1.1 Distance, Position, and Displacement

You see and interact with moving objects every day. Whether you are racing down a ski hill or running for a school bus, motion is part of your everyday life. Long jump athletes are very aware of distance, position, and displacement. Long jumpers run down a stretch of track to a foul line and then jump as far as possible into a sand pit (**Figure 1**). Their goal is to increase the distance of their jumps. To do this, they focus on their speed, strength, and technique. Successful long jumpers master this goal by applying the physics of motion.

LEARNING **TIP**

SI Metric Units
The SI system (le Système international d'unités) provides base units for measuring fundamental physical quantities. Examples of base units are metres (m) for distance and displacement and seconds (s) for time. Some physical quantities use derived units that are defined in terms of a combination of base units. An example of a derived unit is metres per second (m/s), which is the SI unit for speed and velocity.

Figure 1 Long jumpers attempt to maximize the horizontal distance of their jumps.

Describing the Motion of Objects

To understand the motion of objects, we must first be able to describe motion. Physicists use a number of specific terms and units to describe motion. You are likely familiar with many of these terms and units.

Kinematics is the term used by physicists and engineers to describe the study of how objects move. What exactly is motion? **Motion** is a change in the location of an object, as measured by an observer. **Distance**, in physics terms, means the total length of the path travelled by an object in motion. The SI metric base unit for distance is the metre (m). To help you understand the terms that describe motion, imagine that you are at your home in **Figure 2**. You are at the location marked "0 m." If you walk directly from home to your school in a straight line, you will travel a distance of 500 m. If you walk from your school to the library and then return home, you will travel an additional distance of 700 m + 1200 m = 1900 m.

kinematics the study of motion

motion a change in an object's location as measured by a particular observer

distance (*d*) the total length of the path travelled by an object in motion

direction the line an object moves along from a particular starting point

If your friend wants to know how to get to the library from your home, telling him to walk for 1200 m is not very helpful. You also need to tell your friend which direction to go. **Direction** is the line an object moves along from a particular starting point, expressed in degrees on a compass or in terms of the compass points (north, west, east, and south). Directions can also be expressed as up, down, left, right, forward, and backwards. Directions are often expressed in brackets after the distance (or other value). For example, 500 m [E] indicates that the object is 500 m to the east.

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Direction is important when describing motion. If the school in Figure 2 is your starting point, the library is in a different direction from your school than your home is. If the library is your starting point, then your school and home are in the same direction.

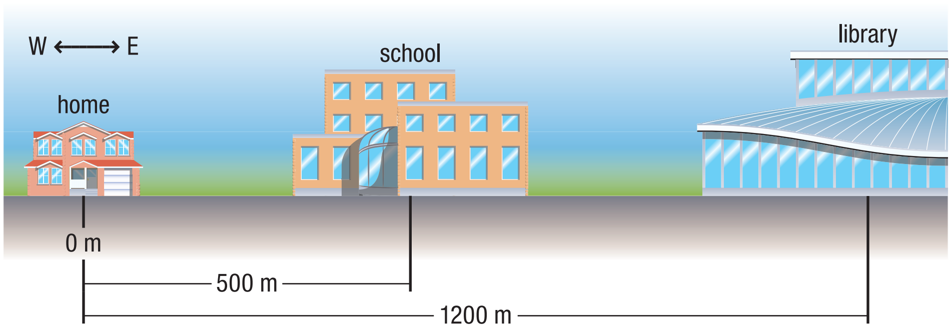

Figure 2 Distance and direction along a straight line

Scalar and Vector Quantities

A **scalar** quantity is a quantity that has magnitude (size) only. Distance is an example of a scalar quantity. Since direction is so important in describing motion, physicists frequently use terms that include direction in their definitions. A **vector** is a quantity that has magnitude (size) and also direction. An arrow is placed above the symbol for a variable when it represents a vector quantity.

scalar a quantity that has only magnitude (size)

vector a quantity that has magnitude (size) and direction

Position and Displacement

Position is the distance and direction of an object from a particular reference point. Position is a vector quantity represented by the symbol $\vec{d}$. Notice the vector arrow above the symbol d. This arrow indicates that position is a vector: it has a direction as well as a magnitude. For example, if home is your reference point, the position of the school in Figure 2 is 500 m [E]. Note that the magnitude of the position is the same as the straight-line distance (500 m) from home to school, but the position also includes the direction (due east [E]). The position of the school from point 0 m can be described by the equation

$$\vec{d}_{\text{school}} = 500\text{ m [E]}$$

Now assume that the library is your reference point, or the point 0 m. The position of the school from the reference point (library) can be described by the equation

$$\vec{d}_{\text{school}} = 700\text{ m [W]}$$

Once the position of an object has been described, you can describe what happens to the object when it moves from that position. This is **displacement**—the change in an object's position. Displacement is represented by the symbol $\Delta\vec{d}$. Notice the vector arrow indicating that displacement is a vector quantity. The triangle symbol Δ is the Greek letter delta. Delta is always read as "change in," so $\Delta\vec{d}$ is read as "change in position." As with any change, displacement can be calculated by subtracting the initial position vector from the final position vector:

$$\Delta\vec{d} = \vec{d}_{\text{final}} - \vec{d}_{\text{initial}}$$

When an object changes its position more than once (experiences two or more displacements), the total displacement $\Delta\vec{d}_T$ of the object can be calculated by adding the displacements using the following equation:

$$\Delta\vec{d}_T = \Delta\vec{d}_1 + \Delta\vec{d}_2$$

WEB LINK

To review scalar and vector quantities,

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position ($\vec{d}$) the distance and direction of an object from a reference point

displacement ($\Delta\vec{d}$) the change in position of an object

Tutorial 1 Calculating Displacement for Motion in a Straight Line

When you walk from one place to another, your position changes. This change in your position is displacement. The displacement can be calculated using your position at the beginning and the end of your journey with the equation $\Delta\vec{d} = \vec{d}_{\text{final}} - \vec{d}_{\text{initial}}$. Remember that position is a vector quantity, so you have to take direction into account. In the following Sample Problems, we will calculate displacements using a range of techniques. Refer to **Figure 3** for the first three Sample Problems.

In Sample Problem 1, we will calculate the displacement of an object with an initial position of 0 m.

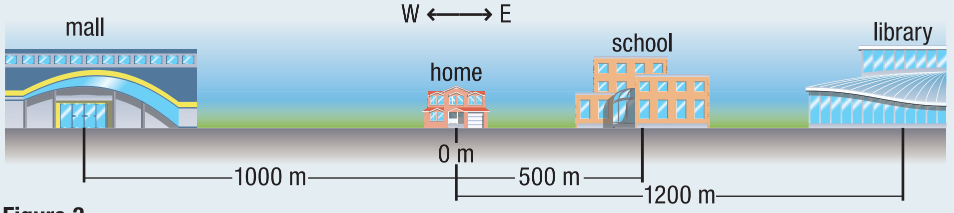

Figure 3

Sample Problem 1: Calculating Displacement from a Zero Starting Point by Vector Subtraction

Imagine that you walk from home to school in a straight-line route. What is your displacement?

Solution

Figure 3 shows that home is the starting point for your journey. When you are at home, your position has not changed. Therefore, your initial position is zero. Your school has a position of 500 m [E] relative to your home.

Given: $\vec{d}_{\text{school}} = 500 \text{ m [E]}$; $\vec{d}_{\text{home}} = 0 \text{ m}$

Required: $\Delta\vec{d}$

Analysis: $\Delta\vec{d} = \vec{d}_{\text{school}} - \vec{d}_{\text{home}}$

Solution:
$$\Delta\vec{d} = \vec{d}_{\text{school}} - \vec{d}_{\text{home}}$$
$$= 500 \text{ m [E]} - 0 \text{ m}$$
$$\Delta\vec{d} = 500 \text{ m [E]}$$

Statement: Your displacement when walking from your home to school is 500 m [E].

Sample Problem 2: Calculating Displacement by Vector Subtraction

What is your displacement if you walk from your school to the library? Note that all positions are measured relative to your home.

Given: $\vec{d}_{\text{school}} = 500 \text{ m [E]}$; $\vec{d}_{\text{library}} = 1200 \text{ m [E]}$

Required: $\Delta\vec{d}$

Analysis: $\Delta\vec{d} = \vec{d}_{\text{library}} - \vec{d}_{\text{school}}$

Solution:
$$\Delta\vec{d} = \vec{d}_{\text{library}} - \vec{d}_{\text{school}}$$
$$= 1200 \text{ m [E]} - 500 \text{ m [E]}$$
$$\Delta\vec{d} = 700 \text{ m [E]}$$

Statement: Your displacement when walking from school to the library is 700 m [E].

Defining the initial starting position of your motion as 0 m will often make displacement problems simpler. In Sample Problem 2, if we had defined 0 m as being the location of the school, it would have been obvious from the diagram that the displacement from the school to the library is 700 m [E].

Sample Problem 3: Calculating Total Displacement by Vector Addition

One night after working at the library, you decide to go to the mall. What is your total displacement when walking from the library to the mall?

Given: $\Delta\vec{d}_1 = 1200 \text{ m [W]}$; $\Delta\vec{d}_2 = 1000 \text{ m [W]}$ (from Figure 3)

Required: $\Delta\vec{d}_T$

Analysis: In this problem, we are not simply calculating a change in position, we are finding the sum of two different displacements. The displacements are given in Figure 3. To calculate the total displacement, we will need to use vector addition. This is simple if both vectors have the same direction.

If the displacement from the library to your home is represented by $\Delta\vec{d}_1$ and the displacement from your home to the mall is represented by $\Delta\vec{d}_2$, then the total displacement, $\Delta\vec{d}_T$, is given by vector addition of these two displacements:

$$\Delta\vec{d}_T = \Delta\vec{d}_1 + \Delta\vec{d}_2$$

Solution:
$$\Delta\vec{d}_T = \Delta\vec{d}_1 + \Delta\vec{d}_2$$
$$= 1200 \text{ m [W]} + 1000 \text{ m [W]}$$
$$\Delta\vec{d}_T = 2200 \text{ m [W]}$$

Statement: When walking from the library to the mall, you experience a displacement of 2200 m [W].

Sample Problem 4: Calculating Total Displacement by Adding Displacements in Opposite Directions

A dog is practising for her agility competition. She leaves her trainer and runs 80 m due west to pick up a ball. She then carries the ball 27 m due east and drops it into a bucket. What is the dog's total displacement?

Solution

In this problem, the given values are displacements. To calculate the total displacement, we will add these two displacement vectors.

Given: $\Delta\vec{d}_1 = 80 \text{ m } [\text{W}]$; $\Delta\vec{d}_2 = 27 \text{ m } [\text{E}]$

Required: $\Delta\vec{d}_T$

Analysis: $\Delta\vec{d}_T = \Delta\vec{d}_1 + \Delta\vec{d}_2$

Solution: $\Delta\vec{d}_T = \Delta\vec{d}_1 + \Delta\vec{d}_2$

$= 80 \text{ m } [\text{W}] + 27 \text{ m } [\text{E}]$

At this point, it appears that we have a problem. We need to add a vector with a direction [W] to a vector with a direction [E]. We can transform this problem so that both vectors point in the same direction. To do so, consider the direction [E] to be the same as "negative" [W]. The vector 27 m [E] is the same as –27 m [W]. We can therefore rewrite the equation as follows.

$= 80 \text{ m } [\text{W}] - 27 \text{ m } [\text{W}]$

$\Delta\vec{d}_T = 53 \text{ m } [\text{W}]$

Statement: The dog's total displacement is 53 m [W].

Practice

1. A golfer hits a ball from a golf tee at a position of 16.4 m [W] relative to the clubhouse. The ball comes to rest at a position of 64.9 m [W] relative to the clubhouse. Determine the displacement of the golf ball. T/I [ans: 48.5 m [W]]
2. A rabbit runs 3.8 m [N] and stops to nibble on some grass. The rabbit then hops 6.3 m [N] to scratch against a small tree. What is the rabbit's total displacement? T/I [ans: 10.1 m [N]]
3. A skateboarder slides 4.2 m up a ramp, stops, and then slides 2.7 m down the ramp before jumping off. What is his total displacement up the ramp? T/I [ans: 1.5 m [up]]

Vector Scale Diagrams

In Tutorial 1, you used algebra to determine the displacement of an object in a straight line. However, there is another method you can use to solve displacement problems: vector scale diagrams. **Vector scale diagrams** show the vectors associated with a displacement drawn to a particular scale. A vector can be represented by a **directed line segment**, which is a straight line between two points with a specific direction. Line segments have magnitude only (**Figure 4(a)**). A directed line segment is a line segment with an arrowhead pointing in a particular direction (**Figure 4(b)**). For example, $\overrightarrow{AB}$ is a line segment in the direction from point A to point B. Line segment $\overrightarrow{BA}$ is the same line segment but in the direction from point B to point A (**Figure 4(c)**). A directed line segment that represents a vector always has two ends. The end with the arrowhead is referred to as the tip. The other end is the tail. A vector scale diagram is a representation of motion using directed line segments drawn to scale with arrowheads to show their specific directions. Vector scale diagrams are very useful in measuring the total displacement of an object from its original position.

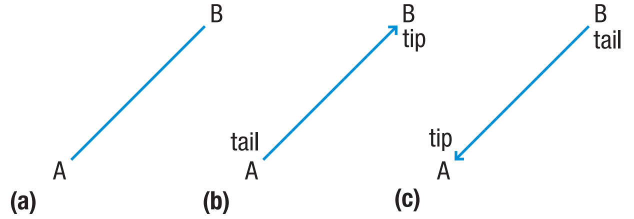

Figure 4 (a) A line segment (b) Directed line segment $\overrightarrow{AB}$ (c) Directed line segment $\overrightarrow{BA}$

vector scale diagram a vector diagram drawn using a specific scale

directed line segment a straight line between two points with a specific direction

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Consider two displacements, $\Delta\vec{d}_1 = 700$ m [W] and $\Delta\vec{d}_2 = 500$ m [W]. We can determine the total displacement that results from adding these vectors together by drawing a vector scale diagram. In general, when drawing a vector scale diagram, you should choose scales that produce diagrams approximately one-half to one full page in size. The larger the diagram, the more precise your results will be.

Figure 5 shows a vector diagram drawn to a scale where 1 cm in the diagram represents 100 m in the real world. Note that each vector in Figure 5 has a tip (the end with an arrowhead) and a tail (the other end). Vectors can be added by joining them tip to tail. This is similar to using a number line in mathematics. Thus, after applying our chosen scale, Figure 5 shows $\Delta\vec{d}_1$ drawn as a vector 7.0 cm in length pointing due west. The tip of $\Delta\vec{d}_1$ is joined to the tail of $\Delta\vec{d}_2$. In other words, the displacement $\Delta\vec{d}_2$ is drawn as a directed line segment that is 5.0 cm long pointing due west, starting where the displacement $\Delta\vec{d}_1$ ends. The total displacement, $\Delta\vec{d}_T$, is the displacement from the tail, or start, of the first vector to the tip, or end, of the second vector. In this case, $\Delta\vec{d}_T$ points due west and has a length of 12 cm. Converting this measurement by applying our scale gives a total displacement of 1200 m [W].

For straight-line motion, vector scale diagrams are not very complex. We will look at more advanced vector scale diagrams in Chapter 2 when we consider motion in two dimensions.

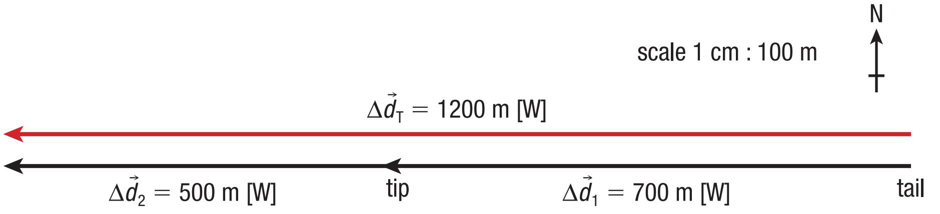

Figure 5 Vector scale diagram

Tutorial 2 Determining Total Displacement for Two Motions in Opposite Directions Using Vector Scale Diagrams

In the following Sample Problem, we will determine displacement by using vector scale diagrams. Consider an example in which motion occurs in two opposite directions.

Sample Problem 1: Using a Vector Scale Diagram to Determine the Total Displacement for Two Motions in Opposite Directions

Imagine that you are going to visit your friend. Before you get there, you decide to stop at the variety store. If you walk 200 m [N] from your home to the store, and then travel 600 m [S] to your friend's house, what is your total displacement?

Solution

Let your initial displacement from your home to the store be $\Delta\vec{d}_1$ and your displacement from the store to your friend's house be $\Delta\vec{d}_2$.

Given: $\Delta\vec{d}_1 = 200$ m [N]; $\Delta\vec{d}_2 = 600$ m [S]

Required: $\Delta\vec{d}_T$

Analysis: $\Delta\vec{d}_T = \Delta\vec{d}_1 + \Delta\vec{d}_2$

Solution: Figure 6 shows the given vectors, with the tip of $\Delta\vec{d}_1$ joined to the tail of $\Delta\vec{d}_2$. The resultant vector $\Delta\vec{d}_T$ is drawn in red, from the tail of $\Delta\vec{d}_1$ to the tip of $\Delta\vec{d}_2$. The direction of $\Delta\vec{d}_T$ is [S]. $\Delta\vec{d}_T$ measures 4 cm in length in Figure 6, so using the scale of 1 cm : 100 m, the actual magnitude of $\Delta\vec{d}_T$ is 400 m.

Statement: Relative to your starting point at your home, your total displacement is 400 m [S].

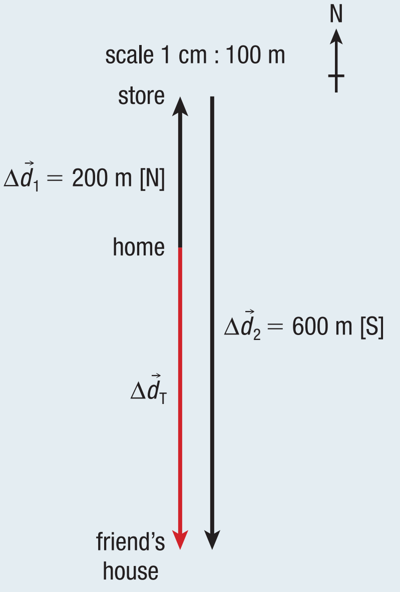

Figure 6 Solution scale diagram for adding vectors with a change in direction

Practice

1. A car drives 73 m [W] to a stop sign. It then continues on for a displacement of 46 m [W]. Use a vector scale diagram to determine the car's total displacement. T/I C [ans: 120 m [W]]
2. A robin flies 32 m [S] to catch a worm and then flies 59 m [N] back to its nest. Use a vector scale diagram to determine the robin's total displacement. T/I C [ans: 27 m [N]]

1.1 Summary

- Motion involves a change in the position of an object.
- Motion can be described using mathematical relationships.
- A scalar is a quantity that has magnitude (size) only.
- A vector is a quantity that has magnitude (size) and direction.
- You can determine the displacement of an object by subtracting the start position from the end position.
- You can determine total displacement by adding two or more displacements together algebraically or by using a vector scale diagram.
- Vectors can be added by joining them tip to tail.

1.1 Questions

1. Which of the following quantities are vectors, and which are scalars? Be sure to explain the reasoning for your answer. K/U C
   (a) A bird flies a distance of 20 m.
   (b) A train is travelling at 100 km/h due north.
   (c) It takes an athlete 10.37 s to run 100 m.
2. Explain the following in your own words: K/U C
   (a) the difference between position and displacement
   (b) the difference between distance and displacement
3. What is the displacement of a locomotive that changes its position from 25 m [W] to 76 m [W]? T/I
4. A car changes its position from 52 km [W] to 139 km [E]. What is the car's displacement? T/I
5. Determine the total displacement for each of the following motions by algebraic methods and by using scale diagrams. T/I C
   (a) $\Delta\vec{d}_1 = 10$ m [W]; $\Delta\vec{d}_2 = 3.0$ m [W]
   (b) $\Delta\vec{d}_1 = 10$ m [W]; $\Delta\vec{d}_2 = 3.0$ m [E]
   (c) $\Delta\vec{d}_1 = 28$ m [N]; $\Delta\vec{d}_2 = 7.0$ m [S]
   (d) $\Delta\vec{d}_1 = 7.0$ km [W]; $\Delta\vec{d}_2 = 12$ km [E]; $\Delta\vec{d}_3 = 5.0$ km [W]
6. A person walks 10 paces forward followed by 3 paces forward, and finally 8 paces backwards. T/I C
   (a) Draw a vector scale diagram representing this person's motion. Use a scale of 1 cm = 1 pace.
   (b) Check your answer by pacing out this motion yourself. How close is your experimental result to that predicted by your vector scale diagram?