LINEAR MOTION

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Applied Physics

Contents

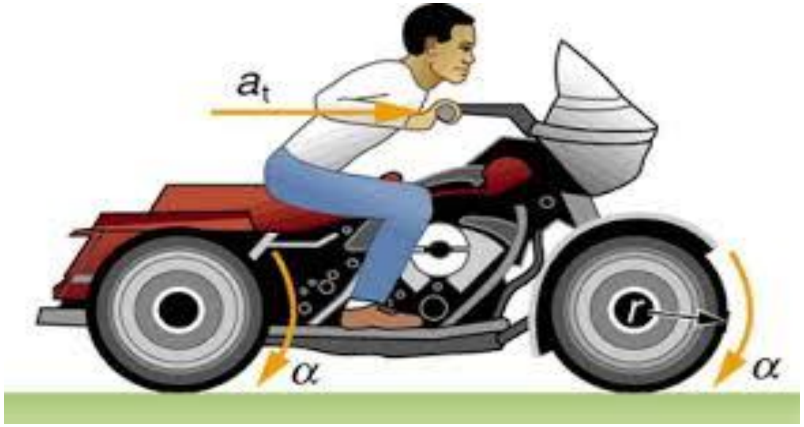
Introduction to Linear Motion

- The word "**Linear**" means "**Straight**" and the word "**Motion**" means **"change in position of a body with respect to frame of reference(surrounding)"**

To Remember:

- Linear Motion is the motion in **One Dimension**
- The motion should be in a **straight line** only.
- The line may be vertical, horizontal, or slanted, but it must be straight.
- All parts of the body move through the same distance in the same direction in same time.
- The motion of the body may not be uniform.

Examples of Linear Motion



Motion & Rest

- **MOTION :**

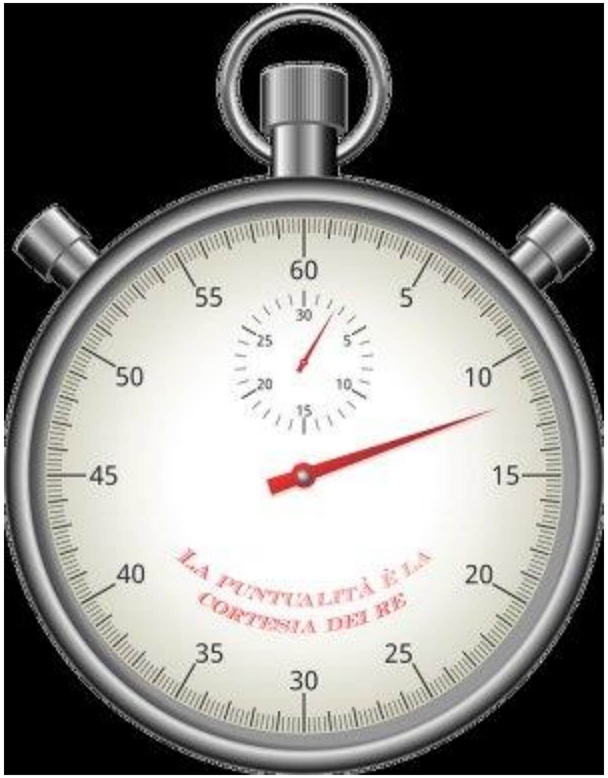
  A body is said to be in Motion if its position changes with respect to its surrounding .

- **REST:**

  A body is said to be in Rest if its position does not change with respect to its surrounding.

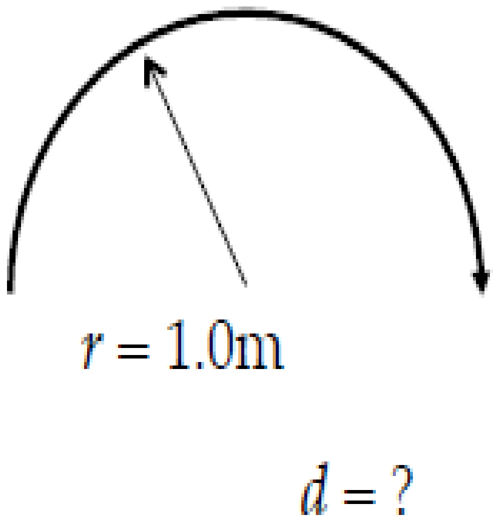
Time

- Time refers to how long an object is in motion for.
- Here, we’ll usually use seconds, but we might use minutes, hours, years, milliseconds, or any other unit of time.



Distance

- Distance is simply how far something travels along its path, whether measured in miles, kilometers, meters, centimeters, feet, or any other unit.



Speed

- Speed = how fast you're going
- Speed is simply a measure of how quickly an object is moving: how much distance it travels in a given time.
- It is a scalar quantity

Formula:

$$speed = \frac{distance}{time}$$

Unit: Standard unit in MKS system is meter/sec (m/s)

Average Speed

- The average speed (where average will be represented by a bar on top of the quantity involved) is the distance traveled in any direction, divided by the time Δt

$$s_{\text{avg}} = \frac{\text{total distance}}{\Delta t} \longrightarrow \textit{Eq. 1}$$

Where, Δ (anything)= final value – initial value

Example Problem

- A swimmer travels one complete lap in a pool that is 50.0-meters long. The first lap is covered in 20.0 seconds, the second leg is covered in 25.0 seconds. What was his average speed for the lap?

Solution:

$$speed = \frac{distance}{time}$$

$$speed = \frac{50+50}{20+25} = 2.22 m/s$$

Displacement

- Displacement is a measure of how far you have “displaced,” or changed your position.
- Displacement is a vector quantity, you need to specify a direction for your displacement.

For instance;

Q# What was your displacement coming to this class?

A# 152 meters, East

Q# How high can you jump?

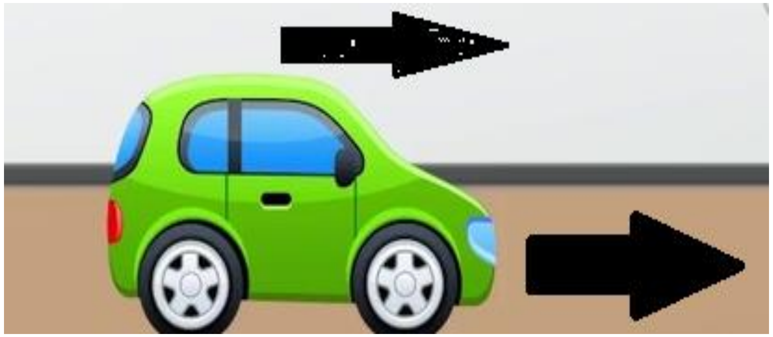
A# 1 meters up.

Types of Displacement

Mainly two types that we'll go through;

1. Horizontal Displacement

- Example: motion of a car

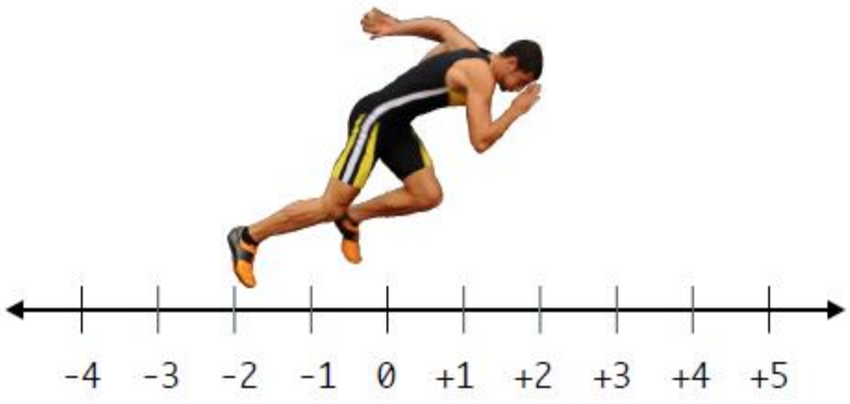


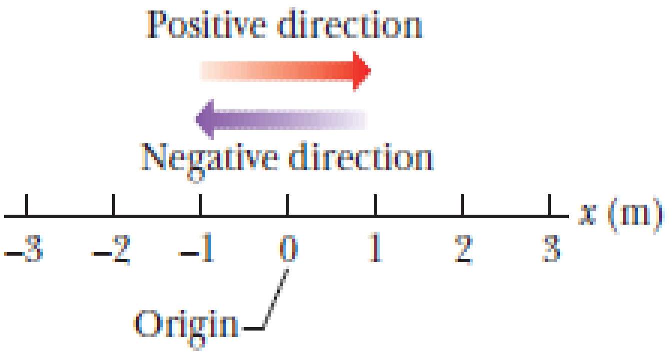
2. Vertical Displacement

- Example : launching of rocket

Horizontal Displacement

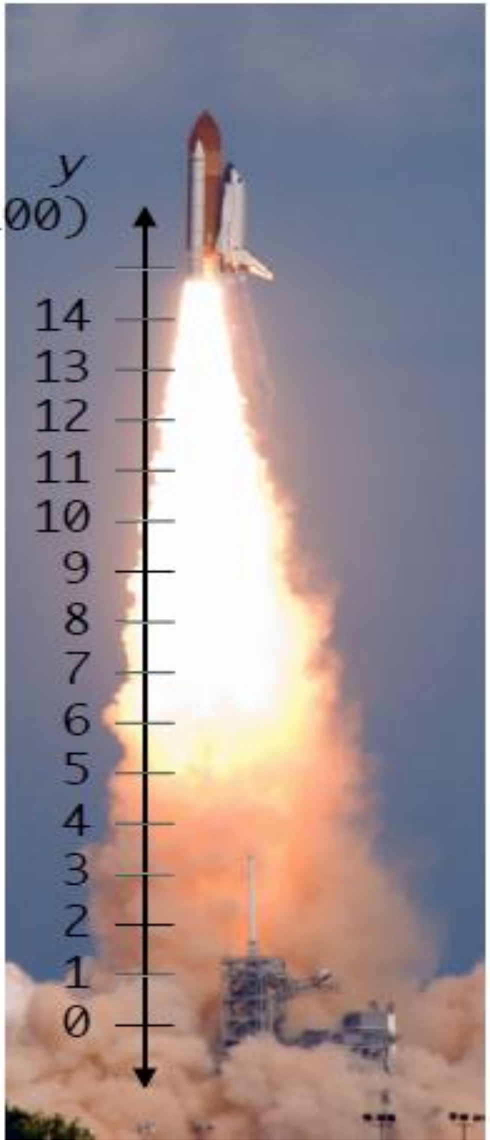
- For horizontal motion, we'll often describe the displacement in regards to an imaginary number line, with "to the right" being the positive-x direction, and "to the left" being the negative-x direction.





Vertical Displacement

- For vertical motion, we'll often describe the displacement in regards to an imaginary number line, with "up" being the positive *y*-direction, and "down" being the negative-*y* direction.



Brainstorming

Here are three pairs of initial and final positions, respectively, along an x axis. Which pairs give a negative displacement: (a) -3 m, $+5$ m; (b) -3 m, -7 m; (c) 7 m, -3 m?

Velocity

- It is the rate of change of displacement.
- It is a vector quantity.
- Formula :

$$v = \vec{r}/t$$

Unit:

It is measured in MKS system of units that is meter per second(m/s)

Average Velocity

Consider a particle moving in space. Let the particle be at point P in Fig. 1 at some initial time t_0 and at point P' some later time t_f.

The initial position of the particle can be specified by a *position vector* $\mathbf{r}_0$ obtained by drawing an arrow from the origin of the coordinate system to point P. Similarly, the position at the later time is specified by a second position vector $\mathbf{r}_f$ that results when an arrow is drawn from the origin to point P'. The position at any other point in the motion is specified by a corresponding position vector $\mathbf{r}$. We can now define the *displacement vector* $\Delta\mathbf{r}$ as the vector difference between the final and the initial position vectors, namely, $\Delta\mathbf{r} = \mathbf{r}_f - \mathbf{r}_0$ (see Fig. 1). Correspondingly, we define the *average velocity* $\overline{\mathbf{v}}$ as the ratio of the displacement vector to the time taken for the displacement to occur, namely,

$$\overline{\mathbf{v}} = \frac{\mathbf{r}_f - \mathbf{r}_0}{t_f - t_0} = \frac{\Delta\mathbf{r}}{\Delta t} \qquad \textbf{Eq. 2}$$

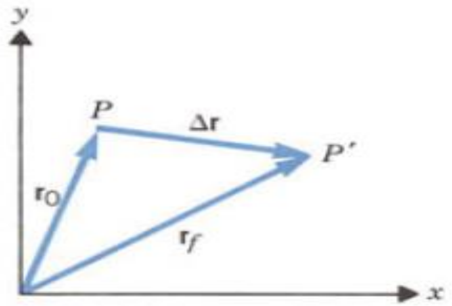


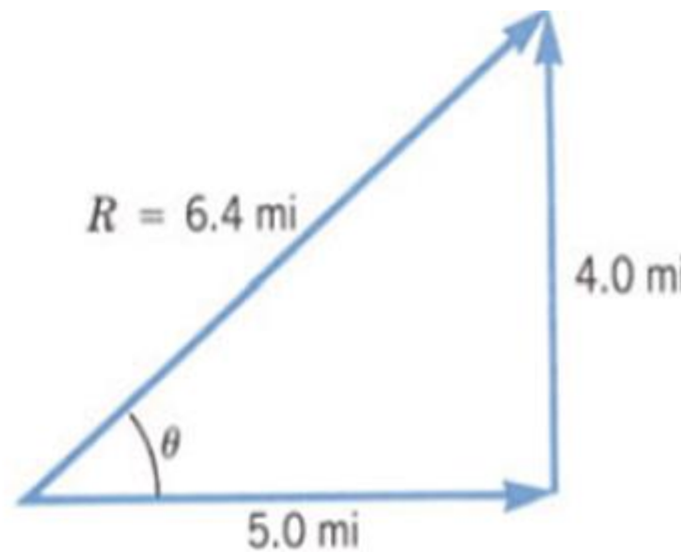
FIGURE 1 The displacement vector $\Delta\mathbf{r}$ is obtained by drawing an arrow from the initial position vector $\mathbf{r}_0$ to the final position vector $\mathbf{r}_f$.

Avg. Speed Vs Avg.Velocity

Consider the walk taken in Fig. Suppose it took 1 h.

Then, by definition, $s_{avg} = \dfrac{\text{total distance}}{\Delta t}$

the average speed of walking was $(4.0\,\text{mi} + 5.0\,\text{mi})/1\,\text{h} = 9\,\text{mi/h}$



whereas the average velocity was $\Delta \mathbf{r}/\Delta t = 6.4\,\text{mi}/1\,\text{h}$

6.4 mi/h in the direction 39° north of east.

Acceleration

- It is the rate of change of velocity.
- It is a vector quantity.
- Mathematically it is represented as,

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

- Its measured in MKS system of units, as m/sec^2
- Acceleration may be positive and negative too.
- Negative acceleration is known Retardation or Deceleration

Average & Instantaneous Acceleration

If there is a velocity change $\Delta \mathbf{v}$ in a certain time Δt, we define the average acceleration as

$$\bar{\mathbf{a}} = \frac{\Delta \mathbf{v}}{\Delta t} \qquad \text{(Eq 4)}$$

or

$$\bar{\mathbf{a}} = \frac{\mathbf{v}_f - \mathbf{v}_0}{t_f - t_0}$$

where the subscripts f and 0 represent final and initial values, respectively. Usually in a problem we start our stopwatch at $t_0 = 0$, so the elapsed time is simply t_f and we drop the subscript f. We may define an instantaneous acceleration as

$$\mathbf{a} = \lim_{\Delta t \to 0} \frac{\Delta \mathbf{v}}{\Delta t} = \frac{d\mathbf{v}}{dt} \qquad \text{(Eq 5)}$$

which is the first derivative of $\mathbf{v}$ with respect to time. Substituting Eq. 3 for $\mathbf{v}$, we write

$$\mathbf{a} = \frac{d}{dt}\left(\frac{d\mathbf{r}}{dt}\right) = \frac{d^2\mathbf{r}}{dt^2} \qquad \text{(Eq 6)}$$

which is the second derivative of $\mathbf{r}$ with respect to time.

Example Problem

The position of a body on the x axis varies as a function of time according to the following equation

$$x(\text{meters}) = (3t + 2t^2)\text{m}$$

Find its velocity and acceleration when $t = 3$ sec.

Solution

Because the body moves in a straight line, $\mathbf{r} = x$. From Eq. 3

$$v = \frac{dx}{dt} = \frac{d}{dt}(3t + 2t^2) = (3 + 4t)\ \text{m/sec}$$

The velocity of the body at $t = 3$ sec is therefore

$$v(t = 3\ \text{sec}) = 3 + 4 \times 3 = 15\ \text{m/sec}$$

From Eq. 5

$$a = \frac{dv}{dt} = \frac{d}{dt}(3 + 4t) = 4\ \text{m/sec}^2$$

Notice that a is a constant, and therefore $a(t = 3\ \text{sec}) = 4\ \text{m/sec}^2$.

Summary

- Speed: Rate of change of distance $speed = \frac{distance}{time}$
- Velocity: Rate of change of displacement $\vec{v} = \frac{\vec{r}}{t}$
- Avg. Speed: $s_{avg} = \frac{\text{total distance}}{\Delta t}.$
- Avg. Velocity: $\bar{\mathbf{v}} = \frac{\mathbf{r}_f - \mathbf{r}_0}{t_f - t_0} = \frac{\Delta \mathbf{r}}{\Delta t}$
- Instantaneous Velocity: $\mathbf{v} = \lim_{\Delta t \to 0} \frac{\Delta \mathbf{r}}{\Delta t} = \frac{d\mathbf{r}}{dt}$
- Acceleration: Rate of change of velocity $\vec{a} = \frac{\vec{v}}{t}$
- Avg. Acceleration: $\bar{\mathbf{a}} = \frac{\Delta \mathbf{v}}{\Delta t}$
- Instantaneous Acceleration: $\mathbf{a} = \lim_{\Delta t \to 0} \frac{\Delta \mathbf{v}}{\Delta t} = \frac{d\mathbf{v}}{dt}$