Chapter 1 Physical Quantities, Motion & Force

PHYSICAL QUANTITIES

Physics is the branch of science which deals with the study of matter, energy, and the interaction between them.

- A **scalar** is a physical quantity that has only a magnitude (size) E.g. : Distance, speed, time, power, energy, etc.
- A **vector** is a physical quantity that has both a magnitude and a direction. E.g. Velocity, displacement, acceleration, force etc.

Some physical quantities like moment of **inertia**, **stress**, etc. are neither scalar nor vector. They are **tensor**.

Seven Fundamental Physical Quantities and their Units

Physical Quantity	SI Unit	Symbol
Length	meter	*m*
Mass	kilogram	*Kg*
Time	second	*S*
Electric Current	ampere	*A*
Temperature	kelvin	*K*
Luminous intensity	candela	*Cd*
Amount of substance	mole	*mol*

Some Derived Physical Quantities and their Units

S.No	Physical Quantity	cgs unit	SI unit	Relation
1.	Force	dyne	newton	1 newton $= 10^5$ dyne
2.	Work	erg	joule	1 joule $= 10^7$ erg

- An object is said to be at rest if it does not change its position with respect to its surroundings with the passage of time.
- A body is said to be in motion if its position changes continuously with respect to the surroundings (or with respect to an observer) with the passage of time.
- The distance travelled by a body is the actual length of the path covered by a moving body irrespective of the direction in which the body moves.

Dispacement

- When a body moves from one position to another, the shortest (straight line) distance between the initial position and final position of the body, alongwith direction, is known as its displacement. The S.I. unit of displacement is metre (m). Displacement is a vector quantity.

Motion

- **Uniform motion :** A body has a **uniform motion** if it travels equal distances in equal intervals of time.
- **Non-uniform motion :** A body has a non-uniform motion if it travels unequal distances in equal intervals of time.

  Speed : Distance travelled by a moving body in (one second) unit time is called speed. The S.I. units of speed is ms^{-1}.

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

- The average distance covered by a body per unit time when the body is moving with non-uniform speed is known as **average speed.**

$$\text{Average speed} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

- **Velocity** of a body is defined as the displacement produced per unit time. It is the distance travelled by a body per unit time in a given direction. The S.I. unit of velocity is m/s.

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

Acceleration

- **Average Velocity :** It is defined as the total displacement covered divided by the total time taken.

$$\text{Average velocity} = \frac{\text{Total displacement}}{\text{Total time taken}}$$

- **Acceleration :** It is defined as the rate of change of velocity with time.

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time taken}} \text{ or } a = \frac{v-u}{t}$$

The S.I. unit of acceleration is m/s^2.

Retardation: Negative acceleration is called 're-tardation' or 'deceleration'.

- A body has uniform acceleration if it travels in a straight line and its velocity increases by equal amounts in equal intervals of time. For example, the motion of a freely falling body.
- A body has a non-uniform acceleration if the velocity increases by unequal amounts in equal intervals of time. In other words, a body has a non-uniform acceleration if its velocity changes at a non-uniform rate.
- **Equations of motion :** These are the equations which give relation between velocity, acceleration, distance covered, time taken for a body in uniform acceleration.

$$v = u + at$$

$$s = ut + \frac{1}{2}at^2$$
$$v^2 - u^2 = 2as$$

- In case the velocity of the object is changing at a uniform rate, then average velocity is given by the arithmetic mean of initial velocity and final velocity for a given period of time, i.e.,

  $$\text{average velocity} = \frac{\text{initial velocity} + \text{final velocity}}{2}$$

  Mathematically, $v_{av} = \dfrac{u + v}{2}$

  when v_{av} is the average velocity, u is the intial velocity and v is the final velocity of the object.

- **Graphical Representation of Motion :**

  (i) **Distance-time graph :** For uniform speed, a graph of distance travelled against time will be a straight line as shown by the line OA in figure given below.

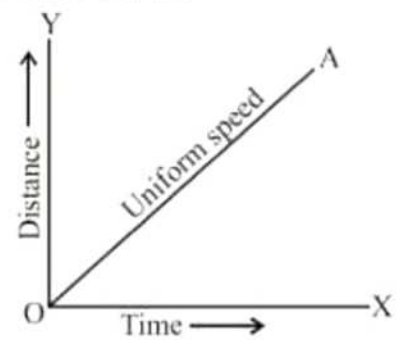


Fig. Distance-time graph for uniform speed

If the speed of a body is non-uniform, then the graph between distance travelled and time is a curved line.

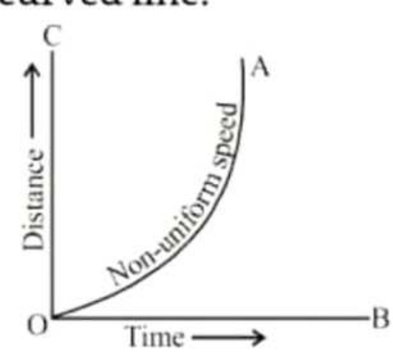


Fig. Distance-time graph for non-uniform speed

(ii) **Velocity-time graphs :**

(a) Velocity-time graph parallel to time axis (uniform motion)

(i) The area of the graph under velocity-time curve gives the displacement of the body.

Displacement = Velocity × Time

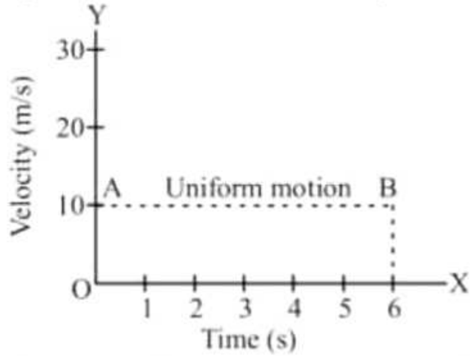


Fig. Velocity-time graph for uniform motion

(ii) The slope of velocity-time graph gives acceleration.

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

If the slope of graph is zero, the acceleration is zero.

(iii) If the slope of velocity-time graph is positive, then acceleration is a positive. If the slope is negative, then acceleration is negative i.e. retardation.

(b) Velocity-time graph is a straight line which is not parallel to time axis (uniform accelerated motion).

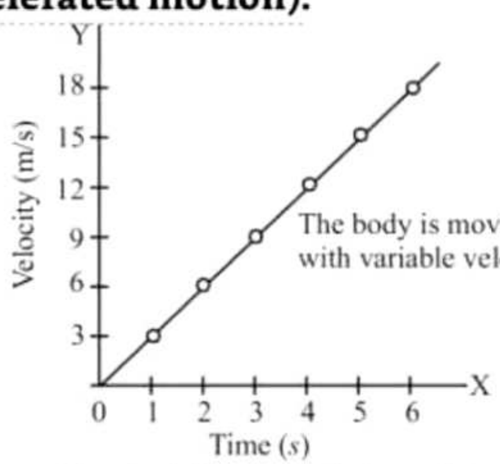


Fig. Graph between velocity and time (motion with uniform acceleration)

(c) The velocity-time graph is a curve for motion with a variable acceleration.

Projectile Motion

Projectile is the name given to a body thrown with some initial velocity in any arbitrary direction and then allowed to move under the influence of a constant acceleration. The motion of a projectile is called projectile motion.

Example : A football kicked by the player, a stone thrown from the top of building, a bomb released from a plane.

The path followed by a projectile is called its **trajectory**, mostly, the trajectory of a projectile is parabolic.

Maximum height (H): When a projectile moves, it covers a maximum distance in vertical direction. This maximum distance is called the maximum height attained by the projectile.

Maximum height $H = \dfrac{U^2 \sin^2 \alpha}{2g}$

Horizontal range (R): The horizontal distance between the point of projection and the point of landing of a projectile.

Maximum range $R = \dfrac{U^2 \sin^2 2\alpha}{g}$

Time of flight (T): The time taken by the projectile to reach the point of landing from the point of projection.

Time of flight $T = \dfrac{2u \sin^2 \alpha}{g}$

Science in Action

- An aeroplane flying at a constant speed, if it releases a bomb, the bomb moves away from the aeroplane and it will be always vertical below the aeroplane as the horizontal component of the velocity of the bomb will be same as that of the velocity of the aeroplane. And thus the horizontal displacement remain same at any instant of time.

- If two bullets are fired horizontally, simultaneously and with different velocities from the same place, both the bullets will hit the ground simultaneously as the initial velocity in the vertically downward direction is zero and same height has to be covered.

FORCE

- Force may be defined as a push or a pull which changes or tends to change the state of rest or uniform motion or direction of motion of a body. SI units is Newton.

  A force can do three things on a body.
  (a) It can change the speed of a body.
  (b) It can change the direction of motion of a body.
  (c) It can change the shape of the body.
- **Newton's First Law of Motion :** If a body is in a state of rest, it will remain in the state of rest and if it in the state of motion, it will remain moving in the same direction with the same velocity unless an external force is applied on it. Its S.I. unit is kg.
  A body with greater mass has greater inertia.
- The momentum of a moving body is defined as the product of its mass and velocity momentum is a vector quantity given by $\vec{p} = m\vec{v}$
  The SI unit of momentum is kilogram meter per second (kgm/s).
- **Newton's Second Law of Motion :** It states the rate of change of momentum of a body is directly proportional to the applied unbalanced force.
  Rate of change in momentum $\propto$ Force applied

- **Newton's Third Law of Motion :** According to this law, to every action, there is an equal and opposite reaction.

  When one object exerts a force (*action*) on another object, then the second object also exerts a force (*reaction*) on the first. These two forces are always equal in magnitude but opposite in direction.

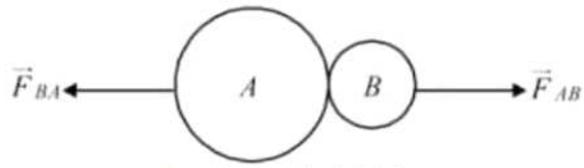
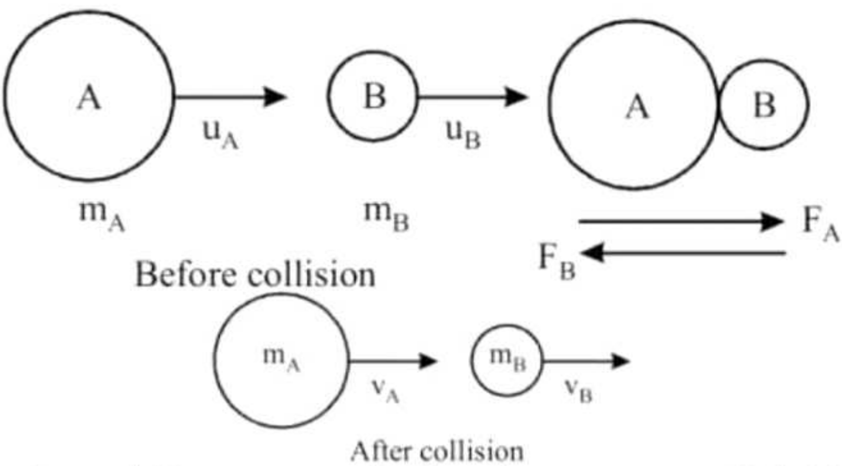


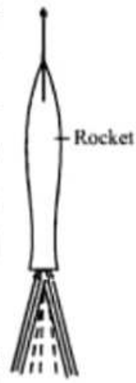
Fig. Newton's third law

- **Conservation of Momentum :** If the external force on a system is zero, the momentum of the system remains constant i.e. In an isolated system, the total momentum remains conserved.



A and B are two balls, the mass and initial velocities are shown, before collision. The two bodies collide and force is exerted by each body. There is change in their velocities due to collision. ($m_A u_A$ + $m_B u_B$) is the total momentum of the two balls A and B before collision and $m_A v_A$ + $m_B v_B$ is their total momentum after the collision. The sum of momentum of the two objects before collision is equal to the sum of momenta after the collision provided there is no external unbalanced force acting on them. This is known as the law of conservation of momentum.

Science in Action



- **Recoiling of a gun:** Guns recoil when fired, because of the law of conservation of momentum. The positive momentum gained by the bullet is equal to negative recoil momentum of the gun and so the total momentum before and after the firing of the gun is zero.
- **Propulsion of Jet and Rockets:** A rocket standing at the launching pad has zero momentum. When the propellants inside the rocket burn, a high velocity blast of hot gases is produced.

  Theses gases pass out through the tail nozzle of the rocket in downward direction with tremendous velocity. Therefore the rocket moves up with such a velocity so as to make the momentum of the system (rocket + emitted gases) zero.

Circular Motion

- Motion of a body along a circular path is called circular motion.
- **Centripetal force** - while a body is moving along a circular path an external force required to act radially inward.

  A pseudo force that is equal and opposite to the centripetal force is called **centrifugal force**.

  Cream separator, centrifugal dryer, etc, work on the principle of centrifugal force.

Friction

Friction is a force that is created whenever two surfaces move or try to move across each other.

Friction always opposes the motion or attempted motion of one surface across another surface.

Instances where friction is important Walking , Driving ,Picking something up, Car brakes.

Exercise

DIRECTIONS : This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which only one is correct.

1. If a body is moving at constant speed in a circular path, its
   (a) velocity is constant and its acceleration is zero
   (b) velocity and acceleration are both changing direction only
   (c) velocity and acceleration are both increasing
   (d) velocity is constant and acceleration is changing direction
2. A graph is plotted showing the velocity of a car as a function of time. If the graph is a straight line, it means that
   (a) the car started at rest
   (b) acceleration was constant
   (c) acceleration was increasing
   (d) velocity was constant
3. If a car is traveling north on a straight road and its brakes are applied, it will
   (a) have no acceleration
   (b) accelerate to the south
   (c) accelerate to the north
   (d) accelerate either east or west
4. An object moves with a uniform velocity when
   (a) the forces acting on the object are balanced
   (b) there is no external force on it
   (c) Both of (a) and (b)
   (d) Either (a) or (b)
5. The acceleration of a car that speeds up from 12 meters per second to 30 meters per second in 15 seconds–
   (a) $2.4 \, m/s^2$
   (b) $1.2 \, m/s^2$
   (c) $2 \, m/s^2$
   (d) $5.2 \, m/s^2$
6. A particle experiences constant acceleration for 20 seconds after starting from rest. If it travels a distance s_1 in the first 10 seconds and distance s_2 in the next 10 seconds, then

(a) $s_2 = s_1$
(b) $s_2 = 2s_1$
(c) $s_2 = 3s_1$
(d) $s_2 = 4s_1$

7. Friction forces act
(a) in the direction of force applied
(b) in the direction of the motion
(c) in the direction opposite to the direction of motion
(d) None of these

8. In which of the following cases, the object does not possess an acceleration or retardation when it moves in
(a) upward direction with decreasing speed
(b) downward direction with increasing speed
(c) with constant speed along circular path
(d) with constant speed along horizontal direction

9. By applying a force of one Newton, one can hold a body of mass
(a) 102 grams
(b) 102 kg
(c) 102 mg
(d) None of these

10. The speed of a falling body increases continuously, this is because
(a) no force acts on it
(b) it is very light
(c) the air exert the frictional force
(d) the earth attract it

11. The effect of frictional force may be minimized by
(a) using a smooth object
(b) using a smooth plane
(c) providing a lubricant at the surface of contact
(d) All of these

12. If an object is in a state of equilibrium
(a) it is at rest
(b) it is in motion at constant velocity
(c) it is in free fall
(d) may be more than one of the above

13. If a boat is moving along at constant speed, it may be assumed that

(a) a net force is pushing it forward
(b) the sum of only vertical forces is zero
(c) the buoyant force is greater than gravity
(d) the sum of all forces is zero

14. When a motorcar makes a sharp turn at a high speed, we tend to get thrown to one side because
(a) we tend to continue in our straight line motion
(b) an unbalanced force is applied by the engine of the motorcar changes the direction of motion of the motorcar
(c) we slip to one side of the seat due to the inertia of our body
(d) All of these

15. When a bus suddenly starts, the standing passengers lean backwards in the bus. It is an example of
(a) Newton's first law
(b) Newton's second law
(c) Newton's third law
(d) None of Newton's law

16. Momentum has the same units as that of
(a) couple
(b) torque
(c) impulse
(d) force

17. When a force of newton acts on a mass of 1 kg that is free to move, the object moves with a
(a) speed of 1 m/s
(b) speed of 1 km/s
(c) acceleration of 10 m/s^2
(d) acceleration of $1 m/s^2$

18. If an object experience a net zero unbalanced force, then the body
(a) can be accelerated
(b) moves with constant velocity
(c) cannot remain at rest
(d) None of these

19. A hockey player pushes the ball on the ground. It comes to rest after travelling certain distance because
(a) the player stops pushing the ball
(b) no unbalanced force action on the wall

(c) the ball moves only when pushes
(d) the opposing force acts on the body.

20. The physical quantity which is the product of mass and velocity of a body is known as
(a) inertia
(b) momentum
(c) force
(d) change in momentum

21. Rate of change of momentum of an object is proportional to the
(a) balanced force applied
(b) applied unbalanced force in the direction of the force
(c) time during which the force is applied
(d) All of these

22. A book of weight 10 N is placed on a table. The force exerted by the surface of the table on the book will be
(a) Zero
(b) 10 N
(c) 20 N
(d) None of these

23. A moving object can come to rest only if it
(a) has a frictional force acting on it
(b) has no net force acting on it
(c) is completely isolated
(d) applies an impulse to something else

24. When a body is stationary-
(a) There is no force acting on it
(b) The force acting on it not in contact with it
(c) The combination of forces acting on it balances each other
(d) The body is in vacuum

25. A rider on horse falls back when horse starts running, all of a sudden because
(a) rider is taken back
(b) rider is suddenly afraid of falling
(c) inertia of rest keeps the upper part of body at rest while lower part of the body moves forward with the horse
(d) None of the above

26. A man getting down a running bus, falls forward because

(a) due to inertia of rest, road is left behind and man reaches forward
(b) due to inertia of motion upper part of body continues to be in motion in forward direction while feet come to rest as soon as they touch the road
(c) he leans forward as a matter of habit
(d) of the combined effect of all the three factors stated in (a), (b) and (c)

27. A force 10 N acts on a body of mass 20 kg for 10 sec. Change in its momentum is
(a) 5 kg m/s
(b) 100 kg m/s
(c) 200 kg m/s
(d) 1000 kg m/s

28. Swimming is possible on account of
(a) first law of motion
(b) second law of motion
(c) third law of motion
(d) newton's law of gravitation

29. A man is at rest in the middle of a pond on perfectly smooth ice. He can get himself to the shore by making use of Newton's
(a) first law
(b) second law
(c) third law
(d) all the laws

30. A parrot is sitting on the floor of a closed glass cage which is in a boy's hand. If the parrot starts flying with a constant speed, the boy will feel the weight of the cage as
(a) unchanged
(b) reduced
(c) increased
(d) nothing can be said

31. A cannon after firing recoils due to-
(a) conservation of energy
(b) backward thrust of gases produced
(c) Newton's third law of motion
(d) Newton's first law of motion

32. Newton's third law of motion leads to the law of conservation of-

(a) angular momentum
(b) energy
(c) mass
(d) momentum

33. The force of friction acting on a car on different roads in the increasing order of magnitude will be
(a) mud, tar, concrete and gravel roads
(b) tar, concrete, gravel and mud roads
(c) concrete, tar, gravel and mud roads
(d) gravel, mud, tar and concrete roads

34. A fish is swimming upward at an angle of 30° with the horizontal. The direction of the force of gravity acting on it is–
(a) upward
(b) downward
(c) horizontal
(d) at an angle upward

35. Two blocks of mass 4 kg and 6 kg are placed in contact with each other on a frictionless horizontal surface. A push of 5N is applied on a heavier mass. The force on the lighter mass will be
(a) 3 N
(b) 2 N
(c) 5 N
(d) 50 N

36. Rockets work on the principle of conservation of
(a) energy
(b) mass
(c) momentum
(d) All of these

37. Motion of an object is the change in position with respect to a reference point known as
(a) origin
(b) initial position
(c) final position
(d) distance

38. Displacement is the
(a) shortest distance between initial and final positions
(b) the actual distance between initial and final positions

(c) the distance traveled by the object
(d) distance traveled by the object in a unit time

39. An object has traveled 10 km in 15 minutes, its displacement will be
(a) 10 km
(b) Can be zero
(c) More than 10 km
(d) All of the above

40. If an object covers equal distances in equal intervals of time, it is said to be in
(a) Circular Motion
(b) Uniform Motion
(c) Oscillatory Motion
(d) Non-uniform Motion

41. Average velocity of an object is obtained by
(a) Dividing the total distance traveled by the total time taken
(b) Half of the sum of the initial velocity and the final velocity
(c) Both (a) and (b)
(d) None of the above

42. Negative value of acceleration signifies
(a) The velocity is increasing
(b) The velocity is decreasing
(c) The velocity remains the same
(d) The object comes to rest

43. In distance-time graphs
(a) Distance is taken along the X- axis
(b) Time is taken along the Y-axis
(c) Straight line indicates uniform motion
(d) Straight line indicates non-uniform motion

44. In velocity-time graphs
(a) Velocity is taken along the Y-axis and Time is taken along the X-axis
(b) Straight line indicates uniform acceleration
(c) Straight line parallel to x-axis indicates uniform motion
(d) All of the above

45. The equation(s) of motion can be represented as

(a) $v = u + at$

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

(c) $2as = v^2 - u^2$

(d) All of these

46. A train travels 40 km at a uniform speed of 30 km h^{-1}. Its average speed after traveling another 40 km is 45 km h^{-1} for the whole journey. Its speed in the second half of the journey is

(a) 45 km h^{-1}

(b) 90 km h^{-1}

(c) 60 km h^{-1}

(d) None of these

47. A man walks on a straight road from his home to market 2.5 km. away with a speed of 5 km/h. Finding the market closed, he instantly turns and walks back home with a speed of 7.5 km/h. The average speed of the man over the interval of time 0 to 40 min. is equal to –

(a) 5 km/h

(b) 25/4 km/h

(c) 30/4 km/h

(d) 45/8 km/h

48. A person is standing in an elevator. In which situation he finds his weight less than actual when –

(a) The elevator moves upward with constant acceleration.

(b) The elevator moves downward with constant acceleration

(c) The elevator moves upward with uniform velocity

(d) The elevator moves downward with uniform velocity

49. A ball is dropped from a window 24 meters high. How long will it take to reach the ground ?

(a) 2.2 s

(b) 1.2 s

(c) 4.5 s

(d) 0.2 s

50. A pitcher throws his fastball horizontally at 42.1 meters per second.

How far does it drop before crossing the plate, 18.3 meters away?

(a) 0.8 m
(b) 1.2 m
(c) 2.2 m
(d) 0.93 m

51. Mohan takes 20 minutes to cover a distance of 3.2 kilometers due north on a bicycle, his velocity in kilometer/hour–

(a) 8.1
(b) 9.6
(c) 1.2
(d) 7.2

52. Two balls A and B of same masses are thrown from the top of the building. A, thrown upward with velocity V and B, thrown downward with velocity V, then –

(a) Velocity of A is more than B at the ground
(b) Velocity of B is more than A at the ground
(c) Both A and B strike the ground with same velocity
(d) None of these

53. A ball is released from the top of a tower of height h meters. It takes T seconds to reach the ground. What is the position of the ball in T/3 seconds –

(a) h/9 meters from the ground
(b) 7h/9 meters from the ground
(c) 8h/9 meters from the ground
(d) 17h/18 meters from the ground

54. When a bus suddenly takes a turn, the passengers are thrown outwards because of –

(a) inertia of motion
(b) acceleration of motion
(c) speed of motion
(d) Both (b) and (c)

55. A thief snatches a purse and runs due west, going 6.0 meters per second. A policeman, 15 meters to the east, sees the event and gives chase. If the officer is a good sprinter, going at 8.5 me-

ters per second, how far does he have to run to catch the thief –

(a) 12 m
(b) 51 m
(c) 61 m
(d) 55 m

56. A car going at 24 meters per second passes a motorcycle at rest. As it passes, the motorcycle starts up, accelerating at 3.2 meters per second squared. If the motorcycle can keep up that acceleration, how long will it take for it to catch the car –

(a) 12 s
(b) 14 s
(c) 20 s
(d) 18 s

57. The initial velocity of a body is 15 m/s. If it is having an acceleration of 10 m/s^2, then the velocity of body after 10 seconds from start –

(a) 110 m/s
(b) 105 m/s
(c) 120 m/s
(d) 115 m/s

Hints & SOLUTIONS

Exercise 1

1. (b)
2. (b)
3. (b)
4. (c) An object moves with a uniform velocity when the forces acting on the object are balanced and there is no external force on it.
5. (b)
6. (c)
7. (b) Friction forces act in the direction opposite to the direction of motion.
8. (d)
9. (a)
10. (d)
11. (d) The effect of frictional force may be minimized by using a smooth object, using a smooth plane or by providing a lubricant at the surface of contact.
12. (d)
12. (d)
14. (d) When a motorcar makes a sharp turn at a high speed, we tend to get thrown to one side because we tend to continue in our straight line motion and an unbalanced force is applied by the engine of the motorcar changes the direction of motion of the motorcar. So, we slip to one side of the seat due to the inertia of our body.
15. (a)
16. (c)
17. (d)
18. (b)
19. (d)
20. (b)
21. (b) Rate of change of momentum of an object is proportional to the applied unbalanced force in the direction of the force.
22. (b)
23. (d)
24. (c)
25. (c)
26. (b)
27. (b)

28. (c)
29. (c)
30. (a)
31. (c)
32. (d)
33. (c)
34. (b)
35. (b) Acceleration on combination of two masses = $F / (m_1 + m_2) = 5 / (4+6) = 0.5\ m\ s^{-2}$. Then, use this value of acceleration to findthe force on lighter object, $F = m\ a = 4 \times 0.5 = 2$ N.
36. (c) Rockets are examples of third law of motion, i.e. the law of conservation of momentum.
37. (a) Motion of an object is the change in position with respect to a reference point called origin.
38. (a) Displacement is the shortest distance between initial and final positions.
39. (d) An object has traveled 10 km in 15 minutes, its displacement will be according to the direction it has followed.
40. (b) If an object covers equal distances in equal intervals of time, it is said to be in uniform motion.
41. (b) Average velocity of an object is obtained by taking the arithmetic mean of the initial and final velocity.
42. (b) Negative value of acceleration signifies deceleration or in other words the velocity is decreasing.
43. (c) In distance-time graphs, the distance is taken along the Y- axis, Time is taken along the X-axis. Straight line indicates uniform motion.
44. (d) In velocity-time graphs, Velocity is taken along the Y-axis and Time is taken along the X-axis. A straight line indicates uniform acceleration and a straight line parallel to X-axis indicates uniform motion.
45. (b) The equations of motion are

   (1) $v = u + at$

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

   (3) $2as = v^2 - u^2$
46. (b) Let speed of the train in later half = x, then the time taken to travel later 40 km = 40/x hours

   Total time taken = 40/30 + 40/x

   Average speed = $\dfrac{80}{4/3 + 40x} = 45$

   Solve the equation to find value of x

47. **(d)** A man walks from his home to market with a speed of5 km/h. Distance = 2.5 km and time = $\frac{d}{v} = \frac{2.5}{5} = \frac{1}{2}$ hr.

and he returns back with speed of 7.5 km/h in rest of time of 10 minutes.

Distance = $7.5 \times \frac{10}{60} = 1.25$ km

So, Average speed

$$= \frac{\text{Total distance}}{\text{Total time}} = \frac{(2.5+1.25)\text{ km}}{(40/60)\text{ hr}} = \frac{45}{8}\text{ km/hr.}$$

48. **(b)** The elevator moves downward with constant acceleration.

49. **(a)** In free fall, the acceleration is 9.8 m/s^2, there is uniform acceleration starting from rest, so

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

and $t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2 \times 24\text{m}}{9.8\text{ m/s}^2}} = 2.2\text{ s}$

50. **(d)** The time it takes the ball to get to the plate, at constant horizontal speed, is (18.3 m)/42.1 m/s) = 0.435 s.

During that time, gravity makes it drop a distance of

$$s = \frac{1}{2}at^2 = \frac{1}{2}(9.8\text{ m/s}^2)(0.435\text{ s})^2 = 0.93\text{ m}$$

51. **(b)** The total distance moved s = 3.2 km (due north)

The total time taken t = 20 minutes

$$= \frac{20}{60}\text{ hours} = \frac{1}{3}\text{ hours}$$

The velocity of the bicycle

$$v = \frac{\text{Total distance covered}}{\text{Total time taken}} = \frac{s}{t}$$

$v = \frac{3.2\text{ km}}{(1/3)\text{ h}} = 9.6\text{ km/h}$ due north

52. **(c)** $v^2 = u^2 + 2gh \Rightarrow v = \sqrt{u^2 + 2gh}$

So, for both the cases velocity will be equal.

53. **(c)** $\because h = ut + \frac{1}{2}gt^2 \Rightarrow h = 0 + \frac{1}{2}gT^2$

After T/3 seconds, the position of ball,

$$h' = 0 + \frac{1}{2}g\left(\frac{T}{3}\right)^2 = \frac{1}{2} \times \frac{g}{9} \times T^2$$

$$h' = \frac{1}{2} \times \frac{g}{9} \times T^2 = \frac{h}{9} m \text{ from top}$$

$\therefore$ Position of ball from ground = $h - \frac{h}{9} = \frac{8h}{9}$ m

54. **(a)** When a bus suddenly takes a turn, the passengers are thrown outwards because of inertia of motion.

55. **(b)** The thief runs a distance s in time t at 6.0 m/s, the policeman runs (s + 15m) in the same time, going 8.5 m/s. For both, time is distance over speed, so

$t = \frac{s}{6.0 \text{ m/s}} = \frac{(s + 15m)}{8.5 \text{ m/s}}$ from which s = 36 m.

The policeman runs 51m.

56. **(b)** Both vehicles travel the same distance. For the car, going at constant speed, the distance is vt, for the motorcycle, it is $\frac{1}{2}$ at^2. Then

$s = (22 \text{ m/s})\, t = \frac{1}{2} (3.2 \text{ m/s}^2)\, t^2$

from which t = 14s.

57. **(d)** The initial velocity of a body u = 15 m/s.

Acceleration of body $a = 10 \text{ m/s}^2$

and time t = 10s

If v is the velocity of body after 10s then from equation

v = u + at

We have v = 15 + 10 (10) = 15 + 100 = 115 m/s

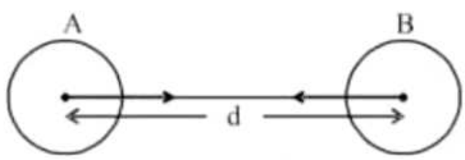
Chapter 2 Gravitation and Properties of Matter

GRAVITATION

- Gravitation is a natural phenomenon by which all physical bodies attract each other.
- On earth, gravity gives weight to physical objects employing a downward force to keep them grounded
- It is weakest force among the four natural forces in nature, i.e. electromagnetic weak & strong nuclear force.

Universal Law of Gravitation

- Every object in the universe attracts every other object with a force which is proportional to the product of their masses and inversely proportional to the square of the distance between them. The force is along the line joining the centres of two objects.



Let two objects A and B of masses M and m lie at a distance d from each other as shown in figure given above. Let the force of attraction between two objects be F. According to the universal law of gravitation, the force between two objects is directly proportional to the product of their masses. That is,

$$F \propto M \times m \qquad \text{... (1)}$$

And the force between two objects is inversely proportional to the square of the distance between them, that is,

$$F \propto \frac{1}{d^2} \qquad \text{... (2)}$$

Combining equations (1) and (2), we get

$$F \propto \frac{M \times m}{d^2} \qquad \text{... (3)}$$

or, $$F = G\frac{M \times m}{d^2} \qquad \text{... (4)}$$

where G is the constant of proportionality and is called the universal gravitation constant. The S.I. unit of G can be obtained by substituting the units of force, distance and mass in Eq. (4) as $N\,m^2\,kg^{-2}$. The accepted value of G is $6.673 \times 10^{-11}\,N\,m^2\,kg^{-2}$.

- When an objects fall down forwards the earth under the gravitational force alone, we say the object are in free-fall. The velocity of a freely falling body changes and is said to be accelerated. This acceleration is called acceleration due to gravity, denoted by 'g'. Unit is m/s^2.

  As $F = ma$ $\quad (\because a = g)$ ...(i)

  $F = mg$ ...(ii)

  and $F = G = \frac{Mm}{d^2}$ (iii) Universal law of Gravitation

  $\therefore \; mg = G = \frac{Mm}{d^2}$ from (ii) and (iii)

  $\therefore \; g = \frac{GM}{d^2}$

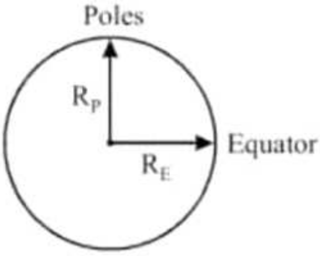
  M = Mass of the earth.

  d = distance between the object and the earth.

  G = Gravitational constant.

  If the object is placed on the earth then $d = R$.

  (R = radius of the earth)



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

- Earth is not a sphere.

  It is flattened at poles.

  Hence R_p – Radius at pole and

  R_E – Radius at equator.

  $R_q > R_p$

  $g \propto \frac{1}{R}$

  $\therefore$ The value of 'g' is more at Poles = ($9.9\,m/s^2$) and less at equator = ($9.8\,m/s^2$)

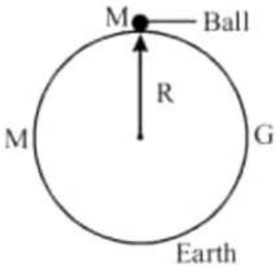
- Calcualte value of g.

$$g = G\frac{M}{R^2}$$

$G = 6.67 \times 10^{-11}\ \text{Nm}^2/\text{kg}^2$

$M = 6 \times 10^{24}$ kg. (Mass of the Earth)

$R = 6.4 \times 10^6$ m



On substituting the given values.

$$g = \frac{6.7 \times 10^{-11}\ \text{Nm}^2\text{kg}^2 \times 6 \times 10^{24}\ \text{kg}}{(6.4 \times 10^6\ \text{m})^2}$$

$g = 9.8\ \text{m/s}^2$.

Mass

- The quantity of matter in a body is called mass. The SI unit of mass is kilogram (kg). Mass is usually denoted by 'm'.

Characteristics of mass

(i) Mass is a scalar quantity.

(ii) The mass of a body remains the same at all places. This means, the mass of a body on the earth, on the moon, or anywhere in the outer space remains the same.

(iii) The mass of a body can be measured with the help of a two-pan balance.

Weight

- The weight of a body on the earth is equal to the force with which the body is attracted towards the earth. Thus, the weight of a body on the earth is equal to the force of gravity exerted by the earth on that body. We know that

  Force of gravity acting on a body = Mass of the body × Acceleration due to gravity

  The force of gravity acting on a body by definition is equal to the weight of that body. So

  Weight of the body = Mass of the body × Acceleration due to gravity

  $W = m \times g = mg$

Weight of a body in a lift

(i) If lift is stationary or moving with uniform speed (either upward or downward), the apparent weight of a body is equal to its true weight.

(ii) If lift is going up with acceleration, the apparent weight of a body is more than the true weight.

(iii) If lift is going down with acceleration, the apparent weight of a body is less than the true weight.

(iv) If the cord of the lift is broken, it falls freely. In this situation the weight of a body in the lift becomes **zero**. This is the situation of weightlessness.

(v) While going down, if the acceleration of lift is more than acceleration due to gravity, a body in the lift goes in contact of the ceiling of lift.

Escape speed (ve) is the minimum speed with which an object just crosses the earth's gravitational field and never comes back.

$$V_e = \sqrt{\frac{2GM}{R}} = \sqrt{2gR}$$

- The escape velocity of Earth is about 11.2 kilometres per second and on moon it is 2.4 km/sec.
- It is times the orbital velocity i.e, $V_e = \sqrt{2}V_o$

The weight of an object can change from one place to the other, from one planet to the other.

- **Weight of an Object on the Moon:** Let the mass of an object be m. Let its weight on the moon be W_m. Let the mass of the moon be M_m and its radius be R_m.

By applying the universal law of gravitation, the weight of the object on the moon will be

$$W_m = G\frac{M_m \times m}{R_m^2} \qquad \dots (1)$$

Let the weight of the same object on the earth be W_e. The mass of the earth is M and its radius is R.

Celestial body	Mass (kg)	Radius (m)
Earth	5.98×10^{24}	6.37×10^6
Moon	7.36×10^{22}	1.74×10^6

From eq. (1) we have,

$$W_e = G\frac{M \times m}{R^2} \qquad \dots (2)$$

Substituting the values from table in eqs. (1) and (2), we get

$$W_m = G\frac{7.36\times10^{22}\ \text{kg}\times \text{m}}{(1.74\times10^{6}\ \text{m})}$$

$W_m = 2.431 \times 10^{10}\, G \times m$ ... (3a)

and $W_e = 1.474 \times 10^{11}\, G \times m$ ... (3b)

Dividing eq. (3a) by eq. (3b), we get

$$\frac{W_m}{W_e} = \frac{2.431\times10^{10}}{1.474\times10^{11}}$$

or $$\frac{W_m}{W_e} = 0.165 \approx \frac{1}{6} \quad \text{... (4)}$$

$$\frac{\text{Weight of the object on the moon}}{\text{Weight of the object on the earth}} = \frac{1}{6}$$

Weight of the object on the moon = $\frac{1}{6}$ × its weight on the earth.

Satellite

It is a heavenly body or an artificial object which revolves round a planet in a particular orbit. The required centripetal force is provided by the gravitational force. Kepler's laws of planetary motion are applicable to them.

(a) **Orbital velocity of a satellite:** Velocity with which the satellite orbits around the planet.

$$v_o = \sqrt{\frac{GM}{R+h}}$$

(b) **Time period of a satellite:** Time taken by it to complete one revolution around the planet.

$$T = \frac{2\pi}{R}\sqrt{\frac{(R+h)^3}{g}}$$

(c) **Height of a satellite above the surface of the planet:**

$$H = \left(\frac{T^2R^2g}{4\pi^2}\right) - R$$

(d) **Total energy of a satellite** orbiting on a circular path is negative with potential energy being negative but twice as the magnitude of positive kinetic energy.

(e) **Binding energy** of a satellite is the energy required to remove it from its orbit to infinity.

B.E. = $\frac{GMm}{2r}$ No energy is required to keep the satellite in its orbit.

Geostationary satellites: The satellites in a circular orbit around the earth in the equatorial plane with a time period of 24 hours, appears to be fixed from any point on earth are called geostationary satellite.

For geostationary satellite, height above the earth's surface = 35800 km and orbital velocity = 3.1 km/s.

Polar Satellites: A satellite that revolves in a polar orbit along north-south direction while the earth rotates around its axis in east west direction.

Weightlessness: A situation where the effective weight of the object becomes zero. An astronaut experiences weightlessness in space satellite because the astronaut as well as the satellite are in a free fall state towards the earth.

PROPERTIES OF MATTER

Elasticity and Plasticity

The property of the body to regain its original configuration (length, or shape) when the deforming forces are removed is called **elasticity**. Quartz and phosphorous bronze, are closed to perfectly lastic body. On the other hand, *if the body does not have any tendency to regain its original configuration on removal of deforming force the body is called plastic body and this property is called* **plasticity**.

Putty and mud are close to perfectly plastic body.

Stress: *The internal restoring force acting per unit area of a body is called stress.*

i.e., *Stress = Restoring force/ Area*

Strain: The ratio of change in configuration to the original configuration is called strain.

i.e., $Strain = \frac{Change\ in\ configuraion}{Original\ configuration}$

Strain being the ratio of two like quantities has **no units** and **dimensions**.

Elastic Limit

Elastic limit is the upper limit of deforming force up to which, if deforming force is removed, the body regains its original form completely and beyond which, if deforming force is increased, the body loses its property of elasticity and gets permanently deformed.

Hooke's law

It states that *within the elastic limit stress is directly proportional to strain.*

i.e., *Stress* $\propto$ *strain*

or Stress = E × strain

Here E is the coefficient of proportionality and is called **modulus of elasticity** or **coefficient of elasticity** of a body.

Young's modulus of elasticity (Y): It is defined as *the ratio of normal stress to the longitudinal strain within the elastic limit.*

$$\text{Thus, } Y = \frac{\textit{Normal stress}}{\textit{Longitudinal strain}}$$

Materials-Ductile, Brittle and Elastomers

(i) **Ductile materials:** *The materials which have large range of plastic extension* are called ductile materials. They can be drawn into thin wires, e.g., copper, silver, aluminium, iron, etc.

(ii) **Brittle materials:** *The materials which have very small range of plastic extension* are called brittle materials. These materials break as soon as stress is increased beyond the elastic limit. e.g., glass, ceramics, cast iron, etc.

(iii) **Elastomers:** *The materials which can be stretched to large values of strain* are called elastomers. *e.g.,* rubber, elastic tissue of aorta, etc.

Fluids

Fluids are the substances that can flow. Therefore liquids and gases both are fluids. The study of fluids at rest is called **fluid statics** or **hydrostatics** and the study of fluids in motion is called **fluid dynamics** or **hydrodynamics**. Both combined are called **fluid mechanics**.

Density (r)