Unit 2
Uniformly Accelerated Motion

Introduction to Uniformly Accelerated Motion

In everyday life, you encounter many instances of motion with constant acceleration. For example, a car speeding up as it merges onto a highway or an object falling freely under gravity are both examples of constant acceleration motion.

Position and Displacement

Position

To study motion, it's crucial to know where you are—this is referred to as **position**. Position is your location relative to a known reference point. For example, saying you are 2 meters from the doorway inside your classroom specifies your position with respect to the doorway as a reference point.

A **frame of reference** is a reference point combined with a set of directions, forming a coordinate system. For example, consider a boy standing inside a moving train. If you observe the train from the ground, the boy seems to move from left to right. However, relative to the train, the boy is at rest.

Position (s) is a measurement of location relative to an origin and can be positive or negative depending on the chosen reference point. The units of position are typically centimeters (cm), meters (m), or kilometers (km).

Displacement

Distance is the total length of the path an object travels. In contrast, **displacement** is the difference between the initial and final positions of an object, representing the shortest distance between the two points. Displacement is a vector quantity, meaning it has both magnitude and direction, while distance is a scalar quantity, meaning it only has magnitude.

For example, if a person walks 70 meters east and then 30 meters west, the distance traveled is 100 meters, but the displacement is only 40 meters east.

Key Concepts

- **Position** is the location of an object with respect to a reference point.

- **Distance** is the actual path length traveled by an object.
- **Displacement** is the change in position of an object and is a vector quantity.

Average Velocity and Instantaneous Velocity

Average Velocity

Velocity is the rate of change of displacement with time, and unlike speed, it is a vector quantity. The **average velocity** of a body is defined as the displacement divided by the time interval during which that displacement occurs.

Mathematically, average velocity (v_{av}) can be expressed as:

$$v_{av} = \frac{\Delta s}{\Delta t}$$

Where:

- Δs is the displacement.
- Δt is the time interval.

If the motion is in the same direction along a straight line, the average speed equals the magnitude of the average velocity. However, this isn't always the case.

Instantaneous Velocity

The **instantaneous velocity** is the velocity of an object at a specific moment in time. It represents how fast the object is moving and in what direction at that instant. Unlike average velocity, which considers the entire motion over a time interval, instantaneous velocity focuses on a specific point in time.

For example, while driving, your car's speedometer shows your instantaneous velocity, not the average velocity for your entire trip.

Key Concepts

- **Average velocity** is the total displacement divided by the total time taken.
- **Instantaneous velocity** is the velocity at a specific instant of time and shows the speed and direction of an object at that moment.

Acceleration

Acceleration is a fundamental concept in physics that describes how the velocity of an object changes over time. It's important to understand that acceleration can involve speeding up, slowing down, or changing direction.

Key Concepts:

- **Average Acceleration**: This is calculated by dividing the change in velocity by the time over which the change occurs. The formula is:

  $a_{avg}=\frac{\Delta v}{\Delta t}=\frac{v-v_0}{t-t_0}$

  Where:

  - Δv is the change in velocity
  - Δt is the time interval
- **Instantaneous Acceleration**: This is the acceleration at a specific moment in time. It's found by taking the limit of the average acceleration as the time interval becomes infinitely small.

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

Units of Acceleration

- The SI unit of acceleration is meters per second squared (m/s^2).

Understanding Acceleration Through Examples

1. **Positive Acceleration**: If a train moves in a straight line and its speed increases, its acceleration is positive.
2. **Zero Acceleration**: If the train moves at a constant speed without changing direction, its acceleration is zero.
3. **Negative Acceleration (Deceleration)**: If the train slows down, the acceleration is negative.

Worked Examples

1. **Example of Average Acceleration**: A car accelerates from rest to a speed of 75 km/h in 5 seconds. The average acceleration can be calculated as follows:

   Convert 75 km/h to meters per second:

$v = 75\ km/h = \frac{75 \times 1000\ m}{3600\ s} = 21\ m/s$

Then, calculate the average acceleration:

$a_{avg} = \frac{21\ m/s - 0\ m/s}{5\ s} = 4.2\ m/s^2$

Exercises

1. **If a body has constant velocity on a straight level surface, what is the magnitude of its acceleration?**
   - **Answer**: The magnitude of its acceleration is zero because the velocity is constant (no change in velocity).
2. **Does the direction of acceleration have to be in the direction of velocity?**
   - **Answer**: No, the direction of acceleration does not have to be in the direction of velocity. For example, when an object is slowing down, the acceleration is in the opposite direction to the velocity.

Graphical Representation of Uniformly Accelerated Motion

When an object is moving with uniform acceleration, its motion can be represented using graphs, including position-time, velocity-time, and acceleration-time graphs. Understanding these graphs helps in analyzing the motion of objects in a clear and visual way.

1. Position-Time Graph

- **Description:** This graph shows how the position of an object changes over time. The position (x) is plotted on the y-axis, and time (t) is plotted on the x-axis.
- **Uniformly Accelerated Motion:** For uniformly accelerated motion, the position-time graph is a curve, specifically a parabola. This is because the relationship between position and time is quadratic, given by the equation $s = v_0 t + \frac{1}{2} a t^2$.
- **Slope:** The slope of the position-time graph at any point gives the instantaneous velocity of the object. Since the graph is curved, the slope changes with time. The slope at a specific point is found by drawing a tangent to the curve at that point. The steeper the slope, the higher the instantaneous velocity.

2. Velocity-Time Graph

- **Description:** This graph shows how the velocity of an object changes over time, with velocity (v) on the y-axis and time (t) on the x-axis.

- **Uniformly Accelerated Motion:** For an object with uniform acceleration, the velocity-time graph is a straight line. If the object starts from rest and accelerates uniformly, the line will start from the origin (0,0) and have a positive slope. If the object has an initial velocity, the line will start above the origin.
- **Area Under the Graph:** The area under the velocity-time graph represents the displacement of the object. For instance, if the graph forms a triangle, the area of that triangle gives the displacement.
- **Slope:** The slope of the velocity-time graph gives the acceleration of the object. For uniform acceleration, the slope is constant, resulting in a straight line.

3. Acceleration-Time Graph

- **Description:** This graph shows how the acceleration of an object changes over time, with acceleration (a) on the y-axis and time (t) on the x-axis.
- **Uniformly Accelerated Motion:** For uniformly accelerated motion, the acceleration remains constant over time. Therefore, the acceleration-time graph is a horizontal line parallel to the time axis.
- **Area Under the Graph:** The area under the acceleration-time graph represents the change in velocity during that time interval.

Key Concepts

- **Position-Time Graph:** A parabola for uniformly accelerated motion; slope represents instantaneous velocity.
- **Velocity-Time Graph:** A straight line; slope represents acceleration, and the area under the graph represents displacement.
- **Acceleration-Time Graph:** A horizontal line; the area under the graph represents the change in velocity.

Exercises

1. **Position-Time Data Analysis:** Plot a position-time graph using given data, find the slope of the tangent at specific times, and draw corresponding velocity-time and acceleration-time graphs.
2. **Graph Interpretation:** Use velocity-time graphs to calculate displacement and understand the relationship between slope and acceleration.

Understanding these graphs allows for a deeper comprehension of the dynamics of uniformly accelerated motion, providing a foundation for more complex concepts in physics.

Relative Velocity in One Dimension

What is Relative Velocity?

Relative velocity refers to the velocity of one object as observed from another object or a different reference frame. It is crucial to understand that any measurement of speed or velocity must be made with respect to a reference frame. When you state that an object has a certain velocity, you must specify the reference frame from which this velocity is measured.

Understanding with an Example:

Imagine two cars, Car A and Car B, moving on the same road. If Car A is moving at 80 km/h and Car B is moving at 65 km/h in the same direction, the speed of Car B as observed from Car A (relative velocity) would be the difference between their speeds. In this case:

- **Relative Velocity of B with respect to A (V_{BA}):** $V_{BA}=V_B-V_A=65\text{ km/h}-80\text{ km/h}=-15\text{ km/h}$

The negative sign indicates that Car B is slower than Car A by 15 km/h.

Key Concept:

- **When Objects Move in Opposite Directions:** The relative velocity is the sum of their individual velocities. $V_{AB}=V_A+V_B$
- **When Objects Move in the Same Direction:** The relative velocity is the difference between their velocities. $V_{AB}=V_A-V_B$

Example Calculation:

Consider two cars:

- Car A: Moving at 80 km/h
- Car B: Moving at 65 km/h, following Car A

Relative Velocity of B with respect to A: $V_{BA}=V_B-V_A=65\text{ km/h}-80\text{ km/h}=-15\text{ km/h}$

This indicates that Car B is 15 km/h slower than Car A.

Summary:

- Relative velocity is the velocity of one object as observed from another reference frame.

- The relative velocity in one dimension can be found by adding or subtracting the velocities depending on whether the objects are moving in the same or opposite directions.

Understanding relative velocity helps in analyzing motion from different perspectives, making it a key concept in physics.