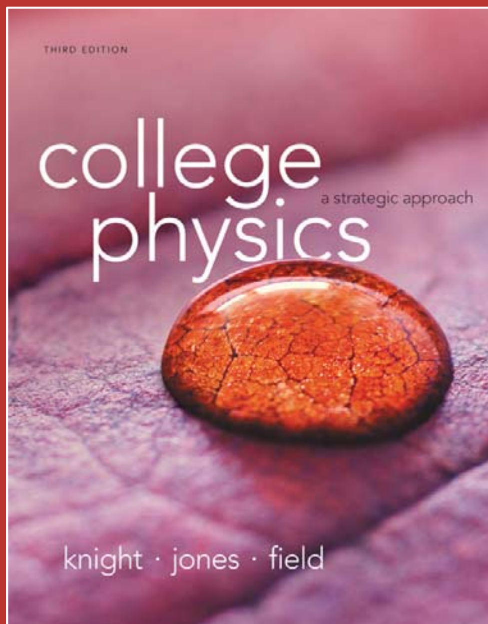

Material in this presentation comes from the following book [Ali]

Lecture Presentation

Chapter 2

Motion in One Dimension

Suggested Simulations for Chapter 2

- **PhETs**
  - *The Moving Man*
  - *Equation Grapher*

Chapter 2 Motion in One Dimension

Chapter Goal: To describe and analyze linear motion.

Slide 2-3

Chapter 2 Preview
Looking Ahead: Uniform Motion

- Successive images of the rider are the same distance apart, so the velocity is constant. This is **uniform motion**.

- You'll learn to describe motion in terms of quantities such as distance and velocity, an important first step in analyzing motion.

Slide 2-4

Chapter 2 Preview
Looking Ahead: Acceleration

- A cheetah is capable of very high speeds but, more importantly, it is capable of a rapid *change* in speed—a large **acceleration**.

- You'll use the concept of acceleration to solve problems of changing velocity, such as races, or predators chasing prey.

Chapter 2 Preview
Looking Ahead: Free Fall

- When you toss a coin, the motion—both going up and coming down—is determined by gravity alone. We call this **free fall**.

- How long does it take the coin to go up and come back down? This is the type of free-fall problem you'll learn to solve.

Chapter 2 Preview
Looking Ahead

Uniform Motion

Successive images of the rider are the same distance apart, so the velocity is constant. This is **uniform motion.**

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Acceleration

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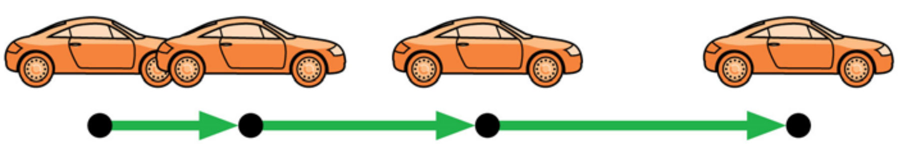
How long does it take the coin to go up and come back down? This is the type of free-fall problem you'll learn to solve.

Text: p. 28

Chapter 2 Preview
Looking Back: Motion Diagrams

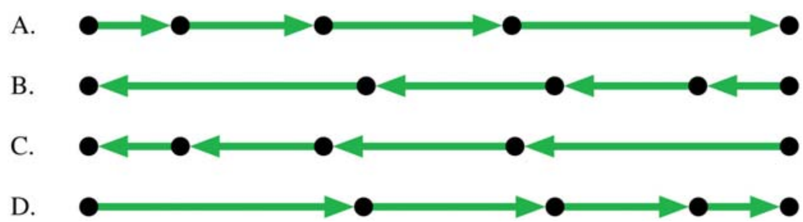
- As you saw in Section 1.5, a good first step in analyzing motion is to draw a motion diagram, marking the position of an object in subsequent times.



- In this chapter, you'll learn to create motion diagrams for different types of motion along a line. Drawing pictures like this is a good staring point for solving problems.

Chapter 2 Preview
Stop to Think

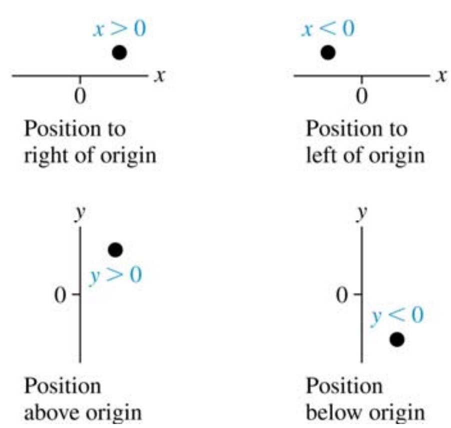
A bicycle is moving to the left with increasing speed. Which of the following motion diagrams illustrates this motion?



Slide 2-9

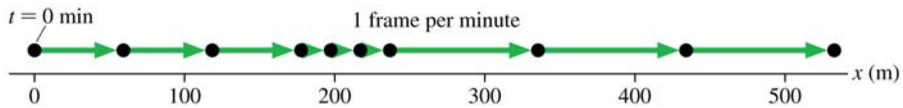
Representing Position

- We will use an ***x*-axis** to analyze horizontal motion and motion on a ramp, with the positive end to the right.
- We will use a ***y*-axis** to analyze vertical motion, with the positive end up.



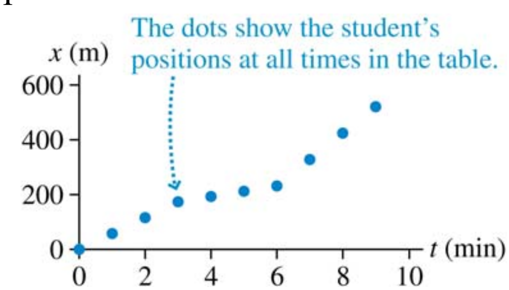
Slide 2-10

Representing Position



The motion diagram of a student walking to school and a coordinate axis for making measurements

- Every dot in the motion diagram of Figure 2.2 represents the student's position at a particular time.
- Figure 2.3 shows the student's motion shows the student's position as a **graph** of *x* versus *t*.

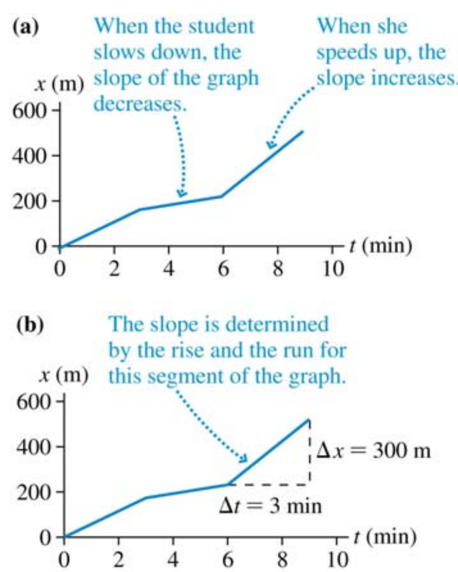


From Position to Velocity

- On a position-versus-time graph, **a faster speed corresponds to a steeper slope**.

$$\text{slope of graph} = \frac{\text{rise}}{\text{run}} = \frac{\Delta x}{\Delta t}$$

- **The slope of an object's position-versus-time graph is the object's velocity at that point in the motion.**



From Position to Velocity

TACTICS BOX 2.1 **Interpreting position-versus-time graphs**

Information about motion can be obtained from position-versus-time graphs as follows:

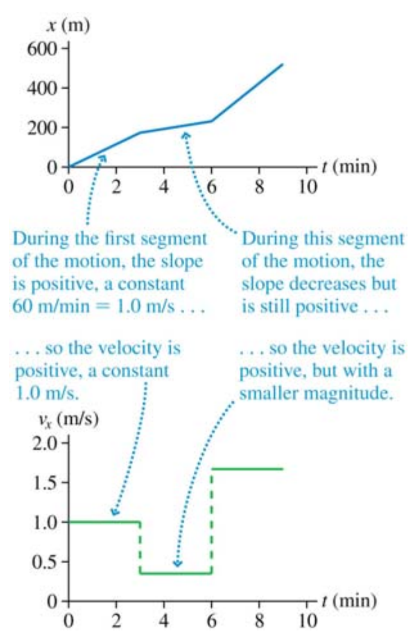
1. Determine an object's *position* at time *t* by reading the graph at that instant of time.
2. Determine the object's *velocity* at time *t* by finding the slope of the position graph at that point. Steeper slopes correspond to faster speeds.
3. Determine the *direction of motion* by noting the sign of the slope. Positive slopes correspond to positive velocities and, hence, to motion to the right (or up). Negative slopes correspond to negative velocities and, hence, to motion to the left (or down).

Exercises 2,3

Text: p. 31

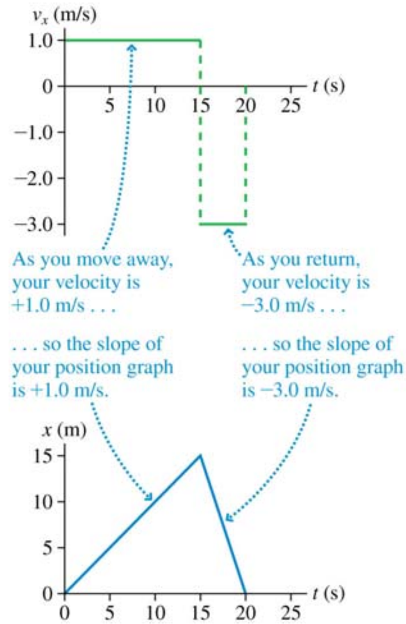
From Position to Velocity

- We can deduce the **velocity-versus-time graph** from the position-versus-time graph.
- The velocity-versus-time graph is yet another way to represent an object's motion.



From Velocity to Position

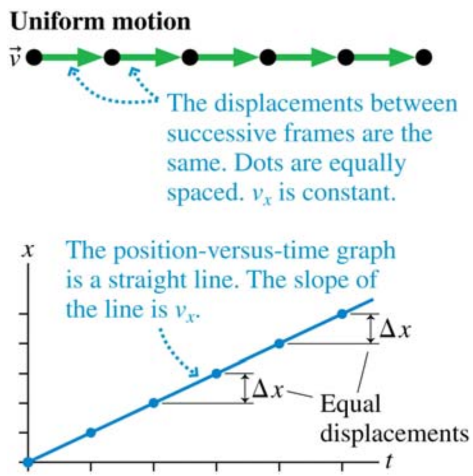
- We can deduce the position-versus-time graph from the velocity-versus-time graph.
- The sign of the velocity tells us whether the slope of the position graph is positive or negative.
- The magnitude of the velocity tells us how steep the slope is.



Slide 2-15

Uniform Motion

- Straight-line motion in which equal displacements occur during any successive equal-time intervals is called **uniform motion** or **constant-velocity motion.**
- **An object's motion is uniform if and only if its position-versus-time graph is a straight line.**



Slide 2-16

Equations of Uniform Motion

- The velocity of an object in uniform motion tells us the amount by which its position changes during each second.

$$v_x = \frac{\text{rise}}{\text{run}} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

$$x_f = x_i + v_x \, \Delta t$$

Position equation for an object in uniform motion (v_x is constant)

$$\Delta x = v_x \, \Delta t$$

- The displacement Δx is proportional to the time interval Δt.

Slide 2-17

Equations of Uniform Motion

Proportional relationships

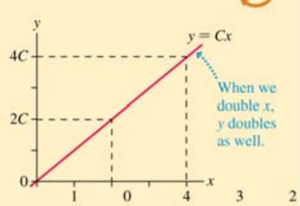
MP

We say that y is **proportional** to x if they are related by an equation of this form:

$$y = Cx$$

y is proportional to x

We call C the **proportionality constant.** A graph of y versus x is a straight line that passes through the origin.



SCALING If x has the initial value x_1, then y has the initial value $y_1 = Cx_1$. Changing x from x_1 to x_2 changes y from y_1 to y_2 The ratio of y_2 to y_1 is

$$\frac{y_2}{y_1} = \frac{Cx_2}{Cx_1} = \frac{x_2}{x_1}$$

The ratio of y_2 to y_1 is exactly the same as the ratio of x_2 to x_1. If y is proportional to x, which is often written $y \propto x$, then x and y change by the same factor:

- If you double x, you double y.
- If you decrease x by a factor of 3, you decrease y by a factor of 3.

If two variables have a proportional relationship, we can draw important conclusions from ratios without knowing the value of the proportionality constant C. We can often solve problems in a very straightforward manner by looking at such ratios. This is an important skill called *ratio reasoning*.

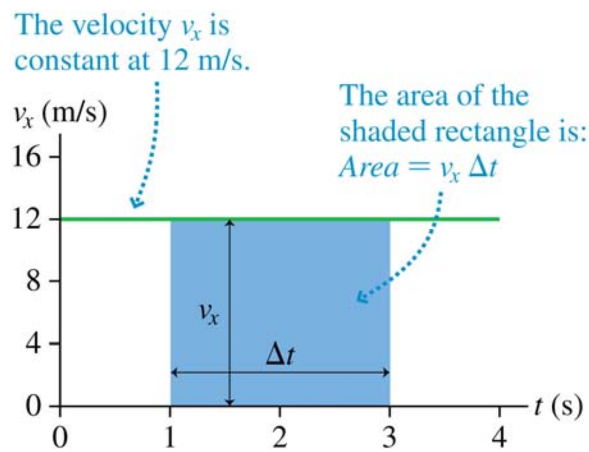
Exercise 11

Text: p. 34

Slide 2-18

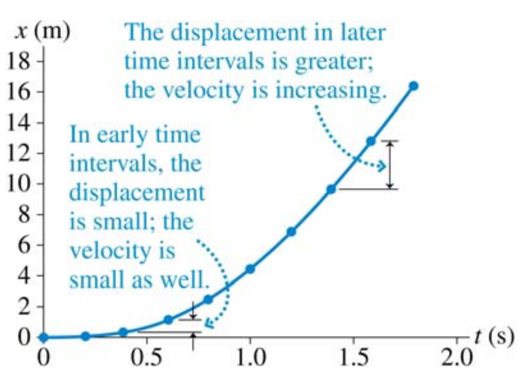
From Velocity to Position, One More Time

- **The displacement Δx is equal to the area under the velocity graph during the time interval Δt.**

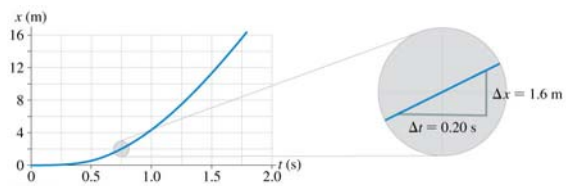


Instantaneous Velocity

- For one-dimensional motion, an object changing its velocity is either speeding up or slowing down.
- An object's velocity—a speed *and* a direction—at a specific *instant* of time t is called the object's **instantaneous velocity.**
- **From now on, the word "velocity" will always mean instantaneous velocity.**

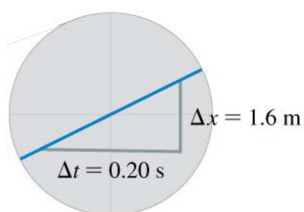


Finding the Instantaneous Velocity



- If the velocity changes, the position graph is a curved line. But we can compute a slope at a point by considering a small segment of the graph. Let's look at the motion in a very small time interval right around $t = 0.75$ s. This is highlighted with a circle, and we show a closeup in the next graph.

Finding the Instantaneous Velocity



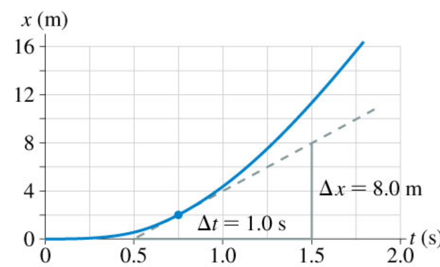
- In this magnified segment of the position graph, the curve isn't apparent. It appears to be a line segment. We can find the slope by calculating the rise over the run, just as before:

$$v_x = (1.6\text{ m})/(0.20\text{ s}) = 8.0\text{ m/s}$$

- This is the slope at $t = 0.75$ s and thus the velocity at this instant of time.

Finding the Instantaneous Velocity

- Graphically, the slope of the curve at a point is the same as the slope of a straight line drawn *tangent* to the curve at that point. Calculating rise over run for the tangent line, we get

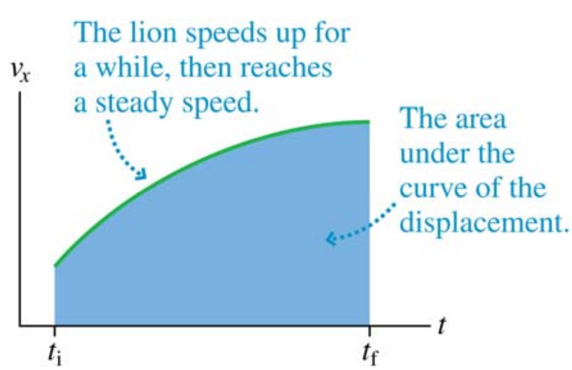


$v_x = (8.0\text{ m})/(1.0\text{ s}) = 8.0\text{ m/s}$

- This is the same value we obtained from the closeup view. The slope of the tangent line is the instantaneous velocity at that instant of time.

Instantaneous Velocity

- Even when the speed varies we can still use the velocity-versus-time graph to determine displacement.
- The area under the curve in a velocity-versus-time graph equals the displacement even for non-uniform motion.



Acceleration

- We define a new motion concept to describe an object whose velocity is changing.
  - The ratio of $\Delta v_x/\Delta t$ is the *rate of change of velocity.*
  - The ratio of $\Delta v_x/\Delta t$ is the *slope of a velocity-versus-time graph.*

$$a_x = \frac{\Delta v_x}{\Delta t}$$

Definition of acceleration as the rate of change of velocity

Units of Acceleration

- In our SI unit of velocity, 60 mph = 27 m/s.
- The Corvette speeds up to 27 m/s in Δt = 3.6 s.

$$a_{\text{Corvette}\,x} = \frac{\Delta v_x}{\Delta t} = \frac{27\text{ m/s}}{3.6\text{ s}} = 7.5\,\frac{\text{m/s}}{\text{s}}$$

- Every second, the Corvette's velocity changes by 7.5 m/s.
- It is customary to abbreviate the acceleration units (m/s)/s as m/s^2, which we say as "meters per second squared."

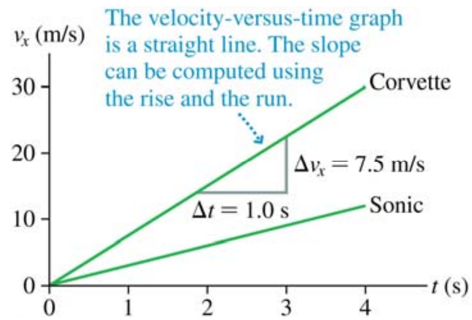
TABLE 2.2 Performance data for vehicles

Vehicle	Time to go from 0 to 60 mph
2011 Chevy Corvette	3.6 s
2012 Chevy Sonic	9.0 s

Representing Acceleration

TABLE 2.3 Velocity data for the Sonic and the Corvette

Time (s)	Velocity of Sonic (m/s)	Velocity of Corvette (m/s)
0	0	0
1	3.0	7.5
2	6.0	15.0
3	9.0	22.5
4	12.0	30.0

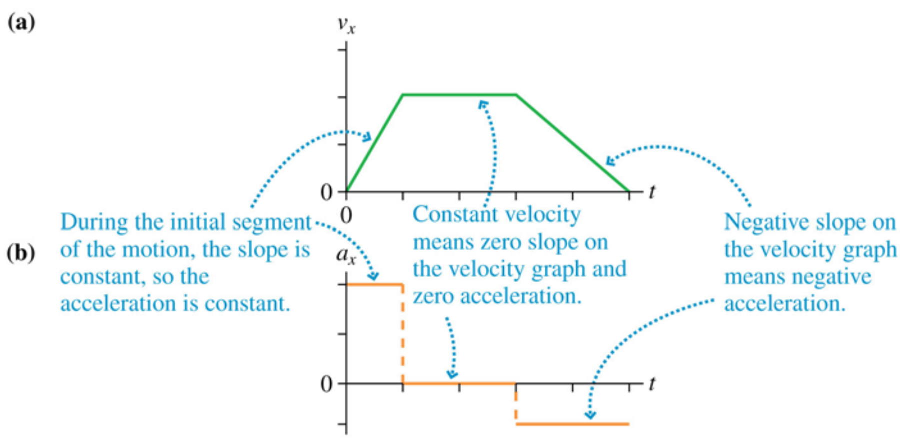


- **An object's acceleration is the slope of its velocity-versus-time graph.**

Slide 2-27

Representing Acceleration

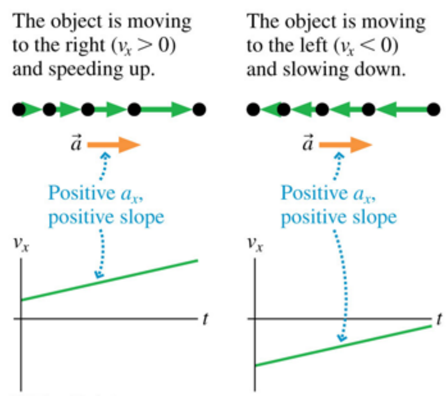
- We can find an acceleration graph from a velocity graph.



Slide 2-28

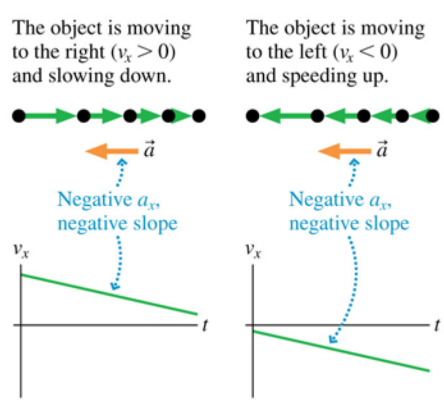
The Sign of the Acceleration

An object can move right or left (or up or down) while either speeding up or slowing down. Whether or not an object that is slowing down has a negative acceleration depends on the direction of motion.



The Sign of the Acceleration (cont.)

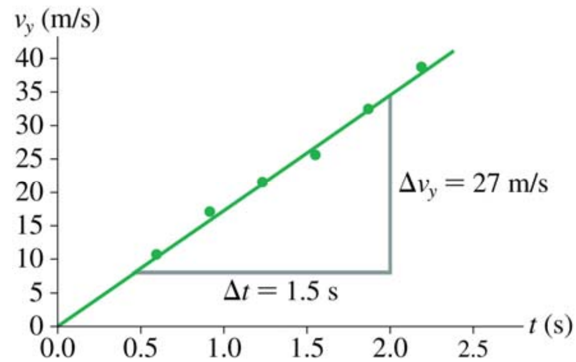
An object can move right or left (or up or down) while either speeding up or slowing down. Whether or not an object that is slowing down has a negative acceleration depends on the direction of motion.



Motion with Constant Acceleration

- We can use the slope of the graph in the velocity graph to determine the acceleration of the rocket.

$$a_y = \frac{\Delta v_y}{\Delta t} = \frac{27\text{ m/s}}{1.5\text{ s}} = 18\text{ m/s}^2$$



Constant Acceleration Equations

- We can use the acceleration to find $(v_x)_f$ at a later time t_f.

$$a_x = \frac{\Delta v_x}{\Delta t} = \frac{(v_x)_f - (v_x)_i}{\Delta t}$$

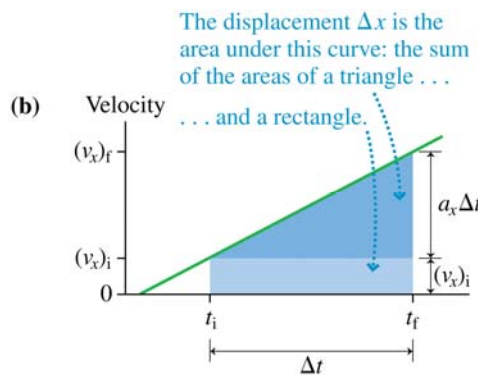
$$(v_x)_f = (v_x)_i + a_x \Delta t$$

Velocity equation for an object with constant acceleration

- We have expressed this equation for motion along the x-axis, but it is a general result that will apply to any axis.

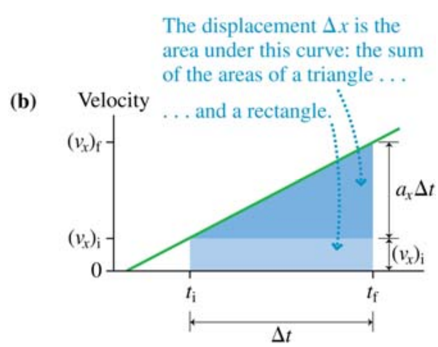
Constant Acceleration Equations

- The velocity-versus-time graph for constant-acceleration motion is a straight line with value $(v_x)_i$ at time t_i and slope a_x.
- The displacement Δx during a time interval Δt is the area under the velocity-versus-time graph shown in the shaded area of the figure.



Slide 2-33

Constant Acceleration Equations



- The shaded area can be subdivided into a rectangle and a triangle. Adding these areas gives

$$x_f = x_i + (v_x)_i\,\Delta t + \tfrac{1}{2}a_x(\Delta t)^2$$

Position equation for an object with constant acceleration

Slide 2-34

Constant Acceleration Equations

- Combining Equation 2.11 with Equation 2.12 gives us a relationship between displacement and velocity:

$$(v_x)_f^2 = (v_x)_i^2 + 2a_x\,\Delta x$$

Relating velocity and displacement for constant-acceleration motion

- Δx in Equation 2.13 is the displacement (not the distance!).

Constant Acceleration Equations

For **motion with constant acceleration**:

- Velocity changes steadily:

Final and initial velocity (m/s)

$$(v_x)_f = (v_x)_i + a_x\Delta t \qquad \textbf{(1)}$$

Acceleration (m/s^2) Time interval (s)

- The position changes as the square of the time interval:

Final and initial position (m) Time interval (s)

$$x_f = x_i + (v_x)_i\,\Delta t + \tfrac{1}{2}a_x(\Delta t)^2 \qquad \textbf{(2)}$$

Initial velocity (m/s) Acceleration (m/s^2)

- We can also express the change in velocity in terms of **distance, not time**:

Final and initial velocity (m/s)

$$(v_x)_f^2 = (v_x)_i^2 + 2a_x\,\Delta x \qquad \textbf{(3)}$$

Acceleration (m/s^2) Change in position (m)

Text: p. 43

Quadratic Relationships

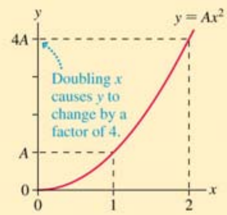
Quadratic relationships

Two quantities are said to have a **quadratic relationship** if y is proportional to the square of x. We write the mathematical relationship as

$$y = Ax^2$$

y is proportional to x^2

The graph of a quadratic relationship is a parabola.



SCALING If x has the initial value x_1, then y has the initial value $y_1 = A(x_1)^2$. Changing x from x_1 to x_2 changes y from y_1 to y_2. The ratio of y_2 to y_1 is

$$\frac{y_2}{y_1} = \frac{A(x_2)^2}{A(x_1)^2} = \left(\frac{x_2}{x_1}\right)^2$$

The ratio of y_2 to y_1 is the square of the ratio of x_2 to x_1. If y is a quadratic function of x, a change in x by some factor changes y by the square of that factor:

- If you increase x by a factor of 2, you increase y by a factor of $2^2 = 4$.
- If you decrease x by a factor of 3, you decrease y by a factor of $3^2 = 9$.

Generally, we can say that:
Changing x by a factor of c changes y by a factor of c^2.

Exercise 19

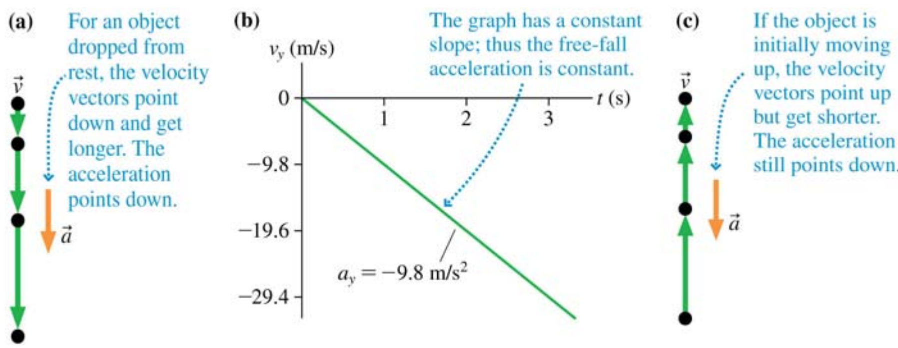
Text: p. 44

Free Fall

- If an object moves under the influence of gravity only, and no other forces, we call the resulting motion **free fall**.
- **Any two objects in free fall, regardless of their mass, have the same acceleration.**
- On the earth, air resistance is a factor. For now we will restrict our attention to situations in which air resistance can be ignored.

Apollo 15 lunar astronaut David Scott performed a classic experiment on the moon, simultaneously dropping a hammer and a feather from the same height. Both hit the ground at the exact same time—something that would not happen in the atmosphere of the earth!

Free Fall



- The figure shows the motion diagram for an object that was released from rest and falls freely. The diagram and the graph would be the same for all falling objects.

Free Fall

- **The free-fall acceleration always points down**, no matter what direction an object is moving.
- Any object moving under the influence of gravity only, and no other force, is in free fall.

$$\vec{a}_{\text{free fall}} = (9.80 \text{ m/s}^2, \text{vertically downward})$$

Standard value for the acceleration of an object in free fall

Free Fall

- g, by definition, is always positive. **There will never be a problem that uses a negative value for g.**
- Even though a falling object speeds up, it has negative acceleration ($-g$).
- Because free fall is motion with constant acceleration, we can use the kinematic equations for constant acceleration with $a_y = -g$.
- g is not called "gravity." g is the *free-fall acceleration*.
- $g = 9.80 \text{ m/s}^2$ only on earth. Other planets have different values of g.
- We will sometimes compute acceleration in units of g.