Motion Basics

State of Motion

If the position of an object does not change with respect to a reference point over time, the object is said to be at rest. If the position changes, the object is in motion. The reference point is a fixed point used to determine rest or motion. Rest and motion are relative terms.

Distance and Displacement

Distance is the total length of the path traveled by a body, a scalar quantity with only magnitude. Displacement is the shortest straight-line distance between the initial and final positions of the body in a specified direction, a vector quantity with magnitude and direction. Both have the SI unit metre (m).

Speed and Velocity

Speed is the ratio of distance traveled to the time taken, a scalar quantity. Average speed is total distance divided by total time. Velocity is displacement per unit time, a vector quantity. Average velocity is total displacement divided by total time. Instantaneous

velocity is the velocity at a particular instant, calculated over a very small time interval. The SI unit for speed and velocity is metre per second (m/s).

Types of Motion

Uniform motion occurs when a body travels equal distances in equal intervals of time, implying constant speed. Non-uniform motion occurs when distances traveled in equal time intervals are unequal, indicating changing speed.

Graphs of Motion

Distance-time graphs plot time on the X-axis and distance on the Y-axis. For an object at rest, the graph is a horizontal line. For uniform motion, the graph is a straight line with constant slope equal to speed. For non-uniform motion, the graph is a curve with changing slope. The slope of a position-time graph gives velocity. Velocity-time graphs show velocity on the Y-axis and time on the X-axis. A horizontal line indicates constant velocity. A straight sloped line indicates uniform acceleration. The area under the velocity-time graph represents displacement. The slope of the velocity-time graph gives acceleration.

Acceleration and Retardation

Acceleration is the rate of increase of velocity per second, a vector quantity with SI unit metre per second squared (m/s^2). Retardation (deceleration) is the rate of decrease of velocity per second and is considered negative acceleration. Acceleration-time graphs show acceleration on the Y-axis and time on the X-axis. A horizontal line on the time axis indicates zero acceleration (rest). A horizontal line above the time axis indicates uniform acceleration. A curve indicates non-uniform acceleration.

Uniform Circular Motion

Uniform circular motion is motion along a circular path at constant speed. Although speed is constant, velocity changes direction continuously, so the motion is accelerated.

The acceleration is directed towards the center of the circle (centripetal acceleration). The centripetal force keeps the object moving in the circular path.

Solved Examples

Example 1: A car travels 100 metres in 20 seconds. Calculate its average speed.

Solution:

Distance, d = 100 m

Time, t = 20 s

Average speed = Distance / Time = 100 m / 20 s = 5 m/s

Example 2: A body moves with uniform velocity of 10 m/s for 5 seconds. Find the distance covered.

Solution:

Velocity, v = 10 m/s

Time, t = 5 s

Distance = Velocity × Time = 10 m/s × 5 s = 50 m

Example 3: A car accelerates uniformly from rest to 20 m/s in 5 seconds. Calculate acceleration.

Solution:

Initial velocity, u = 0 m/s

Final velocity, v = 20 m/s

Time, t = 5 s

Acceleration, a = (v - u) / t = (20 - 0) / 5 = 4 m/s^2

Practice Set

Conceptual Questions

- **Level 1:** Define displacement and explain how it differs from distance.
- **Level 2:** Why is velocity considered a vector quantity while speed is a scalar quantity?

Application-based Question

- **Level 3:** A cyclist moves along a circular track of radius 50 m at a constant speed of 10 m/s. Explain why the cyclist is accelerating even though the speed is constant.

Answer Key

Conceptual Questions

- **Level 1:** Displacement is the shortest distance between the initial and final positions of an object in a specified direction. It differs from distance because distance is the total path length traveled without direction, while displacement includes direction.
- **Level 2:** Velocity is a vector quantity because it has both magnitude and direction, whereas speed is scalar as it has only magnitude.

Application-based Question

- **Level 3:** The cyclist is accelerating because acceleration depends on change in velocity, which includes direction. Even though speed is constant, the direction changes continuously in circular motion, causing centripetal acceleration towards the center.

Uniformly Accelerated Motion

Definition

Uniformly accelerated motion occurs when an object moves along a straight line with constant acceleration.

Equations of Motion

The three main equations for uniformly accelerated motion are:

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

where,

- u = initial velocity (m/s)
- v = final velocity (m/s)
- a = acceleration (m/s²)
- t = time (s)
- s = displacement (m)

Motion in Vertical Direction

For motion vertically upward under gravity (acceleration due to gravity = g = 9.8 m/s²):

- v = u - gt
- h = ut - \frac{1}{2}gt^2
- v^2 = u^2 - 2gh

For motion vertically downward:

- v = u + gt
- h = ut + \frac{1}{2}gt^2
- v^2 = u^2 + 2gh

Solved Examples

Example 1: A ball is thrown upward with an initial velocity of 20 m/s. Calculate the velocity after 2 seconds.

Solution:

Given: u = 20 m/s, t = 2 s, g = 9.8 m/s²

Using $v = u - gt$

$v = 20 - (9.8 \times 2) = 20 - 19.6 = 0.4$ m/s (upward)

Example 2: A car accelerates uniformly from rest to 30 m/s in 10 seconds. Find the acceleration and distance covered.

Solution:

$u = 0$ m/s, $v = 30$ m/s, $t = 10$ s

Acceleration, $a = (v - u) / t = (30 - 0) / 10 = 3$ m/s²

Distance, $s = ut + \frac{1}{2} at^2 = 0 + \frac{1}{2} \times 3 \times (10)^2 = 0.5 \times 3 \times 100 = 150$ m

Practice Set

Conceptual Questions

- **Level 1:** What is meant by uniformly accelerated motion?
- **Level 2:** Write the equation relating final velocity, initial velocity, acceleration, and time.

Application-based Question

- **Level 3:** A stone is dropped from a height of 80 m. Calculate the time taken to reach the ground and the velocity just before impact. (Take $g = 9.8$ m/s²)

Answer Key

Conceptual Questions

- **Level 1:** Uniformly accelerated motion is motion in a straight line with constant acceleration.
- **Level 2:** The equation is $v = u + at$.

Application-based Question

- **Level 3:** Given $h = 80$ m, $u = 0$, $a = g = 9.8$ m/s²

  Using $s = ut + \frac{1}{2}at^2$, $80 = 0 + \frac{1}{2} \times 9.8 \times t^2$

  $t^2 = 80 \times 2 / 9.8 = 16.33$

  $t = 4.04$ s

  Velocity just before impact, $v = u + at = 0 + 9.8 \times 4.04 = 39.6$ m/s

Quick Reference Table

Common Mistakes and Misconceptions

Glossary