

## Chapter 2

### ***Kinematics in One Dimension***

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***Kinematics*** deals with the concepts that are needed to describe motion.

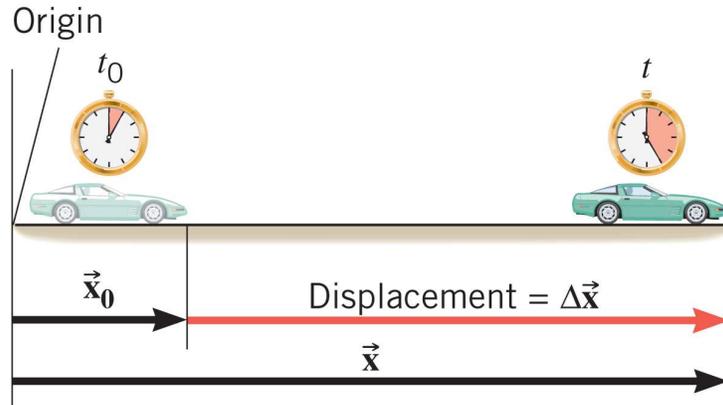
***Dynamics*** deals with the effect that forces have on motion.

Together, kinematics and dynamics form the branch of physics known as ***Mechanics***.

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### 2.1 Displacement



$\vec{x}_0$  = initial position

$\vec{x}$  = final position

$$\Delta\vec{x} = \vec{x} - \vec{x}_0 = \text{displacement}$$

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### 2.1 Displacement

$$\vec{x}_0 = 2.0 \text{ m}$$

$$\Delta\vec{x} = 5.0 \text{ m}$$



$$\vec{x} = 7.0 \text{ m}$$

$$\Delta\vec{x} = \vec{x} - \vec{x}_0 = 7.0 \text{ m} - 2.0 \text{ m} = 5.0 \text{ m}$$

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## 2.1 Displacement

$$\vec{x} = 2.0 \text{ m} \qquad \Delta\vec{x} = -5.0 \text{ m}$$

$$\vec{x}_o = 7.0 \text{ m}$$

$$\Delta\vec{x} = \vec{x} - \vec{x}_o = 2.0 \text{ m} - 7.0 \text{ m} = -5.0 \text{ m}$$

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## 2.1 Displacement

$$\vec{x}_o = -2.0 \text{ m} \qquad \vec{x} = 5.0 \text{ m}$$

$$\Delta\vec{x} = 7.0 \text{ m}$$

$$\Delta\vec{x} = \vec{x} - \vec{x}_o = 5.0 \text{ m} - (-2.0) \text{ m} = 7.0 \text{ m}$$

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## 2.2 Speed and Velocity

**Average speed** is the distance traveled divided by the time required to cover the distance.

$$\text{Average speed} = \frac{\text{Distance}}{\text{Elapsed time}}$$

SI units for speed: **meters per second** (m/s)

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## 2.2 Speed and Velocity

### **Example 1** Distance Run by a Jogger

How far does a jogger run in 1.5 hours (5400 s) if his average speed is 2.22 m/s?

$$\text{Average speed} = \frac{\text{Distance}}{\text{Elapsed time}}$$

$$\begin{aligned} \text{Distance} &= (\text{Average speed})(\text{Elapsed time}) \\ &= (2.22 \text{ m/s})(5400 \text{ s}) = 12000 \text{ m} \end{aligned}$$

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## 2.2 Speed and Velocity

**Average velocity** is the displacement divided by the elapsed time.

$$\text{Average velocity} = \frac{\text{Displacement}}{\text{Elapsed time}}$$

$$\vec{v} = \frac{\vec{x} - \vec{x}_o}{t - t_o} = \frac{\Delta\vec{x}}{\Delta t}$$

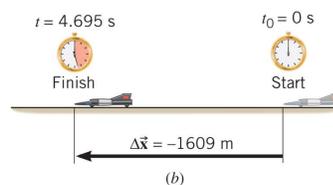
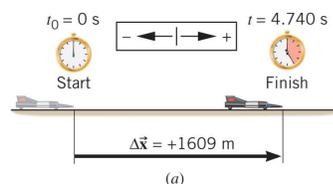
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## 2.2 Speed and Velocity

### Example 2 The World's Fastest Jet-Engine Car

Andy Green in the car *ThrustSSC* set a world record of 341.1 m/s in 1997. To establish such a record, the driver makes two runs through the course, one in each direction, to nullify wind effects. From the data, determine the average velocity for each run.

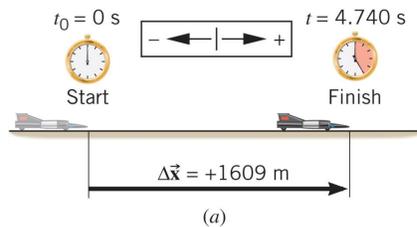


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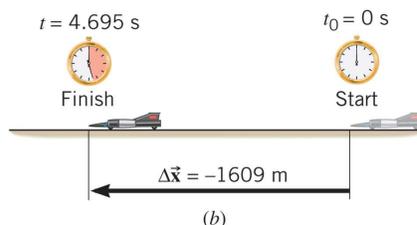
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## 2.2 Speed and Velocity

$$\bar{\mathbf{v}} = \frac{\Delta \bar{\mathbf{x}}}{\Delta t} = \frac{+1609 \text{ m}}{4.740 \text{ s}} = +339.5 \text{ m/s}$$



$$\bar{\mathbf{v}} = \frac{\Delta \bar{\mathbf{x}}}{\Delta t} = \frac{-1609 \text{ m}}{4.695 \text{ s}} = -342.7 \text{ m/s}$$



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## 2.2 Speed and Velocity

The **instantaneous velocity** indicates how fast the car moves and the direction of motion at each instant of time.

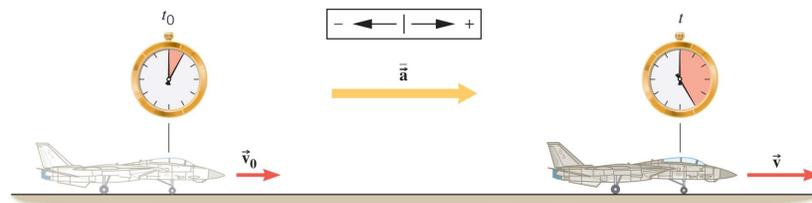
$$\vec{\mathbf{v}} = \lim_{\Delta t \rightarrow 0} \frac{\Delta \vec{\mathbf{x}}}{\Delta t}$$

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### 2.3 Acceleration

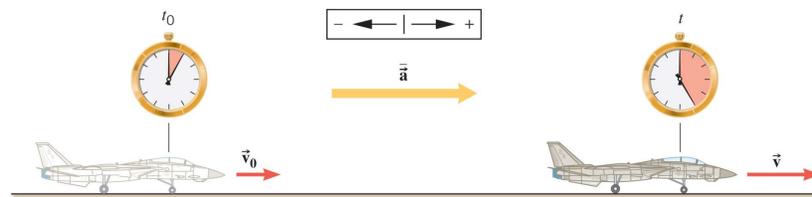
The notion of *acceleration* emerges when a change in velocity is combined with the time during which the change occurs.



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### 2.3 Acceleration



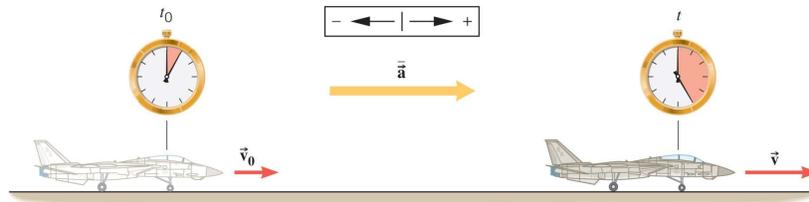
DEFINITION OF AVERAGE ACCELERATION

$$\bar{\mathbf{a}} = \frac{\vec{\mathbf{v}} - \vec{\mathbf{v}}_0}{t - t_0} = \frac{\Delta \vec{\mathbf{v}}}{\Delta t}$$

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### 2.3 Acceleration



#### Example 3 Acceleration and Increasing Velocity

Determine the average acceleration of the plane.

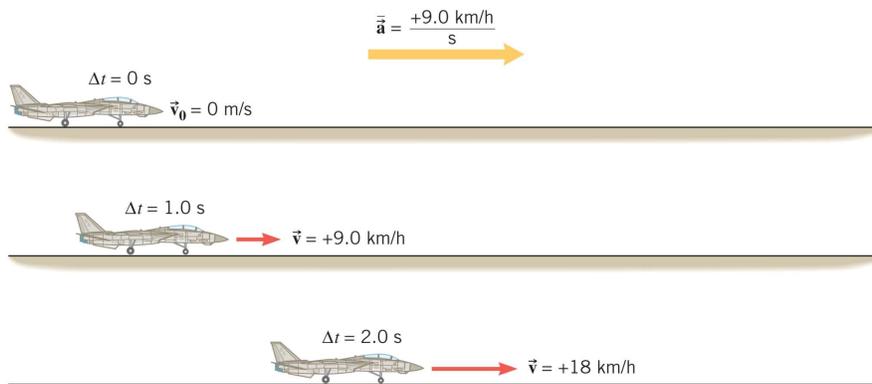
$$\vec{v}_o = 0 \text{ m/s} \quad \vec{v} = 260 \text{ km/h} \quad t_o = 0 \text{ s} \quad t = 29 \text{ s}$$

$$\bar{\mathbf{a}} = \frac{\vec{v} - \vec{v}_o}{t - t_o} = \frac{260 \text{ km/h} - 0 \text{ km/h}}{29 \text{ s} - 0 \text{ s}} = +9.0 \frac{\text{km/h}}{\text{s}}$$

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### 2.3 Acceleration



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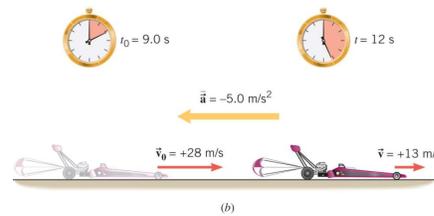
**2.3 Acceleration**

**Example 3** Acceleration and Decreasing Velocity

$$\bar{\mathbf{a}} = \frac{\bar{\mathbf{v}} - \bar{\mathbf{v}}_o}{t - t_o} = \frac{13 \text{ m/s} - 28 \text{ m/s}}{12 \text{ s} - 9 \text{ s}} = -5.0 \text{ m/s}^2$$



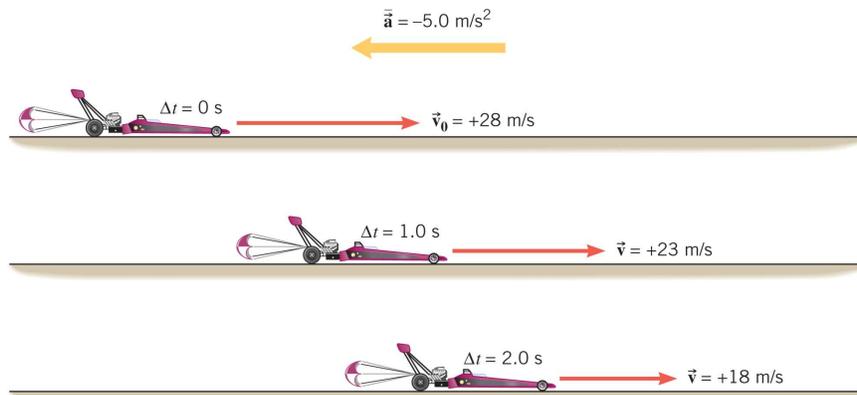
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**2.3 Acceleration**



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### 2.4 Equations of Kinematics for Constant Acceleration

$$\bar{\vec{v}} = \frac{\vec{\mathbf{x}} - \vec{\mathbf{x}}_o}{t - t_o} \qquad \bar{\vec{a}} = \frac{\vec{\mathbf{v}} - \vec{\mathbf{v}}_o}{t - t_o}$$

For one dimensional motion it is customary to dispense with the use of boldface symbols overdrawn with arrows for the displacement, velocity, and acceleration vectors. We will, however, continue to convey the directions with a plus or minus sign.

$$v = \frac{x - x_o}{t - t_o} \qquad a = \frac{v - v_o}{t - t_o}$$

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### 2.4 Equations of Kinematics for Constant Acceleration

Let the object be at the origin when the clock starts.

$$x_o = 0 \qquad t_o = 0$$

$$\bar{v} = \frac{x - x_o}{t - t_o} \quad \longrightarrow \quad \bar{v} = \frac{x}{t}$$



$$x = \bar{v}t = \frac{1}{2}(v_o + v)t$$

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**2.4 Equations of Kinematics for Constant Acceleration**

$$a = \frac{v - v_o}{t - t_o} \quad \Rightarrow \quad a = \frac{v - v_o}{t}$$
$$\Downarrow$$
$$at = v - v_o$$
$$\Downarrow$$
$$v = v_o + at$$

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**2.4 Equations of Kinematics for Constant Acceleration**

Five kinematic variables:

1. displacement,  $x$
2. acceleration (constant),  $a$
3. final velocity (at time  $t$ ),  $v$
4. initial velocity,  $v_o$
5. elapsed time,  $t$

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### 2.4 Equations of Kinematics for Constant Acceleration

$$v = v_o + at$$



$$x = \frac{1}{2}(v_o + v)t = \frac{1}{2}(v_o + v_o + at)t$$

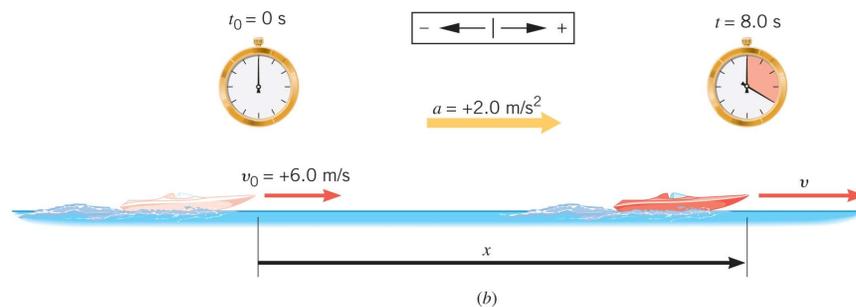


$$x = v_o t + \frac{1}{2} at^2$$

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### 2.4 Equations of Kinematics for Constant Acceleration

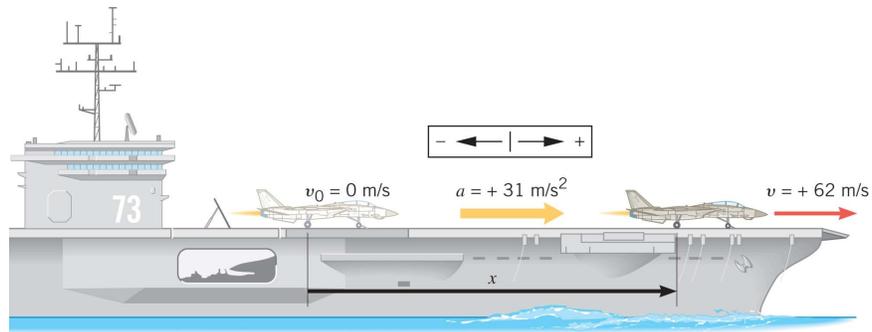


$$\begin{aligned} x &= v_o t + \frac{1}{2} at^2 \\ &= (6.0 \text{ m/s})(8.0 \text{ s}) + \frac{1}{2} (2.0 \text{ m/s}^2)(8.0 \text{ s})^2 \\ &= +110 \text{ m} \end{aligned}$$

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## 2.4 Equations of Kinematics for Constant Acceleration



(b)

### Example 6 Catapulting a Jet

Find its displacement.

$$v_o = 0 \text{ m/s}$$

$$a = +31 \text{ m/s}^2$$

$$x = ??$$

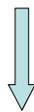
$$v = +62 \text{ m/s}$$

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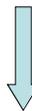
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## 2.4 Equations of Kinematics for Constant Acceleration

$$a = \frac{v - v_o}{t} \quad \Rightarrow \quad t = \frac{v - v_o}{a}$$



$$x = \frac{1}{2}(v_o + v)t = \frac{1}{2}(v_o + v) \frac{(v - v_o)}{a}$$

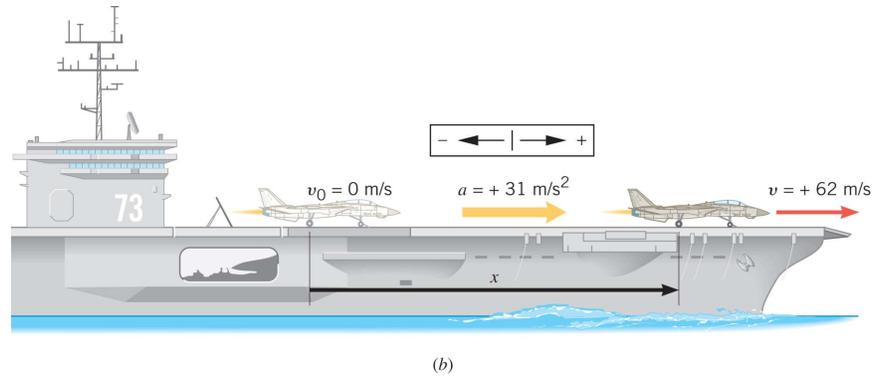


$$x = \frac{v^2 - v_o^2}{2a}$$

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### 2.4 Equations of Kinematics for Constant Acceleration



$$x = \frac{v^2 - v_0^2}{2a} = \frac{(62 \text{ m/s})^2 - (0 \text{ m/s})^2}{2(31 \text{ m/s}^2)} = +62 \text{ m}$$

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### 2.4 Equations of Kinematics for Constant Acceleration

Equations of Kinematics for Constant Acceleration

$$v = v_0 + at$$

$$x = \frac{1}{2}(v_0 + v)t$$

$$v^2 = v_0^2 + 2ax$$

$$x = v_0 t + \frac{1}{2}at^2$$

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### 2.5 Applications of the Equations of Kinematics

#### Reasoning Strategy

1. Make a drawing.
2. Decide which directions are to be called positive (+) and negative (-).
3. Write down the values that are given for any of the five kinematic variables.
4. Verify that the information contains values for at least three of the five kinematic variables. Identify the desired unknown variable and select the appropriate equation.
5. When the motion is divided into segments, remember that the final velocity of one segment is the initial velocity for the next.
6. Keep in mind that there may be two possible answers to a kinematics problem.

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### 2.5 Applications of the Equations of Kinematics

#### Example 8 An Accelerating Spacecraft

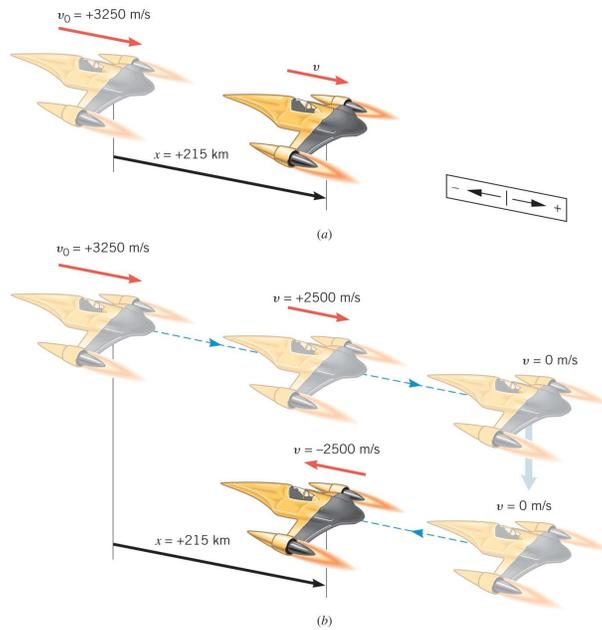
A spacecraft is traveling with a velocity of +3250 m/s. Suddenly the retrorockets are fired, and the spacecraft begins to slow down with an acceleration whose magnitude is  $10.0 \text{ m/s}^2$ . What is the velocity of the spacecraft when the displacement of the craft is +215 km, relative to the point where the retrorockets began firing?

$x$	$a$	$v$	$v_o$	$t$
+215000 m	-10.0 m/s <sup>2</sup>	?	+3250 m/s	

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### 2.5 Applications of the Equations of Kinematics



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### 2.5 Applications of the Equations of Kinematics

$x$	$a$	$v$	$v_o$	$t$
+215000 m	-10.0 m/s <sup>2</sup>	?	+3250 m/s	

$$v^2 = v_o^2 + 2ax \longrightarrow v = \sqrt{v_o^2 + 2ax}$$

$$v = \pm \sqrt{(3250 \text{ m/s})^2 + 2(-10.0 \text{ m/s}^2)(215000 \text{ m})}$$

$$= \pm 2500 \text{ m/s}$$

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### 2.6 Freely Falling Bodies

In the absence of air resistance, it is found that all bodies at the same location above the Earth fall vertically with the same acceleration. If the distance of the fall is small compared to the radius of the Earth, then the acceleration remains essentially constant throughout the descent.

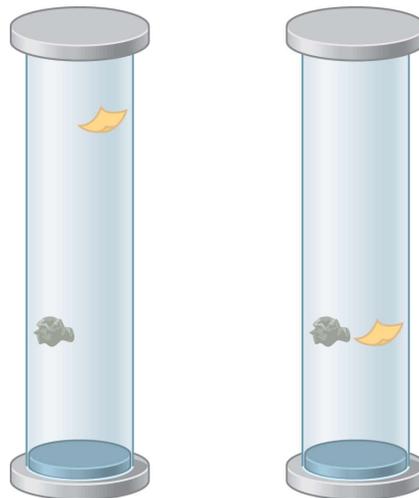
This idealized motion is called *free-fall* and the acceleration of a freely falling body is called the *acceleration due to gravity*.

$$g = 9.80 \text{ m/s}^2 \quad \text{or} \quad 32.2 \text{ ft/s}^2$$

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### 2.6 Freely Falling Bodies



Air-filled  
tube  
(a)

Evacuated  
tube  
(b)

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

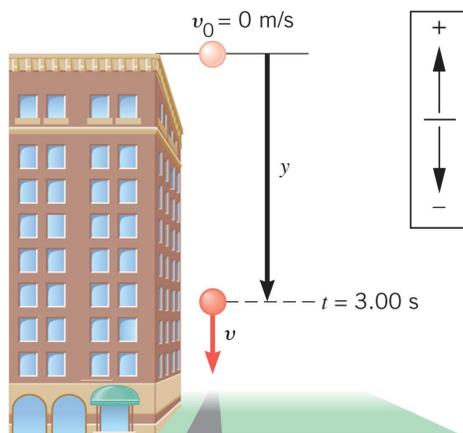
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## 2.6 Freely Falling Bodies

### Example 10 A Falling Stone

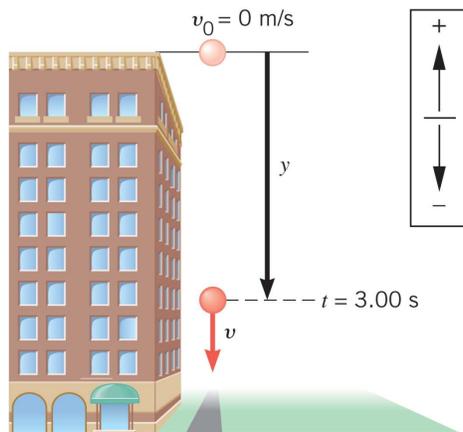
A stone is dropped from the top of a tall building. After 3.00s of free fall, what is the displacement  $y$  of the stone?



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## 2.6 Freely Falling Bodies



$y$	$a$	$v$	$v_0$	$t$
?	$-9.80 \text{ m/s}^2$		$0 \text{ m/s}$	$3.00 \text{ s}$

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## 2.6 Freely Falling Bodies

$y$	$a$	$v$	$v_o$	$t$
?	-9.80 m/s <sup>2</sup>		0 m/s	3.00 s

$$\begin{aligned}
 y &= v_o t + \frac{1}{2} a t^2 \\
 &= (0 \text{ m/s})(3.00 \text{ s}) + \frac{1}{2} (-9.80 \text{ m/s}^2)(3.00 \text{ s})^2 \\
 &= -44.1 \text{ m}
 \end{aligned}$$

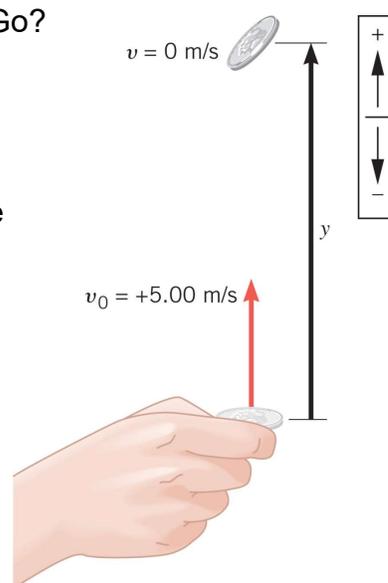
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## 2.6 Freely Falling Bodies

**Example 12** How High Does it Go?

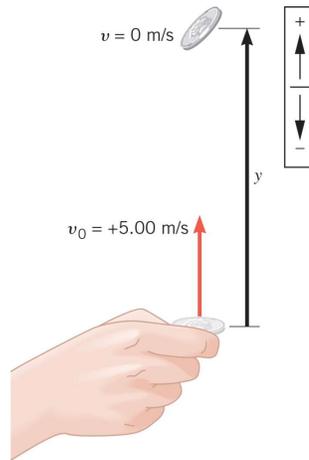
The referee tosses the coin up with an initial speed of 5.00 m/s. In the absence of air resistance, how high does the coin go above its point of release?



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## 2.6 Freely Falling Bodies



$y$	$a$	$v$	$v_o$	$t$
?	$-9.80 \text{ m/s}^2$	$0 \text{ m/s}$	$+5.00 \text{ m/s}$	

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## 2.6 Freely Falling Bodies

$y$	$a$	$v$	$v_o$	$t$
?	$-9.80 \text{ m/s}^2$	$0 \text{ m/s}$	$+5.00 \text{ m/s}$	

$$v^2 = v_o^2 + 2ay \quad \Rightarrow \quad y = \frac{v^2 - v_o^2}{2a}$$

$$y = \frac{v^2 - v_o^2}{2a} = \frac{(0 \text{ m/s})^2 - (5.00 \text{ m/s})^2}{2(-9.80 \text{ m/s}^2)} = 1.28 \text{ m}$$

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## 2.6 Freely Falling Bodies

### Conceptual Example 14 Acceleration Versus Velocity

There are three parts to the motion of the coin. On the way up, the coin has a vector velocity that is directed upward and has decreasing magnitude. At the top of its path, the coin momentarily has zero velocity. On the way down, the coin has downward-pointing velocity with an increasing magnitude.

In the absence of air resistance, does the acceleration of the coin, like the velocity, change from one part to another?

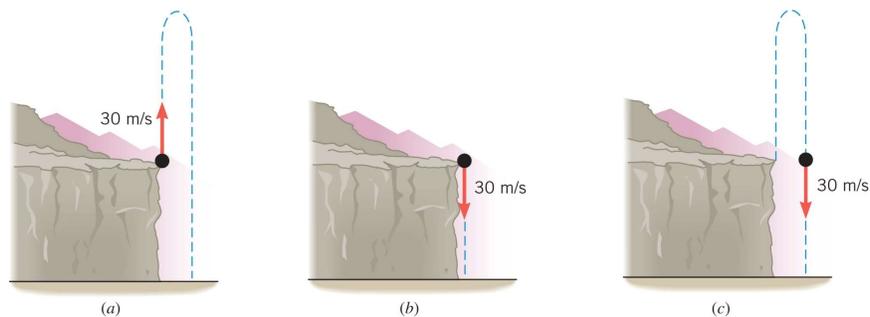
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## 2.6 Freely Falling Bodies

### Conceptual Example 15 Taking Advantage of Symmetry

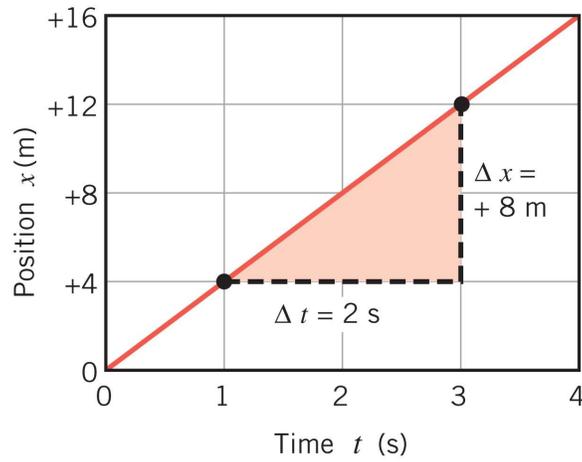
Does the pellet in part *b* strike the ground beneath the cliff with a smaller, greater, or the same speed as the pellet in part *a*?



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**2.7 Graphical Analysis of Velocity and Acceleration**

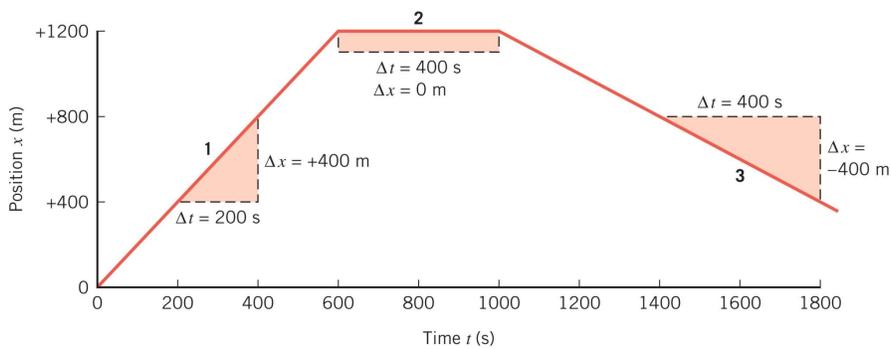
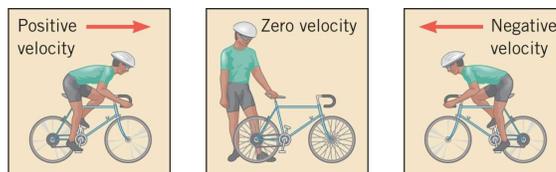


$$\text{Slope} = \frac{\Delta x}{\Delta t} = \frac{+8 \text{ m}}{2 \text{ s}} = +4 \text{ m/s}$$

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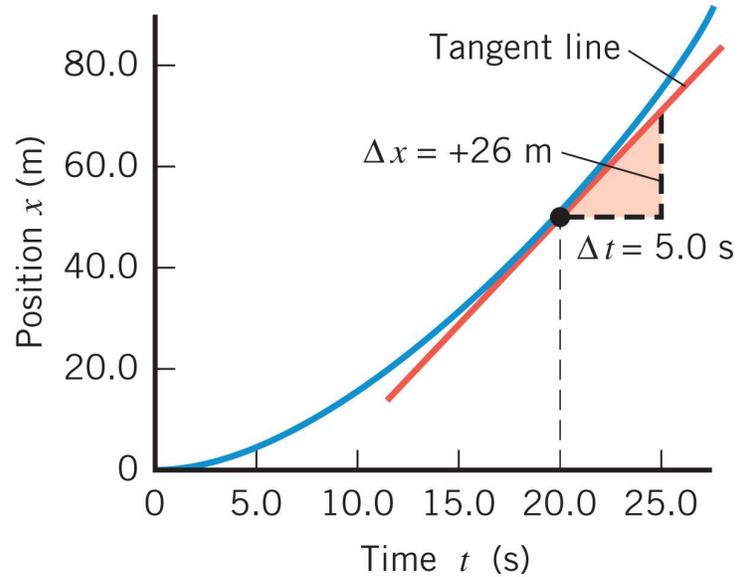
**2.7 Graphical Analysis of Velocity and Acceleration**



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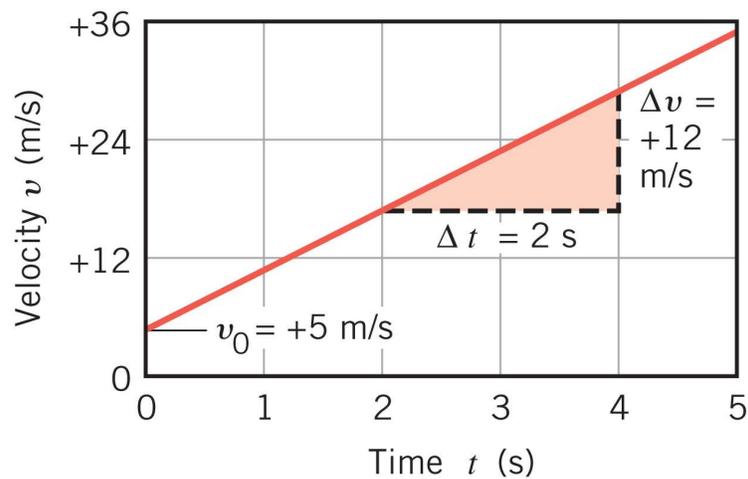
### 2.7 Graphical Analysis of Velocity and Acceleration



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### 2.7 Graphical Analysis of Velocity and Acceleration



$$\text{Slope} = \frac{\Delta v}{\Delta t} = \frac{+12 \text{ m/s}}{2 \text{ s}} = +6 \text{ m/s}^2$$

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