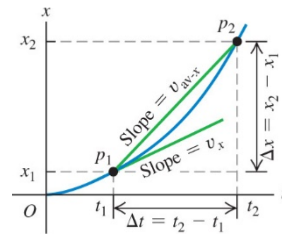
Straight-line motion, average and instantaneous *x*-velocity: When a particle moves along a straight line, we describe its position with respect to an origin *O* by means of a coordinate such as *x*. The particle's average *x*-velocity $\upsilon_{\text{av-}x}$ during a time interval $\Delta t = t_2 - t_1$ is equal to its displacement $\Delta x = x_2 - x_1$ divided by Δt. The instantaneous *x*-velocity υ_x at any time *t* is equal to the average *x*-velocity over the time interval from *t* to $t + \Delta t$ in the limit that Δt goes to zero. Equivalently, υ_x is the derivative of the position function with respect to time. (See Example 2.1.)

$$\upsilon_{\text{av-}x} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1} \qquad (2.2)$$

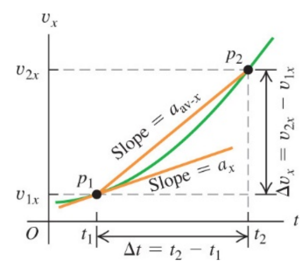
$$\upsilon_x = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt} \qquad (2.3)$$



Average and instantaneous *x*-acceleration: The average *x*-acceleration $a_{\text{av-}x}$ during a time interval Δt is equal to the change in velocity

$$a_{\text{av-}x} = \frac{\Delta \upsilon_x}{\Delta t} = \frac{\upsilon_{2x} - \upsilon_{1x}}{t_2 - t_1} \qquad (2.4)$$

$$a_x = \lim_{\Delta t \to 0} \frac{\Delta \upsilon_x}{\Delta t} = \frac{d\upsilon_x}{dt} \qquad (2.5)$$



$\Delta\upsilon_x = \upsilon_{2x} - \upsilon_{1x}$ during that time interval divided by Δt. The instantaneous x-acceleration a_x is the limit of $a_{\text{av-}x}$ as Δt goes to zero, or the derivative of υ_x with respect to t. (See Examples 2.2 and 2.3.)

Straight-line motion with constant acceleration: When the x-acceleration is constant, four equations relate the position x and the x-velocity υ_x at any time t to the initial position x_0, the initial x-velocity υ_{0x} (both measured at time $t = 0$), and the x-acceleration a_x. (See Examples 2.4 and 2.5.)

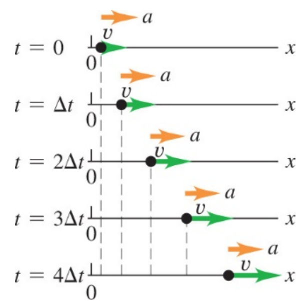
Constant x-acceleration only:

$$\upsilon_x = \upsilon_{0x} + a_x t \qquad (2.8)$$

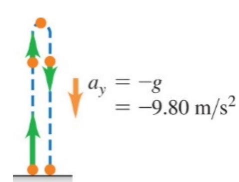
$$x = x_0 + \upsilon_{0x}\, t + \frac{1}{2}\, a_x t^2 \qquad (2.12)$$

$$\upsilon_x^2 = \upsilon_{0x}^2 + 2a_x\left(x - x_0\right) \qquad (2.13)$$

$$x - x_0 = \frac{1}{2}\left(\upsilon_{0x} + \upsilon_x\right)t \qquad (2.14)$$



Freely falling objects: Free fall (vertical motion without air resistance, so only gravity affects the motion) is a case of motion with constant acceleration. The magnitude of the acceleration due to gravity



is a positive quantity, g. The acceleration of an object in free fall is always downward. (See Examples 2.6–2.8.)

