hubble constant

Q.5. Identify the correct statement.
SSC CGL Tier II (07/03/2023)
(a) Newton is a unit of force.
(b) Newton is a unit of power.
(c) Joule is a unit of force.
(d) Joule is a unit of power.

Q.6. Which of the following options is correctly matched ?
SSC CPO 09/11/2022 (Evening)
(a) Units of force -Joule, Horsepower, Torr
(b) Units of work done - Newton, Pascal, Bar
(c) Units of pressure - Pascal, Bar and Torr
(d) Units of volume - Kilogram, Gram, Metre

Q.7. 1 commercial unit of electrical energy is equal to ______ joules.
RRC Group D 19/09/2022 (Morning)
(a) 3.6×10^7 (b) 3.6×10^8 (c) 3.6×10^5 (d) 3.6×10^6

Q.8. Which of the following is a unit of acceleration ?
RRB NTPC CBT - II (16/06/2022) Shift 2
(a) $\frac{m}{s^2}$ (b) $\frac{ft}{s}$ (c) $\frac{m}{s}$ (d) $\frac{sqm}{s}$

Q.9. Which of the following is NOT a SI unit ?
RRB NTPC CBT - II (13/06/2022) Shift 2
(a) Ohm (b) Ampere (c) Newton (d) Calorie

Q.10. Of the units mentioned in the options, which one is the largest as compared to the others ?
SSC MTS 05/10/2021 (Evening)
(a) Hecto (b) Deca (c) Tera (d) Giga

Q.11. Ozone layer thickness is measured in :
RRB NTPC CBT - I (15/03/2021) Morning
(a) Sievert unit (b) Dobson unit
(c) decibels (d) del unit

Q.12. Which of the following does NOT match?
RRB NTPC CBT - I (23/02/2021) Morning
(a) Compass - used for navigation and indicates north - south directions
(b) Cyclotron - measures small magnitude Cyclones.
(c) Actinometer - measures the intensity of radiation
(d) Electroscope - detects the presence of electric charge

Q.13. ____ is a device by which two different photograph of the same object can be viewed together
RRB NTPC CBT - I (05/02/2021) Morning
(a) Stereoscope (b) Stroboscope
(c) Stethoscope (d) Spectroscope

Q.14. A light - year is a unit of____
RRB NTPC CBT - I (01/02/2021) Morning
(a) Distance (b) Intensity of light (c) Time (d) Mass

Q.15. Which of the following instruments is primarily used in military submarines?
RRB NTPC CBT - I (31/01/2021) Morning
(a) Periscope (b) Endoscope
(c) Microscope (d) Telescope

Q.16. The intensity of an earthquake is measured by ____.
RRB NTPC CBT - I (25/01/2021) Evening
(a) Bar (b) Richter Scale
(c) Mercalli scale (d) Kilogram

Q.17. Which of the following units is used to measure the intensity of sound?
RRB NTPC CBT - I (25/01/2021) Morning
(a) Decibel (b) Pascal (c) Curie (d) Joule

Q.18. Which of the following instruments is used to

measure wind speed?
RRB NTPC CBT - I (25/01/2021) Morning
(a) Udometer (b) Anemometer
(c) Ammeter (d) Hygrometer

Q.19. Automobiles are fitted with a device that shows the distance travelled. identify it.
RRB NTPC CBT - I (23/01/2021) Evening
(a) Odometer (b) Autometer
(c) RPM meter (d) Speedometer

Q.20. Which instrument is used to show the direction of flow of current in a circuit?
RRB NTPC CBT - I (19/01/2021) Morning
(a) Voltmeter (b) Ammeter
(c) Galvanometer (d) Rheostat

Q.21. Which of the following devices is used to measure relatively high temperatures, such as are encountered in furnaces?
RRB NTPC CBT - I (07/01/2021) Evening
(a) Ammeter (b) Fluxmeter
(c) Pyrometer (d) Bolometer

Q.22. Which of the following units is used for measuring the amount of a substance ?
RRB NTPC CBT - I (28/12/2020) Morning
(a) Mole (b) Tesla (c) Joule (d) Lux

Q.23. Which device is used to measure the relative density of the fluid?
RPF Constable 25/01/2019 (Morning)
(a) Hygrometer (b) Hydrometer
(c) Lactometer (d) Venturimeter

Q.24. What is the relative density unit ?
RPF Constable 17/01/2019 (Morning)
(a) No Unit (b) kg m^{-1} (c) kg m^{-2} (d) kg m^{-3}

Q.25. One nanometer is :
RRB ALP Tier - I (17/08/2018) Evening
(a) 10^{-9} m (b) 10^{-8} m (c) 10^{-10} m (d) 10^{-11} m

Answer Key :-

1.(a)	2.(b)	3.(d)	4.(d)
5.(a)	6.(c)	7.(d)	8.(a)
9.(d)	10.(c)	11.(b)	12.(b)
13.(a)	14.(a)	15.(a)	16.(c)
17.(a)	18.(b)	19.(a)	20.(c)
21.(c)	22.(a)	23.(b)	24.(a)
25.(a)			

Motion

Motion - It is the change in position of an object with respect to its surroundings in a given interval of time. In daily life, motion is evident in activities such as walking, running or driving.

Examples - A car driving on a highway, birds flying through the sky, fish swimming in water, a train moving on the track etc.

Uniform motion - If an object travels equal distances in equal time intervals, then its motion is said to be uniform motion.

Examples - The movement of the fan's blades, the motion of the earth around the sun, the motion of the pendulum with equivalent amplitude on either side etc.

Non-uniform motion - If unequal distances are traveled by an object in equal time intervals, then its motion is said to be non-uniform.

Examples - A running horse, a man running in a 1000 m race, a bouncy ball, a car colliding with another car etc.

Rest - It refers to a state of no motion or change in position. An object at rest remains stationary relative to its surroundings.

Rest and motion are relative terms i.e., an object in one situation can be at rest but in other situations the same object can be in motion.

Examples - If two cars are going side by side with the same velocity, then with respect to each other, they are in a state of rest, but with respect to roadside trees and persons going on the road, they are in a state of motion.

Types of Motion

According to the nature of the movement, motion is classified into three types.

Linear Motion or Rectilinear Motion

The movement of an object in a straight line, with consistent speed and direction is called linear or rectilinear motion. It occurs when an object's displacement is directly proportional to the time elapsed.

Example - A train moving along a straight line.

Rotatory Motion

The movement of an object around an axis or center point is called rotatory motion. It involves circular or curved paths and is characterized by changes in angular position.

Examples - The spinning of a wheel, the rotation of the Earth on its axis, the movement of the blades of a fan.

Oscillatory Motion

Oscillatory Motion is a repetitive back - and - forth movement around a central equilibrium position. It involves a periodic variation in position, velocity, or other physical quantities, resulting in a regular pattern or cycle.

Examples - A pendulum swinging back and forth in a regular pattern, a vibrating guitar string producing sound waves.

One, Two and Three - Dimensional Motion

One-Dimensional Motion - The movement of an object along a single straight line.

Examples - A person walking in a straight line, a train on a straight railway track etc.

Two-Dimensional Motion - The movement of an object in a plane, involving both horizontal and vertical components of motion.

Examples - Motion of a boat in a river, Motion of earth around the sun etc.

Three-Dimensional Motion - The movement of an object in space, involving changes in position along three perpendicular axes: X, Y, and Z.

Examples - An astronaut floating in space, Motion of a kite, Motion of a flying bird.

Basic Terms Related to Motion

Reference Point - It is a fixed location or fixed point used to determine the position or movement of an object relative to it.

Position - It refers to the specific location or coordinates of an object in space, relative to a chosen reference point.

Path length - It is defined as the total length of the path traversed by an object.

Distance (d) - It is the measurement of the total length between two points, typically measured along the actual path travelled by an object.

Displacement (s) - The shortest path covered by an object from the initial point to the final point.

Displacement = Final point - Initial point. It is a vector quantity. Its SI unit is **m** (meter). It can be positive, negative or zero.

Speed - The rate of change of position of an object in any direction.

Speed = $\frac{Distance\ (d)}{Time\ (t)}$.

It is a scalar quantity. Its SI unit is meter/second (m/s) or ms^{-1}. Its dimension formula is $[M^0L^1T^{-1}]$. It can be positive or zero but can not be negative.

Example - A car travels a distance of 500 km in 10 hours. What is its speed in km/hr ?

Solution - Given, Distance = 500 km and Time = 10 hours.
As we know,
Speed = $\frac{Distance\ (d)}{Time\ (t)} = \frac{500}{10}$ = 50 km/hr.

Types of Speed :-

Uniform Speed - When an object travels equal distances in equal intervals of time, it is termed as uniform speed.

Variable speed - When an object covers a different distance at equal intervals of time, it is termed as variable speed.

Average speed - It is defined as the uniform speed which is given by the ratio of total distance travelled by an object to the total time taken by the object.

Example **-** Using the average speed formula, find the average speed of Sam, who covers the first 200 kilometers in 4 hours and the next 160 kilometers in another 4 hours.

Solution - Given, D_1 = 200 km, D_2 = 160 km, t_1 = 4 hours and t_2 = 4 hours

As we know,

Average Speed = $\frac{Total\ Distance}{Total\ Time\ taken}$

= $\frac{200+160}{4+4}$ = 45 km/hr.

Instantaneous speed - When an object is moving with variable speed, then the speed of that object at any instant of time is termed as instantaneous speed.

Velocity - Velocity is defined as the rate of change in displacement with respect to time.

Velocity = $\frac{Change\ in\ Displacement}{change\ in\ Time}$

It is a vector quantity. Its SI unit is m/s or ms^{-1}. Its dimension formula is $[M^0L^1T^{-1}]$. It can be positive, negative or zero. The magnitude of the velocity of an object is always equal to or less than its speed.

Example - A train travels a distance of 100 m due east in 10 seconds. What is its velocity ?

Solution - Given, Displacement = 100 m and time = 10 s

As we know,

Velocity = $\frac{Displacement}{Time}$ = $\frac{100}{10}$ = 10 m/s due east.

Types of Velocity:-

Uniform Velocity - The motion of an object in which it covers equal displacements in equal intervals of time. It means that the object is moving at a constant speed in a straight line without any change in direction. The magnitude and direction of the velocity remain constant throughout the motion.

Variable Velocity - When a body covers unequal distances in equal intervals of time in a specified direction, the body is said to be moving with a variable velocity. It indicates that the object is not moving at a constant rate and may be accelerating or decelerating.

Average Velocity - The total displacement of an object divided by the total time taken is called average velocity. It represents the overall rate of change in position over a given journey.

Instantaneous Velocity - The velocity of a particle at any instant of time is known as its instantaneous velocity.

Acceleration - The rate of change of velocity with respect to time is called acceleration. It is a vector quantity. Its SI unit is m/s^2 or ms^{-2}. Its dimension is $[M^0L^1T^{-2}]$.

Acceleration (a) = $\frac{Change\ in\ velocity\ (\Delta v)}{Change\ in\ time\ (\Delta t)}$

If in a given time interval (t) the velocity of a body changes from initial velocity (u) to final velocity (v), then acceleration is expressed as -

a = $\frac{Final\ velocity\ (v) - Initial\ velocity\ (u)}{Time\ (t)}$

When the velocity of a body increases with time, acceleration is positive (i.e., the body is said to be accelerated) and when the velocity of a body decreases with time , then acceleration becomes negative (i.e., the body is said to be retarded). Negative acceleration is also called deceleration or retardation.

Example - A scooter travelling at 10 m/s speed up to 20 m/s in 4 sec. Find the acceleration of the scooter.

Solution - Given, Initial velocity = 10 m/s, final velocity = 20 m/s and time = 4 sec.

As we know,

Acceleration = $\frac{Final\ velocity - Initial\ velocity}{time}$

= $\frac{20-10}{4}$ = 2.5 m/s^2.

Types of Acceleration :-

Uniform acceleration - When an object travels in a straight line and its velocity increases by equal amounts in equal intervals of time, then it is called Uniform acceleration.

Example - A body falling down from a height or a body rolling down on a smooth inclined plane.

Non-uniform acceleration or Variable acceleration - The acceleration of a body is said to be non-uniform if its velocity changes by unequal amounts in equal intervals of time.

Example - If a car traveling along a straight road increases its speed by unequal amounts in equal intervals of time.

Instantaneous acceleration - The ratio of change in velocity during a given time interval such that the time interval goes to zero.

Average acceleration - When an object is moving with a variable acceleration, then the average acceleration of the object for the given motion is defined as the ratio of the total change in velocity of the object during motion to the total time.

Average acceleration = $\frac{Total\ change\ in\ velocity}{Total\ \ time\ taken}$

Example - A sparrow, while going back to its nest accelerates to 6 m/s from 3 m/s in 5s. What can we say about its average acceleration?

Solution - Given, Initial velocity = 3m/s, Final velocity = 6m/s, Total time = 5 s.

As we know,

Average acceleration = $\frac{Total\ change\ in\ velocity}{Total\ \ Time\ taken}$

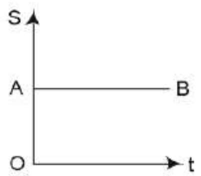
= $\frac{6-3}{5}$ = 0.6 m/s^2.

Graphical Representation of Motion

It is a method of representing a set of variables (physical quantities) pictorially with the help of a line graph where one physical quantity depends on the other physical quantity. Such as displacement - time graphs, velocity - time graphs, displacement - velocity graphs, etc.

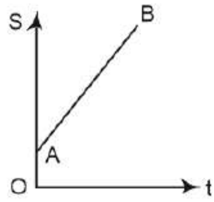
Displacement - Time Graphs

(a) When an object is at rest then the (s-t) graph is a straight line parallel to the time axis.



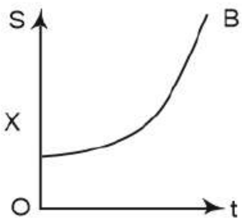
From the graph, it is clear that with the passage of time, there is no change in the position of the body, it remains at point A, i.e., the body is stationary.

(b) When an object is moving with zero acceleration then the (s-t) graph is a straight line with positive slope and the object is initially at some distance from the origin.



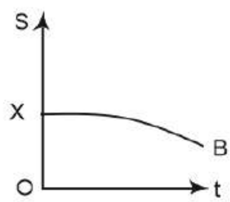
From the graph, it is clear that in equal intervals of time, the body covers equal distances, so the motion is uniform and the graph is a straight line.

(c) When an object is moving with uniform positive acceleration then the (s-t) graph is a curve with positive slope and the object is initially at some distance from the origin.



From the graph, it is clear that in equal intervals of time of one second, the body is covering unequal distances and this distance goes on increasing. That means, with the passage of time, the body is covering more and more distance in equal time i.e., the speed of the body is increasing. Hence, the slope of the graph is positive.

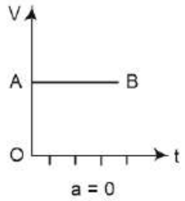
(d) When an object is moving with uniform positive acceleration then the (s-t) graph is a curve with negative slope and the object is initially at some distance from the origin.



From the graph, it is clear that in equal intervals of time of one second, the body is covering unequal distances and this distance is decreasing. That means, with the passage of time, the body is covering lesser and lesser distance in equal time i.e., the speed of the body is decreasing. Hence, the slope of the graph is negative.

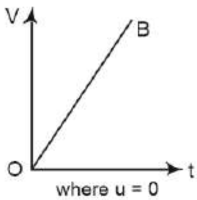
Velocity - Time Graphs

(a) When an object is moving with constant velocity (zero acceleration) then the (v-t) graph is a straight line parallel to the time axis.



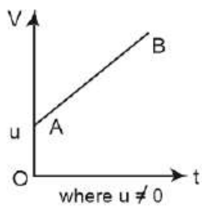
From the graph, it is clear that with the change of time, there is no change in the velocity. Hence, the slope of the graph is zero.

(b) When an object is moving with constant positive acceleration having zero initial velocity then the (v-t) graph is a straight line passing through the origin.



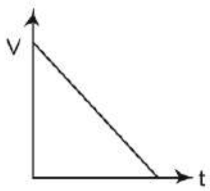
From the graph, it is clear that for equal change in time, velocity changes by equal amount.

(c) When an object is moving with positive constant acceleration having some initial velocity then the (v-t) graph is a straight line.



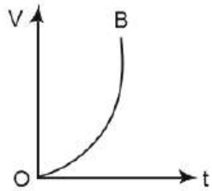
From the graph, it is clear that for equal change in time, velocity changes by equal amount.

(d) When an object is moving with constant negative acceleration having some positive initial velocity then the (v - t) graph is a straight line and slope is negative.



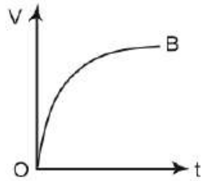
From the graph, it is clear that velocity is decreasing uniformly with time.

(e) When an object is moving with increasing acceleration having zero initial Velocity then the (v-t) graph is a curve.



From the graph, it is clear that for equal change in time, the change in velocity are unequal.

(f) When an object is moving with decreasing acceleration, then the (v-t) graph is a curve.



From the graph it is clear that velocity is decreasing non-uniformly with time.

Equations of Motion

When an object moves along a straight line with uniform acceleration, it is possible to relate its velocity, acceleration during motion and the distance covered by it in a certain time interval by a set of equations known as the equations of motion.

Three Equations of Motion

First Equation of Motion (relation between "velocity and time") :
$v = u + at$

Example - If a car starts from rest and accelerates at 5 m/s² for 10 seconds, what will be its final velocity ?

Solution - Given, Acceleration = 5 m/s², time = 10 sec, initial velocity = 0 m/s
As we know,
$v = u + at \Rightarrow v = 0 + 5 \times 10 \Rightarrow v = 50$ m/s.

Second Equation of Motion (relation between " position and time") :

$s = ut + \frac{1}{2}at^2$

Example - A car initially at rest starts moving with acceleration 0.5 m/s^2 covers a distance of 25 m. Calculate the time required to cover this distance.

Solution - Given, Initial velocity (u) = 0 m/s, acceleration (a) = 0.5 m/s^2, distance travelled (s) = 25m.
As we know,

$s = ut + \frac{1}{2}at^2 \Rightarrow 25 = 0 + \frac{1}{2} \times 0.5 \times t^2$

$\Rightarrow t^2 = \frac{25}{0.25} = 100 \Rightarrow t = 10$ s.

Third Equation of Motion (relation between "position and velocity") :
$v^2 = u^2 + 2as$

where, s = displacement, u = initial velocity, v = final velocity, a= acceleration, t = time.

Example - A body initially at moving with a speed of 18 kmph is accelerated uniformly at the rate of 9 cm/s^2 covers a distance of 200 m. Calculate the final velocity.

Solution - Given, Initial velocity (u) 18 kmph

$= 18 \times \frac{5}{18} = 5$ m/s,
distance travelled = s = 200 m,
acceleration = 9 cm/s^2 = 0.09 m/s^2.
As we know,
$v^2 = u^2 + 2as \Rightarrow v^2 = 5^2 + 2 \times 0.09 \times 200$
$\Rightarrow v^2 = 61 \Rightarrow v = \sqrt{61}$ m/s.

Freely Falling Object

The falling of an object from a height towards the earth under gravitational force is called free fall. Such a body is called a freely falling object. Whenever an object falls towards the earth, an acceleration is involved, this acceleration is due to the earth's gravitational pull and is called acceleration due to gravity.

The value of acceleration due to gravity (g) near the earth surface is 9.8 m/s^2.

The three equations of free fall of an object near the surface of the earth are -
(i) $v = u + gt$
(ii) $h = ut + \frac{1}{2}gt^2$
(iii) $v^2 = u^2 + 2gh$

where h is the height from which the object falls, t is the time of fall, u is the initial velocity and v is the final velocity.
Examples - Fruit falling from the tree, a stone dropped from a hill, meteors falling towards earth.

Motion in a Plane

Motion in a plane means motion in a two-dimensional plane which includes x-axis and y-axis. If an object is in motion such that its position at any time can be given with reference axes (two mutually perpendicular lines passing through the origin).

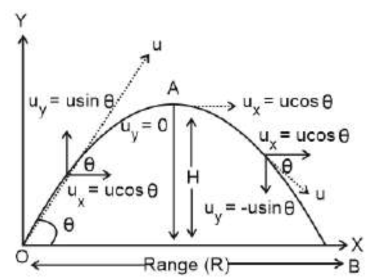
Examples - Projectile motion, circular motion.

Projectile Motion

Projectile motion is when the object is projected into air and gravity is the only force acting upon the object. It follows a curved path known as a projectile trajectory.

Examples - The motion of a bomb dropped from an aeroplane, a ball thrown in a horizontal direction, a ball after hitting the bat.

Projectile Motion Formula



The point O is called the point of projection; θ is the angle of projection.

Component of Velocity - The horizontal component of initial velocity, $u_x = u\cos\theta$, where θ is the angle by which an object is projected near the earth's surface called angle of projection and u is velocity of projection also called muzzle velocity. The vertical component of initial velocity $u_y = u\sin\theta$.

Time of Flight (T) - The total time for which the projectile is in motion.

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

Maximum Height (H_m) - The maximum value of vertical displacement of projectile during its course of motion.

Maximum Height (H_m) = $\frac{(usin\theta)^2}{2g}$

Range (R) - The horizontal displacement of a projectile during its motion.

Horizontal Range (R) = $\frac{u^2\ sin2\theta}{g}$

Maximum horizontal range (R_{max}) = $\frac{u^2}{g}$

(when sin2θ is maximum i.e., θ = 45°).

When range of projectile is maximum, then maximum height of projectile,

$H_{max} = \frac{u^2}{4g} = \frac{R_{max}}{4}$

Circular Motion

It refers to the movement of an object along a curved path, where the object maintains a constant distance from a fixed point. It is of two types - Uniform circular motion and Non-uniform circular motion.

Non - uniform circular motion - It is a circular motion when the speed of the body doesn't remain constant.

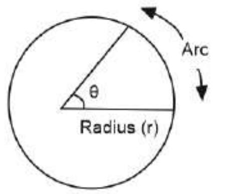
Examples - Spinning of Lattu or spinning top, roller coaster.

Uniform circular motion - When an object follows a circular path at a constant speed, the motion of the object is called uniform circular motion.

Examples - Motion of artificial satellites around the earth, Motion of electrons around the nucleus in an atom, Motion of blades of a windmill.

Terms Related to Uniform Circular Motion

Angular Displacement (θ) - In circular motion, angular displacement is defined as the change in the angle of a body with respect to its initial angular position. Its unit is radian.



Angular displacement = $\frac{Arc}{Radius}$

Angular velocity (ω) - It is the rate of change of angular displacement of an object in a circular motion.

Angular velocity = $\frac{Angular\ displacement}{Time}$ or ω = θ / t, where, ω = angular velocity, θ = position angle, and t = time. It is a vector quantity. Its unit is radian/second.

Angular Acceleration (α)- It is defined as the time rate of change of angular velocity (dω). It is usually expressed in radians per second squared. $\alpha = \frac{d\omega}{dt}$, where dω represents the change in angular velocity, and dt represents the change in time.

Centripetal Acceleration (a_c) - Acceleration acting on the particle undergoing a uniform circular motion towards the centre of the circle is called centripetal acceleration. It always acts on the particle along the radius whose value is given by,

Centripetal acceleration, $a_c = v^2/r = r\omega^2$

where, r is the radius of the circular path and v is the linear velocity of a particle and ω is angular velocity.

Time Period (T) - It is the time for an object to complete one full revolution or cycle in a uniform circular motion. Its SI unit is sec.

$T = \frac{2\pi}{\omega}$

Frequency (f) - The number of revolutions completed by the object on its circular path in a unit of time. Its SI unit is sec^{-1} or Hertz.

Relation between time period and frequency

Time period (T) = $\frac{1}{frequency\ (f)}$

Practice Questions :-

Q.1. _____ is a change of position.

SSC CGL 08/12/2022 (2nd Shift)
(a) Speed (b) Velocity (c) Motion (d) Distance

Q.2. ______ time graph shows speed of an object.
SSC CGL 06/12/2022 (4th Shift)
(a) Velocity (b) Distance
(c) Displacement (d) Acceleration

Q.3. The motion of ________ body is an example of uniformly accelerated motion
SSC CGL 01/12/2022 (4th Shift)
(a) resting (b) Decelerating
(c) parabolic (d) freely falling

Q.4. What is speed?
SSC MTS 15/07/2022 (Morning)
(a) It is the distance covered by an object in a unit time.
(b) It is the velocity of an object per unit time.
(c) It is the force applied on covering a unit distance.
(d) It is the acceleration of an object per unit time.

Q.5. The lifting of an object up and down, the parade of an army and the free fall of a heavy object are all examples of which motion?
SSC CHSL 01/06/2022 (Afternoon)
(a) Rectilinear motion (b) Periodic motion
(c) Rotational motion (d) Oscillatory motion

Q.6. Which of the following statement is NOT correct for an object moving along a straight path in accelerated motion ?
RRB JE 27/06/2019 (Evening)
(a) Its speed keeps changing
(b) It always goes away from the earth
(c) Its velocity always changes
(d) A force is always acting on it

Q.7. The velocity change of an object in every unit time is called ______.
RPF Constable 22/01/2019 (Afternoon)
(a) Angular Displacement (b) Acceleration
(c) Angular momentum (d) Displacement

Q.8. A high jumper runs for a while before taking a high jump so that the inertia of ______ helps him take the long jump.
RRB ALP Tier - I (31/08/2018) Afternoon
(a) motion (b) direction (c) rest (d) shape

Q.9. The rate of change of displacement is called:
RRB ALP Tier - I (29/08/2018) Afternoon
(a) Velocity (b) Speed (c) Distance (d) Acceleration

Q.10. An object, starting from rest, moves with constant acceleration of 4 m/s^2. After 8 s, its speed is:
RRB ALP Tier - I (21/08/2018) Evening
(a) 32 m/s (b) 4 m/s (c) 8 m/s (d) 16 m/s

Q.11. A particle experiences constant acceleration for 20 s after starting from rest. If it travels a distance X_1 in the first 10 s and distance X_2 in the remaining 10 s, then which of the following is true?
RRB ALP Tier - I (21/08/2018) Afternoon
(a) $X_2 = 2X_1$ (b) $X_1 = 3X_2$ (c) $X_2 = X_1$ (d) $X_2 = 3X_1$

Q.12. If a ball is thrown vertically upwards with a velocity of 40 m/s, then what will be the magnitude of its displacement after 6 s ?
(Take g = 10 m/s^2)
RRB ALP Tier - I (20/08/2018) Evening
(a) 60m (b) 80m (c) 40m (d) 20m

Q.13. In which of the following examples will an athlete have maximum accelerated motion ?
RRB ALP Tier - I (20/08/2018) Afternoon
(a) Running on an octagonal track
(b) Running on a rectangular track
(c) Running on a hexagonal track
(d) Running on a circular track

Q.14. Why does a sprinter keep running even after crossing the finishing line?
RRB ALP Tier - I (20/08/2018) Afternoon
(a) He wants to make sure that he crosses the line.
(b) Inertia of rest takes some time to make him stop.
(c) Inertia of motion keeps him moving.
(d) Friction between his shoes and the ground causes him to move beyond the line.

Q.15. A ball, thrown vertically upward, rises to a height of 80 m and returns to its original position. The magnitude of its displacement after 7 s of motion will be _____. (take g = 10 m/s^2)
RRB ALP Tier - I (20/08/2018) Morning
(a) 45 m (b) 125 m (c) 25 m (d) 35 m

Q.16. If the initial velocity of a car is 5 m/s, and the final velocity is 10 m/s in 5 s, then the acceleration is ________.
RRB ALP Tier - I (17/08/2018) Evening
(a) 1 m/s^2 (b) 0.1 m/s^2 (c) 10 m/s^2 (d) 5 m/s^2

Q.17. If the distance travelled by an object is zero, then the displacement of the object:
RRB ALP Tier - I (14/08/2018) Evening
(a) is positive (b) may or may not be zero
(c) is zero (d) is negative

Q.18. Which of the following changes when a body performs uniform circular motion?

RRB ALP Tier - I (14/08/2018) Afternoon
(a) Direction (b) Speed (c) Momentum (d) Mass

Q.19. A rocket is launched to travel vertically upward with a constant velocity of 20 m/s. After traveling for 35 seconds, the rocket develops a snag and its fuel supply is cut off. The rocket then travels like a free body. The height achieved by it is:
RRB ALP Tier - I (14/08/2018) Morning
(a) 800 m (b) 700 m (c) 720 m (d) 680 m

Q.20. The second equation of motion gives the relation between:
RRB ALP Tier - I (10/08/2018) Evening
(a) Position and Velocity (b) Position and time
(c) Velocity and acceleration (d) Velocity and time

Q.21. The first equation of motion gives the relation between:
RRB ALP Tier - I (10/08/2018) Afternoon
(a) velocity and acceleration (b) position and time
(c) velocity and time (d) position and velocity

Q.22. The tendency of undisturbed objects to stay at rest or to keep moving with the same velocity is called
RRB ALP Tier - I (10/08/2018) Morning
(a) momentum (b) force (c) energy (d) inertia

Q.23. If a body takes 't' seconds to go once round the circular path of radius 'r',
the velocity 'v' is given by:
RRB ALP Tier - I (09/08/2018) Evening
(a) $V = \frac{t}{2\pi r}$ (b) $V = \frac{\pi r}{2t}$ (c) $V = \frac{2\pi r}{t}$ (d) $V = \frac{2\pi r^2}{t}$

Q.24. Negative acceleration is in the opposite direction of:
RRB ALP Tier - I (09/08/2018) Morning
(a) velocity (b) force (c) momentum (d) distance

Q.25. Which of the following is a unit of acceleration?
(a) m/s^2 (b) ft/s (c) m/s (d) sqm/s

Answer Key :-

1.(c)	2.(b)	3.(d)	4.(a)
5.(a)	6.(b)	7.(b)	8.(a)
9.(a)	10.(a)	11.(d)	12.(a)
13.(d)	14.(c)	15.(d)	16.(a)
17.(c)	18.(a)	19.(c)	20.(b)
21.(c)	22.(d)	23.(c)	24.(a)
25.(a)			

Force and Laws of Motion

Force

It is a fundamental concept in physics that describes the push or pull applied to an object. It causes objects to accelerate, decelerate, or deform, depending on the nature of the force.

Examples - A force is used when we kick a football, we lift a box from the floor, we stretch a rubber band.

It is a vector quantity. Its SI unit is Newton (kg m/s^2), and its CGS unit is Dyne.
1 Newton = 10^5 dyne.

Fundamental or Basic Forces in Nature

Contact Forces

When two objects are in direct physical contact with each other. These forces arise due to the interaction between the surface of one object and the surface of another object.

Examples of contact forces are :-

Normal Force - They are the upward countervailing force exerted by a surface to support the weight of an object.

Examples - Earth upon us, human hand while holding an object, a nail on a hammer during hammering.

Tension Force - A force experienced by a rope, string, or cable when it is pulled from the opposite end. It doesn't have the pushing ability.

Examples - Plucking a guitar string, stretching the muscles, a swing in a playground.

Applied Force - The external force acting on a system of the body from outside the system.

Examples - The opening and shutting of a door, ball kicking, wet clothing squeezing, cycle pedaling.

Non - Contact Forces

A non-contact force is a force applied to an object by another body that is not in direct contact with it.

Examples of Non-contact forces are :-

Gravitational Force - The force that is present due to the attraction between the two objects.

Electromagnetic Force - It is due to the electric or magnetic affinity of the molecules that generates this force and results in binding of atoms and solids.

Nuclear Force - It is a force that acts between the protons and neutrons of atoms. It can divide based on strength as-

Weak Nuclear Force - The force is present between radioactive decay molecules and is generated during their decay. They are 10^{25} times stronger than gravitational forces.

Strong Nuclear Force - The forces that bind the neutrons and protons together in a nucleus. These forces act between two protons or two neutrons or a proton and a neutron, but only if the particles are very close together. These are 10^{38} times stronger than gravitational forces, 10^{2} times stronger than electrostatic forces and 10^{13} times stronger than the weak forces.

Types of Force

Balanced Force - Forces acting on an object which does not change the state of rest or of uniform motion.

Examples - Aircraft in a steady flight, objects floating in water, fruit hanging from a tree, a person standing still.

Unbalanced Force - A net force acting on an object that is not cancelled out by opposing forces, resulting in acceleration or a change in motion.

Examples - A fruit dropping from a tree, an object sinking in water, turning a cartwheel, a football sailing toward the goal after it was kicked.

Inertia

The tendency of a body to oppose any change in its state of rest or of uniform motion is called inertia. It is related to an object's mass, where objects with more mass have greater inertia.

There are three types of Inertia :-

Inertia of Rest - It is defined as the property of a body to resist any change in its state of rest.

Examples - Falling down of dust particles while dusting a cloth, falling down backwards when a vehicle starts immediately, a book lying on the table will remain at rest until it is moved by some external force .

Inertia of Motion - It is defined as the property of a body to resist any change to its state of uniform motion.

Examples - When the bus is in motion and if the brake is applied suddenly, passengers move forward.

Inertia of Direction - It is defined as a body's ability to resist changes in its motion direction.

Examples - when a bus moving along a straight line takes a right turn, then the passengers bend towards the left side.

Newton's Laws of Motion

In 1687, Sir Isaac Newton presented his three laws of motion in "Principia Mathematica Philosophiae Naturalis".

Newton's laws of motion are fundamental principles that describe the behavior of objects in motion.

There are three Laws of motion.

Newton's First Law of Motion

Every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force.This law is also known as the law of inertia.

Examples - When we shake a tree vigorously, its fruits and leaves fall down. This happens because the fruits and leaves were at rest initially and as the tree is shaken vigorously, the tree moves to and fro but the force is not acting on leaves and fruits, and they try to maintain their states of rest due to inertia and hence fall.

Newton's Second Law of Motion

The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts.

Example - If two stones (one light and the other heavy) are dropped from the top of a building, a person on the ground will find it easier to catch the light stone than the heavy stone. The mass of a body is thus an important parameter that determines the effect of force on its motion.

According to Newton's Second Law of motion :-

Force (F) ∝ Rate of change of momentum

$F \propto \frac{dP}{dt}$

$F = k\frac{dP}{dt}$, where k is proportionality constant.

For a body of fixed mass m,

$\frac{dP}{dt} = \frac{d\,(mv)}{dt} = m\frac{dv}{dt} = ma$

So, Second Law can also be written as
F = k m a

F = ma (For simplicity, k is chosen as 1)

If acceleration a = 0, then

F = 0 (mass of the body can never be zero).

It means that in the absence of external force the body either moves with constant velocity or comes to rest.

By Newton's second law F = ma, here if m = 1 kg and a = 1 m/s^2, then F = 1 N. Thus, 1 N is the force required to produce an acceleration of 1 m/s^2 in a body of mass 1 kg.

Example - Calculate the force needed to speed up a car with a rate of $5ms^{-2}$, if the mass of the car is 1000 kg.

Solution - Given, mass = 1000 kg, acceleration = 5 m/s^2.
As we know,
Force = mass × acceleration
Force = 1000 × 5 = 5000 N.

Newton's Third Law of Motion

For every action, there is an equal and opposite reaction and both acts on two different bodies. So, this law is also known as the law of action and reaction.

Examples - Releasing a balloon full of air has an equal and opposite reaction, the swimmer pushes the water backwards and the water exerts a force on the swimmer in the forward direction.

Momentum

It is defined as the product of an object's mass and its velocity. It is a vector quantity. Its SI unit is kilogram-metre per second (kg·m/s or $kg{\cdot}ms^{-1}$) and the dimensional formula is $[M^1L^1T^{-1}]$. If a body of mass (m) moves with a velocity (v), then momentum (p) is given by p = mv.

Example - A heavy truck traveling on the highway has more momentum than a smaller car traveling at the same speed because it has a greater mass.

Law of Conservation of Momentum - It states that the total momentum of an isolated system remains constant if no external forces are acting on it. This means that the combined momentum of all objects before a collision is equal to the combined momentum after the collision.

Example - Gun and bullet mechanism, inflated Balloon, collision of two objects, Rocket propulsion.

Example - What will be the momentum of stone having mass 10 kg when it is thrown with a velocity of 2 m/s ?

Solution - Given, velocity = 2 m/s and mass = 10 kg.
As we know that,
Momentum = mass × velocity
Momentum = 10 × 2 = 20 kg m/s.

Equation of Conservation of Momentum

Two objects of masses m_1 and m_2 collide with each other when they move along a straight line with velocities u_1 and u_2 respectively. After the collision, they acquire velocities v_1 and v_2 in the same direction.

Total momentum before collision, initial momentum $(P_i) = m_1u_1 + m_2u_2$

Total momentum after collision, final momentum $(P_f) = m_1v_1 + m_2v_2$.

If no other force acts on the system, the total momentum remains conserved.

Therefore, $P_i = P_f \Rightarrow m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

Impulse

When a force acts on an object for a short duration of time, it's called impulse.

Examples - Catching a fast-flying baseball, a boxer delivers a powerful punch.

It is calculated as the product of the force exerted on the object and the duration of time over which the force is applied.

Impulse = change in momentum
= Force x Time.

It is a vector quantity. Its SI unit is Newton-sec or kg-meter/sec and the dimensional formula is $[M^1L^1T^{-1}]$.

Frame of Reference

It is a coordinate system used to describe the position and motion of objects. It provides a fixed point for making measurements and analyzing physical phenomena.

There are two types of frames of reference :-

Inertial Frame of Reference - It is a frame in which Newton's laws of motion work. A frame of reference that moves with constant velocity with respect to an inertial frame is also an inertial frame.

Example - a car at a standstill or a bus moving at constant speed are considered to be inertial frames of reference.

Non-inertial frame of reference - It is accelerating or rotating relative to an inertial frame. In such frames, apparent or fictitious forces may be present. For a non-inertial frame of reference, Newton's laws of motion doesn't hold true.

Example - A car stationary at the traffic light. The car moves forward rapidly when the traffic light turns green. During this acceleration, the car is in a non-inertial frame of reference.

Apparent Weight of a Person in Lift

If a person of mass (m) is in a lift, then the actual weight of the person is mg, which acts on the lift floor in downward direction, due to which the floor offers the reaction (R). This reaction is called the apparent weight of the person.

Relation between R and mg in different situation -

At rest or constant velocity - When the lift or elevator is at rest then the apparent weight of the person is equal to the actual weight of the person.

When the lift is moving uniformly in upward/downward direction - In uniform motion, the apparent weight of the person is equal to the actual weight of the person.

When the lift is accelerating upwards - If lift is accelerating upwards, then the apparent weight of the person is more than the actual weight of the person.

When the lift is accelerating downwards - If the lift is accelerating downwards, then the apparent weight of the person is less than the actual weight of the person.

When the lift is falling freely - In this case, the apparent weight of the person becomes zero i.e., the person feels the condition of weightlessness.

Friction

Friction is a force that opposes the motion of objects that are in contact with each other. It arises due to the interaction between the surfaces of the objects and can hinder or slow down their movement. It can be both beneficial, such as providing grip and control, and detrimental, such as causing wear and heat generation.

Types of Friction

Static Friction (f_s)

The force that prevents the relative motion between two surfaces in contact when at least one of the surfaces is at rest.

Example - pushing a heavy Box, a towel hanging on a rack

$f_s = \mu_s N$ where, f_s = Static Friction Force, μ_s = Static Friction Coefficient, N = normal force (contact force).

Limiting Friction (f_l)

It is the maximum force of static friction that occurs just before a body starts to slide over the surface of another body.

Limiting friction (f_l) = $\mu_l N$
where, μ_l = coefficient of limiting friction and N = normal reaction force.

Kinetic Friction (f_k)

It opposes the motion between two surfaces in contact. It is present when there is relative motion or sliding between the surfaces.

Examples - Sliding a book on a table, writing with a pen, rubbing hands, pressing clothes with an iron, etc.

$f_k = \mu_k N$. where, f_k = kinetic friction Force, μ_k = kinetic friction coefficient (μ_k is less than μ_s), and N = normal force .

Types of Kinetic Friction :-

Rolling Friction - It is the frictional force that occurs when one object rolls on another, like a car's wheels on the ground.

Sliding Friction - The frictional force that opposes the relative motion between the surfaces when one body slides over the other body.

Methods of Reducing Friction

Use of Lubricants - Substances that can reduce the amount of friction and wear and tear of various objects.

Examples - Motor oil, gel, silicone, oil, grease, wax etc.

Polishing - Polishing a surface can make rough surfaces smooth and reduce friction.

Applying Oil - Oil is applied to the hinges of the door to reduce friction and create a smooth movement of the door.

Applying Powder - The powder is sprinkled over a carrom board to decrease the friction between the board surface and the striker.

Centripetal Force

A force that acts on a body moving in a circular path and is directed towards the centre around which the body is moving is called centripetal force.

Examples - Loop of roller coaster, orbiting planets, driving on curves, revolution of electrons around the nucleus, the motion of the moon around the earth.

Centripetal force = Mass × Centripetal acceleration

Centripetal force (F_c) = $\frac{mv^2}{r}$ where m is mass, v is linear velocity and r is the radius of the path.

Centrifugal Force

Centrifugal Force is a pseudo force in a uniform circular motion that acts along the radius and is directed away from the centre of the circle.

Examples - a bike making a turn, Merry - Go - Round, swinging fair ride, Cream Separator.

Practice Questions :-

Q.1. Select the option that is true regarding the following two statements labelled Assertion (A) and Reason (R).
(A): An object slips less on a rough surface than a smooth surface.
(R): When a surface is rough, frictional force increases.
SSC CGL 20/07/2023 (1st shift)
(a) Assertion (A) is true and Reason (R) is false.
(b) Both Assertion (A) and Reason (R) are true but Reason (R) is not a correct explanation of Assertion (A).
(c) Assertion (A) is false and Reason (R) is true.
(d) Both Assertion (A) and Reason (R) are true and Reason (R) is a correct explanation of Assertion (A).

Q.2. What is another name for center - seeking

force?
Selection post 30/06/2023 (Shift - 4)
(a) Van der Waals (b) Centrifugal
(c) Gravitational (d) Centripetal

Q.3. Which type of friction is considered as a self - adjusting force?
SSC MTS 15/05/2023 (Morning)
(a) Kinetic Friction (b) Centripetal Friction
(c) Rolling Friction (d) Static Friction

Q.4. Which of the following is the correct order of friction ?
SSC CHSL 20/03/2023 (2nd Shift)
(a) Static > Rolling > Sliding
(b) Rolling > Static > Sliding
(c) Static > Sliding > Rolling
(d) Sliding > Static > Rolling

Q.5. Which of the following is NOT a non - contact force?
SSC CHSL 15/03/2023 (4th Shift)
(a) Gravitational (b) Electrostatic
(c) Friction (d) Magnetic

Q.6. Which of the following is NOT an application of the third law of motion?
SSC CHSL 15/03/2023 (1st Shift)
(a) A fielder pulls his hands gradually with the moving ball while holding a catch.
(b) Colliding with a player while kicking a football and feeling hurt.
(c) As the sailor jumps in the forward direction, the boat moves backward .
(d) A forward force on the bullet and recoil of the gun.

Q.7. Identify the correct statement about inertia.
SSC CGL 01/12/2022 (3rd Shift)
(a) Greater the mass, greater the inertia
(b) Lesser the weight, greater the inertia
(c) Lesser the mass, greater the inertia
(d) Greater the mass, lesser inertia

Q.8. 'Impulse' can be defined as:
SSC CPO 11/11/2022 (Evening)
(a) the force acting on a body for a very long time
(b) the work done by a body for a short time
(c) the force acting on a body for a short time
(d) the temperature acting on a body for a short time

Q.9. Which of the following statements is correct?
I. Rolling friction is greater than the sliding friction.
II. The frictional force exerted by fluids is called drag.
SSC MTS 22/07/2022 (Morning)
(a) Only I is correct
(b) Neither I nor II is correct
(c) Both I and II are correct
(d) Only II is correct

Q.10. The range of _____ force is of the order of 10^{-16} m.
SSC CGL 13/04/2022 (Morning)
(a) electromagnetic (b) gravitational
(c) strong nuclear (d) weak nuclear

Q.11. Which of the following has the same dimension as that of linear momentum ?
SSC CGL 13/08/2021 (Morning)
(a) Impulse (b) Stress (c) Work (d) Energy

Q.12. A constant force acts on an object of mass 10 kg for a duration of 2 seconds. It increases the object's velocity from 5 meters/second to 10 meters/second. Find the magnitude of the applied force. Now, if the force is applied for a duration of 5 seconds what would be the final velocity of the object?
RRB NTPC CBT - I (12/03/2021) Morning
(a) Applied force = 20 N, Final Velocity = 7.5 meters/second
(b) Applied Force = 25 N, Final Velocity = 7.5 meters/second
(c) Applied Force = 20 N, Final Velocity = 17.5 meters/second
(d) Applied Force = 25 N, Final Velocity = 17.5 meters/second

Q.13. A spring balance is a device commonly used for measuring the ____ acting on an object.
RRB NTPC CBT - I (05/03/2021) Evening
(a) force (b) momentum (c) velocity (d) mass

Q.14. Rockets work on the principle of conservation of:
RRB NTPC CBT - I (31/01/2021) Morning
(a) velocity (b) mass (c) momentum (d) energy

Q.15. What is the other name of Newton's first law of motion?
RRB NTPC CBT - I (04/01/2021) Evening
(a) Law of inertia (b) Law of movement
(c) Law of momentum (d) Law of displacement

Q.16. Which machine part is used to reduce friction between hubs and axles of ceiling fans and in bicycles?

RRB JE 01/06/2019 (Morning)
(a) Ball bearings (b) Springs (c) Nuts (d) Bolts

Q.17. The frictional force on an object in a fluid depends on what?
RRB JE 31/05/2019 (Morning)
(a) Nature of the fluid
(b) All of the options
(c) Shape of the object
(d) Its speed with respect to the fluid

Q.18. Compare rolling friction and sliding friction.
RRB JE 25/05/2019 (Afternoon)
(a) Rolling friction is always equal to sliding friction
(b) Rolling friction is either greater or equal to friction sliding friction
(c) Rolling friction is smaller than the sliding friction
(d) Rolling friction is greater than sliding friction

Q.19. What will be the acceleration produced when a force of 21 N is applied on an object of mass 3 kg?
RRB ALP Tier - I (21/08/2018) Morning
(a) $0.7ms^{-2}$ (b) $7ms^{-2}$ (c) $0.007ms^{-2}$ (d) $70ms^{-2}$

Q.20. A force of 20 N displaces an object through 2 m and does a work of 20 J. The angle between the force and displacement is :
RRB ALP Tier - I (20/08/2018) Afternoon
(a) 60° (b) 30° (c) 90° (d) 0°

Q.21. The characteristic of _______ is used in the breaking pads of cars.
RRB ALP Tier - I (14/08/2018) Evening
(a) positive effect of friction
(b) zero effect of friction
(c) weight impulse force tension action
(d) negative effect of friction

Q.22. Which of the following never occurs singly in nature?
RRB ALP Tier - I (09/08/2018) Afternoon
(a) Inertia (b) Force (c) Velocity (d) Momentum

Q.23. What is the formula for momentum (p) of an object in motion?
(a) $p = mv^2$ (b) $p = m/v$ (c) $p = m + v$ (d) $p = mv$

Q.24. In a uniform circular motion, what is the name of the pseudo force that acts along the radius and is directed away from the center of the circle?
(a) Centripetal force (b) Gravitational force
(c) Centrifugal force (d) Frictional force

Q.25. Which force prevents relative motion between two surfaces when at least one surface is at rest?
(a) Tension force (b) Gravitational force
(c) Normal force (d) Static frictional force

Answer Key :-

1.(d)	2.(d)	3.(d)	4.(c)
5.(c)	6.(a)	7.(a)	8.(c)
9.(d)	10.(d)	11.(a)	12.(d)
13.(a)	14.(c)	15.(a)	16.(a)
17.(b)	18.(c)	19.(b)	20.(a)
21.(a)	22.(b)	23.(d)	24.(c)
25.(d)			

Gravitation

Gravitational Force

Every object in the universe attracts every other object with a force which is called the force of Gravitation. In other words, the force with which the earth pulls the bodies towards it, is called the gravitational force of earth or gravity of the earth. It is also defined as the non-contact force of attraction between any two bodies in the universe.

Examples - Falling of leaves and fruits from a tree downwards towards the ground, downstream flow of river water, the return of a ball thrown up to the earth after reaching a certain height.

Characteristics of Gravitational Force

(a) Gravitational force is a conservative force. It is the weakest force in nature.

(b) The law of gravitation is applicable for all bodies, irrespective of their size, shape and position.

(c) Gravitational force is an action at a distance; It does not need any contact between the two bodies.

(d) Gravitational force is 10^{36} times smaller than electrostatic force and 10^{38} times smaller than strong nuclear force.

(e) It acts along the line joining the center of the two objects. Therefore, it is called the central force.

(f) The gravitational force is directly proportional to the product of the masses of the two bodies. This means a larger mass will yield a larger force.

Universal Law of Gravitation

This law was given by Newton and it is also called Newton's Law of Gravitation. The Law states that every body in the universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

Consider two bodies A and B having masses m_1 and m_2, whose centres are at a distance r from each other. Then Gravitational force is given by

$$F \propto \frac{m_1 \times m_2}{r^2} \Rightarrow F = \frac{G\, m_1 \times m_2}{r^2}$$

where, G is a universal gravitational constant. Its value is same everywhere on the earth or in the universe. The value of G is 6.67×10^{-11} $Nm^2\,kg^{-2}$ and the dimensional formula of G is $[M^{-1}L^3T^{-2}]$. In SI units m is measured in kilogram, F in newton, r in meter.

Example - Calculate the gravitational force of attraction between two metal spheres each of mass 90 kg, if the distance between their centres is 40 cm. Given G = 6.67×10^{-11} N m^2/kg^2. Will the force of attraction be different if the same bodies are taken on the moon, their separation remaining the same?

Solution - Given, Mass of first body (m_1) = 90 kg,
mass of second body (m_2)= 90 kg,
Distance between masses (r) = 40 cm = 40×10^{-2} m,
G = 6.67×10^{-11} N m^2/kg^2.
As we know,

$$F = \frac{G\, m_1 \times m_2}{r^2} = \frac{6.67 \times 10^{-11} \times 90 \times 90}{0.4 \times 0.4}$$

= 3.377×10^{-6} N.

Force of attraction will remain the same for the two bodies whether they are on the earth or on the moon because the force of attraction between two bodies is proportional to the product of the individual masses of the two bodies and inversely proportional to the square of the distance between them.

Universal law of gravitation successfully explained several phenomena like
(i) the force that binds us to the earth.
(ii) the motion of the moon around the earth.
(iii) presence of atmosphere around a planet.

Gravity

Gravity is the force by which a planet or other body draws objects toward its center. The force of gravity keeps all of the planets in orbit around the sun. The gravitational force due to earth is also known as gravity.

Acceleration Due to Gravity (g)

The uniform acceleration produced in a freely falling

object due to the gravitational pull of the earth is known as acceleration due to gravity.
Its unit is m/s^2. It is a vector quantity and its direction is towards the centre of the earth. The value of g is independent of the mass of the object which is falling freely under gravity.

Relation between g and G -

$$g = \frac{GM}{R^2}$$

Where, M = mass of the earth = 6.0×10^{24} kg and R = radius of the earth = 6.37×10^6 m. On the surface of the earth, the value of g is taken as 9.8 ms^{-2}.

Factors Affecting Acceleration Due to Gravity

Variation of g with Altitude and Depth

Variation of g with altitude : As one goes above the surface of Earth, the value of acceleration due to gravity gradually goes on decreasing. If g_h be the value of acceleration due to gravity at a height h from the surface of Earth,

then, $$g_h = \frac{g}{(1+\frac{h}{R})^2}$$

If h<<R then $g_h = g\,(1 - \frac{2h}{R})$. Here R is the radius of earth and h is the height of the body above the surface of earth.

The value of acceleration due to gravity decreases with the increase in height.

Variation of g with depth : The value of acceleration due to gravity decreases with the increase in depth.

$$g_d = g\,(1 - \frac{d}{R})$$

Here g_d be the value of acceleration due to gravity at the depth d.

Variation of g with Latitude

If ω is the angular velocity of rotation of earth about its own axis, then acceleration due to gravity at a place having latitude λ is given by $g' = g - R\omega^2 \cos^2\lambda$.

At poles, λ = 90° and g' = g,
Therefore, there is no effect of rotation of earth about its own axis at poles.

At equator, λ = 0° and $g' = g - R\omega^2$. Therefore, the value of g is minimum at the equator.

If earth stops its rotation about its own axis, then g will remain unchanged at poles.

At the centre of the earth, the value of acceleration due to gravity becomes zero.

Earth is flattened at the poles. Thus, the radius of earth is less at the poles than at the equator. Hence, the value of g is less at equator than at poles.

Gravitational Potential

Gravitational potential (V) : The gravitational potential is the work done per unit mass by some externally applied force to bring a mass from zero potential to infinity. It is a scalar quantity. The SI unit of gravitational potential is J kg^{-1} and the dimensional formula is $[L^2T^{-2}]$.

Gravitational potential (V) = $\frac{-GM}{r}$

Gravitational Potential Energy (U)

Gravitational potential energy of any object at any point in gravitational field is equal to the work done in bringing it from infinity to that point. The SI unit is Joule and its dimensional formula is $[ML^2T^{-2}]$.

Gravitational potential energy associated with two particles of masses m_1 and m_2 separated by a distance r is given by

$$U = \frac{-G\,m_1\,m_2}{r} + k$$

(k = constant of integration)

The gravitational potential energy is zero when r approaches infinity. So the constant is zero and

$$U = \frac{-G\,m_1\,m_2}{r}$$

Satellite

A heavenly object which revolves around a planet is called a satellite. Natural satellites are those heavenly objects which are not man made and revolve around the earth. Artificial satellites are those heavenly objects which are man made and launched for some purposes revolve around the earth.

Type of Satellites

Artificial satellites are of two types :-

Geostationary Satellite - A satellite which appears to be at a fixed position at a definite height to an observer on earth. The height of the satellite above the surface of the earth is 35800 km and radius of orbit is approximately 42400 km. Its time period of rotation is 24 h.

Examples - INSAT - 3D and GSAT - 7.

Polar Satellites - These are those satellites which revolve in polar orbits around earth. A polar orbit is that orbit whose angle of inclination with the equatorial plane of earth is 90°. The height of the satellite above the surface of the earth is ≈ 500 to 800 km. Its period of rotation is around 100 minutes. These satellites are used in forecasting weather, studying the upper region of the atmosphere, in mapping, etc. PSLV series satellites are polar satellites of India.

Time Period of Satellite

Time period of a satellite is the time taken by the satellite to complete one revolution around the earth. It can be calculated by the formula

$$T = 2\pi\sqrt{\frac{R}{g}}$$

where g - acceleration due to gravity and R - radius of earth. If we substitute the numerical values g = 9.8 m s^{-2} and R = 6400 km, we get T = 85 minutes (approx).

Energy of an Orbiting Satellite

If h is the height of the satellite above the Earth's surface and R is the radius of the Earth, then the radius of the orbit of the satellite is r = R + h.

Total energy of a satellite E = Kinetic Energy + Potential Energy.

Since, Kinetic energy, $K = \frac{1}{2} mv^2$

$= \frac{1}{2}\left(\frac{GMm}{r}\right) = \frac{1}{2}\left(\frac{GMm}{R+h}\right)$ and

Potential energy, $U = -\frac{GMm}{r} = -\frac{GMm}{R+h}$

Thus,

Total energy of a satellite,

$E = \frac{1}{2}\left(\frac{GMm}{R+h}\right) + \left(-\frac{GMm}{R+h}\right) = -\frac{1}{2}\left(\frac{GMm}{R+h}\right).$

Binding Energy

The energy required to remove a satellite from its orbit around the earth (planet) to infinity is called binding energy of the satellite. Binding energy of the satellite of mass, m is given by $BE = -\frac{1}{2}\left(\frac{GMm}{r}\right).$

(negative sign refers to the attractive nature of the force between Earth and the satellite)

Escape Velocity

Escape velocity on earth is the minimum velocity with which a body has to be projected vertically upwards from the earth's surface so that it just crosses the earth's gravitational field and never returns. The escape speed (V_e) from the surface of the earth is given by

$V_e = \sqrt{2gR_E} = \sqrt{2\times 9.81 \times 6400 \times 10^3}$

= 11.2 km/sec.

Where, g = 9.81 ms^{-2}, Radius of Earth is 6400 Km.

So, the value of escape velocity is 11.2 km/sec.

Orbital Velocity

Orbital velocity of a satellite is the maximum velocity required to put the satellite into a given orbit around the earth. It is denoted by V_0.

The formula for the orbital velocity is given by,

$$V_o = \sqrt{\frac{GM_e}{R_e+h}}$$

Where, G = gravitational constant with the value 6.673×10^{-11} $N{\cdot}m^2/kg^2$, R_e = radius of the earth, M_e is the weight of the earth and h = height of the satellite from the earth's surface.

If the satellite is revolving near the earth's surface then h can be neglected in comparison to R_e i.e,

$$R_e + h = R_e$$

then, Orbital velocity $V_o = \sqrt{gR_e}$

$= \sqrt{9.8\ m/sec^2 \times 6.4 \times 10^6 metre}$

= 7.92 × 10^3 m/sec = 7.92 km/sec ≈ 8 km/sec.

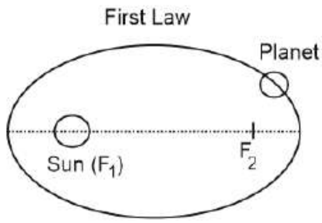
Relation Between Escape Velocity And Orbital Velocity : $V_{escape} = \sqrt{2}\ V_{orbital}$.

The escape velocity is approximately 1.414 times the orbital velocity. This relationship holds true for a circular orbit around a celestial body.

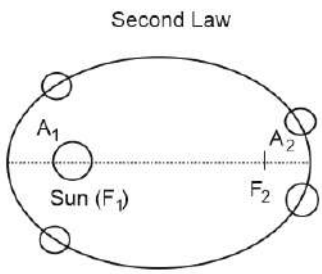
Kepler's Laws of Planetary Motion

Kepler's laws of planetary motion are three fundamental principles that describe the motion of planets around the Sun. They were formulated by the German astronomer Johannes Kepler in the early 17th century based on observations made by the Danish astronomer Tycho Brahe.

First Law (Law of Ellipses) : Every planet orbits the Sun in elliptical paths, with the Sun located at one of the two foci (f) of the ellipse.

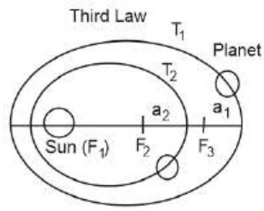


Second Law (Law of Equal Areas) : A line connecting a planet to the Sun sweeps out equal areas (A) in equal time (T) intervals, meaning planets move faster when closer to the Sun and slower when farther away.



Third Law (Law of Periods) : The square of the time period (T) of revolution of a planet is proportional to the cube of the semi-major axis (a) of the ellipse traced out by the planet.

$T^2 \propto a^3 \Rightarrow T^2 = Ka^3$. where K is Kepler's constant.



Mass (m)

Mass of a body is a measure of inertia of the body and hence it is also known as inertial mass. The mass of a body cannot be zero. Mass is a scalar quantity. The SI unit of mass is kilogram.

Weight (W)

The weight of an object is the force with which it is attracted towards the earth. It is a vector quantity. The SI unit of weight is Newton (N).

Weight of a Body at the Moon

The mass and radius of the moon are less than that of the earth, so the force of the gravity at the moon is also less than that of the earth.The weight of an object on the moon will be about one - sixth of what it is on earth.

Weightlessness

It is a situation, in which the effective weight of the body becomes zero. Weightlessness is achieved -
(i) during freely falling under gravity
(ii) inside a spacecraft or satellite
(iii) at the centre of the earth

Practice Questions :-

Q.1. When did Henry Cavendish report the measurement of the gravitational constant with the mass and density of the Earth ?
SSC CGL 19/07/2023 (1st shift)
(a) March 1795 (b) June 1798
(c) April 1796 (d) May 1797

Q.2. According to the Henry Cavendish experiment conducted in 1797-1798, what was the value of the universal constant of gravity?
SSC CHSL 01/06/2022 (Afternoon)
(a) $7.75 \times 10^{-13}\ N\ m^2/\ Kg^2$ (b) $5.75 \times 10^{-10}\ N\ m^2/\ Kg^2$

(c) 6.75 × 10^{-11} $N\ m^2/\ Kg^2$ (d) 3.75 × 10^{-9} $N\ m^2/\ Kg^2$

Q.3. Which law explains about the tides due to the moon and the sun?
SSC MTS 20/10/2021 (Evening)
(a) Law of gravitation (b) Law of reflection
(c) Law of inertia (d) Law of refraction

Q.4. Who among the following is credited with postulating three laws of planetary motion ?
SSC CGL 16/08/2021 (Morning)
(a) Isaac Newton (b) Tycho Brahe
(c) Johannes Kepler (d) Galileo Galilei

Q.5. Among the following, the weakest force is :
RRB NTPC CBT - I (27/03/2021) Morning
(a) Electric force (b) Gravitational force
(c) Buoyant force (d) Nuclear force

Q.6. The value of 'g' is maximum at:
RRB NTPC CBT - I (07/03/2021) Evening
(a) Tropic of cancer (b) Equator
(c) Tropic of capricorn (d) poles

Q.7. The value of 'g' (gravity) varies from the value of 'R' (radius). A student would observe minimum 'g' at the____.
RRB NTPC CBT - I (02/03/2021) Morning
(a) Equator (b) Tropic of Cancer
(c) Tropic of Capricorn (d) Poles

Q.8. If the mass of a person is 60 kg on the surface of earth then the same person's mass on the surface of the moon will be:
RRB NTPC CBT - I (28/12/2020) Morning
(a) 0 kg (b) 360 kg (c) 60 kg (d) 10 kg

Q.9. Which instrument was used to detect gravitational waves for the very first time?
SSC CHSL 17/03/2020 (Evening)
(a) WIGO (b) LIGO (c) TRIGO (d) GIGO

Q.10. What happens to the force of gravitation between two objects when the mass of one object is doubled?
RRB JE 25/05/2019 (Morning)
(a) The force of gravitation is tripled
(b) The force of gravitation is halved
(c) The force of gravitation is four times
(d) The force of gravitation is doubled

Q.11. Which of the following statements is/are INCORRECT ?
A. The value of G on the moon is equal to that on the earth.
B. 26.68 × 10^{-11} N is the force of gravitation between two point masses of 2 kg and 2 kg kept 1 m apart.
C. Newton's law of gravitation is valid in the laboratory only.
D. Force is inversely proportional to the square of the distance between two bodies.
RRB ALP Tier - I (31/08/2018) Evening
(a) Only C (b) C and D only
(c) B, C and D (d) Only A

Q.12. A body has a weight W on the surface of Earth. What is its weight on a planet whose mass is 15 times that of Earth and a radius that is 4 times that of the earth?
RRB ALP Tier - I (31/08/2018) Afternoon
(a) $\frac{15}{16}$W (b) $\frac{15}{4}$W (c) $\frac{16}{9}$W (d) $\frac{16}{7}$W

Q.13. Calculate the work done by the force of gravity when a satellite moves in an orbit of radius 40,000 km around the earth.
RRB ALP Tier - I (31/08/2018) Morning
(a) 8,000 J (b) 4,00,000 J (c) 4,000 J (d) 0 J

Q.14. Which of the following statements is/are correct?
A. The ratio of the force of gravitation between two masses, m_1 and m_2, kept at a distance R on the earth and on the moon is 1 : 1.
B. Nm^2/kg^2 is the SI unit of G (Universal Gravitational Constant).
C. The value of G depends on the distance between the bodies.
D. The value of G depends on the masses of the bodies.
RRB ALP Tier - I (30/08/2018) Afternoon
(a) Only B (b) D, B and C (c) None (d) B and C

Q.15. Consider a planet whose mass and radius are both twice the mass and radius of Earth. The acceleration due to gravity on the surface of the planet is n times that on Earth. The value of n is:
RRB ALP Tier - I (21/08/2018) Evening
(a) 2 (b) 4 (c) 1 (d) $\frac{1}{2}$

Q.16. Consider a hypothetical planet whose mass and radius are both half that of Earth. If g is the acceleration due to gravity on the surface of Earth, the acceleration due to gravity on the planet will be:
RRB ALP Tier - I (20/08/2018) Morning

(a) 2 g (b) $\frac{g}{4}$ (c) g (d) $\frac{g}{2}$

Q.17. The acceleration due to gravity at the surface of the earth (mass M and radius R) is proportional to ___.
RRB ALP Tier - I (17/08/2018) Evening
(a) $\frac{M}{R}$ (b) $\frac{M}{R^2}$ (c) $\frac{M^2}{R}$ (d) MR

Q.18. Consider a hypothetical planet with a mass equal to half that of Earth and radius is one- third that of Earth. If g is the acceleration due to gravity on Earth, the acceleration due to gravity on the planet will be:
RRB ALP Tier - I (17/08/2018) Afternoon
(a) $\frac{5}{2}$ g (b) $\frac{9}{2}$ g (c) $\frac{1}{2}$ g (d) $\frac{3}{2}$ g

Q.19. What will be the force of attraction between two bodies weighing 20 kg and 50 kg, respectively, with a distance of 2 metre between them?
RRB ALP Tier - I (17/08/2018) Morning
(a) 16.67×5^{-10} N (b) 6.67×10^{-11} N
(c) 16.675×10^{-11}N (d) 166.75×10^{-10} N

Answer Key :-

1.(b)	2.(c)	3.(a)	4.(c)
5.(b)	6.(d)	7.(a)	8.(c)
9.(b)	10.(d)	11.(a)	12.(a)
13.(d)	14.(a)	15.(d)	16.(a)
17.(b)	18.(b)	19.(d)	

Work, Energy and Power

Work

Work is defined as the transfer of energy that occurs when a force is applied to an object, and the object is displaced in the direction of the force.

For example - Moving a table, Pushing and pulling a door, Lifting a rock, A batsman hitting a ball, A boat sailing in the river, A cyclist paddling the cycle, etc.

W = F · s
where, W = work done,
F = force applied,
s = displacement or distance with direction.

The SI unit of work is newton-metre (N-m) or joule and the CGS unit is erg. It is a scalar quantity and Dimensional Formula $[M^1L^2T^{-2}]$.
1 joule = 10^7 erg.

Mathematical Form to Define Work

Work done on a body is defined as the product of the force's magnitude and the distance the body moves in the applied force's direction.

W = (F cos**θ**)s.
where, W = work done,
F = force applied,
s = displacement or distance with direction, and
θ = angle between the force and displacement.
The value of work will be maximum at θ = 0° and minimum at θ = 90°**.**

Example **-** A box is pulled with a force of 25 N to produce a displacement of 15 m. If the angle between the force and displacement is 30°, find the work done by the force.

Solution **-** Given, Force (F) = 25 N, Displacement (s) = 15 m,
Angle between F and s, θ = 30°.
As we know,
Work done = F × s × Cos θ
According to question,
Work done = 25 × 15 × Cos 30°
$= 25 \times 15 \times \frac{\sqrt{3}}{2} = 324.75$ J.

Conditions When No Work is Done - As work depends on three factors, that is, force applied on the object, displacement travelled by the body under the force, and an angle between force and displacement.

Case 1- When displacement becomes zero.

Example - A weightlifter holding a 150 kg mass steadily on his shoulder for 30 sec does 'no work' on the load during this time.

Case 2- When the force applied becomes zero.

Example - A ball rolling on a slippery surface is not acted upon by the horizontal force, as there is no friction, but there may be a large displacement.

Case 3 - When the value of cos**θ** becomes zero or angle (**θ**) = 90°.

Example - When a block is rolled down on a smooth surface, the gravitational force there does not work. It is because the force is perpendicular to displacement in this case.

Types of Work

Positive Work - If the applied force displaces the object in its direction, then the work done is known as positive work.

Example - A boy pulls an object towards himself.

Negative Work - If the force and displacement are in the opposite direction, then the work done is known as negative work.

Example - The work that the buoyant force does when a coin sinks.

Zero Work - If the force and displacement act perpendicular to each other, then the work done is known as zero work.

Example - A person standing still with bags in his hands is not doing any work because there is no displacement of the bag.

Conservative and Non-Conservative Forces

Conservative Force

Conservative Force is a type of force that moves an object from one place to another. This force is independent of the path covered by an object and depends upon the initial and final positions only. Work done will remain zero in the closed path. This force is reversible.

Examples - Electrostatic force, Gravitational force, Magnetic force, etc.

Non-Conservative Force

The non-conservative force depends on the area covered by a body and the final and initial position of the particle. Work done will always remain a positive close path. This force is irreversible.

Examples - Frictional force, Air resistance, Viscous force, etc.

Power

Power is defined as the time rate at which work is done or energy is transferred.

Power (P) = $\frac{Work\ (W)}{Time\ (t)}$

= $\frac{Force\ \times\ Displacement}{Time}$ $= Force \times Velocity.$

Power is scalar quantity and its SI unit is J/s or watt (W). Its dimensions are $[M^1L^2T^{-3}]$.

1 watt = 1 joule /second = 1 kg m^2 s^{-3}
There is another unit of power, namely the horse-power (hp), 1 hp = 746 W.

Example - A machine does 192 J of work in 24 Sec. What is the power of the machine?

Solution - Given, work = 192 joule and time = 24 sec.
As we know,

Power = $\frac{work}{time}$ = $\frac{192}{24}$ = 8 watt.

Energy

The capacity of doing work is called energy. It is a scalar quantity. The SI unit of energy is 'joule' (same as that of work) and CGS unit is 'erg'. kilo joule (kJ), a larger energy unit of energy, equals 1000 J.
The dimensional representation of energy is $[M^1 L^2 T^{-2}]$.
1 calorie (cal) = 4.2 joules, 1 kilowatt-hour (kWh) = 3.6 x 10^6 J = 3.6 mega joules (MJ).

Forms of Energy

It exists in various forms, such as kinetic energy (associated with motion), potential energy (related to an object's position or condition), thermal energy (associated with heat), and many other forms, and it can be transformed from one form to another but is always conserved in a closed system.

Kinetic Energy

Kinetic energy is the energy possessed by an object due to its motion.

Examples - Moving Car, Walking & Running, Wind Mills, Bullet fired from a gun, etc.

The kinetic energy of an object increases with its speed. It is directly proportional to the mass of the object and to the square of its velocity. An object with mass (m) and velocity (v) is given by the formula: Kinetic energy, K.E. = $\frac{1}{2}mv^2$.

Example - A ball has a mass of 2Kg, suppose it travels at 10m/s. Find the kinetic energy possessed by it.

Solution - Given, mass = 2 kg and velocity = 10 m/s.
As we know,

Kinetic Energy = $\frac{1}{2}mv^2$

According to question,

Kinetic Energy = $\frac{1}{2} \times 2 \times 10 \times 10 = 100$ J.

Potential Energy

The potential energy of an object is the energy possesses due to its position or configuration.

Examples : Water In Dams & Reservoirs, An object at the top of a hill, A lifted weight, Food before we digest it, A charged battery, A wound spring of a watch etc.

An object's mechanical energy can be the result of its motion (i.e., kinetic energy) and/or the result of its stored energy of position (i.e., potential energy). The sum of kinetic and potential energy is known as mechanical energy.

Gravitational Potential Energy

Gravitational potential energy is the energy of an object due to its vertical height.

If a body of mass (m) is raised through a height (h) against gravity, then its Gravitational Potential Energy, U = mgh where, m is the mass (in kilograms), g is the acceleration due to gravity (9.8 m/s^2 at the surface of the earth) and h is the height (in meters).
Examples - A car that is parked at the top of a hill, Water flowing from the tap, Working of a hydroelectric dam etc.

Example - A mass of 2Kg is taken from the ground to the height of 10m. Find the potential energy of the object. (g = 10 m/s^2)

Solution - Given, mass = 2 kg and height = 10 m.
As we know,
Potential Energy = mgh
According to question,
Potential Energy = $2 \times 10 \times 10 = 200$ J.

Elastic Potential Energy

Elastic potential energy is the energy stored in elastic materials as the result of their stretching or compressing. It can be stored in rubber bands, bungee chords, trampolines, springs, an arrow drawn into a bow, etc.

For objects like springs, elastic potential energy (U) can be calculated using Hooke's Law, where k is the spring constant and x is the displacement from the equilibrium position: U = $\frac{1}{2}kx^2$.

Heat Energy

The energy possessed by a body due to its temperature is heat energy. All matter contains heat energy.

Examples - Solar energy, Fuel cell energy, Melting ice etc.

The heat transfer, Q = m × c × ΔT, where Q refers to the heat transferred, m is mass of the substance, c is the specific heat and ΔT is the temperature difference.
Dimensional Formula : $[M^1 L^2 T^{-2}]$

Electrical Energy

It is defined as the energy which is caused by the movement of the electrons from one point to another within an electric field. It is a type of kinetic energy and associated with an electric current. The formula for electrical energy is $E = V \times I \times t$ joules, where V is the potential difference, I is the current and t is the time.

The SI unit of electrical energy is joule.
1 joule = 1 volt × 1 ampere × 1 second.

Chemical Energy

It is the energy that arises during the chemical reaction when the molecules participating in the reaction have different binding energies.

Examples - Batteries, biomass, petroleum, natural gas, and coal.

Nuclear Energy

It is the energy absorbed or released during a nuclear reaction.

Work Energy Theorem

According to this theorem, Work done by a force in displacing a body is equal to change in its kinetic energy.

Work done = Change in kinetic energy.

Law of Conservation of Energy

According to this law, energy can neither be created or destroyed; it can only be converted from one form to another. The total energy before and after the transformation remains the same.

In mathematical form; Potential energy (PE) + Kinetic energy (KE) = constant i.e. $mgh + \frac{1}{2}mv^2 =$ constant where, PE = potential energy, KE = kinetic energy, m = mass of the body, g = acceleration due to gravity (approx. 9.8 m/s^2), h = height in metres, and v = velocity of body at any time.

In 1842, Julius Robert Mayer discovered the Law of Conservation of Energy.

Transformation of Energy

It is the process of changing energy from one form to another. Energy transformation is also known as energy conversion. The process by which energy is transformed into less useful or more disordered forms, refers to dissipation of energy.

Some Energy Transformation

Microphone (Sound Energy to Electrical Energy); Geothermal Power Plant (Heat Energy to Electrical Energy); Burning of wood (Chemical Energy to Heat and Light Energy); Electric motor (Electrical to Mechanical Energy); Electric generator (Mechanical to Electrical Energy); Steam engine (Heat to Kinetic Energy); Loud speaker (Electrical to Sound Energy); Solar cell (Light to Electrical Energy); Dry cell or Fuel cell or Battery (Chemical to Electrical Energy).

Einstein Mass Energy Equivalence

Einstein proposed the relationship between the mass and energy of objects; and states that mass and energy are the same physical objects that may be converted into one another.

$E = mc^2$

where,
E is the energy of the object in joules, m is its relativistic mass in kilograms, and c is the speed of light (approximately 3×10^8 m/s).

Collision

A collision occurs when two objects come in contact with each other. It is also called impact.

For example, billiard balls colliding, a hammer hitting a nail, a falling object to the floor, etc.

There are two types of collision : (a) elastic collision (b) inelastic collision.

In all collisions the total linear momentum is conserved; the initial momentum of the system is equal to the final momentum of the system.

In an **elastic collision,** momentum as well as the kinetic energy remains conserved.

The elastic collision formula of momentum is given by :
$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

The elastic collision formula of kinetic energy is given by

$$\frac{1}{2} m_1u_1^2 + \frac{1}{2} m_2u_2^2 = \frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2$$

where,
m_1 - mass of 1st body
m_2 - mass of 2nd body
u_1 - initial velocity of 1st body
u_2 - initial velocity of 2nd body
v_1 - final velocity of the 1st body
v_2 - final velocity of the 2nd body
Examples of Elastic Collision : When a ball at a billiard table hits another ball; When a ball is thrown on the ground, it bounces back etc.

In an **inelastic collision,** momentum is conserved but the kinetic energy is not conserved.

When two objects collide under inelastic conditions, the final velocity with which the object moves is given by :

$$v = \frac{m_1v_1 + m_2v_2}{m_1 + m_2}$$

where,
v = final velocity (in m/s)
m_1 = mass of the 1st object (in kg)
m_2 = mass of the 2nd object (in kg)
v_1 = initial velocity of the 1st object (in m/s)
v_2 = initial velocity of the 2nd object (in m/s)

Examples of Inelastic Collisions : The accident between two cars or any other vehicles; A ball falling from a certain altitude and unable to return to its original bounce etc.

Sources of Energy

There are many different sources of energy that can broadly be divided into two categories :

(a) Renewable Energy Sources - Energy derived from natural sources that are replenished at a higher rate than they are consumed. Sunlight and wind are such sources that are constantly being replenished. These sources are freely available in nature and do not cause any pollution.

(b) Non Renewable Energy Sources - These are limited reservoirs of energy and which require a longer time span for replenishment. The fossil fuels (petroleum, coal, natural gas etc) are non -renewable sources of energy.

Fuel

Fuel is a substance or material that can undergo a chemical or nuclear reaction to release energy in the form of heat, light, or other forms of useful energy.

For example - Biogas, Liquefied Petroleum Gas (LPG), wood, coal, petrol, diesel, Compressed Natural Gas (CNG).

Characteristics of an Ideal Fuel

High energy content or high calorific value, Readily available, Efficient combustion, Stable and safe, Low residue, Cost - effective, Versatile etc.

Conventional Sources of Energy

Fossil Fuels

These are hydrocarbon-containing materials such as coal, natural gas or oil, that were formed millions of years ago from dead animals or plants in the ground. Fossil fuels emit carbon dioxide (CO_2) when burnt which is a major greenhouse gas and the primary source of pollution.

Thermal Power Plant

A thermal power plant is a type of power station in which heat energy is converted to electrical energy. They are also called combustion power plants, they operate with energy produced by a steam boiler fueled by coal, natural gas, heating oil, as well as by biomass.

Hydro Power Plant

A hydro power plant is used to transform water's potential energy into electrical energy and can operate constantly. The available electrical energy is proportional to the flow rate and the drop in elevation.

The basic principle of hydropower is using water to drive turbines. Components of a hydroelectric plant are as follows - Water intakes, Dam or weir, Spillways, Turbines, Transformers, Powerhouse, Electrical power transmission lines.

There are three types of hydroelectric power plants: (a) Run-of-the-river power plants, (b) Hydroelectric power plants with a reservoir, (c) Pumped-storage hydroelectric power plants.

Improvements in the Technology for Using Conventional Sources of Energy

Biomass

Biomass is organic matter that can be used to generate energy. It is made of material that comes from living organisms, such as plants and animals. These are called biomass feedstocks.

Bioenergy is a form of renewable energy generated when we burn biomass fuel. Biomass energy can also be a non-renewable energy source.

Biomass sources for energy include wood and wood processing waste (firewood, wood pellets and black liquor from pulp and paper mills etc).

Bio - Gas

Biogas is an environmentally-friendly, renewable energy source produced by the breakdown of organic raw materials such as food scraps, manure, sewage, agricultural waste and animal waste. It is a mixture of methane (CH_4), hydrogen sulphide (H_2S), carbon dioxide (CO_2) and hydrogen (H_2). The difference between biomass and biogas is that, biomass is the raw material and biogas is the end product.

Bio Gas Plant

A biogas plant is a facility that uses organic waste to produce methane-rich gas for energy generation and other uses. It turns waste into sustainable energy and fertilizers, with positive effects on the environment.

A biogas plant is a dome-like structure that has components like A digester or fermentation tank, A gas holder, mixing tank, inlet and outlet chamber.

Advantages of Biogas Plant : Biogas plants are eco-friendly. It can help to fight climate change. It can help to reduce carbon footprint. Biogas burns without smoke and has a high calorific value.

Wind Energy

The process by which the wind is used to generate mechanical power or electricity is said to be wind energy. Wind turbines convert the kinetic energy in the wind into mechanical power. It is a clean and renewable energy source.

Windmill or Wind Turbines

A windmill is a machine that changes the wind's kinetic energy into mechanical energy. The rotation of the blades of a windmill is always in a clockwise direction. Daniel Halladay, a resident of the United States, designed the first windmill in 1854.

There are two types of wind turbines: Horizontal-axis wind turbines and Vertical-axis wind turbines.

A wind turbine basically works on the principle of conversion of energy from one form to another. Wind turbines use wind to make electricity. Wind turns the propeller-like blades of a turbine around a rotor, which spins a generator, and hence creates electricity.

Advantages of Wind Energy : It provides electricity without burning any fuel or polluting the air. It is a clean and renewable energy source. It is an abundant and inexhaustible resource. It requires no recurring expenses for the production of electricity.

Limitations of Wind Energy : Ideal wind sites are often in remote locations. Turbines produce noise and alter visual aesthetics. Wind plants can impact local wildlife. The minimum wind speed necessary for satisfactory working of the wind generator is about 15 km/h.

Non Conventional Sources of Energy

Solar Energy

Solar energy is a powerful source of energy generated by the Sun. It is created by nuclear fusion that takes place in the Sun.

Advantages of Solar Energy : It is good for the Environment and solar power plants can be installed on underutilized land. It is not dependent on other sources of energy. It is Renewable Energy. It is a Pollution free source and also has Low maintenance costs.

Limitations of Solar Energy : Solar energy storage is expensive. Dependent on sunlight. High initial costs of installing panels.

Solar Heat Devices

A solar heat device, also known as a solar thermal collector or solar heater, is a technology designed to capture and utilize solar energy from sunlight to heat a fluid or air, which can then be used for various heating applications.

Examples - Solar cooker, solar cells and solar heater etc.

Solar Cooker : Solar cooker is an apparatus for cooking food using the energy of direct sunlight, typically by means of reflective panels that concentrate the light on to a dark-coloured pot in an insulated box. It is a type of solar thermal collector.

Solar Cooker Working Principle : Sunlight Concentration → Converting Light Energy into Heat Energy → Trapping Heat Energy.

Concave mirrors are used in these types of cookers because these mirrors reflect sunlight into a single focal point.

There are some basic types of solar cookers such as 'box', 'parabolic reflector' and 'panel cookers'.

Solar Cell

Solar cell is an energy conversion device which is used to convert sunlight into electricity by the use of the photovoltaic effect. These cells are made from semiconductors like silicon (Si), germanium (Ge).

The photovoltaic effect is a process that generates voltage or electric current in a photovoltaic cell when it is exposed to sunlight. Photo/light + voltage = Photovoltaic.

Uses : For transportation, in calculators, in solar street lights, for traffic signals, in water pumping, in space exploration, in environmental monitoring, to provide electricity to light houses in remote areas etc.

Energy from the Sea

The oceans contain a huge amount of energy such as tidal energy, wave energy, ocean thermal energy and others.

Tidal Energy

Tidal energy is a renewable source of energy, produced by the surge of ocean waters during the rise and fall of tides. Using specially engineered generators in suitable locations, tidal energy can be converted into useful forms of power, including electricity.

Wave Energy

Waves are a result of wind and ocean interactions. Kinetic and potential energy associated with ocean waves can be harnessed using modular technologies. Wave energy has the advantage of being predictable and less volatile compared to some of the other renewable energy sources.

Ocean Thermal Energy

Ocean Thermal Energy (OTE) is the energy derived from the temperature difference between the surface of the ocean and deeper layers of water. It can be converted into a usable form of energy like electricity.

Geothermal Energy

Geothermal energy is the heat energy from the Earth - Geo (earth) + thermal (heat). It is the use of heat from the Earth's interior under specific natural conditions.

Benefits of Geothermal Energy

(a) Renewable - The heat flowing from Earth's interior is continually replenished by the decay of naturally occurring radioactive elements.

(b) Clean - Modern geothermal power plants emit no greenhouse gases and have life cycle emissions four times lower than solar photovoltaics PV, and 6 to 20 times lower than natural gas.

(c) Baseload - Geothermal power plants produce electricity consistently, regardless of weather conditions.

Nuclear Energy

Nuclear energy is a form of energy released from the nucleus, the core of atoms, made up of protons and neutrons. This source of energy can be produced in two ways : **fission** - when nuclei of atoms split into several parts, or **fusion** - when nuclei fuse together.

Nuclear Fission

Nuclear fission is a nuclear reaction or a decay process in which the heavy nucleus splits into smaller parts (lighter nuclei).
An example of fission is when a uranium isotope $_{92}U^{235}$ bombarded with a neutron breaks into two intermediate mass nuclear fragments.
$_0n^1 + {}_{92}U^{235} \rightarrow {}_{56}Ba^{144} + {}_{36}Kr^{89} + 3\ {}_0n^1 +$ Energy

Nuclear Fusion

In fusion, lighter nuclei combine to form a larger nucleus while releasing massive amounts of energy. Fusion of hydrogen nuclei into helium nuclei is the source of energy of all stars including our sun.
$_1H^2 + {}_1H^2 \rightarrow {}_2He^3 + n + 3.27$ MeV

Nuclear Power Plant

Nuclear power plants are a type of power plant that use the process of nuclear fission in order to generate electricity. Nuclear power reactors use heat produced during atomic fission to boil water and produce pressurized steam. The steam is routed through the reactor steam system to spin large turbine blades that drive magnetic generators to produce electricity.

Nuclear Energy of U^{235} → Heat Energy of Steam → Kinetic Energy of Turbine → Electrical Energy

There are several components of **nuclear power plant** :

(a) Fuel - Enriched uranium oxide is the most commonly used material. It is used simultaneously as a source of energy and of neutrons in order to maintain the chain reaction.

(b) Moderator - It slows down the neutrons released from fission so that they cause more fission. The commonly used moderators are water, heavy water (D_2O) and graphite.

(c) Control rods or blades - These are used to control the rate of reaction, or to halt it.

(d) Coolant - A fluid circulating through the core so as to transfer the heat from it.

(e) Pressure vessel or tubes - Conveying the coolant through the surrounding moderator.

(f) Steam generator - It is used to make steam for the turbine, in a secondary circuit.

Practice Questions :-

Q.1. What type of energy conversion takes place in a battery?
SSC MTS 03/05/2023 (Morning)
(a) Chemical energy into light energy
(b) Chemical energy into electrical energy
(c) Mechanical energy into chemical energy
(d) Chemical energy into sound energy

Q.2. Which of the statements is NOT correct regarding energy ?
SSC CHSL 14/03/2023 (4th Shift)
(a) The energy possessed by a body due to its change in position or shape is called the potential energy.
(b) An object of mass m moving with velocity v has a kinetic energy of $(\frac{mv}{2})$.
(c) The gravitational potential energy of an object of mass, M raised through a height, H from the earth's surface is given by MgH.
(d) An object in motion possesses what is known as the kinetic energy of the object.

Q.3. In an electrical geyser ______ energy is converted to ______.
RRC Group D 14/09/2022 (Evening)
(a) Electrical, heat (b) Electrical, magnetic
(c) Mechanical, electrical (d) Electrical, light

Q.4. Kinetic and potential energies of a body are the components of its ______ energy.
SSC MTS 18/10/2021 (Evening)
(a) chemical (b) electrical (c) mechanical (d) heat

Q.5. The English physicist James Prescott Joule

outlined the basis of the ______.
SSC MTS 14/10/2021 (Afternoon)
(a) principle of conservation
(b) phenomenon of gravitation
(c) theory of vibrating receptacle
(d) concept of diffusion of gases

Q.6. Which of the following is an example of gravitational potential energy?
SSC CHSL 15/04/2021 (Afternoon)
(a) Moving car
(b) Bullet fired from a gun
(c) Water that is behind a dam
(d) Foot kicking a ball

Q.7. Which energy of fossil fuel is transformed into electrical energy at thermal power plants?
RRB JE 27/05/2019 (Afternoon)
(a) Hydroelectric energy (b) Tidal energy
(c) Solar energy (d) Chemical energy

Q.8. In which of the following activities is work NOT done?
RRB ALP Tier - I (20/08/2018) Morning
(a) Ashwin is climbing a bus
(b) Ashwin is running
(c) Ashwin is standing on the platform
(d) Ashwin is walking

Q.9. If a body is whirled in a circle, then the work done on it ________ .
RRB ALP Tier - I (17/08/2018) Evening
(a) is negative (b) cannot be determined
(c) is zero (d) is positive

Q.10. Which of the following can neither be created nor be destroyed ?
RRB ALP Tier - I (14/08/2018) Evening
(a) Momentum (b) Energy (c) Power (d) Velocity

Q.11. A body of 4.0 kg is lying at rest. Under the action of a constant force, it gains a speed of 5 m/s. The work done by the force will be_________ .
RRB ALP Tier - I (09/08/2018) Afternoon
(a) 30 J (b) 50 J (c) 40 J (d) 20 J

Q.12. What happens in an elastic collision with regard to kinetic energy?
(a) Kinetic energy is not conserved.
(b) Kinetic energy is converted into potential energy.
(c) Kinetic energy remains conserved.
(d) Kinetic energy is lost.

Q.13. What is the primary characteristic of an ideal fuel?
(a) High calorific value (b) High residue production
(c) Low availability (d) Inefficient combustion

Q.14. Which of the following elements is NOT typically found in biogas?
(a) Methane (b) Hydrogen sulfide
(c) Carbon dioxide (d) Oxygen

Q.15. What is the primary process that occurs in the digester area of a biogas plant?
(a) Combustion (b) Anaerobic digestion preparation
(c) Fermentation (d) Photosynthesis

Q.16. Which equation describes the relationship between energy (E), relativistic mass (m), and the speed of light (c)?
(a) $E = mc$ (b) $E = mc^3$ (c) $E = mc^2$ (d) $E = m/c^2$

Q.17. Which scenario exemplifies an example of an elastic collision?
(a) A car coming to a stop after a collision with a tree
(b) Two billiard balls colliding on a table and bouncing off each other
(c) A dropped ball hitting the ground and sticking to it
(d) A tennis ball hitting a wall and losing some of its momentum

Q.18. What is the formula for gravitational potential energy (U) of a body raised to a height (h) against gravity?
(a) $U = mg/h$ (b) $U = m + g + h$
(c) $U = mgh$ (d) $U = mh/g$

Q.19. In which of the following processes are Neutrons emitted?
(a) Inverse beta Decay (b) Nuclear fission
(c) Spontaneous Fission (d) Nuclear fusion

Q.20. What type of Reaction takes place in the sun?
(a) Nuclear fusion (b) Nuclear fission
(c) Spontaneous fission (d) Double beta decay

Answer Key :-

1.(b)	2.(b)	3.(a)	4.(c)
5.(a)	6.(c)	7.(d)	8.(c)
9.(c)	10.(b)	11.(b)	12.(c)
13.(a)	14.(d)	15.(c)	16.(c)
17.(b)	18.(c)	19.(b)	20.(a)

System of Particles and Rotational Motion

Rigid Body

A solid body in which deformation is zero or negligible is called rigid body. The distances between all pairs of particles oPPf such a body do not change.

Centre of Mass

The centre of mass is like the "balance point" of an object. For a system of particles, it is defined as that point where the entire mass of the system is imagined to be concentrated.

For a system of n particles having masses m_1, m_2, m_3, m_4,……m_n located at the distance (position vectors) r_1, r_2, r_3, r_4,……r_n then the position vector of centre of mass is,

$$r_{CM} = \frac{m_1 r_1 + m_2 r_2 + m_3 r_3 + \ldots\ldots m_n r_n}{m_1 + m_2 + m_3 + \ldots\ldots m_n}$$

Position of Center of Mass for Different Symmetrical Bodies

Uniform hollow or solid sphere (Centre of the sphere), Uniform rod (Centre of the rod), Uniform circular disc (centre of disc), Hollow or solid cylinder (Middle point of the axis of cylinder), Rectangular or cubical block (Points of inter section of diagonals).

The location of an object's centre of mass is influenced by its size, shape, and how its mass is distributed. Consequently, the centre of mass can be situated either within or outside the material of the object. Importantly, during translational motion, the centre of mass shifts, adjusting its position, whereas during rotational motion, its location remains constant.

Motion of Centre of Mass

The centre of mass of a system of particles moves as if the entire mass of the system were concentrated at the centre of mass and all the external forces were applied at that point. Velocity of centre of mass of a system of two particles, m_1 and m_2 with velocity v_1 and v_2 is given by -

$$V_{cm} = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2}$$

Linear Momentum of a System of Particles

Linear momentum of a system of particles is simply the product of its mass and velocity. It is a vector whose direction is parallel to the velocity of the particle.

The total momentum of a system of particles is equal to the product of the total mass of the system and the velocity of its centre of mass. If no external force acts on the body, then the centre of mass will have constant momentum.

Angular Velocity (ω)

Angular velocity of a body or particle is defined as the ratio of the angular displacement of the body or the particle to the time interval during which this displacement occurs. The direction of angular velocity is along the axis of rotation. The SI unit of angular velocity is radians/s and the dimensional formula is $[T^{-1}]$.

Mathematically it is expressed as $\omega = \frac{d\theta}{dt}$

Angular Acceleration (α)

The angular acceleration of a body is defined as the ratio of the change in the angular velocity to the time interval. The SI unit of angular acceleration is radian s^{-2} .

Mathematically it is expressed as $\alpha = \frac{d\omega}{dt}$

Relation between linear acceleration and angular acceleration, $a = r\alpha$ where ‘r’ is a constant and radius vector of a circle, ‘a’ is linear acceleration and ‘α’ is the angular acceleration.

Torque (τ)

Torque is measured as the product of the magnitude

of the force and the perpendicular distance of the line of action of the force from the axis of rotation. The SI unit for torque is the Newton-metre (Nm) and it is a vector quantity. The dimensional formula of Torque is $[ML^2T^{-2}]$.
Mathematically,
torque (τ) = Force × perpendicular distance,
or $\vec{\tau} = \vec{F} \times \vec{r}$ = rFsinθ
where θ is the angle between r and F.

Angular Momentum (or Moment of Momentum)

The angular momentum of a body about a given axis is the product of moment of inertia (I) and angular velocity of the body about that axis. Its SI unit is joule-second and denoted by L. The Dimensional formula of angular momentum is $[ML^2T^{-1}]$.

Angular momentum, $L = I \times \omega$

Like moment of a force, angular momentum is also a vector quantity.

Conservation of Angular Momentum

If the total external torque on a system of particles is zero, then the total angular momentum of the system is conserved, i.e. remains constant.

If $\tau_{ext} = 0$, we have $\frac{dL}{dt} = 0$ or L = constant.

Note : Corelation of torque (τ) and angular momentum is, $\tau_{ext} = \frac{dL}{dt}$.

Couple

A pair of equal and opposite forces with different lines of action is known as a couple. A couple produces rotation without translation. The resultant force of a couple is zero.

Some common examples - A screwdriver is twisted by the equivalent of a couple, and the steering wheel of an automobile is turned by hand forces that constitute a couple.

The moment of a couple is equal to the product of either force (F) and the perpendicular distance (d) between the line of action of both the forces. It has the same unit and dimension as torque.
Mathematically, it is expressed as -
Moment of couple = F × d.

Equilibrium of Bodies

A rigid body is in equilibrium when the sum of all the external forces acting on it equals zero.

Conditions of Equilibrium

(a) The total force, i.e. the vector sum of the forces, on the rigid body is zero.

(b) The total torque, i.e. the vector sum of the torques on the rigid body are zero.

Types of Equilibrium

There are three types of equilibrium : stable, unstable, and neutral.

Stable equilibrium - It is a state in which a body tends to return to its original position after being slightly disturbed. Potential energy tends to be minimum in this case.

Unstable equilibrium - This equilibrium exists when a point force acts on a body after that the body can't attain its original position. Potential energy tends to be maximum in this case.

Neutral equilibrium - When a body can stay in equilibrium even after being slightly displaced and released. In this case, potential energy remains constant.

Centre of Gravity

The centre of gravity is a geometric property of any object. It is a point where the weight of the body acts and total gravitational torque on the body is zero.

When an object is in a uniform gravitational field, the centre of gravity will be at the same location as the centre of mass.

Centre of Gravity of Some Rigid Bodies

Solid spherical body (Centre of the sphere),