Chapter 9.5- 9.8

9.5

Relating Speed to Distance and Time

If you are in a car that travels 80 km along a road in one hour, we say that you are travelling at, on average, 80 km/h. You might not have been travelling at the same speed all the time: you might have speeded up to 100 km/h to pass other vehicles, or even stopped for gas. But overall, during the entire hour, your average speed was 80 km/h.

Average Speed

To find the speed of a car in units of kilometres per hour (km/h), we divide the distance (in kilometres) by the time (in hours). Therefore speed v is distance Δd divided by the time Δt. (Some examples of units for distance, time, and speed are given in **Table 1**.) **Average speed**, v_{av}, is the total distance divided by the total time for a trip. Transformed into quantity symbols, the defining equation looks like this.

Table 1 Some SI Quantities and Units

Quantity	Quantity symbol	Sample unit	Unit symbol
distance	*d*	millimetre	mm
		centimetre	cm
		metre	m
		kilometre	km
time	*t*	second	s
		minute	min
		hour	h
		year	a
speed	*v*	metres per second	m/s
		kilometres per hour	km/h

$$v_{av} = \frac{\Delta d}{\Delta t}$$

v_{av} is read as "average speed."

Δ is read as "change in" (delta is the fourth capital letter in the Greek alphabet).

Δd is read as "change in distance," "elapsed distance," or "distance."

$\Delta d = d_2 - d_1$, where d_1 is one distance measurement and d_2 is a later distance measurement; d_1 is often zero.

Δt is read as "change in time," "elapsed time," "period of time," or "time."

$\Delta t = t_2 - t_1$, where t_1 is one time measurement and t_2 is a later time measurement.

t_1, the starting time, is often zero.

Quantity symbols (**Table 1**) are italic letters used to represent quantities (such as distance, time, and speed) in scientific equations. These quantity symbols have general international agreement, although alternatives are sometimes suggested. The quantity symbols are not unique because there are only 26 letters in our alphabet, while there are many more quantities. For example, *d* can represent distance, diameter, or density, *t* can communicate time or temperature, and *v* can refer to speed or volume. Quantity symbols are always typed in italics while unit symbols are not. For example, while *m* is the quantity symbol for mass, m is the unit symbol for metres. Quantity symbols are found in equations (e.g., $E = mc^2$) while unit symbols are found with values (e.g., 3.7 m).

Instantaneous Speed

The car in **Figure 1**, at the time the photo was taken, was stationary. Its speed at that moment was 0 km/h. When the car was passing a truck on the road, its speedometer might have shown a speed of 100 km/h. These are examples of instantaneous speeds. **Instantaneous speed** is the speed at which an object is travelling at a particular instant. It is not affected by its previous speed, or by how long it has been moving.

High instantaneous speeds contribute to the seriousness of road traffic accidents. The two most familiar instruments that measure instantaneous speed were designed to improve road safety: the speedometer and the "radar gun."

Figure 1
At this moment the instantaneous speed of the car is zero, but this will change when the traffic light becomes green.

Constant Speed

If the instantaneous speed of a car remains the same over a period of time, then we say that the car is travelling with **constant speed** (or **uniform motion**). Some vehicles have cruise control to keep them moving along at a fairly constant speed. Few objects maintain constant speed over a lengthy period of time, however, often because of friction. However, we often assume constant (uniform) speed for the purposes of simplifying our physics calculations.

The average speed of an object is the same as its instantaneous speed if that object is travelling at constant speed.

Did You Know?

The Greeks did not have a concept of speed until Autolycus of Pitane (about 300 B.C.), defined constant speed as a speed in which equal distances are traversed in equal times. We use the same definition today.

Sample Problem 1

Eiko skates to school, a total distance of 4.5 km (**Figure 2**). She has to slow down twice to cross busy streets, but overall the journey takes her 0.62 h. What is Eiko's average speed during the trip?

$\Delta d = 4.5 \text{ km}$

$\Delta t = 0.62 \text{ h}$

$v_{av} = ?$

$$v_{av} = \frac{\Delta d}{\Delta t}$$

$$= \frac{4.5 \text{ km}}{0.62 \text{ h}}$$

$$= 7.3 \text{ km/h}$$

Eiko's average skating speed is 7.3 km/h.

Figure 2
In-line skating is often a quick way to get to school.

Sample Problem 2

Imagine that you are riding on the Cariboo Dayliner, in the dome car of course (**Figure 3**), and you see a sign that reads 120 km. You decide, after seeing several such signs, that you are going to measure the elapsed time between the next two signs, which are 10 km apart. You read the elapsed time as 390.6 s. Determine the speed of the train in kilometres per hour during the elapsed time.

Figure 3
The Cariboo Dayliner yields a scenic view of Canada.

$\Delta d = 10 \text{ km}$

$\Delta t = 390.6 \cancel{\text{s}} \times \dfrac{1 \cancel{\text{min}}}{60 \cancel{\text{s}}} \times \dfrac{1 \text{ h}}{60 \cancel{\text{min}}} = 0.1085 \text{ h}$

$v_{av} = ?$

$$\begin{aligned} v_{av} &= \frac{\Delta d}{\Delta t} \\ &= \frac{10 \text{ km}}{0.1085 \text{ h}} \\ &= 92 \text{ km/h} \end{aligned}$$

The average speed of your train is 92 km/h.

Sample Problem 3

Kira is trying to predict the time required to ride her bike to the nearby beach. She knows that the distance is 45 km and, from other trips, that she can usually average about 20 km/h, including slowing down for climbing hills. Predict how long the trip will take.

$\Delta d = 45 \text{ km}$

$v_{av} = 20 \text{ km/h}$

$\Delta t = ?$

$$\begin{aligned} v_{av} &= \frac{\Delta d}{\Delta t} \\ \Delta t &= \frac{\Delta d}{v_{av}} \\ &= \frac{45 \cancel{\text{km}}}{20 \frac{\cancel{\text{km}}}{\text{h}}} \\ &= 2.3 \text{ h} \end{aligned}$$

There is an easy method of converting between km/h and m/s.

1 m/s = 3.6 km/h

exactly, because all of the conversion factors used were exact values, by definition.

Alternatively, you can substitute and then rearrange the equation.

$\Delta d = 45 \text{ km}$

$v_{av} = 20 \text{ km/h}$

$\Delta t = ?$

$$\begin{aligned} v_{av} &= \frac{\Delta d}{\Delta t} \\ 20 \frac{\text{km}}{\text{h}} &= \frac{45 \text{ km}}{\Delta t} \\ \Delta t &= \frac{45 \cancel{\text{km}}}{20 \frac{\cancel{\text{km}}}{\text{h}}} \\ &= 2.3 \text{ h} \end{aligned}$$

Kira should be able to make the trip in about 2.3 h.

Did You Know?

On April 15, 1999, a Japanese magnetically levitated train broke its own world speed record by travelling at 552 km/h.

Note that the units in Sample Problem 3 simplify as follows:

$$\frac{\text{km}}{\frac{\text{km}}{\text{h}}} = \cancel{\text{km}} \times \frac{\text{h}}{\cancel{\text{km}}} = \text{h}$$

Sample Problem 4

Janna has a summer job helping with bison research (**Figure 4**). She notes that they graze (move and eat grass) at an average speed of about 110 m/h for about 7.0 h/d. What distance, in kilometres, will the herd travel in two weeks (14 d)?

$$v_{av} = 110 \text{ m/h}$$

$$\Delta t = 7.0 \frac{\text{h}}{\cancel{\text{d}}} \times 14 \cancel{\text{d}} = 98 \text{ h}$$

$$\Delta d = ?$$

$$v_{av} = \frac{\Delta d}{\Delta t}$$

$$\Delta d = v_{av}\Delta t$$

$$= 110 \frac{\text{m}}{\cancel{\text{h}}} \times 98 \cancel{\text{h}}$$

$$= 11 \text{ km}$$

or

$$v_{av} = \frac{\Delta d}{\Delta t}$$

$$110 \frac{\text{m}}{\text{h}} = \frac{\Delta d}{98 \text{ h}}$$

$$\Delta d = 110 \frac{\text{m}}{\cancel{\text{h}}} \times 98 \cancel{\text{h}}$$

$$= 11 \text{ km}$$

According to Janna's observations, after two weeks the bison will have covered a distance of about 11 km.

Figure 4
A few buffalo still roam.

Understanding Concepts

1. **(a)** How is average speed different from instantaneous speed?
   (b) When are they the same?
2. A car and a truck travel along the same highway with the car moving faster than the truck.
   (a) How do their distances travelled compare after the same length of time?
   (b) How do their times compare after travelling the same distance?
3. Holidays might mean a multiday trip to be taken by foot, boat, train, or automobile. The Trans Canada Trail (**Figure 5**), for example, has become a popular hiking and cycling vacation route.

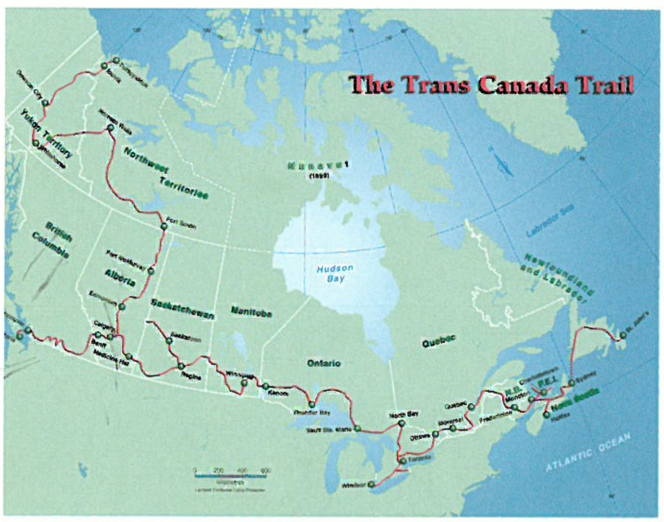


Figure 5

   (a) If two hikers walk the Trans Canada Trail for 6.0 h, and covered 31 km, what is their average speed for the day?
   (b) If three bike riders on the Trail cycle for 6.0 h one day, and cover 85 km, what is their average speed for the day?
   (c) Mary walked for 2.1 h along a portion of the Trans Canada Trail at a speed of 3.6 km/h. What distance did Mary travel?
   (d) What length of time would it take a hiker to travel a total distance of 25.0 km at an average speed of 5.2 km/h?
4. The cruise control of a car is set at 90.0 km/h. What distance is travelled by the car during 2.50 h?
5. Show that 1 m/s = 3.6 km/h.
6. Use the conversion factor in question 5 to convert
   (a) 92 km/h to m/s;
   (b) 21 m/s to km/h.
7. **(a)** The *Breitling Orbiter 3* balloon (**Figure 6**) set world records in 1999 by travelling 40 814 km in 19 d, 21 h, and 47 min. On March 1, 1999, the balloon lifted off from a village in the Swiss Alps. It eventually landed in Egypt on March 21. Calculate the average speed of the balloon.
   (b) Using the average speed you calculated in **(a)**, what length of time did it take the *Breitling Orbiter 3* to cross the Atlantic Ocean, a distance of 6670 km?
   (c) In the final leg of the round-the-world trip, the balloon flew for 18 h at an average speed of 210 km/h. How far did it travel?

Figure 6

8. In 1997, *Thrust SSC*, the world's fastest jet-engine car, travelled 604 m at an average speed of 341 m/s.
   (a) What length of time did this take?
   (b) Convert 341 m/s to kilometres per hour.
9. In a marathon race, one runner moving at 5.0 m/s passes a second runner moving at 4.5 m/s. What is the distance between the runners 10 min after the one runner passed the other?

10. The "hand" of the Canadarm (**Figure 7**) used on the space shuttle can move up to 60 cm/s without a load attached.

(a) What is the minimum time for the Canadarm's hand to move 1.20 m?

(b) When the Canadarm is moving an object, the speed is slightly less than 60 cm/s. To move the same distance of 1.20 m, will the time be more or less than your answer to **(a)**? Explain your answer.

(c) The Canadarm takes 30 s to move some equipment from the cargo bay. During this time, the space shuttle moves 232 km through space. What is the speed of the space shuttle in kilometres per second? in kilometres per hour?

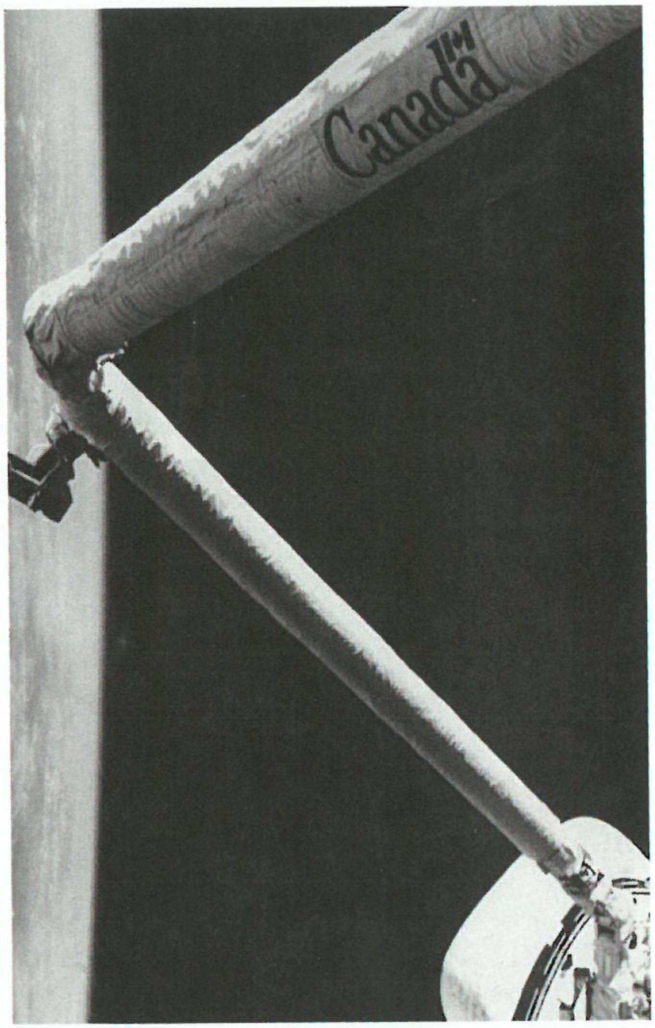


Figure 7

11. The following lab report describes how recordings were taken during a road trip. Complete the Analysis and Evaluation section using the observation, recorded in **Table 2**.

Question

What is the average speed for a multiple-stage car trip to my grandparents' home?

Evidence

Table 2 **A Trip to the Grandparents'**

Time period or stage of trip	Initial odometer reading (km)	Final odometer reading (km)	Initial time (h:min)	Final time (h:min)
1	36 252.1	36 260.7	8:04	8:14
2	36 260.7	36 260.7	8:14	8:32
3	36 260.7	36 542.3	8:32	11:30
4	36 542.3	36 542.3	11:30	11:52
5	36 542.3	36 709.6	11:52	13:27

Analysis and Evaluation

(a) During which time periods was the car moving? Calculate the speed during each of these separate time periods.

(b) Calculate the average speed for the trip as a whole, from the beginning of Stage 1 to the end of Stage 5.

(c) Explain the differences in your answers for (**a**) and (**b**).

8A Evaluate the experimental design. What would have made the design more efficient? Would this modification have changed the answer?

Reflecting

12. Sample Problem 4 on page 357 shows the calculation of the distance moved by the bison herd after 14 d. Is Janna likely to find the bison 11 km away? What does the calculated distance not take into account? What information is missing in the distance the bison move?

Challenge

2 Laws are created, tested, and then used. How would you test the average speed equation (a law)?

3 Relate what you have just learned to driving. How does a car's speed affect the distance it travels during the driver's "reaction time"?

SKILLS HANDBOOK: 8A Evaluating the Evidence

9.6 Investigation

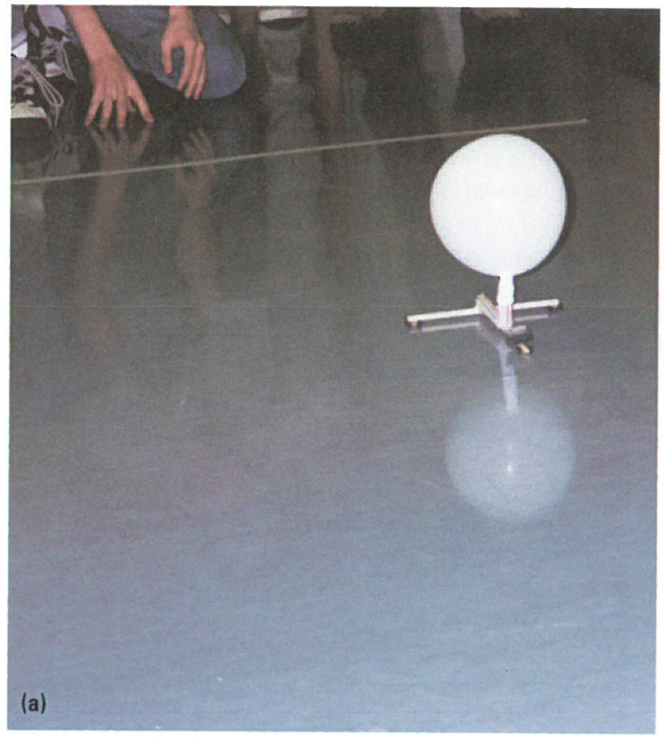
INQUIRY SKILLS MENU

- ○ Questioning
- ○ Hypothesizing
- ○ Predicting
- ● Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Communicating

Balloon Car Contest

The balloon car contest (**Figure 1**) is an exercise in technological problem solving: the trial-and-error approach. As you go around the cycle (**Figure 2**), you either keep refining the same general design or reach a dead end and switch to a completely new approach. Each cycle has its own design, procedure, evidence, and analysis until you reach a product or, in some cases, a process with a satisfactory result. The technological process for producing the balloon car is also a product, and so, perhaps, are one or more technological skills for operating the balloon car.

You will start with a general design and procedure. As you gather evidence you will modify the product (the car) and process (skills for building and operating the car). By trying various designs and techniques, you will produce a car that travels along a 3-m track.



(a)

(b)

Figure 1
Balloon car races

Question

What design, procedures, and skills yield your best balloon car?

Design

Attach a balloon to a toy car. Race the balloon-powered car over 3.00 m. The car must move on its wheels and the sole source of propulsion must be provided by the balloon. Two trials are allowed in the final race. Judge the best car using a variety of perspectives (including technological, economic, and aesthetics or beauty).

(a) Design a table in which to record the quantitative and qualitative evidence gathered in this investigation. The column headings could include *Trial number*, *Distance travelled* (*m*), *Time taken* (*s*), and *Comments*. (K7)

Materials

- balloon
- toy car with wheels
- stopwatch or wristwatch
- metre stick
- other assorted materials as required

SKILLS HANDBOOK: (K7) Creating Tables of Evidence

Procedure

1. Locate a safe place for the trials.
2. Mark out a distance of 3.00 m.
3. Attach the balloon to the car.
4. Release the car with the balloon in the direction of the finish line.
5. Measure and record the time to run 3.00 m or until stopped short of the line.
6. Measure and record any distance travelled under 3.00 m.
7. Modify your car or the process of starting your car to improve its performance.
8. Repeat steps 3–7 as many times as required, adjusting your design to get the most reliable (consistent) and satisfactory results.
9. Race your car against other designs. You will be allowed two trials.

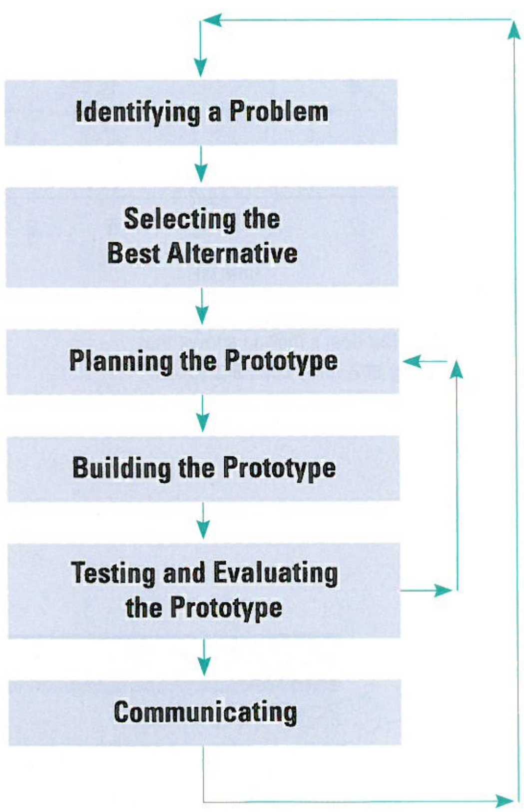


Figure 2
The problem-solving cycle

Analysis and Evaluation

(b) K2 Answer the Question. Include information about the car from a variety of perspectives, including technological, economic, and aesthetics (beauty). Remember to consider procedures and skills, as well as the car itself.

(c) O2 Evaluate your design, procedure, and skills. For example, did you experience any problems making your measurements? How would this affect your evidence? Include any general improvements you would make.

(d) S Present your car and its performance and features to the class.

Understanding Concepts

1. Describe the process of technological problem solving and list some of the things that you learned about this approach.
2. What criteria did you use to help you decide which was your "best" balloon car?
3. Calculate the average speed for the best trial of your balloon car.
4. Describe, in your own words, the motion of your balloon car.

Reflecting

5. As you worked on solving your technological problem, how well did your group work together? What personal attitudes are important in group work?
6. Did you use your knowledge of science to guide your design? If so, in what way?
7. How does technological problem-solving compare with scientific problem-solving?

Challenge

1 Even if you are following an established design, there will be some trial-and-error as you construct your timepiece. Keep a record of your modifications and how they affect your model.

K2 Answering the Question O2 Evaluating the Evidence S Oral Presentations

9.7

Distance–Time Graphs

Imagine that you are a wildlife biologist and have collected information on the distances travelled by a white-tailed deer running at top speed (**Table 1**), escaping from a wolf. Now you need to communicate this information to a colleague. You could use words in either a spoken or written report; you could make a drawing or diagram showing how far the deer travels during a certain time interval; you could present a table of your quantitative observations; or you could plot the information on a graph. Graphs are used to communicate quantitative information visually. Most people, scientists included, can understand a graph more quickly and easily than they can a table of evidence or a couple of paragraphs of text.

Table 1 **A Running White-Tailed Deer**

Time (s)	Distance (m)
0	0
1.0	13
2.0	25
3.0	40
4.0	51
5.0	66
6.0	78

Whether graphs are your first choice or not, most people agree that graphs help us to understand the relationship between two variables. We can see whether the dependent variable increases or decreases with the independent variable. On a distance–time graph, time is usually the independent variable (plotted on the x-axis) and distance is the dependent variable (plotted on the y-axis). **Figure 1** shows a graph for a running deer. The line on this graph is straight and pointing upward to the right. This indicates that there is a direct relationship between distance and time and that the relationship follows the general equation for a straight line.

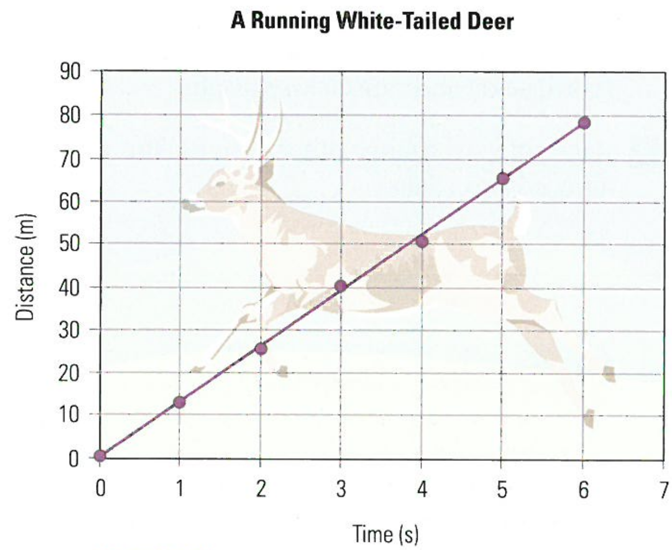


Figure 1
The graph of the deer's motion shows that it was running at a fairly constant speed.

How can the slope of the best-fit line represent both $\Delta d = v\,\Delta t$ (the equation relating distance, speed, and time) and $y = mx + b$ (the general equation for a straight line)? The equations certainly don't look the same. Let's examine both equations more closely.

Recall that

$y = mx + b$ where y is the dependent variable (on the y-axis)
x is the independent variable (on the x-axis)
m is the slope of the line
b is the y intercept of the line.

In the case of a distance–time graph of an object with constant speed,

$$y = mx + b$$

becomes $\Delta d = v\,\Delta t + 0$

or simply $\Delta d = v\,\Delta t$ where Δd (distance travelled) is the dependent variable
Δt (time) is the independent variable
v (speed) is the slope of the line
0 (initial distance, d_1) is the y intercept.

Did You Know?

Top speeds in water:

human	8.4 km/h
sailfish	97 km/h
boat	555 km/h

Now you can see how the general equation for a straight line on a graph, $y = mx + b$, also represents $\Delta d = v\,\Delta t$.

Logic and consistency are two ways of testing scientific knowledge, and your own knowledge too. The idea that distance and time are related directly and linearly passes the test of logic and consistency. We can conclude that the **slope of a line** on a distance–time graph represents speed.

Slope and Speed

The greater the speed, the greater the slope of the line of a distance–time graph. To put it another way, the greater the slope of a line on a distance–time graph, the greater the speed. **Figure 2** is a graph of three different ways of getting around. The fastest means of transportation (the bicycle) has the steepest slope. In-line skates are the next fastest, and walking is the slowest.

Canada's Joanne Malar swims the individual medley of butterfly, backstroke, breaststroke, and freestyle. In training, an overhead video camera records and analyzes the total distances covered during the first five 5.0-s intervals of each lap. We can use the information in **Table 2** to draw a graph comparing Malar's fastest and slowest strokes.

In the first 25.0 s, Malar had travelled the greatest distance during her freestyle lap, and the shortest distance during the breaststroke lap. It is these two strokes that should appear on the graph, which will look like **Figure 3**.

We can extract information on speed simply by looking at the slopes of lines on distance–time graphs. For example, in **Figure 3** we can see that Malar's freestyle lap is considerably faster than her breaststroke lap. But how do we find the actual speeds from a graph? Scientists and engineers want more than a comparison; they want the quantitative (number) value for the speeds depicted by distance–time graphs.

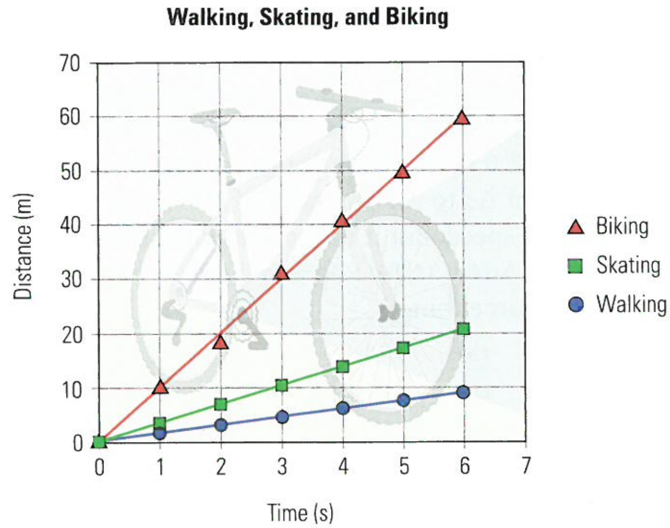


Figure 2
Comparing walking, skating, and biking

Table 2 The 200-m Individual Medley

Time (s)	Butterfly distance (m)	Backstroke distance (m)	Breaststroke distance (m)	Freestyle distance (m)
0.0	0.0	0.0	0.0	0.0
5.0	8.2	8.0	7.5	9.5
10.0	16.2	17.0	15.1	18.5
15.0	24.7	24.5	22.7	27.0
20.0	32.8	31.5	30.5	35.5
25.0	42.0	39.0	36.5	45.0

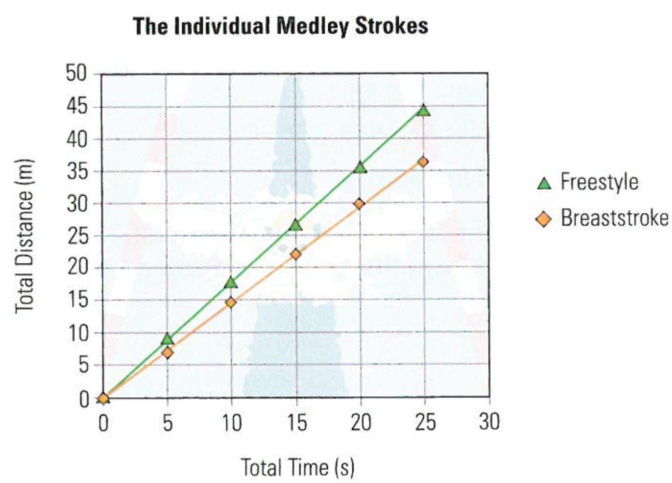


Figure 3
Graph of Malar's fastest and slowest strokes

When you analyze the slopes of graphs you are really comparing the change in distance (Δd) during equal intervals of time (Δt). For example, how can you determine which stroke takes the swimmer farthest in 1.0 s? Mathematically, you are comparing the ratios of Δd to Δt. The ratio of $\Delta d : \Delta t$ is, of course, the speed, but it is also the slope of the line. (Note that Δd to Δt, $\Delta d : \Delta t$, and Δd over Δt all mean the same thing.)

$$\text{slope} = \frac{\text{rise}}{\text{run}}$$

$$v = \frac{\Delta d}{\Delta t}$$

The slope of a distance–time graph is determined from the rise over the run, which also happens to be the distance over the time, which in turn is the speed. **Speed is determined from the slope of the best-fit straight line of a distance–time graph.**

Table 3 gives observed data for the travels of a Hummer on a narrow country road.

The graph (**Figure 4**) shows the total distance travelled during 10 min. Notice that the shape of the line is straight. This means that the speed is fairly constant. We call this constant (or uniform) speed. We use a significant portion (2/3 to 3/4) of the graph to find the average speed of the Hummer. The advantage of the triangle displayed is that the triangle is separated from the x-axis and is easy to see on the graph. A smaller triangle produces more error. The triangle is attached to the line and not to observed data points on the line.

$$\begin{aligned} \text{slope} &= \frac{\text{rise}}{\text{run}} \\ v &= \frac{\Delta d}{\Delta t} \\ &= \frac{(9.0 - 2.0)\ \text{km}}{(9.0 - 2.0)\ \text{min}} \\ &= 1.0\ \text{km/min} \end{aligned}$$

In summary, **the speed of an object in motion can be determined from the slope of a distance–time graph.**

Table 3 A Hummer Travelling on a Country Road

Time (min)	Distance (km)
0	0
1.0	1.0
2.0	1.8
3.0	2.9
4.0	4.2
5.0	5.0
6.0	5.9
7.0	6.9
8.0	8.2
9.0	9.2
10.0	10.0

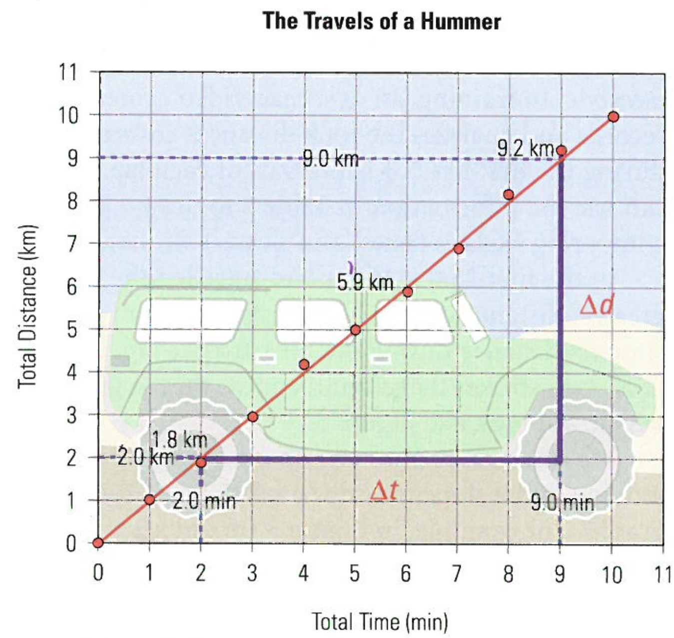


Figure 4
Fairly constant speed from a Hummer (2, 1.8)

Understanding Concepts

1. Explain, in your own words, why a graph is sometimes more useful than an equation.
2. What does the slope of a distance–time graph represent?
3. What interpretation can be made about a moving car if the line on a distance–time graph for the car has the following characteristics?
   - **(a)** a high or steep slope
   - **(b)** a low or less steep slope
   - **(c)** a zero slope
   - **(d)** a short line on the graph
   - **(e)** a long line on the graph
4. Sketch a distance–time graph for a car cruising at 80 km/h.
5. A car leaves Borden-Carleton, PEI, on its way across the Confederation Bridge into New Brunswick. The distances and times from the toll booth in PEI are listed in **Table 4**. They include a short stretch of road beyond the end of the 12.9-km bridge.

Table 4 **Car Crossing Confederation Bridge**

Time (min)	Distance (km)
0.0	0.0
2.0	2.4
4.0	4.8
6.0	7.2
8.0	9.6
10.0	12.0
12.0	14.4

   - **(a)** Plot a distance–time graph using the information in (V) **Table 4**. Draw a best-fit straight line.
   - **(b)** Using your graph, find the distance travelled after 5.0 min.
   - **(c)** Using your graph, find the time required to cross the bridge.
   - **(d)** Was the speed constant during the car's trip across the Confederation Bridge? How do you know?
   - **(e)** Calculate the slope of the graph. What does this slope represent?
   - **(f)** What is the speed of the car in kilometres per hour?
6. In **Figure 5**, the motion of two bicycle riders, Tom and Jerry, is described on a distance–time graph.

Motion of Two Bicycle Riders

Figure 5
These two cyclists are travelling at different speeds.

   - **(a)** From a qualitative observation of the lines on the graph, which rider has the greater speed?
   - **(b)** Calculate the speed of each rider by determining the slope of each line. Does this quantitative result match your answer to (a)?
   - **(c)** If one of the bicycle riders suddenly stopped, how would the graph of that rider change?

Reflecting

7. When studying motion in physics, it is customary to plot time on the horizontal axis and distance on the vertical axis even if distance is the independent variable in a particular experiment. Suggest a reason for this general rule.

Work the Web

Visit www.nelson.science.com and follow the links from Science 10, 9.7 to research the times for the top five finishers in the most recent Toronto Indy race. Compare their average speeds. Other than the characteristics of each car, what are some factors that affect the average speed over the whole race?

Challenge

3 You will need to create graphs to illustrate how cars, travelling at different speeds, cover different distances in the same amount of time. What will be plotted on each axis? What units will you use?

SKILLS HANDBOOK: (V) Graphing

9.8 Case Study

Smart Highways

Figure 1
Major accidents such as the one pictured may be avoided by the use of high-tech highway systems.

Canada is steadily becoming more urbanized and, as more people choose to live in major cities like Toronto, traffic problems are increasing dramatically. Journey times lengthen, wasting the travellers' time; accidents are more frequent, costing society dearly in injury and property damage (**Figure 1**); pollution levels increase, increasing health costs and decreasing quality of life; and human frustration and stress levels become more pronounced.

Automated Highways

A suggested improvement to decrease many traffic problems involves the automation of highways in high traffic areas. The Japanese government and several states in the United States, along with many individual companies and agencies, have been investigating this concept. In 1997 a preliminary test of an automation system was conducted on a short stretch of highway north of San Diego, California.

A fully automated highway system might work by having computers control the entry of cars onto a highway, the speed and spacing of cars on the highway, and the cars' dashboard display screens. Drivers would have available a running display of information such as distance to the next exit, current position, and speed. In some proposals drivers have an emergency override, although that has been a problem with the system design to date. No system can work properly unless all vehicles "cooperate." Therefore, driver override would probably be limited to pulling out of the traffic flow and slowing to a stop on the shoulder of the road.

While on a fully automated highway, a car's steering, braking, and speed would all be computer controlled. An automobile could possibly be retrofitted with all the necessary equipment for $1500 or less, according to manufacturers' current estimates. In one highway model, the roadway has magnetic plugs in it for the car steering system to detect, and each car has sensors to measure the front and rear spacing between it and other vehicles (**Figure 2**). Cars can also detect their position by reflecting infrared light from lane markers. Fixed laser beams can be used to sense cars passing and feed this information to a controlling computer.

(a) Suggest reasons why San Diego was chosen for a trial project.
(b) Why is it important that all vehicles "cooperate" on an automated highway? What might be the result of non-cooperation?
(c) Do you think it would be possible to retrofit all vehicles to use the automated highway? What effect would this have? Would everyone want to retrofit their vehicle? What would be the consequences of some people choosing not to retrofit?

Probably the most important change will be the distances between cars. Improvements can be achieved just by controlling vehicles' spacing and speed because in congested traffic all vehicles must necessarily move at the speed of the slowest. Computer-controlled cars can be merged into traffic and exited smoothly at the same speed as the traffic flow, even when visibility is poor. The really significant factor with automated control is that it should be possible to space vehicles as little as 3 m apart while they travel! Currently, drivers are advised to leave enough space between their vehicle and the one ahead to allow at least two seconds for reaction time in case of accidents. Dramatically reducing this spacing allows many more cars to use the roadway without the necessity of altering traffic flow speed.

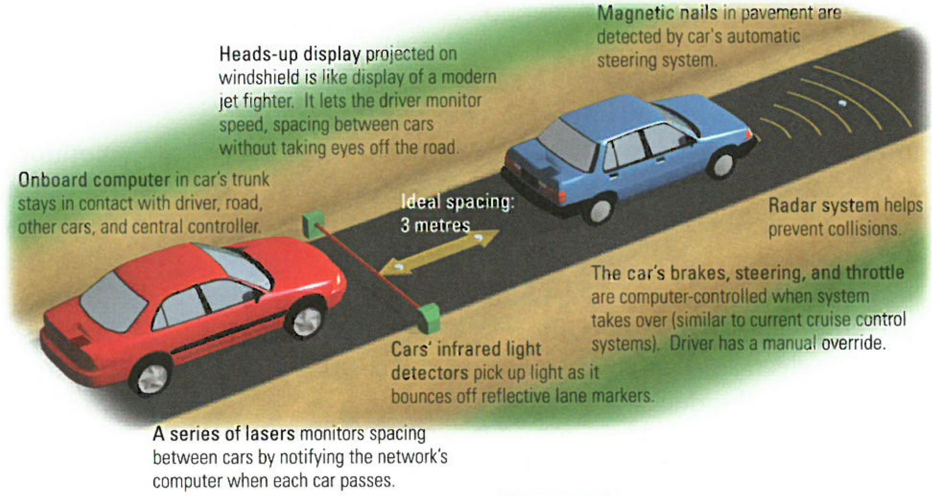


Figure 2

Multiple road and car sensors linked to a central computer control all aspects of traffic flow.

(d) At 90 km/h, what distance in metres is represented by a 2.0-s reaction time interval? What is the distance for 2.0 s at 120 km/h?

(e) Allowing 5.0 m for an average automobile length and 3.0 m spacing between cars, how many *extra* cars could be added by using an automated highway system compared with the reaction-time distance at 90 km/h from the previous question?

Ontario's "Smart Highway"

Hwy. 407 Express Toll Route (ETR) runs east-west across the north of Toronto and is the world's first all-electronic toll highway (**Figure 3**). Although not a complete automated highway, it is certainly a working illustration of the capability of modern electronic technology to monitor and reduce traffic congestion in a large metropolitan area. Within two years

Figure 3

Hwy. 407 is a privately owned electronic toll road.

of its opening in October 1997, more than 250 000 people used this highway on weekdays, and the number is increasing monthly. By August 2001, paying customers will be able to travel 108 km from Brant Street, Burlington, to Brock Road, Pickering, on 4- or 6-lane roads. Future plans include lane expansion to as many as 10 lanes if necessary to accommodate increasing traffic loads.

The electronic toll road, unlike other toll roads with toll booths, does not require any stopping or slowing down. Along Hwy. 407, each vehicle's entry and exit are detected and recorded electronically from an overhead gantry. For local residents who use the highway frequently, the electronic transaction is handled most conveniently by registering a transponder — a small radio transmitter that is attached to the inside of the windshield behind the rear-view mirror. The electronic equipment on the gantries records the location, time, and identity of the transponder and sends this information over a fibre-optic cable to a central computer. The same process occurs when the vehicle leaves the highway at an interchange. The registered owner of the transponder then receives a monthly bill for the use of the road. For vehicles without transponders, a high-quality video recorder sends a video image of the vehicle to a central processing computer which automatically scans and records the vehicle licence plate number. This is done on entry and exit and the bill is sent to the registered owner of the vehicle. The cost of travelling on this highway depends on the type of vehicle, distance travelled and time of day. For example, driving a car on Hwy. 407 will cost 4 ¢/km at night (11 p.m. to 6 a.m.) and 10 ¢/km during peak traffic in the morning and late afternoon. Large trucks can pay up to 30 ¢/km during peak hours.

(f) A car driver enters Hwy. 407 at the Hwy. 410 interchange at 7:35 a.m. and exits at Yonge Street at 7:56 a.m. From the transponder signal, the computer records a distance of 31.02 km. What is the cost to the driver?

(g) One of the controversies discussed in the early stages of this highway project was the potential for electronic speeding tickets. In your own words, describe how this might be done, with equipment now in place.

(h) The private owners of Hwy. 407 have assured the public that speeding will not be monitored and no information will be transmitted to the police. Do you think the OPP should have the right to charge motorists for speeding using evidence from the Hwy. 407 electronic system?

(i) The speed limit on Hwy. 407 is 100 km/h. Was the driver in (f) speeding? Show your work to justify your answer.

Understanding Concepts

1. State in your own words, what is meant by a smart highway.
2. What are the two most important factors controlled by an automated highway system?
3. What are the advantages of an electronic toll highway over a regular toll highway with toll booths?
4. Summarize the costs (disadvantages) and benefits (advantages) of smart highways in a table with two columns: "Costs" and "Benefits." Write as many points in each column as you can.

Making Connections

5. List several different technologies involved in the proposed automation of highways. Are these technologies current or proposed technologies?
6. It is estimated that an automated highway system would significantly cut pollution on highway routes that are now congested or "gridlocked" daily. Explain what factors would affect pollutant emissions.

Exploring

7. (I) Research recent developments toward automated highways in Canada. Briefly describe how one system, either in proposal or already operating, might work.

Work the Web

Visit www.science.nelson.com and follow the links from Science 10, 9.8. Search for current information about automated highway systems and report on the progress that has been made in this area.

SKILLS HANDBOOK: (I) General Research