# 2.2 Distance, Time, and Speed

Imagine you are in a submarine exploring the deepest part of the ocean. How can you tell the rest of your team where you are? You need to describe where you are in such a way that your fellow team members know exactly what you mean. When scientists need to communicate precise information they use **variables**. A variable is a well-defined piece of information with a name and a **value**. The *depth* of a submarine is a variable that describes how far a submarine is below the surface (Figure 2.6).

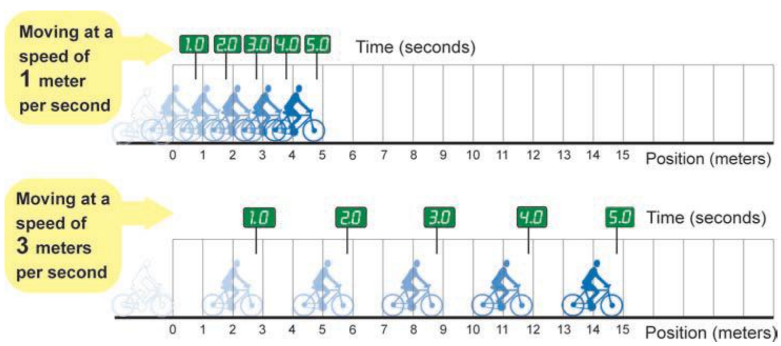
## Speed

### Speed is a motion variable

We use the variable **speed** to describe how quickly something moves. Saying a race car, runner, or plane is "fast" is not enough to accurately describe its speed scientifically. To understand speed we need to be more specific and define speed so we can measure it and give it a precise value. As you will learn in the next section, speed equals distance divided by time.

### An example of speed

Imagine two bicycles moving along the road at different speeds. The illustration below shows the position of each bicycle at one-second intervals. The fast bicycle (bottom) moves 3 meters each second, while the slow bicycle (top) moves only 1 meter each second. The fast bicycle moves three times the speed of the slow one.



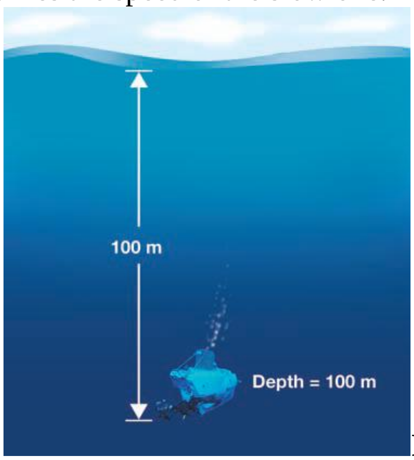




**Figure 2.6:**
*The variable* depth *represents all possible values for the distance between the surface and the submarine. At any moment, the submarine has a specific value of depth. At the moment shown in the picture, the depth is 100 meters.*

## Measuring speed

### Speed is distance divided by time

Speed is a ratio of the distance traveled divided by the time taken. To measure speed you need two values: distance and time. Suppose you drive 150 kilometers (km) in 1.5 hours (h). Your **average speed** is 150 km divided by 1.5 h or 100 km per h (km/h) (Figure 2.7).

### Why "average"?

The speed above is the *average* speed because it really doesn't tell you how fast you are going at any moment during the trip. If you watch the speedometer as you drive, you will see that you are going faster than average some times and slower than average other times. You might even be stopped (speed = 0) for part of the trip. The only way your average speed and actual speed would be the same during the whole trip is if you traveled at a **constant speed**. *Constant* means "does not change" so constant speed is speed that does not change.

### What does “per” mean?

The word *per* means “for every” or “for each.” Saying “100 kilometers per hour” is the same as saying “100 kilometers *for each* hour.” You can also think of *per* as meaning “divided by.” The quantity before the word *per* is divided by the quantity after it. To calculate speed in kilometers per hour, you divide the number of kilometers by the number of hours. 150 km divided by 1.5 h equals 100 km/h.

### Units for speed

Since speed is a ratio of distance over time, the units for speed are distance units over time units. If distance is in kilometers and time in hours, then speed is in kilometers per hour (km/h). Other metric units for speed are cm per second (cm/s) and meters per second (m/s). Your family’s car probably shows speed in miles per hour (mph). Table 2.1 shows different units commonly used for speed.

| Distance | Time | Speed | Abbreviation |
|---|---|---|---|
| Meters | Seconds | Meters per second | m/s |
| Kilometers | Hours | Kilometers per hour | km/h |
| Centimeters | Seconds | Centimeters per second | cm/s |
| miles | hours | Miles per hour | mph |


**Figure 2.7:** *A driving trip with an average speed of 100 km/h.*

## Relationships between distance, speed, and time

### Mixing up distance, speed, and time

A common type of question in physics is: “How far do you go if you drive for two hours at a speed of 100 km/h?” You know how to get speed from time and distance. How do you get distance from speed and time? The answer is the reason mathematics is the language of physics. An *equation* (also called a *formula*) shows you how to get speed, distance, or time if two of the three values are known.

### Calculating speed

Let the letter *d* stand for “distance traveled” and the letter *t* stand for “time taken.” The letter *v* is used to represent “speed” because it refers to the word *velocity (*later we will learn that velocity is speed plus direction). There are three ways to arrange the variables to find either distance, time, or speed. You should be able to calculate any one of the three if you know the other two (Figure 2.8).

### Using formulas

To use a formula, remember that the words or letters stand for values that the variables have (Figure 2.9). You can think of each letter as a box that will eventually hold a number. Maybe you don’t know what the number will be yet, but once you get everything arranged according to the rules, you can fill the boxes with the numbers that belong in each one. The last box left will be your answer.

| Word Formula | Equation |
|---|---|
| speed = distance ÷ time | $v = \frac{d}{t}$ |
| distance = speed x time | $d = vt$ |
| time = distance ÷ speed | $t = \frac{d}{v}$ |

**Figure 2.8:** *Different forms of the speed Equation*

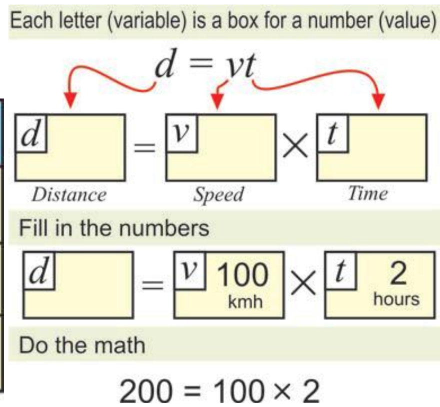



**Figure 2.9:** *Using a formula*

> **Calculating distance from time and speed**
>
> How far do you go if you drive for two hours at a speed of 100 km/h?
> 1. Looking for: You are asked for the distance.
> 2. Given: You are given the speed and the time.
> 3. Relationships: distance = speed × time
> 4. Solution: distance = (100 km/h) × (2 h) = 200 km
>
> **Your turn...**
> a. What is the speed of a snake that moves 20 m in 5 s. **Answer:** 4 m/sec
> b. A train is moving at a speed of 50 km/h. How many hours will it take the train to travel 600 kilometers? **Answer:** 12 hours

## Comparing variables

### You can’t compare values in different units

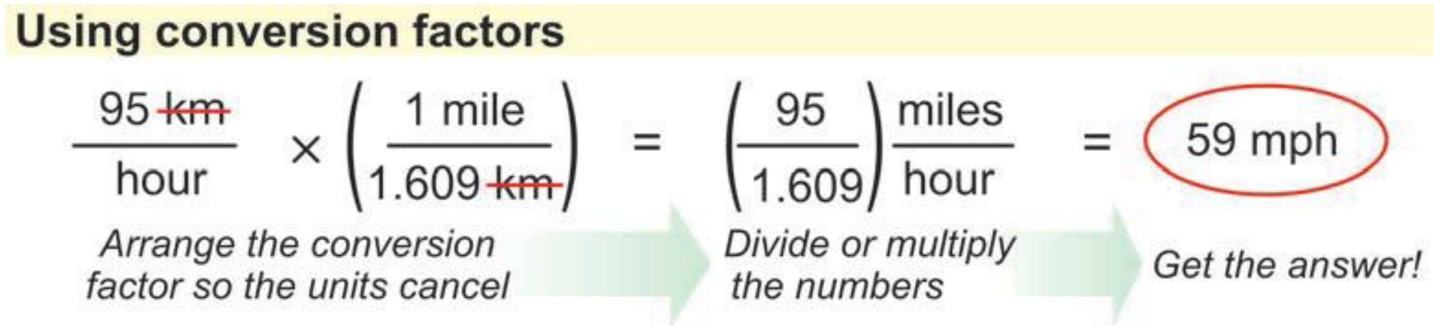
Which is faster: 95 km/h or 75 mph? One speed could get you a speeding ticket and the other might not! In order to compare speeds (or any variables) they must be in the same units. Otherwise it’s like asking how many oranges make ten grapes. Oranges and grapes are not the same, so this question has no sensible answer.

### Units are like languages

Both 95 km/h and 75 mph are speeds per *hour*. That means we only need to convert kilometers to miles to find out which is faster. How many km are in 1 m? A distance of 1 m is the same as 1.609 km. *The distance is the same*, only the values and units are different. Think about finding the word that means “dog” in both Spanish and English. The animal (dog) is the same, only the words are different. Metric and English are two different languages for describing the same things.

### Conversion factors

To convert between units, you multiply and/or divide by **conversion factors**. A conversion factor is a ratio that has the same amount on the top and bottom, *but in different units* (Table 2.2). Any fraction with the same thing on top and bottom has a value of exactly 1. That means you can multiply or divide by a conversion factor without changing the actual quantity; *you only change the unit*. Conversion factors are *translators* between one language of units and another.




**Using conversion factors**

The units are your clue as to whether to multiply or divide. We want to convert 95 kilometers to miles (Figure 2.10). That means we need to get rid of the units of kilometers and end up with units of miles. We flip the conversion factor upside down *so the units of km cancel out!* That tells us we divide 95 by 1.609 to get 59 miles. We now know 95 km/h is the same speed as 59 mph, which is slower than 75 mph.

## How to solve science problems

### Physics problems

Problem solving means using what you already know to figure out something you want to know. Many problems involving speed, distance, and time ask you to calculate something using formulas. Other problems ask you to explain something based on your knowledge of science.

### A four-steptechnique

The technique for solving problems has four steps. Follow these steps and you will be able to see a way to the answer most of the time. You will at least make progress toward an answer every time. The diagram in Figure 2.11 shows the four steps. The table below explains each one.

| Step | What to do |
|---|---|
| 1 | What is the problem asking for? If you can, figure out exactly what variables or values need to be in the answer. |
| 2 | What information are you given? Sometimes this includes numbers or values. Other times it includes descriptive information you must interpret. Look for words like *constant* or *at rest.* In a physics problem, saying something is constant means it does not change. The words “at rest” in physics mean the speed is zero. You may need conversion factors to change units. |
| 3 | What relationships exist between what you are asked to find and what you are given? For example, suppose you are given a speed and time and asked to find a distance. The relationship $v = d \div t$ relates what you are asked to find to what you are given. |
| 4 | Combine the relationships with what you know to find what you are asked for. Once you complete steps 1–3, you will be able to see how to solve most problems. If not, start working with the relationships you have and see where they lead. |

## How to solve design problems

### Different kinds of problems

Consider the following two problems.

1. How far do you travel in 2 hours at 60 mph on a straight road?
2. Create a container that will protect a raw egg from breaking when dropped 10 meters onto a sidewalk.

### “Book” problems

The first problem has a single answer, you go 120 miles in 2 hours at 60 mph. You apply what you know (distance = speed × time) to take what you are given and find the answer.

## Design problems

The second problem is much more challenging (and fun too). You have to use what you know to design a solution that solves the problem. Unlike “book problems,” design problems have many correct solutions limited only by your creativity, ingenuity, skill, and patience (Figure 2.12). The important thing is to create something that “does the job” and fits the requirements. In the egg-drop problem, typical requirements are that the container must weigh less than 1 kg, and cannot be something simply purchased “off the shelf.”

## Solving design problems

Here are some useful steps to help you solve design problems.

1. Write down very clearly everything your solution needs to accomplish.

2. Write down every *constraint* that must also be met. Constraints are limits on cost, weight, time, materials, size, or other things.

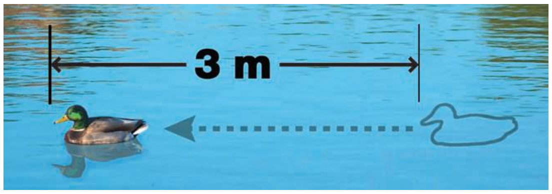
3. Think up an idea that *might* work. Talking with others, doing research, and trying things out are all ways to help.

4. Follow the design cycle.

## 2.2 Section Review

1. Explain how a bicycle can be fast compared to walking and slow compared to driving. How can two opposite words (fast and slow) describe the same speed?

2. If something moves at a constant speed, what do you know about the distance it moves each second?




3. What is the speed of the duck swimming in the picture above if it takes 15 seconds to move the distance shown?

4. Calculate the average speed (in km/h) of a car that travels 280 kilometers in 4 hours.

5. You ride your bicycle at an average speed of 15 km/h for 2 hours. How far did you go?

6. How long (in seconds) will it take you to run 100 meters if you run at 5 m/s?

7. A boat sails at an average speed of 20 km/h for two days. How far does the boat go?

8. The distance between two cities is 300 kilometers. Is this longer or shorter than 200 miles?

9. Can you go 500 kilometers in 8 hours without driving faster than 55 mph?

10. Two students measure the time it takes for a race to finish. One measures 75.5 seconds. The other measures 1 minute and 15.5 seconds. Both students are correct. Why?