CHAPTER 2 | MOTION ALONG A STRAIGHT LINE

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Outline

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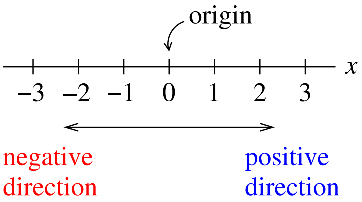
Introduction

- **Kinematics**: the branch of physics describing the motion of bodies without the causes of the motion.
- **One-dimensional (1D) motion**: the motion of bodies along a straight line.
- Objects in this chapter are to be considered as **particles**: (1) point-like or (2) rigid body.

Position

- The **position** of an object moving along the x-axis will be specified by its x-coordinate with respect to the **origin.**



Displacement

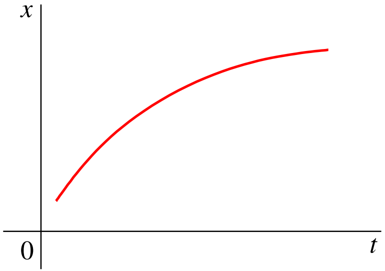
- The **displacement** Δx of an object is the change in its position:

$$\boxed{\Delta x = x_2 - x_1 \qquad \text{(m)}}$$

where x_1 its position at time t_1, and x_2 at a later time t_2.

Position vs Time Graph

- The time-dependent position $x(t)$ of an object will be pictured as a position vs time curve:



Average Velocity

- The **average velocity** v_{avg} gives a rough estimate of “how fast” an object undergoes a displacement over a time interval:

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1} \qquad \text{(m/s)}$$

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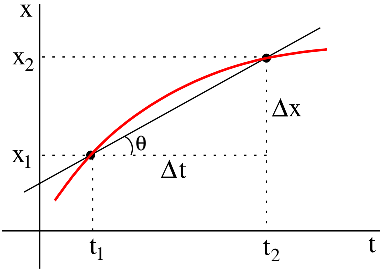
- Average velocity is equal to the slope of the line passing through points (t_1, x_1) and (t_2, x_2), so that

$$v_{\text{avg}} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1} = \tan\theta$$



Average Speed

- **Average speed** s_{avg} is the ratio of the total distance covered by an object to the time interval Δt:

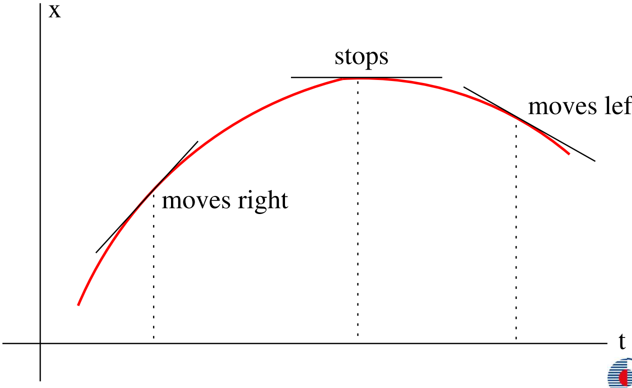
$$s_{avg} = \frac{\text{total distance}}{\Delta t} \qquad \text{(m/s)}$$

(Instantaneous) Velocity

- The (**instantaneous**) **velocity** $v(t)$ of an object gives the information about how fast it is at any given instant t. It is the time-derivative of position $x(t)$:

$$v(t) = \frac{dx}{dt} \qquad (\mathrm{m/s})$$

- $v(t)$ is equal to the slope of x-t curve at any given instant:



Speed

- The magnitude of velocity is called **speed**; it is always a positive quantity.

Average Acceleration

- The rate at which the velocity of an object changes is its **acceleration.**
- If an object have velocity v_1 at time t_1 and velocity v_2 at a later time t_2, its **average acceleration** a_{avg} is given as

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} \qquad \left(\mathrm{m/s^2}\right)$$

(Instantaneous) Acceleration

- The (**instantaneous**) **acceleration** of an object at any given time is

$$a(t) = \frac{dv}{dt} \qquad \left(\mathrm{m/s^2}\right)$$

- The slope of $v(t)$ at any point gives the acceleration of the object at that point.

- Acceleration is also the second derivative of displacement:

$$a(t) = \frac{dv}{dt} = \frac{d}{dt}\left(\frac{dx}{dt}\right) = \frac{d^2x}{dt^2}$$

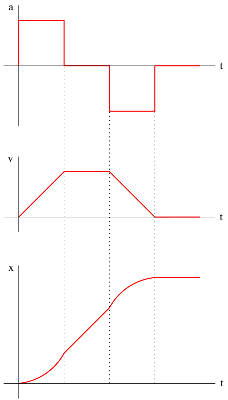


Figure: Successive graphs of acceleration, velocity, and displacement for an object.

1D Motion with Constant Acceleration

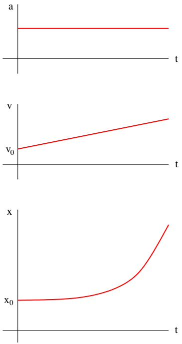


Figure: Representative graphs of $a(t)$, $v(t)$, and $x(t)$ for an object moving with constant acceleration.

- Using the following formulas, you can solve any 1D motion problem with constant acceleration; just learn them by heart:

$$
\begin{aligned}
a &= \text{const.} \\
\\
v &= v_0 + at \\
x &= x_0 + v_0 t + \tfrac{1}{2} a t^2 \\
v^2 &= v_0^2 + 2a\,(x - x_0)
\end{aligned}
$$

1D Motion with Zero Acceleration

- Zero-acceleration means constant-velocity. The following are straightforward:

$$
\begin{aligned}
a &= 0 \\
v &= v_0 \\
x &= x_0 + v_0 t
\end{aligned}
$$

Free-Fall Acceleration

- All the objects near the surface of the earth gravitates always towards the earth because of the downward gravitational force. This is **free-fall acceleration** (or, **gravitational acceleration**).
- In all free-fall problems, we neglect the effects of air.
- The value of free-fall acceleration near the surface of the earth is almost constant and given as

$$g = 9.80\ \mathrm{m/s^2}$$

- To solve free-fall problems we label the vertical axis the y-axis, with its upward positive direction. Also, we take the downward acceleration to be $a = -g$ in our formulas:

$$\begin{aligned} a &= -g \\ \\ v &= v_0 - gt \\ y &= y_0 + v_0 t - \tfrac{1}{2} g t^2 \\ v^2 &= v_0^2 - 2g\,(y - y_0) \end{aligned}$$

- If an object initially at rest is dropped off an elevation of h and hits the ground in time t, it is easy to show that

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