4.1 Motion

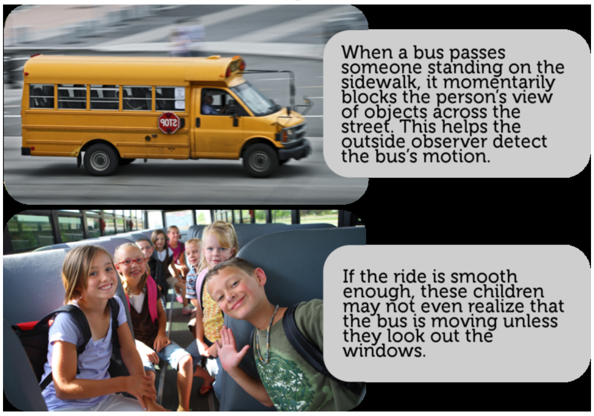
- Define motion.
- Explain how frame of reference is related to motion.

Defining Motion

In science, **motion** is defined as a change in position. An object's position is its location.

Frame of Reference

There's more to motion than objects simply changing position. You'll see why when you consider the following example. Assume that the school bus pictured in the **Figure** 4.2 passes by you as you stand on the sidewalk. It's obvious to you that the bus is moving, but what about to the children inside the bus? The bus isn't moving relative to them, and if they look at the other children sitting on the bus, they won't appear to be moving either. If the ride is really smooth, the children may only be able to tell that the bus is moving by looking out the window and seeing you and the trees whizzing by.



Summary

- Motion is defined as a change of position.
- How we perceive motion depends on our frame of reference. Frame of reference refers to something that is not moving with respect to an observer that can be used to detect motion.

Vocabulary

- **frame of reference**: Something that is not moving with respect to an observer that can be used to detect motion.
- **motion**: Change in position.

4.2 Distance

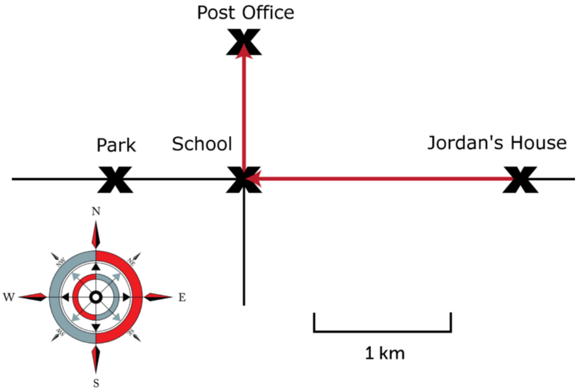
What Is Distance?

Distance is the length of the route between two points. The distance of a race, for example, is the length of the track between the starting and finishing lines. In a 100-meter sprint, that distance is 100 meters.

4.3 Direction

Introducing Direction

Direction can be described in relative terms, such as up, down, in, out, left, right, forward, backward, or sideways. Direction can also be described with the cardinal directions: north, south, east, or west. On maps, cardinal directions are indicated with a compass rose. You can see one in the bottom left corner of the map in the **Figure** 4.4. You can use the compass rose to find directions on the map. For example, to go to the school from Jordan's house, you would travel from east to west. If you wanted to go on to the post office, you would change direction at the school and then travel from south to north.



Position and Displacement

$\vec{d}$

The Big Idea

Speed represents how quickly an object is moving through space. Velocity is speed with a direction, making it a *vector* quantity. If an object's velocity changes with time, the object is said to be accelerating. As we'll see in the next chapters, understanding the acceleration of an object is the key to understanding its motion. We will assume constant acceleration throughout this chapter.

When beginning a one dimensional problem, define a positive direction. The other direction is then taken to be negative. Traditionally, "positive" is taken to mean "to the right"; however, any definition of direction used consistently throughout the problem will yield the right answer.

Key Concepts

- When you begin a problem, define a coordinate system. For positions, this is like a number line; for example, positive $(+x)$ positions can be to the right of the origin and negative $(-x)$ positions to the left of the origin.
- For velocity v you might define positive as *moving to the right* and negative as *moving to the left*. What would it mean to have a **positive position** and a **negative velocity?**

Guidance

Position is the location of the object (whether it's a person, a ball or a particle) at a given moment in time. Displacement is the difference in the object's position from one time to another. Distance is the total amount the object has traveled in a certain period of time. Displacement is a vector quantity (direction matters), where as distance is a scalor (only the amount matters). Distance and displacement are the same in the case where the object travels in a straight line and always moving in the same direction.

Motion and Vectors

When both distance and direction are considered, motion can be represented by a vector. A **vector** is a measurement that has both size and direction. It may be represented by an arrow. If you are representing motion with an arrow, the length of the arrow represents distance, and the way the arrow points represents direction. The red arrows on the map above are vectors for Jordan's route from his house to the school and from the school to the post office. If you want to learn more about vectors, watch the video at this URL:

http://www.youtube.com/watch?v=B-iBbcFwFOk

4.4 Speed

- Define speed, and give the SI unit for speed.
- Show how to calculate average speed from distance and time.
- Describe instantaneous speed.
- Show how to calculate distance or time from speed when the other variable is known.

Introducing Speed

How fast or slow something moves is its **speed**. Speed determines how far something travels in a given amount of time. The SI unit for speed is meters per second (m/s). Speed may be constant, but often it varies from moment to moment.

Average Speed

Even if speed varies during the course of a trip, it's easy to calculate the average speed by using this formula:

$$speed = \frac{distance}{time}$$

Instantaneous Speed

When you travel by car, you usually don't move at a constant speed. Instead you go faster or slower depending on speed limits, traffic lights, the number of vehicles on the road, and other factors. For example, you might travel 65 miles per hour on a highway but only 20 miles per hour on a city street (see the pictures in the **Figure** 4.6.) You might come to a complete stop at traffic lights, slow down as you turn corners, and speed up to pass other cars. Therefore, your speed at any given instant, or your instantaneous speed, may be very different than your speed at other times. Instantaneous speed is much more difficult to calculate than average speed. If you want to learn more about calculating speed, watch the video at this URL:

http://www.youtube.com/watch?v=a8tIBrj84II

FIGURE 4.6
Cars race by in a blur of motion on an open highway but crawl at a snail's pace when they hit city traffic.

4.6 Velocity

- Distinguish between velocity and speed.
- Represent velocity with vector arrows.
- Describe objects that have different velocities.
- Show how to calculate average velocity when direction is constant.

Speed and Direction

Speed tells you only how fast or slow an object is moving. It doesn't tell you the direction the object is moving. The measure of both speed and direction is called **velocity**. Velocity is a vector. A **vector** is measurement that includes both size and direction. Vectors are often represented by arrows. When using an arrow to represent velocity, the length of the arrow stands for speed, and the way the arrow points indicates the direction. If you're still not sure of the difference between speed and velocity, watch the cartoon at this URL:

http://www.youtube.com/watch?v=mDcaeO0WxBI&feature=related

Using Vector Arrows to Represent Velocity

The arrows in the **Figure** 4.10 represent the velocity of three different objects. Arrows A and B are the same length but point in different directions. They represent objects moving at the same speed but in different directions. Arrow C is shorter than arrow A or B but points in the same direction as arrow A. It represents an object moving at a slower speed than A or B but in the same direction as A.

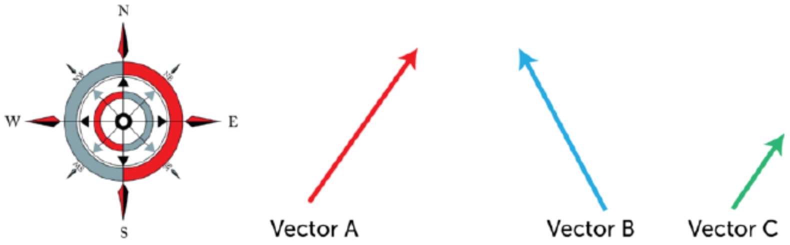


FIGURE 4.10

Differences in Velocity

Objects have the same velocity only if they are moving at the same speed and in the same direction. Objects moving at different speeds, in different directions, or both have different velocities. Look again at arrows A and B from the **Figure** 4.10. They represent objects that have different velocities only because they are moving in different directions. A and C represent objects that have different velocities only because they are moving at different speeds. Objects represented by B and C have different velocities because they are moving in different directions and at different speeds.

Calculating Average Velocity

$$\vec{v}_{avg} = \frac{\vec{d}}{t} \qquad \text{where} \qquad \vec{d} = \vec{d}_f - \vec{d}_o$$

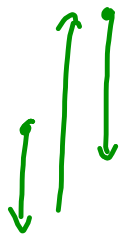
If the object does not change direction the displacement will be the same value as the distance.

9. A car drives 12 m/s [S] for 5.0 seconds, then 18 m/s [N] for 9.0 seconds, and finally 15 m/s [S] for 11 seconds. Calculate the average speed and average velocity. (v_{sp} = 15.5 m/s; v_{avg} = -2.5 m/s or 2.5 m/s [S])

$v_{sp} = \frac{d}{t}$ $\vec{v} = \frac{\vec{d}}{t}$

1st part: $\vec{d} = \vec{v} \times t$

$= (12)(5) = 60\,m$ [S]



2nd: $(18\,m/s)(9\,s) = 162\,m$ [N]

3rd: $(15\,m/s)(11\,s) = 165\,m$ [S]

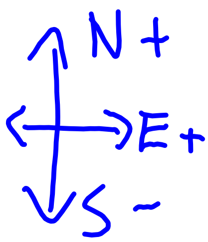
$v_{sp} = \frac{d}{t} = \frac{(60 + 162 + 165)\,m}{(5 + 9 + 11)\,s}$

$= \frac{387\,m}{25\,s} = \boxed{15.5\,m/s}$

vectors

south

$\vec{v}_{avg} = \frac{\vec{d}}{t} = \frac{(-60 + 162 - 165)}{25\,s}$



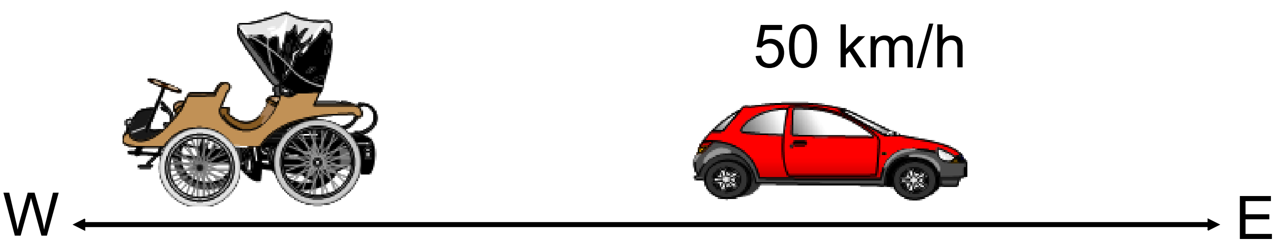
$= -\frac{63\,m}{25\,s} = -2.5\,m/s$

or $2.5\,m/s$ [S]

Frame of Reference Review

Suppose you are in a car traveling 50 km/h East; relative to you what is the velocity of the following cars:

1. The car in front of you is also traveling 50 km/h.
2. The car behind you is driving 40 km/h.
3. A car approaches you driving 60 km/h.
4. A car receeds from you driving 20 km/h.



4.7 Acceleration

- Define acceleration.
- Give examples of acceleration.
- Describe how it feels to accelerate.

Defining Acceleration

Acceleration is a measure of the change in velocity of a moving object. It measures the rate at which velocity changes. Velocity, in turn, is a measure of the speed and direction of motion, so a change in velocity may reflect a change in speed, a change in direction, or both. Both velocity and acceleration are vectors. A vector is any measurement that has both size and direction. People commonly think of acceleration as in increase in speed, but a decrease in speed is also acceleration. In this case, acceleration is negative and called deceleration. A change in direction without a change in speed is acceleration as well.

4.8 Calculating Acceleration from Velocity and Time

- Explain how to calculate average acceleration when direction is constant.
- Identify the SI unit for acceleration.
- Solve simple acceleration problems.

Calculating Average Acceleration in One Direction

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

Calculating acceleration is complicated if both speed and direction are changing or if you want to know acceleration at any given instant in time. However, it's relatively easy to calculate average acceleration over a period of time when only speed is changing. Then acceleration is the change in velocity (represented by Δv) divided by the change in time (represented by Δt):

Ch. 2.7

$$acceleration = \frac{\Delta v}{\Delta t} \quad => \quad \vec{a} = \frac{\vec{v}_f - \vec{v}_o}{t}$$

Guidance

- Acceleration is the rate of change of velocity. So in other words, acceleration tells you how quickly the velocity is increasing or decreasing. An acceleration of 5 m/s^2 indicates that the velocity is increasing by $5m/s$ in the positive direction every second.
- Gravity near the Earth pulls an object downwards toward the surface of the Earth with an acceleration of 9.8 $m/s^2 (\approx 10\ m/s^2)$. In the absence of air resistance, all objects will fall with the same acceleration. The letter $g$is used as the symbol for the acceleration of gravity.
  - When talking about an object's acceleration, whether it is due to gravity or not, the acceleration of gravity is sometimes used as a unit of measurement where $1g = 9.8m/s^2$. So an object accelerating at 2g's is accelerating at $2 * 9.8m/s^2$ or $19.6m/s^2$
- *Deceleration* is the term used when an object's *speed* (i.e. magnitude of its velocity) is decreasing due to acceleration in the opposite direction of its velocity.

Problem Set

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1. A roller coaster car rapidly picks up velocity as it rolls down a slope. As it starts down the slope, its velocity is 4 m/s. But 3 seconds later, at the bottom of the slope, its velocity is 22 m/s. What is its average acceleration? (6.0 m/s^2)

$v_0 = 4 m/s$

$v_f = 22 m/s$

$t = 3 s$

$a = ?$

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

$$a = \frac{22 m/s - 4 m/s}{3 s} = \frac{18}{3}$$

$$= 6.0 m/s^2$$

2. A car accelerates at a rate of 3.0 m/s^2. If its original velocity is 8.0 m/s, how many seconds will it take the car to reach a final velocity of 25.0 m/s? (5.7 s)

$a = 3.0 m/s^2$

$v_0 = 8.0 m/s$

$v_f = 25 m/s$

$t = ?$

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

$$3 = \frac{25 - 8}{t}$$

$$3 \times t = \frac{17}{t} \times t$$

$$\frac{3t}{3} = \frac{17}{3}$$

$$t = \frac{17}{3} = 5.7 s$$

Changing Direction - Calc Displacement

The wind changes the velocity of a glider from 25 m/s [E] to 25 m/s [W] in 32 seconds. a) Calculate the average acceleration of the glider. b) Displacement for the 32 seconds.

$a = ?$

a) $v_0 = 25$ [E]

$v_f = 25$ [W] $= -25$ [E]

$t = 32\text{s}$

$$a = \frac{v_f - v_0}{t} = \frac{-25 - 25}{32\text{s}}$$

$$a = \frac{-50}{32} = -1.6\ \text{m/s}^2$$

b) $\vec{d} = ?$ $\quad \vec{d}_f = \vec{d}_0 + \vec{v}_0 t + \frac{1}{2}\vec{a}t^2$

$$\vec{d}_f = 0 + (25)(32) + \frac{1}{2}(-1.6)(32)^2$$

$$= 800\text{m} - 819.2\text{m}$$

$d_f = -19.2\text{m}$ [E]

or 19.2m [W]

How much time is necessary to change the velocity of a car from 12 m/s [W] to 8 m/s [E] if the acceleration is 2.5 m/s² [E]? What is the resulting displacement?

$t = ?$

$v_0 = -12\ m/s\ [E]$

$v_f = 8\ m/s\ [E]$

$a = 2.5\ m/s^2\ [E]$

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

$2.5 = \frac{8-(-12)}{t}$

$2.5 \times t = \frac{20}{t} \times t$

$2.5t = 20$

$t = \frac{20}{2.5} = 8.0\ s$

b) $\vec{d}_f = ?$

$\vec{v}_f^{\,2} = \vec{v}_0^{\,2} + 2\vec{a}\vec{d}$

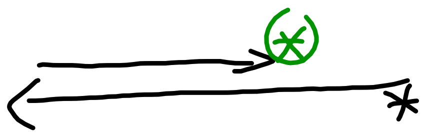
$\vec{d} \rightarrow d_f - d_0$

$(8)^2 = (-12)^2 + 2(2.5)(d_f - 0)$

$64 - 144 = 144 - 144 + 5d_f$

$-80 = 5d_f$

$-16\ m = d_f$



Objects Thrown on Earth

A ball is thrown upwards (on Earth). It takes 5.7 seconds for the ball to reach a velocity of 3.4 m/s. a) Calculate the initial velocity. b) Height above the ground? c) Max height

a) $t = 5.7s$

$v_f = +3.4 m/s$

$v_o = ?$

$g \rightarrow a = -9.81 m/s^2$ ↑ down

$a = \frac{v_f - v_o}{t}$

$-9.81 = \frac{3.4 - v_o}{5.7}$

$-55.9 = 3.4 - v_o$

$v_o = 3.4 + 55.9$

$= 59.3 m/s$

b) $d_f = ?$

$t = 5.7s$

$v_o = 59.3 m/s$

$v_f = 3.4 m/s$

$g = -9.81 m/s^2$

$d_f = d_o + v_o t + \frac{1}{2} g t^2$

$= 0 + (59.3)(5.7) + \frac{1}{2}(-9.81) \times (5.7)^2$

$d_f = 178.6 m$

c) $d_f = ?$ @ max height

$t = ?$

$v_o = 59.3 m/s$

$g = -9.81 m/s^2$

$v_f = 0 m/s$ @ Max height

$v_f^2 = v_o^2 + 2\vec{a}\vec{d}$ ($d_f - d_o$)

$0 = (59.3)^2 + 2(-9.81)(d_f - 0)$

$0 = 3516 - 19.62 d_f$

$-3516 = -19.62 d_f$

$179 m = d_f$