Answer to Essential Question 2.4: The crossing points tell us the time and location at which one car passes another. For instance, the red car passes the green car at $t = 2$ s, +20 m from the origin.

2-5 Acceleration

Let's turn now to motion that is not at constant velocity. An example is the motion of an object you release from rest from some distance above the floor.

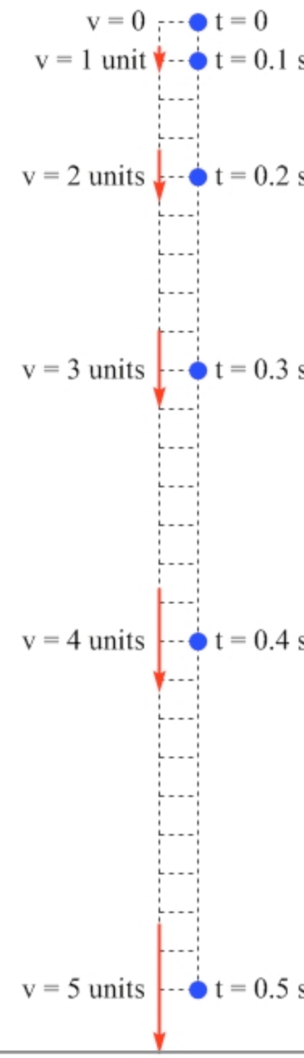

Figure 2.14: A motion diagram, and velocity vectors, for a ball released from rest at $t = 0$. The ball's position and velocity are shown at 0.1-second intervals.

EXPLORATION 2.5A – Exploring the motion diagram of a dropped object

Step 1 - ***Sketch a motion diagram for a ball that you release from rest from some distance above the floor, showing its position at regular time intervals as it falls.*** The motion diagram in Figure 2.14 shows images of the ball that are close together near the top, where the ball moves more slowly. As the ball speeds up, these images get farther apart because the ball covers progressively larger distances in the equal time intervals. How do we know how much space to include between each image? One thing we can do is to consult experimental evidence, such as strobe photos of dropped objects. These photos show that the displacement from one time interval to the next increases linearly, as in Figure 2.14.

Step 2 - ***At each point on the motion diagram, add an arrow representing the ball's velocity at that point. Neglect air resistance.*** The arrows in Figure 2.14 represent the velocity of the ball at the various times indicated on the motion diagram. Because the displacement increases linearly from one time interval to the next, the velocity also increases linearly with time.

Key idea: For an object dropped from rest, the velocity changes linearly with time.
Related End-of-Chapter Exercises: 57 - 60

Another way to say that the ball's velocity increases linearly with time is to say that the rate of change of the ball's velocity, with respect to time, is constant:

$$\frac{\Delta \vec{v}}{\Delta t} = \text{constant} .$$

This quantity, the rate of change of velocity with respect to time, is referred to as the **acceleration**. Acceleration is related to velocity in the same way velocity is related to position.

Average acceleration: a vector representing the average rate of change of velocity with respect to time. The SI unit for acceleration is m/s^2.

$$\bar{\vec{a}} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\text{change in velocity}}{\text{time interval}} .$$ (Equation 2.7: **Average acceleration**)

The direction of the average acceleration is the direction of the change in velocity.

Instantaneous acceleration: a vector representing the rate of change of velocity with respect to time at a particular instant in time. The SI unit for acceleration is m/s^2.

A practical definition of instantaneous acceleration at a particular instant is that it is the slope of the velocity-versus-time graph at that instant. Expressing this as an equation:

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} . \qquad \text{(Equation 2.8: \textbf{Instantaneous acceleration})}$$

Δt is small enough that the acceleration can be considered to be constant over that time interval.

Note that, on Earth, objects dropped from rest are observed to have accelerations of 9.8 m/s^2 straight down. This is known as $\vec{g}$, the acceleration due to gravity.

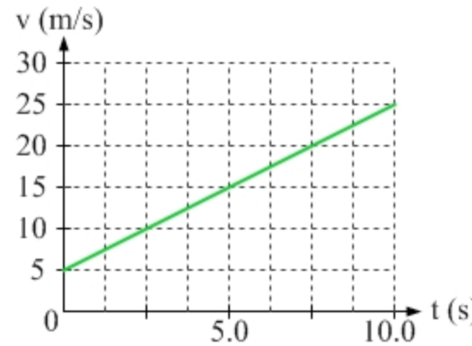

Figure 2.15: A graph of the velocity of a bus as a function of time.

EXPLORATION 2.5B – Graphs in a constant-acceleration situation

The graph in Figure 2.15 shows the velocity, as a function of time, of a bus moving in the positive direction along a straight road.

Step 1 – ***What is the acceleration of the bus? Sketch a graph of the acceleration as a function of time.*** The graph in Figure 2.15 is a straight line with a constant slope. This tells us that the acceleration is constant because the acceleration is the slope of the velocity-versus-time graph. Using the entire 10-second interval, applying equation 2.8 gives:

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{+25 \text{ m/s} - (+5 \text{ m/s})}{10 \text{ s}} = \frac{+20 \text{ m/s}}{10 \text{ s}} = +2.0 \text{ m/s}^2 .$$

The acceleration graph in Figure 2.16 is a horizontal line, because the acceleration is constant. Compare Figures 2.15 and 2.16 to the graphs for the red car in Figure 2.13. Note the similarity between the acceleration and velocity graphs in a constant-acceleration situation and the velocity and position graphs in a constant-velocity situation.

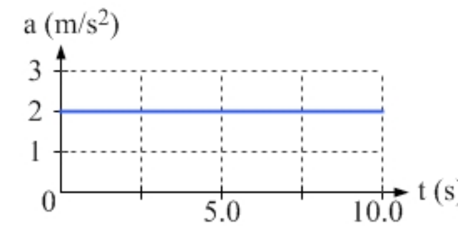

Figure 2.16: A graph of the acceleration of the bus as a function of time.

Step 2 - ***What on the acceleration-versus-time graph is connected to the velocity?*** The connection between velocity and acceleration is similar to that between position and velocity - the area under the curve of the acceleration graph is equal to the change in velocity, as shown in Figure 2.17. This follows from Equation 2.8, which in a constant acceleration situation can be written as $\Delta \vec{v} = \vec{a}\, \Delta t$.

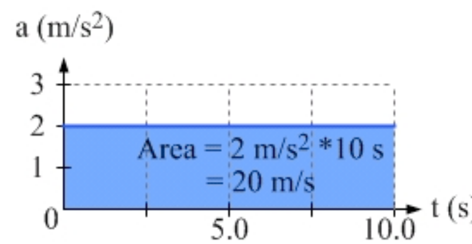

Figure 2.17: In 10 seconds, the velocity changes by +20 m/s. This is the area under the acceleration-versus-time graph over that interval.

Key ideas: The acceleration is the slope of the velocity-versus-time graph, while the area under the acceleration-versus-time graph for a particular time interval represents the change in velocity during that time interval.

Related End-of-Chapter Exercises: 16 and 32.

Essential Question 2.5: Consider the bus in Exploration 2.5B. Would the graph of the bus' position as a function of time be a straight line? Why or why not?