2 Motion

2-1 Speed, Velocity, and Acceleration

Speed vs. Velocity

Vocabulary **Distance:** How far something travels.

Vocabulary **Displacement:** How far something travels in a given direction.

Notice that these two terms are very similar. **Distance** is an example of what we call a *scalar* quantity. In other words, it has magnitude, but no direction. **Displacement** is an example of a *vector* quantity because it has both magnitude and direction.

The SI unit for distance and displacement is the **meter (m).**

Displacements smaller than a meter may be expressed in units of centimeters (cm) or millimeters (mm). Displacements much larger than a meter may be expressed in units of kilometers (km). See Appendix A for the meanings of these and other common prefixes.

Vocabulary **Speed:** How fast something is moving.

$$\textbf{average speed} = \frac{\textbf{distance traveled}}{\textbf{elapsed time}} \quad \text{or} \quad v_{\text{av}} = \frac{d}{\Delta t}$$

Vocabulary **Velocity:** How fast something is moving in a given direction.

$$\textbf{average velocity} = \frac{\textbf{displacement}}{\textbf{elapsed time}} \quad \text{or} \quad \boldsymbol{v}_{\textbf{av}} = \frac{\boldsymbol{\Delta d}}{\Delta t} = \frac{\boldsymbol{d}_{\textbf{f}} - \boldsymbol{d}_{\textbf{o}}}{t_{\text{f}} - t_{\text{o}}}$$

where d_{f} and t_{f} are the final position and time respectively, and d_{o} and t_{o} are the initial position and time. The symbol "Δ" (delta) means "change" so $\boldsymbol{\Delta d}$ is the change in position, or the displacement, while Δt is the change in time.

In this book all vector quantities will be introduced in an equation with **bold type,** while all scalar quantities will be introduced in an equation in regular type. Note that speed is a scalar quantity while velocity is a vector quantity.

The SI unit for both speed and velocity is the **meter per second (m/s).**

When traveling in any moving vehicle, you rarely maintain the same velocity throughout an entire trip. If you did, you would travel at a constant speed in a straight line. Instead, speed and direction usually vary during your time of travel.

If you begin and end at the same location but you travel for a great distance in getting there (for example, when you travel in a circle), you have a measurable average speed. However, since your total displacement for such a trip is zero, your average velocity is also zero. In this chapter, both average speed and average velocity will be written as v_{av}. The "av" subscript will be dropped in later chapters.

Acceleration

Vocabulary **Acceleration:** The rate at which the velocity changes during a given amount of time.

$$\textbf{acceleration} = \frac{\textbf{change in velocity}}{\textbf{elapsed time}} \quad \text{or} \quad \boldsymbol{a} = \frac{\boldsymbol{\Delta v}}{\Delta t} = \frac{v_f - v_o}{t_f - t_o}$$

where the terms v_f and v_o mean final velocity and initial velocity, respectively.

The SI unit for acceleration is the **meter per second squared ($\mathbf{m/s^2}$).**

If the final velocity of a moving object is smaller than its initial velocity, the object must be slowing down. A slowing object is sometimes said to have *negative acceleration* because the magnitude of the acceleration is preceded by a negative sign.

Solved Examples

Example 1: Benjamin watches a thunderstorm from his apartment window. He sees the flash of a lightning bolt and begins counting the seconds until he hears the clap of thunder 10. s later. Assume that the speed of sound in air is 340 m/s. How far away was the lightning bolt a) in m? b) in km? NOTE: The speed of light, 3.0×10^8 m/s, is considerably faster than the speed of sound. That is why you see the lightning flash so much earlier than you hear the clap of thunder. In actuality, the lightning and thunder clap occur almost simultaneously.

a. *Given:* $v_{av} = 340$ m/s
$\Delta t = 10.0$ s

Unknown: $\Delta d = ?$
Original equation: $v_{av} = \dfrac{\Delta d}{\Delta t}$

Solve: $\Delta d = v_{av}\Delta t = (340 \text{ m/s})(10.\text{ s}) = \mathbf{3400\ m}$

b. For numbers this large you may wish to express the final answer in km rather than in m. Because "kilo" means 1000, then 1.000 km = 1000. m.

$$3400\text{ m}\,\frac{(1.000\text{ km})}{1000.\text{ m}} = \mathbf{3.4\ km}$$

The lightning bolt is 3.4 km away, which is just a little over two miles for those of you who think in English units!

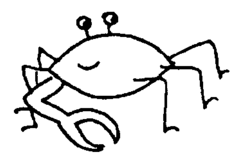
Example 2: On May 29, 2005, Danica Patrick was named the first female Indy 500 Rookie of the Year after her 4th place finish; the best Indy 500 finish of any woman in the event's history. Danica completed the race in a time of 3.174 h. What was Danica's average speed during the 500.0-mi race? NOTE: Generally the unit "miles" is not used in physics exercises. However, the Indianapolis 500 is a race that is measured in miles, so the mile is appropriate here. Don't forget, the SI unit for distance is the meter. (Read more about the Indy 500 at http://www.indy500.com)

Given: $d = 500.0$ mi
$\Delta t = 3.174$ h

Unknown: $v_{av} = ?$
Original equation: $\Delta t = \dfrac{\Delta d}{v_{av}}$

Solve: $v_{av} = \dfrac{\Delta d}{\Delta t} = \dfrac{500.0\text{ mi}}{3.174\text{ h}} = \mathbf{157.5\ mi/h}$

Example 3: The slowest animal ever discovered was a crab found in the Red Sea. It traveled with an average speed of 5.70 km/y. How long would it take this crab to travel 100. km?



Given: $\Delta d = 100.$ km
$v_{av} = 5.70$ km/y

Unknown: $\Delta t = ?$
Original equation: $\Delta t = \dfrac{\Delta d}{v_{av}}$

Solve: $\Delta t = \dfrac{\Delta d}{v_{av}} = \dfrac{100.\text{ km}}{5.70\text{ km/y}} = \mathbf{17.5\ y}$ A long time!

Example 4: Tiffany, who is opening in a new Broadway show, has some limo trouble in the city. With only 8.0 minutes until curtain time, she hails a cab and they speed off to the theater down a 1000.-m-long one-way street at a speed of 25 m/s. At the end of the street the cab driver waits at a traffic light for 1.5 min and then turns north onto a 1700.-m-long traffic-filled avenue on which he is able to travel at a speed of only 10.0 m/s. Finally, this brings them to the theater. a) Does Tiffany arrive before the theater lights dim? b) Draw a distance vs. time graph of the situation.

Solution: First, break this exercise down into segments and solve each segment independently.

Segment 1: (one-way street)

Given: $\Delta d = 1000.$ m
$v_{av} = 25$ m/s

Unknown: $\Delta t = ?$
Original equation: $v_{av} = \dfrac{\Delta d}{\Delta t}$

Solve: $\Delta t = \dfrac{\Delta d}{v_{av}} = \dfrac{1000.\text{ m}}{25\text{ m/s}} = 40.\text{ s}$

Segment 2: (traffic light)

Given: $\Delta t = 1.5 \text{ min}$ $\quad (1.5 \text{ min})\dfrac{(60.\text{ s})}{(1.0 \text{ min})} = 90.\text{ s}$

Segment 3: (traffic-filled avenue)

Given: $\Delta d = 1700.\text{ m}$
$v_{av} = 10.0 \text{ m/s}$

Unknown: $\Delta t = ?$
Original equation: $v_{av} = \dfrac{\Delta d}{\Delta t}$

Solve: $\Delta t = \dfrac{\Delta d}{v_{av}} = \dfrac{1700.\text{ m}}{10.0 \text{ m/s}} = 170.\text{ s}$

total time $= 40.\text{ s} + 90.\text{ s} + 170.\text{ s} = 300.\text{ s}$ $\quad (300.\text{ s})\dfrac{(1.0 \text{ min})}{(60.\text{ s})} = \mathbf{5.0 \text{ min}}$

Yes, she not only makes it to the show in time, but she even has 3.0 minutes to spare to put on her costume and make-up.

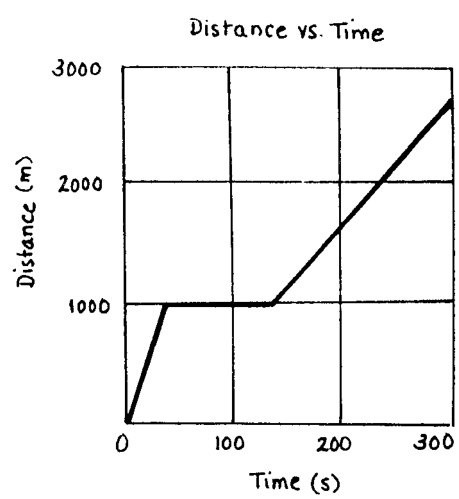
b. The motion of the cab can be described by the following graph.

In Segment 1, the distance of 1000. m was covered in a fairly short amount of time, which means that the cab was traveling quickly. This high speed can be seen as a steep slope on the graph.

In Segment 2, the cab was at rest. Notice that even though the cab did not move, time continued on, resulting in a horizontal line on the graph.

In Segment 3, the distance of 1700. m was covered in a much longer amount of time so the cab was traveling slowly. This low speed is indicated by a slope that is not as steep as that in segment 1.

Remember, all graphs should have titles and the axes should be labeled with the correct units.



Example 5: Grace is driving her sports car at 30 m/s when a ball rolls out into the street in front of her. Grace slams on the brakes and comes to a stop in 3.0 s. What was the acceleration of Grace's car?

Given: $v_o = 30$ m/s
$v_f = 0$ m/s
$\Delta t = 3.0$ s

Unknown: $a = ?$
Original equation: $a = \dfrac{v_f - v_o}{\Delta t}$

Solve: $a = \dfrac{v_f - v_o}{\Delta t} = \dfrac{0 \text{ m/s} - 30 \text{ m/s}}{3.0 \text{ s}} = -10 \text{ m/s}^2$

The negative sign means the car was slowing down.

Practice Exercises

Exercise 1: Hans stands at the rim of the Grand Canyon and yodels down to the bottom. He hears his yodel echo back from the canyon floor 5.20 s later. Assume that the speed of sound in air is 340.0 m/s. How deep is the canyon at this location?

Answer: ____________________

Exercise 2: The world speed record on water was set on October 8, 1978 by Ken Warby of Blowering Dam, Australia. If Ken drove his motorboat a distance of 1000. m in 7.045 s, how fast was his boat moving a) in m/s? b) in mi/h? (Read more about Ken Warby at http://www.kenwarby.com)

Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 3: According to the World Flying Disk Federation, the world distance record for a flying disk throw in the men's 85-years-and-older category is held by Jack Roddick of Pennsylvania, who on July 13, 2007, at the age of 86, threw a flying disk for a distance of 54.0 m. If the flying disk was thrown horizontally with a speed of 13.0 m/s, how long did the flying disk remain aloft? (Jack Roddick was also a physics teacher! Read more about him at http://sumag.ship.edu/sm7roddick.html)

Answer: ______________________

Exercise 4: It is now 10:29 A.M., but when the bell rings at 10:30 A.M. Suzette will be late for French class for the third time this week. She must get from one side of the school to the other by hurrying down three different hallways. She runs down the first hallway, a distance of 35.0 m, at a speed of 3.50 m/s. The second hallway is filled with students, and she covers its 48.0-m length at an average speed of 1.20 m/s. The final hallway is empty, and Suzette sprints its 60.0-m length at a speed of 5.00 m/s. a) Does Suzette make it to class on time or does she get detention for being late again? b) Draw a distance vs. time graph of the situation.

Answer: **a.** ______________________

Exercise 5: A jumbo jet taxiing down the runway receives word that it must return to the gate to pick up an important passenger who was late to his connecting flight. The jet is traveling at 45.0 m/s when the pilot receives the message. What is the acceleration of the plane if it takes the pilot 5.00 s to bring the plane to a halt?

Answer: ______________________

Exercise 6: While driving his sports car at 20.0 m/s down a four-lane highway, Eddie comes up behind a slow-moving dump truck and decides to pass it in the left-hand lane. If Eddie can accelerate at 5.00 m/s^2, how long will it take for him to reach a speed of 30.0 m/s?

Answer: ____________________

Exercise 7: Vivian is walking to the hairdresser's at 1.3 m/s when she glances at her watch and realizes that she is going to be late for her appointment. Vivian gradually quickens her pace at a rate of 0.090 m/s^2. a) What is Vivian's speed after 10.0 s? b) At this speed, is Vivian walking, jogging, or running very fast?

Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 8: A torpedo fired from a submerged submarine is propelled through the water with a speed of 20.00 m/s and explodes upon impact with a target 2000.0 m away. If the sound of the impact is heard 101.4 s after the torpedo was fired, what is the speed of sound in water? (Because the torpedo is held at a constant speed by its propeller, the effect of water resistance can be neglected.)

Answer: ____________________