# Chapter 9.1 - 9.4

CHAPTER

# 9 Distance and Speed

## Getting Started

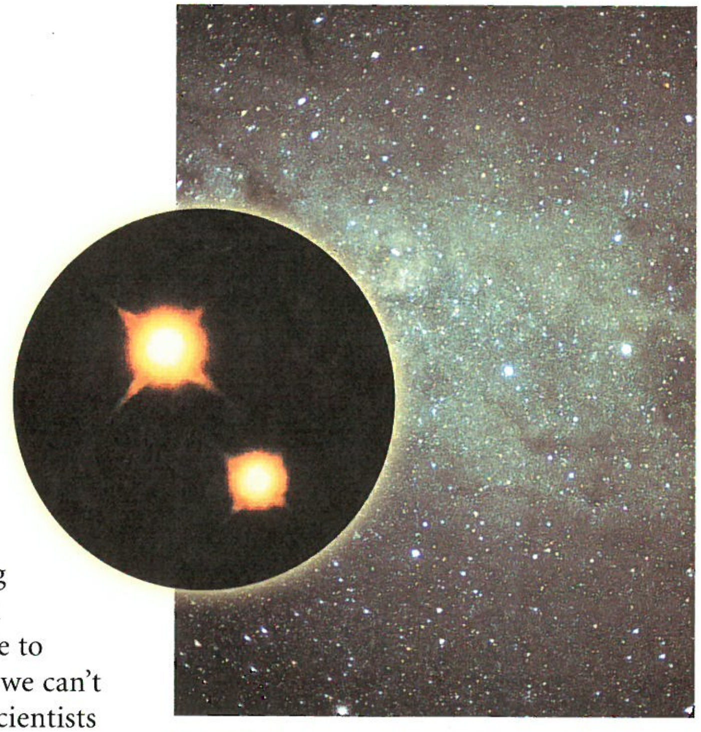

Figure 1
Alpha Centauri, the closest visible star system to our Sun, is 4.3 light years ($4.1 \times 10^{16}$ m) away.

WHAT KINDS OF DISTANCES CAN YOU picture in your mind?

The 100-m race and the 42-km marathon are two commonly known distances. **Distance**, the amount of space between two objects or points, is a quantity that we practise measuring from an early age. The most common unit of distance is the metre. We know approximately how long a metre is because we use it almost daily as a unit of measurement. But some distances are hard to imagine simply because they are so unfamiliar. The human mind just doesn't seem capable of imagining distances like $4.1 \times 10^{16}$ m (**Figure 1**) or $3 \times 10^{-10}$ m (**Figure 2**). What is amazing is that scientists are able to measure this full range of distances — even though we can't really imagine how large and small they might be. Scientists have developed an astonishing variety of tools, from telescopes to microscopes, to measure a wide range of distances. Some people have trained themselves to estimate distances to a high degree of accuracy without using any tools. People who work with measurements every day become more and more accurate with their estimates of distance. For example, surveyors work with distances and angles every day and become pretty good at estimating them.

**Time** is duration between two events and is usually measured in seconds, minutes, or hours. Fortunately we seem to understand time intuitively: we talk about a race lasting about 10 s, or a space shuttle orbiting Earth every 1.5 h. We have a feeling for the passage of time. We understand that we can study an event by investigating what is happening during several successive time periods, such as the distance travelled during each second.

The range of speeds that we encounter on Earth is fairly narrow until we start investigating outside of our normal observations. We might walk at 6 km/h, drive at 100 km/h, or take an airplane that travels at 450 km/h. We need to measure distance and time in order to determine the speed of an object. Scientists and technologists have developed many new devices to measure a wide range of distances and periods of time.

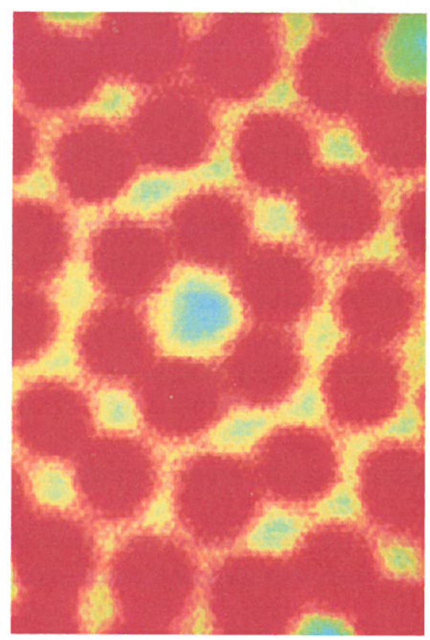

Figure 2
The distance across an atom is about $3 \times 10^{-10}$ m.

## Reflect on your Learning

1. What is your impression of when and where the concepts and measurement of distance, time, and speed got started? Why, do you think, did they start to develop at this point?
2. Suggest several technologies that might have been used to measure distance, time, and speed since these concepts began.
3. If you were to teach someone about the concept of speed, how would you describe speed in your own words?
4. Science and technology are closely related. Provide some examples of how science depends on technology.
5. Why do you think some non-metric units of measurement (such as miles and pounds) persist in Canada even though the system was changed to SI metric in the mid-1970s?
6. How do you and/or scientists express uncertainty about measurements and calculations?

Throughout this chapter, note any changes in your ideas as you learn new concepts and develop your skills.

## Try This Activity Measuring by Hand

Most measurement systems originated when the human body was used to help determine distances. After all, everybody had one! This practice is still very useful when we do not have access to a ruler or tape measure.

- Use a metric ruler, metre stick, or tape measure to determine the answers to the following questions. Memorize the following answers for your own body.

(a) The width of which of your fingers or fingernails is closest to 1.0 cm?

(b) Which part of your hand (width or length) is approximately 10 cm?

(c) What is the maximum span of your spread hand (i.e., width from thumb tip to little-finger tip) in centimetres?

(d) A horizontal distance of 1.0 m is from the tip of your fingers on your outstretched arm to where on your body?

(e) How many of your foot or shoe lengths (plus a fraction, if necessary) equals 1.0 m (**Figure 3**)?

(f) What are the lengths of your natural and stretched strides in metres? Can you stride 1.0 m?

- Now use the answers to the above questions to determine the length, in centimetres or metres, of the following objects. Measure each object at least three times, using different parts of your body each time.

(g) What is the length of your pencil or pen?

(h) What is the length of a page of paper?

(i) What is the length of your desk or table?

(j) What is the length of your room?

Did you always get the same lengths for each object? Why, or why not?

(k) Repeat questions (g)–(j) using a metre stick. Compare the new measurements with those you obtained by using your body. Account for any differences. Which are likely to be more accurate?

- What are the likely maximum and minimum distances you could conveniently measure, using

(l) your finger/fingernail width?

(m) your hand span?

(n) your foot/shoe length?

(o) your stride?

**Figure 3**
How many of your foot lengths make up 1.0 m?

# 9.1 Explore an Issue

**DECISION-MAKING SKILLS MENU**
- ○ Define the Issue
- ● Identify Alternatives
- ● Research
- ● Analyze the Issue
- ● Defend a Decision
- ○ Evaluate

# Progress and Speed on our Highways

In earlier times, people moved about on foot or in handmade vehicles drawn by animals. Travelling was slow and arduous. Journeys of more than a few kilometres were major expeditions, so people generally lived and worked in the same place. Towns were relatively small and compact.

All this has changed in the last few decades, with the development of the internal combustion engine, and other vehicle technology. Many people in North America now live quite far away from their place of work. Our cities have grown quickly and residential suburbs have developed. A large proportion of the population now travels by private vehicle.

As the population of our urban areas continues to grow, more people want to travel daily between the city and the suburbs. This leads to more traffic on the roads and highways. Traffic congestion and noise pollution are nuisances, but chemical pollution is a serious health threat. Motor vehicles are the single largest source of air pollution in urban areas (**Figure 1**). On average, vehicles produce about 75% of the carbon monoxide, 48% of the nitrogen oxides, and 13% of the particulates (solid particles of pollution) in the atmosphere.

As our pace of life increases, and vehicle and highway technologies improve, many of us want to get where we are going in the shortest possible time. Maximum speed has several advantages:

- less time is lost in travelling;
- shorter journey times may mean less driver fatigue;
- vehicles are on the highways for shorter periods of time, reducing congestion; and
- high highway speeds, so long as all vehicles are travelling equally fast and road conditions are good, result in no more accidents than lower speeds.

People in favour of raising highway speed limits use all these reasons in their arguments.

**Figure 1**
Rush-hour traffic in a major metropolitan centre may not involve *rushing*.


**Figure 2**
It is often appropriate to travel slower than the posted speed limit.



**SKILLS HANDBOOK:** (D) Identifying Alternatives

Not everyone agrees that faster is better, though. Those in favour of lowering highway speed limits point out that

- accidents at high speeds tend to be more serious than those at lower speeds;
- travelling fast uses considerably more fuel (and therefore results in more pollution) per kilometre;
- high-speed vehicles need more space between them, so actually take up *more* space on the highways;
- conditions are frequently less than ideal on Canadian roads, so slower driving would result in fewer accidents (**Figure 2**); and
- lower speed limits might even persuade some people to take less polluting forms of public transportation, such as buses or trains.

Of course, even when the posted speed limit is quite high, there are always some people who want to go faster. The police are responsible for enforcing the speed limit. "Speeders" may receive a warning, have "demerit points" recorded on their driver's licence, be fined, or even be charged with a criminal offence such as dangerous driving. The severity of the consequence depends on the car's speed, compared to the speed limit, but is also largely at the discretion of the police officer. The police have a number of ways to identify speeders, including photo-radar, highway patrol cars, and speed traps. But however zealously speeders are identified, and whatever penalties are imposed, we haven't yet found a way of making everybody obey the posted speed limits. Some say that this is another good reason for raising speed limits: Raise the maximum speed and enforce it strictly, they say, and everyone will travel at the same speed, making the highways considerably safer.

Many organizations are looking into the issue of highway speed limits, such as provincial ministries or departments of transportation, municipal governments, various police forces, environmental groups, and many other nongovernmental organizations. They all have views on whether highway speed limits should be lower, higher, or maintained at their present level.

### Understanding the Issue

1. What is the largest source of air pollutants in urban areas?
2. Compare the travelling times of a fast car and a slower truck, that have covered the same distance.
3. Under what conditions might high highway speeds be as safe as slower speeds?

### Work the Web

To research the issue of speed limits, visit www.science.nelson.com and follow the links from Science 10, 9.1.

### Challenge

3 Student drivers must understand both the laws of the road and the practical aspects of driving. Why have the laws of the road and particularly those relating to speed, been established?

## Role Play Raising the Limit

A public meeting is being held to solicit feedback on a proposal to raise the speed limit on all the major highways in the province to 125 km/h. You have been invited to take part and to present your views on this issue.

- Select a role, such as police officer, commercial truck driver, antipollution activist, cottager, student driver, highway engineer, or car designer.
- (D) (G) Using the perspective of your chosen role, research to collect information and prepare your position.
- (R) Assemble your arguments into a short presentation.
- (S) Deliver your presentation at the public meeting.

(G) Defending a Decision (R) Writing for Specific Audiences (S) Oral Presentations

9.2

# Measurement and Calculations

It is important to measure correctly. If we can't trust the measurements, we can put no faith in reports of scientific research. Imagine what would happen if the surveyors were wildly inaccurate in their measurements when the Chalk River particle accelerator was under construction (**Figure 1**). Imagine that the accelerator was made several metres too long, and nobody noticed the error. All the scientists who subsequently worked there would be including those inaccuracies in their calculations, and arriving at faulty conclusions.

**Figure 1**

Surveyors check their measurements during construction of the Chalk River particle accelerator. The facility itself was built during the winter of 1944–45. The first particle accelerator was built in 1959 and given to the University of Montreal. The second was built in 1967 and is currently inoperative because of lack of funds.

## Certainty and Significant Digits

When you are communicating in science you should express how certain you are about your measurements. This is called the degree of certainty or uncertainty. Every measurement has uncertainty, so scientists have come up with ways to express their degree of certainty when stating their results.

There is an international agreement about the correct way to record measurements: record all those digits that are certain plus one uncertain digit, and no more. These "certain-plus-one" digits are called **significant digits**. The **certainty** of a measurement is determined by how many certain digits (plus one) are obtained by the measuring instrument. Certainty is measured by the number of significant digits.

For example, in **Figure 2** the measurement "1 to 4" reads 9.05 cm. The last digit in the measurement, 5, is estimated (a trained guess) by looking between the lines on the scale of the measuring instrument. Two certain digits (the 9 and the 0) plus one uncertain digit (5) yields a certainty of three significant digits. The greater the number of significant digits, the greater the certainty of the measurement.

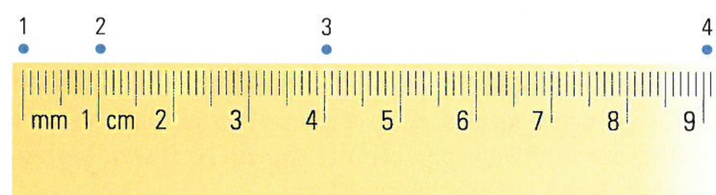


**Figure 2**

The measurement of the distance from the centre of point 1 to the centre of point 4 reads 9.05 cm, with a certainty of three significant digits.

**All digits included in a stated value (except leading zeros) are significant digits.**

The position of the decimal point is not important when counting significant digits; ignore the decimal point. For example, the Start and Finish lines for a rubber duck race along a river are measured as being 30.75 m apart.

This measurement contains four significant digits. **Table 1** gives the certainty of several measurements. Study these examples to learn the rule for counting significant digits.

**Table 1** **Certainty of Measurements**

| Measurement | Certainty |
|---|---|
| 307.0 cm | 4 significant digits |
| 61 m/s | 2 significant digits |
| 0.03 m | 1 significant digit |
| 0.5060 km | 4 significant digits |
| $3.00 \times 10^8$ m/s | 3 significant digits |

## Counted or Defined Values

When you directly count the number of students in your class, this is an exact value. We think of such exact values as containing an infinite number of significant digits. When you use a defined value, such as 100 cm/m or 60 s/min, this is also an exact value. Defined values also have an infinite number of significant digits. Some examples are provided in **Table 2** and **Figure 3**.

**Table 2** **Exact Values**

| Counted values | Defined values |
|---|---|
| 4 dogs | 1000 m/km |
| 10 CDs | 10 mm/cm |
| 3 Blue Jays | 1 h/60 min |

## Certainty Rule for Multiplying and Dividing

While correctly taken measurements yield only significant digits, there is a decision to be made when we multiply or divide measurements. Try multiplying two four-digit numbers together on your calculator. The answer has seven or eight digits. Common sense tells us that the answer can be no more certain than the original numbers. In order to determine the certainty of the answer (as given in significant digits), follow this **certainty rule** or generalization: state those digits that are certain plus one uncertain digit. In other words:

**When multiplying and/or dividing, the answer has the same number of significant digits as the measurement with the fewest number of significant digits.**

This rule ensures that the certainty of the answer depends on the least certain original value.

In our multiplication example, therefore, the answer should have only four significant digits. As with most other rules or generalizations, there are exceptions, but this rule works well most of the time. You can see how it is used in the sample problems below.


**Figure 3**
There are exactly four dogs pulling the sled; not nearly four, or four-and-a-bit: exactly four.

**Sample Problem 1**

Calculate the answer for the following question and state the answer with the correct certainty and units.

Using the equation for the area of a triangle

$$\text{area} = \frac{1}{2} \times \text{base} \times \text{height}$$

or

$$A = \frac{1}{2} bh$$

and given values of $b$ and $h$, find $A$.

$b = 3.2 \text{ cm}$

$h = 10.1 \text{ cm}$

$$A = \frac{1}{2} \times 3.2 \text{ cm} \times 10.1 \text{ cm}$$

$= 16 \text{ cm}^2$, which was rounded to two significant digits from $16.16 \text{ cm}^2$

Note that 3.2 cm with a certainty of two significant digits is multiplied by 10.1 cm with a certainty of three significant digits, so the answer has the certainty of the least certain original number: two significant digits.

## Rounding

We need a rule (generalization) for rounding the answer from a calculation in order to obtain the correct certainty. First you must decide what the certainty (in significant digits) of the answer should be by using the appropriate calculation rule, such as the multiplication and division rule given above.

**If the digit after the digit to be retained as significant is a 5 or greater, round up.**

If the digit after the last significant digit is 4 or less, leave the last significant digit as it is. For example, rounding 9.147 cm to three significant digits would give 9.15 cm and rounding 7.23 g to two significant digits would give 7.2 g.

Remember, for multiple-step calculations, leave all digits in your calculator until you have finished all your calculations, then round the final answer. Otherwise you could be introducing error into your calculations.

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**Sample Problem 2**

Calculate the answer to the following question and state the answer with the correct certainty and units.

Using the equation $A = \frac{1}{2} bh$, and given $b$ and $h$, find $A$.

$b = 6.21$ cm

$h = 8.0$ cm

$$A = \frac{1}{2} \times 6.21 \text{ cm} \times 8.0 \text{ cm}$$

$= 25\ \text{cm}^2$, which was rounded to two significant digits from 24.84

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## Precision Rule for Adding and Subtracting

**Precision** is defined as the place value of the last digit obtained from a measurement or calculation. Precision is measured by the number of decimal places in a measured or calculated value. The following **precision rule** ensures that the precision of the answer depends on the least precise original value.

**When adding and subtracting measured values of known precision, the answer has the same number of decimal places as the measured value with the fewest decimal places.**

For example, when adding values of 1.2 mm, 3.05 mm, and 7.60 mm, the answer can be no more precise (as measured by decimal places) then the least precise value: 1.2 mm. Therefore, the answer (11.85 mm) is rounded off to 11.9 mm.

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**Sample Problem 3**

What is the total distance travelled by a car when the following distances are recorded by different individuals using a variety of instruments? ($\Delta d$ means "distance travelled.")

$\Delta d_1 = 104.2 \text{ km}$

$\Delta d_2 = 11 \text{ km}$

$\Delta d_3 = 0.67 \text{ km}$

$$\Delta d_t = \Delta d_1 + \Delta d_2 + \Delta d_3 = 104.2 \text{ km} + 11 \text{ km} + 0.67 \text{ km}$$
$$= 116 \text{ km}$$

The total distance travelled is 116 km.
The sum displayed on the calculator screen is 115.87 km, which is rounded to 116 km. The least precise measurement is 11 km, since it has the fewest decimal places.

**Sample Problem 4**

A group of students recorded the following measurements using a variety of measuring devices: 5.5 m by strides; 0.597 m with a metre rule; and 0.1262 m with a ruler. What is the total distance measured?

$d_t = 5.5 \text{ m} + 0.597 \text{ m} + 0.1262 \text{ m} = 6.2 \text{ m}$ (rounded from 6.2332 m)
The total distance measured is 6.2 m (to 1 decimal place).

Note that in all the following Sample Problems in this unit, the answer that appears on the calculator is not given: only the rounded answer is provided.

**Did You Know?**

The first interplanetary spacecraft launched by the United States, Mariner 1, never reached its target, Venus, because of one missing hyphen in its software.

## Conventions of Communication

The rules provided above are generalizations. Fortunately, although the generalizations do not always provide the best individual answer, they work most of the time and are simple to use. Conventions of communication are important to any community. They allow members of the community to understand each other without confusion. In this case everyone in the community accepts and uses the same rules, and understands that there are limitations to the rules.

The international community of scientists has agreed on a system of measurement and communication called **SI** (the International System of Units from the French *Système international d'unités*). An international system is very useful for efficiently and accurately exchanging information among scientists. The SI convention includes both quantity and unit symbols. Note that these are symbols (e.g., 60 km/h) and are not abbreviations (e.g., 40 mi./hr.). You should learn and use these symbols in all your scientific communication.

An example of miscommunication is provided by the \$125-million mistake made on a 1999 Earth-to-Mars space probe (**Figure 4**). The specifications for the probe were sent by the contractor in British units but were interpreted by NASA as being in metric units. The probe ended up crashing on Mars instead of orbiting.

**Figure 4**
In October 1999, a Mars probe was destroyed because its makers did not follow the scientific convention of communication.

## Solving Equations

Have you ever tried to solve an equation but found that the unknown variable is mixed up with a group of other variables on the right, instead of being neatly on its own on the left? When doing calculations you often have to rearrange the defining equation to solve for a different variable. A **defining equation** is the definition of a quantity expressed in quantity symbols. In other words, it is the word definition translated into symbols. You will meet several defining equations in this unit. When rearranging an equation you must keep the equation equal by performing the same operation on both sides of the equation, such as multiplying or dividing both sides of the equation by the same value or variable.

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**Sample Problem 5**

Rearrange the following defining equation to solve for the other variables ($b$ and then $h$) in the equation.

**Solve for *b*.**

Defining equation: $A = \frac{1}{2}bh$

Multiply by 2: $2A = bh$

Divide by $h$: $\frac{2A}{h} = b$

Rewrite: $b = \frac{2A}{h}$

**Solve for *h*.**

Defining equation: $A = \frac{1}{2}bh$

Multiply by 2: $2A = bh$

Divide by $b$: $\frac{2A}{b} = h$

Rewrite: $h = \frac{2A}{b}$

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## Converting Units

Sometimes you might be able to convert units in your head by, for example, dividing or multiplying by 1000. However, some unit conversions need to be written down. The method most commonly used is multiplying by conversion factors (equalities), which are memorized or referenced. It is important to pay close attention to the units, which are also converted by multiplying by a conversion factor.

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**Sample Problem 6**

An athlete completed a 5-km race in 19.5 min. Convert this time into hours.

$$t = 19.5\ \cancel{\text{min}} \times \frac{1\ \text{h}}{60\ \cancel{\text{min}}} = 0.325\ \text{h}$$

The athlete finished the race in 0.325 h.

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**Sample Problem 7**

A train is travelling at 95 km/h. Convert 95 km/h into metres per second.

$$v = 95\ \frac{\cancel{\text{km}}}{\cancel{\text{h}}} \times \frac{1\ \cancel{\text{h}}}{60\ \cancel{\text{min}}} \times \frac{1\ \cancel{\text{min}}}{60\ \text{s}} \times \frac{1000\ \text{m}}{1\ \cancel{\text{km}}} = 26\ \text{m/s}$$

Note that the certainty of two significant digits in 95 km/h results in the same certainty for the answer, 26 m/s. The conversion factors are all defined, or exact, values with infinite certainty.

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For more information on measurements and calculations, see (U) Using the Calculator and (W) Calculating in the Skills Handbook.

## Understanding Concepts

1. A system of units is necessary to state and use measurements. What is the SI base unit name and unit symbol for each of the following quantities?
   - **(a)** distance
   - **(b)** time

2. Record the length of the nail in **Figure 5** in centimetres. Indicate which digits are certain and which uncertain.

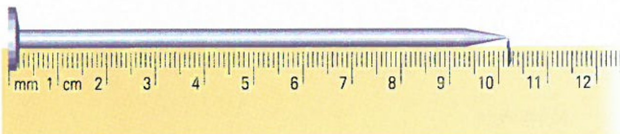


**Figure 5**

3. Copy each of the following measured or calculated values. Place a check mark (✓) above each certain digit and a question mark (?) above each estimated or uncertain digit. Finally, state the certainty as a number of significant digits.
   - **(a)** 7.65 mm
   - **(b)** 20.2 m/s
   - **(c)** 50.0 cm
   - **(d)** 0.084 km

4. Round the following values to a certainty of three significant digits.
   - **(a)** 32.674 km
   - **(b)** 0.003 922 g
   - **(c)** 107.51 s

5. In your own words, state
   - **(a)** the rule for the number of digits allowed in the final answer obtained from a multiplication or division.
   - **(b)** the rule for the number of decimal places allowed in the final answer obtained from addition or subtraction.

6. Complete the following calculations by providing the correctly rounded answer with units.
   - **(a)** $22.4\ \text{h} \times \dfrac{0.1\ \text{mm}}{\text{h}} =$
   - **(b)** $\dfrac{465\ \text{km}}{5.21\ \text{h}} =$
   - **(c)** $18\ \text{cm}^3 \times \dfrac{1.10\ \text{g}}{\text{cm}^3} =$
   - **(d)** $72.5\ \text{min} \times \dfrac{1\ \text{h}}{60\ \text{min}} =$
   - **(e)** $17.5\ \text{mL} + 95\ \text{mL} + 8.25\ \text{mL} =$
   - **(f)** $32.1\ \text{m} + 960\ \text{m} + 20.02\ \text{m} =$
   - **(g)** $0.2\ \text{cm} + 23.91\ \text{cm} + 0.62\ \text{cm} =$
   - **(h)** $13.63\ \text{h} - 0.5\ \text{h} =$
   - **(i)** $35.1\ \text{mm} + 67.04\ \text{mm} =$
   - **(j)** $7.52\ \text{s} + 8.678\ \text{s} + 0.24\ \text{s} =$

7. Solve for the stated variable using the given definition.
   - **(a)** $C = 2\pi r \quad r = ?$
   - **(b)** $D = \dfrac{m}{V} \quad m = ? \quad V = ?$
   - **(c)** $y = mx + b \quad x = ?$
   - **(d)** $A = \dfrac{1}{2}bh \quad b = ?$
   - **(e)** $v = \dfrac{d}{t} \quad d = ?$
   - **(f)** $A = \pi r^2 \quad r = ?$

8. Determine the area of the following shapes to the correct number of significant digits.
   - **(a)** A rectangle with a base of 100.0 m and a height of 12 m
   - **(b)** A triangle with a base of 8.23 cm and a height of 0.68 cm

9. Convert the following quantities into the units stated. Round your answer to the correct number of significant digits.
   - **(a)** 34 min into hours
   - **(b)** 0.510 km into metres
   - **(c)** 0.021 h into seconds
   - **(d)** 25 km/h into metres per second

## Making Connections

10. A soft drink salesperson claims that the company puts exactly 355 mL of pop into each can. Is this possible? What do you think is a better description of the volume?

## Reflecting

11. Comment on this statement: "No measurement can ever be perfect or exact."

12. How are communication systems such as SI like a language?

## Challenge

1 What does it mean for a timepiece to be more reliable, more precise, and more accurate?

# 9.3 Case Study

# Measuring Large and Small Distances

Measuring distances becomes a complicated problem when the thing to be measured is a size that we cannot directly perceive or imagine. We must find some indirect method to calculate the distance in question.

## The Circumference of Earth

One well-documented instance of an indirect measuring technique occurred about 2200 years ago. The Greek astronomer Eratosthenes wanted to know the circumference of Earth. He noted that at noon on the summer solstice the Sun was directly overhead at Syene (modern Aswan in Egypt). However, when he performed the same measurement in Alexandria, on the northern coast (**Figure 1**), he discovered that the Sun's rays were 7° from the vertical. Assuming Earth's surface was evenly curved and knowing the distance between the two cities, he extrapolated the distance for 7° to a distance for 360°. His value for the circumference of Earth, about $4 \times 10^7$ m, is amazingly close to the modern value.

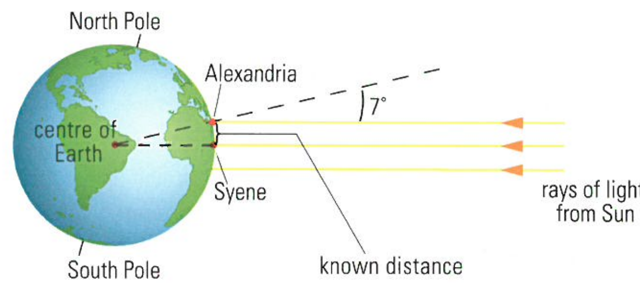


**Figure 1**
Eratosthenes' design for determining the circumference of Earth

It is interesting to note that Eratosthenes' value for the circumference of Earth made many people very uncomfortable. It meant that the known world of that time was a much smaller part of the planet than had previously been thought. In fact, the astronomer Ptolemy incorrectly calculated a much smaller value two hundred years later. Ptolemy's value was accepted until the beginning of modern times (probably because it was less controversial), and was the value that led Columbus to believe that Asia lay within reach by sailing west from Spain.

(a) Based on this information, how far apart were Syene and Alexandria?
(b) Why might people have accepted Ptolemy's value rather than that of Eratosthenes?

## Pillars of Creation

On April 1, 1995, Jeff Hester and Paul Scowen of Arizona State University used NASA's Hubble Space Telescope (HST) to make a series of colour images of the Eagle Nebula. The composite picture shown in **Figure 2** is one of the HST's most famous photographs. Astronomers propose that the gas columns in the picture are the remains of a huge hydrogen gas cloud. We believe that

**Figure 2**
This picture of the Eagle Nebula is very popular as a poster.

new stars are being formed in globular regions within the pillars where the gas is relatively dense.

Recent devices such as the Hubble Telescope have greatly improved the information available and make this an exciting time for astronomers. The accepted value for the distance to the pillars is about 7000 light-years, and the tallest pillar is about 1 light-year long from base to top. Measuring distances in space presents a modern challenge similar to the one faced by Eratosthenes. It isn't possible to go there; therefore, we must use our minds to correctly interpret what we can see.

(c) A light-year is the distance travelled by light in a time of one year. Assume a year length of 365 days and the speed of light to be $3.00 \times 10^8$ m/s. Calculate the number of kilometres from Earth to the Eagle Nebula.

## On Beyond Microscopic

The other side of the measurement coin involves the measuring of things too small to see directly. Before microscopes were invented in the late 1500s, knowledge of living and non-living things was limited to what could be seen directly. With microscopes, scientists discovered that we share our planet with a lot of living things we can't perceive. This was a terrifying idea at the time because this was an unknown microscopic world and many people fear the unknown. More recently, scientists have obtained fairly direct evidence for the existence of atoms.

**Figure 3** shows a photomicrograph of gallium nitride—a typical semiconductor. This photograph represents the first time that people have been able to locate and distinguish atoms in a structure. This technological advance is just as important to semiconductor manufacturers as the ability to see bacteria in a tissue sample is to a medical laboratory technician. The columns of gallium atoms in the photograph are 113 pm or one hundred and thirteen trillionths of a metre apart. (One picometre, pm, is $10^{-12}$ m.)

(d) In a sample of solid nickel metal, such as a Canadian dime, the atoms of nickel are 175 pm apart. If a dime is 18 mm in diameter, how many nickel atoms are there across the diameter of the coin?

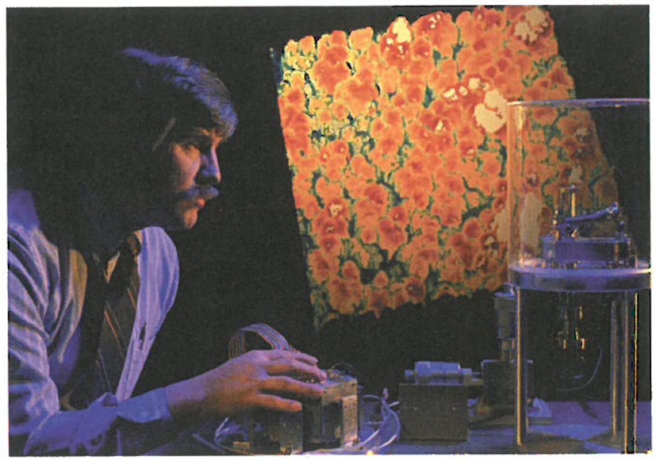

**Figure 3**
In the projection at the rear, the nitrogen atoms are thought to be the much smaller ones within the structure formed by the large gallium atoms.

### Understanding Concepts

1. What are the columns that appear in the Eagle Nebula?
2. List some examples of living organisms discovered after the invention of microscopes.
3. Which are smaller, bacteria or atoms? Explain briefly.

### Making Connections

4. For reasons other than scientific, why is it useful to know
   (a) the circumference of Earth?
   (b) the structure of a semiconductor?
5. The study of astronomy is a good example of the interaction between science and technology. Describe in your own words how science and technology interact in astronomy. Provide an example.

### Exploring

6. Modern medicine is very concerned with viral diseases, which are a problem partly because viruses are extremely small. Research and report on some of the tools and techniques used to examine viruses and their effects.
7. "Black holes" were first predicted theoretically. (I) However, obtaining evidence for black holes presented an interesting challenge. Why is it difficult to directly observe and measure black holes? Research how this problem was solved. Summarize your findings in a short article suitable for publication.

**SKILLS HANDBOOK:** (I) General Research

# 9.4 Investigation

INQUIRY SKILLS MENU

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

## Your Speed

We all depend on ways of transporting ourselves from one place to another. Devices that provide personal transportation, such as bicycles, wheelchairs, and cars, can be evaluated from a wide variety of perspectives. In this investigation you will gather one kind of evidence (the normal, safe speed) by which to judge a transportation device of your choice. You may also use other perspectives, such as safety, esthetics (beauty), economic cost, peer appeal, and environmental impact to evaluate your means of personal transportation.

Once you have completed this investigation you will compare your results with those of other students. Remember: this is not a race. Pay particular attention to how you take your measurements, perform your calculations, and write up your lab report.

**Figure 1**
You will be able to measure your speed over a larger distance if you can work outside.

### Question

What is the speed of your personal transportation device?

### Design

Measure the total distance and the total time in order to calculate the speed of your device for personal transportation. The controlled variables will be the transportation device, the force of propulsion, and the speed. Distance will be the independent variable, and time will be the dependent variable.

(a) Design a neat, labelled table in which to record (K7) your observations.

### Materials

- personal transportation (e.g., shoes, bicycle, skateboard, wheelchair, or cross-country skis)
- distance measuring device (e.g., pace, tape measure, bicycle wheel, odometer)
- timing device (e.g., wristwatch, stopwatch, water clock, or pendulum)
- safety equipment as required (e.g., helmet, wrist guards, reflective clothing)

Use the recommended safety equipment for your chosen means of transport. Use a safe area, away from traffic, and on even, uncluttered ground.

### Procedure

1 Find a safe environment within the school grounds and wear all appropriate safety equipment.

2 Select an appropriate distance over which to travel. Mark the Start and Finish points.

3 Measure and record the total time required to safely transport you or your partner over the total distance (**Figure 1**).

4 Measure and record the total distance travelled in that period of time.



SKILLS HANDBOOK: (K7) Preparing Tables of Evidence (N4) Answering the Question

**5** Repeat steps 3 and 4 at least three times.

**6** Choose a different distance and repeat steps 2 to 5 twice more, giving data for three different distances, in total.

**7** Return all equipment to storage.

## Analysis and Evaluation

(b) Calculate the speed for each trial, using the formula

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

(c) Answer the initial question based on your calculations from (b). (N4)

(d) Evaluate the evidence gathered by making judgments on the Design, Materials, Procedure, and your own skills. (O2)

(e) Compare your results with those of other groups. Explain any similarities and differences.

(f) Evaluate your personal transportation device based only on speed.

(g) How else could you evaluate your chosen means of transport? Would you value your transportation differently, using other perspectives?

(h) Could your answers be used to help you choose a personal transportation system? Why or why not?

(i) Write a formal lab report for this investigation. (Q)

## Challenge

1 How does the timing device you used in this investigation differ from those available to Galileo?

## Understanding Concepts

1. Scientists are always looking for relationships among variables. The following questions investigate such a relationship.
   - **(a)** If the distance of travel increases and the time remains the same, what has happened to the average speed?
   - **(b)** If the distance of travel remains the same and the time increases, what has happened to the average speed?
   - **(c)** If the speed of travel increases and the time remains the same, what happens to the distance travelled?
   - **(d)** If the speed of travel remains the same and the time increases, what happens to the distance travelled?
   - **(e)** If the speed of travel increases and the distance remains the same, what happens to the time required for the trip?
   - **(f)** If the speed of travel remains the same and the distance increases, what happens to the time required for the trip?
2. The relationship between two variables such as speed and distance may be, among others, a direct variation (such as $x$ and $y$ in the formula $y = kx$) or an inverse variation (such as $x$ and $y$ in $y = \frac{k}{x}$). Use these terms to describe the relationship between
   - **(a)** speed and distance;
   - **(b)** speed and time;
   - **(c)** distance and time.
3. Combining the relationships described in the previous question, create an algebraic definition (equation) for the relationships among speed, distance, and time.

## Exploring

4. List at least five different personal transportation devices. Consider when each first came into common use.
   - **(a)** What trends can you detect developing over time? (Consider, for example, materials used, power source, and speed of each means of transportation.)
   - **(b)** What might be the safety and environmental impacts of these trends?
5. (F) Complete a risk-benefit analysis of at least five personal transportation devices.
6. (K) Plan an investigation to find the speed of the traffic passing your school. Your equipment could include a stop watch, "Start" and "Finish" markers, a 30-m tape measure, and a clipboard. Draw conclusions about illegal speeding in your school's neighbourhood.

(O2) Evaluating the Evidence (Q) Lab Reports (F) Analyzing the Issue (K) Planning an Investigation

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 $\Delta d$ divided by the time $\Delta t$. (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."

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

$\Delta d$ 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.

$\Delta t$ 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).