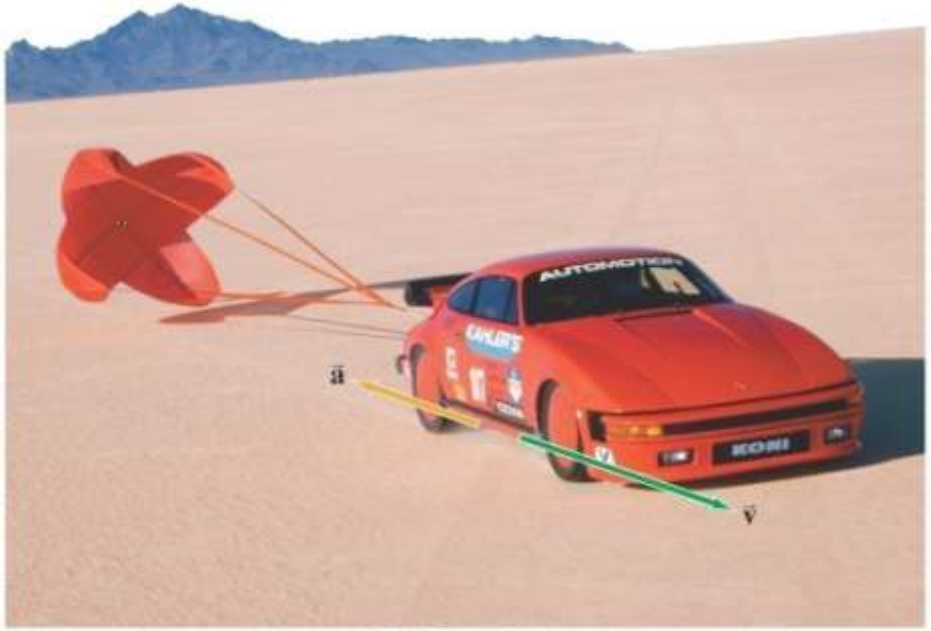
Chapter 2

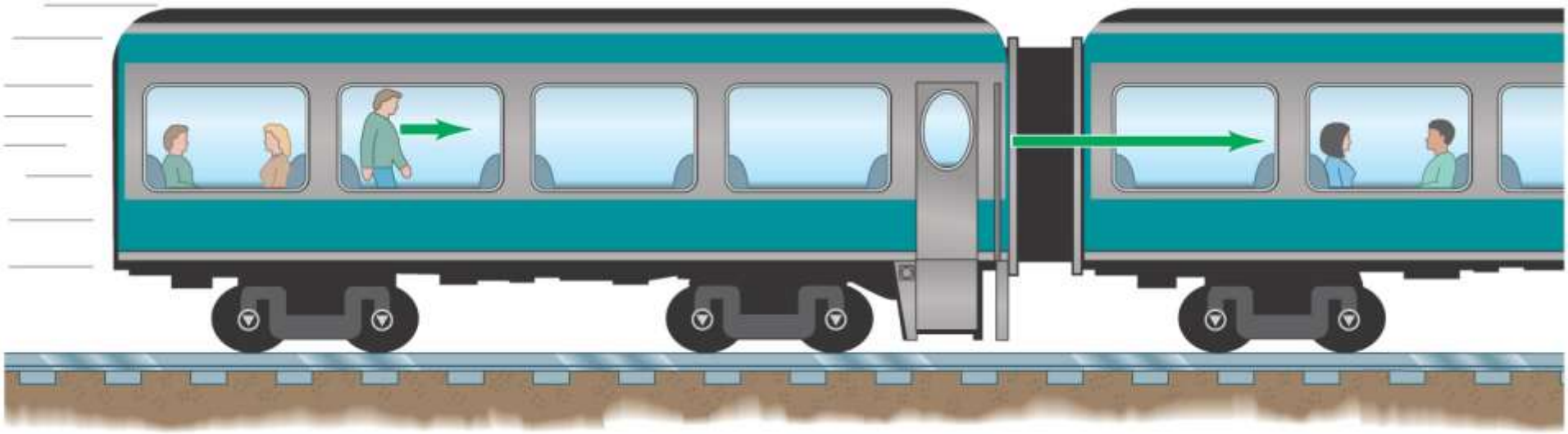
Describing Motion: Kinematics in One Dimension



2-1 Reference Frames and Displacement

Any measurement of position, distance, or speed must be made with respect to a reference frame.

For example, if you are sitting on a train and someone walks down the aisle, their speed with respect to the train is a few miles per hour, at most. Their speed with respect to the ground is much higher.



2-1 Reference Frames and Displacement

Jamiroquai
"Virtual Insanity"
Travelling Without Moving
1997 Video of the Year

2-1 Reference Frames and Displacement

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"Virtual Insanity"
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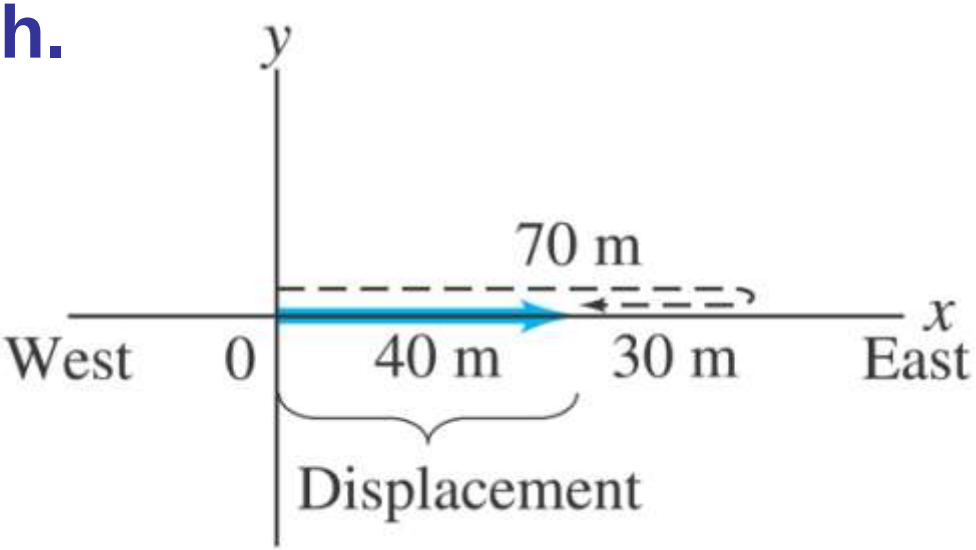
2-1 Reference Frames and Displacement

We make a distinction between distance and displacement.

Displacement (blue line) is how far the object is from its starting point, regardless of how it got there.

Distance traveled (dashed line) is measured along the actual path.

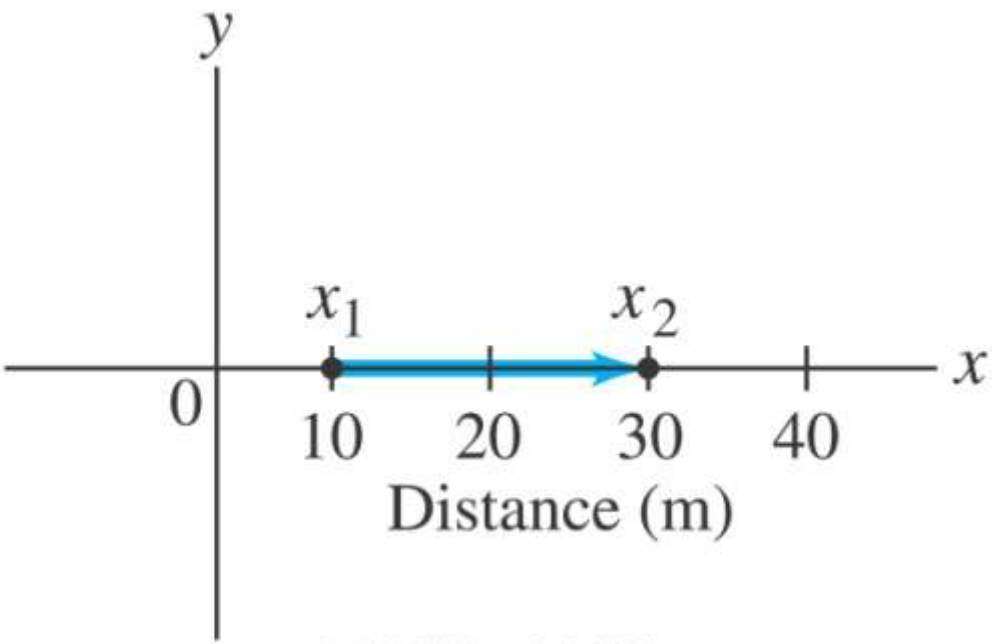


2-1 Reference Frames and Displacement

The displacement is written: $\Delta x = x_2 - x_1$

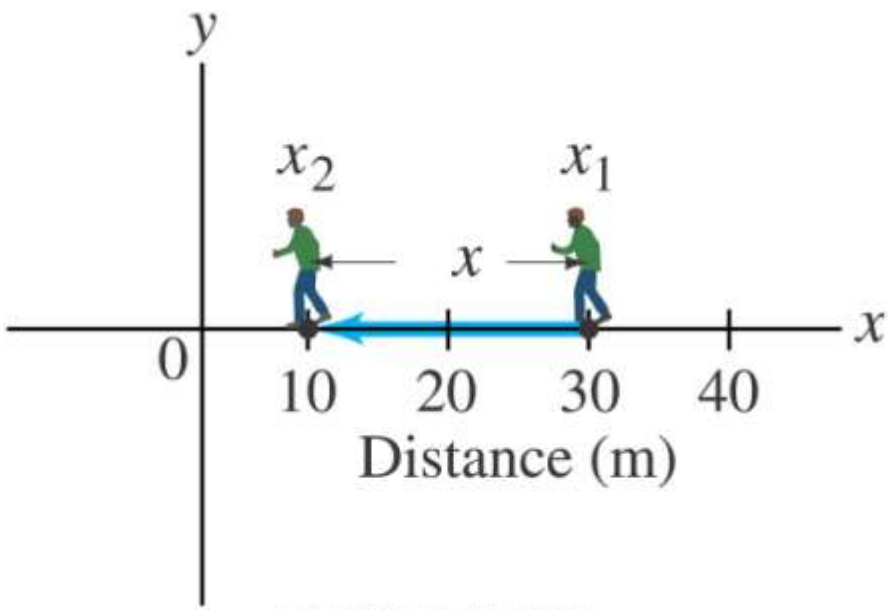
Left:

Displacement is positive.



Right:

Displacement is negative.



2-2 Average Velocity

Speed: how far an object travels in a given time interval

$$\text{average speed} = \frac{\text{distance traveled}}{\text{time elapsed}} \qquad \textbf{(2-1)}$$

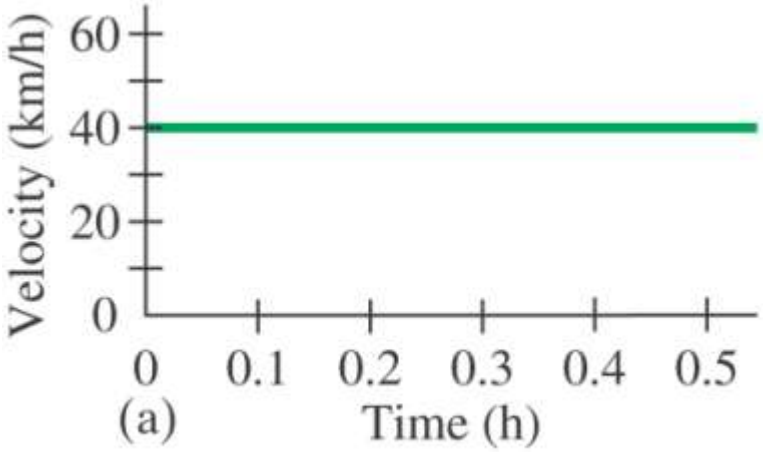
Velocity includes directional information:

$$\text{average velocity} = \frac{\text{displacement}}{\text{time elapsed}}$$

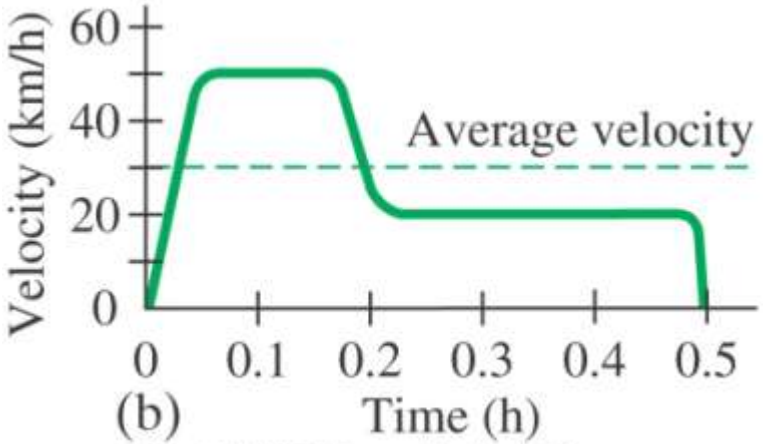
2-3 Instantaneous Velocity

The instantaneous velocity is the average velocity, in the limit as the time interval becomes infinitesimally short.

$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} \qquad \textbf{(2-3)}$$



These graphs show (a) constant velocity and (b) varying velocity.



Conceptual Review

- In an unusual move by the New York State Department of Transportation, all of the "speed limit" signs were replaced with "velocity limit" signs.
  - What would such a sign look like?
  - How could one travel faster than the old speed limit without violating the new velocity limit?

Conceptual Review

- Which device(s) on a car can be used to change …
  - –its speed?
  - –its velocity but not its speed?

Conceptual Review

- A car driving on a circular test track shows a constant speedometer reading of 100 kph for one lap.
  - Describe the car's speed during this time.
  - Describe its velocity.
  - How do the speed and velocity compare?

Conceptual Review

- Is it possible for an object to have …
  - constant speed and changing velocity,
  - changing speed and constant velocity?

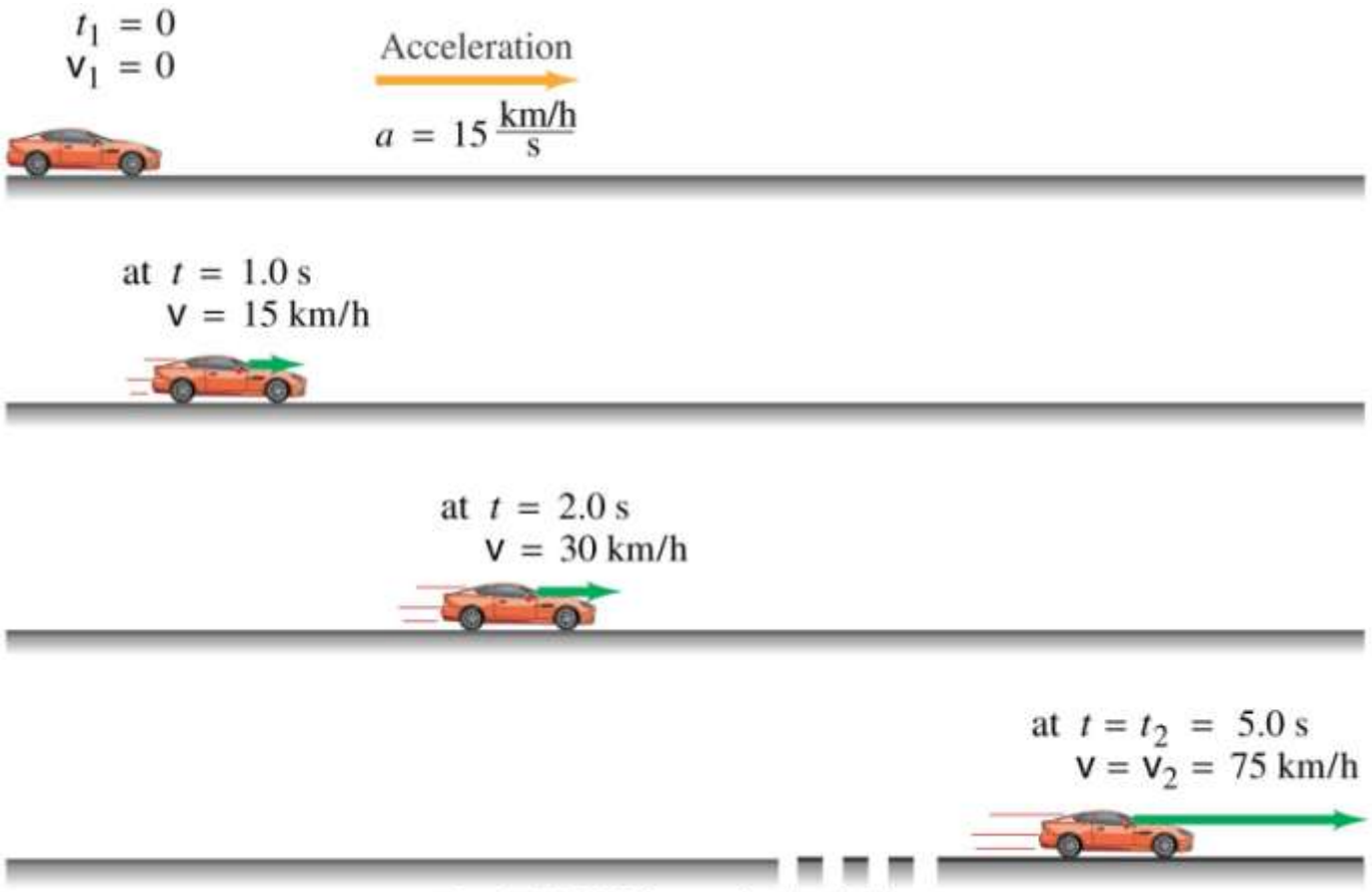
Conceptual Review

- Why are the devices in cars called speedometers and not velocitometers?

2-4 Acceleration

Acceleration is the rate of change of velocity.

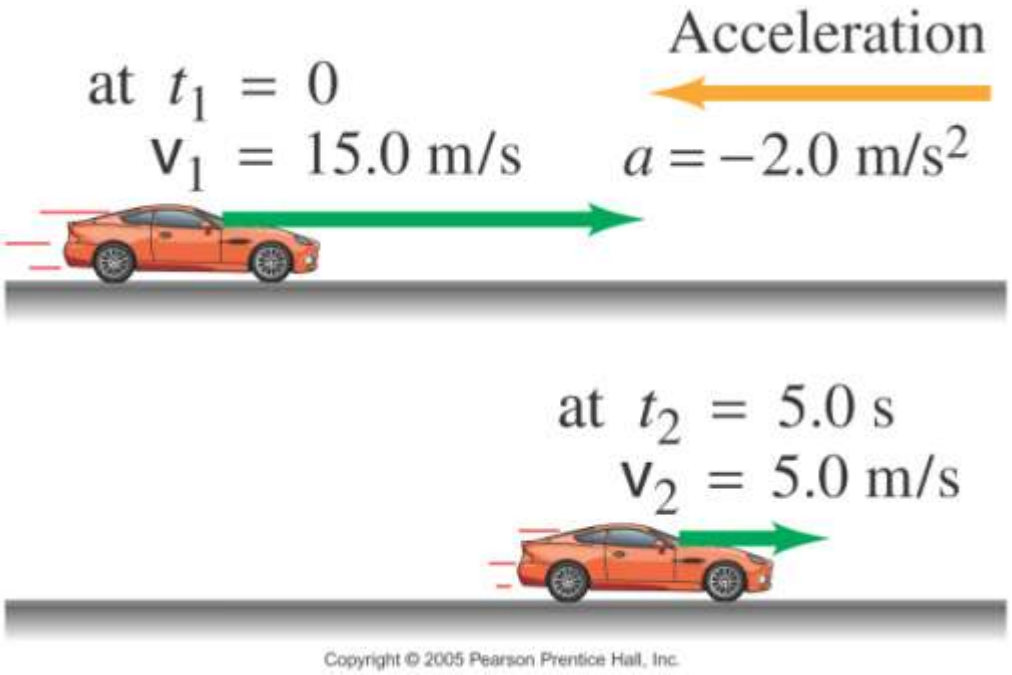
$$\text{average acceleration} = \frac{\text{change of velocity}}{\text{time elapsed}}$$



2-4 Acceleration

Acceleration is a vector, although in one-dimensional motion we only need the sign.

The previous image shows positive acceleration; here is negative acceleration:

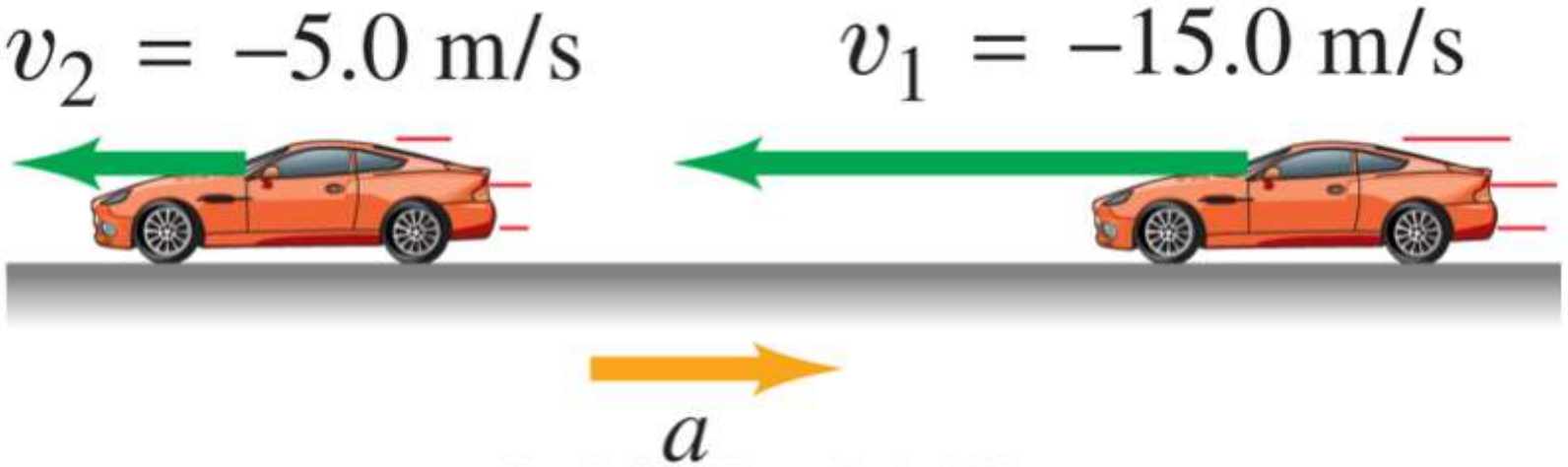


2-4 Acceleration

There is a difference between negative acceleration and deceleration:

Negative acceleration is acceleration in the negative direction as defined by the coordinate system.

Deceleration occurs when the acceleration is opposite in direction to the velocity.



2-4 Acceleration

The instantaneous acceleration is the average acceleration, in the limit as the time interval becomes infinitesimally short.

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} \qquad \textbf{(2-5)}$$

2-5 Motion at Constant Acceleration

The average velocity of an object during a time interval *t* is

$$\bar{v} = \frac{x - x_0}{t - t_0} = \frac{x - x_0}{t}$$

The acceleration, assumed constant, is

$$a = \frac{v - v_0}{t}$$

2-5 Motion at Constant Acceleration

In addition, as the velocity is increasing at a constant rate, we know that

$$\bar{v} = \frac{v_0 + v}{2} \qquad \textbf{(2-8)}$$

Combining these last three equations, we find:

$$x = x_0 + v_0 t + \tfrac{1}{2} a t^2 \qquad \textbf{(2-9)}$$

2-5 Motion at Constant Acceleration

We can also combine these equations so as to eliminate *t*:

$$v^2 = v_0^2 + 2a(x - x_0) \qquad \textbf{(2-10)}$$

We now have all the equations we need to solve constant-acceleration problems.

$$v = v_0 + at \qquad \textbf{(2-11a)}$$

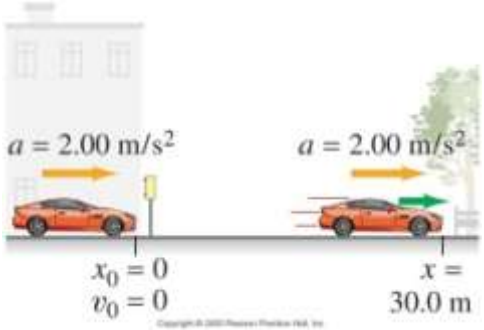
$$x = x_0 + v_0 t + \tfrac{1}{2}at^2 \qquad \textbf{(2-11b)}$$

$$v^2 = v_0^2 + 2a(x - x_0) \qquad \textbf{(2-11c)}$$

$$\bar{v} = \frac{v + v_0}{2}. \qquad \textbf{(2-11d)}$$

2-6 Solving Problems

1. Read the whole problem and make sure you understand it. Then read it again.
2. Decide on the objects under study and what the time interval is.
3. Draw a diagram and choose coordinate axes.
4. Write down the known (given) quantities, and then the unknown ones that you need to find.
5. What physics applies here? Plan an approach to a solution.



2-6 Solving Problems

6. Which equations relate the known and unknown quantities? Are they valid in this situation? Solve algebraically for the unknown quantities, and check that your result is sensible (correct dimensions).

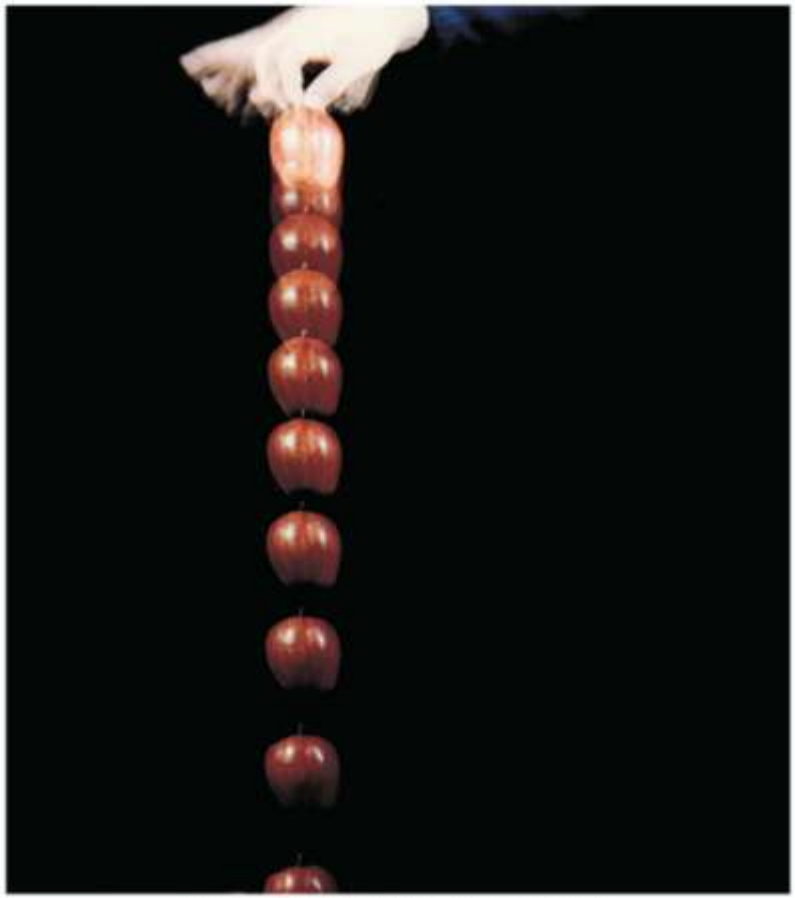
7. Calculate the solution and round it to the appropriate number of significant figures.

8. Look at the result – is it reasonable? Does it agree with a rough estimate?

9. Check the units again.

2-7 Falling Objects

Near the surface of the Earth, all objects experience approximately the same acceleration due to gravity.



This is one of the most common examples of motion with constant acceleration.

2-7 Falling Objects

(a) (b)

In the absence of air resistance, all objects fall with the same acceleration, although this may be hard to tell by testing in an environment where there is air resistance.

2-7 Falling Objects

Coin and Feather Movie

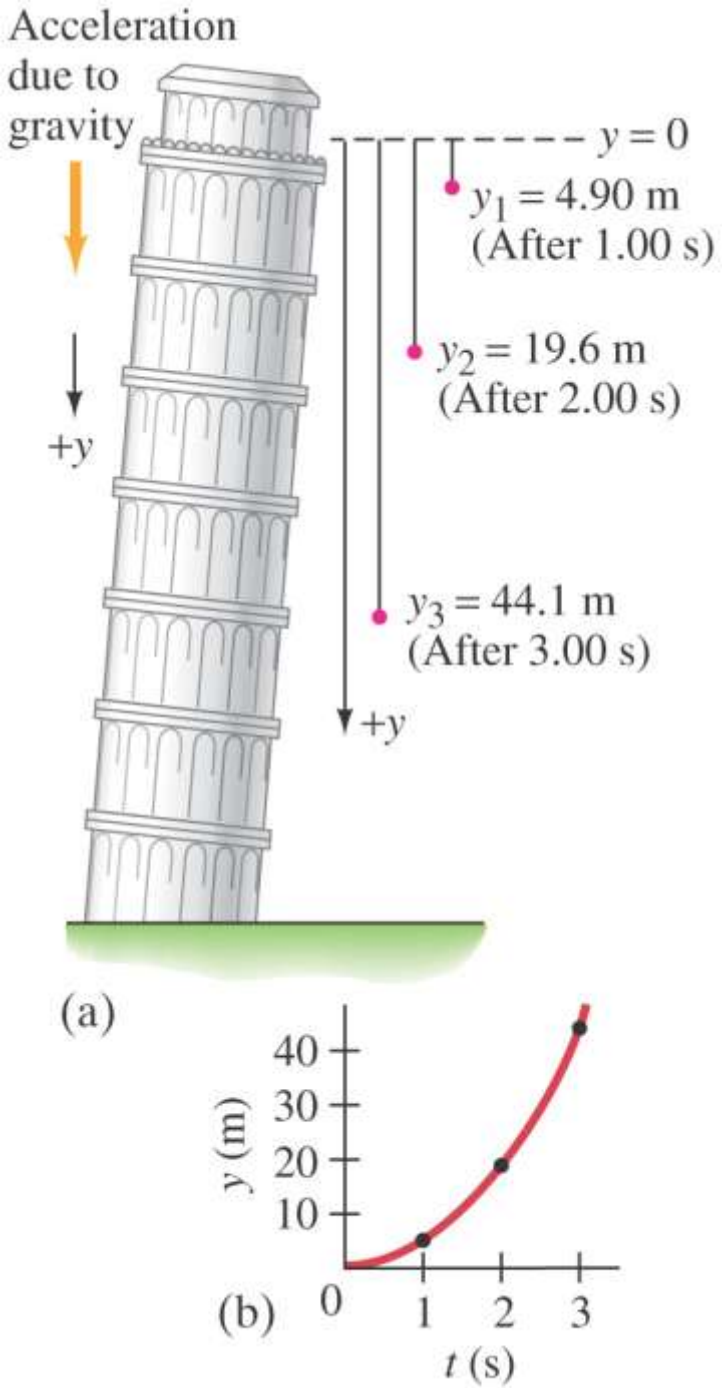
2-7 Falling Objects

Time for a Gizmo!

2-7 Falling Objects

Feather and Hammer on the Moon Movie

2-7 Falling Objects



The acceleration due to gravity at the Earth's surface is approximately 9.80 m/s^2.

Conceptual Review

- Which device(s) on a car can be used to control its acceleration?

Conceptual Review

- Describe a situation when an object has …
  - zero velocity, but non-zero acceleration
  - zero acceleration, but non-zero velocity

Relative Motion…one more time

OK Go

“Here It Goes Again”

Oh No

2007 Grammy award for "Best Short-Form Music Video”

Relative Motion…one more time

OK Go

“Here It Goes Again”

Oh No

2007 Grammy award for "Best Short-Form Music Video”

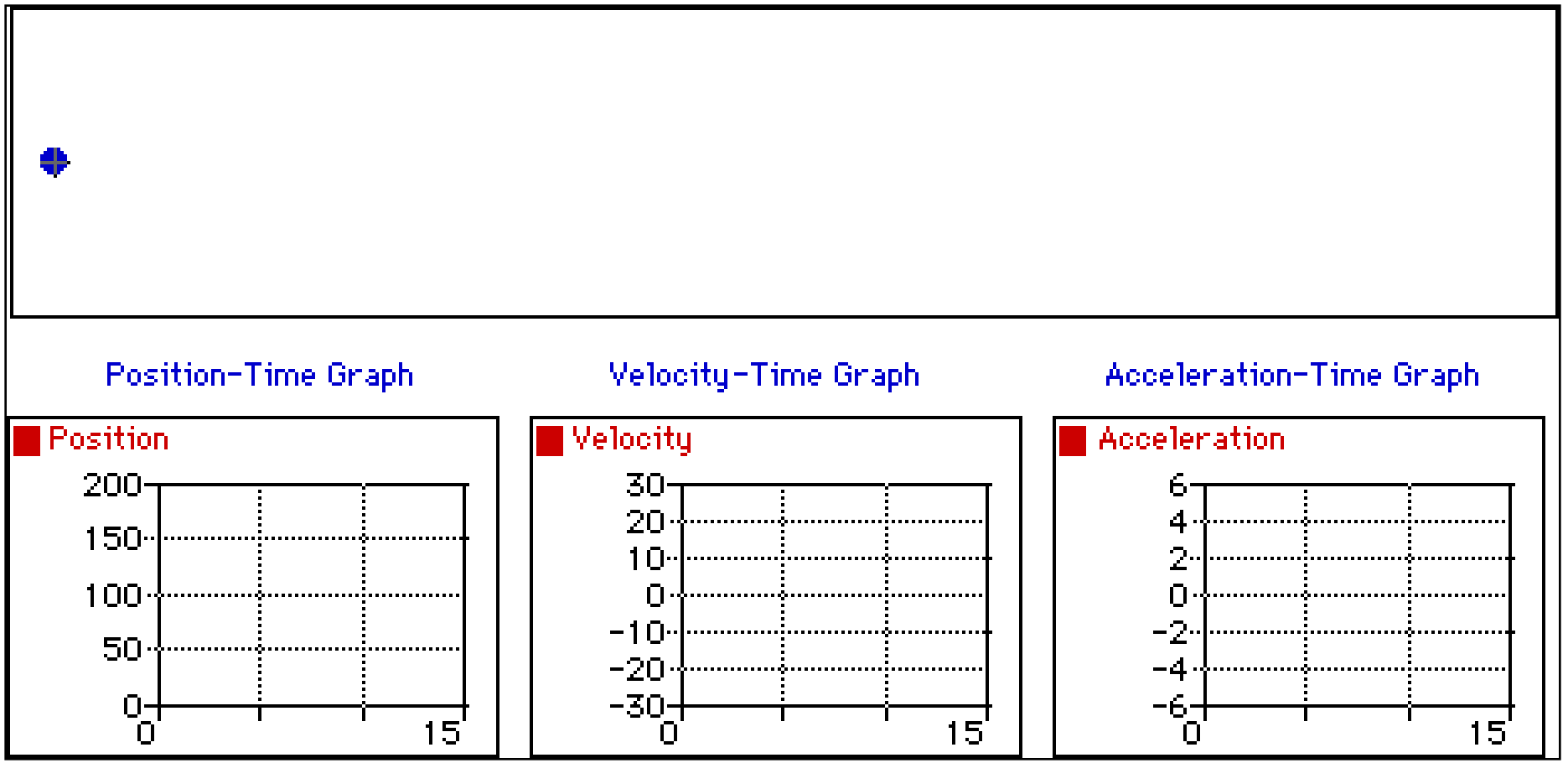
2-8 Graphical Analysis of Linear Motion

On a displacement vs. time graph the slope of the line is equal to the velocity of the object.

On a velocity vs. time graph the slope of the line is equal to the acceleration of the object.

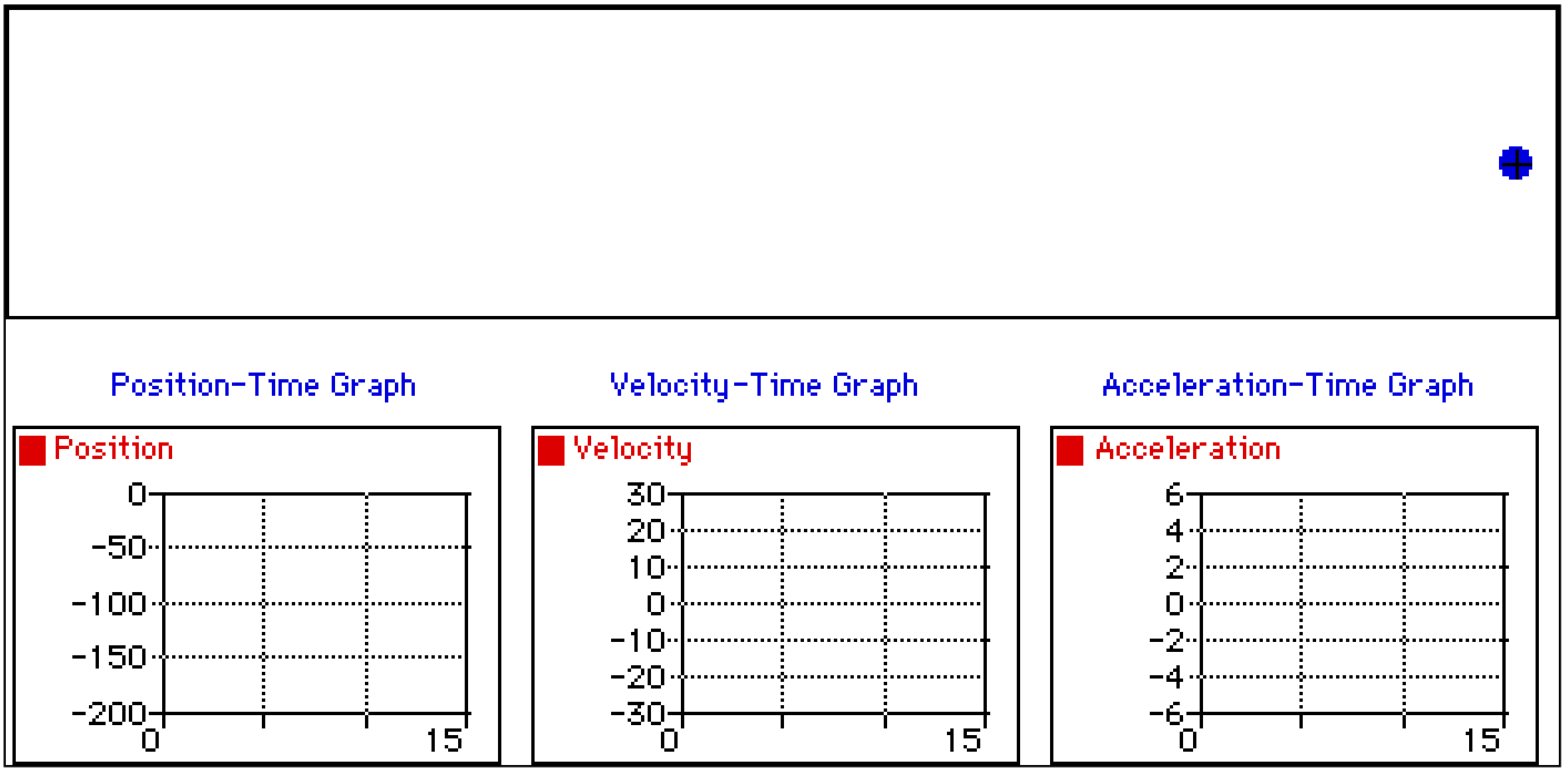
On a velocity vs. time graph the area underneath the curve is equal to the displacement of the object.

2-8 Graphical Analysis of Linear Motion



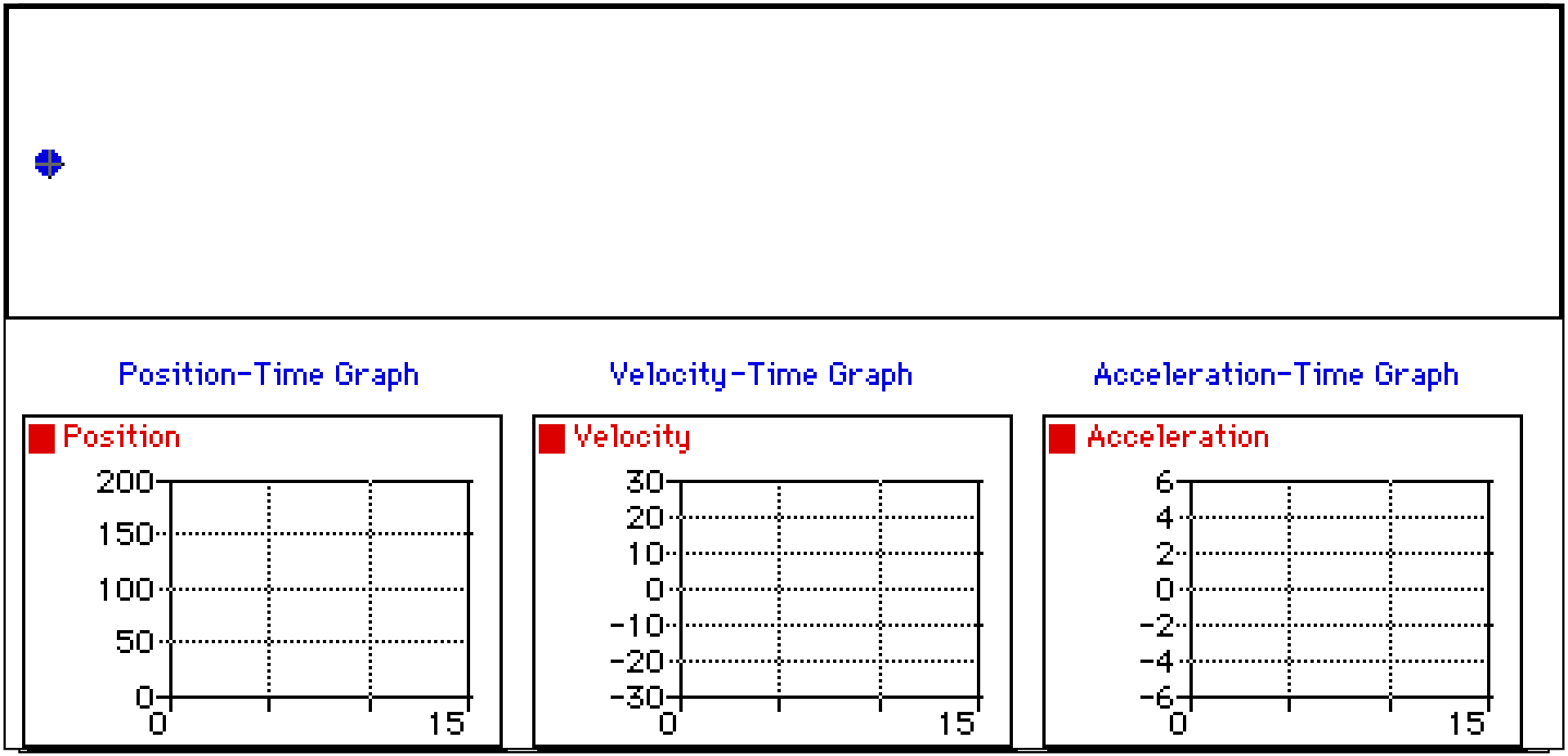
An object traveling with a constant positive velocity

2-8 Graphical Analysis of Linear Motion



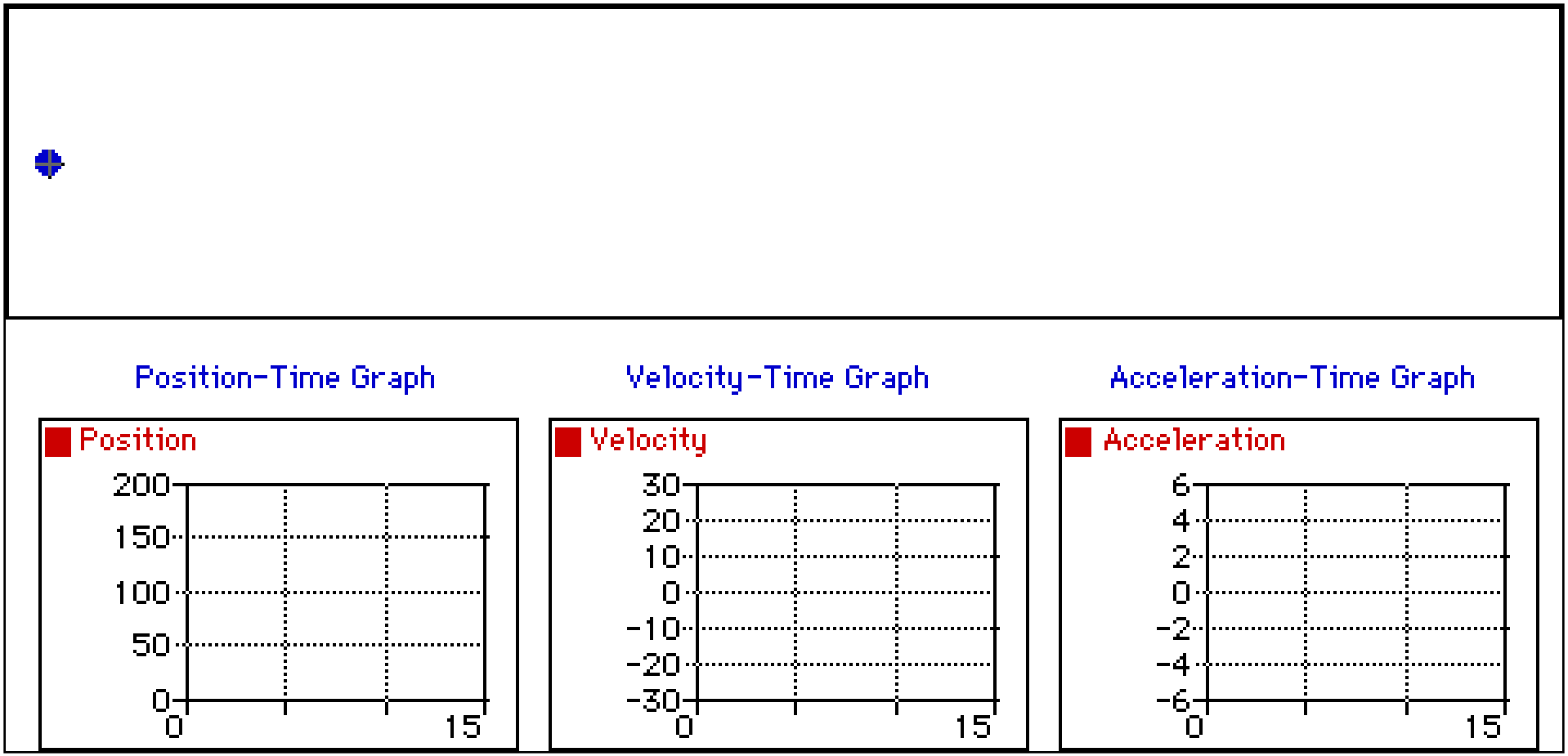
An object traveling with a constant negative velocity

2-8 Graphical Analysis of Linear Motion



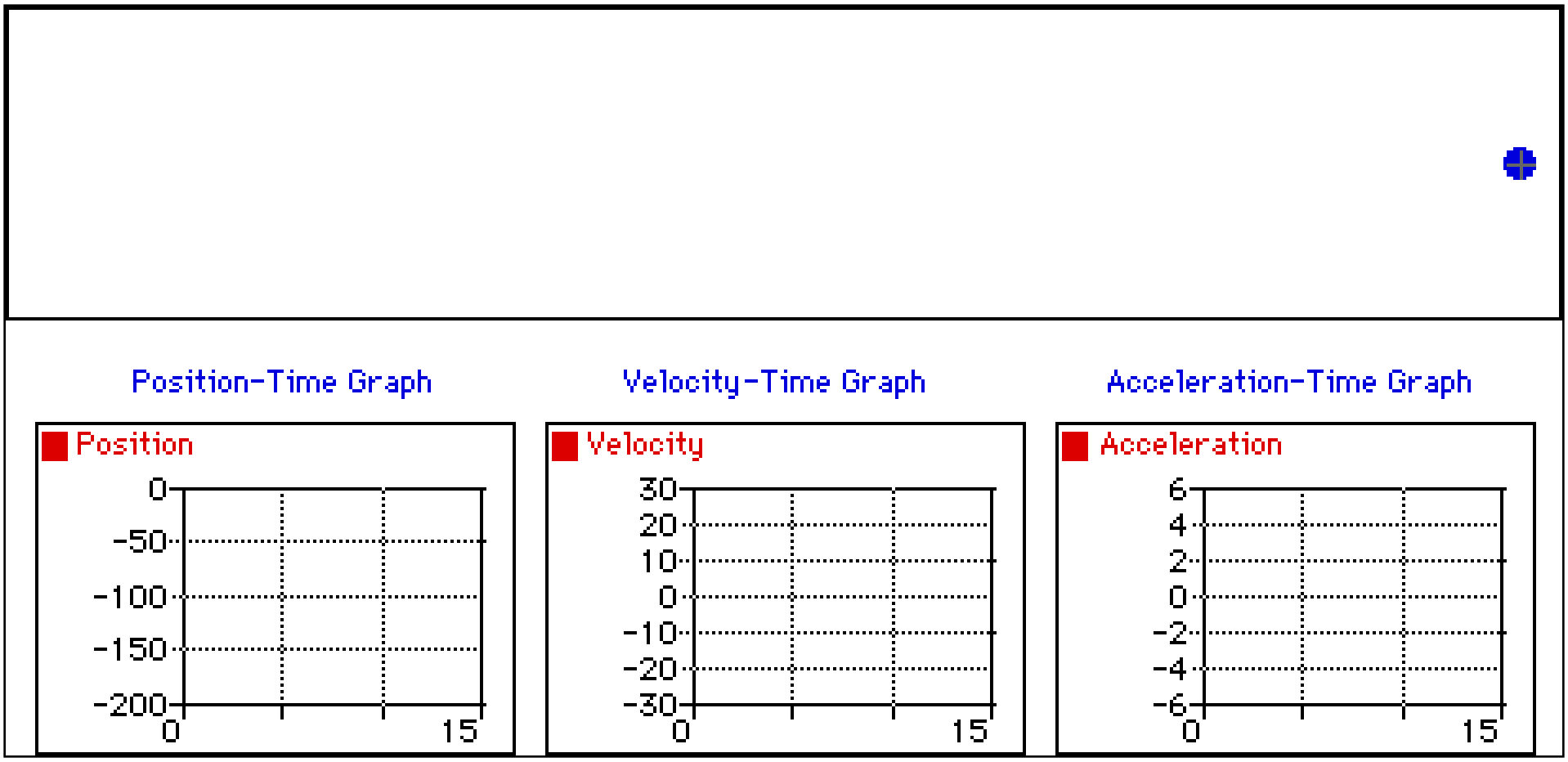
An object traveling with a positive velocity, positive acceleration.

2-8 Graphical Analysis of Linear Motion



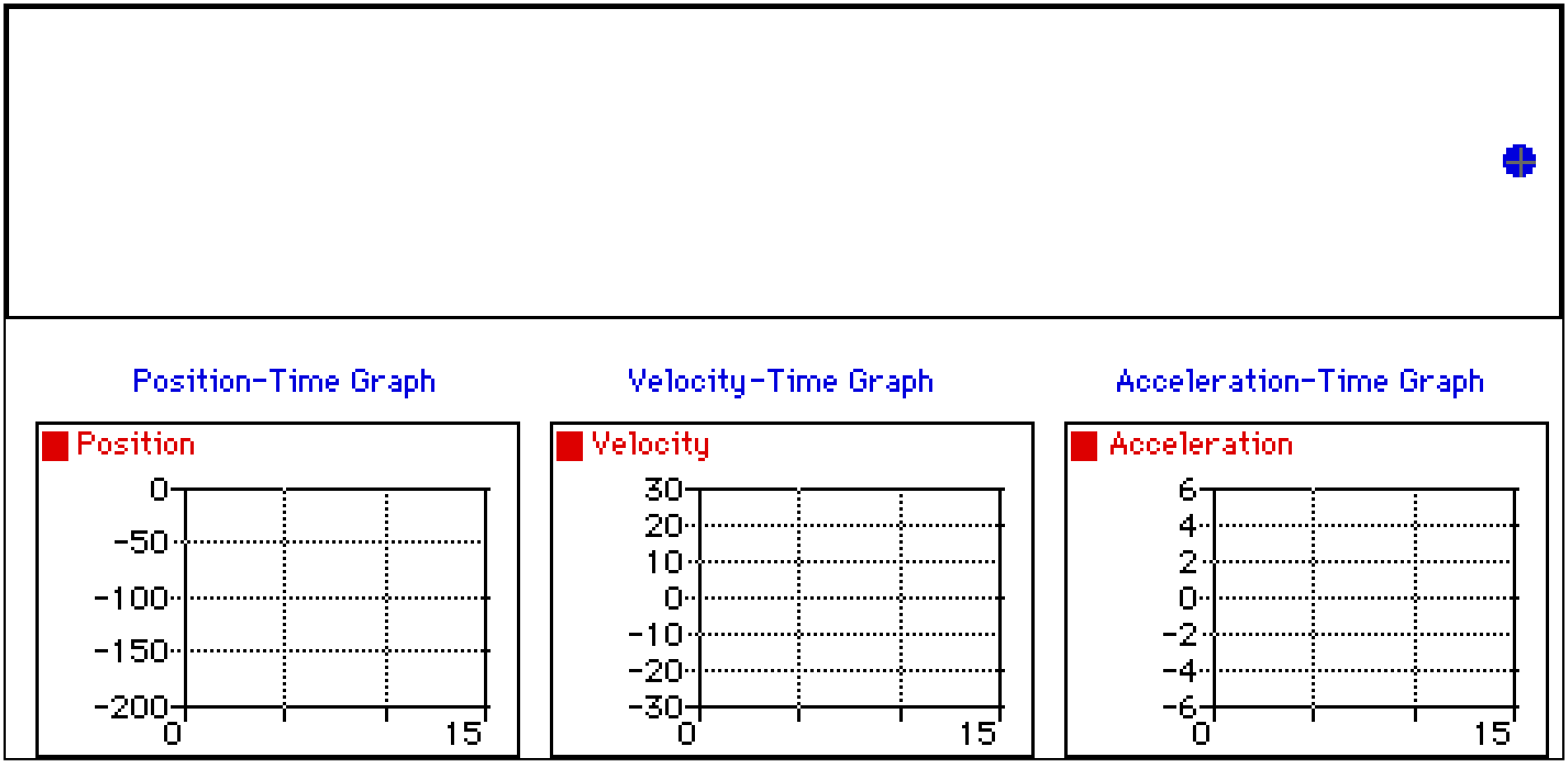
An object traveling with a positive velocity, negative acceleration.

2-8 Graphical Analysis of Linear Motion



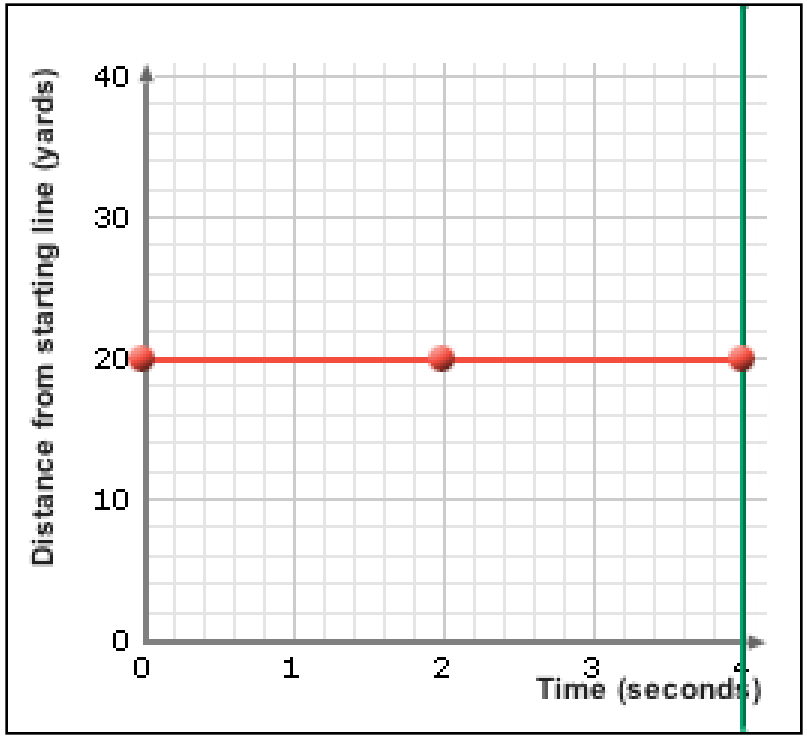
An object traveling with a negative velocity, negative acceleration.

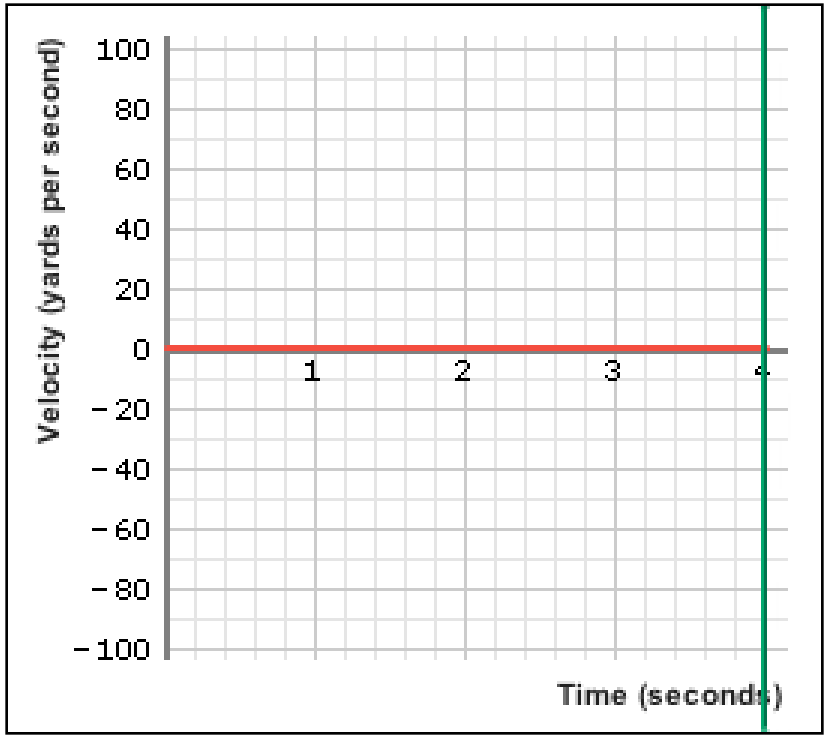
2-8 Graphical Analysis of Linear Motion



An object traveling with a negative velocity, positive acceleration.

2-8 Graphical Analysis of Linear Motion

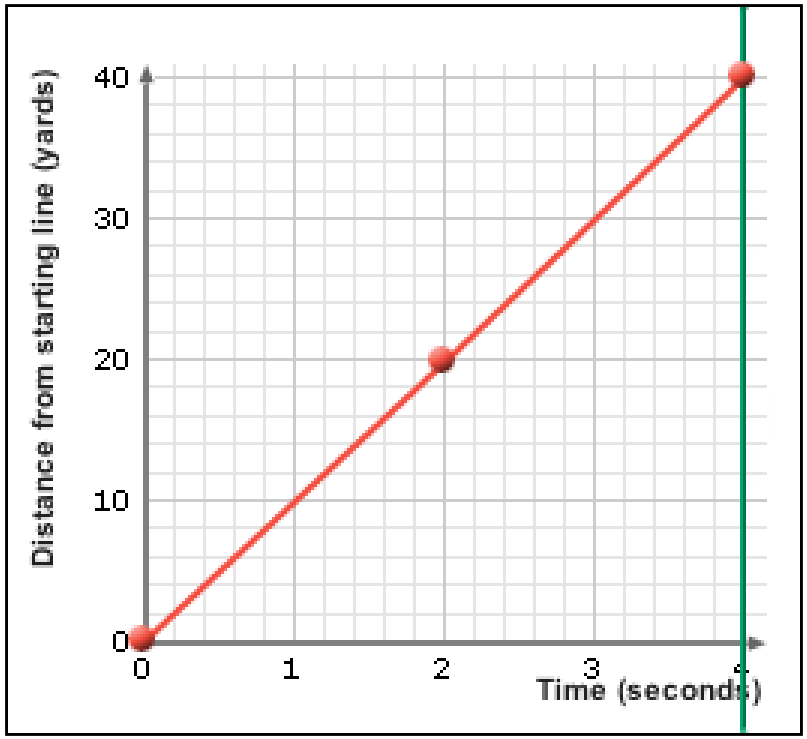


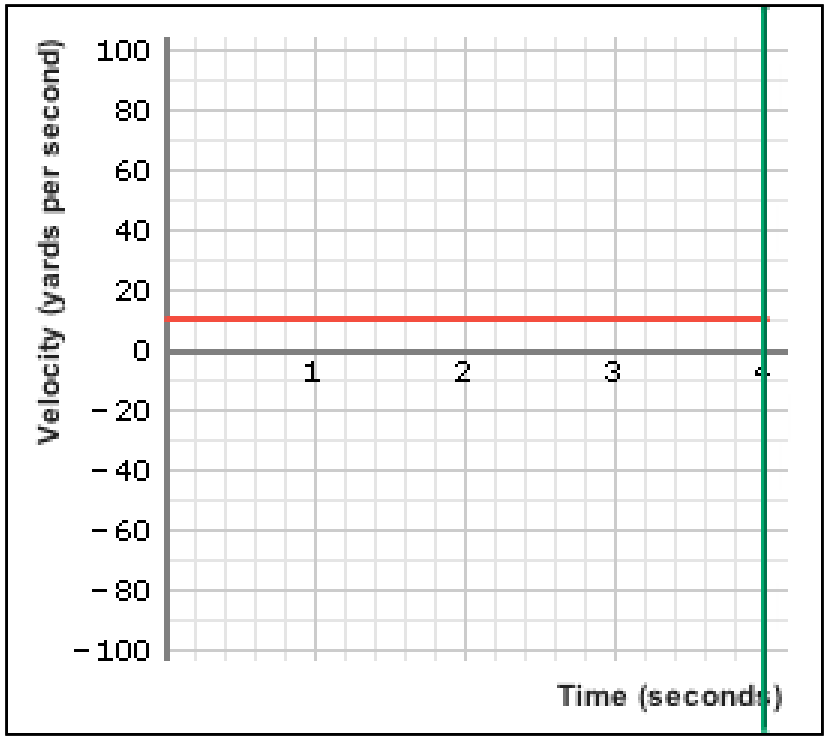


x vs. t graph **v vs. t graph**

Object is standing still at 20 m. **Describing motion**

2-8 Graphical Analysis of Linear Motion

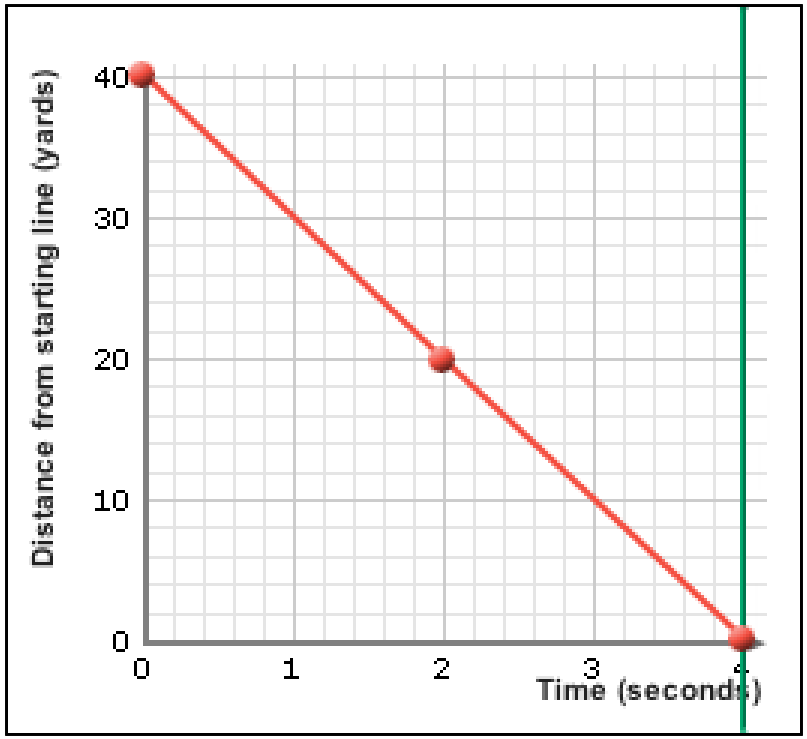


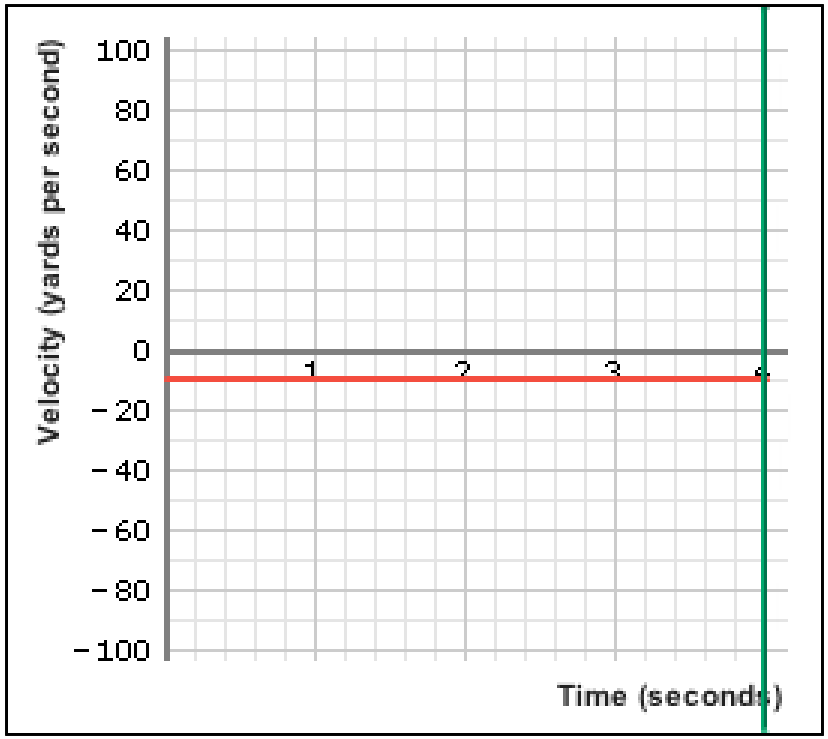


x vs. t graph **v vs. t graph**

Object Describe the motion. Describe the motion. Traveling at a constant 10 m/s

2-8 Graphical Analysis of Linear Motion



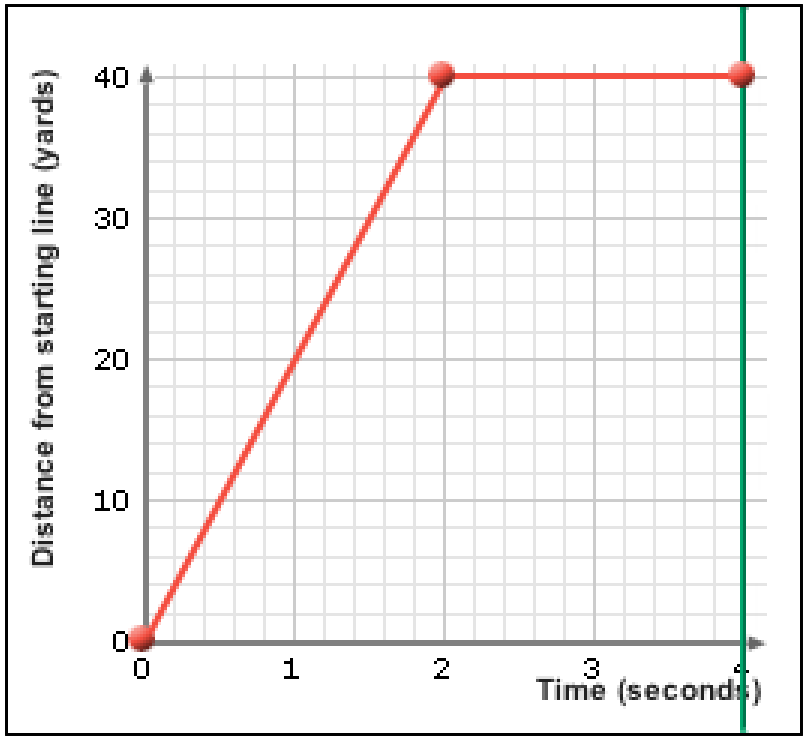


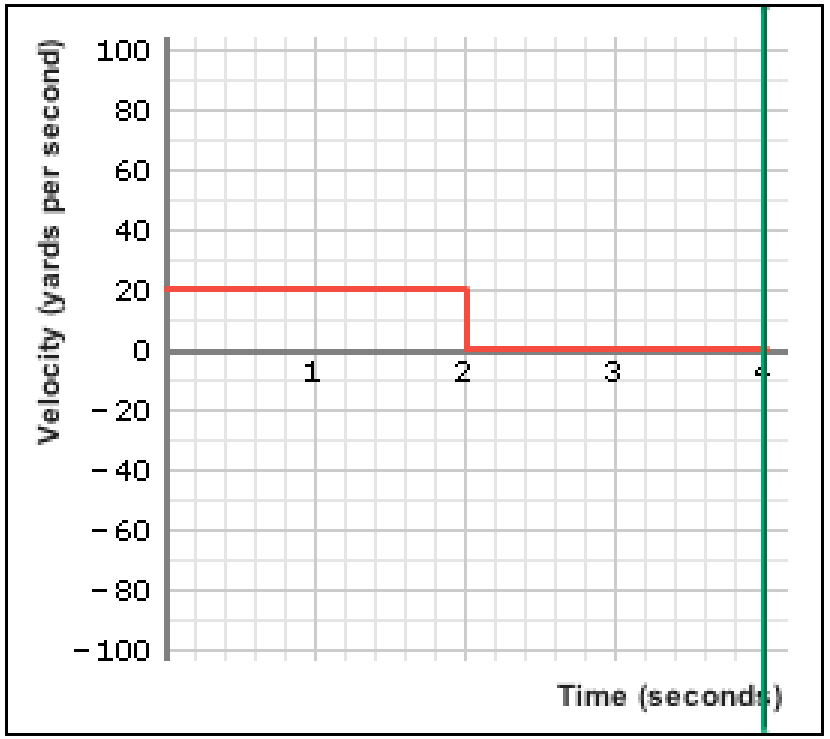
x vs. t graph

v vs. t graph

Object traveling at a constant -10 m/s

2-8 Graphical Analysis of Linear Motion





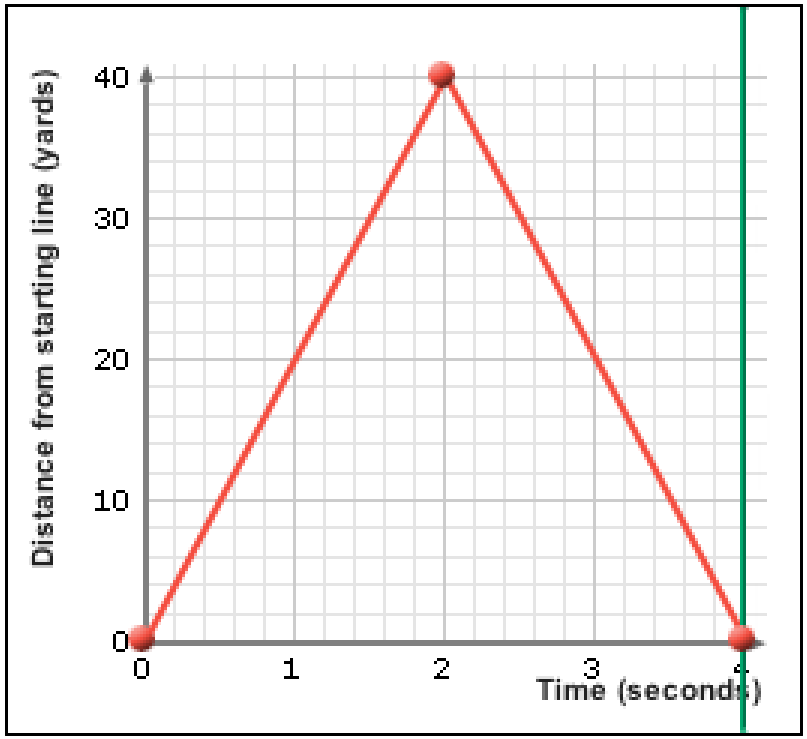
x vs. t graph

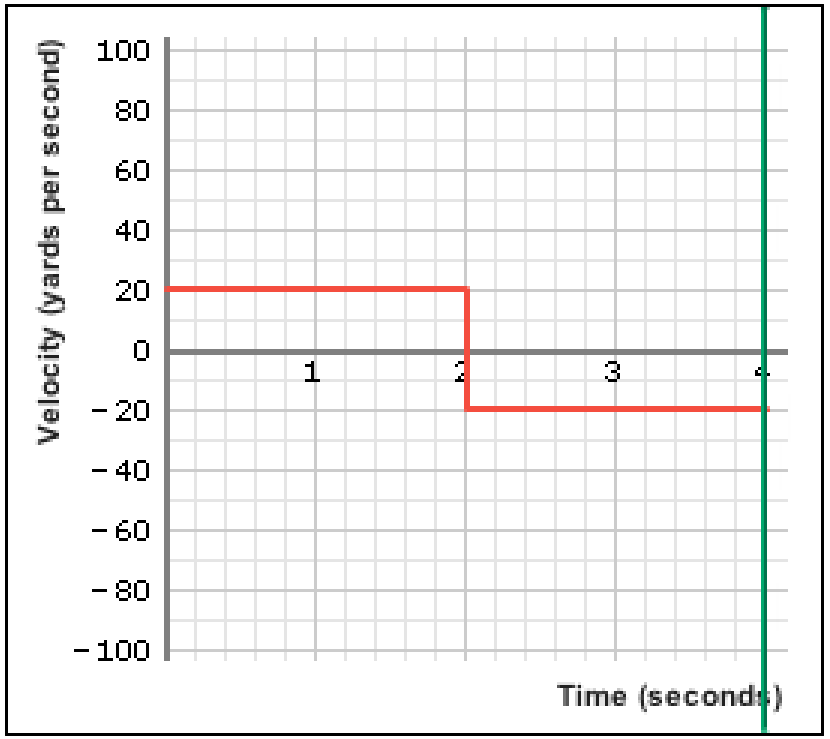
v vs. t graph

Object travels at a constant 20 m/s for 2 seconds and then stands still at 40 m.

Describe the motion

2-8 Graphical Analysis of Linear Motion





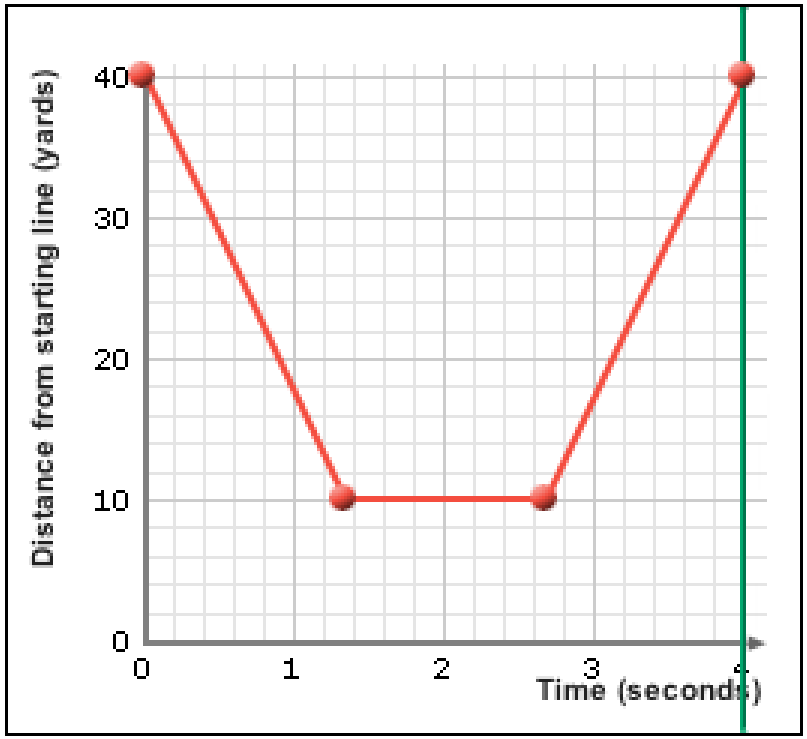
x vs. t graph

v vs. t graph

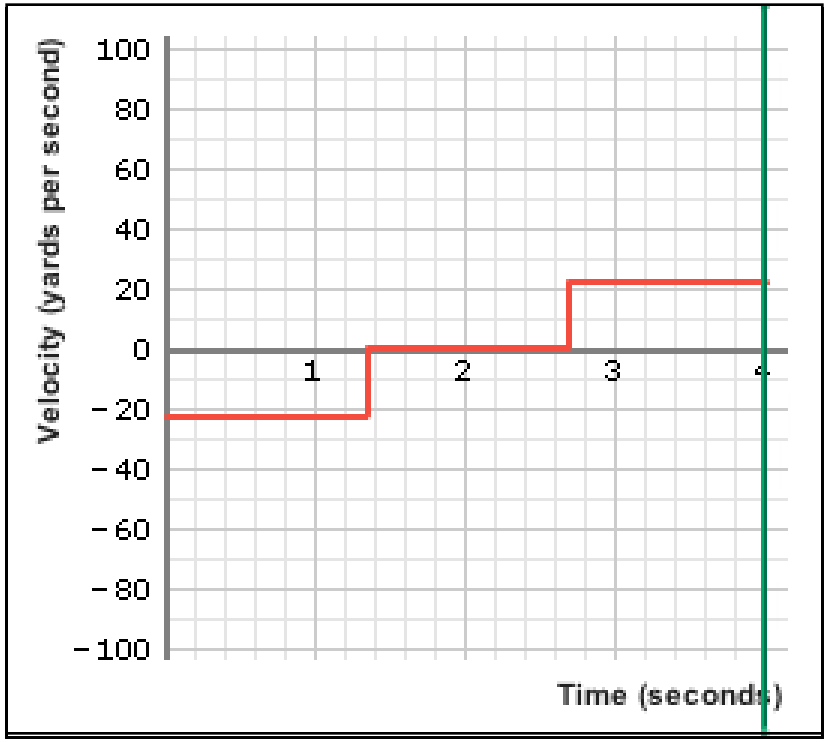
Object travels at a constant 20 m/s for 2 sec and then a constant -20 m/s for 2 sec.

Describe the motion

2-8 Graphical Analysis of Linear Motion



x vs. t graph

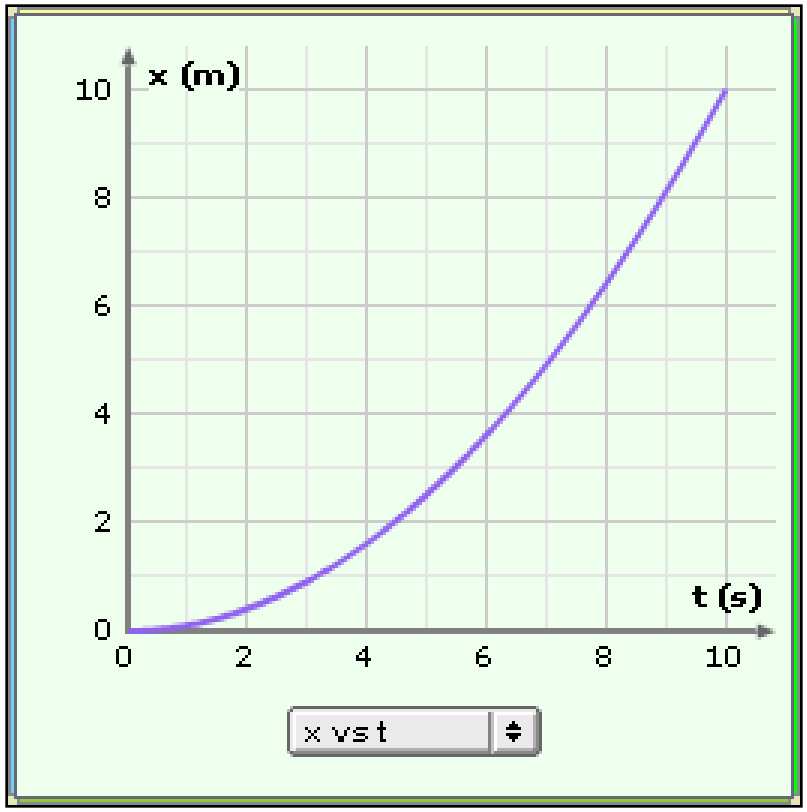


v vs. t graph

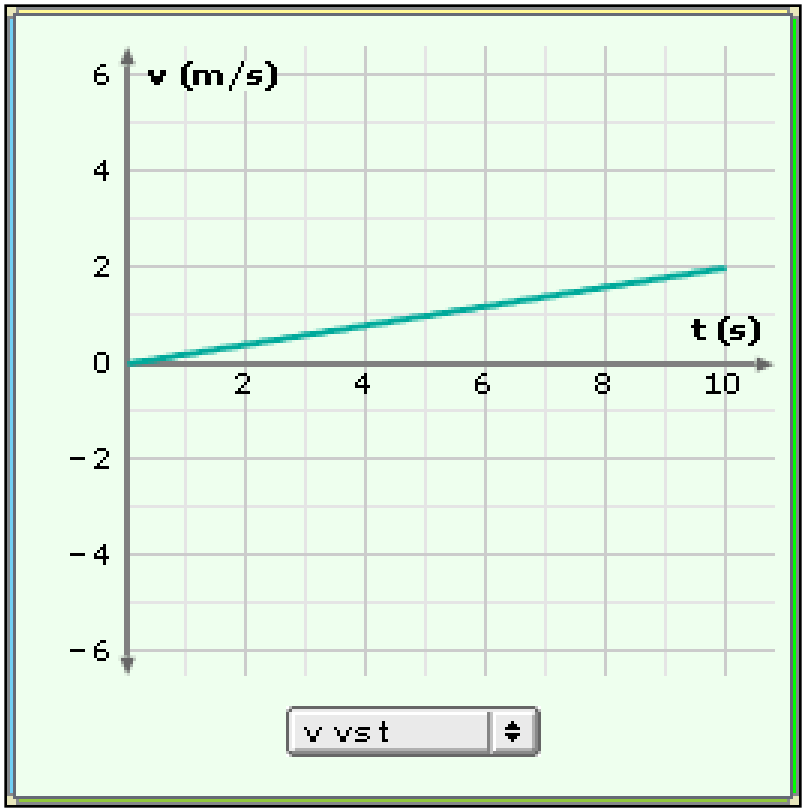
Object travels at a constant negative velocity, stops for a while, then travels at a positive velocity.

Object travels at a constant negative velocity, stops for a while, then travels at a positive velocity.

2-8 Graphical Analysis of Linear Motion



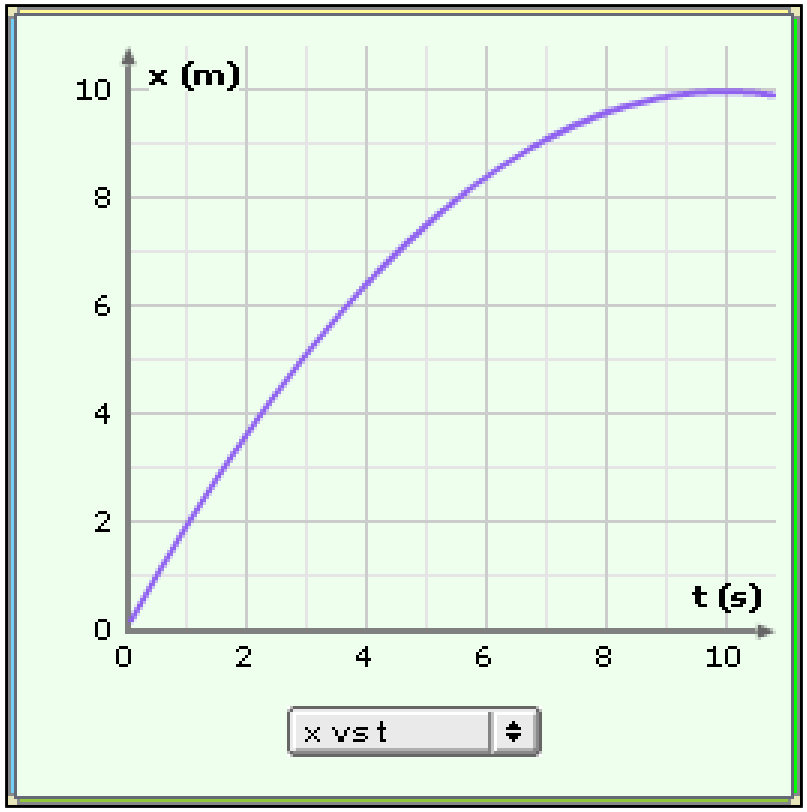
x vs. t graph



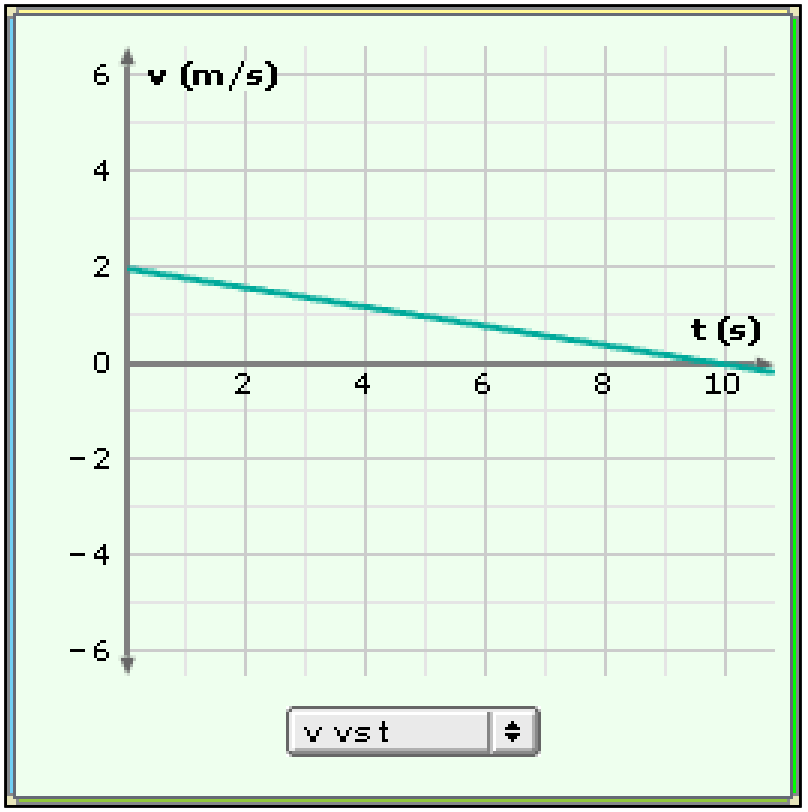
v vs. t graph

Object traveling at constant acceleration of 0.2 m/s^2.

2-8 Graphical Analysis of Linear Motion



x vs. t graph

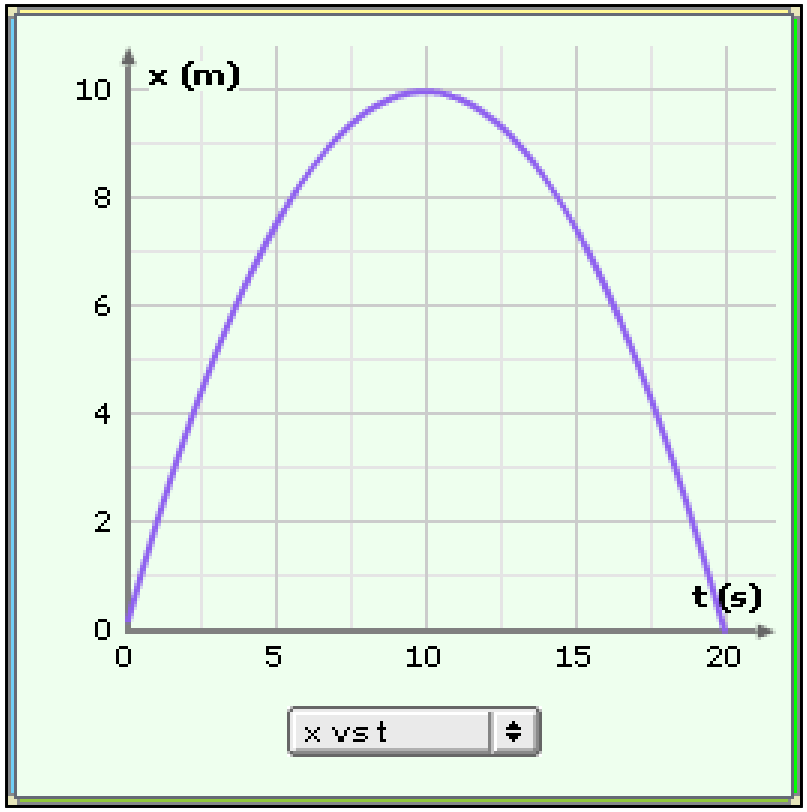


v vs. t graph

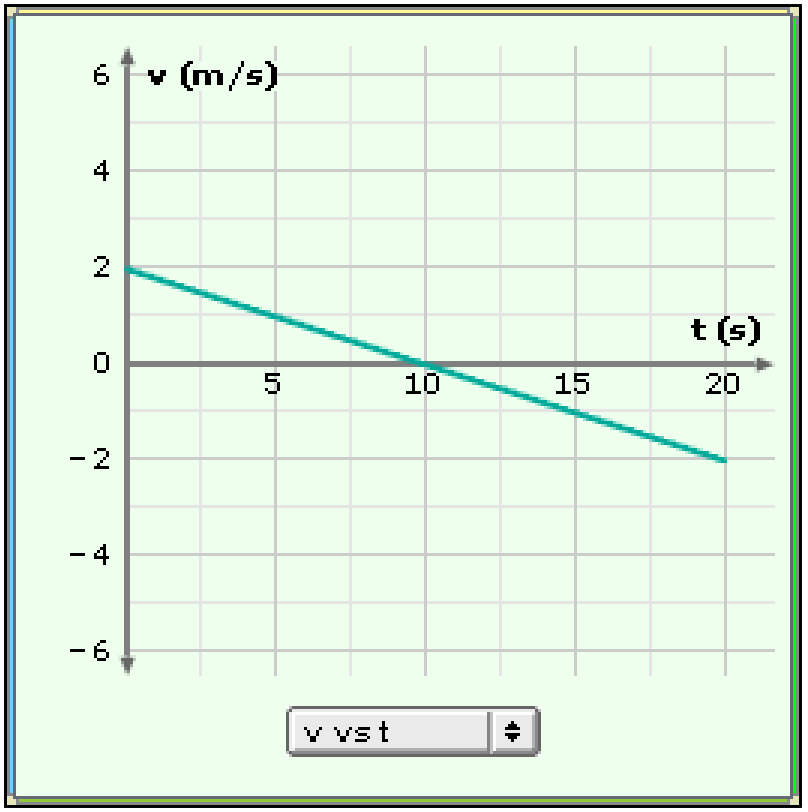
Object traveling at constant acceleration of -0.2 m/s².

Describing motion.

2-8 Graphical Analysis of Linear Motion



x vs. t graph



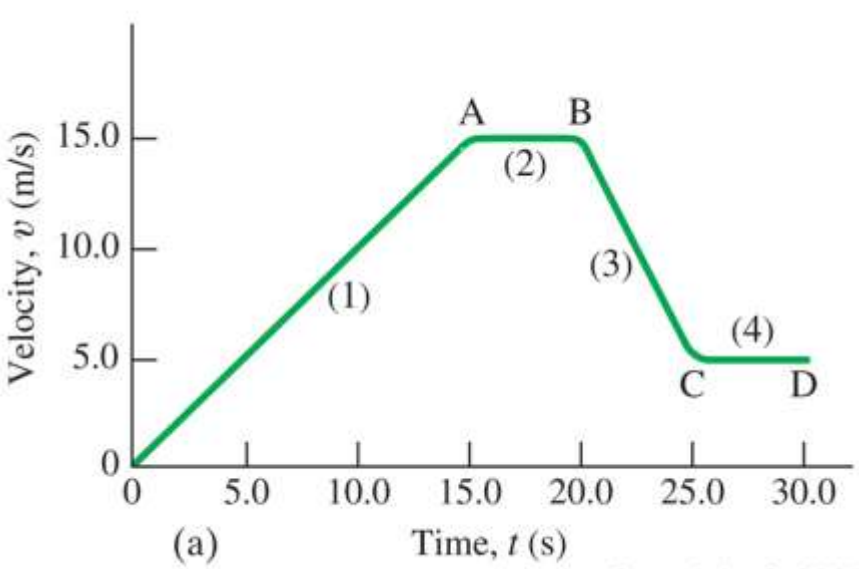
v vs. t graph

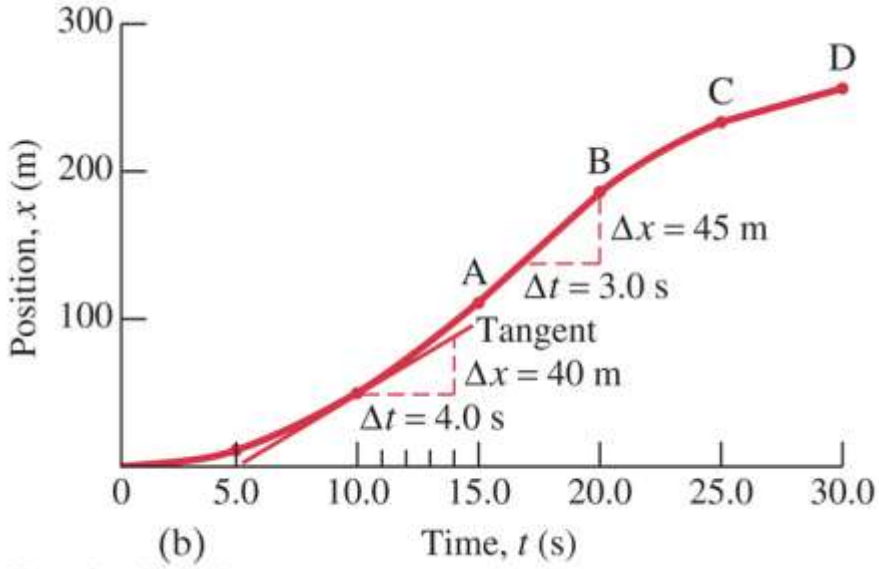
Object traveling at a constant velocity of 10 m/s. Describe the motion

Object traveling at a constant acceleration of -0.2 m/s^2. Notice the velocity goes from being positive to negative.

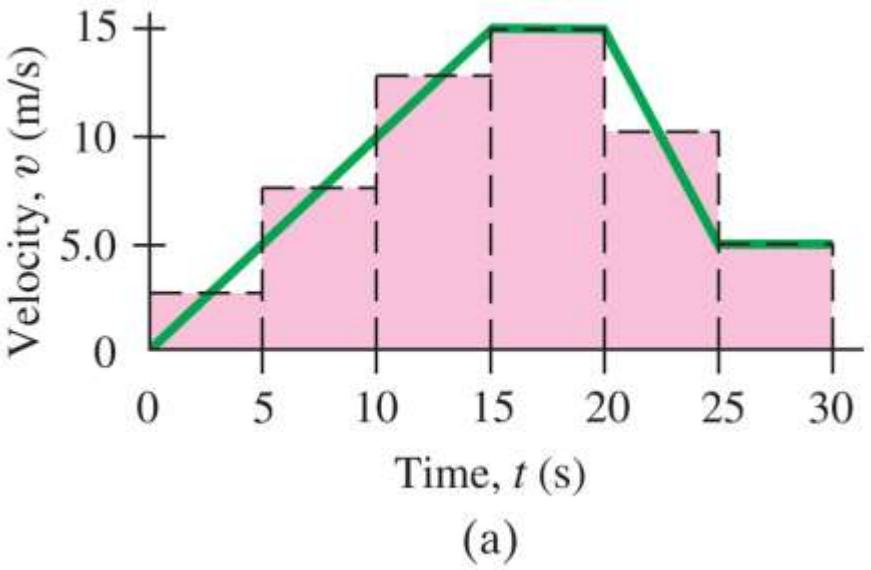
2-8 Graphical Analysis of Linear Motion

On the left we have a graph of velocity vs. time for an object with varying velocity; on the right we have the resulting *x* vs. *t* curve. The instantaneous velocity is tangent to the curve at each point.

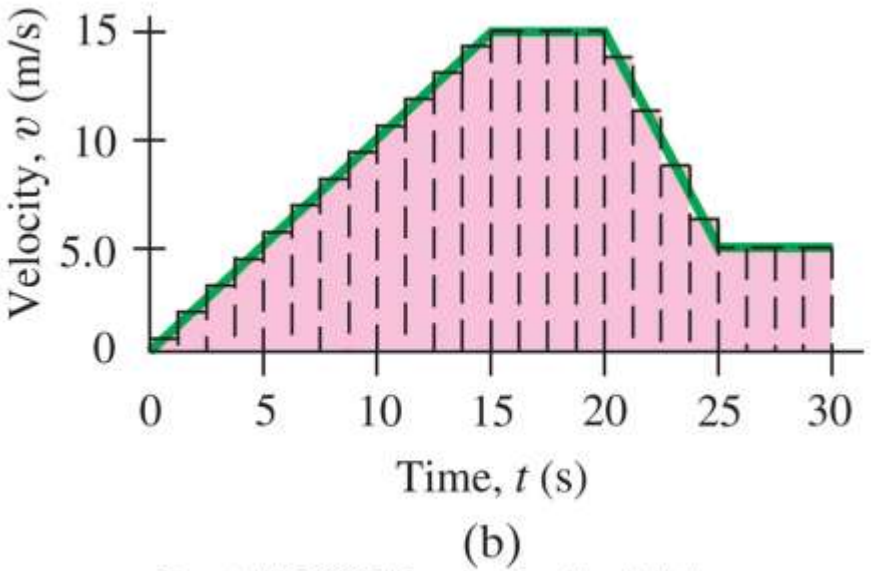




2-8 Graphical Analysis of Linear Motion



(a)



(b)

The displacement, *x*, is the area beneath the *v* vs. *t* curve.

Summary of Chapter 2

- **Kinematics is the description of how objects move with respect to a defined reference frame.**
- **Displacement is the change in position of an object.**
- **Average speed is the distance traveled divided by the time it took; average velocity is the displacement divided by the time.**
- **Instantaneous velocity is the limit as the time becomes infinitesimally short.**

Summary of Chapter 2

- Average acceleration is the change in velocity divided by the time.

- Instantaneous acceleration is the limit as the time interval becomes infinitesimally small.

- The equations of motion for constant acceleration are given in the text; there are four, each one of which requires a different set of quantities.

- Objects falling (or having been projected) near the surface of the Earth experience a gravitational acceleration of 9.80 m/s^2.