CHAPTER

2

Acceleration causes a change in velocity.

Learning Expectations

By the end of this chapter, you will:

Relating Science to Technology, Society, and the Environment

- analyze, on the basis of research, a technology that applies concepts related to kinematics
- assess the impact on society and the environment of a technology that applies concepts related to kinematics

Developing Skills of Investigation and Communication

- analyze and interpret position-time, velocity-time, and acceleration-time graphs of motion in one dimension
- use a velocity-time graph for constant acceleration to derive the equation for average velocity, and solve simple problems in one dimension using these equations
- plan and conduct an inquiry into the motion of objects in one dimension, using vector diagrams and uniform acceleration equations
- solve problems involving uniform and non-uniform linear motion in one dimension using graphical analysis and algebraic equations

Understanding Basic Concepts

- distinguish between the terms constant, instantaneous, and average with reference to acceleration, and provide examples to illustrate each term

Roller coasters are synonymous with thrill, fun, and excitement (Figure 2.1). They are the main attractions in amusement parks. A roller coaster ride is very thrilling because its velocity changes dramatically several times during the trip. This happens because acceleration is one of the important features of the roller coaster. The cars of a roller coaster are pulled by chains up to a certain height and then released. After this release, the roller coaster goes through sharp turns, steep drops and different slopes. Because of these factors, the acceleration and velocity of the cars are different at different points. These changes make the riders feel the churn in their stomachs and fast moving air around them. All of this brings a great deal of excitement to the rider.

The free fall roller coaster is taken to a height, suspended there for a very short time, and then "dropped"! The riders sitting in the seat come down with acceleration equal to the acceleration due to gravity or 9.81 m/s^2.

Roller coasters can be dangerous, but safety systems are installed in them to keep the riders safe and accident free.

Figure 2.1 Roller coasters are thrilling because riders experience frequent changes in velocity. On a free fall roller coaster, riders experience acceleration due to gravity of almost 9.81 m/s^2.

2.1 Acceleration

Section Summary

- Change in velocity is evidence of acceleration.
- Acceleration is defined as rate of change in velocity.
- Acceleration is a vector quantity.
- The same signs for velocity and acceleration mean speeding up.
- The opposite signs for velocity and acceleration mean slowing down.

Installed video screens in aircraft provide passengers with information about the aircraft's velocity during the flight (Figure 2.2). The information includes how the velocity is changing during the trip.

Figure 2.2 The screens provide information such as the aircraft's velocity and direction.

Analyzing Velocity-time Graphs

Like position-time graphs, velocity-time graphs provide useful information about the motion of an object. As velocity is displacement per unit time, the shape of the velocity-time graph will reveal whether the object is at rest, moving at constant speed, speeding up, or slowing down. In the first case (Figure 2.3(a)), a plane travels at a height of 10 600 m with constant velocity of 600 km/h [E] for 5.0 h. In the second case (Figure 2.3(b)), the plane travels at the same height, but with increasing velocity from 0 km/h to 800 km/h. The data for these flights are given in Table 2.1(a) and Table 2.1(b) respectively on the next page.

These tables show the velocity-time data for the airplane. If you graph the data, you can determine the relationship between the two variables, velocity and time. The graph in Figure 2.4(a), on the next page, represents constant velocity or uniform motion and the graph in Figure 2.4(b) represents varying velocity or non-uniform motion.

Figure 2.3(a) A plane flies at a constant speed, so the distances within each time interval are equal. Break the plane's motion into a series of snapshots. Record your data in a data table and then graph it.

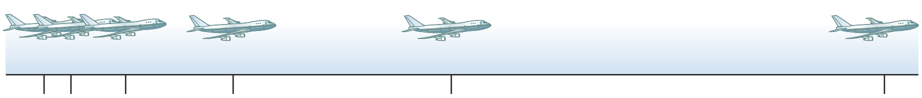

Figure 2.3(b) A plane flies at an increasing speed, so the distances within each time interval increase. Break the plane's motion into a series of snapshots. Record your data in a data table and then graph it.

Table 2.1(a) Plane flies at a constant speed

Time (h)	Velocity (km/h [E])
0.0	600
1.0	600
2.0	600
3.0	600
4.0	600
5.0	600

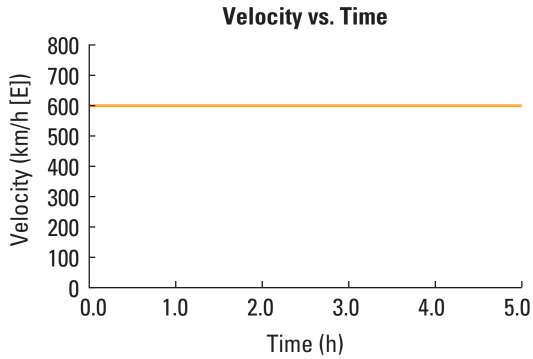

Figure 2.4(a) A velocity-time graph for uniform motion of an airplane

Table 2.1(b) Plane flies at an increasing speed

Time (h)	Velocity (km/h [E])
0.0	0
1.0	160
2.0	320
3.0	480
4.0	640
5.0	800

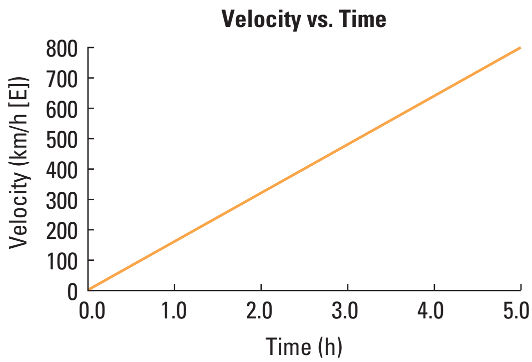

Figure 2.4(b) A velocity-time graph for non-uniform motion of an airplane

The graph in Figure 2.4(a) is a horizontal line and you can calculate its slope as shown below:

$$\begin{aligned}\text{slope} &= \frac{\text{rise}}{\text{run}}\\ &= \frac{\Delta\vec{v}}{\Delta t}\\ &= \frac{\vec{v}_\text{f} - \vec{v}_\text{i}}{t_\text{f} - t_\text{i}}\\ &= \frac{+600\ \text{km/h} - (+600\ \text{km/h})}{5.0\ \text{h} - 0.0\ \text{h}}\\ &= 0\ \text{km/h}^2\end{aligned}$$

The graph in Figure 2.4(b) is a line and you can calculate its slope as shown below:

$$\begin{aligned}\text{slope} &= \frac{\text{rise}}{\text{run}}\\ &= \frac{\Delta\vec{v}}{\Delta t}\\ &= \frac{\vec{v}_\text{f} - \vec{v}_\text{i}}{t_\text{f} - t_\text{i}}\\ &= \frac{+800\ \text{km/h} - (0\ \text{km/h})}{5.0\ \text{h} - 0.0\ \text{h}}\\ &= 160\ \text{km/h}^2\end{aligned}$$

In both cases, the slope of the graph represents the acceleration of the airplane. Note that Figure 2.4(a) shows zero acceleration. **Acceleration** is a vector quantity, represented by the variable $\vec{a}$, and is defined as the change in velocity per unit time. So, $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$.

Acceleration is also called non-uniform motion because the object's speed or direction is changing. The SI unit for velocity is m/s and the change in velocity will have the same unit. The unit for time is seconds. The unit for acceleration is m/s/s or m/s^2.

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Explore More

What can you conclude about the acceleration of an object, if the slope of the line on a velocity-time graph is zero, positive, or negative?

Concept Check

1. What does the slope of a velocity-time graph represent?
2. What is the SI unit for acceleration?
3. Give two more examples of objects that undergo acceleration.

Non-Uniform Motion

Although objects may experience constant velocity over short time intervals, even a car operating on cruise control has fluctuations in speed or direction (Figure 2.5).

Consider another example of you driving an all-terrain vehicle (ATV). After driving your ATV (Figure 2.6) through a field, you see a wide river just ahead, so you quickly bring the vehicle to a complete stop. Notice in Figure 2.7 that, as your ATV slows down, the displacement in each time interval decreases.

Example 2.1 shows the calculations and resulting velocity-time graph for an object that is slowing down uniformly.

Figure 2.5 Consider the kinds of changes in velocity this car experiences during the trip.

Figure 2.6 ATVs can undergo a wide variety of motions.

Figure 2.7 This ATV is undergoing non-uniform motion. It is accelerating, in this case, slowing down.

Example 2.1

The position-time data for an object's non-uniform motion are given in Table 2.2. Using these data,
(a) draw a position-time graph
(b) draw a velocity-time graph
(c) calculate acceleration

Table 2.2

Time (s)	Position (m [forward])
0.0	5.0
10.0	0.0
20.0	−3.0
30.0	−4.0
40.0	−3.0
50.0	0.0

Analysis and Solution
Designate the forward direction as positive.
(a) For the position-time graph, plot the data in Table 2.2 (Figure 2.8):

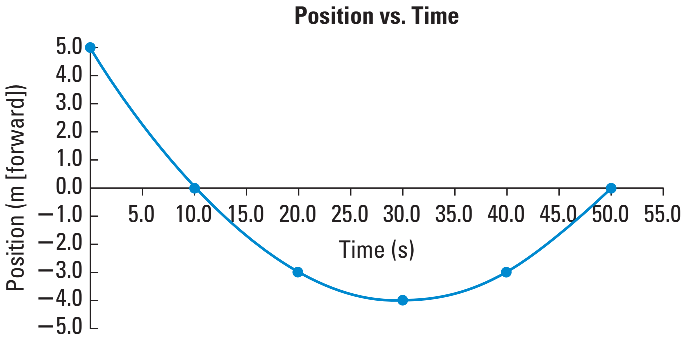


Figure 2.8

(b) Since the position-time graph is non-linear, find the slope of the tangent at 10.0 s, 30.0 s, and 50.0 s (Figures 2.9(a), (b), and (c)).

For Figure 2.9(a):

$$\begin{aligned}\text{slope} &= \frac{\Delta\vec{d}}{\Delta t}\\ &= \frac{-3.0\text{ m} - 3.0\text{ m}}{17.5\text{ s} - 2.5\text{ s}}\\ &= \frac{-6.0\text{ m}}{15.0\text{ s}}\\ &= -0.4\text{ m/s}\end{aligned}$$

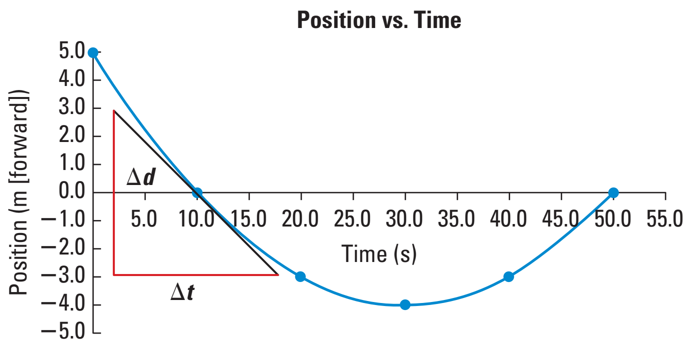


Figure 2.9(a)

For Figure 2.9(b):
This tangent is a horizontal line, so its slope is zero.

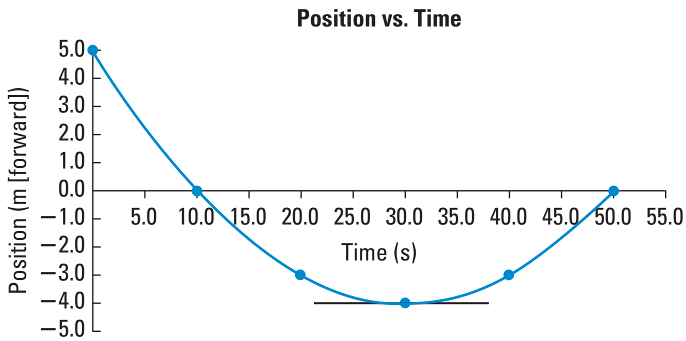


Figure 2.9(b)

For Figure 2.9(c):

$$\text{slope} = \frac{\Delta\vec{d}}{\Delta t}$$
$$= \frac{+1.0\text{ m} - (-1.0\text{ m})}{52.5\text{ s} - 47.5\text{ s}}$$
$$= \frac{+2.0\text{ m}}{5.0\text{ s}}$$
$$= +0.4\text{ m/s}$$

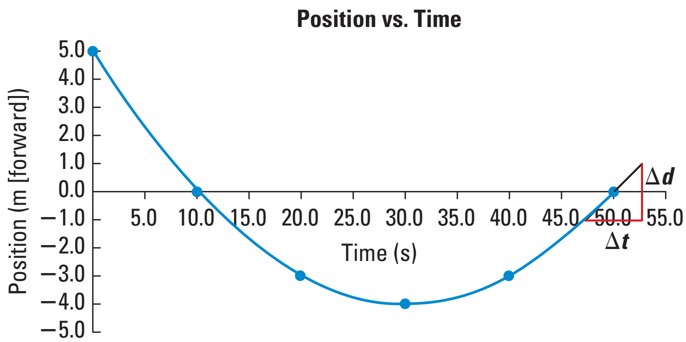


Figure 2.9(c)

The slopes of the tangents give the instantaneous velocities (Table 2.3). Positive sign means that the direction is forward. This data is plotted on a velocity-time graph (Figure 2.10).

Table 2.3

Time (s)	Velocity (m/s [forward])
10.0	−0.4
30.0	0
50.0	0.4

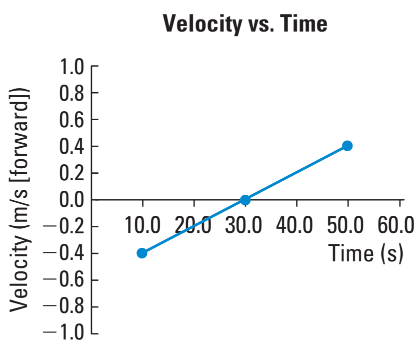
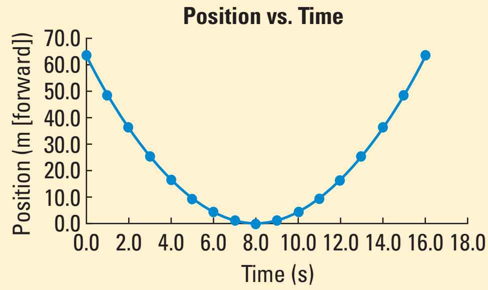


Figure 2.10

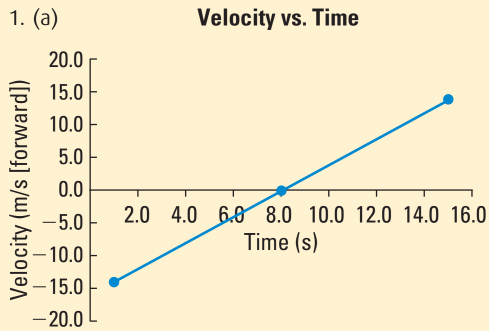
Practice Problems

1. (a) Draw a velocity-time graph from the position-time graph given below.
   (b) Calculate the acceleration during this motion.



Answers

1. (a)



(b) $+2.0\text{ m/s}^2$ [forward]

(c) Find the acceleration by calculating the slope of the velocity-time graph.

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$$
$$= \frac{+0.4 \text{ m/s} - (-0.4 \text{ m/s})}{50.0 \text{ s} - 10.0 \text{ s}}$$
$$= \frac{+0.8 \text{ m/s}}{40.0 \text{ s}}$$
$$= +0.02 \text{ m/s}^2$$

The acceleration of the object is $+0.02 \text{ m/s}^2$. Because the forward direction was designated as positive, the positive sign means that the direction of the acceleration is forward.

Velocity is a vector quantity. Therefore, the change in velocity per unit time, which is acceleration, will also be a vector quantity.

$$\vec{a} = \frac{\vec{v}_{\mathrm{f}} - \vec{v}_{\mathrm{i}}}{\Delta t}$$

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Explore More
What does the direction of the acceleration vector depend on?

The direction and magnitude of vector $\vec{a}$ depends on the magnitude and direction of both vectors $\vec{v}_{\mathrm{f}}$ and $\vec{v}_{\mathrm{i}}$ (Figures 2.11(a), (b), and (c)). We can say that an object is undergoing acceleration if

(a) the magnitude of its velocity changes, while its direction remains the same

(b) the direction of its velocity changes, while its magnitude remains the same

(c) there is a change in the magnitude *and* direction of its velocity

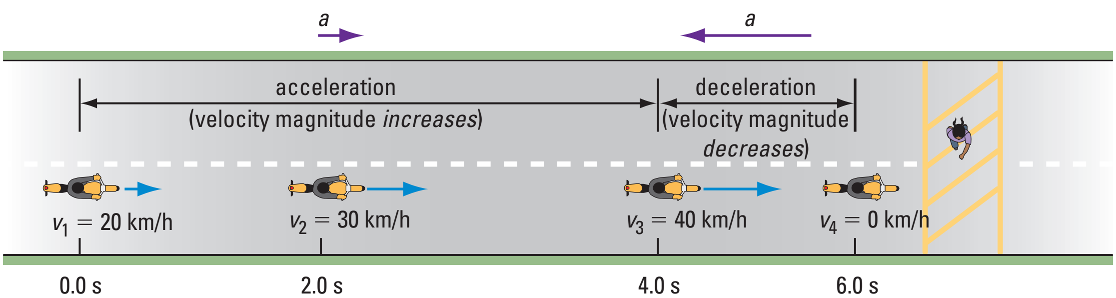

Figure 2.11(a) Change in velocity magnitude but *not* direction

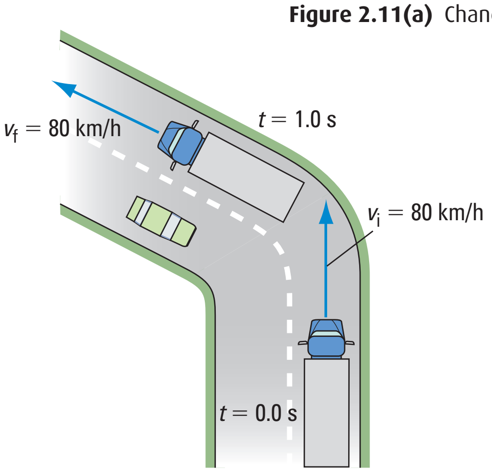

Figure 2.11(b) Change in velocity direction but *not* magnitude

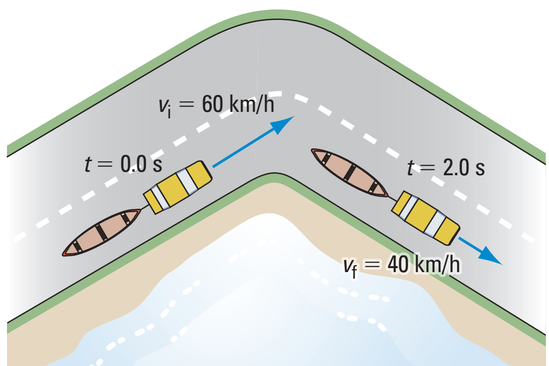

Figure 2.11(c) Change in velocity magnitude *and* direction

Uniform or Constant Acceleration

We know that the rate of change in velocity can also change with time, which means that the acceleration can also change. A common constant acceleration is the acceleration due to gravity (9.81 m/s^2). The direction of acceleration due to gravity acts vertically downwards. By definition,

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

$$\vec{v}_f = \vec{v}_i + \vec{a}\Delta t$$

This equation is called the first equation of motion for constant or uniform acceleration. It shows that the velocity of the object changes from $\vec{v}_i$ to $\vec{v}_f$ by an amount $\vec{a}\Delta t$.

This equation also shows that if the acceleration is uniform, the initial velocity and the velocity at any time have a linear relationship between them.

Consider an example of a car that starts from rest, then moves with an acceleration of 3.0 m/s^2. Refer to Figure 2.12 to see how the velocity will change.

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After 1.0 s, the velocity will be

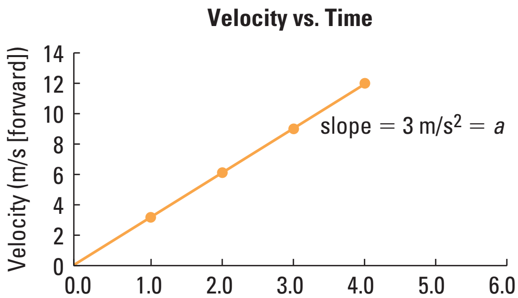

Figure 2.12

$\vec{v}_f = 0 \text{ m/s} + (3.0 \text{ m/s}^2)(1.0 \text{ s}) = 3.0 \text{ m/s}$

After 2.0 s, the velocity will be

$\vec{v}_f = 0 \text{ m/s} + (3.0 \text{ m/s}^2)(2.0 \text{ s}) = 6.0 \text{ m/s}$

After 3.0 s, the velocity will be

$\vec{v}_f = 0 \text{ m/s} + (3.0 \text{ m/s}^2)(3.0 \text{ s}) = 9.0 \text{ m/s}$

And so on ...

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Suggested Activity

- A5 Quick Lab Overview on page 39

Concept Check

1. The position-time graph for a vehicle in a drag race is shown in Figure 2.13.
   (a) From the graph, how do you know the vehicle is speeding up?
   (b) How can you use the slope of the tangent to answer part (a)?
2. What is the shape of the position-time graph for an object undergoing negative acceleration?

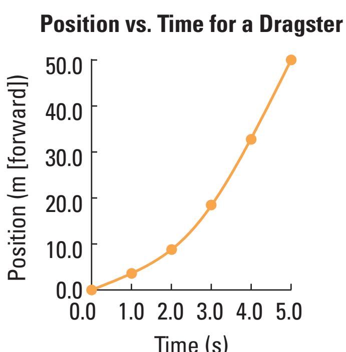


Figure 2.13

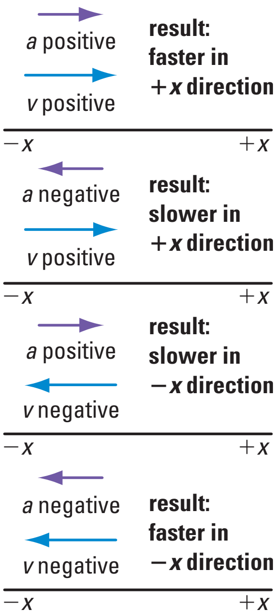
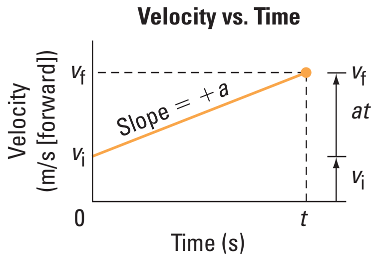


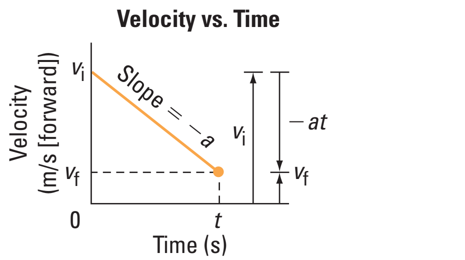
Figure 2.14 Signs of velocity and acceleration

Speeding Up and Slowing Down

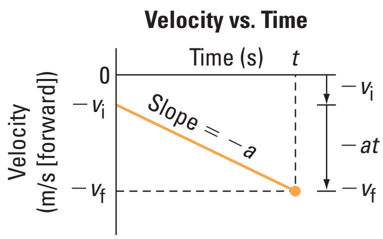
When an object travels with increasing velocities, we say that it is speeding up. Conversely, if it travels with decreasing velocities, we say that it is slowing down. Both velocity and acceleration are vector quantities. How does the direction of velocity relate to the direction of acceleration? The rule of thumb is that if the velocity and acceleration have the same sign (both positive or both negative), then the object will speed up and if their signs are different (one is negative and the other is positive), then the object will slow down. See Figures 2.14 and 2.15.



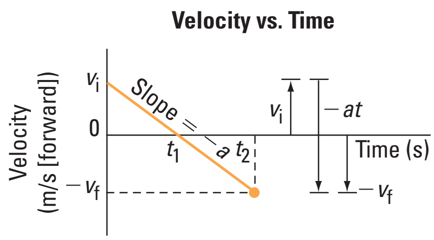
(a) Motion in positive direction — speeding up



(b) Motion in positive direction — slowing down



(c) Motion in negative direction — speeding up



(d) Changing direction

Figure 2.15 Signs of velocity and acceleration

To summarize,

(a) if there is a change in velocity, we say that the object is accelerating.

(b) if the acceleration of an object is in a direction opposite to that of its motion (that is, velocity), it slows down (decelerating).

(c) if an object is moving in the negative direction and its acceleration is also negative, the magnitude of its velocity will increase, which means the object will speed up in the negative direction

Velocity and Acceleration

Objects rarely travel at constant velocity. Think of your journey to school today. Whether you travelled by car or bus, rode a bike, or walked, stop signs, traffic lights, corners, and obstacles caused a variation in your velocity, or rate of travel. If you describe your motion to a friend, you can use a series of velocities at different instances. The more time instances you use to record your motion, the more details about your trip you can communicate to your friend.

Example 2.2

A bird starts flying south. Its motion is described in the velocity-time graph in Figure 2.16.
From the graph, determine
(a) i) whether acceleration is positive, negative, or zero for each section
  ii) if the bird is speeding up or slowing down in each of these sections. Confirm if your answer agrees with the graph.
  iii) the value of the acceleration where it is not zero
(b) when the bird changes direction

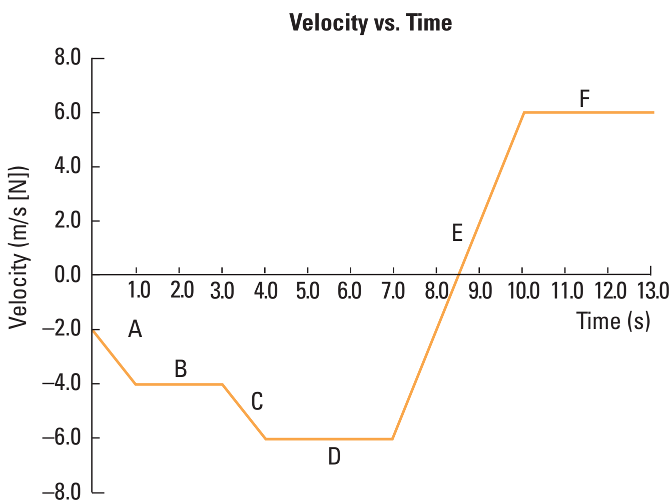
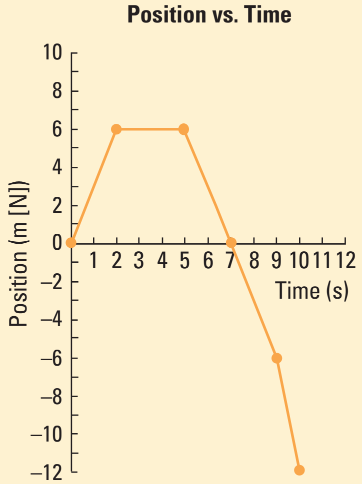


Figure 2.16

Analysis and Solution
(a) Take north as the positive direction.
We know that acceleration for each section is the slope of each section of the velocity-time graph.

Practice Problems

1. 

(a) Describe the motion of the object from the graph above.

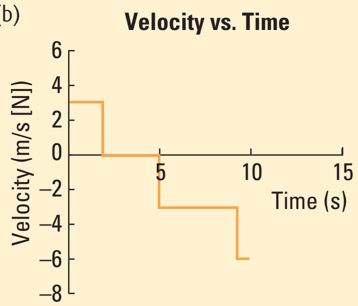
(b) Draw the corresponding velocity-time graph.

(c) Determine the object's displacement.

(d) When is the object stopped?

Answers

1. (a) +3 m/s for 2 s, rest for 3 s, −3 m/s for 4 s, −6 m/s for 1 s

(b) 

(c) −12 m

(d) 2–5 s

Section A

i) The slope of this section is negative, so the acceleration is negative.

ii) The bird is flying south, so its direction is negative. As acceleration is also negative, the bird is speeding up. This is also confirmed by the graph as the magnitude of velocity is increasing in this section.

iii) Acceleration is the slope of the velocity-time graph. In this case,

$$\begin{aligned}\vec{a} &= \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} \\ &= \frac{-4.0 \text{ m/s} - (-2.0 \text{ m/s})}{1.0 \text{ s} - 0 \text{ s}} \\ &= -2.0 \text{ m/s}^2 \\ &= 2.0 \text{ m/s}^2 \text{ [S]}\end{aligned}$$

Section B

i) The graph is horizontal, so the acceleration is zero.

ii) The velocity is a constant as acceleration is zero. This is confirmed by the graph.

iii) Slope of this section is zero.

Section C

i) The slope of this section is negative, so the acceleration is negative.

ii) The bird is flying south, so its direction is negative. As acceleration is also negative, the bird is speeding up. This is also confirmed by the graph as the magnitude of velocity is increasing in this section.

iii) Acceleration is the slope of the velocity-time graph. In this case,

$$\begin{aligned}\vec{a} &= \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} \\ &= \frac{-6.0 \text{ m/s} - (-4.0 \text{ m/s})}{4.0 \text{ s} - 3.0 \text{ s}} \\ &= -2.0 \text{ m/s}^2 \\ &= 2.0 \text{ m/s}^2 \text{ [S]}\end{aligned}$$

Section D

i) The graph is horizontal, so the acceleration is zero.

ii) The velocity is a constant as acceleration is zero. This is confirmed by the graph.

iii) The slope of this section is zero.

Section E

i) The slope of this section is positive, so the acceleration is positive.

ii) Between 7.0 s and 8.5 s, the bird is flying south (negative). As acceleration during this time is positive, the bird is slowing down. This is also confirmed by the graph as the magnitude of velocity is decreasing to zero in this section. Between 8.5 s and 10.0 s, the bird is flying north (positive) and the acceleration is also positive. Hence, the bird is speeding up. This is confirmed by the graph where the magnitude of the velocity is increasing from zero to 6.0 m/s

iii) Acceleration is the slope of the velocity-time graph. In this case,

$$\begin{aligned}\vec{a} &= \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}\\ &= \frac{+6.0\text{ m/s} - (-6.0\text{ m/s})}{10.0\text{ s} - 7.0\text{ s}}\\ &= +4.0\text{ m/s}^2\\ &= 4.0\text{ m/s}^2\text{ [N]}\end{aligned}$$

Section F

i) The graph is horizontal and hence the acceleration is zero.

ii) Velocity is constant, because the acceleration is zero. This is confirmed by the graph.

iii) The slope of this section is zero.

(b) In a velocity-time graph, the change in direction occurs when the velocity changes sign from positive to negative or vice-versa. In this case, this happens at $t = 8.5$ s.

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Take It Further

When jet fighters come in to land on an aircraft carrier, they stop so quickly that pilots sometimes lose consciousness for a few seconds. The same thing can happen when a pilot ejects from an aircraft, due to enormous acceleration. Research and report on the effects of increased acceleration on the human body.

Concept Check

1. If an object has negative acceleration, can we say for sure that it is slowing down?
2. You are given a position-time graph that is a curve. How can you use the slope of the tangent to determine whether the object represented in the graph is speeding up or slowing down? (Hint: How does the slope of the tangent change as you move along the position-time curve?)

Video

A5 Quick Lab

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Graphical Representation of Uniform Acceleration Motion

Purpose

To create, interpret, and analyze acceleration-time, velocity-time, and position-time graphs

Activity Overview

In this Quick Lab, you will create graphs of a walker moving

- toward the sensor with constant velocity (Figure 2.17)
- toward the sensor with steadily increasing velocity
- toward the sensor with steadily decreasing velocity
- away from the sensor with steadily increasing velocity
- away from the sensor with steadily decreasing velocity

You will then compare the slopes of some of these graphs to verify what you have learned in this section.

Your teacher will give you a copy of the full activity.

Prelab Questions

Consider the questions below before beginning this activity.

1. In a position-time graph, what is the slope of the line that represents a stationary object?

2. Describe the velocity of an object if its velocity-time graph is a horizontal line.

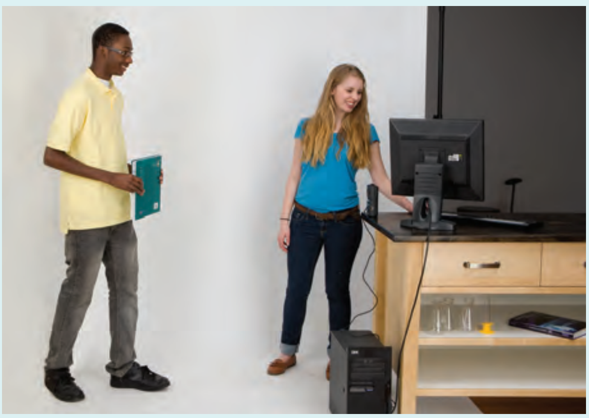


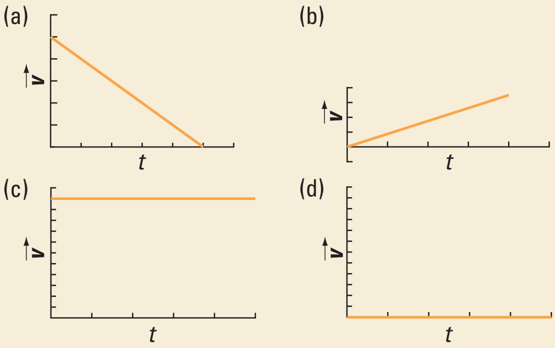
Figure 2.17 Setup for the activity

2.1 Check and Reflect

Key Concept Review

1. When is an object undergoing acceleration?

2. Describe the acceleration of the object in each velocity-time graph below.



Question 2

Connect Your Understanding

3. A sprinter in a championship race accelerates to his top speed in a short time. The velocity-time data for part of the race are given in the table below.

Time (s)	Velocity (m/s [forward])
0.00	0.00
0.12	0.00
0.14	0.00
0.50	2.80
1.00	5.00
2.00	8.00
3.00	9.80
4.00	10.80
5.00	11.30
6.00	11.60
7.00	11.70
8.00	11.80
9.00	11.90
9.83	11.95

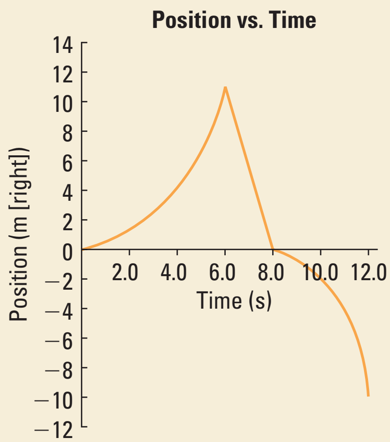
Use the data to find the
(a) average acceleration from 0.00 s to 0.50 s
(b) average acceleration from 0.50 s to 3.00 s
(c) average acceleration from 5.00 s to 6.00 s
(d) Describe what was happening to the acceleration and velocity over 6.00 s.

4. A man is driving his car at a velocity of 100 km/h on a straight road. He sees a traffic jam at a distance and slows down to 12.5 m/s in 3.0 s. What is the average acceleration of the car?

5. A race car is driving at a velocity of 15 m/s. It then accelerates at a rate of 4.5 m/s^2 for 5.0 s. What is the velocity of the race car at the end of the 5.0 s interval?

6. How much time does it take for a motorcycle to start from rest and reach a speed of 30.5 m/s if it accelerates at a rate of 5.0 m/s^2?

7. Refer to the graph given below to answer the following questions.
(a) What is the average velocity between the times 3.0 s and 6.0 s?
(b) What are the signs of velocity and acceleration between 2.0 s and 6.0 s, and 8.0 s and 12.0 s?
(c) Is the average velocity between 6.0 s and 8.0 s positive or negative? Why?



Question 7

Reflection

8. Why do you think it is important to learn about the acceleration of moving objects?

For more questions, go to PHYSICS•SOURCE

2.2 Analyzing Graphs to Study Motion

Section Summary

- Displacement is the area under the velocity-time graph.
- An acceleration-time graph can be made from a velocity-time graph.
- Average velocity can be found by the velocity-time graph.

When a plane flies across Ontario with constant speed and direction, it is said to be undergoing uniform motion (Figure 2.18(a)). If you were sitting in the plane, you would experience a smooth ride. An all-terrain vehicle (ATV) bouncing and careening along a rough trail is constantly changing speed and direction in order to stay on the road. A ride in the ATV illustrates non-uniform motion, or acceleration (Figure 2.19(a)).

You can distinguish between uniform and non-uniform motion by simple observation, gathering data from your observations, and graphing the data (see Figures 2.18(b) and 2.19(b)). One way to analyze graphs is by determining their slopes to obtain further information about an object's motion. Another method of graphical analysis is to find the area under a graph.

Figure 2.18(a) Uniform Motion

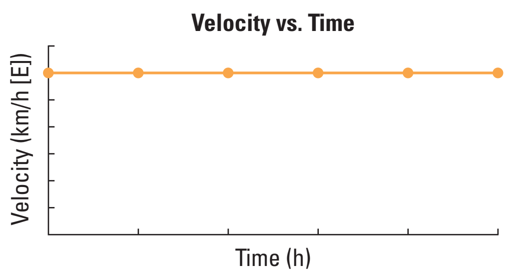


Figure 2.18(b) A graph representing uniform motion

Figure 2.19(a) Non-uniform Motion

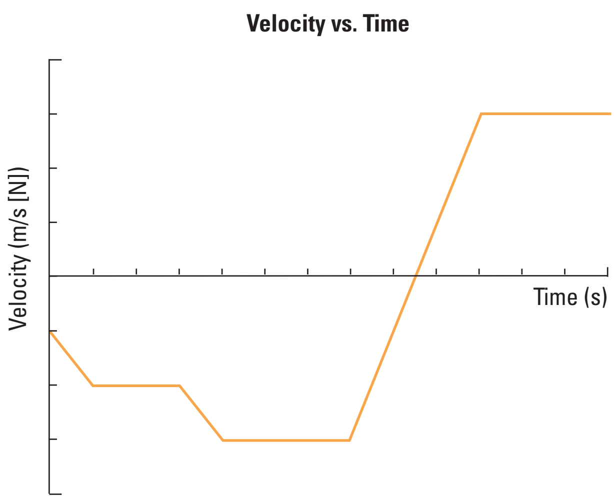


Figure 2.19(b) A graph representing non-uniform motion

Drawing Acceleration-time Graphs from Velocity-time Graphs

PHYSICS•SOURCE

Suggested Activity

- A6 Design a Lab Overview on page 46

Acceleration is the rate of change of velocity. The rate of change on a graph is the slope of a linear graph or the slope of the tangent at a point on a non-linear graph. To draw an acceleration-time graph when given a velocity-time graph, you will find the slopes of the velocity-time graph and then plot the acceleration against time on another graph.

Example 2.3

A group of friends travel in a car to go to a nearby park. The driver starts the car from rest. The car travels on a straight road and reaches a velocity of 12.0 m/s in 12.0 s. After the car travels with this velocity for 4.0 s, the friends decide they want to get coffee from a coffee shop. The driver then slows down for the next 9.0 s, and brings the car to a stop at the coffee shop. Refer to the velocity-time graph in Figure 2.20.

(a) Find the acceleration in each section of the graph.

(b) Draw the corresponding acceleration-time graph.

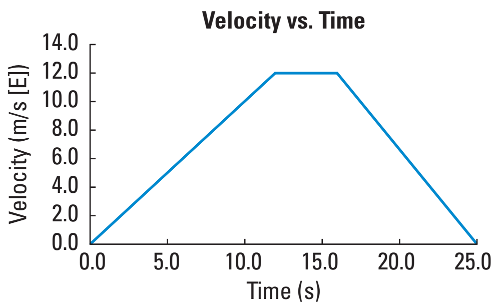


Figure 2.20

Analysis and Solution

(a) Find the slope of each section of the graph which is the acceleration for that part.

i) Between 0 s and 12.0 s:

$t_i = 0 \text{ s}$

$\vec{v}_i = 0 \text{ m/s}$

$t_f = 12.0 \text{ s}$

$\vec{v}_f = 12.0 \text{ m/s}$

$$\text{Slope} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$

$$= \frac{12.0 \text{ m/s} - 0 \text{ m/s}}{12.0 \text{ s} - 0 \text{ s}}$$

$$= 1.0 \text{ m/s}^2$$

ii) Between 12.0 s and 16.0 s:

$t_i = 12.0 \text{ s}$

$\vec{v}_i = 12.0 \text{ m/s}$

$t_f = 16.0 \text{ s}$

$\vec{v}_f = 12.0 \text{ m/s}$

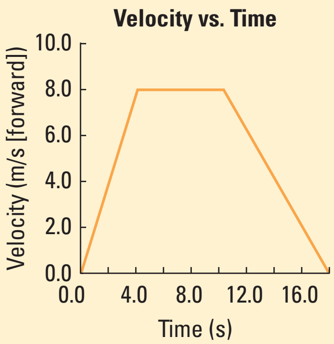
$$\text{Slope} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$

$$= \frac{12.0 \text{ m/s} - 12.0 \text{ m/s}}{16.0 \text{ s} - 12.0 \text{ s}}$$

$$= 0 \text{ m/s}^2$$

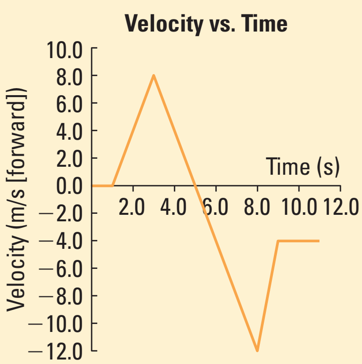
Practice Problems

1. (a) Find the acceleration of each portion of the velocity-time graph.



(b) Draw the corresponding acceleration-time graph.

2. (a) Find the acceleration of each portion of the velocity-time graph.



(b) Draw the corresponding acceleration-time graph.

(c) How does the object move in the last section?

iii) Between 16.0 s and 25.0 s:

$$t_i = 16.0\text{ s}$$
$$\vec{v}_i = 12.0\text{ m/s}$$
$$t_f = 25.0\text{ s}$$
$$\vec{v}_f = 0\text{ m/s}$$

$$\text{Slope} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$
$$= \frac{0\text{ m/s} - 12.0\text{ m/s}}{25.0\text{ s} - 16.0\text{ s}}$$
$$= -1.33\text{ m/s}^2$$

(b) The acceleration-time graph is given in Figure 2.21.

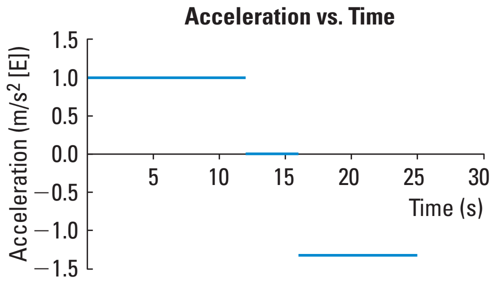
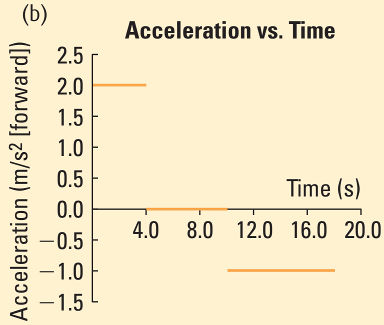


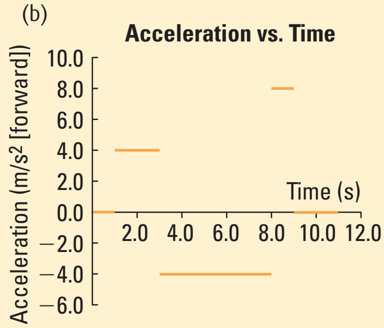
Figure 2.21

Answers

1. (a) 2.0 m/s^2, 0 m/s^2, -1.0 m/s^2
   (b)



2. (a) 0 m/s^2, 4.0 m/s^2, -4.0 m/s^2, 8.0 m/s^2, 0 m/s^2
   (b)



   (c) Backward at 4.0 m/s

Concept Check

1. What is the sign of the acceleration of the car in the given graph in Figure 2.22?
2. If north is positive, sketch position-time, velocity-time, and acceleration-time graphs for an object
   (a) speeding up and going north
   (b) slowing down and going north
   (c) speeding up and going south
   (d) slowing down and going south
3. Copy Table 2.4 and fill in the information by analyzing the position-time, velocity-time, and acceleration-time graphs you made in question 2.

Table 2.4 Analyzing Graphs

Graph Type	Reading the Graph	Slope	Area

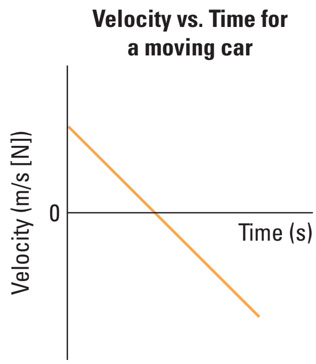


Figure 2.22

Drawing Position-time Graphs from Velocity-time Graphs

Average velocity is defined as the displacement per unit time. It can be found graphically by calculating the slope of a position-time graph.

Displacement of an object can be found from a velocity-time graph by calculating the area under the velocity-time graph. From this displacement, you can find the position of the object. Refer to the next example in which we will find the displacement and position by this method for the graph given in Figure 2.20.

Example 2.4

For the velocity-time graph in Figure 2.20:

(a) find the displacement in each section

(b) sketch a position-time graph from the above quantities

Analysis and Solution

(a) To find the displacement, find the area under the velocity-time graph for each section

i) Between 0 and 12.0 s, there is a triangle below the graph. Therefore, the area under the graph will be $\frac{b \times h}{2}$.

$$\text{Area} = \frac{b \times h}{2} = \frac{12.0\text{ s} \times 12.0\text{ m/s}}{2} = 72.0\text{ m}$$

This means that, during this time, the car moves from 0 m to 72.0 m in the positive direction. Also, as the velocity increases and the acceleration is positive during this time the position-time graph will be a *curved parabola with increasing slope* as shown in Figure 2.23.

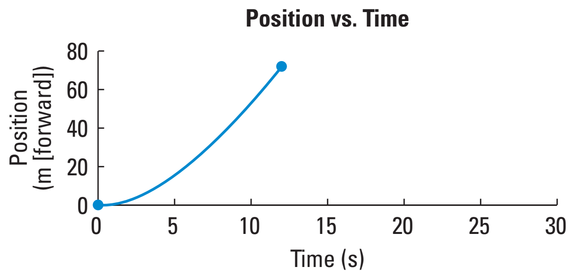


Figure 2.23

ii) Between 12.0 s and 16.0 s, the area under the graph is a rectangle. Hence, the area will be $w \times h$.

$$\text{Area} = w \times h = 4.0\text{ s} \times 12.0\text{ m/s} = 48\text{ m}$$

Therefore, the displacement between 12.0 s and 16.0 s is 48.0 m in the positive direction. But as the velocity is a constant during this time (acceleration = 0 m/s²), the graph will be a straight line with a positive slope. Also, the final displacement of the object will be (72 m + 48 m = 120 m) as shown in the graph in Figure 2.24.

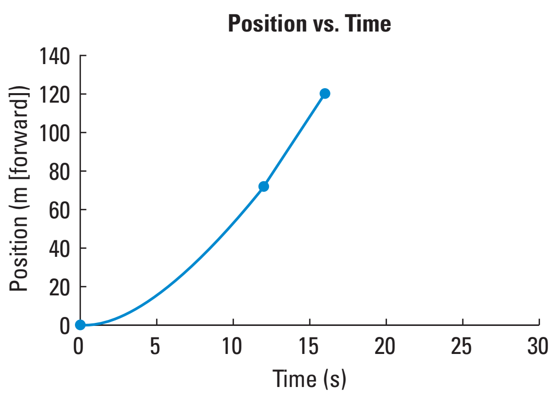


Figure 2.24

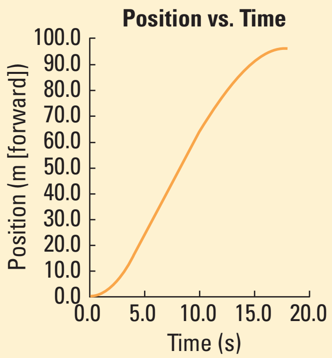
Practice Problems

1. For the velocity-time graph in Practice Problem 1 of Example 2.3,
   (a) find the displacement in each section
   (b) sketch a position-time graph from the above quantities
2. For the velocity-time graph in Practice Problem 2 of Example 2.3,
   (a) find the displacement in each section.
   (b) sketch a position-time graph from the above quantities.
   (c) what is the total displacement of the object?

Answers

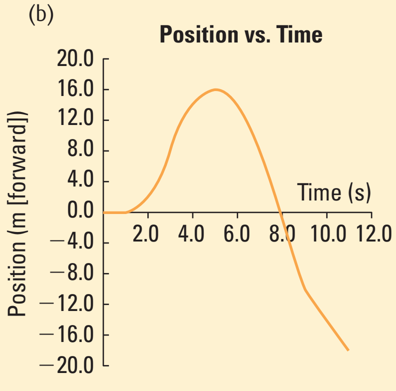
1. (a) 16 m, 48 m, 32 m

   (b)



2. (a) 0 m, 8.0 m, 8.0 m, −18.0 m, −8.0 m, −8.0 m

   (b)



   (c) −18.0 m

iii) Between 16.0 s and 25.0 s, the displacement, or the area under the graph, is a triangle. Therefore, the area will be $\frac{b \times h}{2}$.

$$\begin{aligned} \text{Area} &= \frac{b \times h}{2} \\ &= \frac{9.0\ \text{s} \times 12.0\ \text{m/s}}{2} \\ &= 54.0\ \text{m} \end{aligned}$$

During this time, the velocity of the car is decreasing and the acceleration is negative. But the car is still moving in the positive direction. Hence, the final position will be 120.0 m + 54.0 m = 174.0 m and the graph will be a curve with decreasing slope as shown in Figure 2.25.

(b)

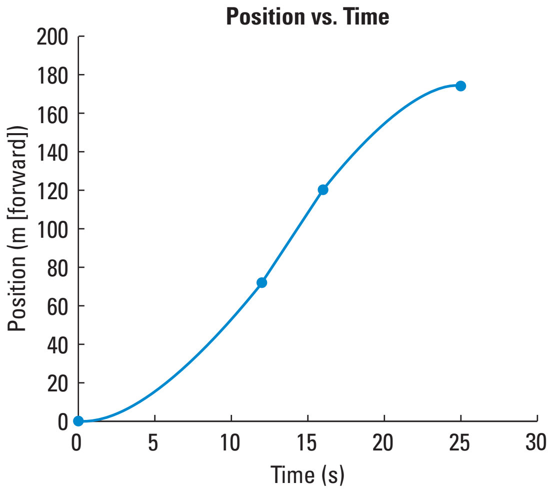


Figure 2.25 Complete position-time graph corresponding to the velocity-time graph in Figure 2.20 on page 42.

Finding Average Velocity from Velocity-time Graphs

An object's velocity can change from time to time. The average velocity can be determined by finding the total displacement and total time, and using the equation $\vec{v}_{\text{ave}} = \frac{\Delta \vec{d}}{\Delta t}$.

To find the average velocity from the velocity-time graph shown in Figure 2.26(a). The total displacement $\Delta \vec{d}$ can be found by finding the area under each section. Each of these quantities will give the displacements for those respective times. If the algebraic sum of these quantities is found and divided by the total time Δt, it will give you the average velocity, $\vec{v}_{\text{ave}}$. The average velocity is shown by the horizontal line in Figure 2.26(b) on the next page.

PHYSICS•SOURCE

Suggested Activity

- A7 Case Study Overview on page 46

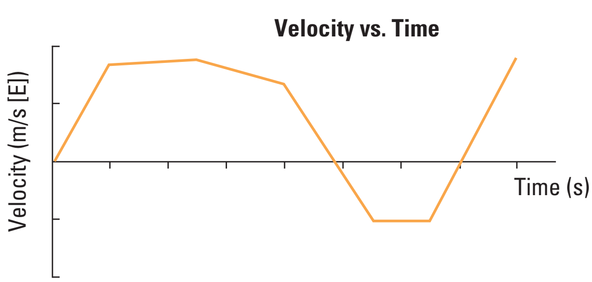


Figure 2.26(a) By using a series of instantaneous velocities at the given times, you can precisely describe your journey.

PHYSICS•SOURCE

Take It Further

In physics, the rate of change of acceleration is jerk or jolt. Its units are m/s^3. Find out more about jerk and report on its applications.

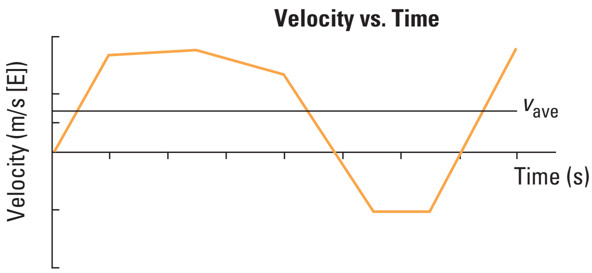


Figure 2.26(b) The straight line represents the average velocity of the journey. It describes your journey but the details of the motion is lost.

A6 Design a Lab

PHYSICS•SOURCE

REQUIRED SKILLS
- Designing an experimental procedure
- Evaluating procedures

Tortoise or Hare?

Question

In your class, who has the fastest acceleration and the fastest average speed in the 50-m dash?

Activity Overview

In this activity, you will design and conduct your own investigation to answer the question above. You will identify variables that influence acceleration. For each variable, you will write a hypothesis on how changes will affect acceleration. You will then conduct your investigation.

Your teacher will give you a copy of the full activity.

Prelab Questions

Consider the questions below before beginning this activity.

1. What are the men's and women's records for the 50-m dash?
2. What factors will influence a sprinter's performance of the 50-m dash?

A7 Case Study

PHYSICS•SOURCE

REQUIRED SKILLS
- Gathering information
- Summarizing information

Traffic Safety Is Everyone's Business

Purpose

To identify the causes of collisions in order to reduce such occurrences.

Activity Overview

In this activity, you will research different traffic safety programs. You will select one and write a report to recommend the program.

Your teacher will give you a copy of the full activity.

Prelab Questions

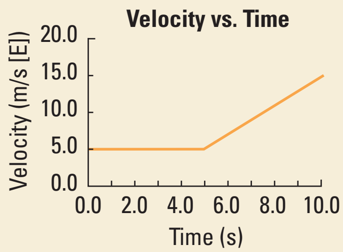
Consider the questions below before beginning this activity.

1. List as many causes of traffic accidents as you can think of.
2. Choose one of the causes. What has been done to reduce this type of accident?

2.2 Check and Reflect

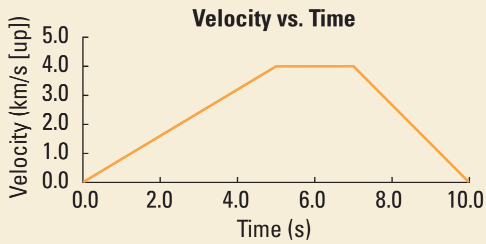
Key Concept Review

1. Use the terms "displacement" and "velocity" to describe how uniformly accelerated motion differs from uniform motion.
2. How can acceleration be calculated from a velocity-time graph?
3. From a velocity-time graph, how can you find out if the object is speeding up or slowing down?
4. Find the acceleration in each segment of the graph.



Question 4

5. (a) Describe the motion in the graph below.
   (b) Find the acceleration in each segment of the graph. Also, state in which segment the object is speeding up, slowing down, or the velocity is constant.

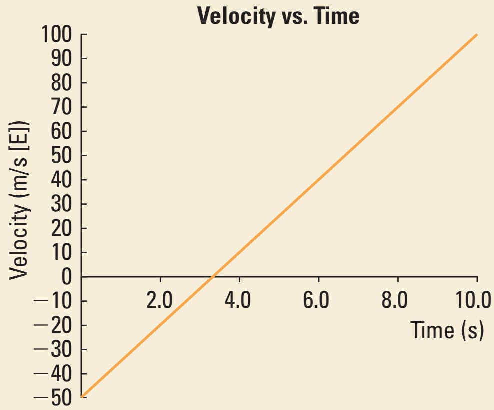


Question 5

6. Describe the velocity-time graph for an object undergoing negative acceleration.
7. What quantity of motion can be determined from the area under a velocity-time graph?
8. Compare and contrast the shape of a velocity-time graph for an object experiencing uniform motion with one experiencing uniformly accelerated motion.
9. Describe the acceleration-time graph of a car travelling forward and applying its brakes.

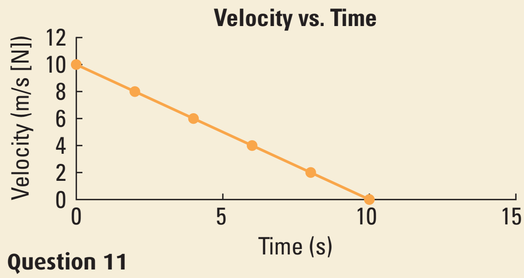
Connect Your Understanding

10. Calculate the acceleration of an object using the velocity-time graph below.



Question 10

11. Construct an acceleration-time graph using the graph given below.



Question 11

12. (a) While driving north from Lake Louise to Jasper, you travel 75 min at a velocity of 70 km/h [N] and another 96 min at 90 km/h [N]. Calculate your average velocity.
    (b) Create a graph for part (a) and check your answer using graphing techniques.
13. A truck initially travelling forward at 14.0 m/s accelerates at 1.85 m/s^2 for 6.00 s. It then travels at the new speed for 35.0 s, when a construction zone forces the driver to push on the brakes, providing an acceleration of -2.65 m/s^2 for 7.0 s. Draw the resulting velocity-time and position-time graphs for this motion.

Reflection

14. What do you think is the most interesting information you learned in this section?

For more questions, go to PHYSICS•SOURCE

2.3 Equations for Uniform Acceleration (Kinematic Equations)

Section Summary

- There are five equations of motion:
  $\vec{v}_f = \vec{v}_i + \vec{a}\Delta t$, $\Delta\vec{d} = \left(\frac{\vec{v}_f + \vec{v}_i}{2}\right)\Delta t$, $\Delta\vec{d} = \vec{v}_i\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$, $\Delta\vec{d} = \vec{v}_f\Delta t - \frac{1}{2}\vec{a}(\Delta t)^2$,
  and $v_f^2 = v_i^2 + 2a\Delta d$

A cylindrical piston, under the deck and the length of a football field, controls the launch of a fighter plane from the deck of an aircraft carrier (Figure 2.27). Too much pressure and the nose gear is ripped off; too little pressure and the plane crashes into the ocean. This propulsion system accelerates a 20 000-kg plane from rest to 74 m/s (266 km/h) in just 2.0 s! To determine the crucial values required for launching a plane, such as flight deck length, final velocity, and acceleration, physicists and engineers use kinematics equations similar to the ones you will know by the end of this section.

Figure 2.27 Planes taking off from the deck of an aircraft carrier.

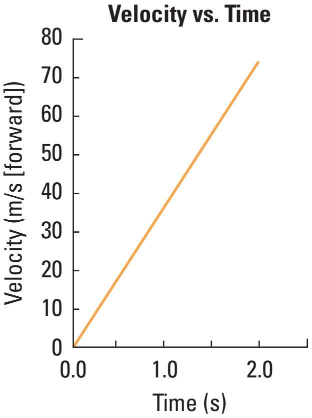


Figure 2.28 The slope of this velocity-time graph represents the plane's acceleration.

Consider the fighter plane taking off from a moving aircraft carrier (Figure 2.27). The plane must reach its takeoff speed before it comes to the end of the carrier's runway. If the plane starts from rest, the velocity-time graph representing the plane's motion is shown in Figure 2.28. Notice that it is a linear graph and the slope is constant. In this case, the acceleration is constant (uniform). We will assume that acceleration is uniform in all problems.

Equations of Motion for Uniform Acceleration

In this section, you will practise your analytical skills by learning how to derive the kinematics equations.

First Equation of Motion

As you learned in section 2.1, the first kinematics equation is derived from the definition of acceleration

$\vec{v}_f = \vec{v}_i + \vec{a}\Delta t$

Example 2.5

A hybrid car with an initial velocity of 10.0 m/s [E] accelerates at 3.0 m/s^2 [E] (Figure 2.29). How long will it take the car to acquire a final velocity of 25.0 m/s [E]?

Figure 2.29

Given

Designate east as the positive direction.

$\vec{v}_i = 10.0$ m/s [E] $= +10.0$ m/s

$\vec{v}_f = 25.0$ m/s [E] $= +25.0$ m/s

$\vec{a} = 3.0$ m/s^2 [E] $= +3.0$ m/s^2

Required

time (Δt)

Analysis and Solution

Use the equation

$\vec{v}_f = \vec{v}_i + \vec{a}\Delta t$

Isolate Δt and solve.

$$\begin{aligned}\Delta t &= \frac{\vec{v}_f - \vec{v}_i}{a} \\ &= \frac{25 \text{ m/s} - 10 \text{ m/s}}{3.0 \text{ m/s}^2} \\ &= \frac{15 \text{ m/s}}{3.0 \text{ m/s}^2} \\ &= 5.0 \text{ s}\end{aligned}$$

Paraphrase

It will take the car 5.0 s to reach a velocity of 25.0 m/s [E].

Practice Problems

1. A motorcycle with an initial velocity of 6.0 m/s [E] accelerates at 4.0 m/s^2 [E]. How long will it take the motorcycle to reach a final velocity of 36.0 m/s [E]?
2. An elk moving at a velocity of 20 km/h [N] accelerates at 1.5 m/s^2 [N] for 9.3 s until it reaches its maximum velocity. Calculate its maximum velocity, in km/h.

Answers

1. 7.5 s
2. 70 km/h [N]

Second Equation of Motion

If $\vec{v}_i$ is the initial velocity and $\vec{v}_f$ is the final velocity, and the acceleration is uniform, then the average velocity, $\vec{v}_{ave}$, is given by the average of the initial and final velocities.

$$\vec{v}_{ave} = \frac{\vec{v}_f + \vec{v}_i}{2}$$

You know that the displacement is the product of the time and average velocity.

$$\Delta\vec{d} = \vec{v}_{ave}\Delta t$$

This is also the area under a velocity-time graph. If you substitute v_{ave} in the second equation above, you will get the second kinematics equation

$$\Delta\vec{d} = \left(\frac{\vec{v}_f + \vec{v}_i}{2}\right)\Delta t$$

Example 2.6

A coal train travelling west at 16.0 m/s is brought to rest in 8.0 s (Figure 2.30). Find the displacement of the coal train while it is coming to a stop. Assume uniform acceleration.

Figure 2.30

Given

Designate west as the positive direction.

$\vec{v}_i = 16.0$ m/s [W] $= +16.0$ m/s

$\vec{v}_f = 0$ m/s [W] $= 0$ m/s

$\Delta t = 8.0$ s

Required

displacement ($\Delta\vec{d}$)

Analysis and Solution

Use the equation $\Delta\vec{d} = \left(\frac{\vec{v}_f + \vec{v}_i}{2}\right)\Delta t$ and solve for $\Delta\vec{d}$.

$$\Delta\vec{d} = \left(\frac{0 \text{ m/s} + 16.0 \text{ m/s}}{2}\right)(8.0 \text{ s})$$

$$= +64 \text{ m}$$

The sign is positive, so the train's direction is west.

Paraphrase

The coal train travels 64 m [W] before it stops.

Practice Problems

1. A dog running at a velocity of 16 m/s [S] slows down uniformly to a velocity of 4.0 m/s [S] in 4.0 s. What is the displacement of the dog during this time?
2. A ball moves up a hill with an initial velocity of 3.0 m/s. Four seconds later, it is moving down the hill at 9.0 m/s. Find the displacement of the ball from its initial point of release.

Answers

1. 40 m [S]
2. −12 m

Third Equation of Motion

If acceleration is uniform, you know $\Delta\vec{d} = \left(\frac{\vec{v}_f + \vec{v}_i}{2}\right)\Delta t$.

Therefore,

$$2\Delta\vec{d} = (\vec{v}_f + \vec{v}_i)\Delta t$$
$$2\Delta\vec{d} = \vec{v}_f\Delta t + \vec{v}_i\Delta t$$

Substitute for $\vec{v}_f$ from $\vec{v}_f = \vec{v}_i + \vec{a}\Delta t$ in the above equation.

$$2\Delta\vec{d} = (\vec{v}_i + \vec{a}\Delta t)\Delta t + \vec{v}_i\Delta t$$
$$2\Delta\vec{d} = \vec{v}_i\Delta t + \vec{a}(\Delta t)^2 + \vec{v}_i\Delta t$$
$$2\Delta\vec{d} = 2\vec{v}_i\Delta t + \vec{a}(\Delta t)^2$$
$$\boxed{\Delta\vec{d} = \vec{v}_i\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2}$$

This is the third kinematics equation.

Example 2.7

A golf ball that is initially travelling at 25 m/s hits a sand trap and slows down with an acceleration of $-20\ \text{m/s}^2$ (Figure 2.31). Find its displacement after 1.0 s.

Figure 2.31

Given

Assign a positive direction for forward and a negative direction for backward.

$\vec{v}_i = +25\ \text{m/s}$

$\vec{a} = -20\ \text{m/s}^2$

$\Delta t = 1.0\ \text{s}$

Required

displacement ($\Delta\vec{d}$)

Analysis and Solution

Use the equation $\Delta\vec{d} = \vec{v}_i\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$ to solve for $\Delta\vec{d}$.

$$\Delta\vec{d} = (25\ \text{m/s})(1.0\ \text{s}) + \frac{1}{2}(-20\ \text{m/s}^2)(1.0\ \text{s})^2$$
$$= +25\ \text{m} + (-10\ \text{m})$$
$$= +15\ \text{m}$$

The sign is positive, so the direction is forward.

Paraphrase

The displacement of the golf ball is 15 m [forward].

Practice Problems

1. A skier is moving down a uniform slope with an initial speed of 3.0 m/s. If the acceleration down the hill is $4.0\ \text{m/s}^2$, find the skier's displacement after 5.0 s.
2. A motorcycle is travelling at 100 km/h on a flat road. The rider applies the brakes to slow down the motorcycle at the rate of $0.80\ \text{m/s}^2$ for 30 s. How far did the motorcycle travel during this time?

Answers

1. 65 m [down]
2. 4.7×10^2 m

Fourth Equation of Motion

Since $\vec{v}_f = \vec{v}_i + \vec{a}\Delta t$

Substitute $\vec{v}_i = \vec{v}_f - \vec{a}\Delta t$ into the equation $\Delta\vec{d} = \vec{v}_i\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$.

So, $\Delta\vec{d} = (\vec{v}_f - \vec{a}\Delta t)\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$

$\Delta\vec{d} = \vec{v}_f\Delta t - \vec{a}(\Delta t)^2 + \frac{1}{2}\vec{a}(\Delta t)^2$

$$\Delta\vec{d} = \vec{v}_f\Delta t - \frac{1}{2}\vec{a}(\Delta t)^2$$

This is the fourth kinematics equation.

Example 2.8

A speedboat slows down at a rate of 5.0 m/s² and comes to a stop (Figure 2.32). If the process took 15 s, find the displacement of the boat.

Figure 2.32

Given

Let forward be the positive direction.

$\vec{v}_f$ = 0.0 m/s (because the boat comes to rest)

Δt = 15 s

$\vec{a}$ = −5.0 m/s² (Acceleration is negative because the boat is slowing down, so its sign must be opposite to that of velocity (positive))

Required

displacement (Δd)

Analysis and Solution

Use the equation $\Delta\vec{d} = \vec{v}_f\Delta t - \frac{1}{2}a(\Delta t)^2$ to solve for $\Delta\vec{d}$.

$$\begin{aligned}\Delta\vec{d} &= (0\text{ m/s})(15\text{ s}) - \frac{1}{2}(-5.0\text{ m/s}^2)(15\text{ s})^2\\ &= +562.5\text{ m}\\ &= +5.6 \times 10^2\text{ m}\end{aligned}$$

The sign is positive, so the direction of displacement is forward.

Paraphrase

The displacement of the speedboat is 5.6×10^2 m [forward].

Practice Problems

1. If the steel cables on an aircraft carrier stops a plane in 150 m with an acceleration of −15 m/s², find the time the plane takes to stop.
2. The 1968 Corvette took 6.2 s to accelerate to 160 km/h [N]. If it travelled 220 m [N], find its acceleration.

Answers

1. 4.5 s
2. 2.9 m/s² [N]

Fifth Equation of Motion

Isolate Δt in the equation $\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$. Remember that, when multiplying or dividing vectors, use the scalar form of the equation:

$$\Delta t = \frac{v_f - v_i}{a}$$

Substitute the expression for Δt into $\Delta d = \left(\frac{v_f + v_i}{2}\right)\Delta t$:

$$\Delta \vec{d} = \left(\frac{v_f + v_i}{2}\right)\left(\frac{v_f - v_i}{a}\right)$$

$$\Delta d = \frac{v_f^2 - v_i^2}{2a}$$

$$v_f^2 = v_i^2 + 2a\Delta d$$

This is the fifth kinematics equation.

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Suggested Activity

- A8 Inquiry Activity Overview on page 54

Example 2.9

A bullet accelerates the length of the barrel of a rifle (0.750 m) with a magnitude of 5.35×10^5 m/s^2 (Figure 2.33). With what speed does the bullet exit the barrel?

Figure 2.33

Given

$a = 5.35 \times 10^5$ m/s^2
$d = 0.750$ m

Required

final speed (v_f)

Analysis and Solution

Use the equation $v_f^2 = v_i^2 + 2a\Delta d$

Since the bullet starts from rest, $v_i = 0$ m/s

$$\begin{aligned} v_f^2 &= (0 \text{ m/s})^2 + 2(5.35 \times 10^5 \text{ m/s}^2)(0.750 \text{ m}) \\ &= 802\ 500 \text{ m}^2/\text{s}^2 \end{aligned}$$

$$\begin{aligned} v_f &= \sqrt{802\ 500 \text{ m}^2/\text{s}^2} \\ &= 896 \text{ m/s} \end{aligned}$$

Paraphrase

The bullet leaves the barrel of the gun with a speed of 896 m/s.

Practice Problems

1. A jetliner lands on a runway at 70 m/s, reverses its engines to provide braking, and comes to a halt 29 s later. Its acceleration is constant over these 29 s.
   (a) What is the jet's acceleration?
   (b) What length of runway did the jet require to come safely to a complete stop?
2. On-ramps are designed so that motorists can move seamlessly into highway traffic. If a car needs to increase its speed from 50 km/h to 100 km/h and the engine can provide a maximum acceleration of magnitude 3.8 m/s^2, find the minimum length of the on-ramp.

Answers

1. (a) -2.4 m/s^2 [forward]
   (b) 1.0 km
2. 76 m

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Take It Further

One of the many applications of kinematics equations is in the field of robotics. Research how the equations are used in this field and report your findings.

General Method of Solving Kinematics Problems

Now that you know five kinematics equations, how do you know which one to use to solve a problem? To answer this question, notice that each of the five kinematics equations has four variables. Each kinematics problem will provide you with three of these variables, as given values. The fourth variable represents the unknown value. When choosing your equation, make sure that all three known variables and the one unknown variable are represented in the equation (see Table 2.5). You may need to rearrange the equation to solve for the unknown variable. It is important to note that the equations are for objects undergoing constant acceleration.

Table 2.5 The Variables in the Five Kinematics Equations

Equation	$\Delta\vec{d}$	$\vec{a}$	$\vec{v}_f$	$\vec{v}_i$	Δt
$\vec{v}_f = \vec{v}_i + \vec{a}\Delta t$		X	X	X	X
$\Delta\vec{d} = \left(\frac{\vec{v}_f + \vec{v}_i}{2}\right)\Delta t$	X		X	X	X
$\Delta\vec{d} = \vec{v}_i\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$	X	X		X	X
$\Delta\vec{d} = \vec{v}_f\Delta t - \frac{1}{2}\vec{a}(\Delta t)^2$	X	X	X		X
$v_f^2 = v_i^2 + 2a\Delta d$	X	X	X	X	

DI Key Activity

A8 Inquiry Activity PHYSICS•SOURCE

REQUIRED SKILLS
- Recording and organizing data
- Drawing conclusions

Finding the Acceleration of Objects Falling Down or Going Up Vertically

Question

Will the acceleration of objects falling down or going up vertically be the same or different?

Activity Overview

In this activity, you will use objects of different masses, material, and shapes. You will drop these objects (Figure 2.34) and/or throw them upwards and record the data to create distance-time and velocity-time graphs of this motion. Then, for each part, you will determine the accelerations to answer the question.

Your teacher will give you a copy of the full activity.

Prelab Questions

Consider the questions below before beginning this activity.

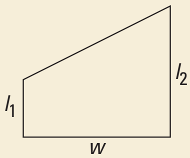
1. If an object is moving at a constant velocity, what is the acceleration of the object?
2. The acceleration of an object is positive and constant. Describe the velocity of the object.

Figure 2.34

2.3 Check and Reflect

Key Concept Review

1. (a) If an object starts from rest, what is $\vec{v}_i$?
   (b) If an object comes to a stop, what is $\vec{v}_f$?
   (c) If an object experiences uniform motion, what is $\vec{a}$?
2. Figure 2.28 on page 48 shows the velocity-time graph of an object undergoing uniformly accelerated motion.
   (a) Use the units on the graph to show that the slope represents acceleration.
   (b) Show how the slope of the graph can be used to derive the first kinematics equation.
3. To calculate the displacement (area) from a velocity-time graph, you can use the formula for the area of a trapezoid, $A = \frac{1}{2}(l_2 + l_1)w$, which is the average of the parallel sides multiplied by the base. Show how this formula and the second kinematics equation are related.



Question 3

4. You can calculate the area under a velocity-time graph by considering that the total area under the graph is made up of a triangle and a rectangle.
   (a) Which part of the third kinematics equation represents the rectangle? Why?
   (b) Which part represents the triangle? Why?

Connect Your Understanding

5. How far will a humanoid robot travel in 3.0 s, accelerating at 1.0 cm/s^2 [forward], if its initial velocity is 5.0 cm/s [forward]?
6. What is the displacement of a logging truck accelerating from 10 m/s [right] to 20 m/s [right] in 5.0 s?
7. How far will a car travel if it starts from rest and experiences an acceleration of magnitude 3.75 m/s^2 [forward] for 5.65 s?
8. Determine the acceleration of a bullet starting from rest and leaving the muzzle 2.75×10^{-3} s later with a velocity of 460 m/s [forward].
9. An aircraft starts from rest and accelerates at 42.5 m/s^2 until it takes off at the end of the runway. How long will it take the aircraft to travel down the 2.6 km runway?
10. If a cyclist traveling at 14.0 m/s skids to a stop in 5.60 s, determine the skidding distance. Assume uniform acceleration.
11. Approaching a flashing pedestrian activated traffic light, a driver must slow down to a speed of 30 km/h. If the crosswalk is 150 m away and the vehicle's initial speed is 50 km/h, what must be the magnitude of the car's acceleration to reach this speed limit?
12. A train's stopping distance, even when full emergency brakes are engaged, is 1.3 km. If the train was travelling at an initial velocity of 90 km/h [forward], determine its acceleration under full emergency braking.
13. A rocket starts from rest and accelerates uniformly for 2.00 s over a displacement of 150 m [W]. Determine the rocket's acceleration.
14. A jet starting from rest reaches a speed of 241 km/h on 96.0 m of runway. Determine the magnitude of the jet's acceleration.
15. What is a motorcycle's acceleration if it starts from rest and travels 350.0 m [S] in 14.1 s?
16. Determine the magnitude of a car's acceleration if its stopping distance is 39.0 m for an initial speed of 97.0 km/h.
17. A typical person can tolerate an acceleration of about -49 m/s^2 [forward]. If you are in a car travelling at 110 km/h and have a collision with a solid immovable object, over what minimum distance must you stop so as to not exceed this acceleration?
18. Determine a submarine's acceleration if its initial velocity is 9.0 m/s [N] and it travels 1.54 km [N] in 2.0 min.

Reflection

19. Why do you think it is important to understand the kinematics equations?

For more questions, go to PHYSICS•SOURCE

CHAPTER REVIEW

Key Concept Review

1. What is a vehicle's displacement if it travels at a velocity of 30.0 m/s [W] for 15.0 min? k

2. How long will it take a cross-country skier, travelling 5.0 km/h, to cover a distance of 3.50 km? k

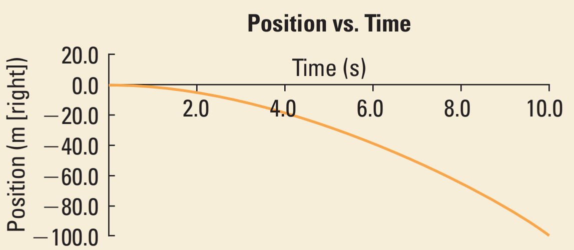
3. If an object thrown directly upwards remains in the air for 5.6 s before it returns to its original position, how long did it take to reach its maximum height? k

4. If an object thrown directly upwards reaches its maximum height in 3.5 s, how long will the object be in the air before it returns to its original position? Assume there is no air resistance. k

5. An object is dropped from rest at a height, *h*. What is the final velocity just before it hits the ground? k

Connect Your Understanding

6. Describe the motion of the object as illustrated in the graph below. c



Question 6

7. Calculate the magnitude of a bullet's acceleration if it travels at a speed of 1200 m/s and stops within a bulletproof vest that is 1.0 cm thick. a

8. The world record for a speedboat is 829 km/h. Heading south, how far will the boat travel in 2.50 min? Assume uniform velocity. a

9. How much faster, on average, is an airliner than a stagecoach if the stagecoach takes 24 h to travel 300 km and the airliner takes 20 min? a

10. A car's odometer reads 22 647 km at the start of a trip and 23 209 km at the end. If the trip took 5.0 h, what was the car's average speed in km/h? a

11. A motorcycle coasts downhill from rest with a constant acceleration. If the motorcycle moves 90.0 m in 8.00 s, find its acceleration and velocity after 8.00 s. a

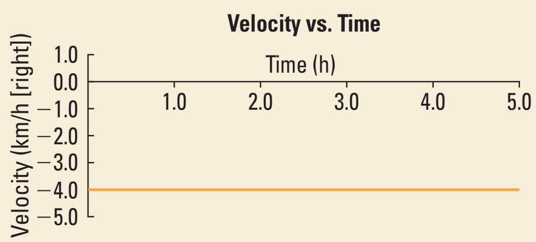
12. A cyclist crosses a 30.0-m bridge in 4.0 s. If her initial velocity was 5.0 m/s [N], find her acceleration and velocity at the other end of the bridge. a

13. An object with an initial velocity of 10.0 m/s [S] moves 720 m in 45.0 s along a straight line with constant acceleration. For the 45.0-s interval, find its average velocity, final velocity, and acceleration. a

14. During qualifying heats for the Molson Indy, a car must complete a 2.88-km lap in 65 s. If the car goes 60 m/s for the first half of the lap, what must be its minimum average speed for the second half to still qualify? a

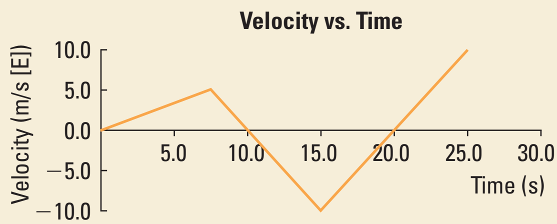
15. A car travelling 19.4 m/s passes a police car at rest. As it passes, the police car starts up, accelerating with a magnitude of 3.2 m/s^2. Maintaining that acceleration, how long will it take the police car to catch up with the speeding motorist? At what speed would the police car be moving? Explain whether or not this scenario is likely to happen. t

16. Calculate displacement and acceleration from the graph below. a



Question 16

17. Describe the motion and find the acceleration in each segment of the graph below. c



Question 17

18. A motorbike increases its velocity from 20.0 m/s [W] to 30.0 m/s [W] over a distance of 200 m. Find the acceleration and the time it takes to travel this distance. a

19. In Ontario, in 1998, the world's fastest fire truck, the Hawaiian Eagle, reached a speed of 655 km/h. It can accelerate at 9.85 m/s^2 [forward]. Starting from rest, how long will it take the Hawaiian Eagle to travel a displacement of 402 m [forward]? a

20. A vehicle is travelling at 25.0 m/s. Its brakes provide an acceleration of −3.75 m/s^2 [forward]. What is the driver's maximum reaction time if she is to avoid hitting an obstacle 95.0 m away? a

21. Off-ramps are designed for motorists to decrease their vehicles' velocities to move seamlessly into city traffic. If the off-ramp is 1.10 km long, calculate the magnitude of a vehicle's acceleration if it reduces its speed from 110.0 km/h to 60.0 km/h. a

22. A racecar accelerates uniformly from 17.5 m/s [W] to 45.2 m/s [W] in 2.47 s. Determine the acceleration of the racecar. a

23. How long will it take a vehicle travelling 80 km/h [W] to stop if the average stopping distance for that velocity is 76.0 m? Assume uniform acceleration. a

24. The Slingshot, an amusement park ride, propels its riders upward from rest with an acceleration of 39.24 m/s^2. How long does it take to reach a height of 27.0 m? a

Question 24

25. Starting from rest, a platform diver hits the water with a speed of 55 km/h. From what height did she start her descent into the pool? a

26. A circus performer can land safely on the ground at speeds up to 13.5 m/s. What is the greatest height from which the performer can fall? a

27. A contractor drops a bolt from the top of a roof located 8.52 m above the ground. How long does it take the bolt to reach the ground, assuming there is no air resistance? a

28. An improperly installed weathervane falls from the roof of a barn and lands on the ground 1.76 s later. From what height did the weathervane fall and how fast was it travelling just before impact? a

29. While attempting to beat the record for tallest Lego structure, a student drops a piece from a height of 24.91 m. How fast will the piece be travelling when it is 5.0 m above the ground and how long will it take to get there? a

30. Weave zones are areas on roads where vehicles are changing their velocities to merge onto and off busy expressways. Suggest criteria a design engineer must consider in developing a weave zone. t

31. Create a flowchart to describe the changes in position, velocity, and acceleration for both uniform and accelerated motion. t

Reflection

32. What can you explain about acceleration that you were not able to explain before reading the chapter? c

Unit Task Link

Design an experiment to calculate the stopping distances for a car moving at different velocities on a road. What will you need to determine the car's acceleration? What will be the dependent and independent variables in your experiment?

For more questions, go to PHYSICS•SOURCE