1. Natural of Physical World and Measurement

1. What is meant by Scientific method?

The scientific method is a step-by-step approach in studying natural phenomena and establishing laws which govern these phenomena.

2. What are the general features of scientific method?

- Systematic Observation
- Controlled experimentation
- Qualitative and quantitative reasoning
- Mathematical modeling
- Prediction and verification or falsification of theories.

3. What type of approaches are followed in studying physics?

- Unification
- Reductionism

4. What is Unification? Give the example.

An attempt to explain various physical phenomena with a few concepts and laws is Unification.

<u>Ex:</u> Newton's universal law of gravitation explains various events like motion of freely falling body, motion of the planets around the sun, motion of the moon around the earth.

5. What is reductionism? Give the example.

An attempt to explain a macroscopic system in terms of its microscopic constituents is reductionism.

<u>Ex:</u> Macroscopic properties like temperature, entropy, etc., of bulk systems can be easily interpreted in terms of the molecular motion(microscopic constituents).

6. What is technology?

Technology is the application of principles of physics for practical purposes.

7. Describe the relation of Physics with Chemistry.

- Studies of structure of atom, radioactivity, X-ray diffraction, etc., in physics have been used in chemistry to arrange elements in periodic table on the basis of atomic numbers.
- It is further helped to know the nature of valence and chemical bonding and to understand the complex chemical structures.
- Inter-disciplinary branches like Physical chemistry and Quantum chemistry plays vital role here.

8. Describe the relation of Physics with Biology.

- It is impossible to study biology without microscope designed using physical principles.
- Invention of electron microscope has made possible to see even the structure of a cell.
- X-ray diffraction and neutron diffraction techniques are helped to understand the structure of nucleic acids, which helps to control vital life processes.
- X-rays are used for diagnostic purposes.
- Radio-isotopes are used in radiotherapy for the treatment of cancer and other diseases.
- Now-a-days biological processes are being studied from the physical point of view.

9. Describe the relation of Physics with mathematics.

- Physics is a quantitative science.
- Physics is closely related to mathematics as a tool for its developement.

10. Describe the relation of Physics with Astronomy.

- Astronomical telescopes are used to study the motion of the planets and other celestial bodies in the sky.
- Radio telescopes are used to observe distant points of the universe.
- Studies of the universe are done using physical principles.

11. Describe the relation of Physics with Geology.

- Diffraction techniques helps to study the crystal structure of various rocks.
- Radioactivity is used to estimate the age of rocks, fossils and the age of the Earth.

12. Describe the relation of Physics with Oceanography.

- Oceanographers seek to understand the physical and chemical processes of the oceans.
- For that, they measure parameters such as temperature, salinity, current speed, gas fluxes and chemical components of the ocean.

13. Describe the relation of Physics with Psychology.

- All the psychological interactions can be derived from a physical process.
- The movements of neurotransmitters are governed by the physical properties of diffusion and molecular motion.
- The function of our brain is related to our underlying dualism (wave -particle nature).

14. What is measurement?

The comparison of any physical quantity with its standard unit is known as measurement.

15. What is physical quantity? Give the examples.

Quantities that can be measured and in terms of which laws of physics are described are called physical quantities. **Ex :** length, mass, time, force, energy, etc.,

16.What is fundamental or base quantities? Give the examples.

The quantities, which cannot be expressed in terms of any other physical quantities, are called fundamental or base quantities.

Ex: length, mass, time, electric current, temperature, luminous intensity and amount of substance.

17.What is derived quantities? Give the examples.

Quantities that can be expressed in term of fundamental quantities are called derived quantities.

Ex: area, volume, velocity, acceleration, force.

18.What is an unit?

An arbitrarily chosen standard of measurement of a quantity, which is accepted internationally is called unit of the quantity.

19.What is System of Units?

A complete set of units which is used to measure all kinds of fundamental and derived quantities is called a system of units.

20.What is the f.p.s system?

The f.p.s system is the British Engineering system in which length, mass and time are measured in foot, pound and second respectively.

21.What is the c.g.s system?

The c.g.s system is the Gaussian system in which length, mass and time are measured in centimeter, gram and second respectively.

22.What is the m.k.s system?

In the m.k.s system, length, mass and time are measured in meter, kilogram and second respectively.

23.What are the advantages of SI unit system?

- ❖ It is a rational system, in which only one unit is used for one physical quantity.
- ❖ It is a coherent system, which means all the derived units can be easily obtained form basic and supplementary units.
- ❖ It is a metric system, which means multiples and submultiples can be expressed as powers of 10.

24.What is the SI standard of length? (or) What is one meter in SI system of units?

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

25.What is the SI standard of mass? (or) What is one kilogram in SI system of units?

One kilogram is the mass of the prototype cylinder of platinum iridium alloy (whose height is equal to its diameter), preserved at the International Bureau of Weights and Measures at Serves, near Paris, France.

26. What is the SI standard of time? (or) What is one second in SI system of units?

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

27.What is the SI standard of electric current? (or) What is one ampere in SI system of units?

One ampere is the constant current, which flows through the two parallel straight conductors of infinite length with negligible cross-section, held one meter apart in vacuum, shall produce a force per unit length of 2×10^{-7} Nm^{-1} between them.

28.What is the SI standard of temperature? (or) What is one kelvin in SI system of units?

One kelvin is the fraction of $\frac{1}{273.16}$ of the thermodynamic temperature of the triple point of the water.

29.What is the SI standard of amount of substance ? (or) What is one mole in SI system of units?

One mole is the amount of substance which contains as many elementary entities as there are atoms in 0.012 kg of pure carbon-12.

30.What is the SI standard of luminous intensity? (or) What is one candela in SI system of units?

One candela is the luminous intensity of a source in a given direction that emits monochromatic radiation of frequency 5.4×10^{-14} Hz and that has a radiant intensity of $\frac{1}{683}$ watt / steradian in that direction.

31.what is length? Give its SI unit.

Length is defined as the distance between any two points in space. Its SI unit is metre.

32.what is one radian?

One radian is the plane angle subtended by an arc whose arc length is equal to its radius.

33.What is one steradian?

One steradian is the solid angle subtended by the partial surface of a sphere whose suface area is equal to the square of its radius.

34.Explain the use of Screw gauge in measuring smaller distances.

- ❖ It is used to measure accurately the dimension of objects upto the maximum of 50 mm.
- ❖ The principle of the instrument is the magnification of linear motion using circular motion of a screw.
- ❖ The least count of the screw gauge is 0.01 mm.

35. Explain the use of vernier caliper in measuring smaller distances.

- It is a versatile instrument for measuring the dimensions of an object like diameter and depth of a hole.
- The least count of the vernier caliper is 0.1 mm.

36. What are the methods adopted in measuring larger distances?

- Triangulation method
- Parallax method
- Radar method

37. What is Parallax?

The shift in the position of an object (say a pen) when viewed with left and right eye alternatively is known as Parallax.

(or)

The apparent chage in position of an object with respect to its background, when viewed from two different locations is called Parallax.

38. What is the abbreviation for RADAR?

The word RADAR stands for RAdio Detection And Ranging.

39. What is 1 light year ? Give its value.

1 light year is the distance travelled by light in vacuum in one year.

1 light year = 9.467×10^{15} m.

40. What is 1 astronomical unit(AU)? Give its value.

1 astronomical unit is the mean distance between earth and the sun.

1 AU = 1.496×10^{11} m.

41. What is 1 parsec (Parallactic second)? Give its value.

1 parsec is the radial distance of an arc of arc length 1 AU subtends an angle of 1 second.

1 parsec = 3.08×10^{16} m = 3.26 light year.

42. Define mass?

Mass of a body is defined as the quantity of matter contained in a body. The SI unit of mass is kilogram.

43. What is the difference between Accuracy and Precision?

S.No.	Accuracy	Precision
1	Measurements close to true value.	Measurements close to each other.
2	All the accuracy values are precised.	All the precised values are not accurate.

44. What is meant by an error? Name its types.

The uncertainity in a measurement is called an error.

Types: Systematic errors, Random errors & Gross errors

45. What is meant by Systematic error?

- Systematic errors are reproducible inaccuracies that are consistently in the same direction.
- These occur offen due to a problem that persists throughout the experiment.

46. What are the Classifications of Systematic errors?

- Instrumental errors
- Imperfections in experimental techniques or procedure.
- Personal errors
- Errors due to external causes.
- Least count error

47. Describe Instrumental errors. How is it minimised?

- It is happened when an instrument is not calibrated properly at the time of manufacture.
- For example, If a measurement is made with a meter scale whose end is worn out, result obtains error.
- These errors can be rectified by using the good quality instruments.

48. Describe Imperfections in experimental technique or procedure. How can it be overcomed?

- These errors arise due to the limitations in the experimental arrangements.
- For example, Calorimeter experiment is done without insulation makes radiation loss. This results errors.
- It can be overcomed by applying necessary correction.

49. Describe the Personal errors.

These errors occur due to individual performing experiment without initial setting up or careless observation without precautions.

50. Describe the errors due to external causes.

These errors are due to external conditions like change in temperature, humidity or pressure during an experiment.

51. Describe the least count error. How can it be minimised?

- Least count is the smallest value that can be measured by an instrument.
- The error due to the measurement in least count is called least count error.
- It can be minimised by using high precision instrument.

52. Describe Random errors. How can it be minimised?

- Random errors may arise due to random and unpredictable variation in experimental conditions like pressure,temperature, voltage supply,etc.,
- It is also due to personal errors.
- These errors are happened by chance, so it is called "Chance error".

- It can be minimised by calculating arithmetic mean of measurements taken. i.e. If 'n' number of readings $a_1, a_2, a_3, ...,a_n$ are done, the arithmatic mean is given by,

$$a_m = \frac{a_1 + a_2 + a_3 + \cdots + a_n}{n}$$

$$a_m = \frac{1}{n}\sum_{i=1}^{n} a_i$$

53. Describe Gross error. How can it be minimised?

The error caused due to the complete carelessness of an observer is called gross error.

Example :

- Reading an instrument without setting properly.
- Taking observations in a wrong manner without considering source of errors and the precautions.
- Recording wrong observations.
- Using wrong values of the observations in calculations.

These errors can be minimised only when an observer is careful and mentally alert.

54. What is meant by Absolute error? Explain.

- The magnitude of difference between true value and measured value of a quantity is called absolute error.
- If $a_1, a_2, a_3, ...,a_n$ are the measured values of any quantity, then the arithmatic mean is the true value of the measurements.

$$a_m = \frac{a_1 + a_2 + a_3 + \cdots + a_n}{n}$$

$$a_m = \frac{1}{n}\sum_{i=1}^{n} a_i$$

- The absolute error is given by,

$$\Delta a_1 = |a_m - a_1|$$
$$\Delta a_2 = |a_m - a_2|$$
....
....
$$\Delta a_n = |a_m - a_n|$$

55. What is meant by mean Absolute error? Explain.

The arithmetic mean of the magnitude of absolute errors in all the measurements is called the mean absolute error.

$$\Delta a_m = \frac{|\Delta a_1| + |\Delta a_2| + |\Delta a_3| + \cdots + |\Delta a_n|}{n}$$

$$\Delta a_m = \frac{1}{n}\sum_{i=1}^{n} |\Delta a_i|$$

56. What is meant by Relative error? Explain.

The ratio between mean absolute error to the mean value is called relative error. This is also called fractional error.

$$Relative\ error = \frac{Mean\ absolute\ error}{Mean\ value}$$
$$= \frac{\Delta a_m}{a_m}$$

57. What is meant by Percentage error? Explain.

The relative error expressed in percentage is called percentage error.

Percentage error = $\frac{\Delta a_m}{a_m}$ x 100 %

58. What are the factors affecting error in final result?

- The errors in the individual measurements.
- Nature of mathematical operations.

59. What are significant figures?

The number of digits which are counted reasonably sure in making a measurement are called significant figures.

60. Explain the significant figures in addition and subtraction with the examples.

In addtion and subtraction, the final result should retain as many decimal places as there are in the original number with the smallest number of decimal places.

Example:

(i) Addition:

3.1 + 1.780 + 2.046 = 6.926 is rounded off to **6.9** as the number 3.1 has least one decimal place.

(ii) Subtraction:

12.637 – 2.42 = 10.217 is rounded off to **10.22** as the number 2.42 has least two decimal places.

61. Explain the significant figures in multipliication and division with the examples.

In multiplication and division, the final result should retain as many significant figures as there are in the original number with the smallest number of significant figures.

Examples:

(i) Multiplication:

1.21 x 36.72 = 44.4312 is rounded off to **44.4** as the number 1.21 has least 3 significant figures.

(ii) Division:

36.72 ÷ 1.2 = 30.6 is rounded off to **31** as the number 1.2 has least 2 significant figures.

62. What is dimension?

The dimensions of a physical quantity are the powers to which the unit of base quantities are raised to represent a derived unit of that quantity.

63. What is dimensional formula? Give an example.

Dimensional formula is an expression which shows how and which of the fundamental units are required to represent the unit of a physical quantity.

Ex: $[M^0LT^{-2}]$ is the dimensional formula of acceleration.

64. What is dimensional equation? Give an example.

When the dimensional formula of a physical quantity is expressed in the form of an equation, such equation is known as the dimensional equation.

Ex: acceleration = $[M^0LT^{-2}]$

65. What is dimensional variables?

Physical quantities, which have dimension and have variable values are called dimensional variables.

Examples: length, velocity, acceleration, etc.,

66. What is dimensionless variables?

Physical quantities,which have no dimension and have variable values are called dimensional variables.

Examples: specific gravity, strain, refractive index,etc.,

67. What is dimensional constants?

Physical quantities, which have dimension and have constant values are called dimensional constants.

Examples: gravitational constant, planck's constant, etc.,

68. What is dimensionless constants?

Physical quantities,which have no dimension and have constant values are called dimensionless constants.

Examples: π, e, numbers, etc.,

69. What is principle of homogeneity of dimensions?

The principle of homogeneity of dimension states that the dimensions of all the terms in a physical expression should be the same.

70. What are the applications of dimensional analysis method?

- Convert a physical quantity from one system of units to another.
- Check the dimensional correctness of a given physical equation.
- Establish relations among various physical quantities.

71. What are the limitations of dimensional analysis method?

- It gives no information about the dimensionless constants like numbers, π, e, etc., in the formula.
- It cannot decide whether the given quantity is a scalar or vector.
- It is not suitable to derive relations involving trignometry, exponential and logarithmic functions.
- It cannot be applied to an equation involving more than three physical quantities.
- It can only check dimensional correctness of an equation but not the correctness of the equation.

5 Marks Q & A:

1. Explain the propagation of error in the sum of two quantities?

- Let ΔA and ΔB be the absolute errors in the two quantities A and B respectively.
- Then,
  Measured value of A = A ± ΔA
  Measured value of B = B ± ΔB
  Consider the sum, Z = A + B
- The error ΔZ in Z is given by,
  Z ± ΔZ = (A ± ΔA) + (B ± ΔB)
  Z ± ΔZ = (A + B) ± (ΔA + ΔB)
  Z ± ΔZ = Z ± (ΔA + ΔB) $[\because Z = A + B]$
  ΔZ = ΔA + ΔB
- The maximum possible error in the sum of two quantities is equal to the sum of the absolute errors in the individual quantities.

2. Explain the propagation of error in the difference of two quantities?

- Let ΔA and ΔB be the absolute errors in the two quantities A and B respectively.
- Then,
  Measured value of A = A ± ΔA
  Measured value of B = B ± ΔB
  Consider the difference, Z = A - B
- The error ΔZ in Z is given by,
  Z ± ΔZ = (A ± ΔA) - (B ± ΔB)
  Z ± ΔZ = (A - B) ± (ΔA + ΔB)
  Z ± ΔZ = Z ± (ΔA + ΔB) $[\because Z = A - B]$
  ΔZ = ΔA + ΔB
- The maximum possible error in the difference of two quantities is equal to the sum of the absolute errors in the individual quantities.

3. Explain the propagation of error in the product of two quantities?

- Let ΔA and ΔB be the absolute errors in the two quantities A and B respectively.
- Then,
  Measured value of A = A ± ΔA
  Measured value of B = B ± ΔB
  Consider the product, Z = A . B -----> (1)
- The error ΔZ in Z is given by,
  Z ± ΔZ = (A ± ΔA) . (B ± ΔB)
  Z ± ΔZ = AB ± A.ΔB ± B.ΔA ± ΔA.ΔB -----> (2)
  Dividing equation (2) by (1) we get,
  $$1 \pm \frac{\Delta Z}{Z} = 1 \pm \frac{\Delta B}{B} \pm \frac{\Delta A}{A} \pm \frac{\Delta A}{A}.\frac{\Delta B}{B}$$
  As $\frac{\Delta A}{A}$ and $\frac{\Delta B}{B}$ are both smaller values, their products $\frac{\Delta A}{A}.\frac{\Delta B}{B}$ can now be neglected. The maximum fractional error in Z is,
  $$\frac{\Delta Z}{Z} = \frac{\Delta A}{A} + \frac{\Delta B}{B}$$
- The maximum fractional error in the product of two quantities is equal to the sum of the fractional errors in the individual quantities.

4. Explain the propagation of error in the division or quotient of two quantities?

- Let ΔA and ΔB be the absolute errors in the two quantities A and B respectively.
- Then,
  Measured value of A = A ± ΔA
  Measured value of B = B ± ΔB
  Consider the division, $Z = \frac{A}{B}$
- The error ΔZ in Z is given by,

$$Z \pm \Delta Z = \frac{A \pm \Delta A}{B \pm \Delta B} = \frac{A\left(1 \pm \frac{\Delta A}{A}\right)}{B\left(1 \pm \frac{\Delta B}{B}\right)}$$

$$Z\left(1 \pm \frac{\Delta Z}{Z}\right) = Z\left(1 \pm \frac{\Delta A}{A}\right)\left(1 \pm \frac{\Delta B}{B}\right)^{-1}$$

- By using binomial theorem,$(1+x)^n = 1+ nx$, when x<<1, we get,

$$1 \pm \frac{\Delta Z}{Z} = \left(1 \pm \frac{\Delta A}{A}\right)\left(1 \mp \frac{\Delta B}{B}\right)$$

$$1 \pm \frac{\Delta Z}{Z} = 1 \pm \frac{\Delta A}{A} \mp \frac{\Delta B}{B} \pm \frac{\Delta A}{A}.\frac{\Delta B}{B}$$

As $\frac{\Delta A}{A}$ and $\frac{\Delta B}{B}$ are both smaller values, their products $\frac{\Delta A}{A}.\frac{\Delta B}{B}$ can now be neglected. The maximum fractional error in Z is,

$$\frac{\Delta Z}{Z} = \frac{\Delta A}{A} + \frac{\Delta B}{B}$$

- The maximum fractional error in the product of two quantities is equal to the sum of the fractional errors in the individual quantities.

5. Explain the propagation of error in the power or a quantity?

- Let ΔA and ΔB be the absolute errors in the two quantities A and B respectively.
- Then,
  Measured value of A = A ± ΔA
  Measured value of B = B ± ΔB
  Consider the n^{th} power of A, $Z = A^n$
- The error ΔZ in Z is given by,

$$Z \pm \Delta Z = (A \pm \Delta A)^n = A^n\left(1 \pm \frac{\Delta A}{A}\right)^n$$

$$Z \pm \Delta Z = A^n\left(1 \pm \frac{\Delta A}{A}\right)^n$$

By using binomial theorem, we solve and get,

$$1 \pm \frac{\Delta Z}{Z} = 1 \pm n\frac{\Delta A}{A}$$

$$\frac{\Delta Z}{Z} = n\frac{\Delta A}{A}$$

The fractional error in the n^{th} power of a quantity is n times the fractional error in that quantity.

6. Explain the rules framed to count significant figures with the examples.

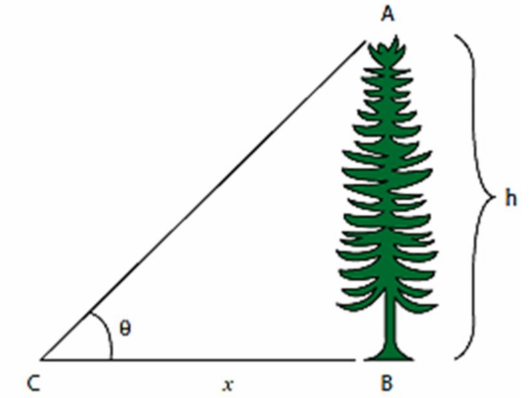
S. No.	Rule	Example
1.	All non-zero digits are significant	1342 has **four** significant figures
2.	All zeros between two non-zero digits are significant	2008 has **four** significant figures
3.	All zeros right to non-zero digit but left to decimal point are significant.	30700. has **five** significant figures
4.	The terminal or trailing zeros in the number without decimal point are not significant.	30700 has **three** significant figures.
5.	All zeros are significant if the number given with measurement unit.	30700 m has **five** significant figures.
6.	If a number is less than1, the zeros between decimal point and first non-zero digit are not significant but the zeros right to last non-zero digit are significant.	(i) 0.00345 has **three** significant figures. (ii) 0.030400 has **five** significant figures. (iii) 40.00 has **four** significant figures.
7.	The number of significant figures doesn't depend on the system of units used	1.53 cm, 0.0153 m, 0.0000153 km all have **three** significant figures.

7. Explain the rules framed for rounding off the numbers with the examples.

S. No.	Rule	Example
1.	If the dropping digit is less than 5, then preceding digit kept unchanged.	7.32 is rounded off to 7.3
2.	If the dropping digit is greater than 5, then preceding digit must be raised by 1.	17.26 is rounded off to 17.3
3.	If the dropping digit is 5 followed by non-zero digits then preceding digit must be raised by1	7.352 is rounded off to 7.4
4.	If the dropping digit is 5 or 5 followed by zero, then preceding digit must be raised by 1 if it is odd.	3.35 & 3.350 are rounded off to 3.4
5.	If the dropping digit is 5 or 5 followed by zero, then preceding digit is not changed if it is even.	3.45 & 3.450 are rounded off to 3.4

8. Explain the Triangulation method to find the height of the tree or the tower.

- Let AB = h be the height of the tree or tower.
- Let C be the the point of observation at distance x from B.
- Place a range finder at C and measure the angle of elevation, ∠ACB = θ as shown in figure.

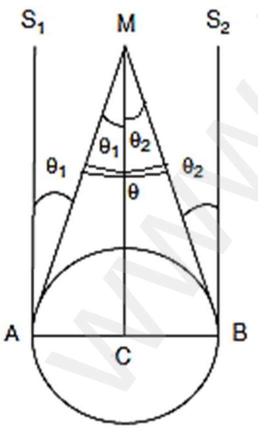


- From $\triangle ABC$, $tan\theta = \frac{AB}{BC} = \frac{h}{x}$

  or $\boxed{h = x \tan\theta}$
- Knowing the distance x, the height h can be determined.

9. Explain the Parallax method to find the distance of the Moon from Earth.

- Let C be the centre of the Earth.
- A & B are two diametrically opposite places on the surface of the Earth.
- AB is the diameter of the Earth and MC is the distance of the Moon from Earth.
- θ_1 & θ_2 are the parallactic angles of the Moon with respect to some distant stars S_1 & S_2 respectively.
- θ_1 and θ_2 are determined by using an astronomical telescope.

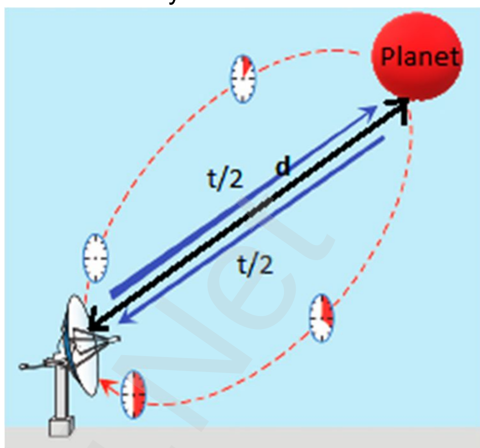


- Thus, the total parallactic angle(parallax) of the Moon subtended on Earth, $\angle AMB = \theta_1 + \theta_2 = \theta$.
- From the figure, $\theta = \frac{AB}{AM} = \frac{AB}{MC}$ $\quad [\because AM = MC]$

  $$\boxed{MC = \frac{AB}{\theta}}$$
- Knowing the values of AB and θ, We can calculate distance of the Moon from Earth (MC).

10. Explain the RADAR method to find the distance of a nearby Planet.

- The word RADAR stands for <u>RA</u>dio <u>D</u>etection <u>A</u>nd <u>R</u>anging.
- In this method, radio waves are sent from transmitters which after reflected from the planet are detected by the receiver.



- By measuring the time interval between the instants the radio waves are sent and received, the distance of the planet(d) can be detemined as,

  Distance = Speed of radio waves X time taken,

  $$\boxed{d = \frac{v \times t}{2}}$$
- Where v is the speed of radio waves and t is the time taken by radio waves to travel forward and backward hence t/2 is the time taken to cover the distance d.

11. Explain the conversion of physical quantity from one system of units to another with the examples.

- The product of the numerical value (n) and its corresponding unit [u] is constant.

  n [u] = constant
- Consider Physical quantity which has dimension 'a' in mass, 'b' in length and 'c' in time.
- If the fundamental unit in one system are M_1 , L_1 & T_1 and in other system are M_2 , L_2 & T_2, then we can write,

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

<u>Example: 1</u>

Convert 76 cm of mercury into Nm^{-2} using the method of dimension.

Data => h = 76 cm ; ρ = 13.6 g cm^{-3} ; g = 980 cm s^{-2}.

<u>**Solution:**</u>

P_1 = hρg =76 x 13.6 x 980 = 1.01 x 10^6 dyne cm^{-2}.

- The dimension formula of pressure P is [M L^{-1} T^{-2}]

  So, **a = 1 , b = -1 , c = -2**

  $$P_1[M_1^a\, L_1^b\, T_1^c] = P_2[M_2^a\, L_2^b\, T_2^c]$$

  $$P_2 = P_1\left[\frac{M_1}{M_2}\right]^a \left[\frac{L_1}{L_2}\right]^b \left[\frac{T_1}{T_2}\right]^c$$

M_1 = 1 g	L_1 = 1 cm	T_1 = 1 s
M_2 = 1 kg	L_2 = 1 m	T_2 = 1 s

$$P_2 = 1.01 \times 10^6 \left[\frac{1\,g}{1\,kg}\right]^1 \left[\frac{1\,cm}{1\,m}\right]^{-1} \left[\frac{1\,s}{1\,s}\right]^{-2}$$

$$P_2 = 1.01 \times 10^6 \left[\frac{10^{-3}\,kg}{1\,kg}\right]^1 \left[\frac{10^{-2}\,m}{1\,m}\right]^{-1} \left[\frac{1\,s}{1\,s}\right]^{-2}$$

$= 1.01 \times 10^6 \times 10^{-3} \times 10^2 \times 1$

$P_2 = 1.01 \times 10^5\ Nm^{-2}$.

Example 2:

If the value of universal gravitational constant in SI is $6.6 \times 10^{-11}\ Nm^2\ kg^{-2}$, then find its value in CGS System?

Solution:

Let G_{SI} be the gravitational constant in SI system and G_{cgs} be in cgs system.

$G_{SI} = 6.6 \times 10^{-11}\ Nm^2\ kg^{-2}$

- The dimensional formula for G is $M^{-1} L^3 T^{-2}$.

a = -1, b = 3, c = -2

$$G_{cgs} = G_{SI}\left[\frac{M_1}{M_2}\right]^a \left[\frac{L_1}{L_2}\right]^b \left[\frac{T_1}{T_2}\right]^c$$

M_1 = 1 kg	L_1 = 1 m	T_1 = 1 s
M_2 = 1 g	L_2 = 1 cm	T_2 = 1 s

$$G_{cgs} = 6.6 \times 10^{-11}\left[\frac{1\,kg}{1\,g}\right]^{-1} \left[\frac{1\,m}{1\,cm}\right]^3 \left[\frac{1\,s}{1s}\right]^{-2}$$

$$G_{cgs} = 6.6 \times 10^{-11}\left[\frac{1\,kg}{10^{-3}\,kg}\right]^{-1} \left[\frac{1\,m}{10^{-2}\,m}\right]^3 \left[\frac{1\,s}{1s}\right]^{-2}$$

$= 6.6 \times 10^{-11} \times 10^{-3} \times 10^6 \times 1$

$G_{cgs} = 6.6 \times 10^{-8}$ dyne $cm^2\ g^{-2}$

12.Check the dimensional correctness of a given equation with the examples.

Example 1:

Consider an equation, **v = u + at**

Apply dimensions on both sides, we get,

$[LT^{-1}] = [LT^{-1}] + [LT^{-2}]\ [T^{-1}]$

$[LT^{-1}] = [LT^{-1}] + [LT^{-1}]$

Since dimensions on both sides are same, the given equation is dimensionally correct.

Example 2:

Consider an equation, $\frac{1}{2}mv^2 = mgh$

Apply dimensions on both sides, we get,

$[M]\ [LT^{-1}]^2 = [M]\ [LT^{-2}]\ [L]$

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

Since dimensions on both sides are same, the given equation is dimensionally correct.

13.Explain how to establish the relation among various physical quantities with the examples.

- If physical quantity Q depends on Q_1, Q_2 and Q_3, then we write, $Q \propto Q_1^a\, Q_2^b\, Q_3^c$

$$Q = k\, Q_1^a\, Q_2^b\, Q_3^c$$

- Where k is dimensionless constant. Applying the dimensions of Q_1, Q_2 and Q_3 and using principle of homogeneity, the powers of M, L and T are made equal on both sides. Then we get values of a, b and c to form relation.

Example 1:

Obtain an expression for the time period of T of a simple pendulum. The time period T depends upon (i) mass 'm' of the bob (ii) length 'l' of the pendulum and (iii) acceleration due to gravity 'g' at the place where the pendulum is suspended. (Constant k = 2π)

Solution:

$T \ \alpha\ m^a\, l^b\, g^c$

$T = k\, m^a\, l^b\, g^c$ -----> (1)

- Here k is dimensional constant. Applying dimensions on both sides, we get,

$[T] = [M^a]\ [L^b]\ [LT^{-2}]^c$

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

- Comparing the powers of M, L, T on both sides, a = 0, b + c = 0, -2c = 1 .
- Solving it, we get, a = 0, b =1/2, c= -1/2
- From equation (1),

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

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

Example 2:

The force F acting on a body moving in a circular path depends on mass of the body (m), velocity and radius (r) of the circular path.Obtain the expression for the force by dimensional analysis method. (Take the value of k = 1)

Solution:

$F \ \alpha\ m^a\, v^b\, r^c$

$F = k\, m^a\, v^b\, r^c$ -----> (1)

- Here k is dimensional constant. Applying dimensions on both sides, we get,

$[M\ L\ T^{-2}] = [M^a]\ [LT^{-1}]^b\ [L]^c$

$[M\ L\ T^{-2}] = [M^a\ L^{b+c}\ T^{-b}]$

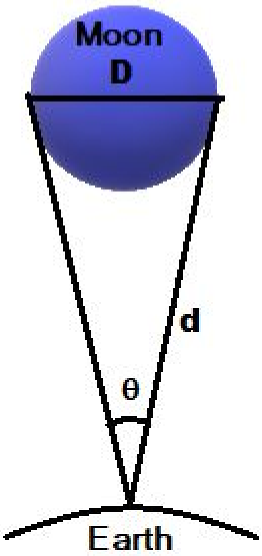
- Comparing the powers of M, L, T on both sides, a = 1, b + c = 1, -b = -2 .
- Solving it, we get, a = 1, b = 2, c= -1
- From equation (1),

$F = m^1\, v^2\, r^{-1}$

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

14. How will you measure the diameter of the Moon using parallax method?

- Let θ be the angle subtended by the Moon at the surface of the Earth.
- d is the distance of the Moon from Earth.
- D is the diameter of the Moon.



- From figure,
  Arc angle, $\theta = \frac{D}{d}$
- From this, diameter of the Moon, D = d . θ
- Knowing the values of **d** and θ, we can calculate the diameter of the Moon.

Mark distribution

Exam	Total marks	Pass mark
Theory	70	15
Practical	20	20 (or) Exam attended
Internal Assessment	10	
Total	100	35

Internal Assessment:

1. **Attendance:** 2
   Above 80% - 2 Marks
   75-80 % - 1 Mark
2. **Internal class test:** 4
   (Calculated to 4 marks from best three test)
3. **Assignment :** 2
4. **Co-curricular activities** 2
   (Any 3 activities out of 33 given)

Total : 10

External Exam:

1. Record Note 3
2. Expt. Skill 2
3. Practical Exam 15

Total : 20

Question Pattern :

Part/ Question type	Marks	No. of questions asked	No. of questions to be answered	Total marks
I 1 marks	1	15	15	15
II Short Q	2	8+1(9)	5+1(6)	12
III Brief Q	3	8+1(9)	5+1(6)	18
IV Long Q	5	5 (with internal choice)	5	25
			மொத்தம்	70

Note : Part II and Part III have one compulsory question respectively.

2. Kinematics

1. What is kinematics?

Kinematics is the branch of mechanics which deals with the motion of objects without taking force into account.

2. What is meant by Frame of reference?

Frame of reference is a coordinate system with respect to which position of an object is described.

3. What is meant by Cartesian coordinate system?

Cartesian coordinate system is the frame of reference with respect to which the position of the object is described in terms of position coordinates(x,y,z).

4. What is the point mass? Give the examples.

The mass of an object, which is concentrated at a point is called "point mass". It has no internal structures like shape and size.

Example:(i) In the event of motion of Earth around the Sun, Earth can be treated as point mass.

(ii) When stone is thrown in space, stone is considered as point mass.

5. What are the types of motion?

- Linear motion
- Circular motion
- Rotational motion
- Vibratory (or) Oscillatory motion.

6. What is linear motion? Give the examples.

When an object is moving in a straight line, it is called linear motion.

Example: (i) An athlete running on a straight track.

(ii) A particle falling vertically downwards.

7. What is circular motion? Give the examples.

When an object is moving in a circular path, it is called circular motion.

Example: (i) The whirling motion of a stone attached to a string.

(ii) The motion of a satellite around the Earth.

8. What is Rotational motion? Give the examples.

If any object is revolving about an axis, the motion is called Rotational motion.

Example: (i) Rotation of a disc about its central axis.

(ii) Spinning of the Earth about its own axis.

9. What is vibratory motion? Give the examples.

If an object executes to and fro motion about a fixed point, it is called vibratory or oscillatory motion.

Example: (i) Vibration of a string on a guitar.

(ii) movement of a swing.

10. What is one dimensional motion? Give the examples.

Motion of a particle along a straight line is called one dimensional motion.

Example: (i) Motion of a train along a straight track.

(ii) An object falling freely down under gravity.

11. What is two dimensional motion? Give the examples

Curved motion of a particle in a plane is called two dimensional motion.

Example: (i) Motion of a coin on a carrom board.

(ii) An insect crawling over the floor.

12. What is three dimensional motion?Give the examples

If a particle moving in a three dimensional space, then it is called three dimensional motion.

Example: (i) A bird flying in the sky.

(ii) Random motion of molecules.

(iii) Flying kite on a windy day.

13. What is Scalar? Give examples

A physical quantity which can be described only by magnitude is called Scalar.

Ex: Distance, mass, temperature, speed, energy, etc.,

14. What is Vector? Give examples

A physical quantity which can be described by both magnitude and direction is called Vector.

Ex: Force, velocity, displacement, acceleration, etc.,

15. How to denote a vector quantity?

A vector quantity can be geometrically represented by line arrow, in which lengh of the line denotes magnitude and arrow denotes its direction.

16. What are the types of vectors?

- Equal vectors
- Collinear vectors
- Parallel vectors
- Anti-parallel vectors
- Unit vectors
- Orthogonal unit vectors

17. What is equal vectors?

Two vectors of same physical quantity having same magnitude and direction are called equal vectors.

18. What is collinear vectors?

Two vectors acting along the same line act either both in same direction or opposite to each other are called collinear vectors.

19. What is parallel vectors?

Two vectors act in the parallel lines along the same direction are called parallel vectors.

20. What is anti-parallel vectors?

Two vectors act in the parallel lines along the opposite directions are called anti-parallel vectors.

21. What is unit vector?

A vector with unit magnitude is called unit vector. It is equal to the ratio of a vector and its magnitude.

$$\hat{A} = \frac{\vec{A}}{|\vec{A}|}$$

22. What is orthogonal unit vector?

If unit vectors are mutually perpendicular to each other, then they are called orthogonal unit vectors.

23. State triangle law of addition of two inclined vectors.

It is stated that if two vectors are represented by the two adjacent sides of a triangle in same order, then the resultant is given by the third side of the triangle in opposite order.

24. Define Scalar or Dot product of two vectors.

The scalar or dot product of two vectors is defined as the product of the magnitude of the both vectors and the cosine of the angle between them.

$$\vec{A}\cdot\vec{B} = ABCos\theta = C$$

25. Define Vector or Cross product of two vectors.

The Vector or Cross product of two vectors is defined as the product of the magnitude of the both vectors and the sine of the angle between them.

$$\vec{A}\times\vec{B} = ABSin\theta\ \hat{n} = \vec{C}$$

26. State right hand thumb rule in vector product.

According to this law, if the curvature of the right hand fingers represents rotating direction of a vector $\vec{A}$ towards another vector $\vec{B}$, then the stretched thumb points out the direction of resultant vector $\vec{C}$.

27. What is distance? Give its unit.

Distance is the actual path length travelled by an object in the given interval of time during the motion. Its unit is metre.

28. What is displacement? Give its unit.

Displacement is the shortest distance between initial and final position of the object in the given interval of time during the motion. Its unit is metre.

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29. What are the differences between distance and displacement?

S. No.	Distance	Displacement
1	It is total length of path travelled.	It is shortest distance between initial and final position of an object.
2	It is a scalar quantity.	It is a vector quantity.
3	It can be zero or positive but not negative	It can be zero, positive and negative.
4	It may be equal to or greater than the displacement.	It may be equal to or less than the distance.
5	It has many values between two positions of an object.	It has only one value between two positions of an object.

30. Define average velocity.

The average velocity is defined as the ratio of change in displacement vector to the corresponding time interval. $\vec{v}_{avg} = \frac{\Delta\vec{r}}{\Delta t}$

31. Define average speed.

The average speed is defined as the ratio of total path length travelled by the particle to a given interval of time.

32. Define speed.

The speed is defined as the change of distance with respect to time.

33. Define instantaneous velocity or velocity. Give its unit.

The velocity at an instant is defined as the change in position vector with respect to time. Its unit is ms^{-1}.

$$\vec{v} = \lim_{\Delta t\to 0}\frac{\Delta\vec{r}}{\Delta t} = \frac{d\vec{r}}{dt}$$

34. What are the differences between velocity and average velocity?

S.No	Velocity (or) Instantaneous velocity	Average velocity
1.	Velocity at an instant of time (or) Rate of change of displacement vector	Ratio of change in displacement vector to the time interval.
2.	It is measured at particular instant of time in motion.	It is measured for a given interval of time in motion.
3.	$\vec{v} = \lim_{\Delta t\to 0}\frac{\Delta\vec{r}}{\Delta t} = \frac{d\vec{r}}{dt}$	$\vec{v}_{avg} = \frac{\Delta\vec{r}}{\Delta t}$

35. What is momentum (or) linear momentum? Give its unit.

The momentum or linear momentum is the product of mass of a particle and its velocity. Its unit is kg ms^{-1} . i.e. $\vec{p} = m\vec{v}$

36. What is relative velocity?

The velocity of one object with respect to another object is called relative velocity.

37. What is uniform motion?

If an object is moving with constant velocity, then the motion is called uniform motion.

38. What is non-uniform or accelerated motion?

If an object is moving with various velocity with time, then the motion is called non-uniform or accelerated motion.

39. What is uniform accelerated motion?

If change in velocity of an object in given interval of time is constant, then the motion is called uniform accelerated motion.

40. What is non-uniform accelerated motion?

If change in velocity of an object in given interval of time is not constant, then the motion is called non-uniform accelerated motion.

41. Define average acceleration.

Average acceleration is defined as the ratio of change in velocity over the given time interval.

$$\vec{a}_{avg} = \frac{\Delta\vec{v}}{\Delta t}$$

42. Define instantaneous acceleration or acceleration. Give its unit.

The acceleration at an instant is defined as the change in velocity with respect to time. Its unit is ms^{-2}.

$$\vec{a} = \lim_{\Delta t\to 0}\frac{\Delta\vec{v}}{\Delta t} = \frac{d\vec{v}}{dt}$$

43. What is free fall of a body?

The motion of a body falling towards the Earth from a small altitude, purely under gravitational force is called free fall of a body.

44. What is meant by a projectile? Give the examples.

An object is thrown in the air with some initial velocity and allowed to move under gravity is called a projectile.

Ex:

- An object dropped from window of a moving train
- A bullet fired from a rifle.
- A ball thrown in any direction.

45. What are the types of projectile motion?

- Projectile given initial velocity in the horizontal direction.
- Projectile given initial velocity at an angle to the horizontal.

46. What are the assumptions made in projectile motion?

- Air resistance is neglected.
- The effect due to rotation of Earth and curvature of earth is negligible.
- The acceleration due to gravity is constant throughout the motion of the projectile.

47. What is trajectory?

The path followed by the projectile is called trajectory.

48. What is time of flight?

The time interval between the instant of projection and the instant when the projectile hits the ground.

49. What is horizontal range?

The maximum horizontal distance between the point of projection and the point where the projectile hits the ground.

50. What is maximum height?

The maximum vertical distance travelled by the projectile during its journey is called maximum height.

51. What is angular displacement? Give its unit.

The angle described by the particle about the axis of rotation in a given time is called angular displacement. Its unit is radian.

$$\theta = \frac{S}{r}$$

52. Define one radian.

One radian is defined as the angle subtended by the arc of unit radius and unit arc length.

53. What is angular velocity? Give its unit.

The rate of change of angular displacement is called angular velocity. Its unit is rad s^{-1} .

$$\omega = \lim_{\Delta t\to 0}\frac{\Delta\theta}{\Delta t}$$

54. What is angular acceleration? Give its unit.

The rate of change of angular velocity is called angular acceleration. Its unit is rad s^{-2} .

$$\vec{\alpha} = \lim_{\Delta t\to 0}\frac{\Delta\vec{\omega}}{\Delta t}$$

55. What is tangential acceleration?

The acceleration which is acting along the direction of linear velocity and tangent to the circular motion is called tangential acceleration.

56. What is uniform circular motion?

When an object is moving on a circular path with constant speed, it is called uniform circular motion.

57. What is non-uniform circular motion?

When an object is moving on a circular path with change in speed and direction, it is called non-uniform circular motion.

58. What is centripetal acceleration or radial acceleration or normal acceleration?

The acceleration which is acting towards the center along the radial direction and perpendicular to linear velocity of circular motion is called centripetal acceleration.

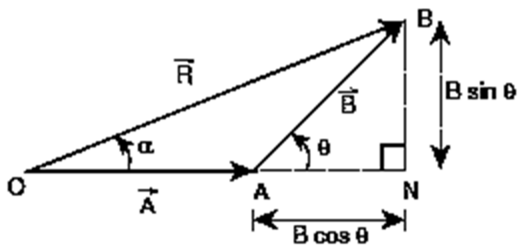
59. How do you deduce that two vectors are perpendicular?

If the scalar product of two vectors results zero, they are said to be mutually perpendicular.

5 Marks Q & A:

1. **Find the magnitude and direction of resultant of the two vectors by using triangle law of vector addition.**

- Let $\vec{A}$ and $\vec{B}$ are two vectors they are inclined at angle θ between them.
- According to triangle law of vector addition, head of the vector $\vec{A}$ is connected to tail of the vector $\vec{B}$ and both are represented in adjescent side of a triangle in some order.
- Let $\vec{R}$ be the resultant vector, which is represented in third closing side of the triangle in opposite order.
- Let α be the angle made by the resultant vector $\vec{R}$ with vector $\vec{A}$.
- Thus we can write, $\vec{R} = \vec{A} + \vec{B}$



(a) Magnitude of resultant vector :

- From ⊿ABN,

$$\cos\theta = \frac{AN}{B} \;;\; AN = B\cos\theta$$
$$\sin\theta = \frac{BN}{B} \;;\; BN = B\sin\theta$$

- From ⊿OBN,

$OB^2 = ON^2 + BN^2$

$$R^2 = (A + B\cos\theta)^2 + (B\sin\theta)^2$$

$$R^2 = A^2 + B^2\cos^2\theta + 2AB\cos\theta + B^2\sin^2\theta$$

$$R = |\vec{A} + \vec{B}| = \sqrt{A^2 + B^2 + 2AB\cos\theta}$$

(b) Direction of resultant vector :

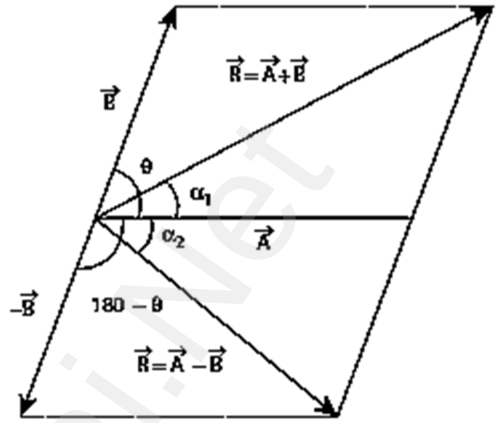
- From ⊿OBN,

$$\tan\alpha = \frac{BN}{ON} = \frac{BN}{OA + AN}$$

$$\tan\alpha = \frac{B\sin\theta}{A + B\cos\theta}$$

2. **Discuss Subtraction of two vectors geometrically and write the equations for magnitude and direction of resultant vector.**

- Let $\vec{A}$ and $\vec{B}$ are two vectors they are inclined at angle θ between them.
- Obtain $-\vec{B}$ as in figure and now angle between $\vec{A}$ and $\vec{B}$ is $180^0 - \theta$.



- Thus, Resultant $\vec{R} = \vec{A} + (-\vec{B}) = \vec{A} - \vec{B}$
- According to triangle law of vectors,

(a) Magnitude of difference :

$$R = |\vec{A} - \vec{B}| = \sqrt{A^2 + B^2 + 2AB\cos(180^0 - \theta)}$$

Since, $\cos(180^0 - \theta) = -\cos\theta$

$$|\vec{A} - \vec{B}| = \sqrt{A^2 + B^2 - 2AB\cos\theta}$$

(b) Direction of difference :

$$\tan\alpha = \frac{B\sin(180^0 - \theta)}{A + B\cos(180^0 - \theta)}$$

But $\sin(180^0 - \theta) = \sin\theta$

$$\tan\alpha = \frac{B\sin\theta}{A - B\cos\theta}$$

3. **Tabulate linear and angular equations of motion.**

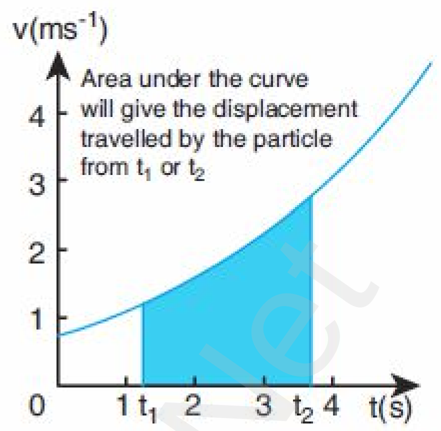
S.No.	Linear equation of motion	Angular equation of motion
1.	$v = u + at$	$\omega = \omega_0 + \alpha t$
2.	$S = ut + \frac{1}{2}at^2$	$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$
3.	$v^2 = u^2 + 2aS$	$\omega^2 = \omega_0^2 + 2\alpha\theta$
4.	$S = \left(\frac{v+u}{2}\right)t$	$\theta = \left(\frac{\omega + \omega_0}{2}\right)t$

4. Give the Comparison of the properties of Scalar and Vector product.

S. No	Scalar / Dot product	Vector / Cross product
1	Product quantity C=$\vec{A}\cdot\vec{B}$ is always a scalar. $\vec{A}\cdot\vec{B} = +ve$ if θ is acute (θ<90⁰) $\vec{A}\cdot\vec{B} = -ve$ if θ is obtuse ($90^0 > \theta < 180^0$)	Product quantity $\vec{C} = \vec{A}\times\vec{B}$ is always a Vector. $\vec{C}$ is always orthogonal to $\vec{A}$ & $\vec{B}$ but $\vec{A}$ and $\vec{B}$ may or may not be mutually orthogonal.
2	It obeys Commutative law. $\vec{A}\cdot\vec{B} = \vec{B}\cdot\vec{A}$	It doesn't obey Commutative law. $\vec{A}\times\vec{B} \neq \vec{B}\times\vec{A}$. But, $\vec{A}\times\vec{B} = -\vec{B}\times\vec{A}$ and $\lvert\vec{A}\times\vec{B}\rvert = \lvert\vec{B}\times\vec{A}\rvert$.
3	It obeys Distributive law. $\vec{A}\cdot(\vec{B}+\vec{C}) = \vec{A}\cdot\vec{B}+\vec{A}\cdot\vec{C}$	It obeys Distributive law. $\vec{A}\times(\vec{B}+\vec{C}) = \vec{A}\times\vec{B}+\vec{A}\times\vec{C}$
4	When $\vec{A}$ & $\vec{B}$ are parallel, $\theta = 0^0$, $(\vec{A}\cdot\vec{B})_{max} = AB$	When $\vec{A}$ & $\vec{B}$ are parallel, $\theta = 0^0$, $(\vec{A}\times\vec{B})_{min} = 0$
5	When $\vec{A}$ & $\vec{B}$ are anti-parallel, $\theta = 180^0$, $(\vec{A}\cdot\vec{B})_{min} = -AB$	When $\vec{A}$ & $\vec{B}$ are anti-parallel, $\theta = 180^0$, $(\vec{A}\times\vec{B})_{min} = 0$
6	When $\vec{A}$ & $\vec{B}$ are perpendicular, $\theta = 90^0$, $\vec{A}\cdot\vec{B} = 0$	When $\vec{A}$ & $\vec{B}$ are perpendicular, $\theta = 90^0$, $(\vec{A}\times\vec{B})_{max} = AB\,\hat{n}$
7	Self-dot product of a vector, $\vec{A}\cdot\vec{A} = AA\cos 0^0 = A^2$	Self-cross product of a vector, $\vec{A}\times\vec{A} = AA\sin 0^0\hat{n} = \vec{0}$
8	Self-dot product of a unit vector, $\hat{n}\cdot\hat{n} = 1\times 1\cos 0^0 = 1$ $\hat{\imath}\cdot\hat{\imath} = \hat{\jmath}\cdot\hat{\jmath} = \hat{k}\cdot\hat{k} = 1$	Self-cross product of a unit vector, $\hat{n}\times\hat{n} = 1\times 1\sin 0^0\hat{n} = \vec{0}$ $\hat{\imath}\times\hat{\imath} = \hat{\jmath}\times\hat{\jmath} = \hat{k}\times\hat{k} = \vec{0}$
9	Dot product of orthogonal unit vectors, $\hat{\imath}\cdot\hat{\jmath} = \hat{\jmath}\cdot\hat{k} = \hat{k}\cdot\hat{\imath} = 0$	Cross product of orthogonal unit vectors, $\hat{\imath}\times\hat{\jmath} = \hat{k}$; $\hat{\jmath}\times\hat{\imath} = -\hat{k}$; $\hat{\jmath}\times\hat{k} = \hat{\imath}$; $k\times\hat{\jmath} = -\hat{\imath}$; $\hat{k}\times\hat{\imath} = \hat{\jmath}$; $\hat{\imath}\times\hat{k} = -\hat{\jmath}$
10	Scalar product of vector components, $\vec{A}\cdot\vec{B} = (A_x\hat{\imath}+A_y\hat{\jmath}+A_z\hat{k})\cdot(B_x\hat{\imath}+B_y\hat{\jmath}+B_z\hat{k})$ $\vec{A}\cdot\vec{B} = A_xB_x + A_yB_y + A_zB_z$	Vector product of vector components, $\vec{A}\cdot\vec{B} = \begin{vmatrix}\hat{\imath} & \hat{\jmath} & \hat{k}\\ A_x & A_y & A_z\\ B_x & B_y & B_z\end{vmatrix} = \hat{\imath}(A_yB_z - A_zB_y) + \hat{\jmath}(A_zB_x - A_xB_z) + \hat{k}(A_xB_y - A_yB_x)$

5. Elucidate the significance of velocity – time graph.

- ❖ By using velocity – time graph we can find out the distance and displacement by calculating the area under the curve.



- ❖ We know, velocity $v = \frac{dx}{dt}$

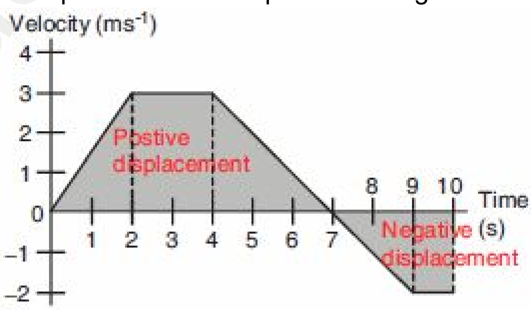
or $dx = v\,dt$

By integrating both sides, we get,

$$\int_{x_1}^{x_2} dx = \int_{t_1}^{t_2} v\,dt$$

Displacement, $x_2 - x_1$ = Area under the curve

- ❖ If area under the curve is negative, the displacement of the particle is negative



6. Discuss about relative velocity.

- ❖ When two objects A and B moving with different velocities, then the velocity of one object with respect to another is called relative velocity.

(a) <u>Case 1 :</u> A and B moving in same direction.

- ❖ Let V_A and V_B are the uniform velocities of A and B respectively.
- ❖ If A and B are moving in same direction,

The relative velocity of A with respect to B is,

$$\overrightarrow{V_{AB}} = \overrightarrow{V_A} - \overrightarrow{V_B}$$

The relative velocity of B with respect to A is,

$$\overrightarrow{V_{BA}} = \overrightarrow{V_B} - \overrightarrow{V_A}$$

- ❖ Thus, magnitude of relative velocity of one object with respect to other is equal to difference in magnitude of two velocities.

(b) Case 2 : A and B moving in opposite direction.

- Let V_A and V_B are the uniform velocities of A and B respectively.
- If A and B are moving in opposite direction,

The relative velocity of A with respect to B is,
$$\overrightarrow{V_{AB}} = \overrightarrow{V_A} - (-\overrightarrow{V_B}) = \overrightarrow{V_A} + \overrightarrow{V_B}$$

The relative velocity of B with respect to A is,
$$\overrightarrow{V_{BA}} = -\overrightarrow{V_B} - \overrightarrow{V_A} = -(\overrightarrow{V_A} + \overrightarrow{V_B})$$

- Thus, magnitude of relative velocity of one object with respect to other is equal to sum of magnitude of two velocities.

(c) Case 3 : A and B moving with an angle θ.

- Let V_A and V_B are the uniform velocities of A and B respectively inclined at an angle θ between them.
- The relative velocity of A with respect to B is
$$\overrightarrow{V_{AB}} = \overrightarrow{V_A} - \overrightarrow{V_B}$$

Then, the magnitude of $\overrightarrow{V_{AB}}$ is given by,
$$V_{AB} = \sqrt{V_A^2 + V_B^2 - 2V_A V_B cos\theta}$$

The direction of $\overrightarrow{V_{AB}}$ is given by,
$$tan\beta = \frac{V_B sin\theta}{V_A - V_B cos\theta}$$

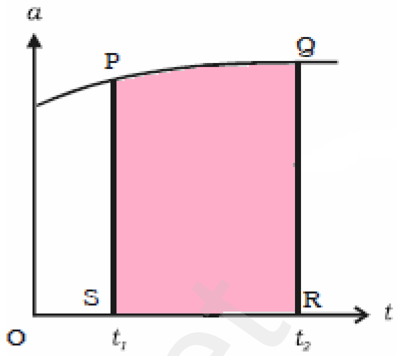
- **(1) When θ = 0°** (V_A & V_B in same direction)
  $V_{AB} = V_A - V_B$ along the direction of $\overrightarrow{V_A}$.
  $V_{BA} = V_B - V_A$ along the direction of $\overrightarrow{V_B}$.
- **(2) When θ = 180°** (V_A & V_B in opposite direction)
  $V_{AB} = V_A + V_B$ along the direction of $\overrightarrow{V_A}$.
  $V_{BA} = V_B + V_A$ along the direction of $\overrightarrow{V_B}$.
- **(3) When θ = 90°**
  (V_A & V_B in perpendicualr direction)
  $V_{AB} = \sqrt{V_A^2 + V_B^2}$ along the direction of $\overrightarrow{V_A}$.
  $V_{BA} = \sqrt{V_B^2 + V_A^2}$ along the direction of $\overrightarrow{V_B}$.

7. Write the expression for magnitude and direction of relative velocity of rain with respect to man.

- If velocity of man $\overrightarrow{V_M}$ is right angle to velocity of rain $\overrightarrow{V_R}$ falling veritically downwards, Then the relative velocity of the rain with respect to the man is,
$$\overrightarrow{V_{RM}} = \overrightarrow{V_R} - \overrightarrow{V_M}$$
- Magnitude $V_{RM} = \sqrt{V_R^2 + V_M^2}$
  Direction $\theta = tan^{-1}\frac{V_M}{V_R}$
- In order to save himself from rain he should hold the umbrella at an angle θ with the verticle.

8. Elucidate the significance of acceleration–time graph.

- By using acceleration– time graph we can find out the speed and velocity by calculating the area under the curve.



- We know, acceleration $a = \frac{dv}{dt}$
  or dv = a dt

By integrating both sides, we get,
$$\int_{v_1}^{v_2} dv = \int_{t_1}^{t_2} a\, dt$$
Velocity, $V_2 - V_1$ = Area under the curve

9. Obtain kinematic equations for uniformally accelerated motion.

- Consider an object moving along a straight line with uniform or constant acceleration ‘a’.
- Let ‘u’ be the initial velocity at time t=0 and ‘v’ be the final velocity at time t.
- Let ‘S’ be the displacement.

(a) Velocity – time relation :

- Acceleration, $a = \frac{dv}{dt}$
  or $dv = a\, dt$
- By integrating both sides, we get,
$$\int_u^v dv = \int_0^t a\, dt = a\int_0^t dt = a[t]_0^t$$
$$v - u = at$$
$$\boxed{v = u + at}$$

(b) Displacement – time relation :

- Velocity, $v = \frac{dS}{dt}$
  or $dS = v\, dt = (u + at)dt$
  $[\because v = u + at]$
- By integrating both sides, we get,
$$\int_0^S dS = \int_0^t (u + at)\, dt$$
$$\int_0^S dS = u\int_0^t dt + a\int_0^t t dt$$
$$\boxed{S = ut + \frac{1}{2}at^2}$$

(c) Velocity - displacement relation :

- Acceleration, $a = \frac{dv}{dt} = \frac{dv}{dS}\frac{dS}{dt} = \frac{dv}{dS}v$

$$ds = \frac{1}{a}v\,dv$$

- By integrating both sides, we get,

$$\int_0^S dS = \frac{1}{a}\int_u^v v\,dv = \frac{1}{a}\left[\frac{v^2}{2}\right]_u^v$$

$$S = \frac{1}{2a}(v^2 - u^2)$$

$$v^2 - u^2 = 2aS$$

$$\boxed{v^2 = u^2 + 2aS}$$

(d) Displacement – average velocity relation :

- Final Velocity, $v = u + at$

$$at = v - u \quad \text{-----> (1)}$$

- We know displacement,

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

- Substituting equation(1) , we get,

$$S = ut + \frac{1}{2}(v-u)t$$

$$S = ut + \frac{1}{2}vt - \frac{1}{2}ut$$

$$\boxed{S = \frac{(u+v)\,t}{2}}$$

10. Derive the equations of motion for a particle falling vertically.

- Consider an object of mass 'm' falling from a height h.
- Assume that there is no air resistance and acceleration due to gravity is constant near the surface of the Earth.
- If the object is thrown with an initial velocity u along the Y-axis, then its final velocity and displacement at any time 't' is v and y respectively. Further acceleration a is equal to g.
- Therefore equations of motion are,

$$v = u + gt$$

$$y = ut + \frac{1}{2}gt^2$$

$$v^2 = u^2 + 2gy$$

- Suppose initial velocity u = 0, then

$$v = gt$$

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

$$v^2 = 2gy$$

- Time taken by the object to reach the ground(T), If t= T and y = h, then

$$h = \frac{1}{2}gT^2$$

$$T = \sqrt{\frac{2h}{g}}$$

- The Speed of the object when it reaches the ground,

$$v_{ground}^2 = 2gh$$

$$v_{ground} = \sqrt{2gh}$$

11. Derive the equations of motion for a particle projected vertically upward.

- Consider an object of mass 'm' thrown vertically upward with an initial velocity u.
- Assume that there is no air resistance and acceleration due to gravity is constant near surface of the Earth.
- The final velocity and displacement at any time 't' is v and y respectively. Further acceleration a is equal to -g.
- Therefore equations of motion are,

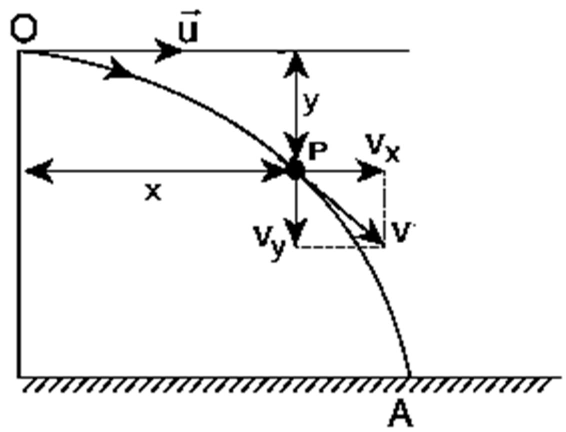
$$v = u - gt$$

$$y = ut - \frac{1}{2}gt^2$$

$$v^2 = u^2 - 2gy$$

12. Obtain the following expressions in the event of horizontal projection of a projectile from the top of a tower of height 'h' (a) the path of the projectile (b) time of flight (c) horizontal range (d) resultant velocity and (e) speed of the projectile when hits the ground.

- Consider an object is thrown horizontally with initial velocity u along x-direction.
- Since acceleration due to gravity acts vertically downwards, velocity along the horizontal x-direction u_x doesn't change throught the motion. Whereas velocity along the y-direction u_y is changed.



(a) <u>The path of the projectile :</u>

(i) Motion along horizontal direction:

- The horizontal distance travelled by the projectile at a point P after a time t can be written as,

$$S_x = u_x t + \frac{1}{2}a_x t^2$$

- Here, $S_x = x$, $u_x = u$ and $a_x = 0$, Therefore,

$$x = ut$$

$$t = \frac{x}{u} \text{ ---------> (1)}$$

(ii) Motion along downward direction:

- The downward distance travelled by the projectile at a point P after a time t can be written as,

$$S_y = u_y t + \frac{1}{2} a_y t^2$$

- Here, $S_y = y$, $u_y = 0$ and $a_y = g$, Therefore,

$$y = \frac{1}{2} g t^2$$

- Substituting equation (1), we get,

$$y = \frac{1}{2} g \left(\frac{x}{u}\right)^2 = \left(\frac{g}{2u^2}\right) x^2$$

$$y = Kx^2 \text{ --------> (2)}$$

Where $K = \frac{g}{2u^2}$ is a constant.

- The equation(2) represents the equation of a parabola. Thus, the path travelled by the projectile is a parabola.

(b) Time of flight : (T_f)

- The time of flight(T_f) is the time taken by the projectile to hit the ground after thrown.
- The downward distance travelled by the projectile at a time t can be written as,

$$S_y = u_y t + \frac{1}{2} a_y t^2$$

- Here substituting the values $S_y = h$, $t = T_f$, $u_y = 0$, and $a_y = g$ we get,

$$h = \frac{1}{2} g T_f^2$$

- Therefore, $\boxed{T_f = \sqrt{\frac{2h}{g}}}$

(c) Horizontal range : (R)

- The horizontal range(R) is the maximum horizontal distance covered by the projectile from the foot of the tower to the point where the projectile hits the ground.
- The horizontal distance travelled by the projectile at a time t can be written as,

$$S_x = u_x t + \frac{1}{2} a_x t^2$$

- Here, $S_x = R$, $u_x = u$, $a_x = 0$ and $t = T_f$

$$R = uT_f$$

- Therefore, $\boxed{R = u\sqrt{\frac{2h}{g}}}$ $\quad \left[\because T_f = \sqrt{\frac{2h}{g}}\right]$

(d) Resultant Velocity at any time : (v)

- The velocity of the projectile at point p after the time t has two components V_x and V_y.
- The velocity component along x-direction is,

$$v_x = u_x + a_x t$$

Since, $u_x = u$, $a_x = 0$, we get, $v_x = u$

- The velocity component along y-direction is,

$$v_y = u_y + a_y t$$

Since, $u_y = 0$, $a_y = g$, we get, $v_y = gt$

- Hence the resultant velocity at any time t is,

$$\vec{v} = v_x \hat{i} + v_y \hat{j}$$

$$\vec{v} = u\,\hat{i} + gt\,\hat{j}$$

- The magnitude of resultant velocity or speed is given by,

$$v = \sqrt{v_x^2 + v_y^2}$$

$$\boxed{v = \sqrt{u^2 + g^2 t^2}}$$

(e) Speed of the projectile when hits the ground :

- As the horizontal component of the velocity is same as initial velocity, $v_x = u$
- The vertical component of the velocity at a time t is,

$$v_y = u_y + a_y t$$

- Here $u_y = 0$, $a_y = g$ and $t = T_f$. Substituting this we get,

$$v_y = gT_f$$

or $$v_y = g\sqrt{\frac{2h}{g}}$$

$$v_y = \sqrt{2gh}$$

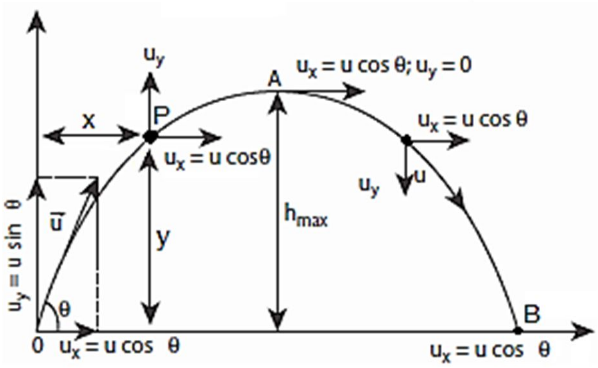
- The speed of the projectile when hits the ground,

$$v = \sqrt{v_x^2 + v_y^2}$$

$$\boxed{v = \sqrt{u^2 + 2gh}}$$

13. Obtain the following expressions in the event of angular projection of a projectile with the horizontal (a) the path of the projectile (b) maximum height (c) time of flight (d) horizontal range.

- Consider an object is thrown with initial velocity u at an angle θ with the horizontal.
- Since acceleration due to gravity acts vertically downwards, velocity along the horizontal x-direction u_x doesn't change throught the motion. Whereas velocity along the y-direction u_y is changed.



❖ **The path of the projectile :**

(i) Motion along x-direction:

❖ The horizontal distance travelled by the projectile at a point P after a time t can be written as,

$$S_x = u_x t + \frac{1}{2} a_x t^2$$

❖ Here, $S_x = x$, $u_x = u \cos\theta$ and $a_x = 0$, Therefore,

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

$$t = \frac{x}{u\cos\theta} \text{ ---------> (1)}$$

(ii) Motion along y-direction:

❖ The downward distance travelled by the projectile at a point P after a time t can be written as,

$$S_y = u_y t + \frac{1}{2} a_y t^2$$

❖ Here, $S_y = y$, $u_y = u \sin\theta$ and $a_y = -g$, Therefore,

$$y = u\sin\theta \cdot t - \frac{1}{2} g t^2$$

❖ Substituting equation (1), we get,

$$y = u\sin\theta \cdot \frac{x}{u\cos\theta} - \frac{1}{2} g \left(\frac{x}{u\cos\theta}\right)^2$$

$$y = x\tan\theta - \frac{1}{2} g \frac{x^2}{u^2\cos^2\theta}$$

❖ Thus, the path travelled by the projectile is an inverted parabola.

❖ **Maximum Height : (h_{max})**

❖ The maximum vertical distance travelled by the projectile during its journey is called maximum height.

❖ For the vertical part of the motion,

$$v_y^2 = u_y^2 + 2a_y S_y$$

❖ Here, $V_y = 0$, $S_y = h_{max}$, $u_y = u \sin\theta$ and $a_y = -g$, Therefore,

$$0 = u^2\sin^2\theta - 2gh_{max}$$

$$\boxed{h_{max} = \frac{u^2\sin^2\theta}{2g}}$$

❖ **Time of flight : (T_f)**

❖ The time of flight(T_f) is the time taken by the projectile to hit the ground after thrown.

❖ The downward distance travelled by the projectile at a time t can be written as,

$$S_y = u_y t + \frac{1}{2} a_y t^2$$

❖ Here substituting the values $S_y = 0$, $t = T_f$, $u_y = u \sin\theta$, and $a_y = -g$ we get,

$$0 = u\sin\theta . T_f - \frac{1}{2} g T_f^2$$

Therefore, $\boxed{T_f = \frac{2u\sin\theta}{g}}$

❖ **Horizontal range : (R)**

❖ The horizontal range(R) is the maximum horizontal distance distance between the point of projection and the point where the projectile hits the ground.

❖ The horizontal distance travelled by the projectile at a time t can be written as,

$$S_x = u_x t + \frac{1}{2} a_x t^2$$

❖ Here, $S_x = R$, $u_x = u \cos\theta$, $a_x = 0$ and $t = T_f$

$$R = u\cos\theta \cdot T_f$$

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

$$\left[\because T_f = \frac{2u\sin\theta}{g}\right]$$

❖ Therefore, $\boxed{R = \frac{u^2\sin 2\theta}{g}}$

$$[\because \sin 2\theta = 2\sin\theta \cdot \cos\theta]$$

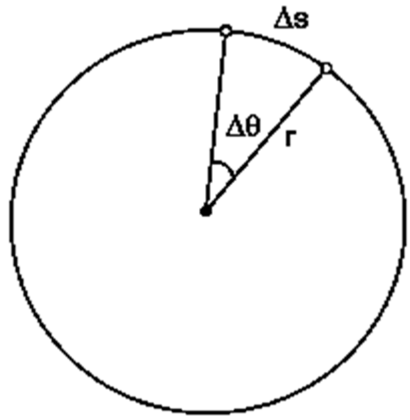
❖ For maximum range, $\sin 2\theta = 1$

$$2\theta = \frac{\pi}{2}$$

$$\theta = \frac{\pi}{4}$$

The maximum range is, $\boxed{R = \frac{u^2}{g}}$

14. Obtain the relation between linear velocity and angular velocity.



- Consider an object moving along a circle of radius r. In a time Δt, the object travels an arc distance ΔS as shown in figure. The corresponding angle subtended is $\Delta\theta$.
- From figure, the ΔS can be written as,

$$\Delta S = r\Delta\theta$$

- Dividing both sides by Δt, we get,

$$\frac{\Delta S}{\Delta t} = r\frac{\Delta\theta}{\Delta t}$$

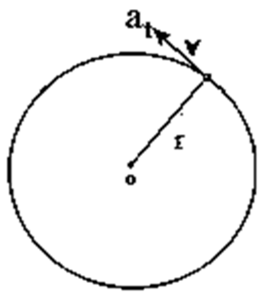
- In the limit $\Delta t \to 0$, the above equation becomes,

$$\frac{dS}{dt} = r\frac{d\theta}{dt}$$

- Here, $v = \frac{dS}{dt}$ and $\omega = \frac{d\theta}{dt}$, therefore,

$$\boxed{v = r\omega}$$

15. Derive an expression for tangential acceleration in the circular motion.



- Consider the circular motion of radius r with linear velocity v and angular velocity ω. In this,

$$v = r\omega$$

- Differentiating the above equation with respect to time, we get,

$$\frac{dv}{dt} = r\frac{d\omega}{dt}$$

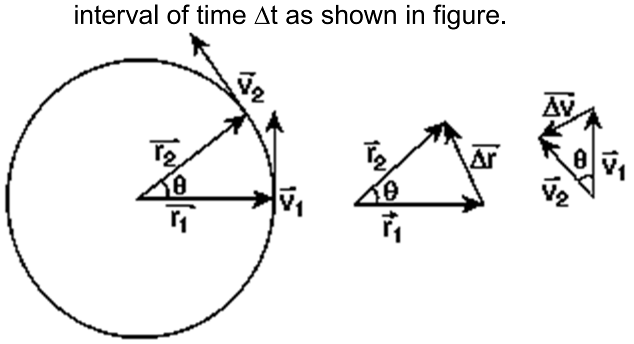
- Here, $a_t = \frac{dv}{dt}$ and $\alpha = \frac{d\omega}{dt}$, therefore,

$$\boxed{a_t = r\alpha}$$

where a_t is the tangential acceleration and α is the angular acceleration

16. Derive an expression for centripetal acceleration in the uniform circular motion.

- Consider the position vectors and velocity vectors shift through the some angle θ in a small interval of time Δt as shown in figure.



- In uniform circular motion,

$$r = |\vec{r_1}| = |\vec{r_2}| \text{ and } v = |\vec{v_1}| = |\vec{v_2}|$$

- From figure, the geometrical relationship between the magnitude of position and velocity vectors is given by,

$$\frac{\Delta r}{r} = -\frac{\Delta v}{v} = \theta$$

- Here the negative sign implies that Δv points radially inward, towards the center of the circle.

$$\Delta v = -v\left(\frac{\Delta r}{r}\right)$$

- Dividing both sides by Δt, we get,

$$\frac{\Delta v}{\Delta t} = -\frac{v}{r}\left(\frac{\Delta r}{\Delta t}\right)$$

- Applying the limit $\Delta t \to 0$, We get,

$$\frac{dv}{dt} = -\frac{v}{r}\left(\frac{dr}{dt}\right)$$

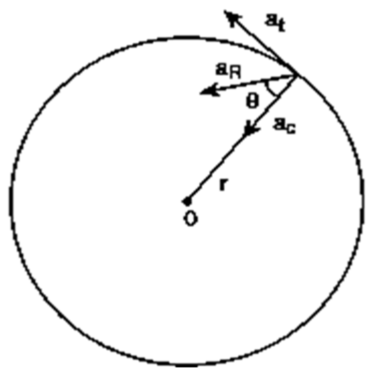
- Since $a_c = \frac{dv}{dt}$ and $v = \frac{dr}{dt}$, We can write,

$$\boxed{a_c = -\frac{v^2}{r}}$$

Where a_c is the centripetal acceleration.

17. Derive an expression for magnitude and direction of total acceleration in the non-uniform circular motion.

- Consider the non-uniform circular motion of an object. (**Ex:** vertical circular motion)
- In non-uniform circular motion both centripetal and tangential acceleration act on the object as shown in figure.



- The resultant acceleration is obtained by vector sum of centripetal and tangential acceleration.
- Hence, $\vec{a_R} = \vec{a_t} + \vec{a_c}$
- Therefore, the magnitude of resultant acceleration is given by,

$$a_R = \sqrt{a_t^2 + a_c^2}$$

$$\boxed{a_R = \sqrt{a_t^2 + \left(\frac{v^2}{r}\right)^2}} \quad \left[\because a_c = \frac{v^2}{r}\right]$$

- The angle of resultant acceleration with the radial vector is,

$$tan\theta = \frac{a_t}{a_c} = \frac{a_t}{\left(\frac{v^2}{r}\right)}$$

3. Laws of motion

1. State the Newton's first law of motion.

Every body continues its state of rest or in uniform motion until external force acting on it.

2. What is inertia? What are its types?

The inability of an object to change its state of rest or motion.

Types :

- Inertia of rest
- Inertia of motion
- Inertia of direction

3. What is inertia of rest? Give an example.

The inability of an object to change its state of rest is called inertia of rest.

Example:

When a bus start to move from rest position, all the passengers inside the bus suddenly will be pushed back. Here passengers cannot change their state of rest on its own that's why they pushed back.

4. What is inertia of motion? Give an example.

The inability of an object to change its state of motion on its own is called inertia of rest.

Example:

When a bus in motion suddenly braked, all the passengers inside the bus will move forward. Here passengers cannot change their state of motion on its own that's why they moved forward.

5. What is inertia of direction? Give an example.

The inability of an object to change its state of direction on its own is called inertia of rest.

Example:

When a stone attached to a string is in whirling motion suddenly cut out, the stone will move in the tangential direction of the circle. Here the whirling stone cannot change its state of direction on its own that's why it couldn't continue its circular motion.

6. State Newton's second law of motion.

The force acting on an object is equal to the rate of change of its momentum.

7. Define one Newton.

One Newton is defined as the force which acts on 1 kg of mass to give an acceleration 1 ms^{-2} in the direction of the force.

8. State Newton's third law.

For every action there is an equal and opposite reaction.

9. What is free body diagram?

Free body diagram is a simple tool to analyse the motion of the object using Newton's laws.

10. What are the steps followed in developing the free body diagram?

- Identify the forces acting on the object
- Represent the object as a point.
- Draw the vectors representing the forces acting on the object.

11. What is concurrent forces?

The lines of forces acting at a common point are called concurrent forces.

12. What is coplanar forces?

The lines of forces they are in the same plane are called coplanar forces.

.

13. State Lami's theorem.

If a system of three concurrent and coplanar forces is in equilibrium, each force is directly proportional to sine of the angle between the other two forces.

14. State law of conservation of total linear momentum.

If there is no external force acting on the system, the total linear momentum of the system is always a constant vector.

15. What is impulsive force or impulse? Give its unit.

If a very large force acts on an object in a very short time, the force is called impulsive force.Its unit is Ns.

$$J = F \times \Delta t$$

16. Illustrate the average force with the examples.

- When a cricket player catches the ball, he pulls his hands gradually in the direction of the ball's motion because to reduce average large force which hurts his hands.
- When a car meets with an accident, the air bag system inside a car prevents the passengers by reducing average forces acting on them.
- When a two wheeler bumps on the road, the shock absorbers make comfort to rider by reducing average force.
- Jumping on a concrete cemented road is more dangerous than jumping on the sand since the sand reduces the average force on jumping.

17. What is meant by static friction?

Static friction is the force which opposes the initiation of motion of an object on the surface.

18. What is meant by kinetic friction?

Kinetic friction is the force which opposes the motion of an object during movement.

19. Define angle of friction.

The angle of friction is defined as the angle between the normal force(N) and resultant force(R) of normal force and maximum friction force(f_s^{max}).

20. Define angle of repose.

The angle of repose is defined as the angle of the inclined plane at which the object starts to slide.

21. Describe the applications of angle of repose.

- Antilons make sand traps in such way that its angle of inclination is made equal to angle of repose. So that insects enter the edge of the trap start to slide towards the bottom where the antilons hide itself.
- Children sliding boards are always inclined just above the angle of repose. So that children playing on that slide smoothly. At the same time, much greater inclined angle may hurt the sliding children.

22. Compare the static and kinetic friction.

S.No.	Static friction	Kinetic friction
1.	It opposes initiation of motion.	It opposes relative motion of the object with respect to the surface.
2.	Independent of surface contact	Independent of surface contact
3.	μ_s depends on the nature of material in mutual contact.	μ_k depends on the nature of material and temperature of the surface.
4.	Depends on the magnitude of applied force.	Independent of magnitude of applied force.
5.	It takes values from 0 to μ_sN.	It is always equal to μ_kN.
6.	$f_s^{max} > f_k$	$f_k < f_s^{max}$
7.	$\mu_s > \mu_k$	$\mu_k < \mu_s$

23. State the empirical laws of static and kinetic friction.

- The empirical law of static friction states that the static frictional force is directly proportional to the normal force. i.e. $f_s = \mu_s N$ where, $0 \le f_s \le \mu_s N$.
- The empirical law of kinetic friction states that the kinetic frictional force is directly proportional to the normal force. i.e. $f_k = \mu_k N$.

24. What is rolling friction?

The rolling friction is the minimal force, which opposes the rotational motion of the wheel on the surface.

25. What is centripetal force?

If a particle is in uniform circular motion with respect to an inertial frame, there is a force acting towards the center of the circle is called centripetal force.

26. Suggest a few methods to reduce friction.

- By using lubricants in machinary parts.
- By using ball bearings.

27. What is meant by pseudo force?

The pseudo force is a fictitious force. It is just an apparent but it makes real effect. It is represented only in non-inertial frames.

Example : centrifugal force.

28. What are inertial frames?

The frame of reference, which is not accelerated, is known as inertial frame. Newton's laws are applicable in these frames.

29. What are non-inertial frames?

The frame of reference, which is accelerated, is known as non-inertial frame. Newton's laws are not applicable in these frames.

30. Illustrate the centripetal force with the examples.

- In the whirling motion of a stone tied with a string, the centripetal force is given by tensional force through the string.
- In the motion of satellites around the Earth, the gravitational force gives the centripetal force.
- When a car is moving on a circular track, the frictional force between road and tyre gives the centripetal force.
- When the planets orbit around the Sun experience the centripetal force towards the sun is given by the gravitational force of the Sun.

31. What is meant by banking of tracks?

When the coefficient of static friction is not enough on the leveled circular road, the outer edge of the road is slightly raised compared to the inner egde to avoid skidding. It is called banking of tracks.

32. What is centrifugal force?

If a particle is in circular motion with respect to a non-inertial frame, there is a pseudo force acting away from the center of the circle is called centrifugal force.

33. Compare the centripetal and centrifugal forces.

S.No.	Centripetal force	Centrifugal force
1.	It is a real force given by external agencies like gravitational force, tensional force, normal force,etc.	It is a pseudo force or fictitious force cannot be derived from any external agencies.
2.	Acts in both inertial and non-inertial frames	Acts only in non-inertial frames(rotating frames)
3.	It acts towards the axis of rotation or center of the circular motion.	It acts away from the axis of rotation or center of the circular motion
4.	Real force and has real effects.	Pseudo force but has real effects.
5.	It orginates from interaction of two objects	It orginates from inertia of the object.
6.	It is included in free body diagram for both inertial and non-inertial frames.	It is included in free body diagram for only non-inertial frames.
7.	Magnitudely it is equal to centrifugal force.	Magnitudely it is equal to centripetal force.

Conceptual Questions:

34. Why it is not possible to push a car from inside?

It is not possible to push a car from inside because the pushing force is equalised by the reactional force of the car seat.

35. There is a limit beyond which polishing of a surface increases frictional resistance rathar than decreasing it why?

Polishing the surface beyond the certain limit induces the electrostatic addisive force on the surface, which will inturn developes the frictional resistance.

36. Can a single isolated force exist in nature? Explain your answer.

No. It cannot. According to Newton's third law "For every action there is an equal and opposite reaction". So the forces always exist in pairs.

37. Why does a parachute descend slowly?

The large area covered by the parachute experiences more air resistive force acting opposite to downward gravitational force. So that the parachute descends slowly.

38. When we walk on ice one should take short steps. Why?

As the surface of the ice is very smooth, in order to avoid skidding, short steps help us to make necessary static friction to walk.

39. When a person walks on a surface, the frictional force exerted by the surface on the person is opposite to the direction of motion. True or false?

False. When the person walks on the surface, he pushes the surface backward, whereas surface gives frictional force forward which is in the direction of motion.

40. Can the coefficient of friction be more than one?

Yes. The coefficient of friction can be more than one. It means friction is greater than normal force. For example, rubber has coefficient of friction 1.16.

41. Can we predict the direction of motion of a body from the direction of force on it?

No. It cannot. The direction of motion can be along the direction of force or opposite to force or perpendicular force or without the force.

42. The momentum of a system of particle is always conserved. True or false?

False. The momentum of a system of particle is conserved only when external force acting on it is zero.

43. When you walk on the tiled floor where water is spilled, you are likely to slip. Why?

Water on tiled floor reduces the coefficient of friction of the surface. So when we walk on wet tile, it drags our leg to slide. Now the friction becomes kinetic friction, which is much weaker than static friction. That's why we likely to slip.

44. When a bicycle moves in the forward direction, what is the direction of frictional force in the rear and front wheels?

- When a bicycle moves in the forward direction, static friction in the rear wheel acts forward.
- So that front wheel gets backward static friction. When wheels slip friction becomes kinetic friction.
- In addition to static friction, rolling friction also acts both wheels in the backward direction.

45. Under What condition will a car skid on a leveled circular road?

When a car moves on a leveled circular road with greater speed, static friction given by road not able provide enough centripetal force to turn. So that car will start to skid.

46. It is dangerous to stand near the open door (or) steps while travelling in the bus. Why?

When the bus takes sudden turn, the person standing near the open door or steps is pushed away from the bus due to centrifugal force.

5 Marks Q & A:

1. Discuss the significance of Newton's laws.

(a) Newton's laws are vector laws.

- From Newton's 2nd law, $\vec{F} = m\vec{a}$
- It can be written in the components as,

$$F_x\hat{\imath} + F_y\hat{\jmath} + F_z\hat{k} = ma_x\hat{\imath} + ma_y\hat{\jmath} + ma_z\hat{k}$$

- By comparing components on both sides,
- $F_x = ma_x$. The acceleration along x-direction depends on component of force along x direction.
- $F_y = ma_y$. The acceleration along y-direction depends on component of force along y direction.
- $F_z = ma_z$. The acceleration along z-direction depends on component of force along z direction.
- So that Force acting along one direction doesn't affect force acting along the other direction.

(b) The acceleration experienced by the body at time depends only on the force at that instant.

- Time dependent force can be written as,

$$\vec{F}(t) = m\vec{a}(t)$$

- So that acceleration of the object doesn't depend on the previous history of the force.
- For example, when a ball is bowled, the acceleration of the ball leaves the hand doesn't depend on the force in which it is bowled.

(c) Direction of motion doesn't depend on the direction of force.

Case(i): Force and motion in the same direction.

When an apple falls from a tree, direction of motion of the apple is along the gravitational force.

Case(ii): Force and motion not in the same direction.

The Moon experiences a force in different direction when it revolves elliptically around the Earth.

Case(iii): Force and motion in the opposite direction.

If an object is thrown vertically upwards, the direction of motion and gravitational force are opposite.

Case(iv): Zero net force, but there is motion.

When a raindrop gets detached from the cloud, downward gravitational force is equalised by the air drag (viscous) force in upward direction in certain time. Now raindrops moves with constant velocity without the net force till the surface of the Earth.

(d) Net force of multiple forces provides acceleration.

If multiple forces $\vec{F_1}, \vec{F_2}, \vec{F_3}, \ldots \vec{F_n}$ act on the same body, then the total force ($\vec{F}_{net}$) is equal to the vector sum of the individual forces. Their net force provides the acceleration.

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots + \vec{F}_n$$

(e) Newton's 2nd law is second order differential equation

- Since the acceleration is the second order derivative of position vector of the body, i.e. $\left[\vec{a} = \frac{d^2\vec{r}}{dt^2}\right]$ the force can be written as,

$$\vec{F} = m\vec{a} = m\frac{d^2\vec{r}}{dt^2}$$

- So that Newton's 2nd law is second order differential equation.

(f) Newton's first and second laws are internally consistent.

- If force acting on the body is zero, according to Newton's 2nd law,

$$m\frac{d\vec{v}}{dt} = 0$$

- It implies $\vec{v}$ = constant. It is essentially Newton's first law. Though Newton's 2nd law is internally consistent with first law, it cannot be derived from each other.

(g) Newton's second law is cause and effect relation.

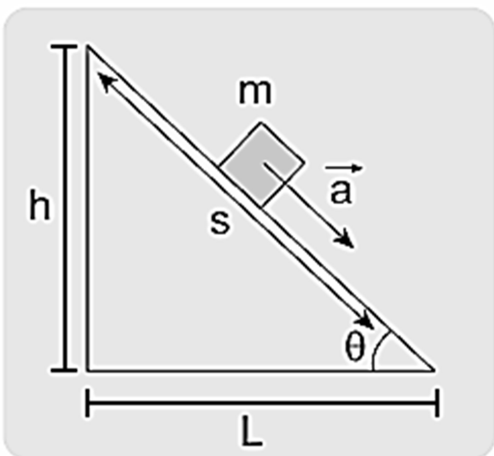
- Since Newton's 2nd law is cause and effect relation, conventionally cause (Force) should be written in right and effect ($m\vec{a}$) in the left of the equation.

$$m\vec{a} = \vec{F}$$

$$\frac{d\vec{p}}{dt} = \vec{F}$$

2. Obtain the expressions for acceleration and speed of an object moving in an inclined plane.

- When an object of mass m slide on a frictionless inclined surface at an angle θ.
- The forces acting on the object is (i) Downward gravitational force (ii) Normal force perpendicular to the inclined surface.



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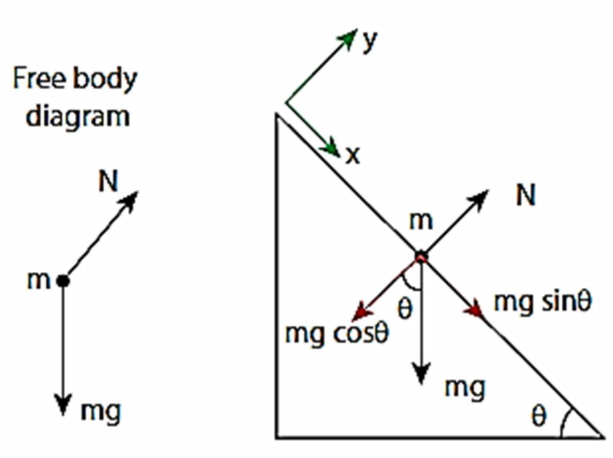
- To draw free body diagram the block is assumed to be point mass. Now the coordinate system is taken parallel to inclined surface.
- The gravitational force mg is resolved into mgsinθ and mgcosθ. They are parallel and perpendicular to inclined surface respectively.
- The angle made by the mg with mg cosθ is θ as shown in figure.



- As the normal force N is compensated by mgcosθ, there is no motion along y-axis.

$$-mgcos\theta\hat{j} + N\hat{j} = 0$$
$$N\hat{j} = mgcos\theta\hat{j}$$

- Comparing components on both sides,

$$N = mgcos\theta$$

- Since the component mgsinθ is not compensated by any force, the object starts to slide along x-direction. By using Newton's 2nd law, We write,

$$mgsin\theta\hat{\imath} = ma\hat{\imath}$$

- Comparing components on both sides,

$$mgsin\theta = ma$$

- The acceleration of the object is, $\boxed{a = gsin\theta}$
- If θ =90^0 , the object moves vertically downward with acceleration *a = g* .
- Applying 3rd equation of motion along x-direction, we get,

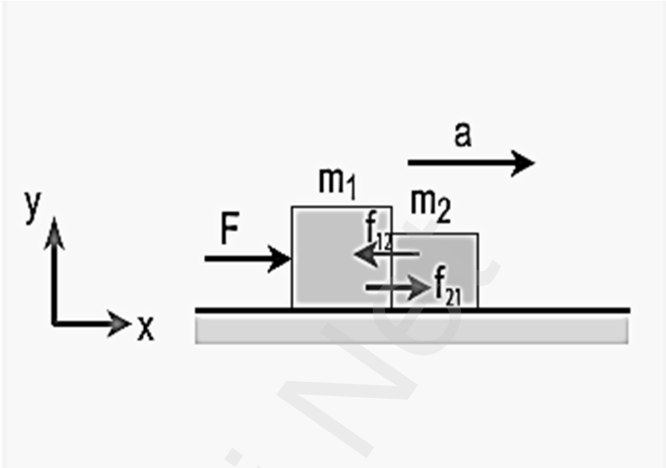
$$v^2 = u^2 + 2aS$$

- Here the initial speed u = 0 and a = gsinθ , the speed of the object sliding can written as,

$$\boxed{v = \sqrt{2Sg\ sin\theta}}$$

3. Obtain the expressions for acceleration of two bodies of different masses and show that forces acting on each other is equal and opposite.

- Consider two blocks of masses m_1 and m_2 (m_1>m_2) kept in contact with each other on horizontal frictionless surface as shown in figure.



- By the application of a horizontal force F, both the blocks move with acceleration a simultaneously along F.
- If m = m_1 + m_2 , according to Newton's 2nd law,

$$\vec{F} = m\vec{a}$$

- If motion is along x-direction,

$$F\hat{\imath} = ma\hat{\imath}$$

- Comparing the components on both sides,

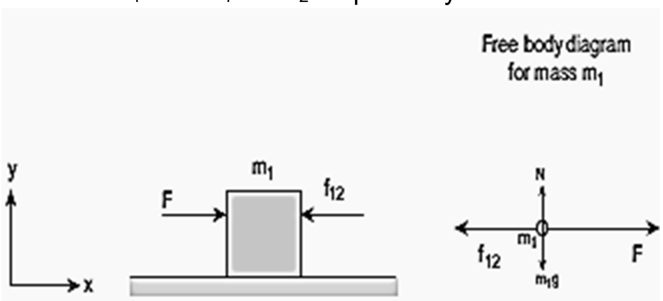
$$F = ma$$
$$F = (m_1 + m_2)a \qquad [m = m_1 + m_2]$$

- The acceleration of the system is given by,

$$\boxed{a = \frac{F}{m_1 + m_2}}$$

<u>Proof :</u> **Forces acting on each other is equal and opposite.**

- Let f_{12} and f_{21} are forces of contact exerted by m_2 on m_1 and m_1 on m_2 respectively.



- According to the above free body diagram,

$$F\hat{\imath} - f_{12}\hat{\imath} = m_1a\hat{\imath}$$

- By comparing the components, we get,

$$F - f_{12} = m_1a$$
$$f_{12} = F - m_1a$$

- Substituting the value of 'a', we get,

$$f_{12} = F - m_1\left(\frac{F}{m_1 + m_2}\right)$$

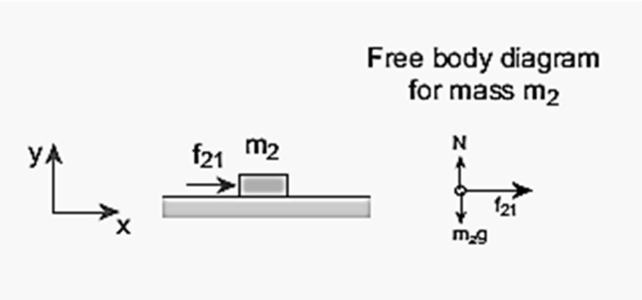
$$f_{12} = F\left[1 - \frac{m_1}{m_1 + m_2}\right]$$

$$f_{12} = \frac{Fm_2}{m_1 + m_2}$$

- In vector form, the contact force on m_1 by m_2 is given by,

$$\vec{f}_{12} = -\frac{Fm_2}{m_1 + m_2}\hat{\imath}$$

The –ve sign indicates that $\vec{f}_{12}$ is along negative x-direction.



- According to the above free body diagram,

$$f_{21}\hat{\imath} = m_2 a\hat{\imath}$$

- By comparing the components, we get,

$$f_{21} = m_2 a$$

- Substituting the value of 'a', we get,

$$f_{21} = \frac{Fm_2}{m_1 + m_2}$$

- In vector form, the contact force on m_1 by m_2 is given by,

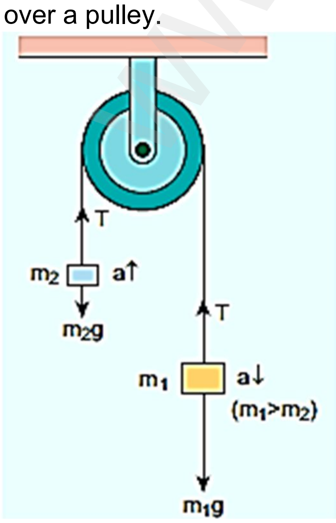
$$\vec{f}_{21} = \frac{Fm_2}{m_1 + m_2}\hat{\imath}$$

$\vec{f}_{21}$ is along positive x-direction.

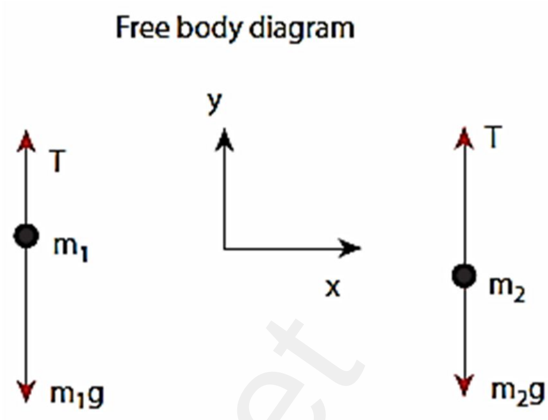
- Therefore, $\vec{f}_{12} = -\vec{f}_{21}$, which confirm Newton's 3rd law.

Explain the motion of blocks connected by a string in verticle direction.

- Consider two blocks of masses m_1 and m_2 (m_1>m_2) are connected by a light inextensible string that passes over a pulley.



- Let T be the tension in the string. When the system is released m_1 moves downward and m_2 moves upward with the same acceleration 'a'.



(a) To find acceleration:

- Applying Newton's 2nd law for m_2, we get,

$$T\hat{\jmath} - m_2 g\hat{\jmath} = m_2 a\hat{\jmath}$$

- Comparing the components on both sides,

$$T - m_2 g = m_2 a \quad \text{------> (1)}$$

- Applying Newton's 2nd law for m_1, we get,

$$T\hat{\jmath} - m_1\hat{\jmath} = -m_1 a\hat{\jmath}$$

The –ve sign on R.H.S denotes m_1 moves along the negative y-direction.

- Comparing the components on both sides,

$$T - m_1 g = -m_1 a$$

$$m_1 g - T = m_1 a \quad \text{-------> (2)}$$

- Adding equations (1) & (2), we get,

$$m_1 g - m_2 g = m_1 a + m_2 a$$

$$(m_1 - m_2)g = (m_1 + m_2)a$$

$$a = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)g \quad \text{---→ (3)}$$

- If $m_1 = m_2$, then a = 0. It shows if masses are equal whole system will be at rest.

- In vector form, $\vec{a} = -\left(\frac{m_1 - m_2}{m_1 + m_2}\right)g\,\hat{\jmath}$ for m_1

$$\vec{a} = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)g\,\hat{\jmath} \quad \text{for } m_2$$

(b) To find the tension in the string :

- Substituting equation (3) in (1), we get,

$$T - m_2 g = m_2\left(\frac{m_1 - m_2}{m_1 + m_2}\right)g$$

$$T = m_2 g + m_2\left(\frac{m_1 - m_2}{m_1 + m_2}\right)g$$

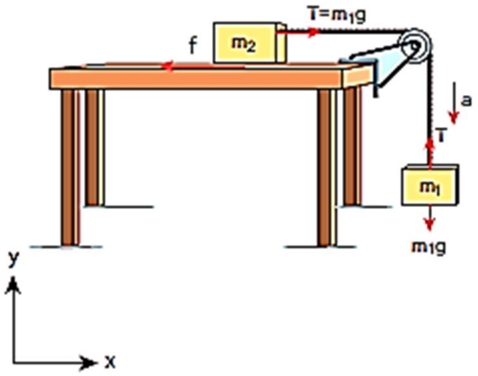
$$T = m_2 g\left(1 + \frac{m_1 - m_2}{m_1 + m_2}\right)$$

$$T = m_2 g\left(\frac{m_1 + m_2 + m_1 - m_2}{m_1 + m_2}\right)$$

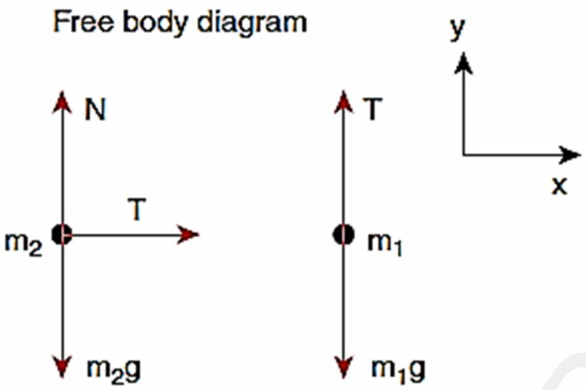
$$T = \left(\frac{2m_1 m_2}{m_1 + m_2}\right)g$$

5. Explain the motion of blocks connected by a string in horizontal direction.

- Consider the m_2 is kept on a frictionless horizontal table.The mass m_2 is connected with hanging mass m_1 by a string which pass through a small pulley as shown in figure.



- As both the blocks are connected to the unstretchable string, m_1 moves downward and m_2 moves horizontal with same acceleration.
- Forces acting on m_1 and m_2 are as shown in free body diagram.



- Applying Newton's 2[nd] law for m_1, we get,

$$T\hat{j} - m_1 g\hat{j} = -m_1 a\hat{j}$$

- Comparing the components on both sides,

$$T - m_1 g = -m_1 a \text{ ------> (1)}$$

- Applying Newton's 2[nd] law for m_2, we get,

$$T\hat{i} = m_2 a\hat{i}$$

- Comparing the components on both sides,

$$T = m_2 a \text{ ------> (2)}$$

- As gravitation force on m_2 and Normal force are balanced, there is no vertical acceleration in m_2.

$$N\hat{j} - m_2 g\hat{j} = 0$$

- Comparing the components on both sides,

$$N - m_2 g = 0$$
$$N = m_2 g$$

- Substituting equation (2) in (1), we get,

$$m_2 a - m_1 g = m_1 a$$
$$m_2 a + m_1 a = -m_1 g$$
$$\boxed{a = \left(\frac{m_1}{m_1 + m_2}\right) g} \longrightarrow (3)$$

- Substituting equation (3) in (2), we get,

$$\boxed{T = \left(\frac{m_1 m_2}{m_1 + m_2}\right) g}$$

- It is shown that tension in the string for horizontal motion is half that in vertical motion for same m_1 and m_2.

6. State and Prove the law of conservation of linear momentum.

- **Statement :** If there is no external force acting on the system, the total linear momentum of the system is always a constant vector.
- When two particles interact with each other, F_{12} and F_{21} are the forces exerted by the particle 2 on 1 and by the particle 1 on 2 respectively.
- According to Newton's 3[rd] law,

$$\vec{F}_{12} = -\vec{F}_{21} \text{------->(1)}$$

- According to Newton's 2[nd] law,

$$\vec{F}_{12} = \frac{d\vec{p}_1}{dt} \quad and \quad \vec{F}_{21} = \frac{d\vec{p}_2}{dt} \longrightarrow (2)$$

Here p_1 and p_2 are the linear momentum of particle 1 and 2.

- Substituting equation (2) in (1), we get,

$$\frac{d\vec{p}_1}{dt} = -\frac{d\vec{p}_2}{dt}$$
$$\frac{d\vec{p}_1}{dt} + \frac{d\vec{p}_2}{dt} = 0$$
$$\frac{d}{dt}(\vec{p}_1 + \vec{p}_2) = 0$$
$$\boxed{\vec{p}_1 + \vec{p}_2 = constant}$$

- Hence the the total linear momentum ($\vec{p}_1 + \vec{p}_2$) of the system is a constant vector.

7. Using conservation of linear momentum, find the recoil velocity of a gun when a bullet is fired from it.

- Consider $\vec{p}_1$ and $\vec{p}_2$ are the initial momentum of a bullet and a gun before firing.
- Since initially both the gun and bullet are at rest,

$$\vec{p}_1 = 0 \;\; and \;\; \vec{p}_2 = 0$$

- Hence, total linear momentum before firing can be written as,

$$\vec{p}_1 + \vec{p}_2 = 0$$

- When the gun is fired, the momentum of the bullet changes from $\vec{p}_1$ to $\vec{p}_1'$ and the momentum of the gun changes from $\vec{p}_2$ to $\vec{p}_2'$.
- According to conservation of linear momentum, total linear momentum after firing must be equal to total linear momentum before firing. So that,

$$\vec{p}_1' + \vec{p}_2' = 0 \text{ ------> (1)}$$

- Let m_b & m_g are the mass of the bullet and the gun and v_b & v_g are the velocity and recoil velocity of the bullet and the gun respectively.
- Hence $\vec{p}_1'$ and $\vec{p}_2'$ can be written as,

$$\vec{p}_1' = m_b \vec{v}_b \quad \text{and} \quad \vec{p}_2' = m_g \vec{v}_g$$

- Substituting the valus of $\vec{p}_1'$ and $\vec{p}_2'$ in equation (1), we get,

$$m_b \vec{v}_b + m_g \vec{v}_g = 0$$

- Hence, the recoil velocity of the gun is given by,

$$\vec{v}_g = -\frac{m_b}{m_g} \times \vec{v}_b$$

8. Obtain the impulse – momentum equation.

- If a large force F acts on a object in a very short time dt, Newton's 2nd law can be written as,

$$F = \frac{dp}{dt}$$

$$dp = F\,dt$$

- Integrating over the time from an initial time t_i to a final time t_f, we get

$$\int_{p_i}^{p_f} dp = \int_{t_i}^{t_f} F\,dt$$

Here p_i and p_f are the initial and final momentum at time t_i and t_f .

- If force F is constant over the time interval, then

$$\int_{p_i}^{p_f} dp = F \int_{t_i}^{t_f} dt$$

$$p_f - p_i = F(t_f - t_i)$$

$$\boxed{\Delta p = F\Delta t} \text{ ------>(1)}$$

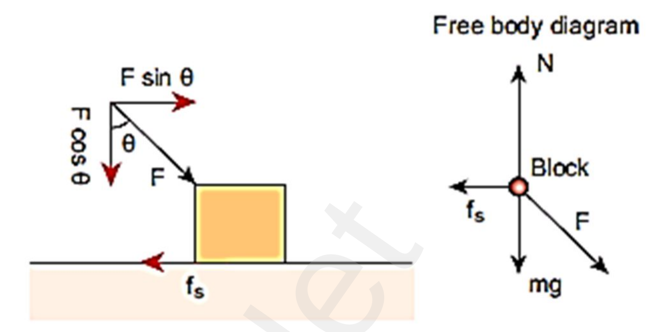
$$\Delta p = J \qquad [\because J = F\,\Delta t]$$

- Here $\Delta p = p_f - p_i$, change in momentum and $\Delta t = t_f - t_i$, time interval.
- The equation (1) is called momentum – impulse equation.

9. Using free body diagram, show that it is easy to pull an object than push it.

(a) Pushing an object :

- When an object is pushed at an arbitrary angle θ, the applied force F can be resolved into two components as shown in figure.



- From the diagram the normal force N is balance by the total downward force mg + Fcosθ. Thus,

$$N_{push} = mg + F\cos\theta$$

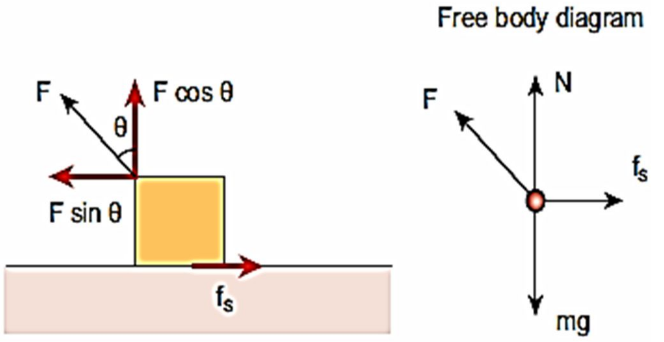
- In this case, maximum static friction f_s^{max} can be written as,

$$f_s^{max} = \mu_s N_{push}$$

$$f_s^{max} = \mu_s (mg + F\cos\theta) \text{ --->(1)}$$

(b) Pulling an object :

- When an object is pulled at an arbitrary angle θ, the applied force F can be resolved into two components as shown in figure.



- From the diagram the normal force N is balance by the total downward force mg - Fcosθ. Thus,

$$N_{pull} = mg - F\cos\theta$$

- In this case, maximum static friction f_s^{max} can be written as,

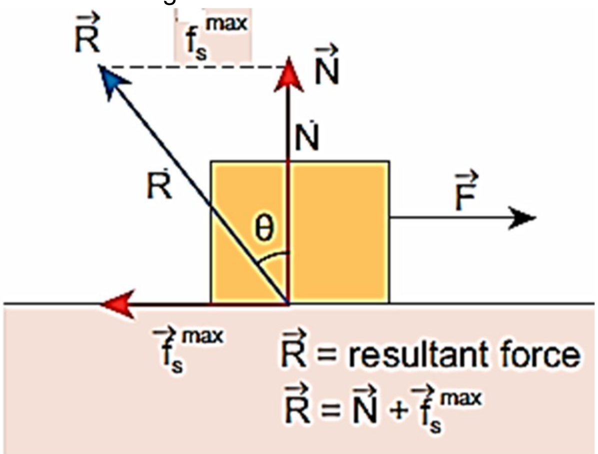
$$f_s^{max} = \mu_s N_{pull}$$

$$f_s^{max} = \mu_s (mg - F\cos\theta) \text{--->(2)}$$

- From equation (1) and (2), to overcome f_s^{max} and to move the object, it is easier to pull an object than to push it.

10. Prove that the coefficient of static friction is equal to tangent of the angle of friction.

- Let N be the normal force, f_s^{max} be the maximum friction force, R be the resultant force of N and f_s^{max} and θ be the angle between R and f_s^{max} as shown in figure.



- From the figure, the resultant force is given by,

$$R = \sqrt{(f_s^{max})^2 + N^2}$$

- And from the figure,

$$tan\theta = \frac{f_s^{max}}{N}$$

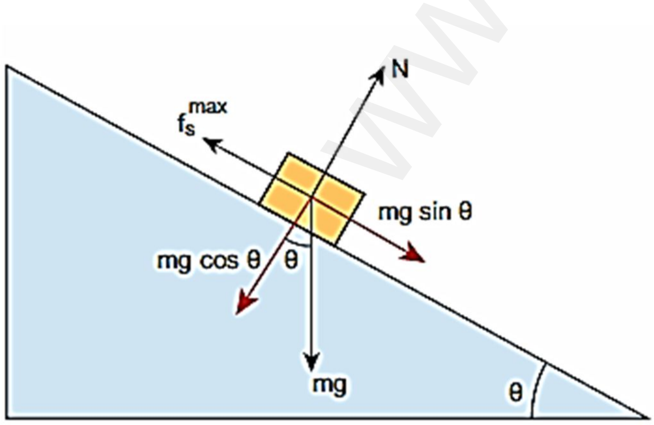
- Since $f_s^{max} = \mu_s N$, $\quad \mu_s = \frac{f_s^{max}}{N}$
- Hence, $tan\theta = \mu_s$

or $\boxed{\mu_s = tan\theta}$

- Therefore, the coefficient of static friction is equal to tangent of the angle of friction.

11. Show that in an inclined plane, the angle of friction is equal to angle of repose.

- Consider an inclined plane on which an object is placed as shown in figure.



- Let θ be the angle of inclined plane with the horizontal, which is made equal to the angle of repose. So that the object placed on it start to slide.
- From the figure, the component mg cosθ is balanced by Normal force N can be written as,

$$N = mg\,cos\theta$$

- When the object start to slide, the maximum static friction is given by,

$$f_s^{max} = \mu_s N$$

$$f_s^{max} = \mu_s\, mg\, cos\theta \text{ ----->(1)}$$

- From the figure, f_s^{max} can also be wrtten as,

$$f_s^{max} = mg\, sin\theta \text{ ----->(2)}$$

- Equating equation (1) and (2), we get

$$\mu_s\, mg\, cos\theta = mg\, sin\theta$$

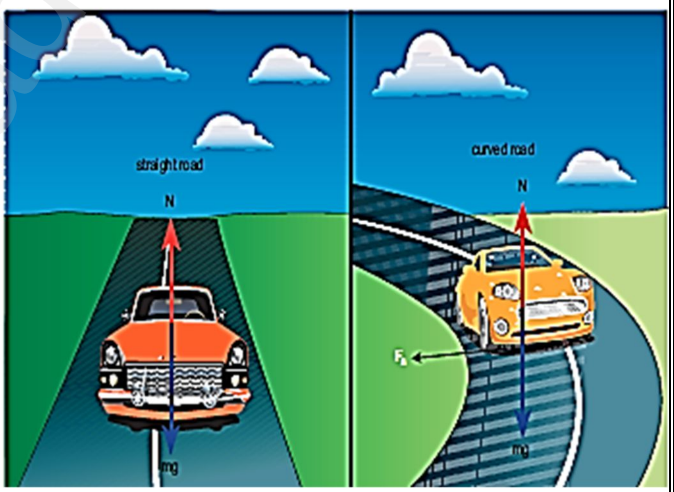
$$\mu_s = \frac{sin\theta}{cos\theta}$$

$$\boxed{\mu_s = tan\theta} \text{ ------> (3)}$$

- It shows that equation (3) is like the definition of angle of friction $\mu_s = tan\theta$ where θ is the angle of friction.
- Thus, the angle of repose θ in equation (3) is same as the angle of friction.

12. Obtain the conditions for safe and unsafe(skid) turn of a car on a leveled circular road.

- Consider a car of mass 'm' moving at a speed 'v' in the circular track of radius 'r' .



- When the car is on the road, the normal force N is balanced by gravitational force mg is given by,

$$N = mg$$

- When the car turns on the circular track, the static friction provides the centripetal force can be expressed as,

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

- As we know, $F_s \le \mu_s mg$, there are two conditions possible.

(a) For safe turn :

$$\frac{mv^2}{r} \leq \mu_s mg \quad (or) \ \mu_s \geq \frac{v^2}{rg} \quad (or) \quad \sqrt{\mu_s rg} \geq v$$

- In this case static friction gives necessary centripetal force to bend the car on the road.
- Here the co-efficient of friction between tyre and the surface of the road determines what maximum speed the car can have for safe turn.

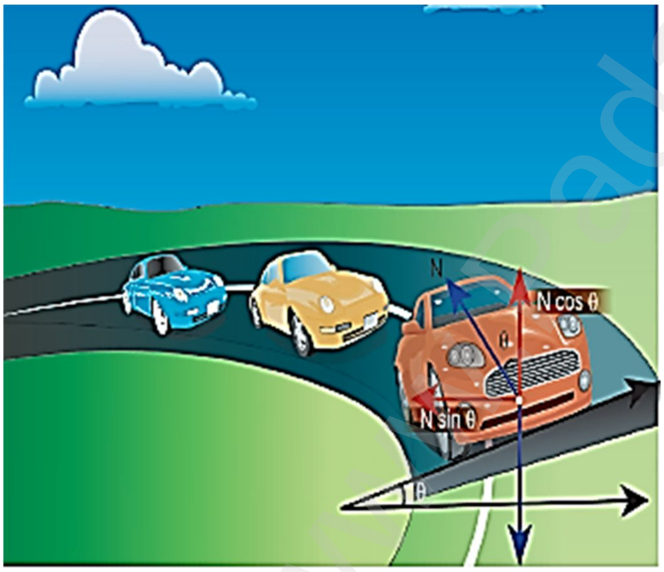
(b) For unsafe(skid) turn :

$$\frac{mv^2}{r} > \mu_s mg \quad (or) \ \mu_s < \frac{v^2}{rg}$$

- In this case, static friction is not able to provide enough centripetal force to turn, the car will start to skid.

13. Obtain the expression for safe speed of a car when it turns on a banking of tracks and discuss how it prevents from skidding.

- Consider a banking of track, whose outer edge is raised at an angle θ with the horizontal as shown in figure.



- So that the normal force makes same angle θ with the vertical, can be resolved into N cosθ and N sinθ
- From the diagram, the component N cosθ is balanced by mg is written as,

$$N\,cos\theta = mg \quad \text{----->}\ (1)$$

- From the diagram, the centripetel force is given by N sinθ can be written as,

$$N\,sin\theta = \frac{mv^2}{r} \longrightarrow (2)$$

- Dividing equation (2) by (1), we get

$$tan\theta = \frac{v^2}{rg}$$

$$v = \sqrt{rg\,tan\theta}$$

- The banking angle θ and radius of curvature of the road or track(r) determines the safe speed of the car at the turning.
- When the car just exceeds the safe speed, it will start to skid outward but the frictional force will provide additional centripetal force to prevent the outward skidding.
- When the car little slows the safe speed, it will start to skid inward but frictional force will reduce centripetal force to prevent the inward skidding.
- However, frictional force cannot prevent the car from skidding when the car speed is much greater than the safe speed.

14. Calculate the centripetal acceleration of moon towards the Earth.

- The centripetal acceleration is given by,

$$a = \frac{v^2}{r} = r\omega^2 \qquad [\because v = r\omega]$$

- If R_m is the distance between Earth and the Moon, r = R_m. The centripetal acceleration of the Moon due to Earth's gravity is written as,

$$a_m = R_m\omega^2$$

- As we know the angular velocity, $\omega = \frac{2\pi}{T}$

$$a_m = R_m\left(\frac{2\pi}{T}\right)^2 = R_m\frac{4\pi^2}{T^2}$$

- Here, R_m = 60R = 60 x 6.4 x 10^6 = 384 x 10^6 m [R – Radius of the Earth]

  T = 27.3 days = 27.3 x 24 x 60 x 60 =2.358 x 10^6 s
- Substituting the values, we get,

$$a_m = \frac{384 \times 10^6 \times 4 \times 3.14 \times 3.14}{2.358 \times 10^6 \times 2.358 \times 10^6}$$

$$a_m = 0.00272\ m\,s^{-2}$$

- The centripetal acceleration of the Moon towards the Earth, $a_m = 0.00272\ m\,s^{-2}$

4. Work, Enegy and Power

1. What is work? Give its SI unit and dimension.
- Work is said to be done by the force when the force applied on a body displaces it. Its SI unit is joule.

$$W = \vec{F}.\vec{dr} = F\ dr\ cos\theta$$

- Work is a scalar quantity. Its dimentional formula is $[ML^2T^{-2}]$.

2. Explain how the definition of work in physics is different from general perception.
- In general, any activity refers to work. It may be physical or mental work.
- But in Physics, work is treated as a physical quantity with a precise definition.

3. Define Energy. Give its SI unit and dimension.
- Energy is defined as the capacity to do work. Its SI unit is joule.
- Energy magnitudely equal to work. It is also a scalar. Its dimension is $[ML^2T^{-2}]$.

4. Write some other units used in energy and equate them to joule.
- 1 erg (CGS unit) = 10^7 J
- 1 electron volt (1 eV) = 1.6×10^{-19} J
- 1 calorie (1 cal) = 4.186 J
- 1 kilowatt hour (1kWh) = 3.6×10^6 J =1 unit.

5. What are the types of mechanical energy?
- Kinetic energy.
- Potential energy.

6. What is Kinetic energy?

The energy possessed by a body by virtue of its motion is called Kinetic energy.

7. State Work – Kinetic energy theorem.

The work done by the force on the body changes the kinetic energy of the body. This is called Work – Kinetic energy theorem.

8. What is Potential energy?

The energy possessed by a body by virtue of its its position is called Potential energy.

9. What are the types of Potential energy?
- Gravitational potential energy.
- Elastic potential energy.
- Electrostatic potential energy.

10. What is elastic potential energy?

The potential energy possessed by a spring due to a deforming force which stretches or compress the spring is termed as elastic potential energy.

11. What is conservative force? Give examples.
- If the work done by or against the force in moving body doesn't depend the nature of the path between initial and final position of the body, the force is called conservative force.
- **Example:** Elastic spring force, electrostatic force, magnetic force, gravitational force, etc.

12. What is non-conservative force?Give examples.
- If the work done by or against the force in moving body depends on the path between initial and final position of the body, the force is called non-conservative force.
- **Examples:** Frictional forces, viscous force

13. Write difference between conservative and non-conservative forces.

S. No.	Conservative force	Non-conservative force
1.	It is independent of path.	It depends on the path.
2.	Work done in a round trip is zero.	Work done in a round trip is not zero.
3.	Work done is completely recoverable.	Work done is not completely recoverable.
4.	Total energy remains constant.	Energy dissipated as heat energy.
5.	Force is the negative gradient of potential energy.	No such relation exist.

14. State law of conservation of energy.

The law of conservation of energy states that energy can neither be created nor be destroyed. One form of energy can be transformed to another form but total energy of an isolated system remains constant.

15. Define power. Give its unit.
- Power is defined as the rate of work done or energy delivered. Its unit is watt.
- $Power(P) = \frac{Work\ done(W)}{Time\ taken(t)}$

16. Define average power.
- The average power is defined as the ratio of the total work done to the total time taken.
- $Average\ Power(P_{avg}) = \frac{Total\ Work\ done}{Total\ Time\ taken}$

17. Define instantaneous power.
- The instantaneous power is defined as the power delivered at an instant. (i.e $\Delta t \rightarrow 0$)
- $P_{avg} = \frac{dw}{dt}$

18. Define one watt.

One watt is defined as the power when one joule of work is done in one second.

19. Write some other units used in power and equate them to watt.
- 1 kW = 10^3 W
- 1 MW = 10^6 W
- 1 GW = 10^9 W
- 1 hp (horse power) = 746 W

20. What is meant by collision? Give the examples.
- The interaction of two bodies with or without physical contacts, is known as collision.
- **Examples:** Carom, billiards, marbles, etc.

21. What are the types of collisions?
- Elastic collision.
- Inelastic collision.

22. What is elastic collision? Give an example.
- The collision in which total kinetic energy before collision is equal to the total kinetic energy after collision, is known as elastic collision.
- **Example:** electron-electron collision.

23. What is inelastic (or) plastic collision? Give an example.
- The collision in which total kinetic energy before collision is not equal to the total kinetic energy after collision, is known as inelastic collision.
- **Example:** Clay putty or bubblegum is thrown on a moving vehicle.

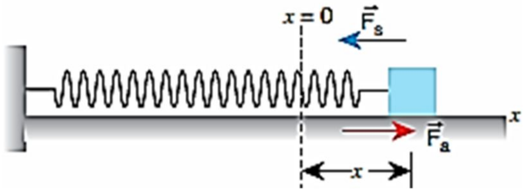
24. Compare between elastic and inelastic collisions.

S. No.	Elastic collision	Inelastic collision
1.	Total momentum is conserved.	Total momentum is conserved.
2.	Total kinetic energy is conserved.	Total kinetic energy is not conserved.
3.	Forces involved are conservative forces.	Forces involved are non-conservative forces.
4.	Mechanical energy is not dissipated.	Mechanical energy is dissipated into heat, light, sound, etc.

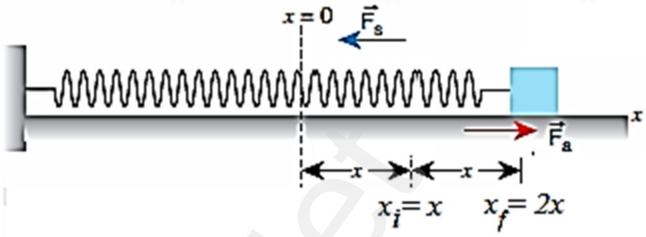
25. Define COR (or) coefficient of restitution(e).
- It is defined as the ratio of velocity of seperation after collision to the velocity of approach before collision.
- In general, values of COR(**e**) lies beween 0<e<1.
- For perfect elastic collision, e = 1.
- For perfect inelastic collision, e = 0.

Conceptual Questions:

26. A spring which initially in unstretched condition, is first stretched by a length x and again by a further length x. The work done in the first case W_1 is one third of the work done in second case W_2 . True or false?
- True.



- In 1st case, $x_i = 0$ and $x_f = x$
- $W_1 = \frac{1}{2}k(x_f^2 - x_i^2) = \frac{1}{2}k(x^2 - 0) = \frac{1}{2}kx^2$



- In 2nd case, $x_i = x$ and $x_f = 2x$
- $W_2 = \frac{1}{2}k(x_f^2 - x_i^2)$
- $W_2 = \frac{1}{2}k(4x^2 - x^2) = \frac{1}{2}3kx^2 = 3W_1$
- Therefore, $W_1 = \frac{W_2}{3}$

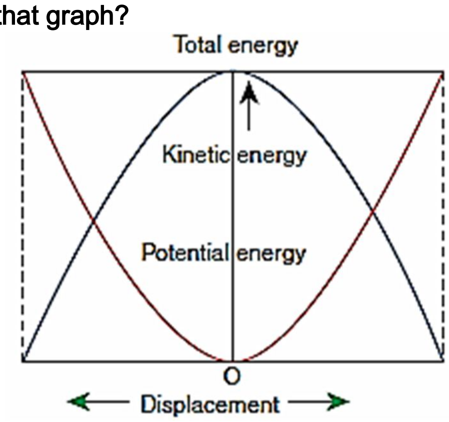
27. Which is conserved in inelastic collision? Total energy (or) Kinetic energy?

Total energy, because in the inelastic collison total kinetic energy after the collision is changed.

28. Is there any net work done by external forces on a car moving with a constant speed along a straight road?

No. When the car is moving with constant speed in a straight road, according to Newton's law there will be no acceleration and external force. Hence, there is no external work done on a car.

29. A car starts from rest and moves on a surface with uniform acceleration. Draw the graph of kinetic energy versus displacement. What information do you can get from that graph?



In a frictionless environment, the energy gets transferred from kinetic to potential and potential kinetic repeatedly such that the total energy of the car remains constant.

30. A charged particle moves towards another charged particle. Under what conditions the total momentum and the total energy of the system conserved?

When they undergo collision process, the total momentum and the total energy of the system are conserved.

5 Marks Q & A:

1. Write a brief note on work done.

❖ Work is said to be done by the force when the force applied on a body displaces it. Its SI unit is joule.

$$W = \vec{F}.\overrightarrow{dr} = F\ dr\ cos\theta$$

❖ Work is a scalar quantity. Its dimentional formula is $[ML^2T^{-2}]$.

❖ The work done by the force depends on the force (F), displacement(dr) and the angle(θ) between them.

❖ Work done is zero in the following cases.

(i) **When the force is zero (F =0)**
Ex: A body is moving on a horizontal frictionless surface without force.

(ii) **When the displacement is zero (dr =0)**
Ex: When force is applied on a regid wall, there is no dispalcement.

(iii) **When the force and displacement are perpendicular (θ = 90°)**
Ex: When a body moves in a horizontal direction, the gravitational force and displacement are perpendicular to each other.

❖ Work done is negative, when the force and displacement are opposite to each other.

Ex: When the goal keeper catches the ball in foot ball game, the applied force and displacement of the ball are opposite to each other till the ball comes to rest.

2. Describe the work done by a constant force.

❖ When a constant force F acts on a body, the small work done(dw) by the force for the smaller displacement(dr) is given by,

$$dw = (Fcos\theta)dr$$

❖ The total work done from initial (r_i) and final (r_f) dispalcement is given by,

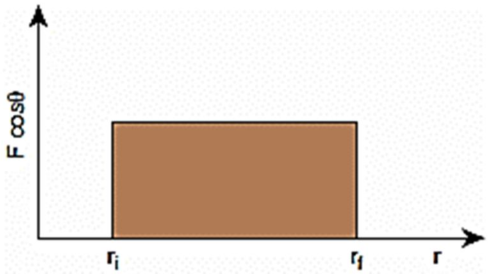
$$W = \int_{r_i}^{r_f} dW$$

$$W = \int_{r_i}^{r_f} (Fcos\theta)\,dr$$

$$W = (Fcos\theta)\int_{r_i}^{r_f} dr$$

$$W = (Fcos\theta)(r_f - r_i)$$

❖ The graphical representation of the work done by a constant force is shown in figure.



3. Describe the work done by a variable force.

❖ When a variable force F acts on a body, the small work done(dw) by the force for the smaller displacement is given by,

$$dw = (Fcos\theta)dr$$

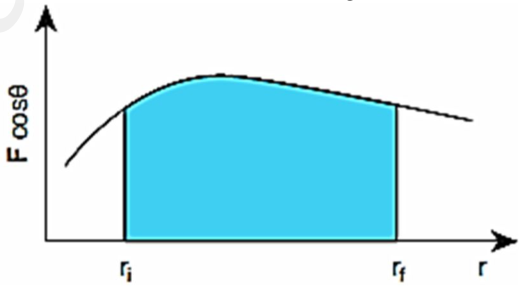
Where F and θ are variables.

❖ The total work done from initial (r_i) and final (r_f) dispalcement is given by,

$$W = \int_{r_i}^{r_f} dW$$

$$W = \int_{r_i}^{r_f} (Fcos\theta)\,dr$$

❖ The graphical representation of the work done by a variable force is shown in figure.



4. State and prove Work – Energy theorem.

❖ Work-Energy theorem: The work done by the force on the body changes the kinetic energy of the body.

❖ Cosider a body of mass m at rest on a frictionless horizontal surface.

❖ The work(W) done by the constant force (F) for a displacement (s) in the same direction is,

$$W = Fs \text{ --------> (1)}$$

❖ The constant force is given by,

$$F = ma \text{ -------> (2)}$$

❖ The 3rd equation of motion can be written as,

$$v^2 = u^2 + 2as$$

$$a = \frac{v^2 - u^2}{2s}$$

- Substituting the value of 'a' in equation(2), we get,

$$F = m\left(\frac{v^2 - u^2}{2s}\right) --\rightarrow (3)$$

- Substituting equation(3) in (1), We have,

$$W = m\left(\frac{v^2 - u^2}{2s}\right)s$$

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

- As the right hand side of the equation represents change in kinetic energy(ΔKE) of the body, then we can write,

$$\boxed{W = \Delta KE}$$

- This is the equation of Work-Energy theorem.

5. Derive the relation between momentum and kinetic energy.

- Consider an object of mass m moving with a velocity $\vec{v}$.
- The linear momentum is, $\vec{p} = m\vec{v}$ ------->(1)
- KInetic energy is, $KE = \frac{1}{2}mv^2$ ---------->(2)
- Multiply and divide the equation(2) by 'm',we get,

$$KE = \frac{1}{2}\frac{m^2(\vec{v}.\vec{v})}{m}$$

$$KE = \frac{1}{2}\frac{(m\vec{v}).(m\vec{v})}{m}$$

$$KE = \frac{1}{2}\frac{(\vec{p}.\vec{p})}{m} \qquad [\because p = mv]$$

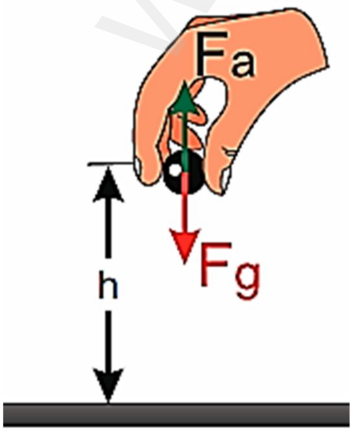
$$KE = \frac{p^2}{2m} \qquad [\because \vec{p}.\vec{p} = p^2]$$

- The magnitude of linear momentum can be written as,

$$\boxed{p = \sqrt{2m(KE)}}$$

6. Derive an expression for the potential energy near the surface of the Earth.

- Consider a body of mass m being moved from ground to the height h against the gravitational force as shown in figure.



- The gravitational force force acting on the body is,

$$\vec{F}_g = -mg\,\hat{j}$$

- If the body is lifted with constant velocity, the applied force (F_a) is equal and opposite to the gravitational force (F_g). So that,

$$\vec{F}_a = -\vec{F}_g = mg\,\hat{j}$$

- The gravitational potential energy(U) can be written as,

$$U = \int \vec{F}_a \cdot \overrightarrow{dr} = \int |\vec{F}_a||\overrightarrow{dr}|cos\theta$$

- Since the force and displacement are in the same direction, $\theta = 0^0$. Hence, $cos0^0 = 1$, $|\vec{F}_a| = mg$ and $|\overrightarrow{dr}|$= dr.

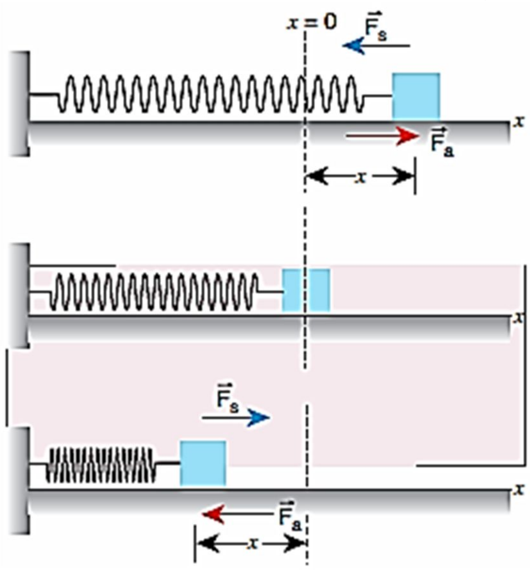
$$U = mg\int_0^h dr$$

$$U = mg[r]_0^h$$

$$\boxed{U = mgh}$$

7. Obtain an expression for elastic potential energy of a spring stretched along horizontal direction.

- Consider a spring-mass system. One end of the spring is fixed to a rigid wall and the other end is attached to the mass 'm', which is placed on a smooth horizontal table as shown in figure.



- Here x=0 is the equilibrium position of the mass. In this position potential energy is zero.
- Now the spring is stretched by a distance 'x' along the direction of applied force $\vec{F}_a$.
- So that a restoring force($\vec{F}_s$) is set in the spring, which is equal and opposite to the applied force.

$$\vec{F}_a = -\vec{F}_s$$

- According to Hooke's law,

$$\vec{F_s} = -k\vec{x}$$

The –ve sign indicates that the spring force is always opposite to the displacement $\vec{x}$. Here k is the force constant.

- Now the applied force can be written as,

$$\vec{F_a} = k\vec{x}$$

- The work done by the applied force on the spring stretched to a smaller displacement $\overrightarrow{dx}$, is stored as elastic potential energy(dU).

$$dU = \vec{F_a} \cdot \overrightarrow{dx} = |\vec{F_a}||\overrightarrow{dx}|cos\theta$$

- For the displacement $\vec{x}$,

$$U = \int dU = \int_0^x F_a\, dx\, cos\theta$$

- Since $F_a = kx$ and θ = 0, the potential energy can be written as,

$$U = \int_0^x kx\, dx$$

$$U = k\left[\frac{x^2}{2}\right]_0^x$$

$$U = \frac{1}{2}kx^2$$

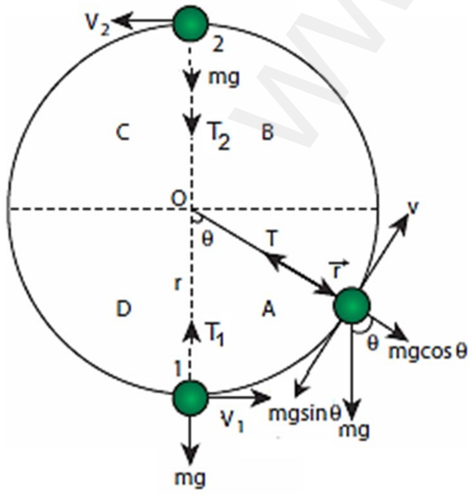
- If the position of the mass changed from x_i to x_f , the potential energy can be written as,

$$U = \tfrac{1}{2}k\left(x_f^2 - x_i^2\right)$$

- Thus, we observe that the elastic potential energy depends on force constant k and elongation or compression x.

8. Obtain an expression for difference in tension of a string at lowest and highest points of a vertical circular motion of a body. Also find minimum speed of the body at lowest and highest points.

- Consider a body mass 'm' attached to one end of a massless inextensible string, which executes vertical circular motion as shown in figure.



- Let $\vec{r}$ be the radius of the circle, which is equal to length of the string, and θ be the angle made by the radial vector $\vec{r}$ with the vertical downward direction.

- In the tangential direction, applying Newton's 2nd law,

$$mgsin\theta = ma_t$$

$$mgsin\theta = -m\left(\frac{dv}{dt}\right) ---\to (1)$$

Where $a_t = -\frac{dv}{dt}$ is tangential retardation.

- In the radial direction,

$$T - mgcos\theta = ma_r$$

$$T - mgcos\theta = \frac{mv^2}{r} ---\to (2)$$

Where $a_r = \frac{v^2}{r}$ is the centripetal acceleration.

- Consider v_1 , T_1 and v_2 , T_2 are the velocities and tensions at lowest point 1 and highest point 2 respectively.

- <u>Tension at lowest point (1) :</u>
Here θ = 0^0 , T= T_1 and v = v_1 . Substituting these values in equation (2), we get,

$$T_1 - mg = \frac{mv_1^2}{r}$$

$$T_1 = \frac{mv_1^2}{r} + mg ---\to (3)$$

- <u>Tension at highest point (2) :</u>
Here θ = 180^0 , T= T_2 and v = v_2 . Substituting these values in equation (2), we get,

$$T_2 + mg = \frac{mv_2^2}{r}$$

$$T_2 = \frac{mv_2^2}{r} - mg ---\to (4)$$

- From equations (3) & (4), it is seen that $T_1 > T_2$.

- <u>Difference in tension :</u>
Subtracting equation(4) from (3), we get,

$$T_1 - T_2 = \frac{mv_1^2}{r} + mg - \frac{mv_2^2}{r} + mg$$

$$T_1 - T_2 = \frac{m}{r}[v_1^2 - v_2^2] + 2mg ---\to (5)$$

- Applying law of conservation of energy at point 1 and 2, we have,
Total energy at point 1 = Total energy at point 2

$$E_1 = E_2$$

$$U_1 + KE_1 = U_2 + KE_2 ---\to (6)$$

Where U_1 , U_2 and KE_1 , KE_2 are the potential and kinetic energies at points 1 and 2.

- Here $U_1 = 0$ (since point 1 is base point), $U_2 = mg(2r)$, $KE_1 = \frac{1}{2}mv_1^2$ and $KE_2 = \frac{1}{2}mv_2^2$, So that from equation(6),

$$0 + \frac{1}{2}mv_1^2 = mg(2r) + \frac{1}{2}mv_2^2$$

- Rearranging we get,

$$\frac{1}{2}m(v_1^2 - v_2^2) = 2mgr$$
$$v_1^2 - v_2^2 = 4gr \longrightarrow (7)$$

- Substituting equation(7) in (5), we have,

$$T_1 - T_2 = \frac{m}{r}[4gr] + 2mg$$

- Therefore, the difference in tension is,

$$\boxed{T_1 - T_2 = 6mg}$$

- **Minimum speed at the highest point (2) :** If the tension $T_2 = 0$, the body will get minimum speed to move on vertical circle. Therefore, from equation (4), we get,

$$0 = \frac{mv_2^2}{r} - mg$$
$$\frac{mv_2^2}{r} = mg$$
$$v_2^2 = rg$$
$$\boxed{v_2 = \sqrt{gr}} \longrightarrow (8)$$

- Hence, the body must have a speed $v_2 \geq \sqrt{gr}$ at point 2 to stay in the circular path.
- **Minimum speed at the lowest point (1) :** To have minimum speed at point 2, the body must have minimum speed at point 1.
- From equation(7),

$$v_1^2 - v_2^2 = 4gr$$

- Substituting $v_2 = \sqrt{gr}$, we get,

$$v_1^2 - gr = 4gr$$
$$v_1^2 = 5gr$$
$$\boxed{v_1 = \sqrt{5gr}} \longrightarrow (9)$$

- Hence, the body must have a speed $v_1 \geq \sqrt{5gr}$ at point1 to stay in the circular path.
- From equations (8) and (9), it is clear that, the minimum speed v_1 at point 1 should be $\sqrt{5}$ times greater than the minimum speed v_2 at point 2 in order to loop the circle.

9. Derive the relation between power and velocity.

- The work done by a force $\vec{F}$ for a displacement $\vec{dr}$ can be written as,

$$dw = \vec{F} \cdot \vec{dr}$$

- Dividing by 'dt' on both sides,

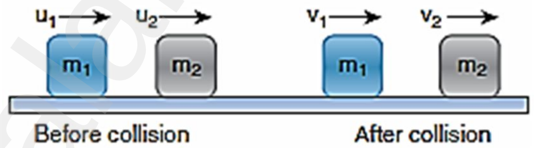
$$\frac{dw}{dt} = \vec{F} \cdot \frac{\vec{dr}}{dt}$$

- But, the power $P = \frac{dw}{dt}$ and the velocity $\vec{v} = \frac{\vec{dr}}{dt}$, Therefore,

$$\boxed{P = \vec{F} \cdot \vec{v}}$$

10. Arrive at an expression for elastic collision in one dimension and discuss various cases.

- Consider two elastic bodies of masses m_1 and m_2 moving in a straight line along +ve x-direction on a frictionless horizontal surface as shown in figure.



- Let u_1 & v_1 and u_2 & v_2 be the initial and final velocities of masses m_1 & m_2 respectively.
- When $u_1 > u_2$, collision happends. For elastic collision, the total linear momentum and kinetic energies of two masses before and after collision must remain same.
- According to law of conservation of linear momentum,

$$\begin{Bmatrix}\text{Total linear momentum} \\ \text{before collision } (p_1)\end{Bmatrix} = \begin{Bmatrix}\text{Total linear momentum} \\ \text{after collision } (p_2)\end{Bmatrix}$$

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$
$$m_1(u_1 - v_1) = m_2(v_2 - u_2) \longrightarrow (1)$$

- For elastic collision,

$$\begin{Bmatrix}\text{Total kinetic energy} \\ \text{before collision } (KE_1)\end{Bmatrix} = \begin{Bmatrix}\text{Total kinetic energy} \\ \text{after collision } (KE_2)\end{Bmatrix}$$

$$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$$
$$m_1(u_1^2 - v_1^2) = m_2(v_2^2 - u_2^2)$$
$$m_1(u_1 + v_1)(u_1 - v_1) = m_2(v_2 + u_2)(v_2 - u_2) \longrightarrow (2)$$

- Dividing equation (2) by (1), we get,

$$\frac{m_1(u_1 + v_1)(u_1 - v_1)}{m_1(u_1 - v_1)} = \frac{m_2(v_2 + u_2)(v_2 - u_2)}{m_2(v_2 - u_2)}$$
$$u_1 + v_1 = v_2 + u_2$$
$$u_1 - u_2 = v_2 - v_1$$
$$u_1 - u_2 = -(v_1 - v_2) \longrightarrow (3)$$

- It shows that for any elastic head on collision, relative speed before collision is equal and opposite to relative speed after collision.
- From equation (3),

$$v_1 = v_2 + u_2 - u_1 \longrightarrow (4)$$

and

$$v_2 = u_1 + v_1 - u_2 \longrightarrow (5)$$

- **To find final velocities v_1 and v_2 :**
Substituting equation(5) in (1), we get,

$$m_1(u_1 - v_1) = m_2(u_1 + v_1 - u_2 - u_2)$$
$$m_1(u_1 - v_1) = m_2(u_1 + v_1 - 2u_2)$$
$$m_1u_1 - m_1v_1 = m_2u_1 + m_2v_1 - 2m_2u_2$$
$$m_1u_1 - m_2u_1 + 2m_2u_2 = m_1v_1 + m_2v_1$$
$$(m_1 - m_2)u_1 + 2m_2u_2 = (m_1 + m_2)v_1$$
$$v_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)u_1 + \left(\frac{2m_2}{m_1 + m_2}\right)u_2 \longrightarrow (6)$$

- Simillarly, substituting equation(4) in (1), we get,

$$v_2 = \left(\frac{2m_1}{m_1 + m_2}\right)u_1 + \left(\frac{m_2 - m_1}{m_1 + m_2}\right)u_2 \longrightarrow (7)$$

Case 1: When two bodies have same mass. i.e. $m_1 = m_2$

- From equations (6) & (7),
$v_1 = u_2$ and $v_2 = u_1$
- It shows that after collision their velocities are exchanged.

Case 2 : When two bodies have same mass and second mass is at rest. i.e. $m_1 = m_2$ & $u_2 = 0$.

- From equations (6) & (7),
$v_1 = 0$ and $v_2 = u_1$
- It shows that after collision when 1st body comes to rest, the 2nd body moves with the initial velocity of 1st body.

Case 3 : The 1st body is very much lighter than 2nd body and second mass is at rest.. i.e. $m_1 << m_2$ & $u_2 = 0$.

- In this case, $m_1 + m_2 \approx m_2$ and $\frac{m_1}{m_2} \approx 0$
- From equation (6),

$$v_1 = \left(\frac{m_1}{m_2} - 1\right)u_1 + 2\,u_2$$
$$v_1 = (0 - 1)u_1 + 2\,(0)$$
$$v_1 = -u_1$$

- From equation (7),

$$v_2 = \left(2 \times \frac{m_1}{m_2}\right)u_1 + \left(1 - \frac{m_1}{m_2}\right)u_2$$
$$v_2 = (0)u_1 + 1\,(0)$$
$$v_2 = 0$$

- It shows that after collision 1st body returns back with its initial velocity and the 2nd body remains at rest.

Case 4 : The 2nd body is very much lighter than 1st body and second mass is at rest.. i.e. $m_2 << m_1$ & $u_2 = 0$.

- In this case, $m_1 + m_2 \approx m_1$ and $\frac{m_2}{m_1} \approx 0$
- From equation (6),

$$v_1 = \left(1 - \frac{m_2}{m_1}\right)u_1 + \left(2 \times \frac{m_2}{m_1}\right)u_2$$
$$v_1 = (1 - 0)u_1 + 0$$
$$v_1 = u_1$$

- From equation (7),

$$v_2 = 2\,u_1 + \left(\frac{m_2}{m_1} - 1\right)u_2$$
$$v_2 = 2\,u_1 + (0 - 1)\,(0)$$
$$v_2 = 2\,u_1$$

- It shows that after collision 1st body moves with its initial velocity and the 2nd body moves with two times the initial velocity of 1st body.

11. Arrive an expression for common velocity after collision in one-dimensional perfect inelastic collision of two bodies.

- Consider a perfect inelastic collision of two masses m_1 and m_2 moving in a straight line along +ve x-direction on a frictionless horizontal surface.
- After the collision, the objects stick together and move with common velocity 'v' as shown in figure.

- .According to law of conservation of linear momentum,

$$\left\{\begin{matrix}\text{Total linear momentum} \\ \text{before collision } (p_1)\end{matrix}\right\} = \left\{\begin{matrix}\text{Total linear momentum} \\ \text{after collision } (p_2)\end{matrix}\right\}$$

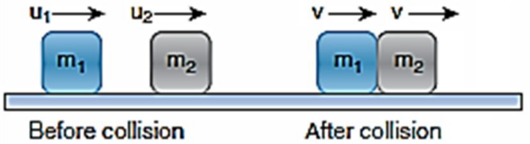
$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$

- Hence, the common velocity after collision is,

$$\boxed{v = \frac{m_1u_1 + m_2u_2}{(m_1 + m_2)}}$$

12.Find the loss of kinetic energy in one-dimensional perfect inelastic collision of two bodies.

- Consider a perfect inelastic collision of two masses m_1 and m_2 moving in a straight line along +ve x-direction on a frictionless horizontal surface.
- After the collision, the objects stick together and move with common velocity 'v' as shown in figure.



- Total kinetic energy before collision,

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

- Total kinetic energy after collision,

$$KE_f = \frac{1}{2}(m_1 + m_2)v^2$$

- Then the loss of kinetic energy is,

$$\Delta Q = KE_i - KE_f$$

$$\Delta Q = \frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 - \frac{1}{2}(m_1 + m_2)v^2$$

- But $v = \frac{m_1u_1+m_2u_2}{(m_1+m_2)}$, therefore loss of kinetic energy,

$$\boxed{\Delta Q = \frac{1}{2}\left(\frac{m_1m_2}{m_1 + m_2}\right)(u_1 - u_2)^2}$$

5. Motion of System of Particles and Rigid bodies

1. What is a rigid body?

A rigid body is the one, which maintains its dimension and fixed shape even when an external force acts on it.

2. Define center of mass.

The center of mass of a body is defined as a point where the entire mass of the body appears to be concentrated.

3. What is a point mass?

A point mass is a hypothetical point which has non-zero mass and no size or shape.

4. Define torque. Give its unit.

Torque is defined as the moment of the external applied force about a point or axis of rotation. Its unit is N m.

i.e. $\vec{\tau} = \vec{r} \times \vec{F}$

5. Give the examples of torque in day-to-day life.

- The opening and closing of a hinged door.
- Turning of a nut using a wrench.

6. What are the conditions in which force can not produce torque?

- Force $\vec{F}$ acts along or opposite to the direction of $\vec{r}$. i.e. $\theta = 0^0$ or $\theta = 180^0$.
- Force acts at the reference point. i.e. r = 0.

7. Define angular momentum. Give its unit.

The angular momentum of a point mass is defined as the moment of its linear momentum. Its unit is kg m^2 s^{-1} .

i.e. $\vec{L} = \vec{r} \times \vec{p}$

8. What is meant by mechanical equilibrium of a rigid body?

A rigid body is said to be in mechanical equilibrium when both its linear momentum and angular momentum remain constant.

9. What are the types of equilibrium?

- Translational equilibrium
- Rotational equilibrium
- Static equilibrium
- Dynamic equilibrium
- Stable equilibrium
- Unstable equlibrium
- Neutral equilibrium

10. What are translational equilibrium conditions?

- Linear momentum is constant
- Net force is zero

11. What are rotational equilibrium conditions?

- Angular momentum is constant
- Net torque is zero

12. What are static equilibrium conditions?

- Linear and angular momentum are zero
- Net force and net torque are zero

13. What are dynamic equilibrium conditions?

- Linear and angular momentum are constant
- Net force and net torque are zero

14. What are the stable equilibrium conditions?

- Linear and angular momentum are zero
- The body tries to come back to equilibrium if slightly disturbed and released.
- The center of mass of the body shifts slightly higher if disturbed from equilibrium
- Potential energy of the body is minimum and it increases if disturbed.

15. What are the unstable equilibrium conditions?

- Linear and angular momentum are zero
- The body cannot come back to equilibrium if slightly disturbed and released.
- The center of mass of the body shifts slightly lower if disturbed from equilibrium
- Potential energy of the body is not minimum and it decreases if disturbed.

16. What are the neutral equilibrium conditions?

- Linear and angular momentum are zero
- The body remains at the same equilibrium if slightly disturbed and released.
- The center of mass of the body does not shifts higher or lower if disturbed from equilibrium
- Potential energy remains same even if disturbed.

17. Distinguish between stable and unstable equilibrium.

S.No.	Stable equilibrium	Unstable equilibrium
1.	The body returns back to equilibrium after slight disturbance.	The body does not return back to equilibrium after slight disturbance.
2.	The center of mass of the body shifts higher during disturbance.	The center of mass of the body shifts lower during disturbance.
3.	Potential energy is minimum and increased during disturbance.	Potential energy is maximum and decreased during disturbance.

18. Define a couple.

A couple is defined as a pair of forces, which are equal and opposite and seperated by a perpendicular distance causes a turning effect.

19. Define moment of a couple.

The moment of a couple is defined as the turning effect caused by a pair of forces, which are equal and opposite and seperated by a perpendicular distance.

20. Give some examples for couple.

- Opening a cap of a pen.
- Turning a steering wheel of a car.
- opening a water tap.

21. State principle of moments.

When an object is in equilibrium the sum of the anticlockwise moments about a turning point must be equal to the sum of the clockwise moments.

22. What is center of gravity?

The center of gravity of a body is the point at which the entire weight of the body acts irrespective of the position and orientation of the body.

23. What do you mean by the moment of inertia? Give its unit and dimension.

The moment of inertia is a measure of rotational inertia. Its unit is kg m^2 and dimension is M L^2.

24. Define moment of inertia.

Moment of inertia is defined as the sum of the products of the mass and the square of the perpendicular distance to the axis of rotation of each particle in a body rotating about an axis.

$$i.e.\ \ I = \sum_{i=0}^{n} m_i\, r_i^2$$

25. Mention any two physical significance of moment of inertia.

- ❖ Lesser the moment of inertia, greater the speed of rotation.
- ❖ Greater the mass concentrated away from the axis of rotaion, greater the moment of inertia.

26. What is radius of gyration? Give its unit.

The radius of gyration of an object is the perpendicular distance between the axis of rotation and the center of mass of the object. Its unit is metre.

27. Define radius of gyration.

Radius of gyration is defined as the root mean square (rms) distance of the particles of the body from the axis of rotation.

$$i.e.\ K = \sqrt{\frac{r_1^2 + r_2^2 + r_3^2 + \cdots + r_n^2}{n}}$$

28. State parallel axis theorem.

The moment of inertia of a body about any axis is equal to the sum of its moment of inertia about a parallel axis through its center of mass and the product of the mass of the body and the square of the perpendicular distance between the two axes.

i.e. $I = I_C + md^2$

29. State perpendicular axis theorem.

The moment of inertia of a plane laminar body about an axis perpendicular to its plane is equal to the sum of moments of inertia about two perpendicular axes lying in the plane of the body such that all the three axes are mutually perpendicular and concurrent.

i.e. $I_z = I_x + I_y$

30. State law of conservation of angular momentum.

When no external torque acts on the body, the net angular momentum of a rotating rigid body remains constant.

31. Distinguish between sliding and slipping.

S.No.	Sliding	Slipping
1.	The translation is more than rotation.	The rotation is more than translation.
2.	Relative velocity between point of contact and the surface is non-zero.	Relative velocity between point of contact and the surface is zero.
3.	It happens when the moving vehicle suddenly stopped on a slippery road.	It happens when the vehicle is start to move on a slippery road or in mud.

32. What is the condition for pure rolling?

In pure rolling, the total kinetic energy must be equal to the sum of kinetic energies of translational and rotational motion.

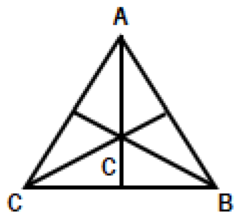
33. Comparison of translational and rotational quantities.

S. No	Translational Motion	Rotational motion about a fixed axis
1.	Displacement, x	Angular displacement, θ
2.	Time, t	Time, t
3.	Velocity, $v = \frac{dx}{dt}$	Angular velocity, $\omega = \frac{d\theta}{dt}$
4.	Acceleration, a= $\frac{dv}{dt}$	Angular acceleration, $\alpha = \frac{d\omega}{dt}$
5.	Mass, m	Moment of inertia, I
6.	Force, $F = ma$	Torque, $\tau = I\alpha$
7.	Linear momentum, $p = mv$	Angular momentum, L = $I\omega$
8.	Impulse, $F\,\Delta t = \Delta p$	Angular Impulse, $\tau\,\Delta t = \Delta L$
9.	Work done by force, w = Fs	Work done by torque, $w = \tau\theta$
10.	Kinetic energy, $KE = \frac{1}{2}mv^2$	Rotational Kinetic energy, $KE = \frac{1}{2}I\omega^2$
11.	Power, $P = Fv$	Rotational Power, $P = \tau\omega$

34. Find out the center of mass for the given geometrical structures. a) Equilateral triangle b) Cylinder c) Square.

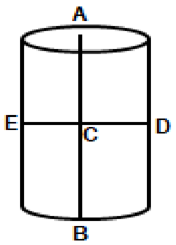
- ❖ For evenly distributed mass, center of mass will be at the geometrical center of the uniform shape.

a) <u>Center of mass for equilateral triangle :</u>



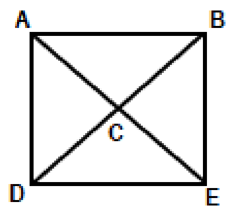
Draw the Perpendicular lines from vertices A, B and C to opposite sides. The lines meet at one point C, which is the center of mass.

b) <u>Center of mass for Cylinder :</u>



Draw the perpendicular cross line ED at the mid of the height of the cylinder. This intersect the axis of cylinder at C, Which is the center of mass.

c) <u>Center of mass for Square :</u>



Draw the diagonals AE and BD, which will intersect at C. The point C is the center of mass.

Conceptual Questions:

35. When a tree is cut, the cut is made on the side facing the direction in which the tree is required to fall. Why?

The side on which the cut is made is no longer supported by the normal force from the bottom, therefore, the gravitational force acts on the tree, tries to rotate it. The torque provided by the gravity will rotate the tree such that the tree falls on the side where it was cut.

36. Why does a porter bend forward while carrying a sack of rice on his back?

A porter bends forward while carrying a sack of rice on his back because to change the position of centre of gravity such that he gets the stability.

37. Why is it much easier to balance a meter scale on your fingertip than balancing on a match stick?

The center of gravity of the meter scale is higher than the center of gravity of the matchstick. Higher the center of gravity makes lesser torque. So that it is easier to balance a meter scale on your fingertip than balancing on a match stick.

38. Two identical water bottles one empty and the other filled with water are allowed to roll down an inclined plane. Which one of them reaches the bottom first? Explain your answer.

Water filled bottle. Because the moment of inertia of the empty bottle is higher than the moment of inertia of the water filled bottle.

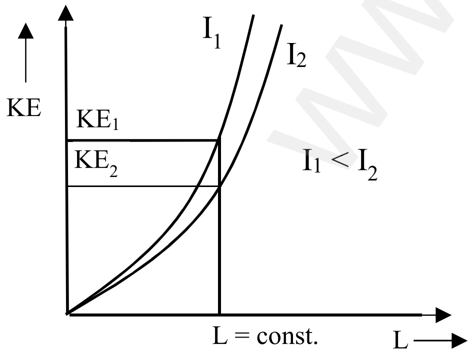
39. Write the relation between angular momentum and rotational kinetic energy. Draw a graph for the same. For two objects of same angular momentum, compare the moment of inertia using the graph.

Relation: Rotational kinetic energy,

$$KE = \frac{L^2}{2I}$$

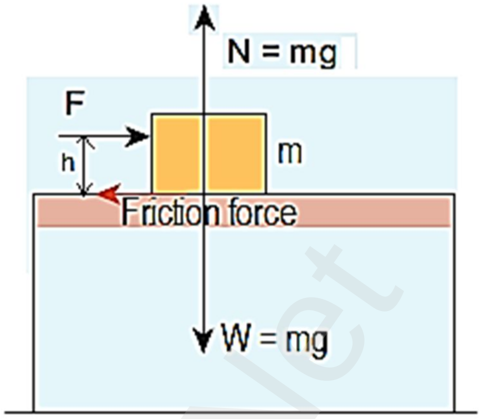
where L is angular momentum and I is moment of inertia.

Graph between KE and L :



The graph shows that of the two bodies of same angular momentum, those one have less rotational kinetic energy has higher moment of inertia.

40. A rectangle block rests on a horizontal table. A horizontal force is applied on the block at a height h above the table to move the block. Does the line of action of the normal force N exerted by the table on the block depend on h?



- Yes. The line of action of the normal force N exerted by the table on the block depend on h.
- When height of the appiled force 'h' increases, a torque is produced by the applied force and frictional force such that block start to tilt.
- To balance this effect, line of action of normal force shift away from applied force and make a opposite torque, joining with gravitational force 'W'.

41. Three identical solid spheres move down through three inclined planes A, B and C all same dimensions. A is without friction, B is undergoing pure rolling and C is rolling with slipping. Compare the kinetic energies E_A, E_B and E_C at the bottom.

- In this case, when three identicle solid spheres starts to move on the inclined planes, they all have same potential energy.
- During the motion, the potential energy is converted into kinetic energy.
- According to law of conservation of energy, at the bottom all the potential energy is converted into kinetic energy.
- Such that all three spheres have same kinetic energy at the bottom whatever be the type of motion. i.e. $E_A = E_B = E_C$.

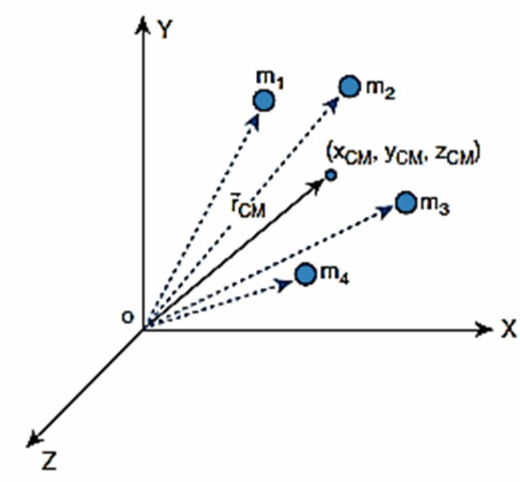
42. Give an example to show that the following statement is false. 'Any two forces acting on a body can be combined into single force that would have same effect'.

- Consider two equal and opposite forces acting on a wheel.
- If two foces combined and acting on single point on the wheel, there will be no effect. However, if they act seperatly on the edges of the wheel, there will be a rotating effect.
- This example falsifies the given statement.

5 Marks Q & A:

1. Find the center of mass for a collection of 'n' point masses.

- Consider the point masses $m_1, m_2, m_3, ... m_n$ whose position coordinates from orgin O along X-direction are $x_1, x_2, x_3, ... x_n$ as shown in figure.



- The equation for the X coordinate of the center of mass is,

$$X_{CM} = \frac{\sum m_i x_i}{\sum m_i}$$

Where, $\sum m_i = M$, is the total mass of all the particles.

- Hence,

$$X_{CM} = \frac{\sum m_i x_i}{M}$$

- Similarly, the Y and Z coordinates of center of mass can be written as,

$$Y_{CM} = \frac{\sum m_i y_i}{M}$$

$$Z_{CM} = \frac{\sum m_i z_i}{M}$$

- The position of the center of mass of these masses is (X_{CM} , Y_{CM} , Z_{CM}). In general, the position of center of mass in vector form can be expresssed as,

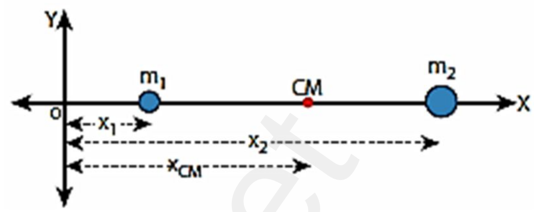
$$\vec{r}_{CM} = \frac{\sum m_i \vec{r}_i}{M}$$

Where, $\vec{r}_{CM} = X_{CM}\hat{\imath} + Y_{CM}\hat{\jmath} + Z_{CM}\hat{k}$ is the position vector of the center of mass and $\vec{r}_i = X_i\hat{\imath} + Y_i\hat{\jmath} + Z_i\hat{k}$ is the position vector of the distributed point mass.

2. Find the center of mass of two point masses by shifting the origin.

- Consider the point masses m_1 and m_2 which are positioned as x_1 and x_2 along X-axis. The center of mass can be found in this system in three ways as follows.

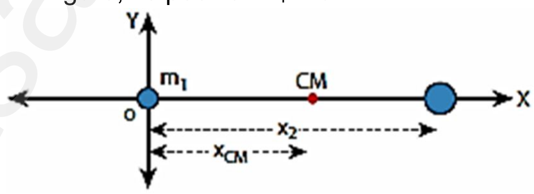
- <u>When the masses are on positive X-axis :</u>
  - The origin is taken arbitrarily as shown in figure.



  - The center of mass along X-axis is,

$$X_{CM} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$$

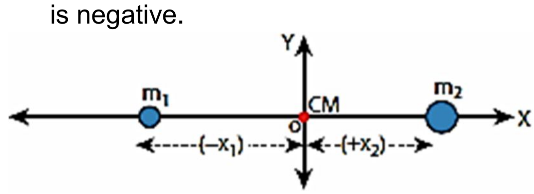
- <u>When the origin coincides with any one of the masses:</u>
  - If the orgin coincide with mass m_1 as shown in figure, its position $x_1 = 0$.



  - The center of mass along X-axis is,

$$X_{CM} = \frac{m_1(0) + m_2 x_2}{m_1 + m_2} = \frac{m_2 x_2}{m_1 + m_2}$$

- <u>When the origin coincides with center of the mass itself :</u>
  - If the origin coincide with center of mass as shown in figure, $X_{CM} = 0$. Hence, the position x_1 is negative.



  - The center of mass along X-axis is,

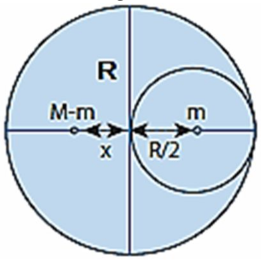
$$0 = \frac{m_1(-x_1) + m_2 x_2}{m_1 + m_2}$$

$$m_1 x_1 = m_2 x_2$$

  - The above equation is known as principle of moments.

3. From a uniform disc of radius R, a small disc of radius $\frac{R}{2}$ is cut and removed as shown in the diagram. Find the center of mass of the remaining portion of the disc.

- Let us consider the mass of the uncut full disc be M. Its center of mass would be at the geometric center of the disc on which the origin coincides.
- Now the small disc of the mass m is cut from the disc M. So that the center of mass the small disc is at R/2 as shown in figure.



- Hence, the center of mass of remaining disc is shifted to x distance left to the origin.
- Applying principle of moments,

$$(M-m)x = (m)\frac{R}{2}$$
$$x = \left[\frac{m}{(M-m)}\right]\frac{R}{2} \dashrightarrow (1)$$

- If σ is the surface mass density (i.e. $\sigma = \frac{M}{\pi R^2}$), the mass m of small disc is,

$$m = surface\ mass\ density \times surface\ area$$
$$m = \sigma \times \pi\left(\frac{R}{2}\right)^2$$
$$m = \frac{M}{\pi R^2} \times \pi\left(\frac{R}{2}\right)^2 = \frac{M}{\pi R^2} \times \pi \times \frac{R^2}{4} = \frac{M}{4}$$

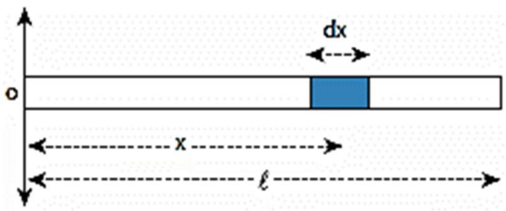
- Substituting the value of m in equation(1), we get,

$$x = \left[\frac{\frac{M}{4}}{\left(M-\frac{M}{4}\right)}\right]\frac{R}{2} = \left[\frac{\frac{M}{4}}{\left(\frac{3M}{4}\right)}\right]\frac{R}{2}$$
$$x = \frac{R}{6}$$

- Therefore, the center of mass of the remaining portion is at a distance of R/6 left to the center of disc.

4. Locate the center of mass of a uniform rod of mass M and length ℓ.

- Consider a uniform rod of mass M and length ℓ whose one end coincides with the origin as shown in figure.



- The rod is along x-axis. Let dm be the small mass of elemental length dx at a distance x from the origin.
- If λ is the linear mass density (i.e. $\lambda = \frac{M}{\ell}$), the mass of small element dm is,

$$dm = \frac{M}{\ell}dx$$

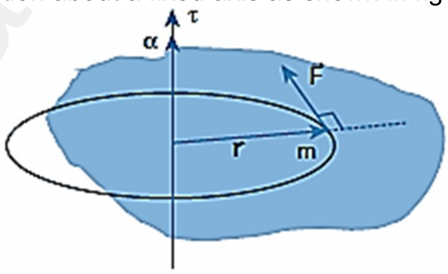
- Now the center of mass of the rod is,

$$X_{CM} = \frac{\int x dm}{\int dm}$$
$$X_{CM} = \frac{\int_0^\ell x\frac{M}{\ell}dx}{M} = \frac{1}{\ell}\int_0^\ell x\,dx$$
$$X_{CM} = \frac{1}{\ell}\left[\frac{x^2}{2}\right]_0^\ell = \frac{1}{\ell}\left[\frac{\ell^2}{2}\right]$$
$$X_{CM} = \frac{\ell}{2}$$

- Therefore, the center of mass of the uniform rod is at its geometrical center.

5. Obtain the relation between torque and angular acceleration.

- Consider a rigid body rotating about a fixed axis. A point mass m in the body will execute a circular motion about a fixed axis as shown in figure.



- Let $\vec{F}$ be a tangential force acting on the point mass produces the torque for rotation and $\vec{r}$ be the position vector of the point mass.
- The torque produced by the force on the point mass m about the axis of rotation is written as,

$$\tau = rF\sin 90^0 = rF \qquad [\because \sin 90^0 = 1]$$
$$\tau = r\,ma \qquad [\because F = ma]$$
$$\tau = r\,m\,r\alpha = mr^2\alpha \qquad [\because a = r\alpha]$$
$$\tau = mr^2\alpha \dashrightarrow (1)$$

- For all particles of the body, $mr^2 = \sum m_i r_i^2$
- Therefore, $\tau = (\sum m_i r_i^2)\alpha$

$$\tau = I\alpha$$

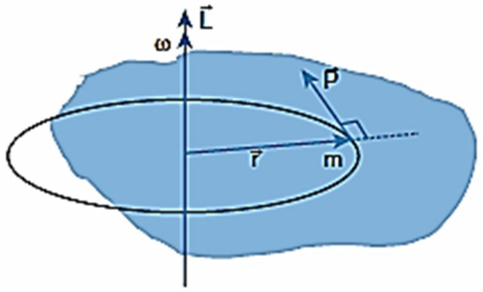
Where, $I = \sum m_i r_i^2$, moment of inertia of the rigid body.

- In vector form,

$$\vec{\tau} = I\vec{\alpha}$$

6. Obtain the relation between angular momentum and angular velocity.

- Consider a rigid body rotating about a fixed axis. A point mass m in the body will execute a circular motion about a fixed axis as shown in figure.



- let $\vec{L}$ be the angular momentum which is perpendicular to position vector $\vec{r}$ and linear momentum vector $\vec{p}$.
- As the angular momentum is the moment of linear momentum,

$$L = r\,p\sin 90^0 \qquad [\because \sin 90^0 = 1]$$
$$L = r\,mv = rm\,r\omega \qquad [\because p = mv]$$
$$L = mr^2\omega$$

- For all particles of the body, $mr^2 = \sum m_i r_i^2$
- Therefore, $L = (\sum m_i r_i^2)\omega$

$$L = I\omega$$

Where, $I = \sum m_i r_i^2$, moment of inertia of the rigid body.

- In vector form,

$$\vec{L} = I\vec{\omega}$$

7. Obtain the relation between torque and angular momentum.

- The angular momentum expression is,

$$L = I\omega ---\rightarrow (1)$$

- The torque expression is,

$$\tau = I\alpha = I\left(\frac{d\omega}{dt}\right) \qquad \left[\because \alpha = \frac{d\omega}{dt}\right]$$
$$\tau = \frac{d(I\omega)}{dt} ---\rightarrow (2)$$

- Substituting equation(1) in (2), we get,

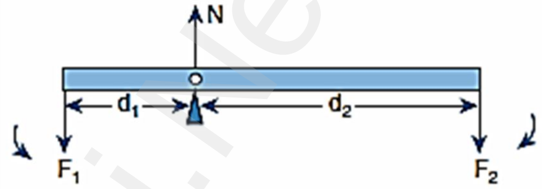
$$\tau = \frac{dL}{dt}$$

- In vector form,

$$\vec{\tau} = \frac{d\vec{L}}{dt}$$

8. State and prove principle of moments. Also get the expression for mechanical advantage.

- <u>**Statement :**</u> When an object is in equilibrium the sum of the anticlockwise moments about a turning point must be equal to the sum of the clockwise moments.
- <u>**Proof :**</u>
  Consider a light rod of negligible mass which is pivoted at a point along its length.
- Let two parallel forces F_1 and F_2 act at the two ends at distances d_1 and d_2 from the point of pivot and the normal reaction force N at the point of pivot as shown in figure.



- Since the rod has to remain stationary in horizontal position, it should be in transitional and rotational equilibrium. Then, both the net force and net torque must be zero.
- For net force to be zero,

$$-F_1 + N - F_2 = 0$$

- For net torque to be zero,

$$d_1F_1 - d_2F_2 = 0$$
$$d_1F_1 = d_2F_2 --\rightarrow (1)$$

- The above equation represents principle of moments.
- The beam balance used for weighing goods uses this principlpe with $d_1 = d_2$ and $F_1 = F_2$.
- <u>**Mechanical Advantage (MA) :**</u>
  From the equation(1),

$$\frac{F_1}{F_2} = \frac{d_2}{d_1} --\rightarrow (2)$$

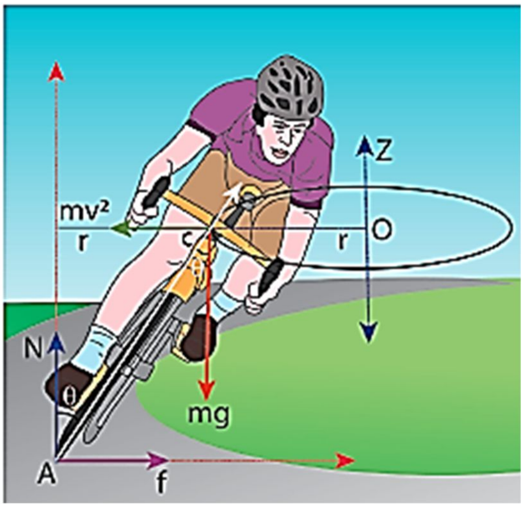
- If F_1 is the load and F_2 is our effort, we get advantage when $d_1 < d_2$ .This implies that $F_1 > F_2$. Hence we can lift a large load with small effort.
- In equation(2), the term $\left(\frac{d_2}{d_1}\right)$ is called mechanical advantage of the simple lever. The pivot point is called fulcrum.
- Thus, the mechanical advantage(MA) is expressed as,

$$Mechanical\ Advantage(MA) = \frac{d_2}{d_1}$$

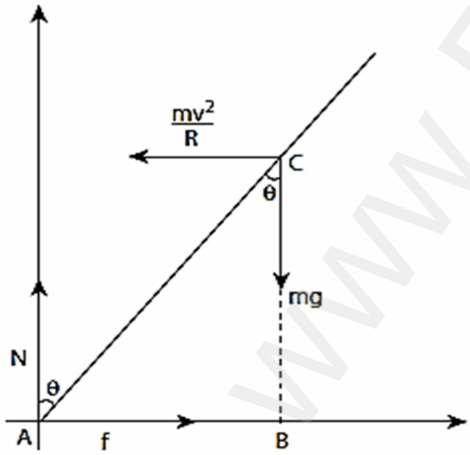
- There are many simple machines that work on the above principle.

9. Explain why a cyclist bends while negotiating a curve road? Arrive at the expression for angle of bending for a given velocity.

- Consider a cyclist negotiating a circular level road(not banked) of radius r with a speed v about the center O as shown in figure.



- Let m be the mass of the system, which includes cycle and cyclist and C be the center of gravity of this system.
- Let us consider horizontal is along x-axis and vertical is along Z-axis.
- The system as a frame rotating about Z-axis and the system is at rest in this rotating frame Z.
- In this rotating frame, the centrifugal force $\frac{mv^2}{r}$ acts away from center O and passing through the center of gravity C as shown below.



- As the system is in rotational equilibrium, the net torque must be zero. Thus,

$$\vec{\tau}_{net} = 0$$

$$-mg\ AB + \frac{mv^2}{r} BC = 0$$

Here, the clock wise moment (mg AB) is taken as negative and the anti clockwise moment $\left(\frac{mv^2}{r} BC\right)$ is taken as positive.

$$mg\ AB = \frac{mv^2}{r} BC$$

- But from ΔABC, AB = AC sinθ & BC = AC cosθ. Therefore, the above equation can be written as,

$$mg\ AC\ sin\theta = \frac{mv^2}{r} AC\ cos\theta$$

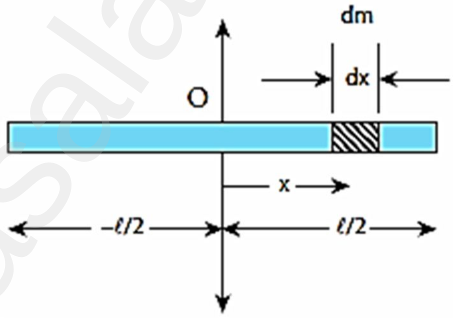
$$tan\theta = \frac{v^2}{rg}$$

$$\theta = tan^{-1}\left[\frac{v^2}{rg}\right]$$

- It shows that while negotiating a circular road of radius r at velocity v, a cyclist has to bend an angle θ from vertical, to avoid a fall.

10. Obtain the expression for moment of inertia of a uniform rod.

- Consider a uniform rod of mass M and length ℓ as shown in figure.



- Let us consider the rod is along the x-axis and the moment of inertia of the rod is found about the axis, which passes through center of mass (here the geometrical center) of the rod 'O'.
- Now the moment of inertia of an infinitesimal small mass 'dm' of length dx of the rod, which is at a distance 'x' from O can be expressed as,

$$dI = (dm)x^2 \longrightarrow (1)$$

- The moment of inertia(I) of the entire rod can be found by integrating the equation(1) as,

$$I = \int dI = \int_{-l/2}^{+l/2} (dm)x^2 \longrightarrow (2)$$

- If λ is linear mass density(i.e. $\lambda = \frac{M}{\ell}$), the small mass dm can be written as,

$$dm = \lambda\ dx = \frac{M}{\ell}\ dx$$

- Substituting the 'dm' value in equation(2), we get,

$$I = \int_{-l/2}^{+l/2} \left(\frac{M}{\ell}\ dx\right) x^2 = \frac{M}{\ell} \int_{-l/2}^{+l/2} x^2\ dx$$

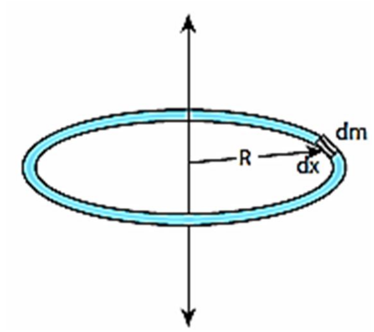
$$I = \frac{M}{\ell}\left[\frac{x^3}{3}\right]_{-l/2}^{+l/2}$$

$$I = \frac{M}{\ell}\left[\frac{\ell^3}{24} + \frac{\ell^3}{24}\right] = 2\frac{M}{\ell}\left[\frac{\ell^3}{24}\right]$$

$$I = \frac{1}{12}M\ell^2$$

11. Obtain the expression for moment of inertia of a uniform ring.

- Consider a uniform ring of mass M and radius R as shown in figure.



- The moment of inertia of the ring is found about the axis, which passes through its center and perpendicular to the plane.
- Now the moment of inertia of an infinitesimal small mass 'dm' of length dx of the ring, which is at a distance 'R' from the center can be expressed as,

$$dI = (dm)R^2 \longrightarrow (1)$$

- The moment of inertia(I) of the entire ring can be found by integrating the equation(1) as,

$$I = \int dI = \int_0^{2\pi R} (dm)R^2 \longrightarrow (2)$$

- If λ is linear mass density (i.e. $\lambda = \frac{M}{2\pi R}$), the small mass dm can be written as,

$$dm = \lambda\, dx = \frac{M}{2\pi R}\, dx$$

- Substituting the 'dm' value in equation(2), we get,

$$I = \int_0^{2\pi R}\left(\frac{M}{2\pi R}\, dx\right)R^2 = \frac{MR}{2\pi}\int_0^{2\pi R} dx$$

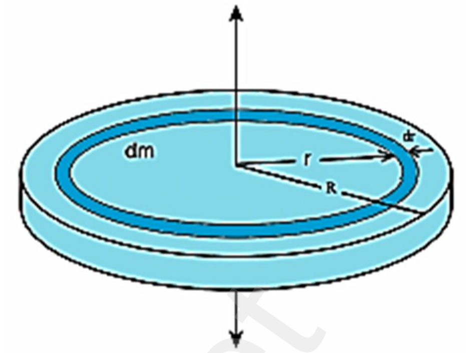
$$I = \frac{MR}{2\pi}[x]_0^{2\pi R}$$

$$I = \frac{MR}{2\pi}[2\pi R - 0]$$

$$I = MR^2$$

12. Obtain the expression for moment of inertia of a uniform disc.

- Consider a uniform disc of mass M and radius R as shown in figure.



- The moment of inertia of the disc is found about the axis, which passes through its center and perpendicular to the plane. This disc is made up of many infinitesimally small rings.
- Now consider the moment of inertia of an ring, which has infinitesimal small mass 'dm' , thickness dr and radius 'r', which can be expressed as,

$$dI = (dm)r^2 \longrightarrow (1)$$

- The moment of inertia(I) of the entire disc can be found by integrating the equation(1) as,

$$I = \int dI = \int_0^R (dm)r^2 \longrightarrow (2)$$

- If σ is surface mass density (i.e. $\sigma = \frac{M}{\pi R^2}$), the small mass dm can be written as,

$$dm = \sigma\, 2\pi r\, dr = \frac{M}{\pi R^2}\, 2\pi r\, dr = \frac{2M}{R^2}\, r\, dr$$

- Substituting the 'dm' value in equation(2), we get,

$$I = \int_0^R\left(\frac{2M}{R^2}\, r\, dr\right)r^2 = \frac{2M}{R^2}\int_0^R r^3 dr$$

$$I = \frac{2M}{R^2}\left[\frac{r^4}{4}\right]_0^R$$

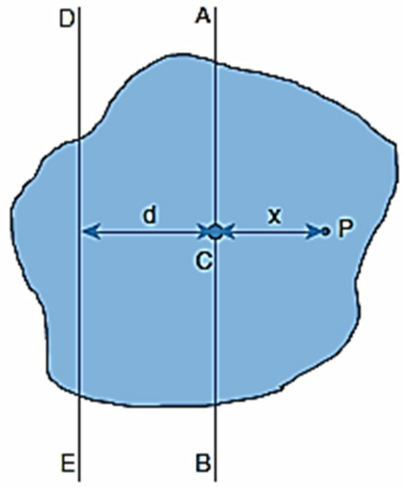
$$I = \frac{2M}{R^2}\left[\frac{R^4}{4} - 0\right]$$

$$I = \frac{1}{2}MR^2$$

13. State and prove parallel axis theorem.

- <u>Statement :</u> The moment of inertia of a body about any axis is equal to the sum of its moment of inertia about a parallel axis through its center of mass and the product of the mass of the body and the square of the perpendicular distance between the two axes.

- **Proof :**
  Let us consider a rigid body as shown in figure.



- Let I_C be the moment of inertia of the body about an axis AB, which passes through center of mass.
- Consider I is the moment of inertia of the body to be found about an axis DE, which is parallel to AB. and d is the perpendicular distance between DE and AB.
- Let P be the point mass of mass m, which is located at a distance x from its center of mass.
- The moment of inertia of the point mass about the axis DE is,

$$dI = m(x+d)^2$$

- The moment of inertia of the whole body about the axis DE is,

$$I = \sum m(x+d)^2$$
$$I = \sum m(x^2+d^2+2xd)$$
$$I = \sum (mx^2+md^2+2dmx)$$
$$I = \sum mx^2 + \sum md^2 + 2d\sum mx$$

- Here, $\sum mx^2 = I_C$, the moment of inertia of the body about the center of mass and $\sum mx = 0$ (since x has +ve and –ve values about the axis AB)
- Therefore, The moment of inertia of the whole body about the axis DE can be expressed as,

$$I = I_C + \sum m\, d^2$$

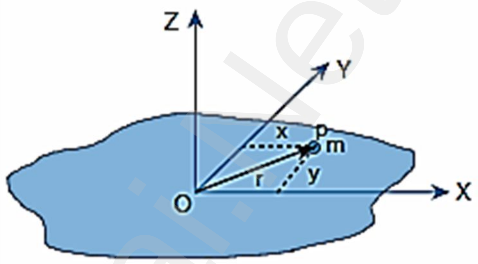
- But $\sum m = M$, mass of the whole body. Thus,

$$I = I_C + Md^2$$

- Hence, the parallel axis theorem is proved.

14. State and prove perpendicular axis theorem.

- **Statement :** The moment of inertia of a plane laminar body about an axis perpendicular to its plane is equal to the sum of moments of inertia about two perpendicular axes lying in the plane of the body such that all the three axes are mutually perpendicular and concurrent.
- Consider a plane laminar object of negligible thickness on which the origin O lies. The mutually perpendicular axes X and Y are lying on the the plane and z-axis is perpendicular to palne as shown in figure.



- Let us consider a point mass P of mass m, which is at a distance r from origin O.
- The moment of inertia of the point mass about the Z-axis is,

$$dI_Z = mr^2$$

- The moment of inertia of the whole body about the Z-axis is,

$$I_Z = \sum mr^2$$

- Here, $r^2 = x^2 + y^2$, So that,

$$I_Z = \sum m(x^2+y^2)$$
$$I_Z = \sum mx^2 + \sum my^2$$

- But $\sum mx^2 = I_Y$, the moment of inertia of the body about the Y-axis and $\sum my^2 = I_X$, the moment of inertia of the body about the X-axis.
- Therefore, $I_Z = I_Y + I_X$

  or $I_Z = I_X + I_Y$

- Hence, the perpendicular axis theorem is proved.

15. Discuss the conservation of angular momentum with example.

- According to law of conservation of angular momentum, when no external torque acts on the body, the net angular momentum of a rotating rigid body remains constant.

  i.e. If $\tau = \frac{dL}{dt} = 0$, L = Constant.

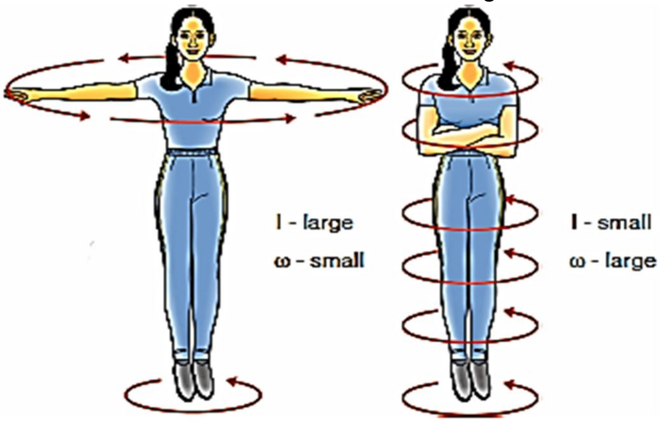
- But $L = I\omega$, So that,

$$I\omega = Constant$$

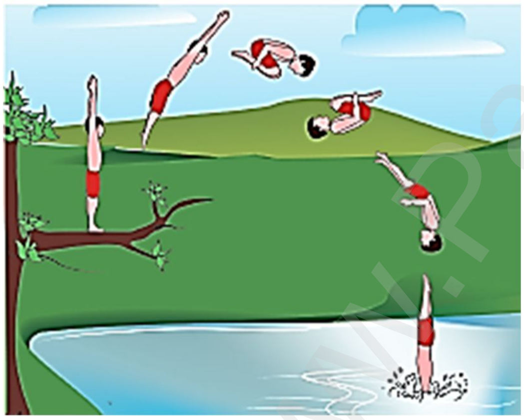
or
$$I \alpha \frac{1}{\omega}$$

- It shows that if the moment of inertia I increases, the angular velocity ω decreases and vice versa.

- **Example:**
    - The ice dancer spins slowly when the hands are stretched out as this position increases moment of inertia and spis faster when the hands are brought close to the body as it decreases moment of inertia as shown in figure.

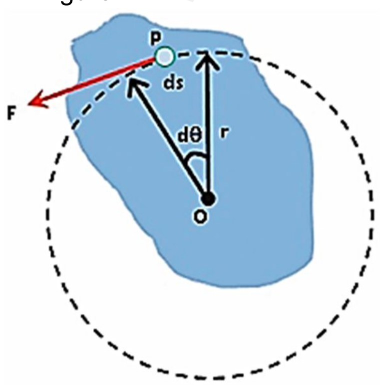


- A diver while in air increases the number of somersaults by curling his body close, to decrease the moment of inertia as shown in figure.



16. Find the work done by a torque.

- Consider a rigid body rotating about a fixed axis. Let P be a point on the body which rotates about the axis perpendicular to the plane of the paper as shown in figure.



- When a tangential force applied on the body, it produces a small displacement ds on the point P.

- Now the work done by a force F for the displacement 'ds' is,

$$dw = F\,ds$$

- From the figure, ds can be expressed as,

$$ds = r\,d\theta$$

- Substituting ds value, dw becomes,

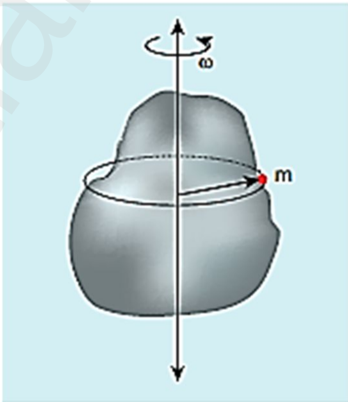
$$dw = F\,r\,d\theta$$

$$dw = \tau\,d\theta \qquad [\because Torque\ \tau = F\,r]$$

- This the work done by a torque.

17. Obtain an expression for rotational kinetic energy.

- Consider a rigid body with all particles rotating with angular velocity ω about an axis as shown in figure.



- The tangential velocity v is varied for every particle in rotation, based on its positions from the axis of rotation.

- If m_i is the mass of a ith particle with tangential velocity v_i , situated at a distance r_i from axis of rotation, the kinetic energy of this particle is,

$$KE_i = \frac{1}{2} m_i v_i^2$$

- We know, $v_i = r_i\omega$, so that,

$$KE_i = \frac{1}{2} m_i (r_i\omega)^2 = \frac{1}{2}(m_i r_i^2)\omega^2$$

- Now the kinetic energy for whole body is,

$$KE_i = \frac{1}{2}\left(\sum m_i r_i^2\right)\omega^2$$

- But $\sum m_i r_i^2 = I$, the moment of inertia of the whole body. Therefore, the rotational kinetic energy becomes,

$$KE_i = \frac{1}{2} I\omega^2$$

18. Obtain the relation between rotational kinetic energy and angular momentum.

- Consider a rigid body of moment of inertia 'I' rotate with angular velocity ω.
- The angular momentum of the rigid body is,

$$L = I\omega$$

- The rotational kinetic energy of the rigid body is,

$$KE = \frac{1}{2} I\omega^2$$

- Multiplying and dividing the R.H.S of the equation by L, we get,

$$KE = \frac{1}{2}\frac{I^2\omega^2}{I} = \frac{1}{2}\frac{(I\omega)^2}{I}$$

$$KE = \frac{L^2}{2I}$$

- This is the relation between rotational kinetic energy and angular momentum.

19. Arrive at an expression for kinetic energy in pure rolling with center of mass as reference.

- As the pure rolling consist of both translational and rotational motion, the total kinetic energy of pure rolling is the sum of kinetic energies of translational and rotational motion.

$$KE = KE_{TRANS} + KE_{ROT}$$

- If M be the mass of the rolling object, V_{CM} be the velocity of center of mass, I_{CM} be the moment of inertia about the center of mass and ω be the angular velocity, then,

$$KE = \frac{1}{2} M v_{CM}^2 + \frac{1}{2} I_{CM}\omega^2$$

- But $I_{CM} = MK^2$ and $\omega = \frac{v_{CM}}{R}$. Here K is the radius of gyration. So that,

$$KE = \frac{1}{2} M v_{CM}^2 + \frac{1}{2}(MK^2)\frac{v_{CM}^2}{R^2}$$

$$KE = \frac{1}{2} M v_{CM}^2 + \frac{1}{2} M v_{CM}^2\left(\frac{K^2}{R^2}\right)$$

$$KE = \frac{1}{2} M v_{CM}^2\left[1 + \frac{K^2}{R^2}\right]$$

20. Arrive at an expression for kinetic energy in pure rolling with point of contact as reference.

- If I_O is the moment of inertia of the object about the point of contact, the rotational kinetic energy is,

$$KE = \frac{1}{2} I_O\omega^2$$

- By parallel axis theorem,

$$I_O = I_{CM} + MR^2$$

- But $I_{CM} = MK^2$ and $\omega = \frac{v_{CM}}{R}$. Here K is the radius of gyration. So that,

$$I_O = MK^2 + MR^2$$

- Substituting the values of I_O and ω in KE relation, we get,

$$KE = \frac{1}{2}(MK^2 + MR^2)\frac{v_{CM}^2}{R^2}$$

$$KE = \frac{1}{2} M v_{CM}^2\left[1 + \frac{K^2}{R^2}\right]$$

21. A solid sphere is undergoing pure rolling. What is the ratio of its translational and rotational kinetic energy?

- The expression for total kinetic energy in pure rolling is,

$$KE = KE_{TRANS} + KE_{ROT} \longrightarrow (1)$$

- For any object the total kinetic energy can be arrived as,

$$KE = \frac{1}{2} M v_{CM}^2 + \frac{1}{2} M v_{CM}^2\left(\frac{K^2}{R}\right) \longrightarrow (2)$$

- Comparing the equations (1) & (2), we get,

$$KE_{TRANS} = \frac{1}{2} M v_{CM}^2$$

$$KE_{ROT} = \frac{1}{2} M v_{CM}^2\left(\frac{K^2}{R}\right)$$

- Now the ratio between KE_{TRANS} and KE_{ROT} is,

$$KE_{TRANS} : KE_{ROT} = 1 : \left(\frac{K^2}{R}\right)$$

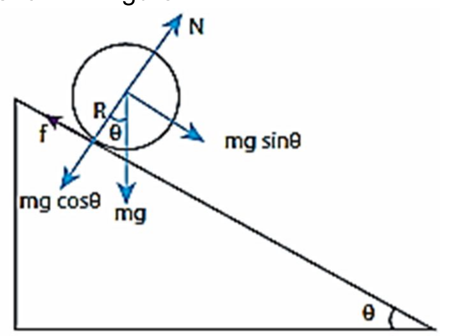
- For solid sphere, $\frac{K^2}{R} = \frac{2}{5}$, Therefore,

$$KE_{TRANS} : KE_{ROT} = 1 : \frac{2}{5}$$

or $$KE_{TRANS} : KE_{ROT} = 5 : 2$$

22. Discuss the rolling on inclined plane and arrive at the expressions for the acceleration, the final velocity and the time taken for rolling down the inclined plane.

- Consider a round object of mass m and radius R is rolling down on an inclined plane without slipping as shown in figure.



(a) Acceleration of the rolling object :

- From the figure, it is seen that the component of gravitational force(mg cosθ) perpendicular to inclined plane is balanced by the normal force N.
- Therefore, the component of gravitational force (mg sinθ) parallel to inclined plane and the frictional force f, combinely causes the motion.
- For translational motion,

$$mg\ sin\theta - f = ma \longrightarrow (1)$$

- For rotational motion, let us take a torque with respect to the center of the object. mg sinθ cannot make any torque as it passes through the center of the object, but the frictional force f can set a torque as,

$$\tau = Rf$$

- But we know, $\tau = I\alpha$,thus,

$$Rf = I\alpha$$

- Substituting, the angular acceleration $\alpha = \frac{a}{R}$ and the moment of inertia $I = mK^2$, we get,

$$Rf = mK^2\left(\frac{a}{R}\right)$$

$$f = ma\left(\frac{K^2}{R^2}\right) \longrightarrow (2)$$

- Substituting equation (2) in (1), we have,

$$mg\ sin\theta - ma\left(\frac{K^2}{R^2}\right) = ma$$

$$mg\ sin\theta = ma + ma\left(\frac{K^2}{R^2}\right)$$

$$a\left(1+\frac{K^2}{R^2}\right) = g\ sin\theta$$

$$a = \frac{g\ sin\theta}{\left(1+\frac{K^2}{R^2}\right)} \longrightarrow (3)$$

(b) Final velocity of the rolling object :

- When the object starts rolling on the inclined plane at the height h from rest, initial velocity u = 0 and the length of the inclined plane $s = \frac{h}{sin\theta}$.
- Substituting the values of u, s and 'a' in 3rd equation of motion $v^2 = u^2 + 2as$,

$$v^2 = 2 \times \frac{g\ sin\theta}{\left[1+\frac{K^2}{R^2}\right]}\left[\frac{h}{sin\theta}\right]$$

$$v^2 = \frac{2gh}{\left[1+\frac{K^2}{R^2}\right]}$$

$$v = \sqrt{\frac{2gh}{\left[1+\frac{K^2}{R^2}\right]}} \longrightarrow (4)$$

(c) Time taken for rolling down the inclined plane :

- If the object starts rolling from rest, initial velocity u = 0. Therefore, from 1st equation of motion $v = u + at$,

$$v = at$$

or

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

- Substituting equations (3) & (4), we have,

$$t = \frac{\sqrt{\frac{2gh}{\left[1+\frac{K^2}{R^2}\right]}}}{\frac{g\ sin\theta}{\left(1+\frac{K^2}{R^2}\right)}}$$

$$t = \sqrt{\frac{2gh}{\left[1+\frac{K^2}{R^2}\right]}} \times \left[\frac{\left(1+\frac{K^2}{R^2}\right)}{g\ sin\theta}\right]$$

$$t = \sqrt{\frac{2h\left(1+\frac{K^2}{R^2}\right)}{g\ sin^2\theta}}$$

- It suggest that for a given inclined angle, the object with least value of radius of gyration K will reach the bottom of the inclined plane first.

6. Gravitation

1. State Ptolemy's Geocentric model theory.

According to the Geocentric model, the Earth is at the center of the universe and all celestial objects including the Sun, the Moon, and other planets orbit the Earth.

2. State Copernicus Heliocentric model theory.

According to the Heliocentric model, Sun was considered to be at the center of the solar system and all planets including the Earth orbited the Sun in circular orbits.

3. State Kepler's First law (Law of orbits).

Each planet moves around the Sun in an elliptical orbit with the Sun at one of the foci.

4. State Kepler's Second law (Law of area).

The radial vector (line joining the Sun to a planet) sweeps equal areas in equal intervals of time.

5. State Kepler's Third law (Law of period).

The square of the time period of revolution of a planet around the Sun in its elliptical orbit is directly proportional to the cube of the semi-major axis of the ellipse. i.e. $T^2 \alpha a^3$.

6. State Newton's universal law of gravitation.

The force of attraction between any two bodies in the universe is directly proportional to the product of their masses and is inversely proportional to the square of the distance between them.

$$i.e. \quad \vec{F} = G\frac{M_1 M_2}{r^2}\,\hat{r}$$

7. Define gravitational constant. What is its value?

The gravitational constant is defined as the gravitational force experienced between two bodies of unit masses, which are seperated by unit distance.Its value is $G = 6.67 \times 10^{-11}\ Nm^2\ kg^{-2}$.

8. Define gravitational field intensity (or) gravitational filed. Give its unit.

The gravitational field intensity at a point is defined as the gravitational force experienced by unit mass placed at that point. Its unit is $N\ kg^{-1}$ (or) $m\ s^{-2}$.

$$i.e. \quad \vec{E} = \frac{\vec{F}}{M} = \frac{GM}{r^2}\,\hat{r}$$

9. State Superposition principle for gravitational field.

the total gravitational field due to all masses in the system is given by the vector sum of gravitational field due to the individual masses.

$$i.e. \quad \vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \cdots + \vec{E}_n = \sum_{i=1}^{n} \frac{GM}{r_i^2}\,\hat{r}_i$$

10. Define Gravitational potential energy. Give its unit.

The gravitational potential energy is defined as the work done to bring the mass m_2 from infinity to a distance 'r' in the gravitational field of mass m_1. Its unit is joule.

$$i.e. \quad U(r) = -G\frac{m_1 m_2}{r}$$

11. Define Gravitational potential. Give its unit.

The gravitational potential at a distance r due to a mass is defined as the amount of work required to bring unit mass from infinity to the distance r.

$$i.e. \quad V(r) = -\frac{Gm}{r}$$

12. What is acceleration due to gravity?

The acceleration experienced by the object near the surface of the Earth due to its gravity is called acceleration due to gravity.

$$i.e. \quad |g| = \frac{GM_e}{R_e^2}$$

13. What is meant by escape speed of the Earth?

The minimum speed required by an object to escape Earth's gravitational field is called the escape speed.

$$i.e. \quad v_e = \sqrt{2gR_E} = 11.2\ km\ s^{-1}$$

14. What is meant by the Orbital speed of the satellite around the Earth?

The orbital speed is the horizontal speed given to the satellite, to orbit the Earth at a calculated height from the Earth's surface.

$$i.e. \quad v = \sqrt{\frac{GM_E}{(R_E + h)}}$$

15. What are geo-stationary satellites?

The satellites revolving the Earth at the height of 36000 km above the equator, are appear to be stationary when seen from Earth is called geo-stationary satellites.

16. What are Polar satellites?

The satellites which revolve from north to south of the Earth at the height of 500 to 800 km from the Earth surface are called Polar satellites.

17. What is meant by state of weightlessness?

When downward acceleration of the object is equal to the acceleration due to the gravity of the Earth, the object appears to be weightless. This is called the state of weightlessness.

18. Why do the astronauts experience weightlessness inside the spacecraft?

The spacecraft orbits the Earth and the astronauts inside it get the same gravitational force of the Earth. So the astronauts don't fell any reactional force from the floor of the spacecraft. Hence, the astronauts experience weightlessness inside the spacecraft.

19. Why there is no lunar and solar eclipse every month?

Since Moon's orbit is tilted 5^0 with respect to Earth's orbit, only during certain periods of the year, the Sun, Earth and Moon align in straight line leading to either lunar eclipse or solar eclipse depending on the alignment.

20. Why do we have seasons on Earth?

The seasons in the Earth arise due to the rotation of Earth around the Sun with 23.5^0 tilt. The part of the Earth nearer to the Sun becomes summer, and other becomes winter during this tilt rotation.

21. Why do Pole stars appear stationary? Name our Pole star.

Pole star is a star located exactly above the Earth's axis of rotation. Hence, it appears to be stationary. The Star Polaris is our pole star.

22. If Kepler's third law was "$r^3 T^2$ = constant" instead of "$\frac{r^3}{T^2}$ = constant", (i) what would be the new law of gravitation? (ii) Would it still be an inverse square law? (iii) How would the gravitational force change with distance? (iv) In this new law of gravitation, will Neptune experience greater gravitational force or lesser gravitational force when compared to the Earth?

(i) The new law of gravitation becomes,

$$F = GMmr^4 \quad ; \quad G = \frac{4\pi^2}{k}$$

(ii) No. It would not be an inverse square law.

(iii) The gravitational force is directly proportional to the fourth power of the distance.

(iv) In this new law of gravitation, Neptune will get greater gravitational force than the Earth.

23. Water falls from the top of a hill to the ground. Why?

This is because the top of the hill is a point of higher gravitational potential than the surface of the Earth i.e. $V_{hill} > V_{ground}$.

24. Suppose you move towards east-west along the same latitude. Will the value of g′ (variation of g with latitude) change?

No. It will not change.

25. Will the angular momentum of a planet be conserved? Justify your answer.

Since the angular velocity of the planet in the orbital motion is constant, the angular momentum of the planet is conserved.

26. Is potential energy the property of a single object? Justify.

No. Potential energy is a property of a system rather than of a single object. An object's gravitational potential is due to its position relative to the surroundings within the Earth-object system.

27. What is the difference between gravitational potential and gravitational potential energy?

S.No.	Gravitational potential	Gravitational potential energy
1.	It is the potential energy per unit mass.	It is the potential energy of a mass.
2.	It is written as, $V(r) = -\frac{Gm}{r}$	It is written as, $U(r) = -G\frac{m_1 m_2}{r}$
3.	Its unit is Joule / kilogram .	Its unit is Joule .

28. Why is the energy of a satellite (or any other planet) negative?

The negative sign in the total energy of a satellite (or any other planet) implies that the satellite or the planet is bound to the Earth or the Sun and it cannot escape from the Earth.

29. Define weight.

Weight is defined as the product of mass and acceleration due to gravity. It is also known as gravitational force. $i.e.\ W = mg$

30. How will you prove that Earth itself is spinning?

Consider a light source as Sun and a globe as Earth. If the globe is allowed to spin near the light source, we may find 'light and shadow' at particular part of the globe periodically. Similarly 'day and night' event happens periodically in the Earth. Hence, it proves that the Earth itself spinning as the globe.

Conceptual Questions:

31. In the following, what are the quantities conserved and non-conserved? a) Linear momentum of a planet b) Angular momentum of a planet c) Total energy of a planet d) Potential energy of a planet.

a) Linear momentum of the planet is not conserved as its linear velocity changes during the orbital motion.

b) Angular momentum of the planet is conserved as its angular velocity is constant during orbital motion

c) Total energy of a planet is also conserved because the sum of its potential and kinetic energy is constant.

d) As the distance between Sun and planet changes during the elliptical motion, potential energy of the planet is not conserved.

32. The work done by Sun on Earth in one year will be Zero, Non zero, positive or negative?

The work done by the Sun on Earth in one year or at any finite interval of time will always be *Zero*, because centripetal force raised by Sun on Earth and the direction of displacement of Earth is perpendicular throughout the orbital motion.

33. If a comet suddenly hits the Moon and imparts energy, which is more than the total energy of the Moon, what will happen?

If it so happens, could replace the moon by comet in orbiting the earth, by the principles of elastic collision in space.

34. If the Earth's pull on the Moon suddenly disappears, what will happen to the Moon?

If the Earth's pull on the Moon suddenly disappears, the moon will travel along the tangent of the orbit.

35. If the Earth has no tilt, what happens to the seasons of the Earth?

If the Earth has no tilt, there will be no season as like now and the duration of day and night will be equal throughtout the year.

36. A student was asked a question 'why are there summer and winter for us? He replied as 'since Earth is orbiting in an elliptical orbit, when the Earth is very far away from the Sun(aphelion) there will be winter, when the Earth is nearer to the Sun(perihelion) there will be summer'. Is this answer correct? If not, what is the correct explanation for the occurrence of summer and winter?

No. The occurrence of summer and winter is due to Earth's tilt. Due to this tilt, one hemisphere near to the sun gets summer and another one has winter.

37. The following photographs are taken from the recent lunar eclipse, which occurred on January 31, 2018. Is it possible to prove that Earth is a sphere from these photographs?

When we observe the shadow of Earth on the moon, it seems outline of the shadow is curved one. Therefore, we can prove Earth surface is curved and hence Earth would be a sphere.

7. Properties of matter

1. What is matter? Name their forms.

Matter is a physical substance. The various forms of matter are Solid, liquid and gas.

2. Write a short note on Solids.

- Solid is a form of matter in which atoms are well bound each other through various types of bonding.
- It has a definite shape and volume.
- Ex: Ice cube.

3. Write a short note on liquids.

- Liquid is a form of matter in which atoms or molecules are losely bound. So that they wander around. It is formed when a solid is heated above the melting point.
- It has a fixed volume and has no definite shape.
- Ex: Water.

4. Write a short note on gases.

- Gas is a form of matter in which atoms or molecules have weak bond or no bond at all. So that they move freely and quickely. It is formed when a liquid is heated above the boiling point.
- It has no definite shape and volume but it adopts the shape and volume of the container.
- Ex: Stream.

5. What is meant by melting?

The process of changing of Solid in to liquid is called melting.

6. What is meant by evaporation?

The process of changing of liquid in to gas is called evaporation.

7. What are the additional physical states of matter available in extreme environments?

The additional physical states of matter available in extreme environments are plasma, Bose-Einstein condensates and quark-gluon plasmas.

8. What is deforming force?

The force, which changes the size or shape of a body is called a deforming force.

9. What is elasticity? Give examples.

Elasticity is the property of a body in which it regains its origional shape and size after the removal of deforming force. Ex: Rubber,metals, steel ropes.

10. What is plasticity? Give an example.

Plasticity is the property of a body in which it does not regains its origional shape and size after the removal of deforming force. Ex: Glass.

11. What is restoring force?

When a body is subjected to a deforming force, internal force is developed against it. This internal force is called restoring force.

12. What is Stress? Give its unit and dimension.

The force per unit area is called as stress. Its unit is N m^{-2} or pascal and the dimension is $[ML^{-1}T^{2}]$.

$$Stress, \sigma = \frac{Force}{Area} = \frac{F}{A}$$

13. What are the types of stress?

- ***Longitudinal stress or normal stress*** – The stress normal to cross section. $i.e. \quad \sigma_n = \frac{F_n}{\Delta A}$
- ***Shearing stress*** – The stress tangential to cross section area. $i.e. \quad \sigma_t = \frac{F_t}{\Delta A}$
- ***Volume stress*** – The stress, which happens everwhere normal to the body. $i.e. \quad \sigma_v = \frac{F}{A}$

14. What are the types of longitudinal stress?

- ***Tensile stress*** : The longitudinal stress, which elongates the body.
- ***Compressive stress*** : The longitudinal stress, which compress the body.

15. What is strain?

Strain is a measure of deformation of a body, When a force is applied on it. It is the ratio of change in size to the original size.

$$i.e.\ Strain, \varepsilon = \frac{Change\ in\ size}{Original\ size}$$

16. What are the types of strain?

- Longitudinal strain.
- Shearing strain.
- Volume strain.

17. Define longitudinal strain.

The longitudinal strain is defined as the ratio of increase in length to the original length.

$$i.e. \quad \varepsilon_l = \frac{\Delta l}{l}$$

18. What are the types of longitudinal strain?

- ***Tensile strain*** : Increase of length from its original.
- ***Compressive stress*** : Decrease of length from its original.

19. Define shearing strain.

The Shearing strain is defined as the angle of shear.

$$i.e. \quad \varepsilon_s = Angle\ of\ shear = \theta$$

20. Define volume strain.

The volume strain is defined as ratio of change in volume to the original volume.

$$i.e. \quad \varepsilon_v = \frac{\Delta V}{V}$$

21. What is meant by elastic limit?

The maximum stress within which the body regains its original size and shape after the removal of deforming force is called the elastic limit.

22. State Hooke's law.

Hooke's law states that the stress is directly proportional to the strain with in the elastic limit of the body. i.e. $\sigma \propto \varepsilon$.

23. Define modulus of elasticity. Name its types.

Modulus of elasticity is defined as the ratio of the stress to the strain.

<u>Types:</u> (a) Young's modulus
(b) Bulk modulus.
(c) Rigidity (or) shear modulus.

24. Define Young's modulus. Give its unit.

Young's modulus is defined as the ratio of tensile or compressive stress to the tensile or compressive strain. Its unit is N m^{-2} or pascal.

$$i.e. \quad Y = \frac{\sigma_t}{\varepsilon_t} \quad or \quad Y = \frac{\sigma_c}{\varepsilon_c}$$

25. Define Bulk modulus. Give its unit.

Bulk modulus is defined as the ratio of volume stress to the volume strain. Its unit is N m^{-2} or pascal.

$$i.e. \quad K = \frac{\sigma_n}{\varepsilon_v} = \frac{\Delta P}{\left(\frac{\Delta V}{V}\right)}$$

26. What is compressibility?

The reciprocal of the bulk modulus is called compressibility. It is defined as the fractional change in volume per unit increase in pressure.

$$i.e. \quad C = \frac{1}{K} = -\frac{\varepsilon_v}{\sigma_n} = \frac{\left(\frac{\Delta V}{V}\right)}{\Delta P}$$

27. Define rigidity or shear modulus. Give its unit.

The rigidity modulus is defined as the ratio of shearing stress to the shearing strain(angle of shear). Its unit is N m^{-2} or pascal.

$$i.e. \quad \eta_R = \frac{\sigma_s}{\varepsilon_s} = \frac{\left(F_t/_{\Delta A}\right)}{\theta}$$

28. Define poisson's ratio.

Poisson's rato(μ) is defined as the ratio of relative contraction(lateral strain) to the relative expansion (longitudinal strain).

29. What are the applications of elasticity?

- Elasticity is used in structural engineering in which bridges and buildings are designed such a way that it can withstand load of flowing traffic, the force of winds and even its own weight.
- The material of high Young's modulus is used in constructing beams.

30. Why do we prefer steel for design of heavy-duty machines and iron rods in the construction of buildings?

We prefer steel for design of heavy-duty machines and iron rods in the construction of buildings because steel has higher Young's modulus and elasticity than other materials like aluminium, copper and iron.

31. Define Pressure. Give its unit and dimension.

The pressure is defined as the force acting per unit area. Its unit is N m^{-2} or pascal and dimension is $[ML^{-1}T^{-2}]$.

$$i.e. \quad P = \frac{F}{A}$$

32. Define 1 atm or atmospheric pressure. Give its value.

Atmospheric pressure is defined as the pressure exerted by the atmosphere at sea level.

1 atm = 1.013×10^5 N m^{-2}.

33. Define density of a fluid. Give its unit and dimension.

The density of a fluid is defined as its mass per unit volume. Its unit is kg m^{-3} and dimension is $[ML^{-3}]$.

$$i.e. \quad \rho = \frac{m}{V}$$

34. Define relative density or specific gravity.

The relative density of a substance is defined as the ratio of the density of a substance to the density of water at 4 ^{0}C.

35. State Pascal's law.

If the pressure in a liquid is changed at a particular point, the change is transmitted to the entire liquid without being diminished in magnitude.

36. What is buoyancy?

The upward force exerted by a fluid that opposes the weight of an immersed object in a fluid is called upthrust or buoyant force and the phenomenon is called buoyancy.

37. State Archimedes principle.

It states that when a body is partially or wholly immersed in a fluid, it experiences an upward thrust equal to the weight of the fluid displaced by it and its upthrust acts through the centre of gravity of the liquid displaced.

38. State law of floatation.

The law of floatation states that a body will float in a liquid if the weight of the liquid displaced by the immersed part of the body equals the weight of the body.

39. Give the examples of floating bodies.

- A swimming person.
- Ice cubes float on water.
- A ship float on the sea.

40. Define viscosity.

Viscosity is defined as 'the property of a fluid to oppose the relative motion between its layers'.

41. State Newton's law of viscosity.

It states that the force of viscosity F acting tangentially between two layers of a liquid is proportional to (i) area A of the liquid and (ii) the velocity gradient $\frac{dv}{dx}$.

$$i.e. \quad F = -\eta A \frac{dv}{dx}$$

42. Define coefficient of viscosity. Give its unit and dimension.

The coefficient of viscosity is defined as the force of viscosity acting between two layers per unit area and unit velocity gradient of the liquid. Its unit is Nsm^{-2} and dimension is $[ML^{-1}T^{-1}]$.

43. What is streamlined flow of the liquid?

When a liquid flows such that each particle of the liquid passing through a point moves along the same path with the same velocity as its predecessor then the flow of liquid is said to be a streamlined flow.

44. What is meant by tube of flow?

If we assume a bundle of streamlines having the same velocity over any cross section perpendicular to the direction of flow then such bundle is called a 'tube of flow'.

45. What is meant by the critical velocity of the liquid?

Critical velocity is the velocity below which flow of liquid becomes streamlined.

46. What is turbulent flow of the liquid?

When the speed of the moving fluid exceeds the critical speed, the motion becomes irregular. This flow of liquid is called turbulent flow.

47. What is Reynold's number? Write its formula.

Reynold's number(R_c) is a dimensionless number, which is used to find out the nature of flow of the liquid.

$$i.e. \quad R_c = \frac{\rho v D}{\eta}$$

Where, ρ - density of the liquid
v – the velocity of flow of liquid.
D- diameter of the pipe.
η - the coefficient of viscosity of the fluid

S.No.	Reynold's number	Flow
1.	$R_c < 1000$	Streamlined flow
2.	$1000 < R_c < 2000$	Unsteady
3.	$R_c > 2000$	Turbulent flow

48. State law of similarity.

It states that when there are two geometrically similar flows, both are essentially equal to each other, as long as they embrace the same Reynold's number.

49. What is the terminal velocity?

The maximum constant velocity acquired by a body while falling freely through a viscous medium is called the terminal velocity.

50. State Stoke's law.

The viscous force F acting on a spherical body of radius r depends directly on
i) radius (r) of the sphere
ii) velocity (v) of the sphere
and iii) coefficient of viscosity η of the liquid

$$i.e. \quad F = 6\pi\eta av$$

51. Explain the Stoke's law application in raindrop falling.

According to Stoke's law, terminal velocity is directly proportional to square of radius of the spherical body. So that smaller raindrops having less terminal velocity float as cloud in air. When they gather as bigger drops get higher terminal velocity and start falling.

52. Write the applications of Stoke's law.

- Floatation of clouds
- Hurting of larger raindrops.
- Parachute riding.

53. What are the applications of viscosity?

- Viscosity of liquids helps in choosing the lubricants for various machinery parts. Low viscous lubricants are used in light machinery parts and high viscous lubricants are used in heavy machinery parts.
- As high viscous liquids damp the motion, they are used in hydraulic brakes as brake oil.
- Blood circulation through arteries and veins depends upon the viscosity of fluids.
- Viscosity is used in Millikan's oil-drop method to find the charge of an electron.

54. What is meant by cohesive force?

The force between the like molecules which holds the liquid together is called 'cohesive force'.

55. What is meant by adhesive force?

The force between the unlike molecules which holds the solid and liquid together is called 'adhesive force'.

56. What is meant by sphere of influence?

The range at which the influence of the molecular forces can be felt in all directions is called sphere of influence. Its value is about 10^{-9} m or 10 Å .

57. Define Surface tension. Give its unit and dimension.

The surface tension of a liquid is defined as the force of tension acting perpendicularly on both sides of an imaginary line of unit length drawn on the free surface of the liquid.

$$i.e. \quad T = \frac{F}{l}$$

(or)

The surface tension of a liquid is defined as the energy per unit area of the surface of a liquid.

$$i.e. \quad T = \frac{W}{\Delta A} = surface\ energy$$

Its unit is $N\ m^{-1}$ and dimension is $[MT^{-2}]$.

58. How do water bugs and water striders walk on the surface of water?

When the water bugs or water striders are on the surface of the water, its weight is balanced by the surface tension of the water. Hence, they can easily walk on it.

59. Give some examples for surface tension.
- Clinging of painting brush hairs, when taken out of water.
- Needle float on the water.
- Camphor boat.

60. What are factors affecting the surface tension of a liquid?
- Contamination or impurities - increase surface tension
- Dissolved substances - increase surface tension
- Electrification - decrease surface tension
- Temperature - decrease surface tension

61. What is surface energy of a liquid? Give its unit.

The work done in increasing the unit surface area of the liquid against the surface tension is called 'surface energy'. Its unit is J m^{-2} or N m^{-1} .

$$Surface\ energy = \frac{W}{\Delta A} = T$$

62. What is angle of contact?

The angle between the tangent to the liquid surface at the point of contact and the solid surface is known as the angle of contact.

63. What is meant by capillarity or capillary action? Name their types.

The rise or fall of a liquid in a narrow tube is called capillarity or capillary action.

Types: (i) Capillary rise. (ii) Capillary fall.

64. What are the practical applications of capillarity?
- Rising of Oil in the cotton wick of earthen lamp.
- Rising of Sap from root to plant's leaves and branches.
- Absorption of ink by a blotting paper.
- Draining of tear fluid from the eye.
- Absorption of Sweat by cotton dress.

65. What are the applications of surface tension?
- Oil pouring on the water reduces suface tension. So that the floating mosquitoe eggs drown and killed.
- Finely adjusted surface tension of the liquid makes droplets of desired size, which helps in desktop printing, automobile painting and decorative items.
- Specks of dirt are removed from the cloth when it is washed in detergents added hot water, which has low surface tension.
- A fabric can be made waterproof, by adding suitable waterproof material (wax) to the fabric. This increases the angle of contact due to surface tension.

66. State Bernoulli's theorem.

According to Bernoulli's theorem, the sum of pressure energy, kinetic energy, and potential energy per unit mass of an incompressible, non-viscous fluid in a streamlined flow remains a constant.

$$i.e. \quad \frac{P}{\rho} + \frac{1}{2}v^2 + gh = constant$$

67. What physical quantity actually do we check by pressing the tyre after pumping?

After pumping the tyre, we actually check the compressibility of air by pressing the tyre. For smooth riding, rear tyre should have less compressibility than the front.

68. Which one of these is more elastic steel or rubber? Why?

Steel is more elastic than rubber because the steel has higher young's modulus than rubber. That's why, if equal stress is applied on both steel and rubber, the steel produces less strain.

69. A spring balance shows wrong readings after using for a long time. Why?

When the spring balances have been used for a long time they develop elastic fatigue in them and therefore the reading shown by such balances will be wrong.

70. What is the effect of temperature on elasticity?

If the temperature of the substance increases, its elasticity decreases.

71. Distinguish between streamlined flow and turbulent flow.

S. NO.	Streamlined flow	Turbulent flow
1.	The particles are flowing in the same direction.	The particles are flowing randomly.
2.	The flow is steady.	The flow is speedy.
3.	The velocity of flow is less than the critical velocity.	The velocity of flow is greater than the critical velocity.
4.	The value of Reynold's number is less than 1000.	The value of Reynold's number is greater than 2000.
5.	Ex: Water flowing in the stream.	Ex: Water flowing in the flood.

72. Two streamlines cannot cross each other. Why?

No two streamlines can cross each other. If they do so, the particles of the liquid at the point of intersection will have two different directions for their flow, which will destroy the steady nature of the liquid flow.

73. Distinguish between cohesive and adhesive forces.

S. NO.	Cohesive force	Adhesive force
1.	It exists between similar molecules.	It exists between dissimilar molecules.
2.	It can be hydrogen bonds or Van der Waal attraction	It can be either mechanical or electrostatis forces.
3.	Ex: Molecular force between liquid molecules.	Ex: Molecular force between liquid and solid.

74. What happens to the pressure inside a soap bubble when air is blown into it?

When air is blown into the soap bubble, the radius of the bubble is increased. So that the excess pressure inside it decreases.

75. A drop of oil placed on the surface of water spreads out. But a drop of water place on oil contracts to a spherical shape. Why?

- ❖ A drop of oil placed on the surface of water spreads because the force of adhesion between water and oil molecules dominates the cohesive force of oil molecules.
- ❖ On the other hand, cohesive force of water molecules dominates the adhesive force between water and oil molecules. So drop of water on oil contracts to a spherical shape.

76. State the principle and usage of Venturimeter.

- ❖ Bernoulli's theorem is the principle of Venturimeter.
- ❖ Venturimeter is used to measure the rate of flow or flow speed of the incompressible fluid flowing through a pipe.

Conceptual Questions:

77. Why coffee runs up into a sugar lump (a small cube of sugar) when one corner of the sugar lump is held in the liquid?

The coffee runs up into the pores of sugar lump due to capillary action of the liquid.

78. Why two holes are made to empty an oil tin?

When oil comes out from a hole of an oil tin, pressure inside it decreased than the atmosphere. Therefore, the surrounding air rush up into the same hole prevents the oil to come out. Hence two holes are made to empty the oil tin.

79. We can cut vegetables easily with a sharp knife as compared to a blunt knife. Why?

Since the stress produced on the vegetables by the sharp knife is higher than the blunt knife, vegetables can be cut easily with the sharp knife.

80. Why the passengers are advised to remove the ink from their pens while going up in an aeroplane?

When an aeroplane ascends, the atmospheric pressure is decreased. Hence, the ink from the pen will leak out. So that, the passengers are advised to remove the ink from their pens while going up in the aeroplane.

81. We use straw to suck soft drinks. why?

When we suck the soft drinks through the straw, the pressure inside the straw becomes less than the atmospheric pressure. Due to the difference in pressure, the soft drink rises in the straw and we are able to enjoy it conveniently.

8. Heat and Thermodynamics

1. What is heat? Give its unit.

Heat is the energy in transit, which flows from an object of higher temperature to lower one. Its unit is joule.

2. What is meant by temperature? Give its unit.

Temperature is the degree of hotness or coolness of a body. Its unit is kelvin.

3. State Boyle's law.

When the gas is kept at constant temperature, the pressure of the gas is inversely proportional to the volume.

$$i.e.\quad P \propto \frac{1}{V}$$

4. State Charles' law.

When the gas is kept at constant pressure, the volume of the gas is directly proportional to absolute temperature.

$$i.e.\quad V \propto T$$

5. Define Avogadro's number. Give its value.

The Avogadro's number (N_A) is defined as the number of carbon atoms contained in exactly 12g of Carbon-12. Its value is 6.023 x 10^{23} mol^{-1} .

6. What is one mole?

One mole is the amount of the substance, which contains Avagadro number of particles.

7. Write the equation of state for an ideal gas or write ideal gas law.

$$PV = NkT \quad (or) \quad PV = \mu RT$$

Where, P – Pressure ; V – Volume
μ - No. of moles ; N – No. of particles.
k – Boltzmann constant(1.381x$10^{-23}$$JK^{-1}$)
R- Universal gas constant
T - Temperature

8. Define heat capacity. Give its unit.

Heat capacity is defined as the amount of heat energy required to raise the temperature of a substance by 1 Kelvin or 1^0C. Its unit is J K^{-1}.

$$i.e.\quad S = \frac{\Delta Q}{\Delta T}$$

9. Define specific heat capacity. Give its unit.

Specific heat capacity of a substance is defined as the amount of heat energy required to raise the temperature of 1kg of a substance by 1 Kelvin or 1^0C. Its unit is J kg^{-1} K^{-1}.

$$i.e.\quad s = \frac{\Delta Q}{m\,\Delta T} = \frac{S}{m}$$

10. Define molar specific heat capacity. Give its unit.

Molar specific heat capacity is defined as heat energy required to increase the temperature of one mole of substance by 1K or 1^0C. Its unit is J mol^{-1} K^{-1}.

$$i.e.\quad C = \frac{\Delta Q}{\mu\,\Delta T} = \frac{S}{\mu}$$

11. What is thermal expansion?

The increase in dimension of a body due to the increase in its temperature is called thermal expansion.

12. What are the kinds of thermal expansion?

- **Linear expansion** - The expansion in length.
- **Area expansion** - The expansion in area.
- **Volume expansion** - The expansion in volume.

13. Define coefficient of linear expansion. Give its unit.

The coefficient of linear expansion is defined as the fractional change in length per small change in temperature. Its unit is $^0C^{-1}$ or K^{-1} .

$$i.e.\quad \alpha_L = \frac{\Delta L}{L\,\Delta T}$$

14. Define coefficient of area expansion. Give its unit.

The coefficient of area expansion is defined as the fractional change in area per small change in temperature. Its unit is $^0C^{-1}$ or K^{-1} .

$$i.e.\quad \alpha_A = \frac{\Delta A}{A\,\Delta T}$$

15. Define coefficient of volume expansion. Give its unit.

The coefficient of volume expansion is defined as the fractional change in volume per small change in temperature. Its unit is $^0C^{-1}$ or K^{-1} .

$$i.e.\quad \alpha_V = \frac{\Delta V}{V\,\Delta T}$$

16. What is anomalous expansion of water?

When water is cooled from room temperature it first contracts in volume and becomes increasingly dense as do other liquids, but at 4^0 C water reaches its maximum density. On further cooling from 4^0C to 0^0C, not like other liquids, it starts expanding and becomes less dense. This unusual behaviour of water is called anomalous expansion of water.

17. What are the different processes of change of states?

- Melting (solid to liquid)
- Evaporation (liquid to gas)
- Sublimation (solid to gas)
- Freezing / Solidification (liquid to solid)
- Condensation (gas to liquid)

18. Define latent heat capacity. Give its unit.

Latent heat capacity of a substance is defined as the amount of heat energy required to change the state of a unit mass of the material. Its unit is J kg^{-1} .

$$i.e.\quad L = \frac{Q}{m}$$

19. What is latent heat of fusion?

The latent heat for a solid - liquid state change is called the latent heat of fusion (L_f).

20. What is latent heat of vaporization?

The latent heat for a liquid - gas state change is called the latent heat of fusion (L_v).

21. What is latent heat of sublimation?

The latent heat for a solid - gas state change is called the latent heat of sublimation (L_s).

22.What is triple point?

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

[Triple point temperature of the water = 273.1 K
Triple point pressure of the water = 611.657 Pa]

23.What is meant by Calorimetry?

Calorimetry means the measurement of the amount of heat released or absorbed by thermodynamic system during the heating process.

24.What are three modes of heat transfer?

- Conduction
- Convection
- Radiation

25.What is Conduction?

Conduction is the process of direct transfer of heat through matter due to temperature difference.

26.What is thermal conductivity or coefficient of thermal conductivity? Give its unit.

The quantity of heat transferred through a unit length of a material in a direction normal to unit surface area due to a unit temperature difference under steady state conditions is known as thermal conductivity of a material. Its unit is J s^{-1} m^{-1} K^{-1} or W m^{-1} K^{-1} .

$$i.e.\quad K = \frac{Q\,L}{A\,\Delta T\,t}$$

27.What is steady state?

The state at which temperature attains constant value everywhere and there is no further transfer of heat anywhere is called steady state.

28.What is meant by convection?

Convection is the process in which heat transfer is by actual movement of molecules in fluids such as liquids and gases.

29.What is meant by radiation? Give the examples.

Radiation is a form of energy transfer from one body to another by electromagnetic waves.

Example: 1. Solar energy from the Sun.
2. Radiation from room heater.

30.State Newton's law of cooling.

Newton's law of cooling states that the rate of loss of heat of a body is directly proportional to the temperature difference between that body and its surroundings.

31.State Prevost theory of heat exchange.

Prevost theory states that all bodies emit thermal radiation at all temperatures above absolute zero irrespective of the nature of the surroundings.

32.What is a black body?

A black body is a idealized physical body which absorbs and radiates all kinds of electromagnetic wavelengths.

33.State Stefan Boltzmann law.

Stefan Boltzmann law states that, the total amount of heat radiated per second per unit area of a black body is directly proportional to the fourth power of its absolute temperature.

$$i.e.\quad E = \sigma T^4$$

Where σ = 5.67 X 10^{-8} W m^{-2} K^{-4}, Stefan's constant.

34.Define emissivity.

Emissivity is defined as the ratio of the energy radiated from a material's surface to that radiated from a perfectly black body at the same temperature and wavelength.

35.State Wien's displacement law.

Wien's law states that, the wavelength of maximum intensity of emission of a black body radiation is inversely proportional to the absolute temperature of the black body.

$$i.e.\quad \lambda_m = \frac{b}{T}$$

Where, b =2.898 x 10^{-3} m K , Wien's constant.

36.What is thermodynamics?

Thermodynamics is a branch of physics, which describes the laws governing the process of conversion of work into heat and conversion of heat into work.

37.Differentiate the thermodynamic system and the surrounding with examples.

- A thermodynamic system is a finite part of the universe.
- The remaining part of the universe is called surrounding.

Examples :

S.No.	Thermodynamic system	Surrounding
1.	Bucket of water	Open atmosphere
2.	Air molecules	Outside air
3.	Human body	Open atmosphere
4.	Fish in the sea	Sea of water

38.What is meant by thermal equilibrium?

Two systems are said to be in thermal equilibrium with each other if they are at the same temperature, which will not change with time.

39.What is meant by mechanical equilibrium?

System is said to be in mechanical equilibrium if no unbalanced force acts on the thermodynamic system or on the surrounding by thermodynamic system.

40.What is meant by chemical equilibrium?

If there is no net chemical reaction between two thermodynamic systems in contact with each other then it is said to be in chemical equilibrium.

41. What is meant by thermodynamic equilibrium?

If two systems are set to be in thermodynamic equilibrium, then the systems are at thermal, mechanical and chemical equilibrium with each other.

42. What is thermodynamic or state variables? Give the examples

A set of variables used to represent the state of a thermodynamic system is called thermodynamic or state variables.

Example: Pressure, temperature, volume, internal energy, etc.,

43. What are the types of thermodynamic variables?

- Extensive variable
- Intensive variable.

44. What is extensive variable?

The variable, which depends on the size or mass of the system, is called extensive variable.

Example: Volume, total mass, entropy, internal energy, heat capacity etc.,

45. What is intensive variable?

Intensive variables do not depend on the size or mass of the system.

Example: Temperature, pressure, specific heat capacity, density etc.,

46. What is equation of state? Give the examples.

The equation, which connects the state variables in a specific manner, is called equation of state.

Example: a) Ideal gas equation.
b) Van der Waals equation.

47. State zeroth law of thermodynamics.

The zeroth law of thermodynamics states that if two systems A and B are in thermal equilibrium with a third system C, then A and B are in thermal equilibrium with each other.

48. What is internal energy?

The internal energy of a thermodynamic system is the sum of kinetic and potential energies of all the molecules of the system with respect to the center of mass of the system.

$$i.e.\ \ U = E_K + E_P$$

49. What is internal kinetic energy?

The energy due to molecular motion including translational, rotational and vibrational motion is called internal kinetic energy (E_K).

50. What is internal potential energy?

The energy due to molecular interaction is called internal potential energy (E_P).

51. What is Joule's mechanical equivalent of heat? or Define one Calorie.

The energy required to raise the temperature of 1g of an object by 1^0C is called Joule's mechanical equivalent of heat or one Calorie.

[Joule's mechanical equivalent = 4.186 J = 1 calorie]

52. State first law of thermodynamics.

It states that 'Change in internal energy (ΔU) of the system is equal to the difference between heat supplied to the system (Q) and the work done by the system (W) on the surroundings'. i.e. $\Delta U = Q - W$.

53. Tabulate the changes occur on internal energy, heat supplied to the system and work done by the system depending upon the various factors.

Factors	Internal energy(U)	Heat supplied(Q)	Work done (W)
System gains heat	increases	positive	-
System loses heat	decreases	negative	-
Work done on the system	increases	-	negative
Work done by the system	decreases	-	positive

54. What is quasi-static process?

A quasi-static process is an infinitely slow process in which the system changes its variables (P,V,T) so slowly such that it remains in thermal, mechanical and chemical equilibrium with its surroundings throughout.

55. What is P-V diagram? why it is used?

P-V diagram is a graph between pressure P and volume V of the system. It is used to calculate the amount of work done by the gas during expansion or on the gas during compression.

56. What is specific heat capacity at constant pressure?

The amount of heat energy required to raise the temperature of one kg of a substance by 1 K or 1^0C by keeping the pressure constant is called specific heat capacity of at constant pressure (S_P).

57. What is specific heat capacity at constant volume?

The amount of heat energy required to raise the temperature of one kg of a substance by 1 K or 1^0C by keeping the volume constant is called specific heat capacity of at constant volume (S_V).

58. What is molar specific heat capacity at constant pressure?

The amount of heat energy required to raise the temperature of one mole of a substance by 1 K or 1^0C by keeping the pressure constant is called molar specific heat capacity of at constant pressure (C_p).

59. What is molar specific heat capacity at constant volume?

The amount of heat energy required to raise the temperature of one mole of a substance by 1 K or 1^0C by keeping the volume constant is called molar specific heat capacity of at constant volume (C_v).

60. What is isothermal process?

Isothermal process is a process in which the temperature remains constant but the pressure and volume of a thermodynamic system will change.

61.What is isotherm?

The pressure - volume graph for constant temperature is also called isotherm.

62.What is adiabatic process?

Adiabatic process is a process in which no heat flows into or out of the system (Q = 0).

63.What is isobaric process?

Isobaric process is a thermodynamic process that occurs at constant pressure. Even though pressure is constant in this process, temperature, volume and internal energy are not constant.

64.What is isochoric process?

Isochoric process is a thermodynamic process in which the volume of the system is kept constant. But pressure, temperature and internal energy continue to be variables.

65.What is cyclic process?

Cyclic process is a thermodynamic process in which the thermodynamic system returns to its initial state after undergoing a series of changes.

66.What is the Limitation of first law of thermodynamics?

The first law of thermodynamics explains well the inter convertibility of heat and work. But it does not indicate the direction of change.

Example:

- According to 1st law of thermodynamics, heat energy can flow from hot body to cold and vice versa. However, in nature heat flows only from hot body to cold.
- When brake is applied in a car, it stops due to friction. The work done against this friction is converted into heat. But this heat is not reconvertible to the kinetic energy of the car.

67.What is reversible process? Give the examples.

A thermodynamic process, which retrace the path in the opposite direction in such a way that the system and surroundings pass through the same states as in the initial direct process is called reversible process.

Example: A quasi–static isothermal expansion of gas, slow compression and expansion of a spring.

68.What are the conditions for reversible process?

- The process should proceed at an extremely slow rate.
- The system should remain in mechanical, thermal and chemical equilibrium state at all the times with the surroundings, during the process.
- No dissipative forces such as friction, viscosity, electrical resistance should be present.

69.What is irreversible process? Give the examples.

A thermodynamic process, which does not retrace the path in the opposite direction as like direct process is called irreversible process.

Example: All natural processes are irreversible.

- The gas molecules came out from the bottle will never get back in to it.
- Suppose one drop of an ink is dropped and spreads in the water. It is impossible to get the ink droplet back.
- When an object hits the earth from some height all the kinetic energy of the object is converted to kinetic energy of the molecules at the earth surface. This spreaded kinetic energy cannot be retrieved back by the object to go up.

70.State Clausius form of second law of thermodynamics

Clausius form of second law of thermodynamics states that "Heat always flows from hotter object to colder object spontaneously".

71.What is reservoir? Name its types.

Reservoir is defined as a thermodynamic system, which has very large heat capacity. Giving or taking heat will not not affect the reservoir's temperature.

Types: (a) Hot reservoir (Or) Source.
(b) Cold reservoir (Or) Sink.

72.What is heat engine? Name their parts.

Heat engine is a device, which takes heat as input and converts this heat in to work by undergoing a cyclic process.

Parts: (a) Hot reservoir
(b) Working substance
(c) Cold reservoir.

73.What is hot reservoir or Source?

Hot reservoir is a thermodynamic system, which supplies heat to the engine. It is always maintained at a high temperature T_H.

74.What is working substance?

Working substance is a substance like gas or water, which converts the heat supplied into work.

75.What is Cold reservoir or Sink?

Cold reservoir is a thermodynamic system, which receives heat from the engine. It is always maintained at a low temperature T_L.

76.Define efficiency of the heat engine.

The efficiency of the heat engine is defined as the ratio of the work done (out put) to the heat absorbed (input) in one cyclic process.

77.State Kelvin – Planck statement .

It is impossible to construct a heat engine that convert the heat completely into work in a cycle. This implies that no heat engine in the universe can have 100% efficiency.

78.What is Carnot engine?

A reversible heat engine operating in a cycle between two temperatures in a particular way is called a Carnot Engine.

79.What is carnot's cycle?

The working substance is subjected to four successive reversible processes, which is called Carnot's cycle.

80.What are the processes involved in a Carnot engine?

- Quasi-static isothermal expansion
- Quasi-static adiabatic expansion
- Quasi-static isothermal compression
- Quasi-static adiabatic compression

81.What are the important results arrived in efficiency of Carnot engine?

- Efficiency of heat engines(η) is always less than one since $T_L < T_H$ and also it is practically impossible to make $T_L = 0$ K.
- η doesn't depend on working substance. But it depends on temperature difference between source and sink.
- When $T_H = T_L$ the efficiency η = 0. No engine can work having source and sink at the same temperature.
- Carnot engine is a reversible engine. But the practical heat engines like petrol engine, deisel engine and steam engine are not perfectly reversible. So that they have less efficiency than Carnot engine.

82.State Carnot theorem.

Carnot theorem states that no heat engine working in a cycle between two constant temperature reservoirs can be more efficient than a reversible Carnot engine working between the same reservoirs.

83.What is meant by entropy?

Entropy is nothing but 'measure of disorder'. All natural process occur such that the disorder should always increases.

84.State second law of thermodynamics in terms of entropy.

It states that the entropy always increases for all natural process (irreversible process). However, entropy doen't change for reversible process.

85.Why does heat flow from a hot object to a cold object?

When heat flows from a hot object to a cold object, the entropy increases. Suppose heat flows from cold to hot object, entropy will decrease, which violates 2nd law of thermodynamics.

86.Define coefficient of performance (COP).

Coefficient of performance(COP) is defined as the ratio of heat extracted from the cold body (sink) to the external work done by the compressor W. It is used to measure efficiency of refridgerator.

$$i.e.\quad COP = \beta = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L}$$

87.What are the inferences arrived in COP of refridgerator?

- The greater the COP, the better is the condition of the refrigerator. A typical refrigerator has COP around 5 to 6.
- Lesser the difference in the temperatures of the cooling chamber and the atmosphere, higher is the COP of a refrigerator.
- In the refrigerator, the heat is flowed from cold object to hot object by doing external work. It increases the entropy and thereby obeys 2nd law of thermodynamics.

88.'An object contains more heat'- is it a right statement? If not why?

No. 'Heat' is the energy in transit and it is not a quantity. Therefore, the statement 'An object contains more heat' is wrong, instead 'Object is hot' will be appropriate.

89.Obtain an ideal gas law from Boyle's and Charles' law.

- According to Boyle's law, $P \propto \frac{1}{V}$ When T= const.
- According to Charles' law, $V \propto T$ When P= const
- Combining these two we get,

$$PV = CT$$

Where C is positive constant, which is proportional to no. of particles in the gas.

i.e. $C \propto N$ or $C = kN$

Where k is Boltzmann constant.

- Therefore, PV = NkT
- This is called ideal gas law.

90.Are internal energy and heat energy the same? Explain.

No. Internal energy and heat energy are different. Internal energy depends on size or mass of the system. Hot water with high temperature in a tumbler has less internal energy than the normal water with low temperature in the bucket. Moreover, heat energy flows form hot to cold irrespective of internal energy.

91. Did Joule convert mechanical energy to heat energy? Explain.

No. Joule actually converted mechanical energy into internal energy not into heat energy. Because heat energy is not a quantity. It is a energy in transit.

92. Can we measure the temperature of the object by touching it?

No, we cannot. If we touch both a carpet and a tile, we feel tile is cooler than the carpet even though both are at same room temperature. Because the tile transfer heat energy at higher rate than the carpet. Therefore, by touching the object we can measure only the rate of heat energy transfer, not the temperature.

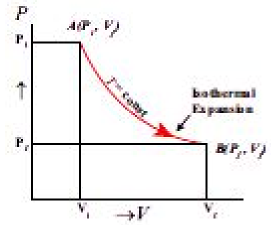
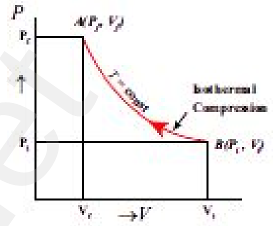
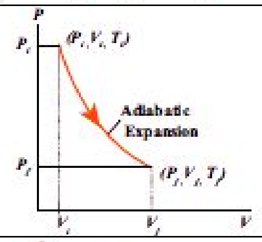
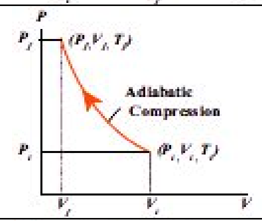
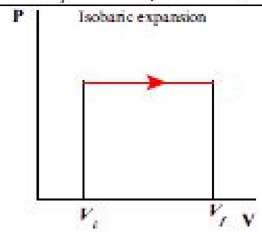
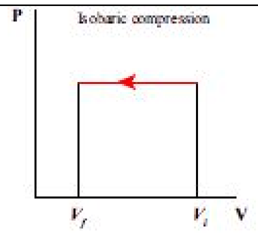
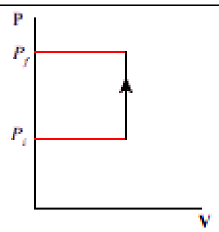
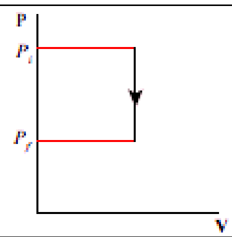
93. Explain why the specific heat capacity at constant pressure is greater than the specific heat capacity at constant volume.

To increase the temperature of the gas at constant volume requires less heat than increasing the temperature of the gas at constant pressure. Therefore, specific heat capacity at constant pressure(S_P) is always greater than the specific heat capacity at constant volume(S_V).

94. Give equation of state and work done expression for isothermal, adiabatic, isobaric and isochoric.

Process	Equation of state	Work done (ideal gas)
Isothermal expansion (T =const.)	PV = Constant (P↓ and V↑)	$W = \mu RT\ ln\left(\frac{V_f}{V_i}\right)$ (W>0 , Q >0)
Isothermal compression (T =const.)	PV = Constant (P↑ and V↓)	$W = \mu RT\ ln\left(\frac{V_f}{V_i}\right)$ (W<0 , Q <0)
Adiabatic expansion (T↓)	PV^{γ} = Constant (P↓ and V↑)	$W = \frac{\mu R}{\gamma - 1}(T_i - T_f)$ (W>0 , Q = 0)
Adiabatic compression (T↑)	PV^{γ} = Constant (P↑ and V↓)	$W = \frac{\mu R}{\gamma - 1}(T_i - T_f)$ (W< 0 , Q = 0)
Isobaric expansion (P=constant)	$\frac{V}{T} = constant$ (V↑ and T↑))	$W = P(V_f - V_i) = P\Delta V$ (W>0 , Q >0)
Isobaric compression (P=constant)	$\frac{V}{T} = constant$ (V↓ and T↓))	$W = P(V_f - V_i) = P\Delta V$ (W<0 , Q <0)
Isochoric (V=constant)	$\frac{P}{T} = constant$ (P↑ and T↑)	W = 0 , Q > 0
Isochoric (V=constant)	$\frac{P}{T} = constant$ (P↓ and T↓)	W = 0 , Q < 0

95. Draw the PV diagram for a) Isothermal process b) Adiabatic process c) isobaric process d) Isochoric process.

Process	P - V Diagram
Isothermal expansion (T =const.)	
Isothermal compression (T =const.)	
Adiabatic expansion (T↓)	
Adiabatic compression (T↑)	
Isobaric expansion (T↑)	
Isobaric compression (T↓)	
Isochoric (T↑)	
Isochoric (T↓)	

96. If the piston of a container is pushed fast inward, will the ideal gas equation be valid in the intermediate stage? If not, why?

No. It is not valid. Ideal gas equation is only valid for equilibrium state. When the piston is pushed fast inward, it goes to non-equilibrium state, in which we cannot determine pressure, temperature or internal energy by using ideal gas equation.

97. Can the given heat energy be completely converted to work in a cyclic process? If not, when can the heat can completely converted to work?

No. For non-cyclic process like an isothermal expansion, the heat is completely converted into work.

98. How does the water kept in an earthen pot become cool during summer? Does the earthern pot act as a refrigerator?

No. cyclic process is the necessity for heat engine or refrigerator. In earthern pot, the cooling process is not due to any cyclic process. The cooling happens due to evaporation of water through the pores of the pot by taking heat energy from the water inside the pot.

99. When two objects of same mass are heated or cooled at equal rates, which one does faster?

The object with smaller specific heat capacity will have a faster temperature increase during heating and faster temperature drop during cooling.

100. During the day, sunrays warm up the land more quickly than sea water but during the night time it is vice versa. Why?

- It is because land has less specific heat capacity than water. As a result during the day, the air above the land becomes less dense due to expansion and rises. At the same time the cooler air above the sea flows to land and it is called 'sea breeze'.

- During the nighttime, the air molecules above sea are warmer than air molecules above the land. So the cooler air molecules from the land replace air molecules above the sea. It is called 'land breeze'.

101. All reversible processes are quasi-static but all quasi-static processes need not to be reversible. Explain with example..

when we push the piston very slowly(quasi-static process), due to the friction between the cylinder wall and the piston some amount of energy is lost to the surroundings, which cannot be retrieved back. Though it is a quasi-static process, it is not reversible.

9. Kinetic Theory of Gases

1. State Postulates of kinetic theory of gases.

- All the molecules of a gas are identical, elastic spheres.
- The molecules of different gases are different.
- The number of molecules in a gas is very large and the average separation between them is larger than size of the gas molecules.
- The molecules of a gas are in a state of continuous random motion.
- The molecules collide with one another and with the walls of the container.
- These collisions are perfectly elastic so that there is no loss of kinetic energy during collisions.
- Between two successive collisions, a molecule moves with uniform velocity.
- The molecules do not exert any force of attraction or repulsion on each other except during collision. The molecules do not possess any potential energy and the energy is wholly kinetic.
- The collisions are instantaneous. The time spent by a molecule in each collision is very small compared to the time elapsed between two consecutive collisions.
- These molecules obey Newton's laws of motion even though they move randomly.

2. What is the microscopic origin of pressure?

According to kinetic theory, microscopic origin of pressure is the force exerted by molecules or atoms impacting on the walls of a container.

3. What is the microscopic origin of temperature?

According to kinetic theory, microscopic origin of temperature is the average kinetic energy of the molecules.

4. State Boyle's law.

Boyle's law states that pressure of a given gas is inversely proportional to its volume provided the temperature remains constant.

$$P \propto \frac{1}{V} \quad ; T = constant$$

5. Deduce Boyle's law based on kinetic theory.

- From kinetic theory equations,

$$PV = \frac{2}{3}U \quad and \quad U = N\epsilon$$

- We get,

$$PV = \frac{2}{3}N\epsilon$$

- For constant temperatures, average kinetic energy ϵ is constant. Thus,

$$PV = Constant$$

$$or \qquad P \propto \frac{1}{V} \quad ; T = constant$$

- This is called Boyle's law.

6. State Charles' law.

For a fixed pressure, the volume of the gas is proportional to internal energy of the gas or average kinetic energy of the gas and the average kinetic energy is directly proportional to absolute temperature.

$$V \propto U \ or \ V \propto \in \propto T \quad ; P = constant$$

7. Deduce Charles' law based on kinetic theory.

- From kinetic theory equations,

$$PV = \frac{2}{3}U$$

$$PV = \frac{2}{3}U = \frac{2}{3}N\epsilon = \frac{2}{3}N\left(\frac{3}{2}KT\right) = NKT$$

- At constant pressure, we get,

$$V \propto U \ or \ V \propto \in \propto T \quad ; P = constant$$

- This is called Charle's law.

8. State Avagadro's law.

Avagadro's law states that at constant temperature and pressure, equal volumes of all gases contain the same number of molecules.

9. Deduce Avagadro's law based on kinetic theory.

- For two different gases at the same temperature and pressure, the kinetic theory equation can be expressed as,

$$P = \frac{1}{3}\frac{N_1}{V}m_1\overline{v_1^2} = \frac{1}{3}\frac{N_2}{V}m_2\overline{v_2^2} \longrightarrow (1)$$

- At the same temperature, average kinetic energy per molecule is same for two gases, so that,

$$\frac{1}{2}m_1\overline{v_1^2} = \frac{1}{2}m_2\overline{v_2^2} \longrightarrow (2)$$

- Dividing equation(1) by (2), we get,

$$N_1 = N_2$$

- This is Avagadro's law.

10. Define root mean square speed (v_{rms}).

Root mean square speed (v_{rms}) is defined as the square root of the mean of the square of speeds of all molecules.

$$v_{rms} = \sqrt{\overline{v^2}} = \sqrt{\frac{3kT}{m}} = 1.73\sqrt{\frac{kT}{m}}$$

11. Why the Moon has no atmosphere?

The escape speed of gases on the surface of Moon is much less than the root mean square speeds of gases due to low gravity. Due to this all the gases escape from the surface of the Moon.

12. Why the Earth's atmosphere has no hydrogen?

As the root mean square speed(v_{rms}) of hydrogen is much higher than that of nitrogen, which is majority in atmosphere, hydrogen can easily escape from the earth's atmosphere.

13. Define Mean or average speed.

Mean or average speed is defined as the mean (or) average of all the speeds of molecules.

$$\bar{v} = \frac{v_1 + v_2 + v_3 + \cdots + v_N}{N}$$

$$or \quad \bar{v} = \sqrt{\frac{8RT}{\pi M}} = \sqrt{\frac{8kT}{\pi M}} = 1.60\sqrt{\frac{kT}{M}}$$

14. Define Most probable speed.

Most probable speed is defined as the speed acquired by most of the molecules of the gas.

$$v_{mp} = \sqrt{\frac{2RT}{M}} = \sqrt{\frac{2kT}{M}} = 1.41\sqrt{\frac{kT}{M}}$$

15. What is degrees of freedom?

The minimum number of independent coordinates needed to specify the position and configuration of a thermo-dynamical system in space is called the degree of freedom of the system.

16. Give examples for degrees of freedom.

- A free particle moving along x-axis needs only one coordinate to specify it completely. So its degree of freedom is one.
- Similarly, a particle moving over a plane has two degrees of freedom.
- A particle moving in space has three degrees of freedom.

17. Tabulate the degrees of freedom of monoatomic, diatomic and triatomic molecules.

Type of molecule	Degrees of freedom (f)							
	Low temperature				High temperature			
	Trans	Rot	Vib	Tot	Trans	Rot	Vib	Tot
Monoatomic (He,Ne,Ar)	3	0	0	**3**	3	0	0	**3**
Diatomic (H_2,N_2,O_2)	3	2	0	**5**	3	2	2	**7**
Linear triatomic (CO_2)	3	2	0	**5**	3	2	2	**7**
Non-linear triatomic (H_2O,SO_2)	3	3	0	**6**	3	3	0	**6**

18. State law of equipartition of energy.

According to kinetic theory, the average kinetic energy of system of molecules in thermal equilibrium at temperature T is uniformly distributed by $\frac{1}{2}kT$ to all degrees of freedom. This is called law of equipartition of energy.

19. What is mean free path?

The average distance travelled by the molecule between collisions is called mean free path (λ).

$$\lambda = \frac{kT}{\sqrt{2}\pi d^2 P}$$

20. What are the factors affecting the mean free path?

- Mean free path increases with increasing temperature.
- Mean free path increases with decreasing pressure and diameter of the gas molecules.

21. What is Brownian motion?

The random (Zig - Zag path) motion of pollen suspended in a liquid is called Brownian motion.

22. What is the reason for Brownian motion?

According to kinetic theory, any particle suspended in a liquid or gas is continuously bombarded from all the directions so that the mean free path is almost negligible. This leads to the Brownian motion.

23. What are the factors affecting the Brownian motion?

- Brownian motion increases with increasing temperature.
- Brownian motion decreases with bigger particle size, high viscosity and density of the liquid (or) gas.

10. Oscillations

1. What is periodic motion? Give the examples.

Any motion, which repeats itself after a regular interval of time, is known as periodic motion.

Ex: (i) Hands in pendulum clock.
(ii) Swing of a cradle.
(iii) The revolution of the Earth around the Sun.
(iv) Waxing and waning of Moon, etc.

2. What is non-periodic motion? Give the examples.

Any motion, which does not repeat itself after a regular interval of time, is known as non-periodic motion.

Ex: (i) Occurance of Earthquake.
(ii) eruption of volcano, etc.

3. What will happen if the motion of the Earth around the Sun is not a periodic motion?

Intervals of Seasons happen in the Earth will be changed. This will affect all the living environments.

4. What is oscillatory or vibratory motion? Give the examples.

When an object or a particle moves back and forth repeatedly about a reference point for some duration of time it is said to have Oscillatory (or vibratory) motion.

Ex: (i) Our heart beat
(ii) Swinging motion of the wings of an insect.
(iii) Grandfather's clock (pendulum clock), etc.

5. All the oscillatory motions are periodic whereas all periodic motions need not be oscillatory. Explain.

All oscillatory motions like heart beat, pendulam clock, etc. are regularly repeated periodic motion whereas some period motions like motion of the Earth around the Sun, bouncing motion of the kangaroos,etc. do not have to and fro motion as like oscillatory motion.

6. What is simple harmonic motion(SHM)?

Simple harmonic motion is a special type of oscillatory motion in which the acceleration or force on the particle is directly proportional to its displacement from a fixed point and is always directed towards that fixed point.

7. All the Simple harmonic motions are oscillatory whereas all oscillatory motions need not be simple harmonic. Explain.

A simple harmonic motion is a special type of oscillatory motion. In some oscillatory motions as like SHM, the acceleration or force on the particle is not directly proportional to its displacement from a fixed point.

8. What is displacement of the vibrating particle?

The distance travelled by the vibrating particle at any instant of time from its mean position is known as displacement of the vibrating particle.

9. What is amplitude of the vibrating particle?

The maximum displacement from the mean position is known as amplitude (A) of the vibrating particle.

10. Define time period.

The time period(T) is defined as the time taken by a particle to complete one oscillation. $i.e.\ \ T = \frac{2\pi}{\omega}$

11. What is frequency? Give its unit.

The number of oscillations produced by the particle per second is called frequency(f). Its unit is s^{-1} or Hz.

$$i.e.\ \ f = \frac{1}{T}$$

12. What is angular frequency? Give its unit.

The number of cycles (or revolutions) per second is called angular frequency(ω). Its unit is rad s^{-1} .

$$i.e.\ \ \omega = 2\pi f$$

13. What is phase? Give its unit.

The physical quantity, which specifies the position and direction of a vibrating particle from its mean position at any instant is called Phase(φ). Its unit is radian.

$$i.e.\ \ \varphi = \varphi_0 + \omega t$$

14. What is epoch? Give its unit.

The phase of the vibrating particle at time t=0 is called epoch or initial phase(φ_0). Its unit is radian.

15. What is angular oscillation?

When a body is allowed to rotate freely about a given axis, the oscillation is known as the angular oscillation.

16. What is mean position?

The point at which the resultant torque acting on the body is taken to be zero is called mean position.

17. What is meant by angular harmonic oscillation and angular harmonic oscillator?

When the angular acceleration or torque of the particle, which undergoes angular oscillation is directly proportional to angular displacement and is always directed towards the mean position is called angular harmonic oscillation. The system corresponding to it is called angular harmonic oscillator.

18. Compare the Simple and Angular harmonic motion.

S. No.	Simple Harmonic motion	Angular Harmonic motion
1.	The displacement of the particle is measured in terms of linear displacement $\vec{r}$.	The displacement of the particle is measured in terms of angular displacement or angle of twist $\vec{\theta}$.
2.	Acceleration of the particle is $\vec{a} = -\omega^2\vec{r}$	Angular acceleration of the particle is $\vec{\alpha} = -\omega^2\vec{\theta}$
3.	Force, $\vec{F} = m\vec{a}$, where m is called mass of the particle.	Torque, $\vec{\tau} = I\vec{\alpha}$, where I is called moment of inertia of a body.
4.	The restoring force $\vec{F} = -k\vec{r}$, where k is restoring force constant.	The restoring torque $\vec{\tau} = -K\vec{\theta}$, where the symbol K (kappa) is called restoring torsion constant. It depends on the property of a particular torsion fiber.
5.	Angular frequency $\omega = \sqrt{\frac{k}{m}}$ rad s-1	Angular frequency $\omega = \sqrt{\frac{K}{I}}$ rad s-1

19.What is stiffness constant or force constant or spring constant? Give its unit.

Force per unit length of a spring is called stiffness constant or force constant or spring constant(k). It is a measure of stiffness of the spring. Its unit is Nm^{-1}.

$$i.e. \quad k = -\frac{F}{x}$$

20.Write the equations for effective spring constant of the springs connected in series and parallel.

- The effective spring constant for series connection,

$$\frac{1}{k_s} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \cdots + \frac{1}{k_n} = \sum_{i=1}^{n} \frac{1}{k_i}$$

If $k_1 = k_2 = k_3 = ... = k_n = k$,

$$\frac{1}{k_s} = \frac{n}{k} \quad or \quad k_s = \frac{k}{n}$$

- The effective spring constant for parallel connection,

$$k_p = k_1 + k_2 + k_3 + \cdots + k_n = \sum_{i=1}^{n} k_i$$

If $k_1 = k_2 = k_3 = ... = k_n = k$,

$$k_p = n\,k$$

21.What is flexibility constant or compliance? Give its unit.

The reciprocal of stiffness constant is called flexibility constant or compliance. Its unit is $m\,N^{-1}$.

$$i.e. \quad C \propto \frac{1}{k}$$

22.State laws of simple pendulam.

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

- <u>Law of length:</u>

For a given value of acceleration due to gravity, the time period of a simple pendulum is directly proportional to the square root of length of the pendulum.

$$i.e. \quad T \propto \sqrt{l} \quad ; \quad g = constant$$

- <u>Law of acceleration:</u>

For a fixed length, the time period of a simple pendulum is inversely proportional to square root of acceleration due to gravity.

$$i.e. \quad T \propto \frac{1}{\sqrt{g}} \quad ; \quad l = constant$$

- <u>Law of mass:</u>

Time period of oscillation is independent of mass of the simple pendulum.

- <u>Law of amplitude:</u>

The time period is independent of amplitude of the oscillation for small angled oscillation.

23.If the potential energy is minimum then its second derivative is positive, why?

If the potential energy is minimum, it denotes stable equilibrium. For stable equilibrium, second derivative of potential energy should be positive.

24.Name the types of oscillations.

- Free oscillation
- Damped oscillation
- Maintained oscillation
- Forced oscillations
- Resonance

25.What is Free oscillation? Give the examples.

When an oscillator is allowed to oscillate with its natural frequency. Such oscillation is known as free oscillation.

<u>Examples:</u>

- Vibration of a tuning fork.
- Vibration in a stretched string.
- Oscillation of a simple pendulum.
- Oscillations of a spring-mass system.

26.What is Damped oscillation? Give the examples.

If the amplitude of the oscillation is gradually decreased due to air resistance, such an oscillation is called as Damped oscillation.

<u>Examples:</u>

- The oscillations of a pendulum (including air friction) or pendulum oscillating inside an oil filled container.
- Electromagnetic oscillations in a tank circuit.
- Oscillations in a dead beat and ballistic galvanometers.

27.What is Maintained oscillation? Give an example.

When the losing energy is suppiled to damped oscillation, if it oscillate with constant amplitude, such oscillation is known as Maintained oscillation.

<u>Example:</u>

The vibration of a tuning fork getting energy from a battery or from external power supply.

28.What is Forced oscillation? Give an example.

When the oscillator is forced to oscillate with the frequency of external periodic agency, not with its natural frequency, such oscillation is called Forced oscillation.

<u>Example:</u>

Sound boards of stringed instruments.

29.What is Resonance? Give an example.

When the frequency of external periodic agency is matched with natural frequency of the vibrating body, the body starts to vibrate with maximum amplitude. This is known as Resonance.

<u>Example:</u>

The breaking of glass due to sound.

30.Soldiers are not allowed to march on a bridge. Why?

When Soldiers march on the bridge, their stepping frequency may match on the natural frequency of the bridge. If it so, the bridge will vibrate with larger amplitude due to resonance. This may collapse the bridge.

11. Waves

1. What is a wave? Give the examples.

The disturbance, which carries energy and momentum from one point in space to another point in space without the transfer of the medium, is known as a wave.

Examples: (i) Ocean Waves.
(ii) Standing waves in plucking rubber.
(iii) Ripples formed on water surface.

2. What are the characteristics of wave motion?

- For the propagation of the waves, the medium must possess both inertia and elasticity, which decide the velocity of the wave in that medium.
- In a given medium, the velocity of a wave is a constant whereas the constituent particles in that medium move with different velocities at different positions. Velocity is maximum at their mean position and zero at extreme positions.
- Waves undergo reflections, refraction, interference, diffraction and polarization.

3. What are the types of wave motion based on medium requirement?

- Mechanical wave motion.
- Non mechanical wave motion.

4. What is mechanical wave? Give the examples.

Waves, which require a medium for propagation, are known as mechanical waves.

Examples: sound waves, ripples formed on the surface of water, etc.

5. What is non-mechanical wave? Give an example.

Waves, which do not require any medium for propagation, are known as non-mechanical waves.

Example: light (Electromagnetic wave)

6. What are the types of wave motion based on mode of propagation?

- Transverse wave motion.
- Longitudinal wave motion.

7. What is transverse wave motion? Give an example.

The wave motion in which the constituents of the medium oscillate or vibrate about their mean positions in a direction perpendicular to the direction of propagation is known as transverse wave motion.

Example: light (Electromagnetic wave)

8. What is longitudinal wave motion? Give an example.

The wave motion in which the constituents of the medium oscillate or vibrate about their mean positions in a direction parallel to the direction of propagation is known as longitudinal wave motion.

Example: Sound waves travelling in air.

9. What is meant by crest and trough?

Crest is the highest point and trough is the lowest point in transverse wave.

10. What is meant by compression and rarefaction?

Compression is the place of high density and pressure and rarefaction is the place of low density and pressure in the medium where the longitudinal wave propagates.

11. Distinguish between transverse and longitudinal waves.

S.No.	Transverse Waves	Longitudinal waves
1.	The direction of vibration of particles of the medium is perpendicular to the direction of propagation of waves.	The direction of vibration of particles of the medium is parallel to the direction of propagation of waves.
2.	The disturbances are in the form of crests and troughs.	The disturbances are in the form of compressions and rarefactions.
3.	Transverse waves are possible in elastic medium.	Longitudinal waves are possible in all types of media (solid, liquid and gas).

12. Define wavelength. Give its unit.

Wavelength(λ) is defined as the distance between successive crests or troughs in case of transverse wave (or) the distance between successive compressions or rarefactions in case of longitudinal wave. Its unit is meter.

13. Define frequency of a wave. Give its unit.

The frequency(f) of a wave is defined as the number of waves crossing a point per second. Its unit is Hz.

14. Define time period of a wave. Give its unit.

Time period(T) of a wave is defined as the time taken by one wave to cross a point. Its unit is second.

$$i.e. \quad T = \frac{1}{f}$$

15. What is wave velocity or phase velocity?

Wave velocity(v) is the distance travelled by a wave in one second.

$$i.e. \quad v = \lambda f$$

16. What is wave number? Give its unit.

The number of cycles per unit distance or number of waves per unit distance is called wave number(k). Its unit is rad m^{-1}. It is also called angular wave number.

$$i.e. \quad k = \frac{2\pi}{\lambda}$$

17. What is wave vector?

The wave vector ($\vec{k}$) is a vector which points the direction of wave propagation. Its magnitude is wave number(k).

18.What are the factors affecting speed of sound in gases?

- Pressure
- Temperature
- Density
- Moisture or Humidity
- Wind

19.How the factors affecting speed of sound in gases?

- **Effect of pressure:** For a fixed temperature, Speed of sound is independent of pressure.
- **Effect of temperature:** The speed of sound is directly proportional to square root of temperature in kelvin. $i.e. \quad v \propto \sqrt{T}$
- **Effect of density:** The speed of sound is inversely proportional to square root of density. $i.e. \quad v \propto \frac{1}{\sqrt{\rho}}$
- **Effect of moisture or humidity:** The speed of sound increases with rise in humidity.
- **Effect of wind:** The speed of sound increases in the direction of wind blowing and it decreases in opposite direction of wind blowing.

20.State law of reflection of sound waves.

- The angle of incidence of sound is equal to the angle of reflection.
- When the sound wave is reflected by a surface then the incident wave, reflected wave and the normal at the point of incidence all lie in the same plane.

21.What is meant by specular reflection?

The reflection of sound on a harder flat surface is called specular reflection. Here wavelength of sound must be smaller than the dimesion and irregularities of the reflecting surface.

22.What are the applications of sound reflection?

- Stethoscope
- Echo
- SONAR
- Reverberation

23.What is meant by an echo?

An echo is a repetition of sound produced by the reflection of sound waves from a wall, mountain or other obstructing surfaces.

24.What is meant by SONAR? Write its principle.

SONAR is the abbreviation of the sentence "SOund NAvigation and Ranging". It is a device used to locate the position and motion of an object immersed in the water by using the principle of reflection of sound.

25.What is meant by Reverberation?

Reverberation is the phenomenon of multiple reflection of sound in an enclosure.

26.What is Progressive or travelling wave?

A wave that propagates in a medium continuously is known as progressive wave or travelling wave.

27.What are the characteristics of progressive waves?

- Particles in the medium vibrate about their mean positions with the same amplitude.
- The phase of every particle ranges from 0 to 2π.
- No particle remains at rest permanently. During wave propagation, particles come to the rest position only twice at the extreme points.
- Transverse progressive waves are characterized by crests and troughs whereas longitudinal progressive waves are characterized by compressions and rarefactions.
- When the particles pass through the mean position they always move with the same maximum velocity.
- The displacement, velocity and acceleration of particles separated from each other by nλ are the same, where n is an integer, and λ is the wavelength.

28.State superposition principle of waves.

If two are more waves in a medium move simultaneously, when they overlap, their total displacement is the vector sum of the individual displacements.

$i.e. \quad \vec{y} = \vec{y_1} + \vec{y_2} + \ldots$

29.What is interference of waves?

Interference is a phenomenon in which two waves superimpose to form a resultant wave of greater, lower or the same amplitude.

30.What is beats?

When two or more waves superimpose each other with slightly different frequencies, then a sound of periodically varying amplitude at a point is observed. This phenomenon is known as beats.

31.What is standing or stationary wave?

When two progressive waves of same amplitude and velocity moving in opposite direction interfere each other form a pattern is called standing or stationary wave.

32.What are the characteristics of Stationary waves?

- Stationary waves are characterised by the confinement of a wave disturbance between two rigid boundaries.
- Certain points in the region in which the wave exists have maximum amplitude, called as anti-nodes and at certain points the amplitude is minimum or zero, called as nodes.
- The distance between two consecutive nodes (or) anti-nodes is $\frac{\lambda}{2}$.
- The distance between a node and its neighbouring anti-node is $\frac{\lambda}{4}$.
- The transfer of energy along the standing wave is zero.

33.What is a Sonometer?

A Sonometer is a device for demonstrating the relationship between the frequency of the sound produced by a plucked string, and the tension, length and mass per unit length of the string.

34.What are the similarities between progressive and stationary waves?

S.No.	Progressive Waves	Stationary waves
1.	Crests and troughs are formed in transverse progressive waves.	Crests and troughs are formed in transverse stationary waves.
2.	Compression and rarefaction are formed in longitudinal progressive waves.	Compression and rarefaction are formed in longitudinal stationary waves.

35.Distinguish between progressive and stationary waves.

S.No.	Progressive Waves	Stationary waves
1.	These waves move forward or backward in a medium i.e., they will advance in a medium with a definite velocity.	These waves neither move forward nor backward in a medium i.e., they will not advance in a medium.
2.	All the particles in the medium vibrate such that the amplitude of the vibration for all particles is same.	Except at nodes, all other particles of the medium vibrate such that amplitude of vibration is different for different particles. The amplitude is minimum or zero at nodes and maximum at antinodes.
3.	These wave carry energy while propagating.	These waves do not transport energy.

36.What is fundamental frequency?

The lowest natural frequency of the vibrating system is called the fundamental frequency(f_1).

37.What are over tones?

The natural frequencies above the fundamental frequency are called over tones ($f_2, f_3, f_4, ...$) .

38.What is harmonic?

Harmonic is the integer multiple of fundamental frequency. If $f_n = n f_1$, n is the harmonic.

39.State the laws of transverse vibrations in stretched strings.

$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$

❖ **The law of length:**

For a given tension(T) and mass per unit length(μ), the frequency is inversely proportional to vibrating length(l).

$$i.e. \quad f \propto \frac{1}{l} \quad ; \ T \ and \ \mu = constant.$$

❖ **The law of tension:**

For a given vibrating length(l) and mass per unit length(μ), the frequency is directly proportional to square root of the tension(T).

$$i.e. \quad f \propto \sqrt{T} \quad ; \ l \ and \ \mu = constant.$$

❖ **The law of mass:**

For a given vibrating length(l) and tension(T), the frequency is inversely proportional to square root of the mass per unit length(μ).

$$i.e. \quad f \propto \frac{1}{\sqrt{\mu}} \quad ; \ l \ and \ T = constant.$$

40.What is Sound power? Give its unit.

The average sound energy emitted or transmitted per second is called sound power. Its unit is J s^{-1}.

41.Define intensity of sound. Give its unit.

The intensity of sound is defined as the sound power transmitted per unit area taken normal to the propagation of the sound wave. Its unit is W m^{-2} .

42.State inverse square law of sound intensity.

For a fixed source, the sound intensity is inversely proportional to the square of the distance from the source.

$$i.e. \quad I \propto \frac{1}{r^2} \quad for \ fixed \ source$$

43.Define loudness.

The loudness of sound is defined as the degree of sensation of sound produced in the ear or the perception of sound by the listener.

44.Distinguish between intensity of sound and loudness.

S. No.	Intensity of sound	Loudness
1.	It is sound power transmitted per unit area taken normal to the propagation of the sound wave	It is degree of sensation of sound produced in the ear or the perception of sound by the listener.
2.	For a given sound source, it is constant.	For a given sound source, it may vary.
3.	It does not depend on observer.	It depends both on intensity of sound and observer.

45.State Weber-Fechner's law.

Loudness (L) is proportional to the logarithm of the actual intensity (I) measured with an accurate non-human instrument.

$$i.e. \quad L \propto \ln I \quad or \quad L = k \ln I$$

46.What is sound intensity level? Give its unit.

The difference between two loudnesses is called sound intensity level(ΔL). Its unit is bel or decibel.

$$\Delta L = L_1 - L_0 = ln\left[\frac{I_1}{I_0}\right] bel \qquad ; \ k = 1$$

$$or \quad \Delta L = L_1 - L_0 = 10 \ ln\left[\frac{I_1}{I_0}\right] \ decibel \ ; k = 10$$

For practical purpose,

$$\Delta L = L_1 - L_0 = 10 \ log\left[\frac{I_1}{I_0}\right] \ decibel$$

$$\left[\textbf{Note}: \quad 1 \ decibel = 1db = \frac{1}{10} \ bel\right]$$

47.What is organ pipe? Name its types.

Organ pipe is a simplest form of wind instrument. It is made up of a wooden or metal pipe which produces the musical sound.

<u>Types:</u> **(i)** Closed organ pipe
(ii) Open organ pipe

48.Write a short note on Closed organ pipe.

- Closed organ pipe is a pipe with one end closed and other end open. **(E.g)** Flute, whistle, etc.,
- The frequency of n[th] harmonic, $f_n = (2n-1)f_1$
- The ratio of frequencies of harmonics,
$$f_1 : f_2 : f_3 : f_4 \ldots = 1:3:5:7:\ldots$$

49.Write a short note on Open organ pipe.

- Open organ pipe is a pipe with both the ends open. **(E.g)** Nathaswaram, clarinet, etc.,
- The frequency of n[th] harmonic, $f_n = n\, f_1$
- The ratio of frequencies of harmonics,
$$f_1 : f_2 : f_3 : f_4 \ldots = 1:2:3:4:\ldots$$

50.What is meant by end correction in resonanace air column apparatus?

Antinodes are not exactly formed at the open end of the resonance air column apparatus but smaller distance away from this end. This smaller distance is called end correction.

51.What is Doppler effect?

When the source and the observer are in relative motion with respect to each other and to the medium in which sound propagates, the frequency of the sound wave observed is different from the frequency of the source. This phenomenon is called Doppler Effect.

52.What is Doppler shift?

The Doppler shift is a shift in the wavelength of light or sound that depends on the relative motion of the source and the observer.

$$i.e. \qquad \Delta\lambda = \frac{v}{c}\lambda$$

53.Explain an application of Doppler effect.

- Doppler effect is used to find the velocities at which distant objects like stars or galaxies move towards or away from Earth.
- <u>Red shift:</u> If the spectral lines of the star are found to shift towards the red end of the spectrum, then the star is receding away from the Earth.
- <u>Blue shift:</u> If the spectral lines of the star are found to shift towards the blue end of the spectrum, then the star is approaching Earth.
- Let Δλ be the Doppler shift. Then, $\Delta\lambda = \frac{v}{c}\lambda$, where v is the velocity of the star.

54.Tabulate the formulas for apparent frequency of various cases in Dopper effect.

Case	Event	Apparent frequency
1.	Source moves towards a stationary observer.	$f' = f\left(1+\frac{v_s}{v}\right)$
2.	Source moves away from a stationary observer.	$f' = f\left(1-\frac{v_s}{v}\right)$
3.	Observer moves towards a stationary Source.	$f' = f\left(1+\frac{v_o}{v}\right)$
4.	Observer moves away from a stationary Source.	$f' = f\left(1-\frac{v_o}{v}\right)$
5.	Source and Observer approach each other.	$f' = \left(\frac{v+v_o}{v-v_s}\right)f$
6.	Source and Observer recede from each other.	$f' = \left(\frac{v-v_o}{v+v_s}\right)f$
7.	Source chases the Observer.	$f' = \left(\frac{v-v_o}{v-v_s}\right)f$
8.	Observer chases the Source.	$f' = \left(\frac{v+v_o}{v+v_s}\right)f$

Conceptual Questions :

55.Why is it that transverse waves cannot be produced in a gas?. Can the transverse waves can be produced in solids and liquids?

Transverse waves are produced only in rigid medium like solids and it cannot be produced in non-rigid mediums like liquid and gases.

56.Why is the roar of our national animal different from the sound of a mosquito?

Roaring of our national animal produces a sound of low frequency and high intensity or loudness whereas mosquito produces sound of high frequency and low intensity or loudness. So that their sounds different.

57.A sound source and listener are both stationary and a strong wind is blowing. Is there a Doppler effect?

Yes. Doppler effect happends not only due to relative motion of source and observer but also due to relative motion of the medium.

58.In an empty room why is it that a tone sounds louder than in the room having things like furniture etc.

In the empty room, sound energy is less absorbed and well reflected by the wall whereas in the furnishing room, sound energy is more absorbed by the things. Therefore, tone sound is louder in the empty room than in the furnishing room.

59.How do animals sense impending danger of hurricane?

Animal's ears are very sensitive to low frequencies. So they easily sense low frequencies produced by hurricane and prevent themselves.

60.Is it possible to realize whether a vessel kept under the tap is about to fill with water?

Yes. Since the vessel acts as a closed organ pipe, when the vessel is about to fill with water, decrease of vibrating length of air column changes the frequency of sound. Thus, we can realize the sound of fill.