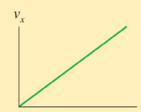
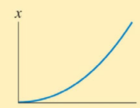
1D Kinematics
(including free fall)

1

Motion with constant acceleration

An object with constant acceleration has a constantly changing velocity. Its velocity graph is linear; its position graph is a parabola.





Kinematic equations for motion with constant acceleration:

$a = \frac{\Delta v}{\Delta t}$

$v = \frac{\Delta x}{\Delta t}$

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

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

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

2

SYNTHESIS 2.1 Describing motion in one dimension

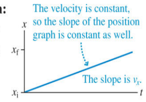
We describe motion in terms of position, velocity, and acceleration.

For **all motion:**

Velocity is the rate of change of position, in m/s. $v_x = \frac{\Delta x}{\Delta t}$

Acceleration is the rate of change of velocity, in m/s^2. $a_x = \frac{\Delta v_x}{\Delta t}$

For **uniform motion:**
- acceleration is zero
- velocity is constant
- position changes steadily



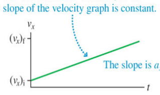
Final and initial position (m)

$$x_f = x_i + v_x \Delta t \quad (2.4)$$

Velocity (m/s) — Time interval (s)

For **motion with constant acceleration:**
- acceleration is steady; it does not change

The acceleration is constant, so the slope of the velocity graph is constant.



- velocity changes steadily

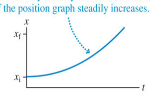
Final and initial velocity (m/s)

$$(v_x)_f = (v_x)_i + a_x \Delta t \quad (2.11)$$

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

- the position changes as the square of the time interval

The velocity steadily increases, so the slope of the position graph steadily increases.



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

$$x_f = x_i + (v_x)_i \Delta t + \frac{1}{2} a_x (\Delta t)^2 \quad (2.12)$$

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

- we can also express the change in velocity in terms of **displacement, not time**

This gives us a third equation, which is useful for many kinematics problems.

Final and initial velocity (m/s)

$$(v_x)_f^2 = (v_x)_i^2 + 2 a_x \Delta x \quad (2.13)$$

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

3

ConcepTest 2 **Kinematics**

If the velocity of an object is non-zero ($v \neq 0$), can the acceleration of the object be zero?

1. yes
2. no
3. depends on the velocity

Follow-up: How about the other way around? Can an object have a non-zero acceleration, but zero velocity?

0 of 5

4

ConcepTest 4 **Kinematics**

If the velocity of an object is zero ($v = 0$), can the acceleration of the object be non-zero ($a \neq 0$)?

1. yes
2. no
3. depends on the velocity

0 of 5

5

Give a specific example for each of the following situations:

1) $a = 0$ but $v \neq 0$

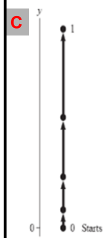
2) $v = 0$ but $a \neq 0$

3) $v < 0$ and $a > 0$

2.15

6

Indicate whether the quantities in the table are positive (+), negative (-) or zero (0).

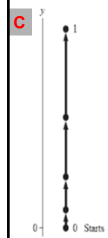


	A	B	C	D
initial position				
final position				
initial velocity				
final velocity				
accel.				

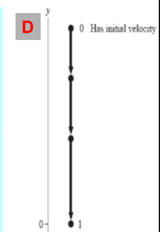
1.30 PHYS 21: Chap. 2, Pg 7

7

Indicate whether the quantities in the table are positive (+), negative (-) or zero (0).



	A	B	C	D
initial position	0	0	0	+
final position	+	-	+	0
initial velocity	+	0	0	-
final velocity	0	-	+	-
accel.	-	-	+	-

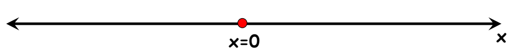


PHYS 21: Chap. 2, P 1.30

8

The kinematic variables for position, velocity and acceleration have 8 possible combinations of signs, such as (x,v,a) = (+,-,+) for example.

List all 8 combinations. Draw a motion diagram for each case and draw the corresponding velocity and acceleration vectors.



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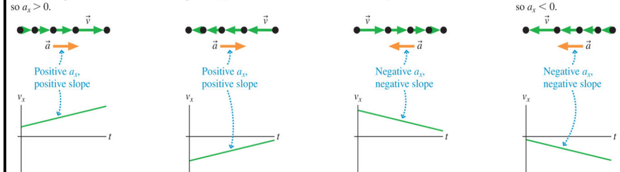
KEY CONCEPT **FIGURE 2.26** Determining the sign of the acceleration.

The object is moving to the right, so $v_x > 0$. Because it is speeding up, its acceleration vector points in the same direction as its velocity (i.e., to the right), so $a_x > 0$.

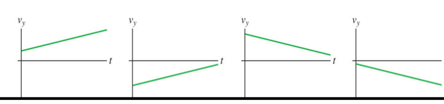
The object is moving to the left, so $v_x < 0$. Because it is slowing down, its acceleration vector points opposite to its velocity (i.e., to the right), so $a_x > 0$.

The object is moving to the right, so $v_x > 0$. Because it is slowing down, its acceleration vector points opposite to its velocity (i.e., to the left), so $a_x < 0$.

The object is moving to the left, so $v_x < 0$. Because it is speeding up, its acceleration vector points in the same direction as its velocity (i.e., to the left), so $a_x < 0$.



STOP TO THINK 2.5 An elevator is moving downward. It is slowing down as it approaches the ground floor. Adapt the information in Figure 2.26 to determine which of the following velocity graphs best represents the motion of the elevator.



, Pg 10

10

A truck driver has a shipment of apples to deliver to a store 500 miles away. The trip usually takes him 8 hours. Today he is daydreaming and realizes 150 miles into his trip that he is running a half hour later than his usual pace at this point.

How fast must he drive for the remainder of the trip in order to complete the trip in the usual amount of time?

v = 68.6 mph

3+2:5 2.57 PHYS 21: Chap. 2, Pg 11

11

A truck driver has a shipment of apples to deliver to a store 500 miles away. The trip usually takes him 8 hours. Today he is daydreaming and realizes 150 miles into his trip that he is running a half hour later than his usual pace at this point.

How fast must he drive for the remainder of the trip in order to complete the trip in the usual amount of time?

SOLUTION

$$v_{avg} = \frac{500\ miles}{8\ hrs} = 62.5\ \frac{miles}{hr}$$

v = 68.6 mph

Normally: $t_1 = \frac{150\ miles}{62.5\ mph} = 2.4\text{ hrs}$ $t_2 = \frac{350\ miles}{62.5\ mph} = 5.6\text{ hrs}$

But today: $t_1 = 2.9\text{ hrs}$ $t_2 = 5.1\text{ hrs}$

So to make up lost time: $v_{fast} = \frac{350\ miles}{5.1\ hrs} = 68.6\ \frac{miles}{hr}$

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12

A truck driver has a shipment of apples to deliver to a store 500 miles away. The trip usually takes him 8 hours. Today he is daydreaming and realizes halfway into his trip (at the 250 mile mark) that he is running a half hour later than his usual pace at this point.

How fast must he drive for the remainder of the trip in order to complete the trip in the usual amount of time?

v = 71.4 mph

3+2: 5

2.57

13

A truck driver has a shipment of apples to deliver to a store 500 miles away. The trip usually takes him 8 hours. Today he is daydreaming and realizes halfway into his trip (at the 250 mile mark) that he is running a half hour later than his usual pace at this point.

How fast must he drive for the remainder of the trip in order to complete the trip in the usual amount of time?

$v_{avg} = \frac{500\ miles}{8\ hrs} = 62.5\,\frac{miles}{hr}$

v = 71.4 mph

SOLUTION

Normally each half of the trip requires: $t_1 = t_2 = \frac{250\ miles}{62.5\ mph} = 4\text{ hrs}$

But today: $t_1 = 4.5\text{ hrs}$ $t_2 = 3.5\text{ hrs}$

So to make up lost time: $v_{fast} = \frac{250\ miles}{3.5\ hrs} = 71.4\,\frac{miles}{hr}$

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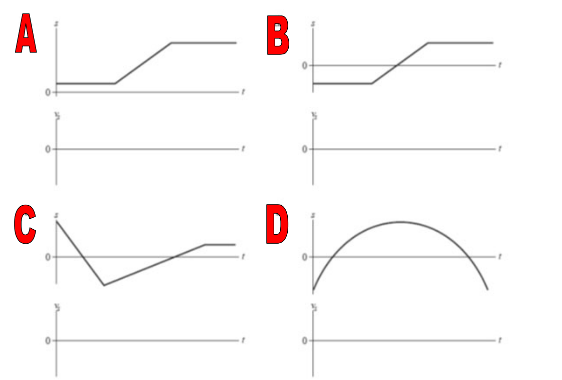
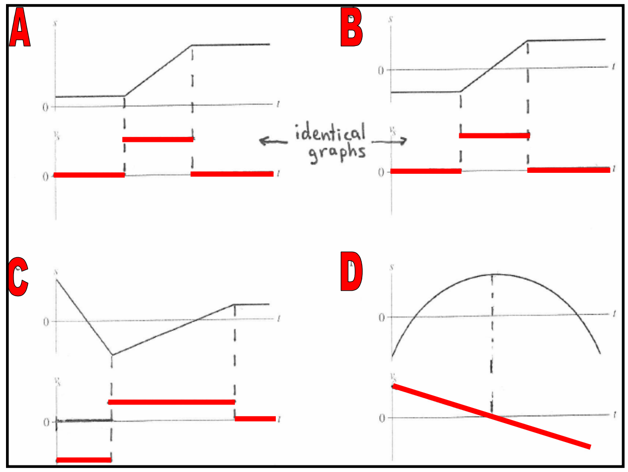
For the x vs. t graphs, draw corresponding v vs. t graphs.



2.7

15



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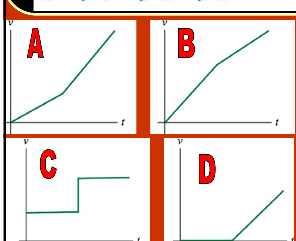
ConcepTest 3 Speed and Position

Which of the following v vs. t graphs matches the motion diagram?

1. A
2. B
3. C
4. D



Follow-up: Which of these figures could be the x vs. t graph?

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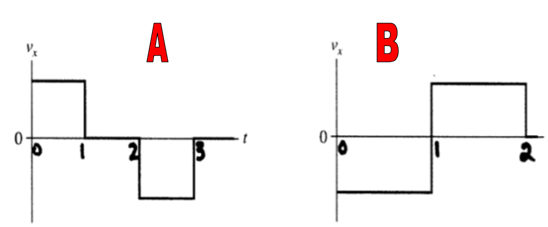
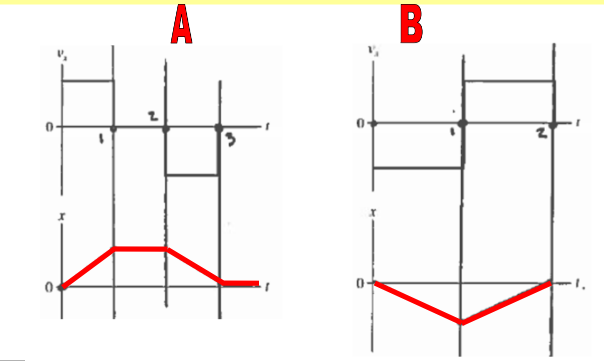
For the v vs. t graphs, draw corresponding x vs. t graphs. Describe the motion in words. Assume that $x_0 = 0$.



2.8

18

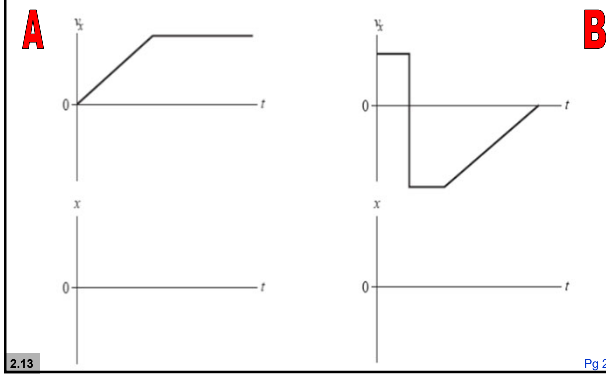
For the v vs. t graphs, draw corresponding x vs. t graphs.
Describe the motion in words. Assume that x_0 = 0.



2.8 PHYS 21: Chap. 2, Pg 19

19

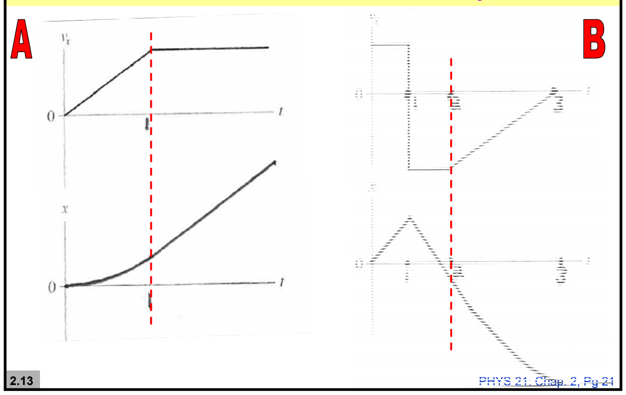
For the v vs. t graphs, draw corresponding x vs. t graphs.
Describe the motion in words. Assume that x_0 = 0.



2.13 Pg 20

20

For the v vs. t graphs, draw corresponding x vs. t graphs.
Describe the motion in words. Assume that x_0 = 0.

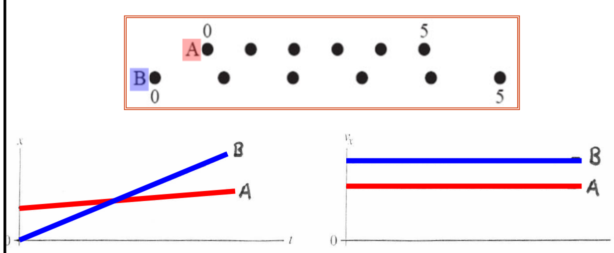


2.13 PHYS 21: Chap. 2, Pg 21

21

Draw x vs. t and v vs. t graphs for each motion diagram.
Show the motion of both cars A and B on the same graph.

Do the cars have the same position at one instant in time?
Do the cars have the same velocity at one instant in time?
Show these points on the motion diagram and your graphs.



2.11 PHYS 21: Chap. 2, Pg 22

22

Draw x vs. t and v vs. t graphs for each motion diagram.
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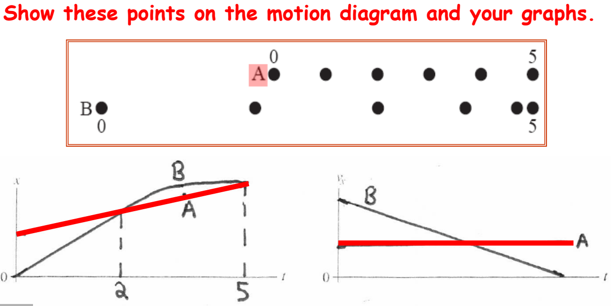
Show these points on the motion diagram and your graphs.



2.12 PHYS 21: Chap. 2, Pg 23

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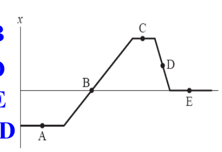
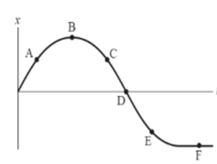
a) Where is the object moving the slowest (without being at rest)? **B**
b) Where is it moving the fastest? **D**
c) Where is the object at rest? **ACE**
d) Has constant non-zero velocity? **BD**
e) Moving to the left? **D**



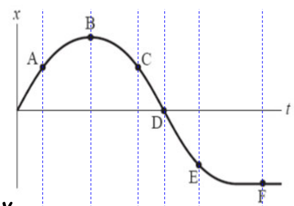
a) Where is the object moving the fastest?
b) Moving to the left?
c) Speeding up?
d) Slowing down?
e) Turning around?

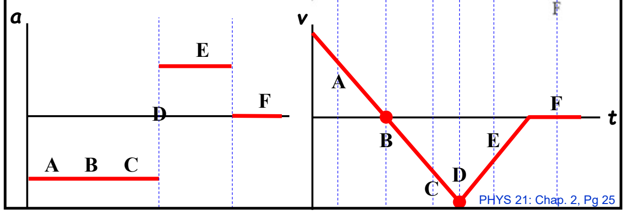


2.8-2.9 PHYS 21: Chap. 2, Pg 24

24

a) Where is the object moving the fastest? **D**
b) Where is it moving to the left? **CDE**
c) Speeding up? **C**
d) Slowing down? **AE**
e) Turning around? **B**





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25

Sketch x vs. t and v vs. t graphs for the following:

1) A parachutist opens her parachute at an altitude of 1500 m. She descends slowly at a constant speed of 5 m/s. Start your graph when the parachute opens.

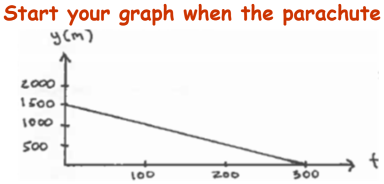
2) A rabbit hops to the right at a steady speed of 1 m/s for 4 seconds. Then it sees a coyote and instantly increases its speed to 3 m/s.

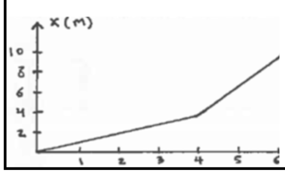
3) Quarterback Bill throws the ball to the right at a speed of 15 m/s. It is intercepted 45 m away by Tom, who is running to the left at 7.5 m/s and carries the ball 60 m for a touchdown. Draw a graph of the ball.

2.10 PHYS 21: Chap. 2, Pg 26

26

Sketch x vs. t and v vs. t graphs for the following:
1) A parachutist opens her parachute at an altitude of 1500 m. She descends slowly at a constant speed of 5 m/s. Start your graph when the parachute opens.





2) A rabbit hops to the right at a steady speed of 1 m/s for 4 secs. Then it sees a coyote and instantly increases its speed to 3 m/s.

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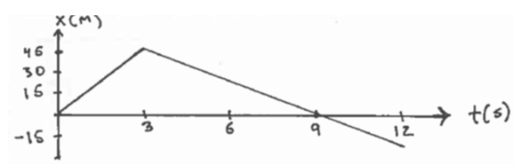
Sketch x vs. t and v vs. t graphs for the following:

3) Quarterback Bill throws the ball to the right at a speed of 15 m/s. It is intercepted 45 m away by Tom, who is running to the left at 7.5 m/s and carries the ball 60 m for a touchdown. Draw a graph of the ball.



2.10 PHYS 21: Chap. 2, Pg 28

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Sketch x vs. t and v vs. t graphs for the following:

1) A car starts from rest, steadily speeds up to 40 mph in 15 s, moves at a constant speed for 30 s, then comes to a halt in 5 s.

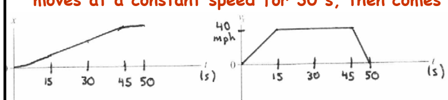
2) A rock is dropped from a bridge. It is moving 30 m/s when it hits the ground 3 s later.

3) A pitcher throws a baseball at 40 m/s. One-half second later, the batter hits a line drive at 60 m/s. The ball is caught 1 s after it is hit.

2.10 PHYS 21: Chap. 2, Pg 29

29

1) A car starts from rest, steadily speeds up to 40 mph in 15 s, moves at a constant speed for 30 s, then comes to a halt in 5 s.



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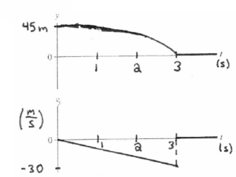

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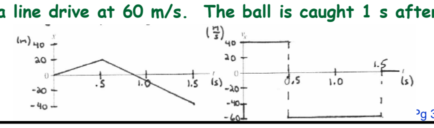

2.10 Pg 30

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This is truer than you think …

Frank and Ernest

PHYS 11: Chap. 2, Pg 31

31

Free Fall

PHYS 22: Chap. 26, Pg 32

32

ConcepTest 3 Free Fall

A ball is thrown straight up into the air. At the top of its rise (maximum height), what is the magnitude of the ball's acceleration?

1. a > g
2. a = g
3. 0 < a < g
4. a = 0
5. a < 0

What is the velocity of the ball at that point?

0 of 5

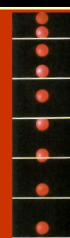
PHYS 11: Chap. 2, Pg 33

33

ConcepTest 2 Kinematics

What is the direction of the velocity and the acceleration for the ball in the following stop-action photo?

1. v is up, a is up
2. v is up, a is down
3. v is down, a is up
4. v is down, a is down
5. hmm, I just don't know



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ConcepTest 5 Free Fall

A rock is thrown straight down from a bridge. Immediately after being released, what is the magnitude of the rock's acceleration?

1. a > g
2. a = g
3. 0 < a < g
4. a = 0
5. a < 0

Follow-up: Just before hitting the river, what is the rock's acceleration?

0 of 5

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Tangible

Dropping a $100 bill

w = 15.6 cm
w/2 = 7.8 cm
t = 0.126 s

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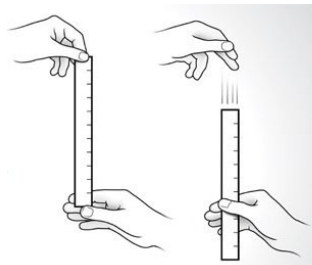
Tangible

Measuring Reaction Time



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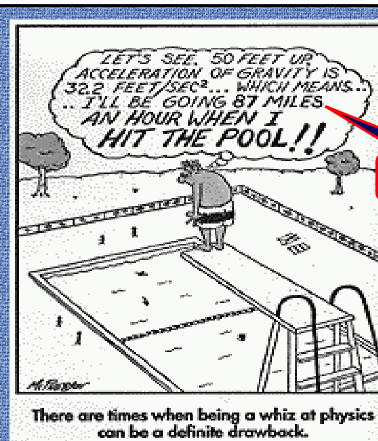

Is this right?

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see page 51

PROBLEM-SOLVING APPROACH

The first step in solving a seemingly complicated problem is to break it down into a series of smaller steps. In worked examples in the text, we use a problem-solving approach that consists of four steps: *strategize, prepare, solve,* and *assess*. Each of these steps has important elements that you should follow when you solve problems on your own.

STRATEGIZE The Strategize step of the solution is where you address the *big-picture* questions about the problem. Here, you take a step back from the details of the problem to ask:

- **What kind of problem is this?** From reading the problem statement, try to categorize the problem in terms of what you've learned in the chapter. If, for instance, the problem refers to a bicyclist riding at a constant 7.0 m/s, this suggests the problem is about uniform motion.
- **What's the correct general approach?** What principles, strategies, and tactics that you've learned are relevant in solving this problem? For example, if you're given a position-versus-time graph and are asked to find the velocity, the principle that the velocity is related to the slope of the position graph is likely to be important.
- **What should the answer look like?** Is a numerical answer asked for? Do you need a graph or a sketch?

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MP™ Problem-Solving Strategy

PREPARE The Prepare step of a solution is where you identify important elements of the problem and collect information you will need to solve it. It's tempting to jump right to the Solve step, but a skilled problem solver will spend the most time on this step, the preparation. Preparation includes:

- **Drawing a picture.** In many cases, this is the most important part of a problem. The picture lets you model the problem and identify the important elements. As you add information to your picture, the outline of the solution will take shape. For the problems in this chapter, a picture could be a motion diagram or a graph—or perhaps both.
- **Collecting necessary information.** The problem's statement may give you some values of variables. Other important information may be implied or must be looked up in a table. Gather everything you need to solve the problem and compile it in a list.
- **Doing preliminary calculations.** There are a few calculations, such as unit conversions, that are best done in advance of the main part of the solution.

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SOLVE The Solve step of a solution is where you actually do the mathematics or reasoning necessary to arrive at the answer needed. This is the part of the problem-solving strategy that you likely think of when you think of "solving problems." But don't make the mistake of starting here! The Prepare step will help you be certain you understand the problem before you start putting numbers in equations.

ASSESS The Assess step of your solution is very important. When you have an answer, you should check to see whether it makes sense. Ask yourself:

- **Does my solution answer the question that was asked?** Make sure you have addressed all parts of the question and clearly written down your solutions.
- **Does my answer have the correct units and number of significant figures?**
- **Does the value I computed make physical sense?** In this book all calculations use physically reasonable numbers. You will not be given a problem to solve in which the final velocity of a bicycle is 100 miles per hour! If your answer seems unreasonable, go back and check your work.
- **Can I estimate what the answer should be to check my solution?**
- **Does my final solution make sense in the context of the material I am learning?**

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A policeman hiding behind a billboard sees a speeding car zoom by him at a constant speed of 35 m/s. The policeman starts from rest and takes up the chase, accelerating at 5 m/s² until he catches the culprit.

How long does it take him to catch the speeding car?

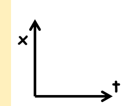
t = 14 s

Kinematic equations for motion with constant acceleration:

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

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

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



Can you represent this problem graphically?

3+2:5

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A policeman hiding behind a billboard sees a speeding car zoom by him at a constant speed of 35 m/s. The policeman starts from rest and takes up the chase, accelerating at 5 m/s² until he catches the culprit.

How long does it take him to catch the speeding car?

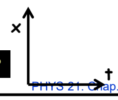
SOLUTION

t = 14 s

$$x_{car} = v_{car} t \quad = \quad x_{police} = \frac{1}{2} a_{police} t^2$$

$$v_{car} t = \frac{1}{2} a_{police} t^2 \quad \Rightarrow \quad t = \frac{2 v_{car}}{a_{police}} = \frac{2\left(35\,\frac{m}{s}\right)}{5\,\frac{m}{s^2}} = 14\ s$$

Can you represent this problem graphically?



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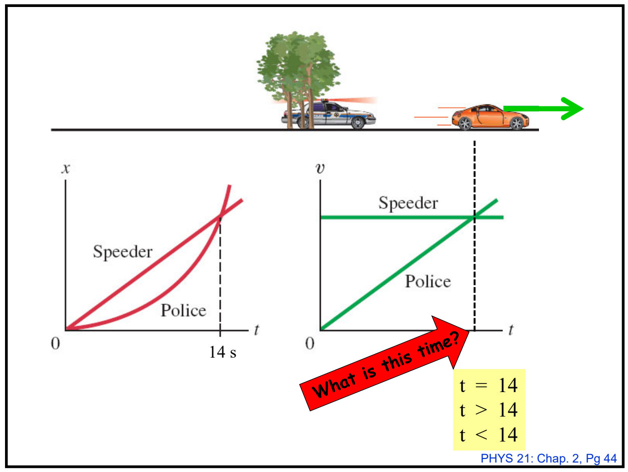

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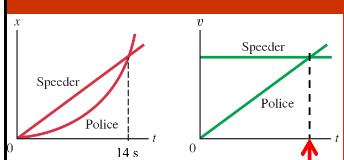
ConcepTest 6 Speeding Ticket!

The policeman catches the speeder at t = 14 s, as seen on the left. At what time does the policeman have the same velocity as the speeder, as seen on the right?

1. t < 14 s
2. t = 14 s
3. t > 14 s



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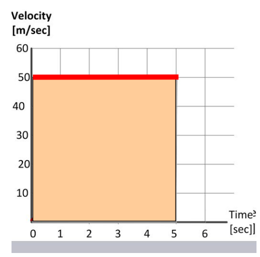
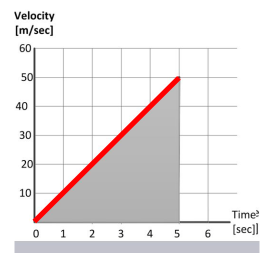
area under v vs. t curve = displacement





area = height · width
= $v \cdot \Delta t$
= displacement!

area = $\frac{1}{2}$ base · height
= $\frac{1}{2} \Delta t \cdot v_f$
= $\frac{1}{2} \Delta t \cdot a \Delta t = \frac{1}{2} a (\Delta t)^2$
= displacement!

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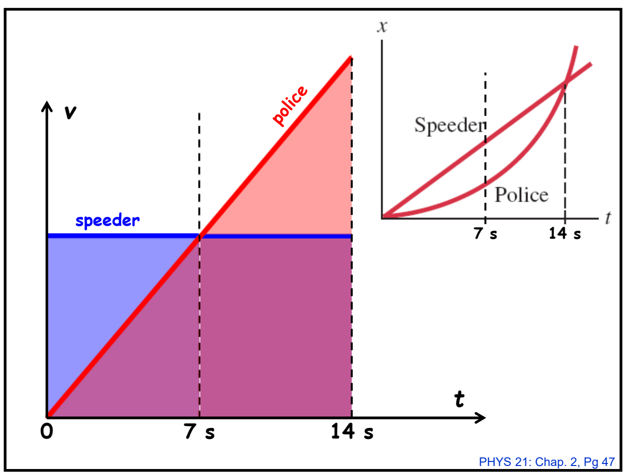

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