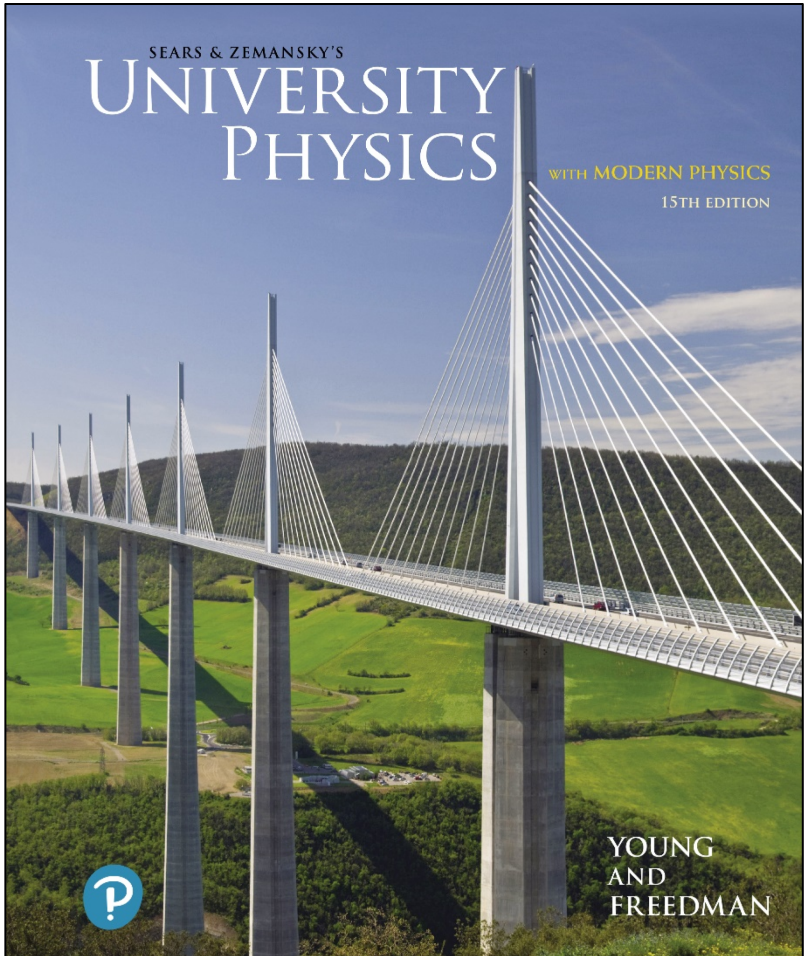
University Physics with Modern Physics

Fifteenth Edition



Chapter 2

Motion Along a Straight Line

Learning Goals for Chapter 2

Looking forward at …

- how the ideas of **displacement** and **average velocity** help us describe straight-line motion.
- the meaning of **instantaneous velocity**; the difference between velocity and speed.
- how to use **average acceleration** and **instantaneous acceleration** to describe changes in velocity.
- how to solve problems in which an object is falling freely under the influence of gravity alone

Introduction

- **Kinematics** is the study of motion.
- ***Velocity*** and ***acceleration*** are important physical quantities.
- A typical runner gains speed gradually during the course of a sprinting foot race and then slows down after crossing the finish line.

Displacement, time, and average velocity

- A particle moving along the *x*-axis has a coordinate *x*.

- The change in the particle's coordinate is

$$\Delta x = x_2 - x_1.$$

$$v_{\text{av-}x} = \Delta x / \Delta t.$$

- The average x-velocity of the particle is

Average *x*-velocity of a particle in **straight-line motion** during time interval from t_1 to t_2

x-component of the particle's displacement

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

Final *x*-coordinate minus initial *x*-coordinate

Time interval

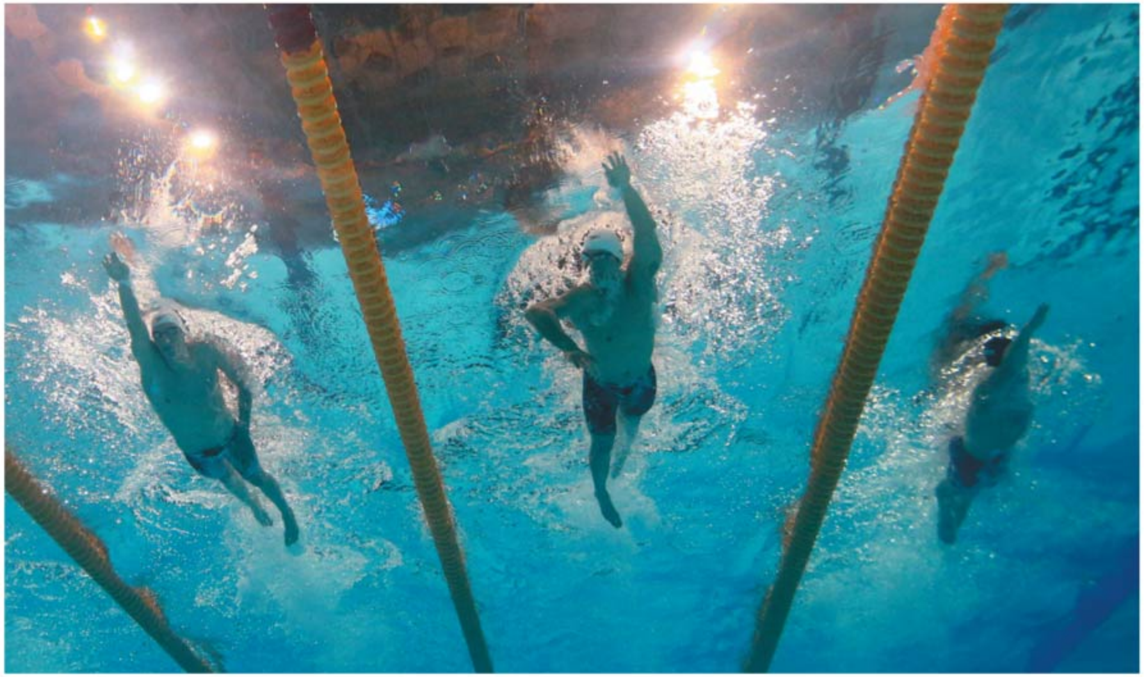
Final time minus initial time

Rules for the sign of *x*-velocity

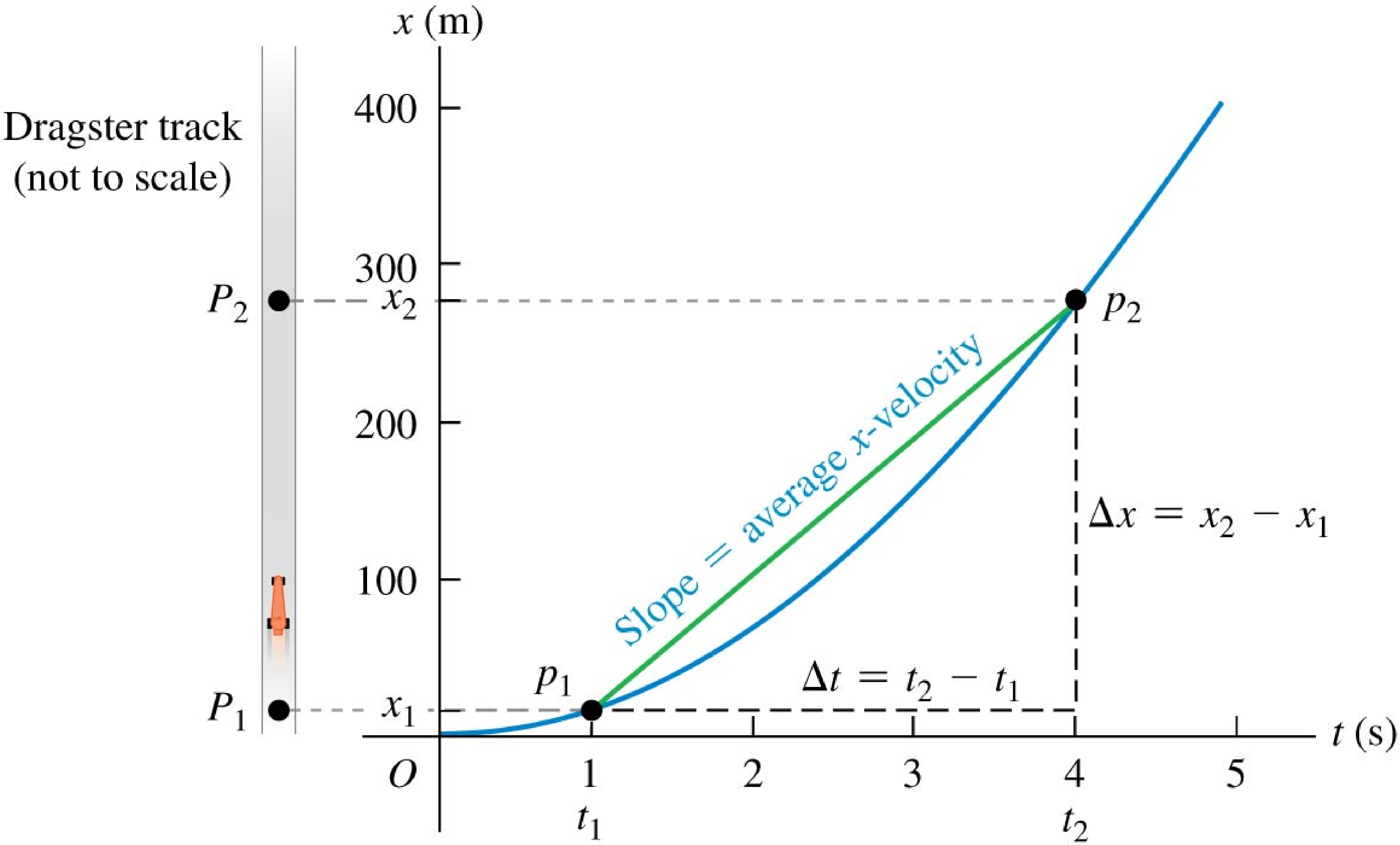
If *x*-coordinate is:	. . . *x*-velocity is:
Positive & increasing (getting more positive)	Positive: Particle is moving in $+x$-direction
Positive & decreasing (getting less positive)	Negative: Particle is moving in $-x$-direction
Negative & increasing (getting less negative)	Positive: Particle is moving in $+x$-direction
Negative & decreasing (getting more negative)	Negative: Particle is moving in $-x$-direction

Average velocity

- The winner of a 50-m swimming race is the swimmer whose average velocity has the greatest magnitude.
- That is, the swimmer who traverses a displacement Δx of 50 m in the shortest elapsed time Δt.



A position-time graph



Instantaneous velocity

- The **instantaneous velocity** is the velocity at a specific instant of time or specific point along the path and is given by $\boldsymbol{v_x = dx/dt}$.
- The average speed is ***not necessarily*** the magnitude of the average velocity! (Recall the difference between distance and displacement.)

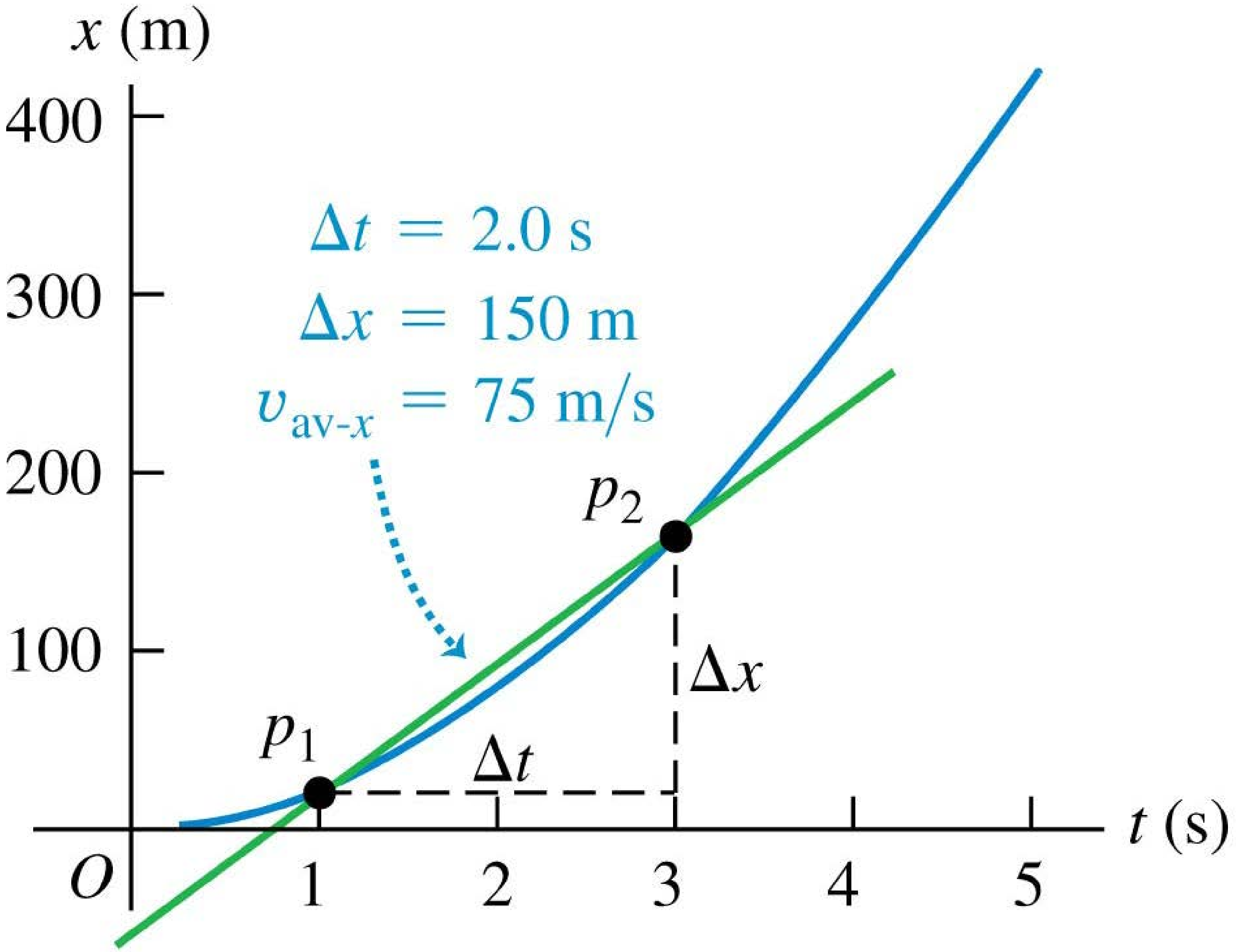
The **instantaneous** ***x*-velocity** of a particle in **straight-line motion** ...

$$v_x = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

... equals the limit of the particle's average *x*-velocity as the time interval approaches zero ...

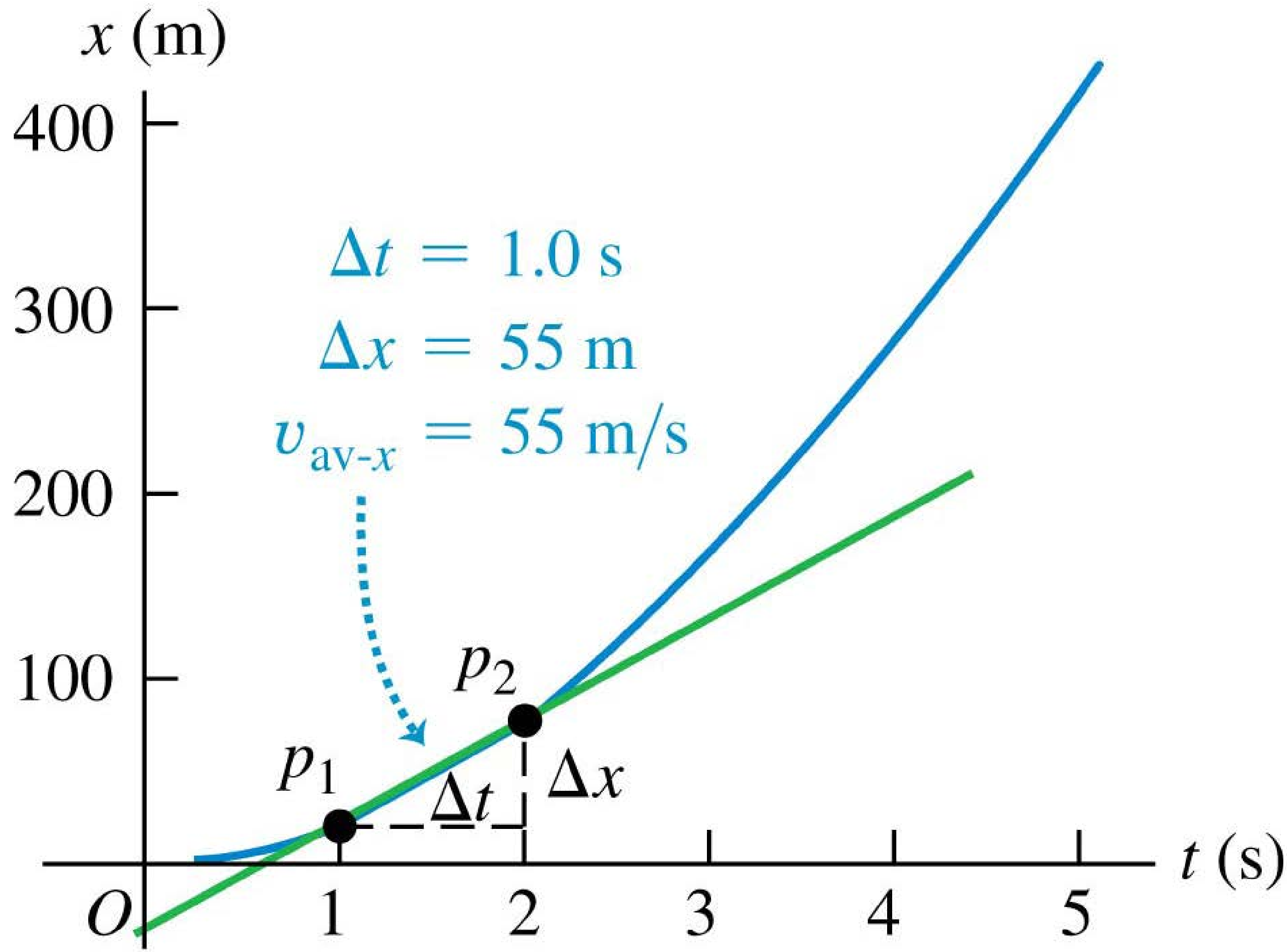
... and equals the instantaneous rate of change of the particle's *x*-coordinate.

Finding velocity on an *x-t* graph



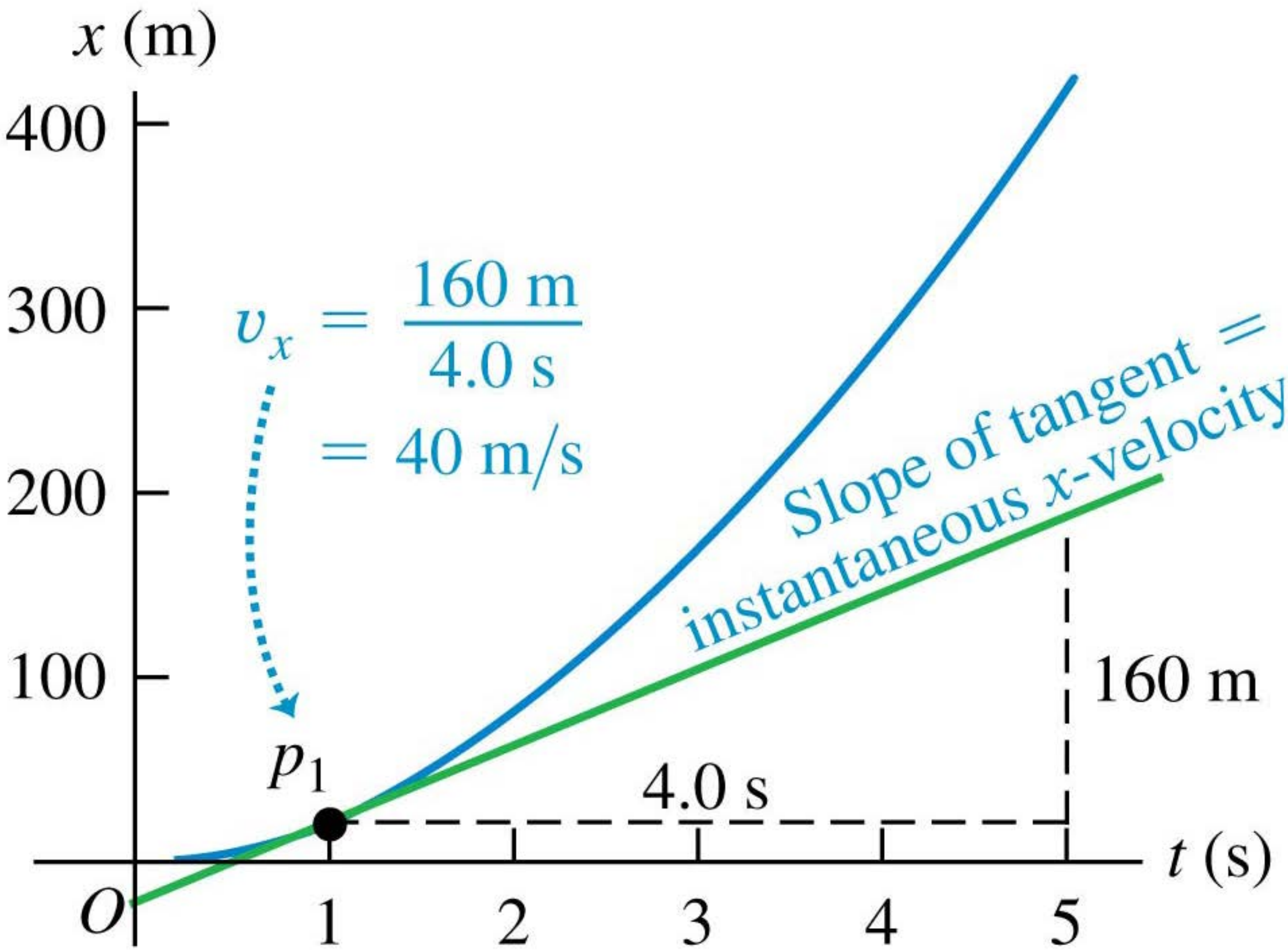
As the average x-velocity $v_{\text{av-}x}$ is calculated over shorter and shorter time intervals ...

Finding velocity on an *x*-*t* graph



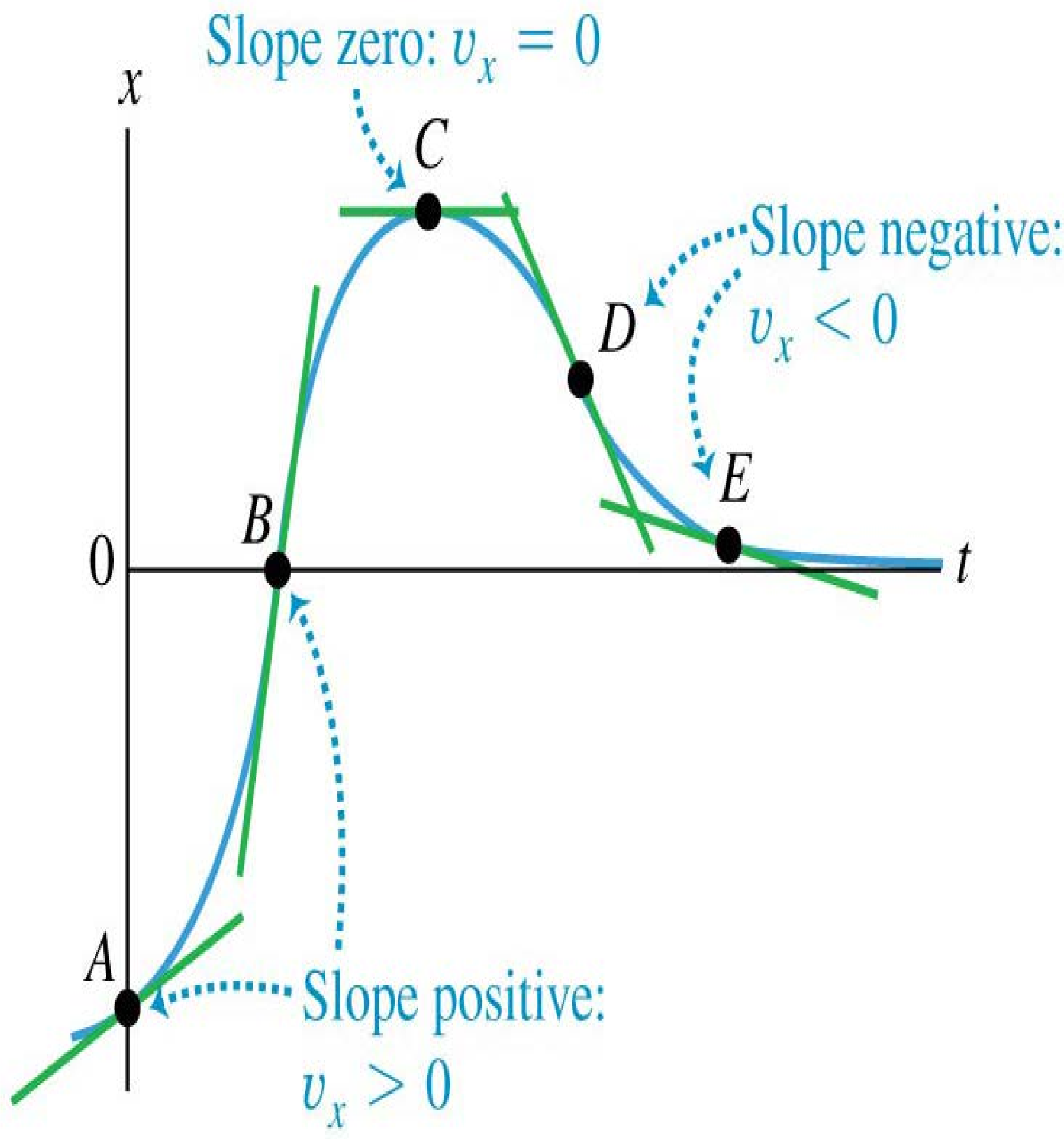
... its value $v_{av\text{-}x} = \Delta x/\Delta t$ approaches the instantaneous *x*-velocity.

Finding velocity on an *x*-*t* graph



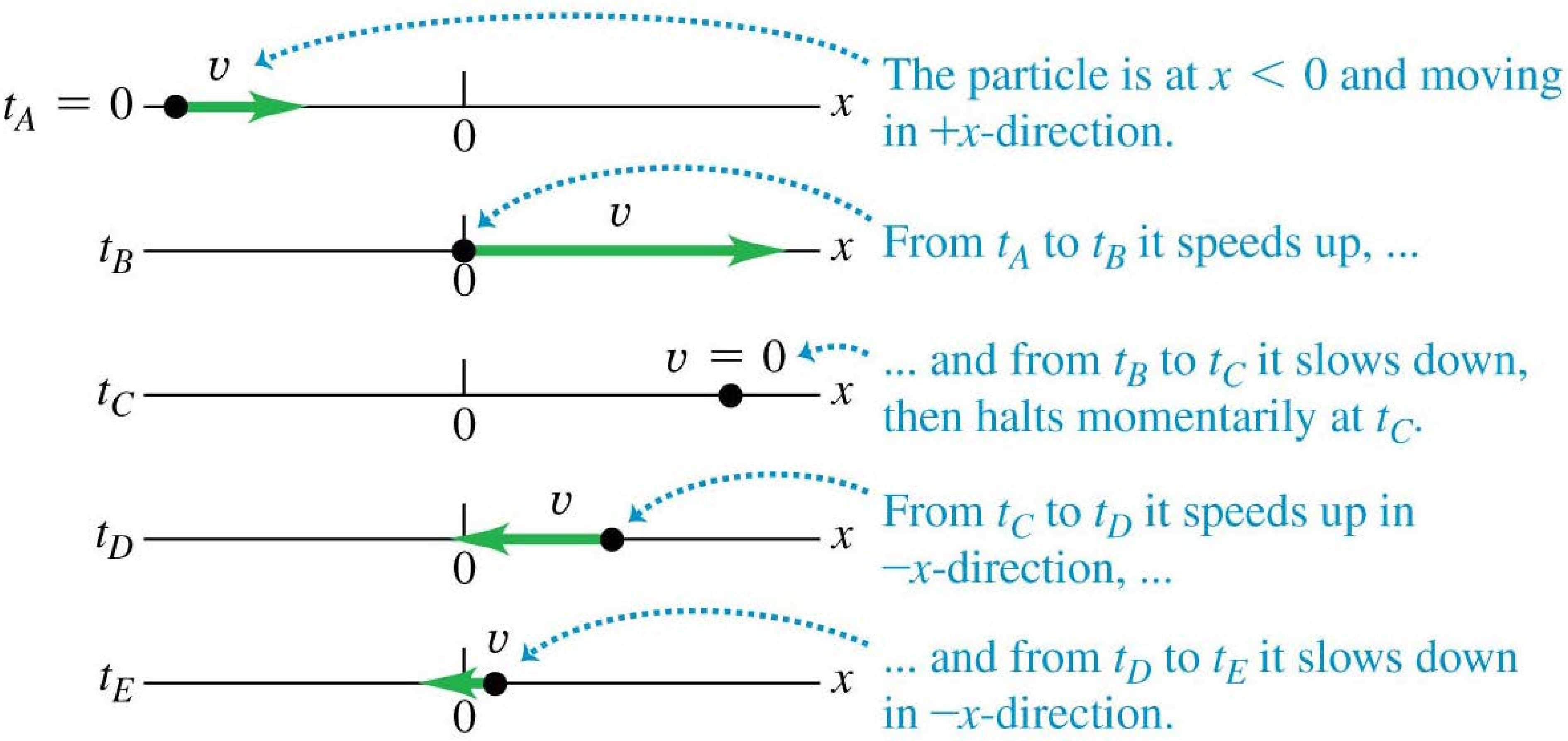
The instantaneous x-velocity v_x at any given point equals the slope of the tangent to the x-t curve at that point.

x-t graphs: determining instantaneous velocity



Motion diagrams

- Here is a ***motion diagram*** of the particle in the previous *x*-*t* graph.



Average acceleration

- Acceleration describes the rate of change of velocity with time.
- The *average x*-acceleration is

Average *x*-acceleration of a particle in **straight-line motion** during time interval from t_1 to t_2

Change in *x*-component of the particle's velocity

$$a_{\text{av-}x} = \frac{\Delta v_x}{\Delta t} = \frac{v_{2x} - v_{1x}}{t_2 - t_1}$$

Final *x*-velocity minus initial *x*-velocity

Time interval

Final time minus initial time

Instantaneous acceleration

- The ***instantaneous*** acceleration is $a_x = dv_x/dt$.

The **instantaneous** **x-acceleration** of a particle in **straight-line motion** ...

$$a_x = \lim_{\Delta t \to 0} \frac{\Delta v_x}{\Delta t} = \frac{dv_x}{dt}$$

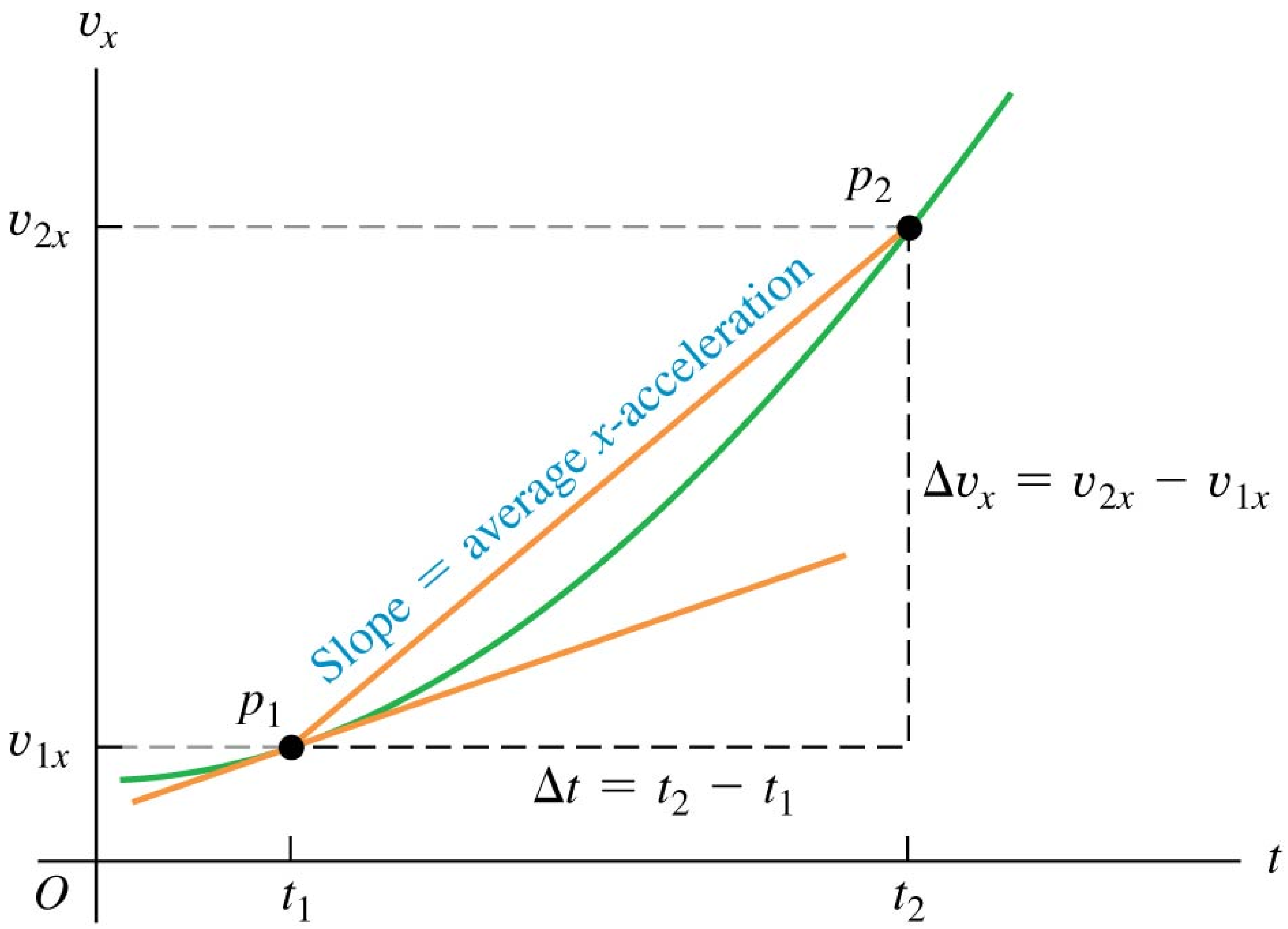
... equals the limit of the particle's average x-acceleration as the time interval approaches zero ...

... and equals the instantaneous rate of change of the particle's x-velocity.

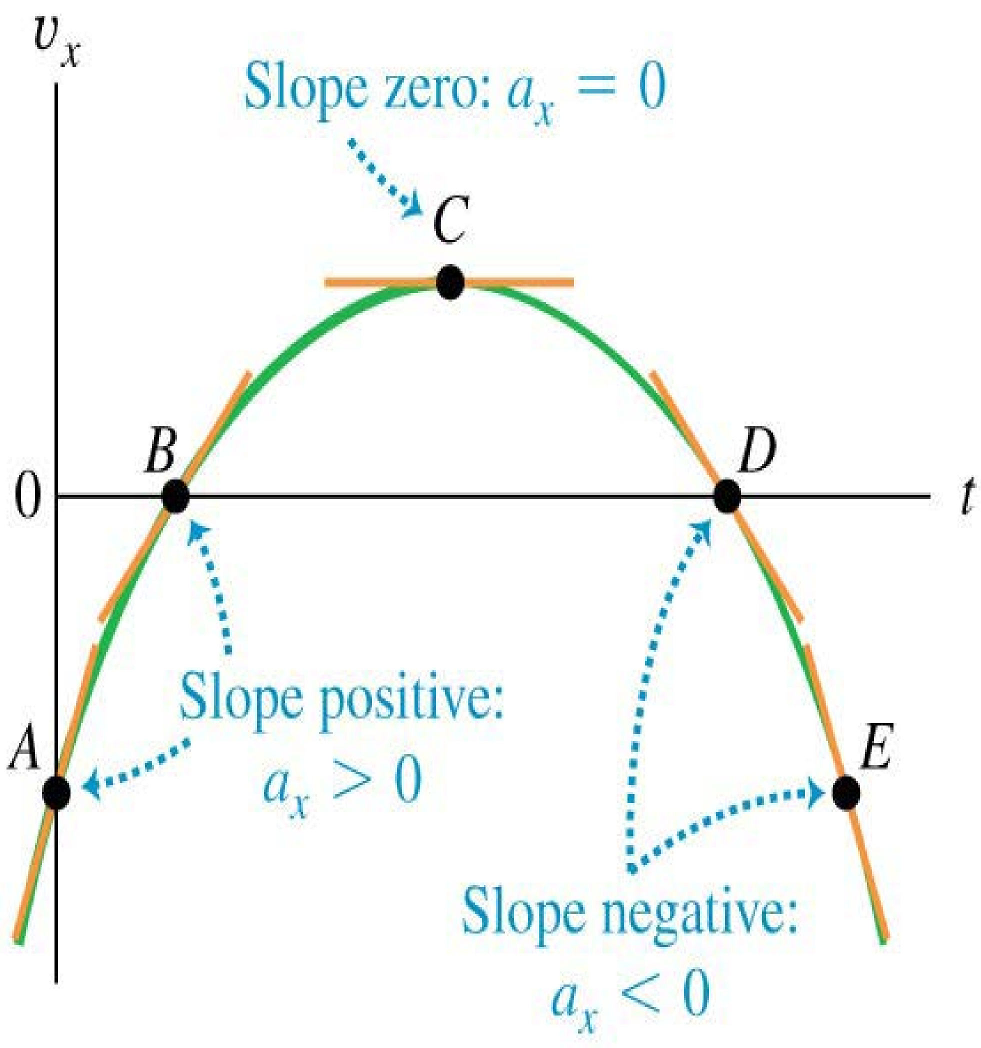
Rules for the sign of *x*-acceleration

If *x*-velocity is:	. . . *x*-acceleration is:
Positive & increasing (getting more positive)	Positive: Particle is moving in $+x$-direction & speeding up
Positive & decreasing (getting less positive)	Negative: Particle is moving in $+x$-direction & slowing down
Negative & increasing (getting less negative)	Positive: Particle is moving in $-x$-direction & slowing down
Negative & decreasing (getting more negative)	Negative: Particle is moving in $-x$-direction & speeding up

Finding acceleration on a v_x-t graph

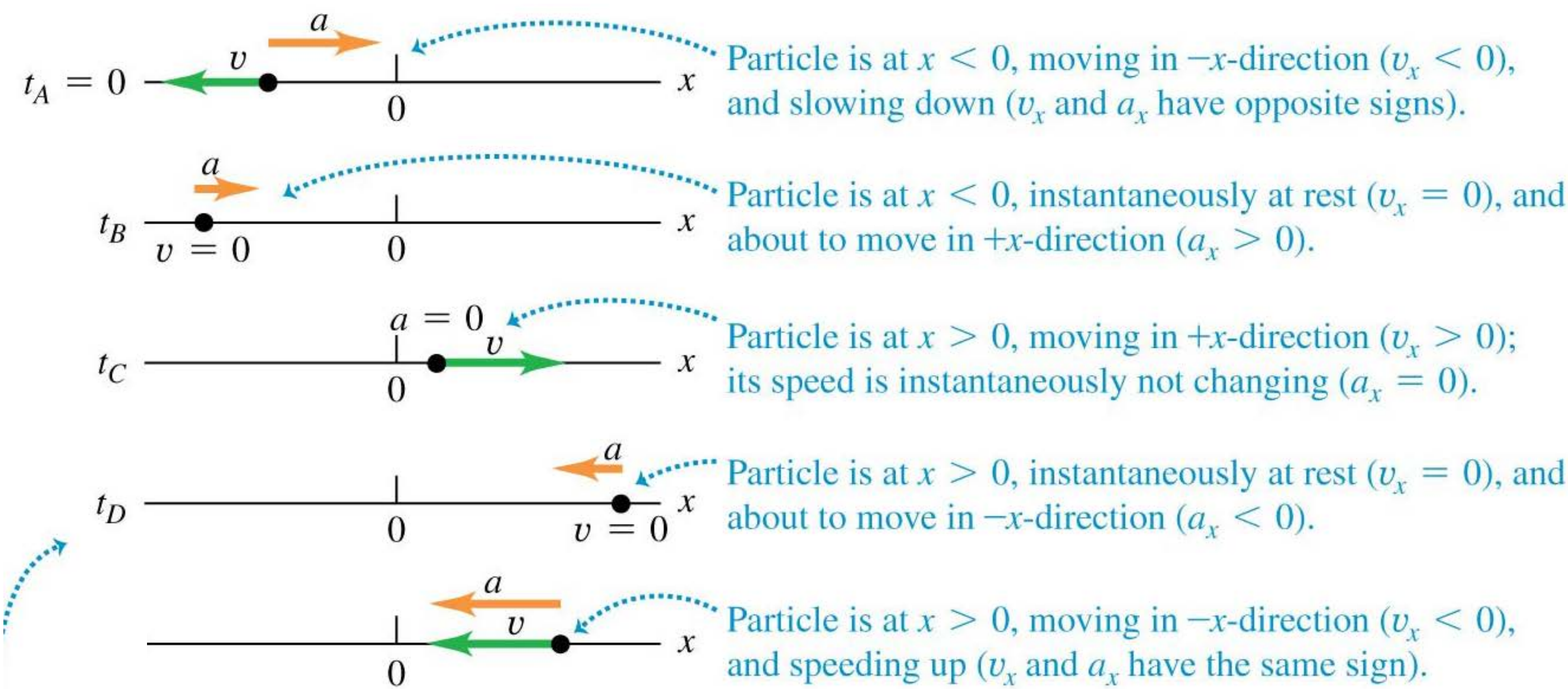


v_x-t graph: determining instantaneous acceleration

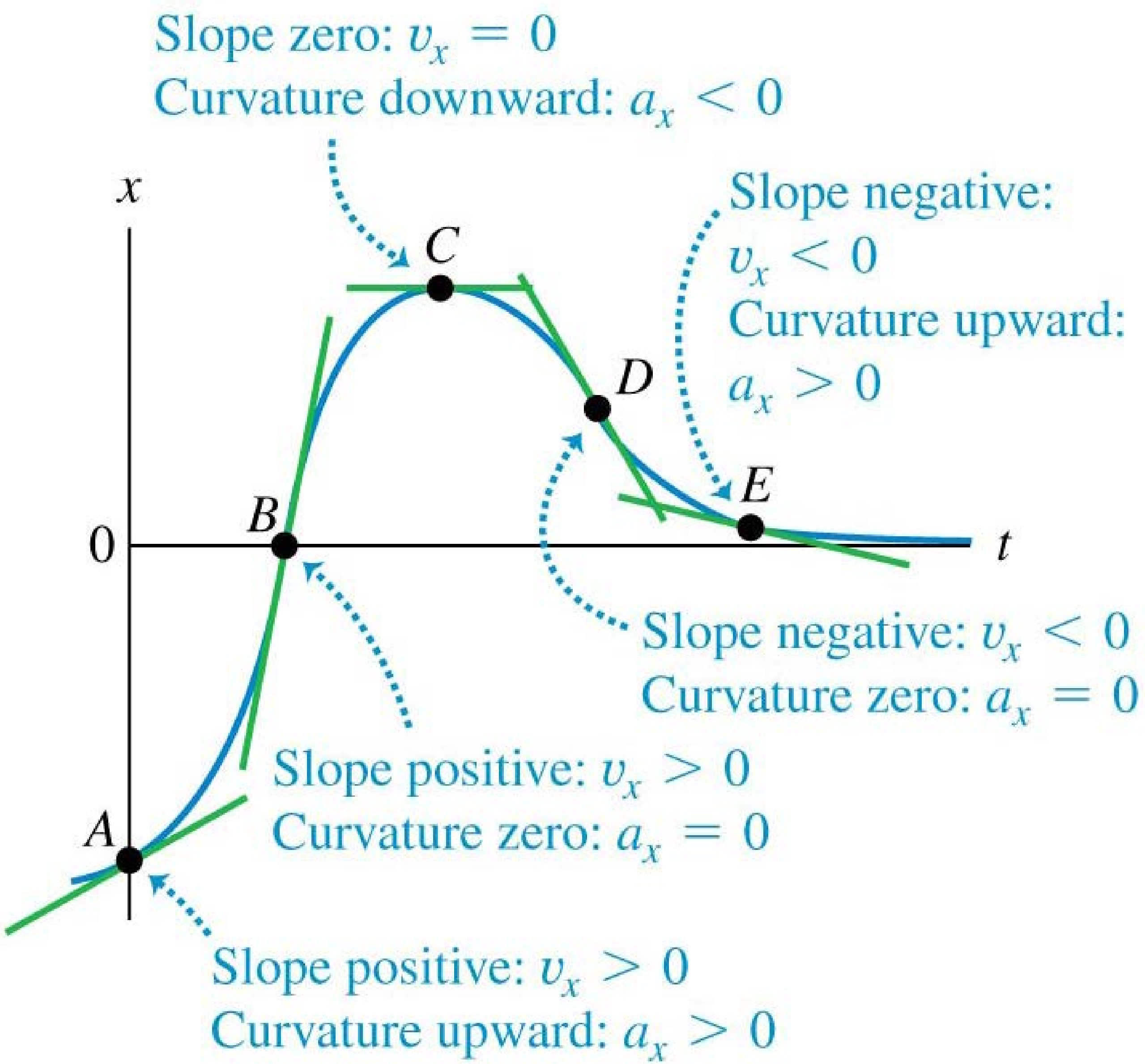


Motion diagrams

- Here is the motion diagram for the particle in the previous v_x-t graph.



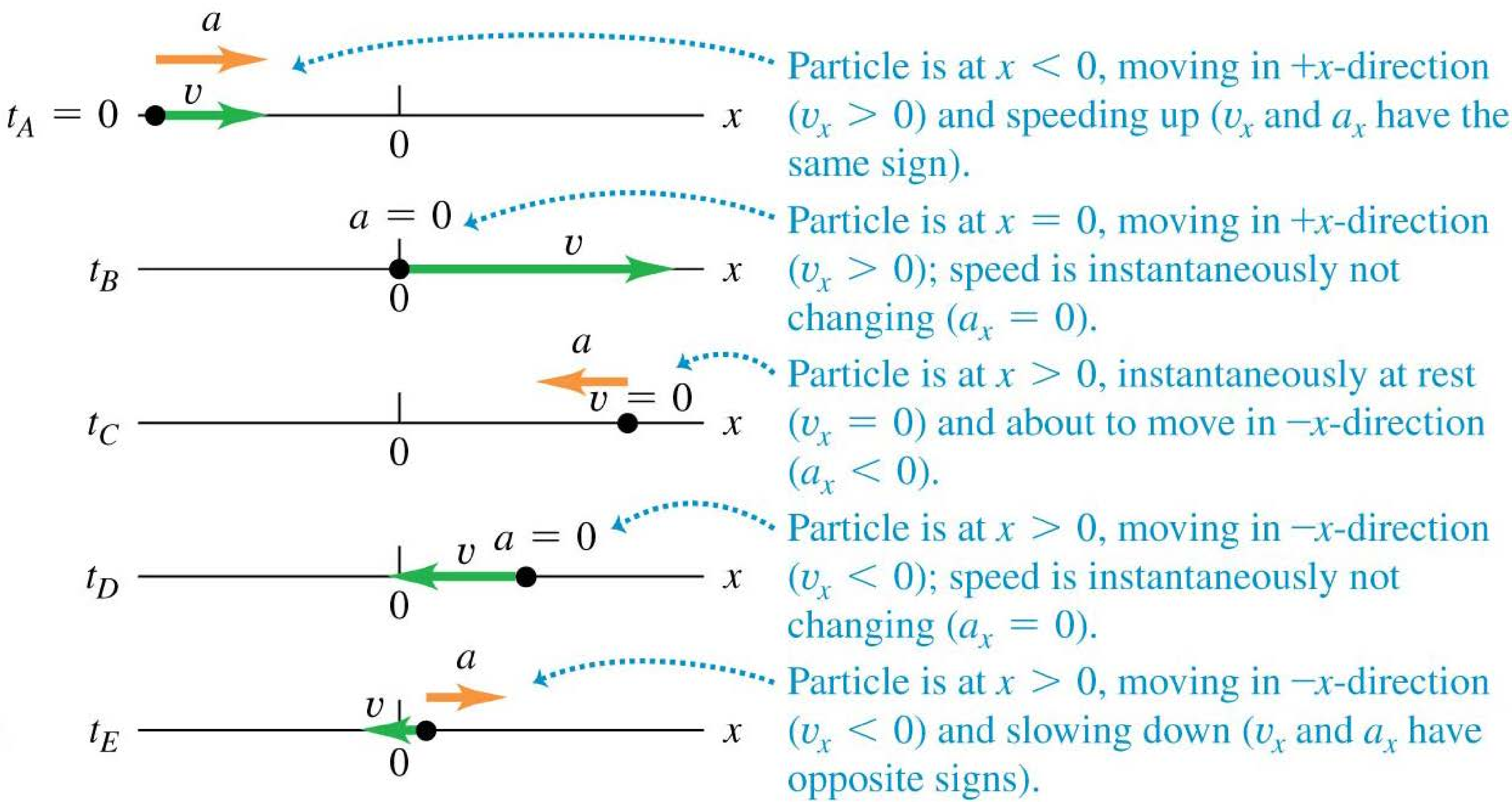
A *x*-*t* graph



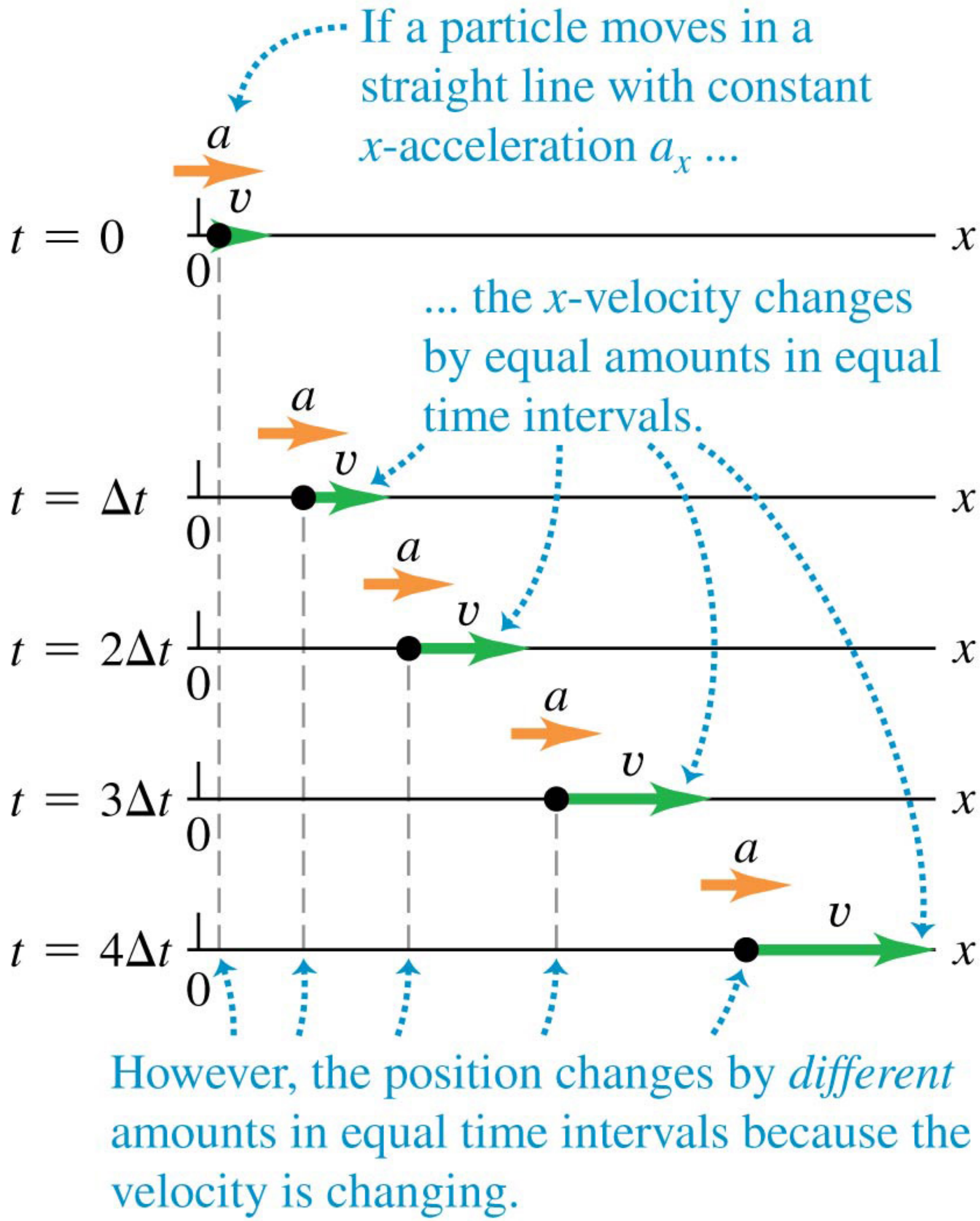
Slope zero: $v_x = 0$
Curvature downward: $a_x < 0$
x
C
Slope negative:
$v_x < 0$
Curvature upward:
$a_x > 0$
D
E
B
0
t
Slope negative: $v_x < 0$
Curvature zero: $a_x = 0$
Slope positive: $v_x > 0$
Curvature zero: $a_x = 0$
A
Slope positive: $v_x > 0$
Curvature upward: $a_x > 0$

Motion diagrams

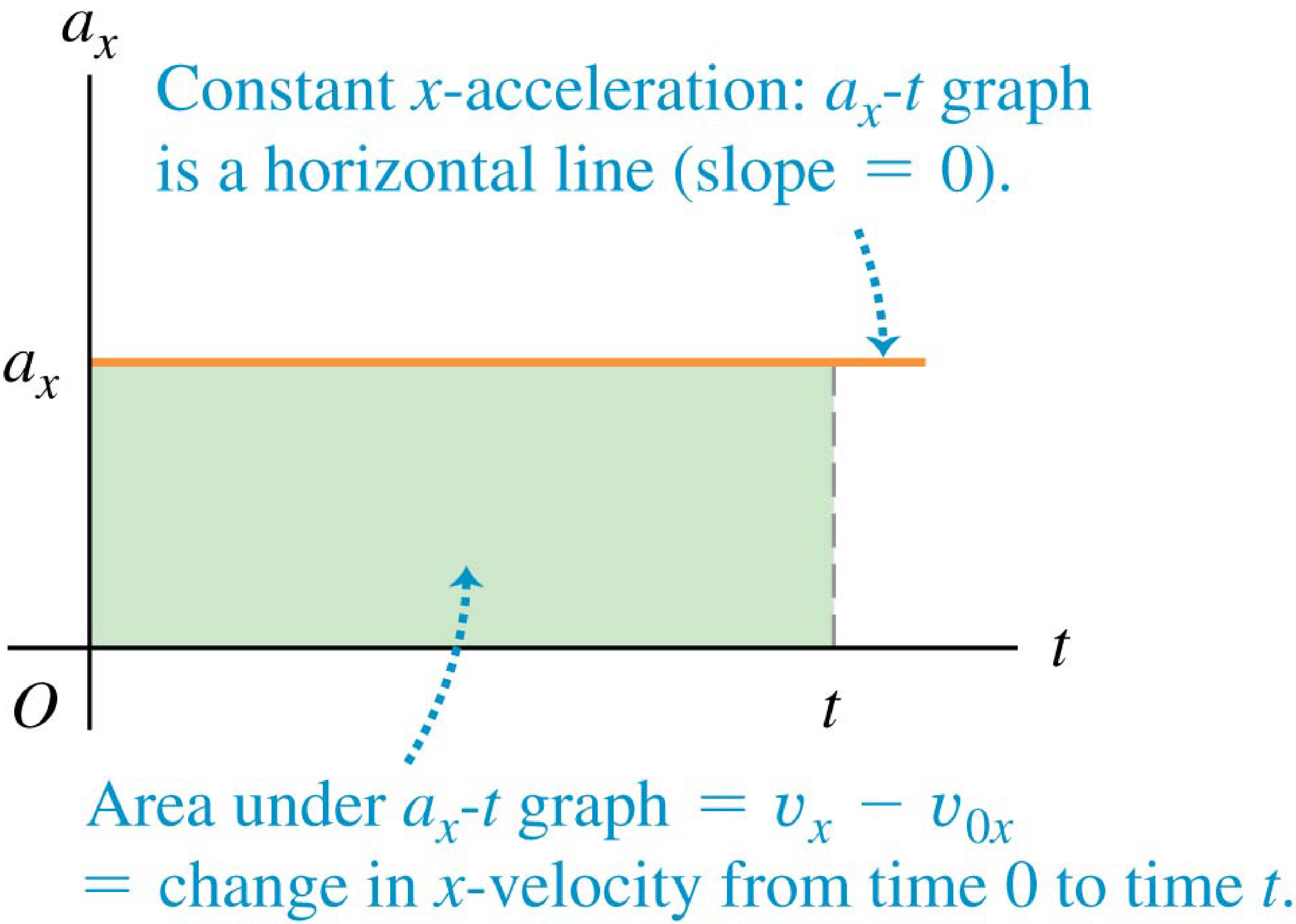
- Here is the motion diagram for the particle in the previous v_x-t graph.



Motion with constant acceleration



Motion with constant acceleration



A position-time graph

(a) A race car moves in the x-direction with constant acceleration.

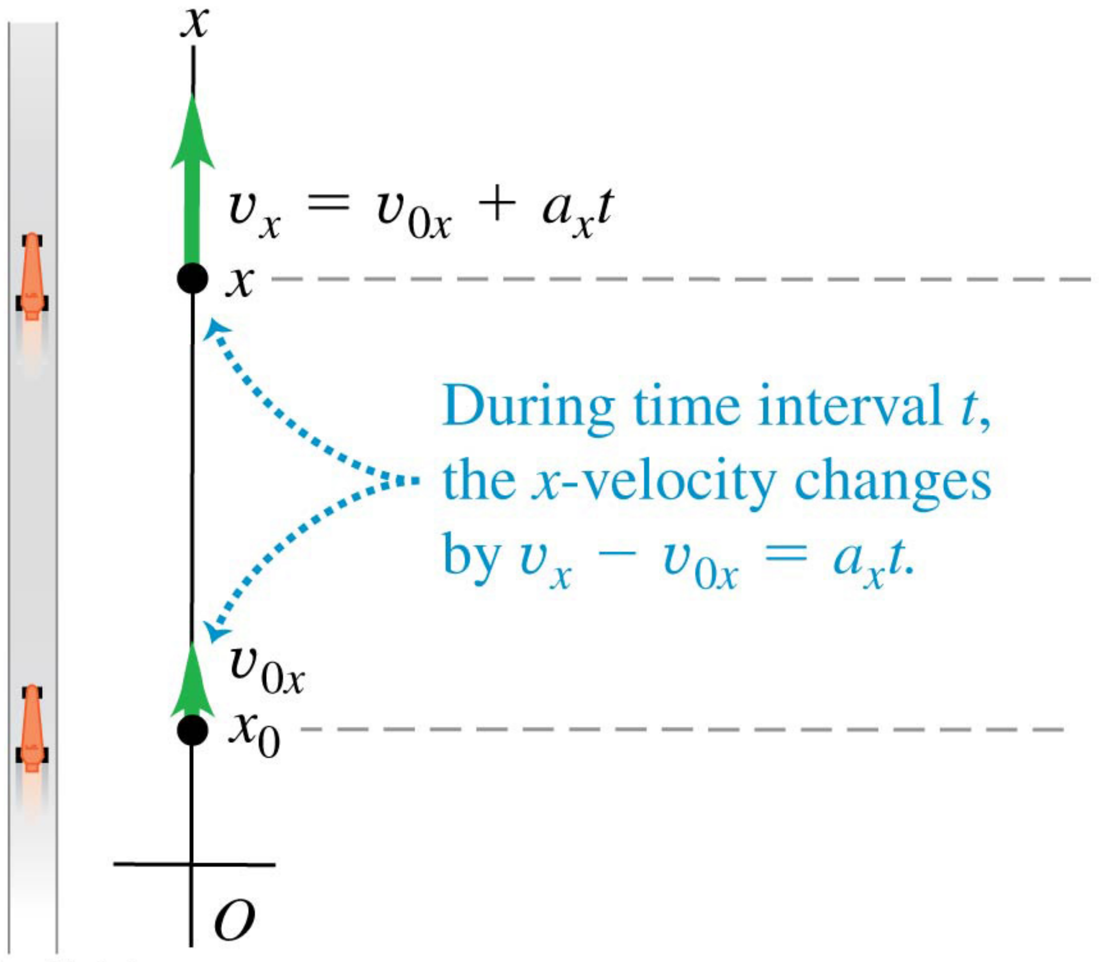


Figure 2.19b

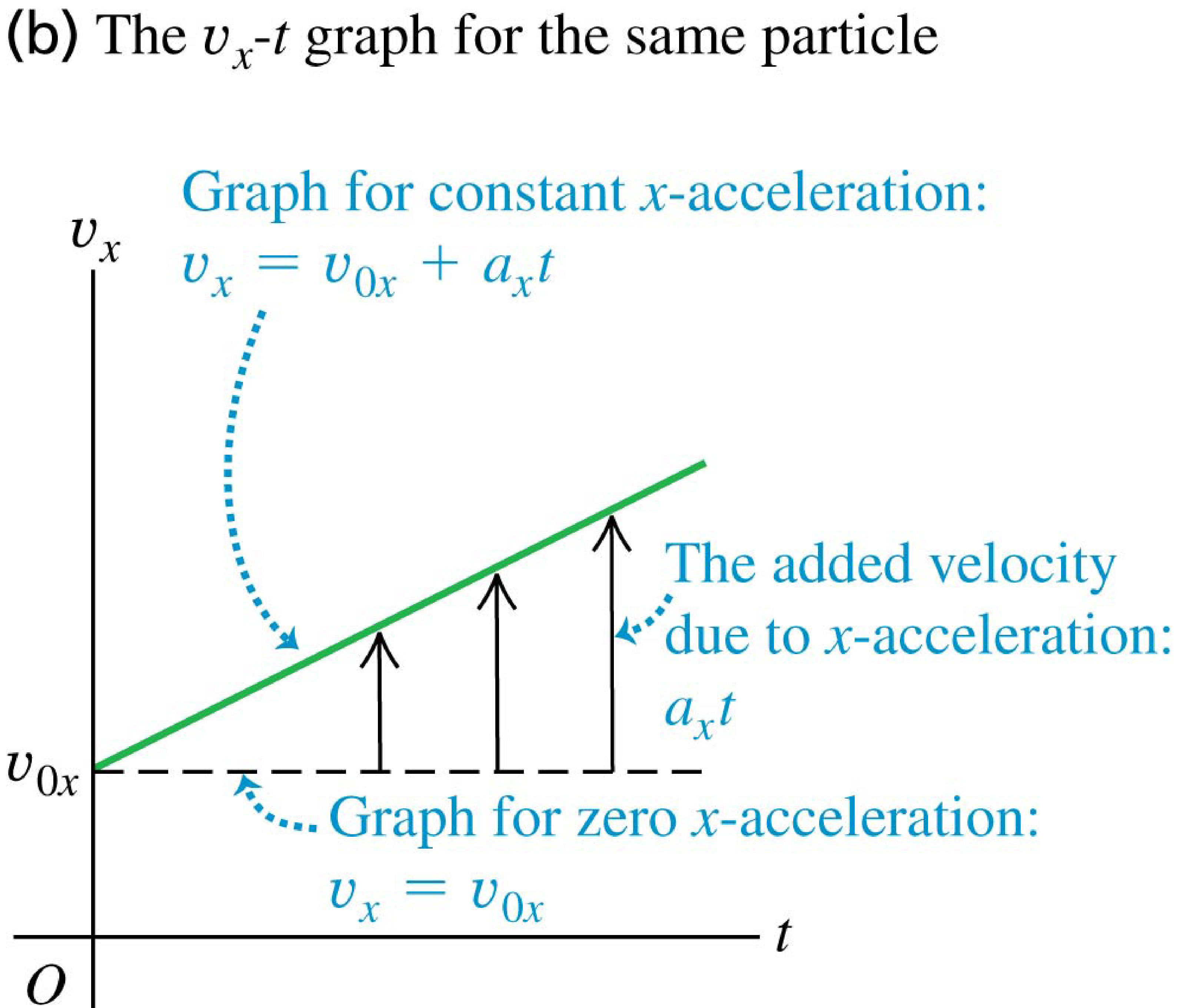
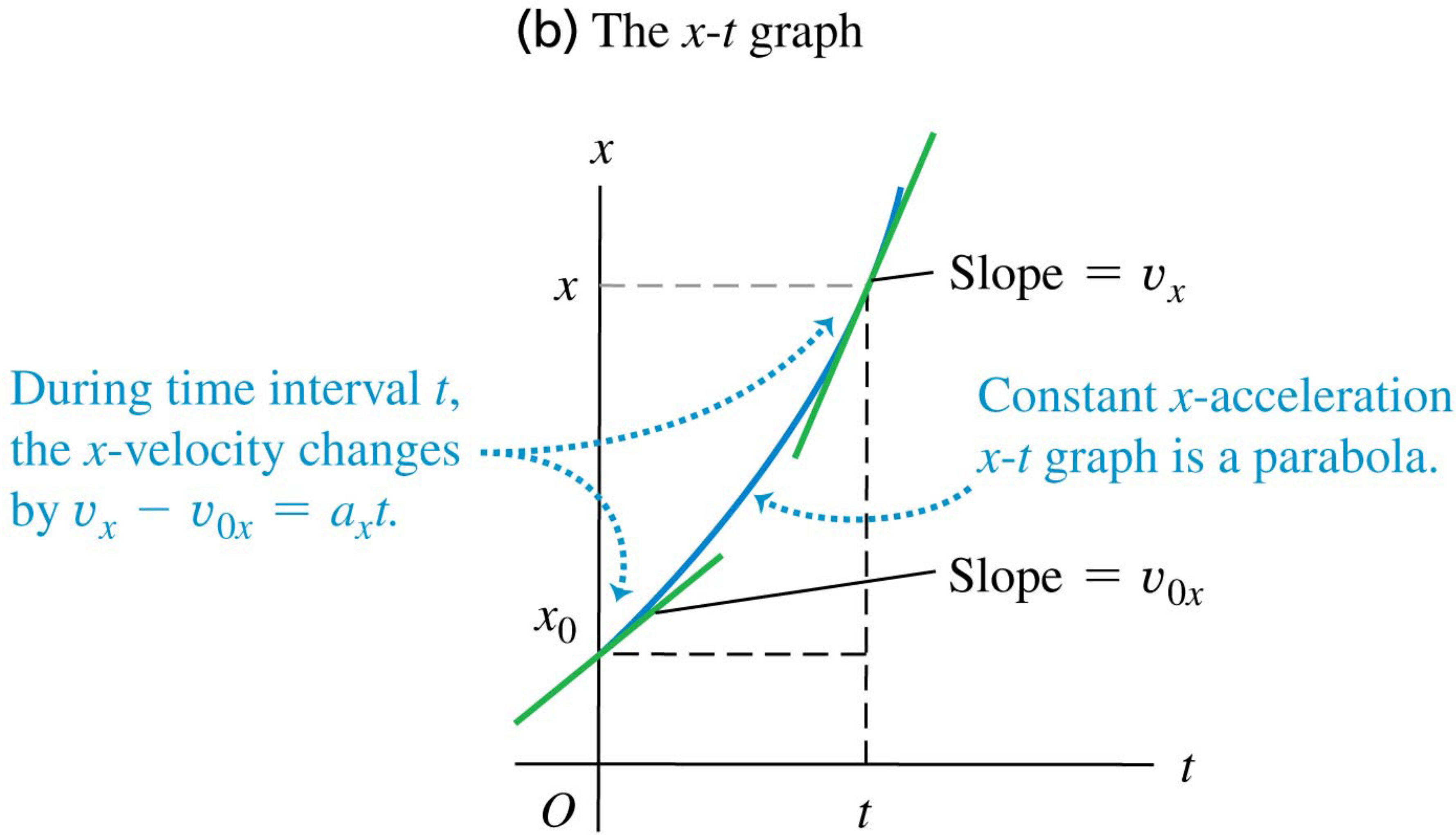

(b) The v_x-t graph for the same particle
Graph for constant x-acceleration:
$v_x = v_{0x} + a_x t$
v_x
The added velocity due to x-acceleration:
$a_x t$
v_{0x}
Graph for zero x-acceleration:
$v_x = v_{0x}$
t
O

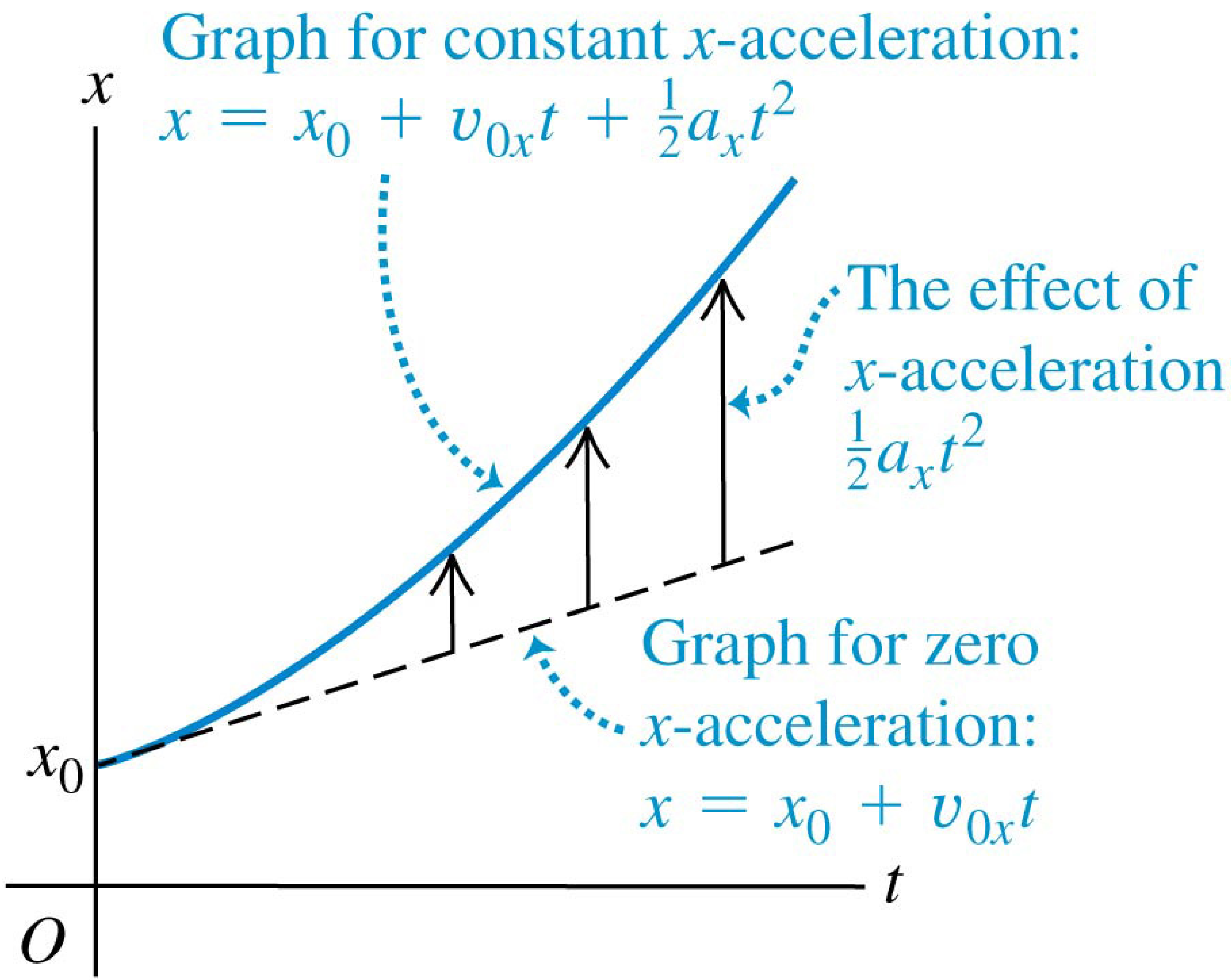
Figure 2.18b



(b) The x-t graph
x
x
Slope $= v_x$
During time interval t, the x-velocity changes by $v_x - v_{0x} = a_x t$.
Constant x-acceleration: x-t graph is a parabola.
Slope $= v_{0x}$
x_0
t
O
t

Figure 2.19a

(a) An x-t graph for a particle moving with positive constant x-acceleration



Notes on acceleration and x-t graphs

- For constant acceleration depicted on a x-t graph, a parabola always results.
- For positive acceleration, the parabola is concave upwards.
- For negative acceleration, the parabola is concave downwards.

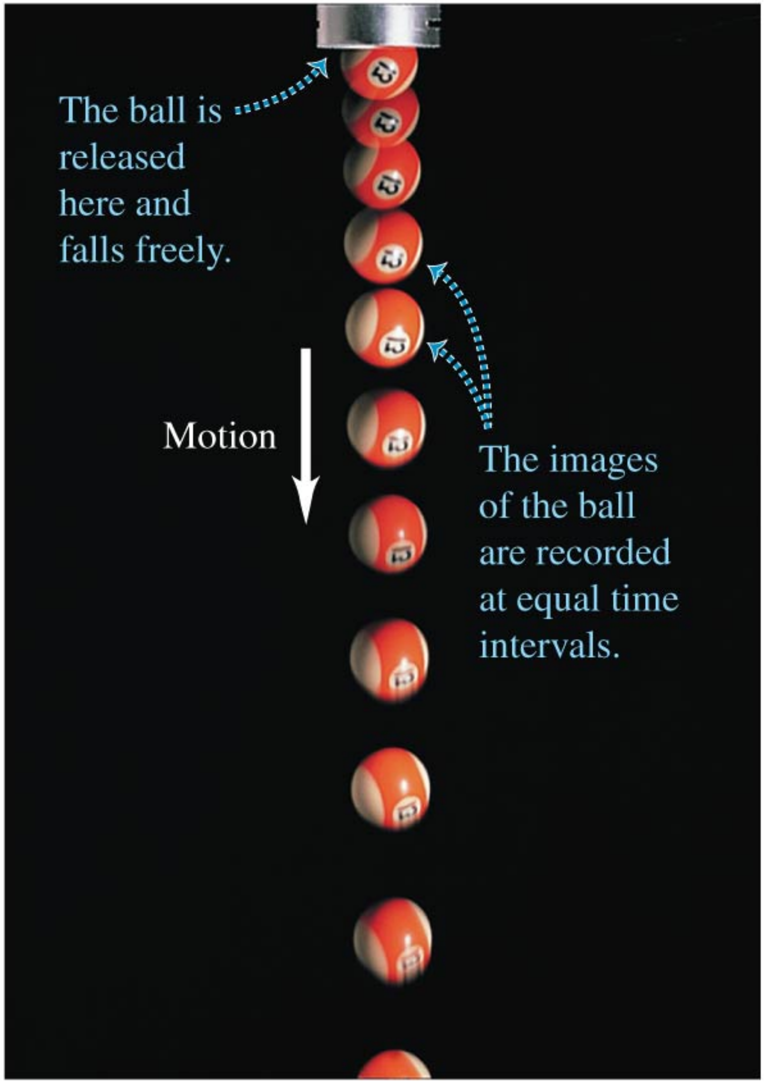
The equations of motion with constant acceleration

- The four equations below apply to any straight-line motion with constant acceleration a_x.

Equation		Includes Quantities			
$v_x = v_{0x} + a_x t$	(2.8)	t		v_x	a_x
$x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2$	(2.12)	t	x		a_x
$v_x^2 = v_{0x}^2 + 2a_x(x - x_0)$	(2.13)		x	v_x	a_x
$x - x_0 = \frac{1}{2}(v_{0x} + v_x)t$	(2.14)	t	x	v_x	

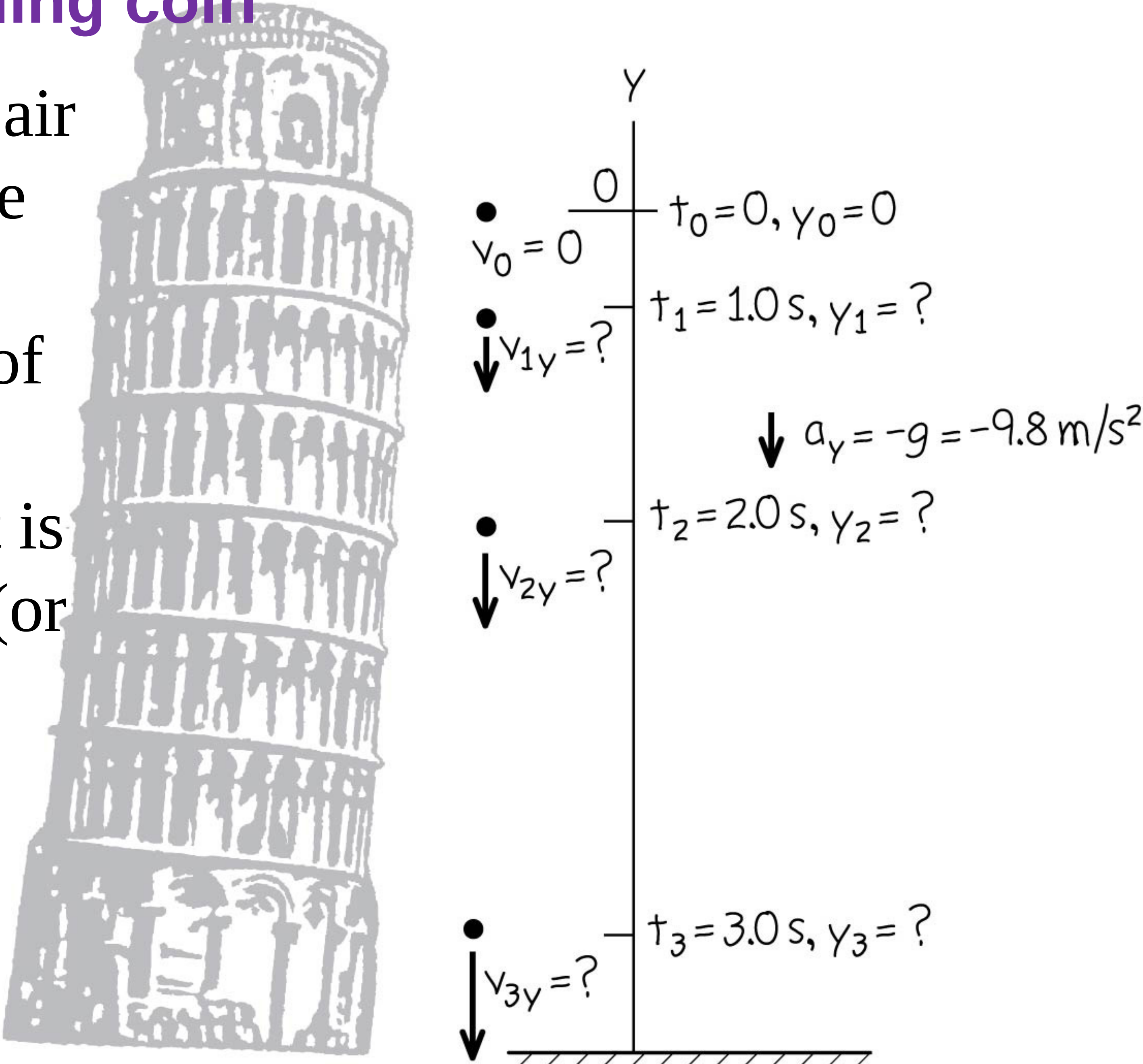
Freely falling bodies

- **Free fall** is the motion of an object under the influence of only gravity.
- In the figure, a strobe light flashes with equal time intervals between flashes.
- The velocity change is the same in each time interval, so the acceleration is constant.



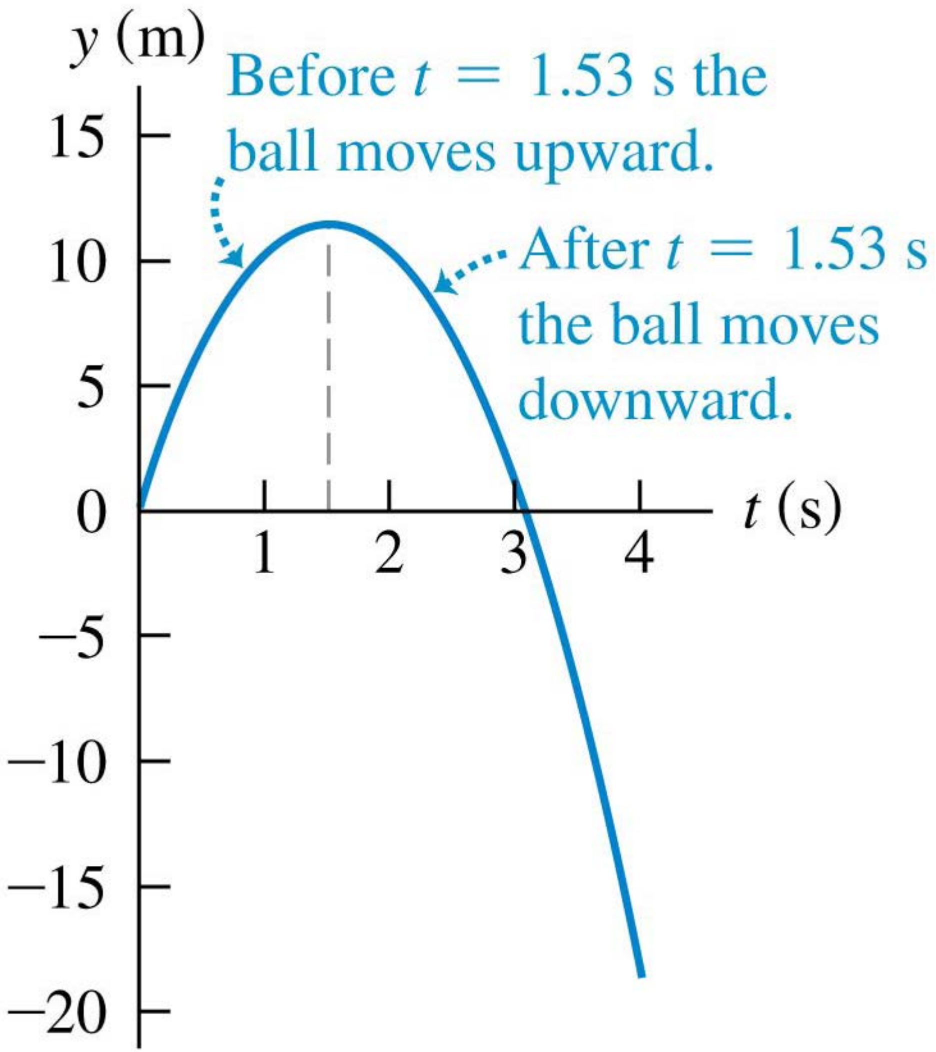
A freely falling coin

If there is no air resistance, the downward acceleration of any freely falling object is g = 9.8 m/s^2 (or = 32 ft/s^2).



Up-and-down motion in free fall

- Position as a function of time for a ball thrown upward with an initial speed of 15.0 m/s.



Up-and-down motion in free fall

- Velocity as a function of time for a ball thrown upward with an initial speed of 15.0 m/s.
- The vertical velocity, but ***not the acceleration***, is zero at the highest point.