1.1 Position, Motion, and Displacement

Section Summary

- Position is defined using a coordinate system with a reference point.
- Change in position is a proof of motion; and motion results in change in position.
- Distance is the length of the actual path travelled. It is a scalar quantity.
- Displacement is the straight line between the initial and final positions. It is a vector quantity.
- Position-time graphs give a lot of information about the motion of an object.

The physicists and engineers at NASA think about the motion of Earth when they are launching rockets (Figure 1.2). A surgeon thinks about blood flow and how to stop it while performing surgery. Imagine the amount of research that goes into designing a race car to make it safe and reliable to drive (Figure 1.3). Cars, washing machines, dryer, fans, etc. have become very important in our daily lives. Mechanical engineers design several movable things like robots, automobiles, and different kinds of machines by using physics principles. **Mechanics** is the field of physics in which we study the motion of objects. **Kinematics** explains the "what" and the "how" of motion.

Figure 1.2 A United Launch Alliance Delta II rocket being launched.

Figure 1.3 Race car in motion

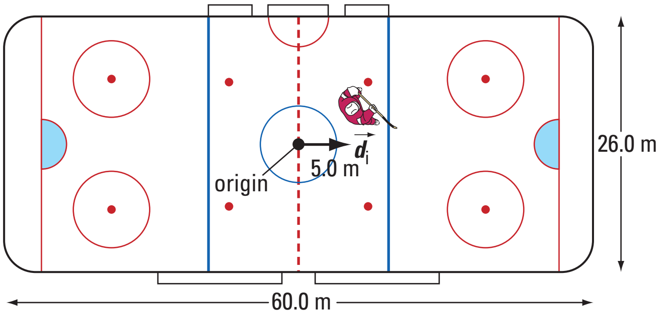

Figure 1.4 The player's position is 5.0 m [east of the origin] or simply 5.0 m [E]. The player is at a distance of 5.0 m from the origin.

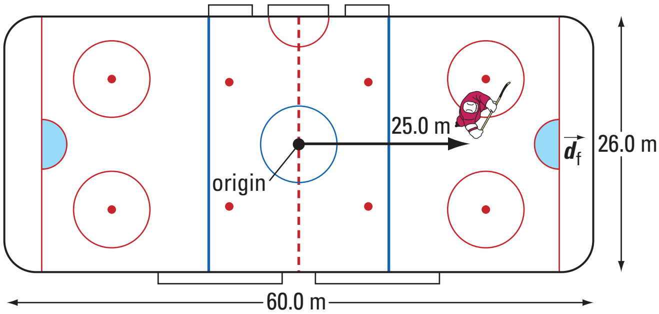

Figure 1.5 The player's position has changed. A change in position is called displacement.

Scalars and Vectors

In order to locate players on the ice during a hockey game, you need a reference system. In this case, select the centre of the ice as the reference point, also called the **origin**. You can then measure the straight-line distances, d, of players from the origin, such as 5.0 m. If you specify a distance and a direction from the origin along with the distance, then you define a player's **position**, $\vec{d}$, for example, 5.0 m [E] (Figure 1.4). The arrow over the variable indicates that the variable is a vector quantity. The number and unit are called the **magnitude** of the vector. Distance, which has a magnitude but no direction associated with it, is an example of a **scalar quantity**. **Vector quantities** have both magnitude and direction. Position is an example of a vector quantity.

If the player, initially 5.0 m [east of the origin], skates to the east end of the rink to the goal area, his position changes. It is now 25.0 m [east of the origin] or 25.0 m [E] (Figure 1.5). You can state that he has travelled a straight-line distance of 20.0 m, and has a displacement of 20.0 m [E] relative to his initial position.

Distance travelled is the length of the path taken to move from one position to another, regardless of direction. **Displacement**, $\Delta\vec{d}$, is the change in position. The player's displacement is written as

$$\Delta\vec{d} = 20.0 \text{ m [E]}$$

where Δ is the Greek letter delta that means "change in." Calculate the change in a quantity by subtracting the initial quantity from the final quantity. In algebraic notation, $\Delta R = R_f - R_i$. You can calculate the displacement of the player in the following manner:

$$\begin{aligned}\Delta\vec{d} &= \vec{d}_f - \vec{d}_i \\ &= 25.0 \text{ m [E]} - 5.0 \text{ [E]} \\ &= 20.0 \text{ m [E]}\end{aligned}$$

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Explore More

What is the difference between mass and weight as they relate to scalar and vector quantities?

Sign Conventions

How would you determine your final distance and displacement if you moved from a position 5.0 m [W] to a position 10.0 m [E] (Figure 1.6)?

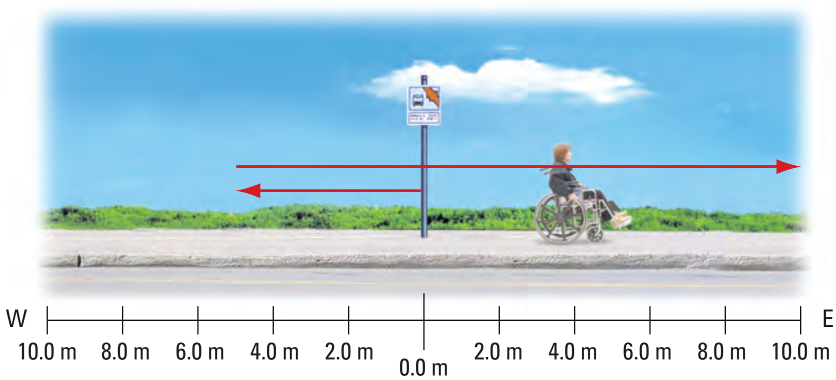

Figure 1.6 The person travels a distance of 5.0 m + 10.0 m = 15.0 m.

To calculate the distance travelled in the scenario on the previous page, you need to add the magnitudes of the two position vectors.

$$\Delta d = 5.0\text{ m} + 10.0\text{ m} \\ = 15.0\text{ m}$$

To find displacement, you need to subtract the initial position, $\vec{d}_i$, from the final position, $\vec{d}_f$. Let $\vec{d}_i = 5.0$ m [W] and $\vec{d}_f = 10.0$ m [E].

$$\Delta\vec{d} = \vec{d}_f - \vec{d}_i \\ = 10.0\text{ m [E]} - 5.0\text{ m [W]}$$

Note that subtracting a vector is the same as adding its opposite, so the negative west direction is the same as the positive east direction.

$$\Delta\vec{d} = 10.0\text{ m [E]} - 5.0\text{ m [W]} \\ = +10.0\text{ m [E]} + 5.0\text{ m [E]} \\ = +15\text{ m [E]}$$

Another way of solving for displacement is to designate the east direction as positive and the west direction as negative (Figure 1.7). The two position vectors become $\vec{d}_i = 5.0$ m [W] $= -5.0$ m and $\vec{d}_f = 10.0$ m [E] $= +10.0$ m.

Now calculate displacement:

$$\Delta\vec{d} = \vec{d}_f - \vec{d}_i \\ = +10.0\text{ m} - (-5.0\text{ m}) \\ = +15.0\text{ m}$$

Since east is positive, the positive sign indicates that the person has moved 15.0 m east.

For all subsequent problems in this book, you will be using plus and minus signs to indicate direction. This method is more flexible for problem solving and easier to use.

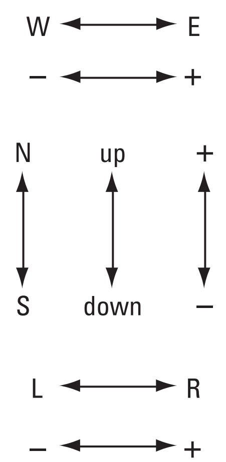

Figure 1.7 Let east be positive and west negative. Similarly, north, up, and right are usually designated as positive.

Concept Check

1. Figure 1.8 shows the surface of a rectangular table ABCD. Choose the corner labelled A as the starting position. Move the object following the arrow towards the corner labelled B. Continue moving the object along the side labelled BC until it reaches point P. Stop and measure the displacement (shown by the dotted arrow from A to P) and the distance covered (length AB + length BP).
   (a) Are the two measured quantities the same or different?
   (b) Repeat these steps by moving the object and following the arrows from A through B and C and stopping at Q. Are the two measured quantities the same or different?
   (c) Is (are) there any point(s) on the table where distance and displacement will be the same. Explain why?

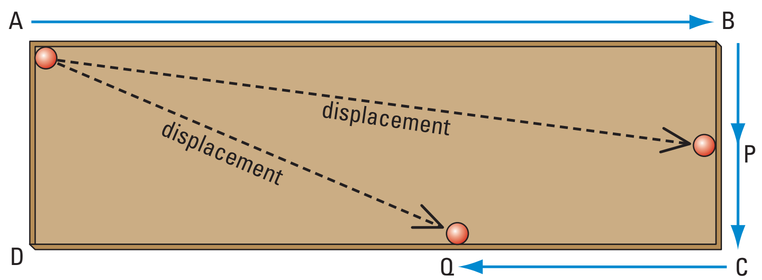

Figure 1.8 Distance and displacement

Example 1.1

A traveller initially standing 1.5 m to the right of the inukshuk moves so that she is 3.5 m to the left of the inukshuk (Figure 1.9). Determine the traveller's displacement algebraically

(a) using directions

(b) using plus and minus signs

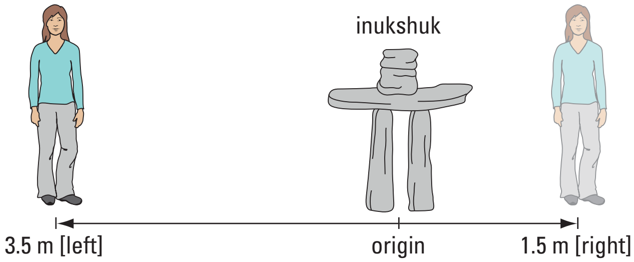

Figure 1.9

Given

Choose the inukshuk to be the reference point.

$\vec{d}_i = 1.5$ m [right]

$\vec{d}_f = 3.5$ m [left]

Required

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

Analysis and Solution

To find displacement, use the equation $\Delta\vec{d} = \vec{d}_f - \vec{d}_i$.

(a) $\Delta\vec{d} = \vec{d}_f - \vec{d}_i$

$= 3.5 \text{ m [left]} - 1.5 \text{ m [right]}$

$= 3.5 \text{ m [left]} - (-1.5 \text{ m [left]})$

$= 3.5 \text{ m [left]} + 1.5 \text{ m [left]}$

$= 5.0 \text{ m [left]}$

(b) Consider right to be positive.

$\vec{d}_i = 1.5 \text{ m [right]} = +1.5 \text{ m}$

$d_f = 3.5 \text{ m [left]} = -3.5 \text{ m}$

$\Delta\vec{d} = \vec{d}_f - \vec{d}_i$

$= -3.5 \text{ m} - (+1.5 \text{ m})$

$= -3.5 \text{ m} - 1.5 \text{ m}$

$= -5.0 \text{ m}$

The answer is negative, so the direction is left.

Paraphrase

The traveller's displacement is 5.0 m [left] of her initial position.

Note that the direction of *displacement* is relative to initial position, whereas the direction of *position* is relative to the designated origin, in this case, the inukshuk.

Practice Problems

1. Sprinting drills include running 40.0 m [N], walking 20.0 m [N], and then sprinting 100.0 m [N]. What is the sprinter's displacement from the initial position?
2. To perform a give and go, a basketball player fakes out the defence by moving 0.75 m [right] and then 3.50 m [left]. What is the player's displacement from the starting position?
3. While building a wall, a bricklayer sweeps the cement back and forth. If she swings her hand back and forth, a distance of 1.70 m, four times, calculate the distance and displacement her hand travels during that time.

Answers

1. 160.0 m [N]
2. 2.75 m [left]
3. 6.80 m, 0 m

Position-time Graphs

Position-time graphs give a visual representation of the motion of an object.

If the object is stationary, the graph is a horizontal line, as shown in Figure 1.10, because the position does not change with time.

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Suggested Activity

- A2 Quick Lab Overview on page 12

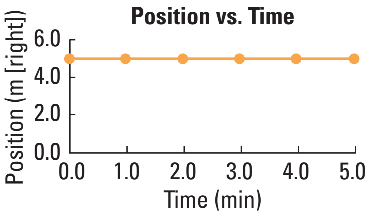


Figure 1.10 Position-time graph for a stationary object

If an object goes through equal displacement in equal time intervals, the corresponding position-time graph is a straight line. This type of motion with no change in direction is called **uniform motion**. Figure 1.11 shows several examples of position-time graphs for a car travelling with uniform motion.

If the displacements that occur in equal time intervals are not equal, then the graph is not a straight line, but is a curve.

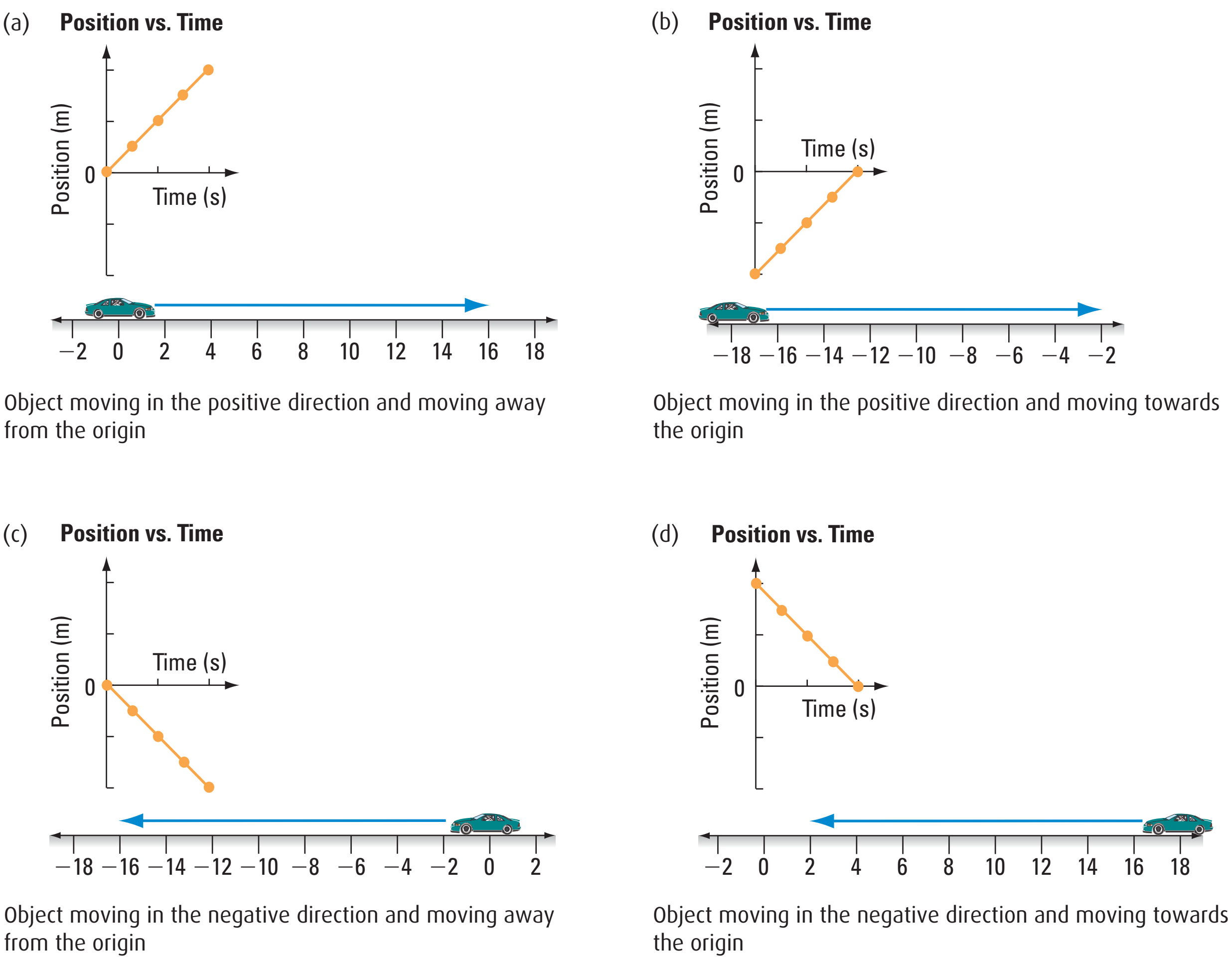


Figure 1.11 Position-time graphs for uniform motion

Concept Check

1. A person walks steadily from −18 km to 18 km, passing through the origin.
   (a) What do you think the position-time graph for the walk will look like?
   (b) Draw the position-time graph for the walk.
   (c) Are your answers in parts (a) and (b) the same or different? Explain.

Example 1.2

At the end of the school day, student A and student B say goodbye and head in opposite directions, walking at constant rates. Student B heads west to the bus stop while student A walks east to her house. After 3.0 min, student A is 300 m [E] and student B is 450 m [W] (Figure 1.12). Graph the position of each student on one graph after 3.0 min.

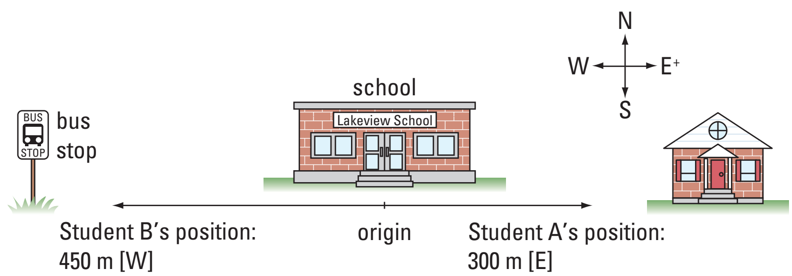


Figure 1.12

Given

Choose east to be positive.

$\Delta\vec{d}_A = 300 \text{ m [E]} = +300 \text{ m}$

$\Delta\vec{d}_B = 450 \text{ m [W]} = -450 \text{ m}$

$\Delta t = 3.0 \text{ min}$

Required

position-time graph

Analysis and Solution

Since east is the positive direction, plot student A's position (3.0 min, +300 m) above the time axis and student B's position (3.0 min, −450 m) below the time axis (Figure 1.13).

Paraphrase

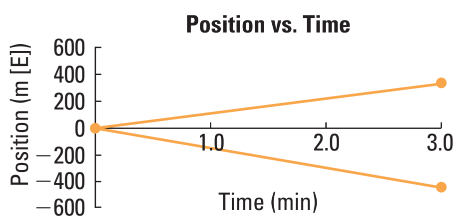


Figure 1.13

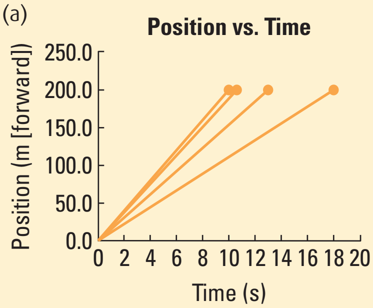
Practice Problems

1. A wildlife biologist measures how long it takes four animals to cover a displacement of 200 m [forward].
   (a) Graph the data from the table below.
   (b) From your graph, estimate how long it takes the Elk and Grizzly bear to cover 150 m.

Animal	Time Taken (s)
Elk	10.0
Coyote	10.4
Grizzly bear	18.0
Moose	12.9

Answers

1. (a)



(b) 7.5 s, 13.5 s

Example 1.3

Two rollerbladers, A and B, are having a race. B gives A a head start of 5.0 s (Figure 1.14). Each rollerblader moves with a uniform motion. Assume that the time taken to reach uniform motion is negligible. If A travels 100.0 m [right] in 20.0 s and B travels 112.5 m [right] in 15.0 s,

(a) graph the motions of both rollerbladers on the same graph.

(b) find the time, position, and displacement at which B catches up with A.

Given

Choose right to be positive.

$\Delta\vec{d}_A = 100.0 \text{ m [right]} = 100.0 \text{ m}$

$\Delta t_A = 20.0 \text{ s}$

$\Delta\vec{d}_B = 112.5 \text{ m [right]} = 112.5 \text{ m}$

$\Delta t_B = 15.0$ s, started 5.0 s later

Required

(a) position-time graph

(b) time (Δt), position ($\vec{d}$), and displacement ($\Delta\vec{d}$) when B catches up with A

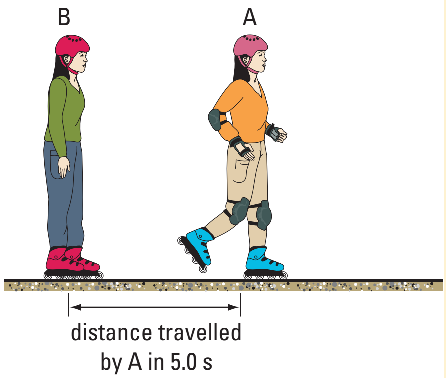


Figure 1.14

Analysis and Solution

(a) Assume that $t = 0.0$ s at the start of A's motion. Thus, the position-time graph of A's motion starts at the origin. A's final position is +100.0 m at 20.0 s.

The position-time graph for B's motion starts at 0.0 m and 5.0 s (because B started 5.0 s after A). B starts moving after 5.0 s for 15.0 s. Thus, at 20.0 s (5.0 s + 15.0 s), B's position is +112.5 m.

Each rollerblader travels with a constant velocity, so the lines connecting their initial and final positions are straight (Figure 1.15(a)).

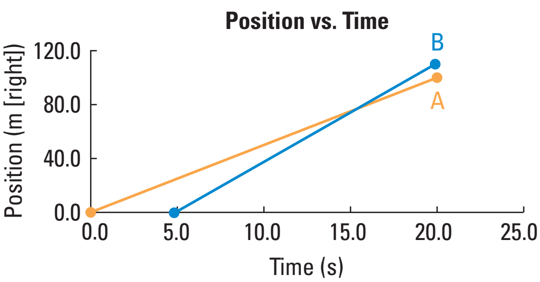


Figure 1.15(a)

(b) On the graph in Figure 1.15(a), look for a point of intersection. At this point, both rollerbladers have the same final position. From the graph, you can see that this point occurs at $t = 15.0$ s. The corresponding position is +75.0 m (Figure 1.15(b)).

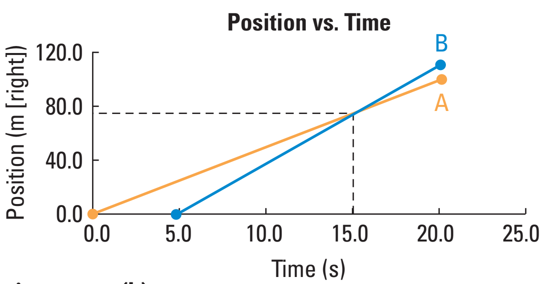


Figure 1.15(b)

Practice Problems

1. The two rollerbladers in Example 1.3 have a second race in which they each travel the original time and distance. In this race, they start at the same time, but B's initial position is 10.0 m left of A. Take the starting position of A as the reference.
   (a) Graph the motions of the rollerbladers.
   (b) Find the time, position, and B's displacement at which B catches up with A.

Answers

1. (b) $t = 4.0$ s
   $\vec{d} = 20.0$ m [right]
   $\Delta\vec{d} = 30.0$ m [right]

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Take It Further

Understanding how biological systems move is a branch of physics known as biomechanics. For automobile manufacturers, understanding how the human body moves during a car accident is very important. Today, crash test dummies are used to study, collect, and analyze data on how the human body moves during a vehicular collision. Research the history of crash test dummies.

To find B's displacement, find the change in position: $\Delta\vec{d} = \vec{d}_f - \vec{d}_i$.
Both A and B started from the same position, $\vec{d}_i = 0$. Since they both have the same final position at the point of intersection, $\vec{d}_f = +75.0$ m.

$$\Delta\vec{d} = +75.0 \text{ m} - 0.0 \text{ m}$$
$$= +75.0 \text{ m}$$

The answer is positive, so the direction is to the right.

Paraphrase

(b) B catches up with A 15.0 s after A started. B's position and displacement are 75.0 m [right] of the origin.

A1 Skill Builder Activity

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Using a Motion Sensor

Activity Overview

In this Skill Builder, you learn how to set-up a motion sensor (Figure 1.16) and use it, with the aid of a computer, to collect data and plot graphs for a moving object.

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

Figure 1.16

DI Key Activity

A2 Quick Lab

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Video

Match a Graph

Purpose

To approximate the type of motion to the position-time graph provided.

Activity Overview

In this activity, your teacher will provide different position-time graphs. Using a motion sensor, you will move away from the sensor in such a way that the graph of the motion captured approximates each position-time graph (Figure 1.17).

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

Figure 1.17 Setup for the activity

Prelab Questions

Consider the questions below before beginning this activity.

1. What types of motion can objects undergo?
2. What are some words used to describe motion?

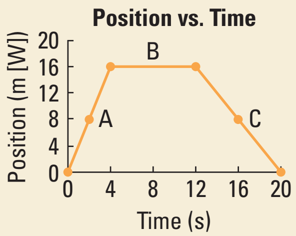
1.1 Check and Reflect

Key Concept Review

1. When an object is at rest, what can you say about its position, displacement, and distance?
2. For an object travelling with uniform motion, how does the displacement change over equal time intervals?
3. A camper kayaks 16 km [E] from a camping site, stops, and then paddles 23 km [W].
   (a) What is the camper's final position with respect to the campsite?
   (b) What is the total displacement of the camper?
   (c) What is the distance covered by the camper? Is it the same as the displacement? Explain.

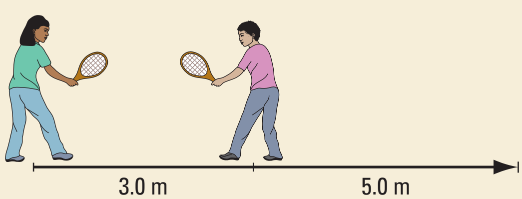
Connect Your Understanding

4. For the graph given below:
   (a) Describe the motion of the object in stages A, B, and C.
   (b) What is the displacement of the object at the end of each stage?
   (c) What is the total displacement (between the initial and final positions)?
   (d) What is the total distance covered?



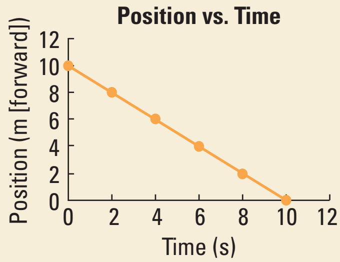
Question 4

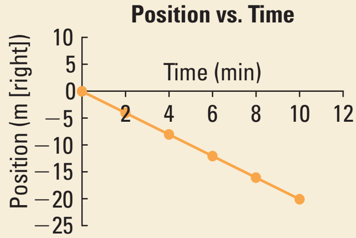
5. Below, two children play catch using an autuk (a type of sealskin racquet). Standing 3.0 m apart, the child on the right tosses the ball to the child on the left, and then moves 5.0 m [right] to catch the ball again. Determine the horizontal distance and displacement the ball travels from its initial position (ignore any vertical motion).

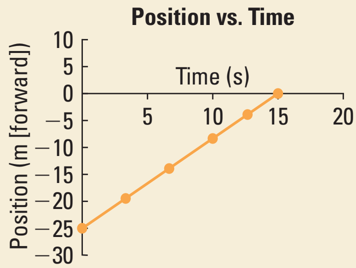


Question 5

6. For the graphs given below:
   (a) What is the displacement in each case?
   (b) Is it necessary that the position points for an object and its final displacement have the same sign? Explain using the graphs below.







Question 6

7. A person's displacement is 50.0 km [W]. What is his final position if he started at 5.0 km [E]?

Reflection

8. What do you know about the difference between distance and displacement that you did not know before?

For more questions, go to PHYSICS•SOURCE