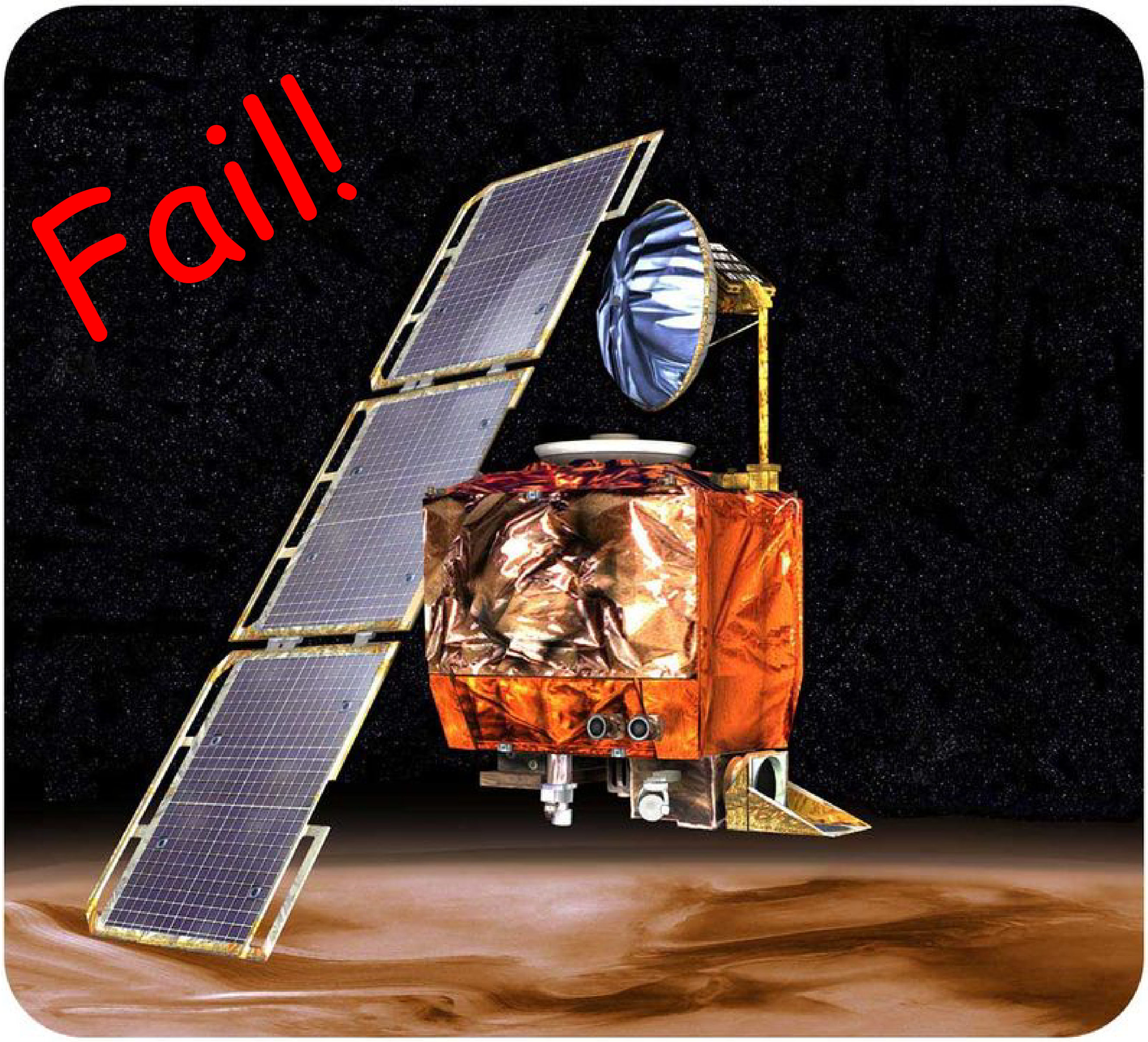
CHAPTER **2**

# Scientific Research and Technology

## Chapter Outline



# The Gimli Glider

The **Gimli Glider** is the nickname of an Air Canada aircraft that was involved in a notable aviation incident in July 1983. On 23 July, Air Canada Flight 143, a Boeing 767-233 jet, ran out of fuel at an altitude of 41,000 feet (12,500 m) ASL, about halfway through its flight from Montreal to Edmonton via Ottawa. The crew was able to glide the aircraft safely to an emergency landing at Gimli Industrial Park Airport, a former Royal Canadian Air Force base in Gimli, Manitoba.[1] The subsequent investigation revealed company failures and a chain of human errors that combined to defeat built-in safeguards. In addition, fuel loading was miscalculated due to a misunderstanding of the recently adopted metric system, which replaced the imperial system.

Mayday Episode: Gimli Glider

# 2.1 Scientific Investigation

## Lesson Objectives

- List the steps of a scientific investigation.
- Describe the relationship of ethics to scientific research.

## Lesson Vocabulary

- control
- ethics
- experiment
- field study
- hypothesis
- manipulated variable
- observation
- replication
- responding variable

## Introduction

Investigation is at the heart of science. It is how scientists do research. Scientific investigations produce evidence that helps answer questions and solve problems. If the evidence cannot provide answers or solutions, it may still be useful. It may lead to new questions or problems for investigation. As more knowledge is discovered, science advances.

## Steps of a Scientific Investigation

Scientists investigate the world in many ways. In different fields of science, researchers may use different methods and be guided by different theories and hypotheses. However, most scientists, including physical scientists, usually follow the general approach shown in **Figure** 2.1. This approach typically includes the following steps:

- Identify a research question or problem.
- Form a hypothesis.
- Gather evidence, or data, to test the hypothesis.
- Analyze the evidence.
- Decide whether the evidence supports the hypothesis
- Draw conclusions.
- Communicate the results.

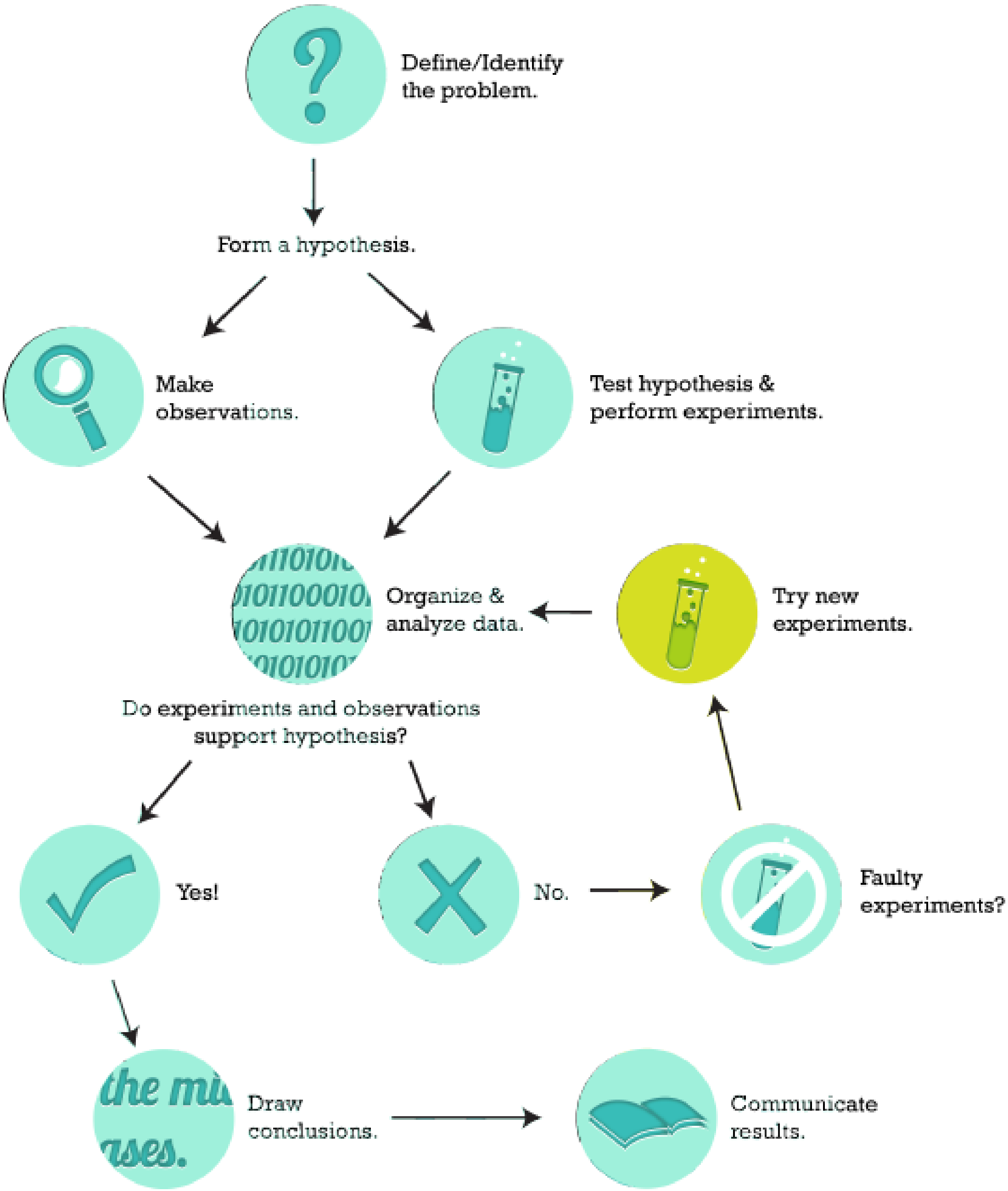


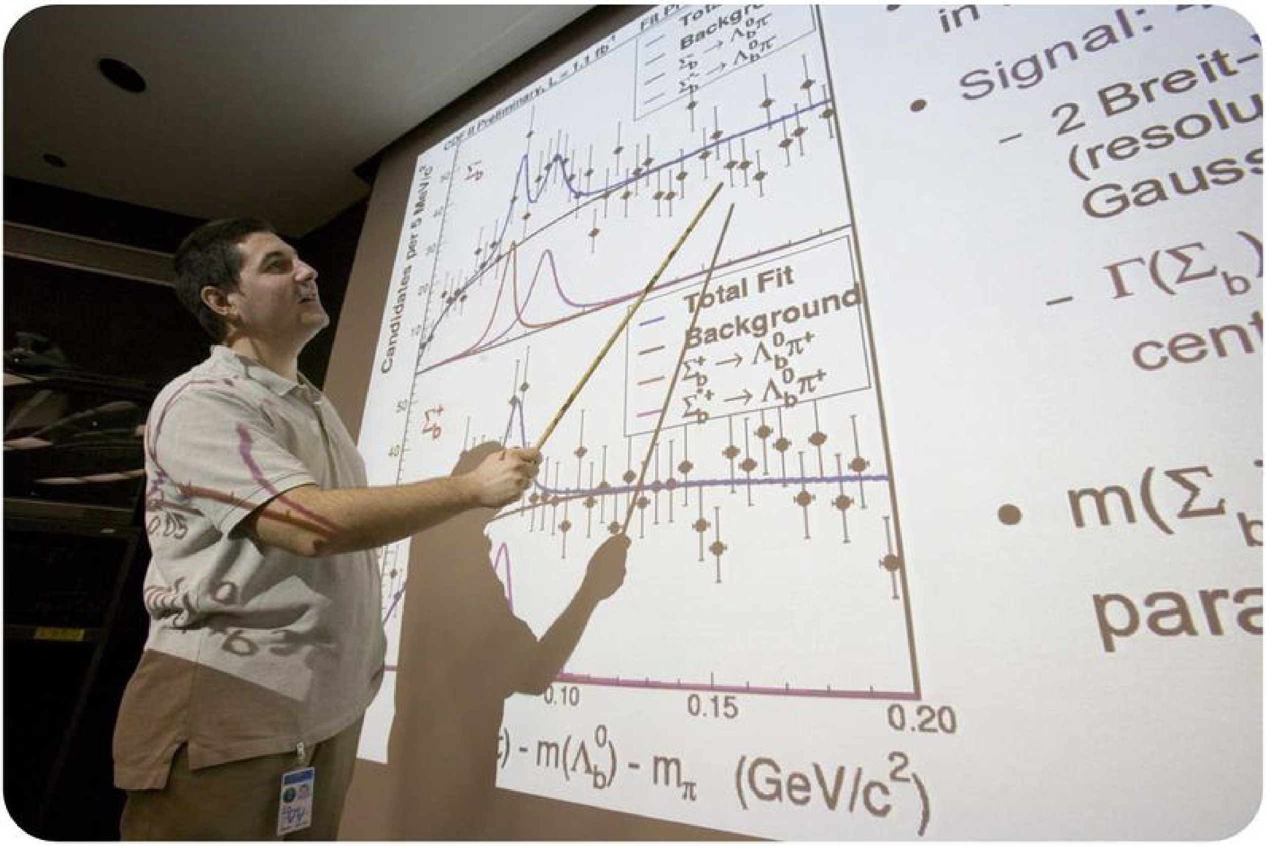
FIGURE 2.1

This diagram shows the steps of a scientific investigation. Other arrows could be added to the diagram. Can you think of one? (*Hint*: Sometimes evidence that does not support one hypothesis may lead to a new hypothesis to investigate.)

## Doing Experiments

An **experiment** is a controlled scientific study of specific variables. A variable is a factor that can take on different values. There must be at least two variables in an experiment. They are called the manipulated variable and the responding variable.

- The **manipulated variable** (also called the "independent variable") is a factor that is changed by the researcher. For example, Tara will change the temperature of a magnet (see **Figure** 2.3). Temperature is the manipulated variable in her experiment.
- The **responding variable** (also called the "dependent variable") is a factor that the researcher predicts will change if the manipulated variable changes. Tara predicts the number of paper clips attracted by the magnet will be greater at lower temperatures. Number of paper clips is the responding variable in her experiment.



## Ethics and Scientific Research

**Ethics** refers to rules for deciding between right and wrong. Ethics is an important issue in science. Scientific research must be guided by ethical rules, including those listed below. The rules help ensure that the research is done safely and the results are reliable. Following the rules furthers both science and society. You can learn more about the role of ethics in science by following the links at this URL: http://www.files.chem.vt.edu/chem-ed/ethics/index.html#resources.

### Ethical Rules for Scientific Research

- Scientific research must be reported honestly. It is wrong and misleading to make up or change research results.
- Scientific researchers must try to see things as they really are. They should avoid being biased by the results they expect or want to get.
- Researchers must be careful. They should take pains to avoid errors in their data.
- Researchers studying human subjects must tell their subjects about any potential risks of the research. Subjects also must be told that they can refuse to participate in the research.
- Researchers must inform coworkers, students, and members of the community about any risks of the research. They should proceed with the research only if they have the consent of these groups.
- Researchers studying living animals must treat them humanely. They should provide for their needs and do what they can to avoid harming them (see **Figure** 2.6).

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# 2.2 Science Skills

## Lesson Objectives

- Explain how measurements are made in scientific research.
- Describe how to keep good records in scientific investigations.
- Demonstrate how to use significant figures and scientific notation.
- Calculate descriptive statistics and use data graphs.
- Identify the role of models in science.
- Describe how to stay safe when doing scientific research.

## Lesson Vocabulary

- accuracy
- Kelvin scale
- mean
- model
- precision
- range
- scientific notation
- SI
- significant figures

### Using SI Units

The measurement system used by most scientists is the International System of Units, or **SI**. **Table** 2.2 lists common units in this system. SI is easy to use because everything is based on the number 10. Basic units are multiplied or divided by powers of ten to arrive at bigger or smaller units. Prefixes are added to the names of the basic units to indicate the powers of ten. For example, the meter is the basic unit of length. The prefix *kilo-* means 1000, so a kilometer is 1000 meters. Can you infer what the other prefixes in the table mean? If not, you can find out at this URL: http://physics.nist.gov/cuu/Units/prefixes.html.

TABLE 2.2: **Common SI Units**

| Variable | Basic SI Unit (English Equivalent) | Related SI Units | Equivalent Units |
|---|---|---|---|
| Length | meter (m) | kilometer (km) | = 1000 m |
| | (1 m = 39.37 in) | decimeter (dm) | = 0.1 m |
| | | centimeter (cm) | = 0.01 m |
| | | millimeter (mm) | = 0.001 m |
| | | micrometer ($\mu$m) | = 0.000001 m |
| | | nanometer (nm) | = 0.000000001 m |
| Volume | cubic meter ($m^3$) | liter (L) | = 1 $dm^3$ |
| | (1 $m^3$ = 1.3 $yd^3$) | milliliter (mL) | = 1 $cm^3$ |
| Mass | gram (g) | kilogram (kg) | = 1000 g |
| | (1 g = 0.04 oz) | milligram (mg) | = 0.001 g |

### Measuring Temperature

The SI scale for measuring temperature is the **Kelvin scale**. However, some scientists use the Celsius scale instead. If you live in the U.S., you are probably more familiar with the Fahrenheit scale. **Table** 2.3 compares all three temperature scales. What is the difference between the boiling and freezing points of water on each of these scales?

TABLE 2.3: **Temperature Scales**

| Scale | Freezing Point of Water | Boiling Point of Water |
|---|---|---|
| Kelvin | 273 K | 373 K |
| Celsius | 0°C | 100°C |
| Fahrenheit | 32°F | 212°F |

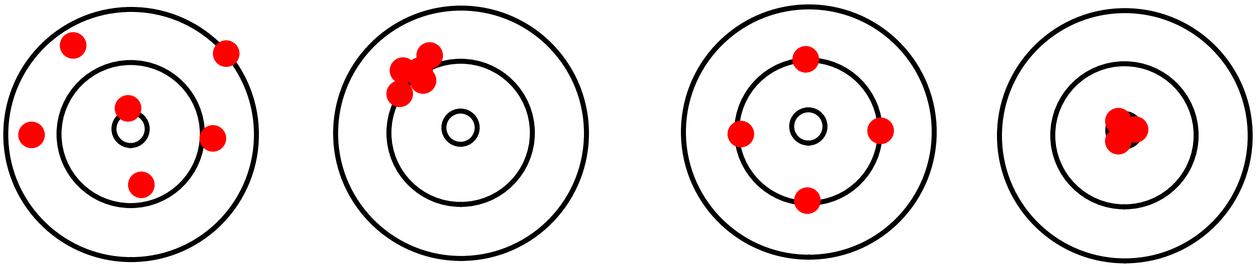
Each 1-degree change on the Kelvin scale is equal to a 1-degree change on the Celsius scale. This makes it easy to convert measurements between Kelvin and Celsius. For example, to go from Celsius to Kelvin, just add 273. How would you convert a temperature from Kelvin to Celsius?

### Accuracy and Precision

Measurements should be both accurate and precise.

- **Accuracy** is how close a measurement is to the true value. For example, 66 mL is a fairly accurate measurement of the liquid in **Figure** 2.7.
- **Precision** is how exact a measurement is. A measurement of 65.5 mL is more precise than a measurement of 66 mL. But in **Figure** 2.7, it is not as accurate.

You can think of accuracy and precision in terms of a game like darts. If you are aiming for the bull's-eye and get all of the darts close to it, you are being both accurate and precise. If you get the darts all close to each other somewhere else on the board, you are precise, but not accurate. And finally, if you get the darts spread out all over the board, you are neither accurate nor precise.



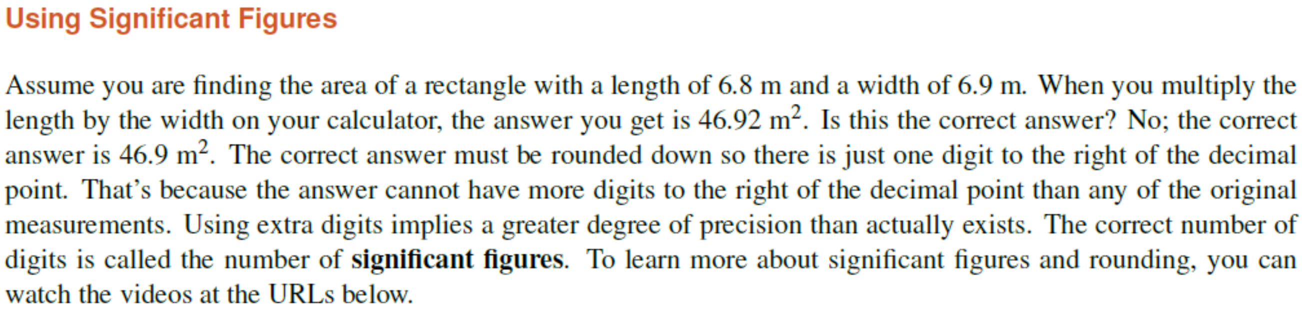
## Keeping Records

Record keeping is very important in scientific investigations. Follow the tips below to keep good science records.

- Use a bound laboratory notebook so pages will not be lost. Write in ink for a permanent record.
- Record the steps of all procedures.
- Record all measurements and observations.
- Use drawings as needed.
- Date all entries, including drawings.

## Calculating Derived Quantities

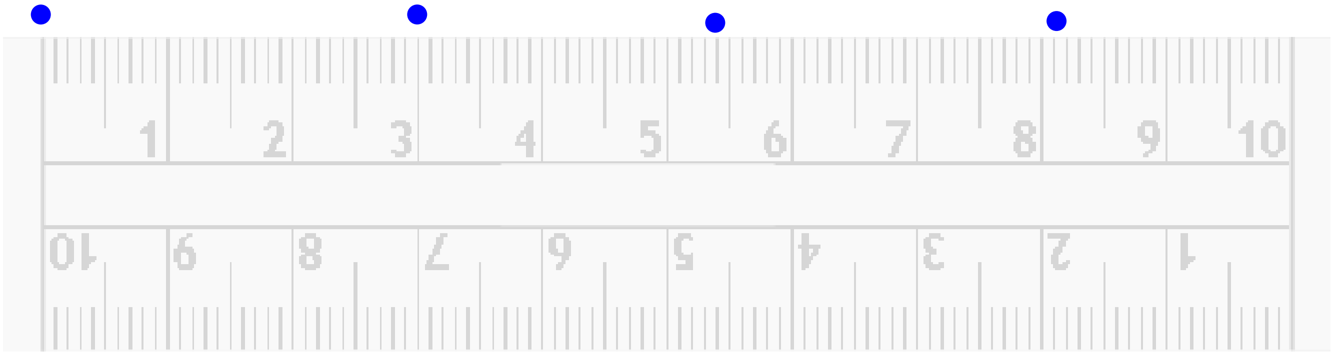
Derived quantities are quantities that are calculated from two or more different measurements.



## Using Significant Figures

Assume you are finding the area of a rectangle with a length of 6.8 m and a width of 6.9 m. When you multiply the length by the width on your calculator, the answer you get is 46.92 m$^2$. Is this the correct answer? No; the correct answer is 46.9 m$^2$. The correct answer must be rounded down so there is just one digit to the right of the decimal point. That's because the answer cannot have more digits to the right of the decimal point than any of the original measurements. Using extra digits implies a greater degree of precision than actually exists. The correct number of digits is called the number of **significant figures**. To learn more about significant figures and rounding, you can watch the videos at the URLs below.

All of the certain digits, plus one (an estimated number), of a measurement are considered to be significant digits.



You need to communicate how confident you are in your measurements in science. There is an international agreement about the correct way to record measurements and this is using significant digits.

There are certain rules that must be followed when calculating significant digits.

# Rules for Identifying/Counting Significant Digits

1. Digits from 1-9 are always significant/counted.
   i.e. 475 ( 3 significant digits)
   34.5 ( 3 significant digits)

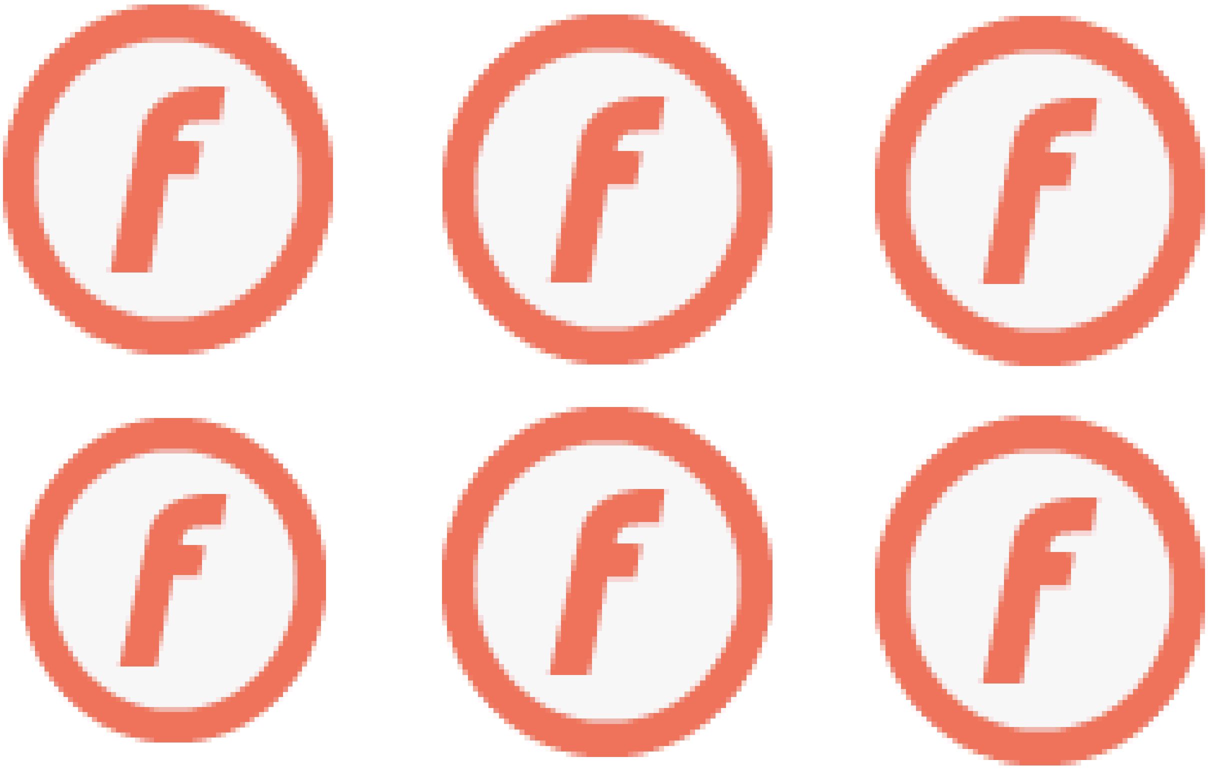
2. Any Zeros between two other significant digits are significant/counted.
   i.e. 7005 ( 4 significant digits)
   307 (3 significant digits)

3. Leading zeros are not significant/counted
   i.e. 0.0045 ( 2 significant digits)
   0.03 m ( 1 significant digits)

4. Trailing zeros are only significant (counted) if there is a decimal place in the number
   i.e. 4560 (3 significant digits)
   4560.00 ( 6 significant digits)

note: counted or defined values are considered to have an infinate number of significant figures
i.e. 25 students
60 seconds/min

# Lets Try a Few



# Addition and Subtraction

When adding or subtracting, the answer has the same number of decimal places as the value with the fewest decimal places (because it is the least precise).

i.e. if given 3 distances and asked to find the total distance

$D_1 = 106.7\text{km}$ $\quad D_2 = 14\text{km}$ $\quad D_3 = 0.59\text{km}$

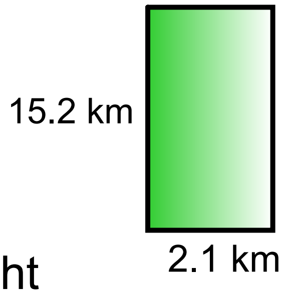
$$D_{total} = D_1 + D_2 + D_3$$
$$D_{total} = 106.7\text{km} + 14\text{km} + 0.59\text{km}$$
$$D_{total} = 121.29\text{km}$$

The correct way to record this distance would be 121 because the lowest number of decimal places is none.

Try it: What is the total distance walked if Student A walked 3.1km, Student B walked 2.45 km, and Student C walked 2.195 km?

# Multiplying and Dividing

Consider the area calculation for the rectangular field depicted to the right:



Remember that these side lengths are measurements so the last digit to the right is an estimation (it could be 0 or 2 etc.).

When an estimated digit multiplies (or divides) another digit that result is then an estimate. Let us calculate the area of that rectangle the old fashioned way - by hand:

*highlight or circle the estimated digits as you work through the problem*

$$\begin{array}{r} 15.2 \\ \underline{\text{x } 2.1} \\ 152 \\ \underline{3040} \\ 31.92 \end{array}$$

# Multiplying and Dividing

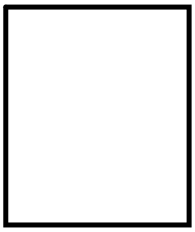
When multiplying or dividing, the answer has as many significant figures/digits as the measurement with the fewest significant figure

i.e. given a base = 3.2cm
height = 10.1 cm

Area = base x height
Area = 3.2cm x 10.1 cm
Area = 32.32 cm

The correct way to write this would be 32 cm because 2 significant figures is the lowest number

Try it: What is the area of a rectangle with a length of 5.0 cm and a width of 7.55 cm?



A = l x w

# Warm-up

**Determine the correct number of significant figures in each:**

- a) 3427
- b) 0.00456
- c) 123 453
- d) 172
- e) 0.000984
- f) 0.502
- g) 3100.0 x $10^{13}$

**Solve. Use the correct number of significant figures for each answer:**

a) 17.34
4.900
+ 23.1

b) 9.80
- 4.762

c) 3.9 x 6.05 x 420

d) 14.1 / 5 =

### Using Scientific Notation

Quantities in science may be very large or very small. This usually requires many zeroes to the left or right of the decimal point. Such numbers can be hard to read and write accurately. That's where scientific notation comes in. **Scientific notation** is a way of writing very large or small numbers that uses exponents. Numbers are written in this format:

$$a \times 10^b$$

The letter $a$ stands for a decimal number. The letter $b$ stands for an exponent, or power, of 10.

## Organizing Data

In a scientific investigation, a researcher may make and record many measurements. These may be compiled in spreadsheets or data tables. In this form, it may be hard to see patterns or trends in the data. Descriptive statistics and graphs can help organize the data so patterns and trends are easier to spot.

*Example:* A vehicle checkpoint was set up on a busy street. The number of vehicles of each type that passed by the checkpoint in one hour was counted and recorded in **Table** 2.4. These are the only types of vehicles that passed the checkpoint during this period.

TABLE 2.4: **Data Table**

| Type of Vehicle | Number |
|---|---|
| 4-door cars | 150 |
| 2-door cars | 50 |
| SUVs | 80 |
| vans | 50 |
| pick-up trucks | 70 |

### Descriptive Statistics

A descriptive statistic sums up a set of data in a single number. Examples include the mean and range.

- The **mean** is the average value. It gives you an idea of the typical measurement. The mean is calculated by summing the individual measurements and dividing the total by the number of measurements. For the data in **Table** 2.4, the mean number of vehicles by type is: $(150+50+80+50+70) \div 5 = 80$ (There are two other words people can sometimes use when they use the word "average." They might be referring to a quantity called the "median" or the "mode." You'll see these quantities in later courses, but for now, we'll just say the average is the same thing as the mean.)
- The **range** is the total spread of values. It gives you an idea of the variation in the measurements. The range is calculated by subtracting the smallest value from the largest value. For the data in **Table** 2.4, the range in numbers of vehicles by type is: $150 - 50 = 100$.

### Graphs

Graphs can help you visualize a set of data. Three commonly used types of graphs are bar graphs, circle graphs, and line graphs. **Figure** 2.10 shows an example of each type of graph. The bar and circle graphs are based on the data in **Table** 2.4, while the line graph is based on unrelated data. You can see more examples at this URL: http://www.beaconlearningcenter.com/weblessons/kindsofgraphs/default.htm.

- Bar graphs are especially useful for comparing values for different types of things. The bar graph in **Figure** 2.10 shows the number of vehicles of each type that passed the checkpoint.
- Circle graphs are especially useful for showing percents of a whole. The circle graph in **Figure** 2.10 shows the percent of all vehicles counted that were of each type.
- Line graphs are especially useful for showing changes over time. The line graph in **Figure** 2.10 shows how distance from school changed over time when some students went on a class trip.

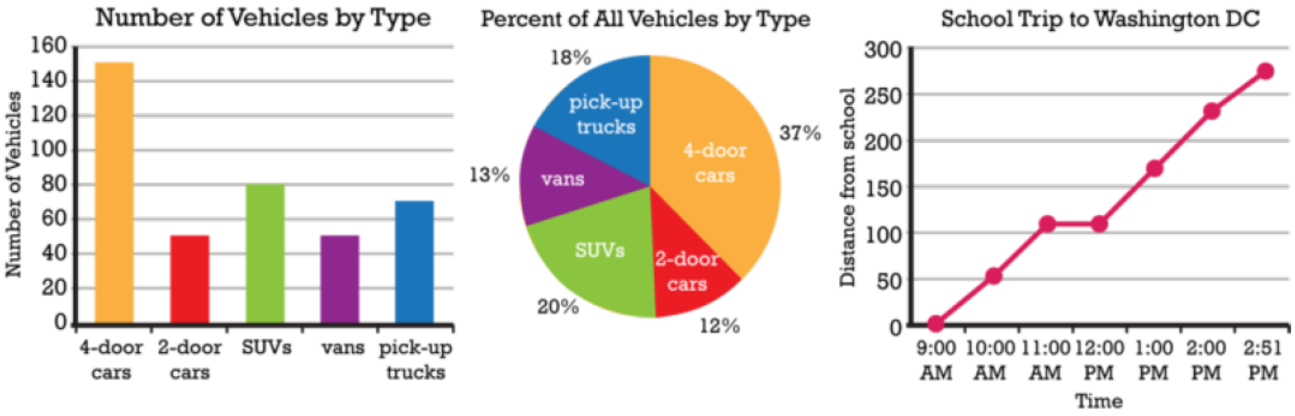


FIGURE 2.10

These are three commonly used types of graphs. When would you want to use a bar graph? What about a line graph?

## Using Models

Did you ever read a road map, sketch an object, or play with toy trucks or dolls? No doubt, the answer is yes. What do all these activities have in common? They all involve models. A **model** is a representation of an object, system, or process. For example, a road map is a representation of an actual system of roads on the ground.

Models are very useful in science. They provide a way to investigate things that are too small, large, complex, or distant to investigate directly. **Figure** 2.11 shows an example of a model in chemistry. To be useful, a model must closely represent the real thing in important ways, but it must be simpler and easier to manipulate than the real thing. Do you think the model in **Figure** 2.11 meets these criteria?

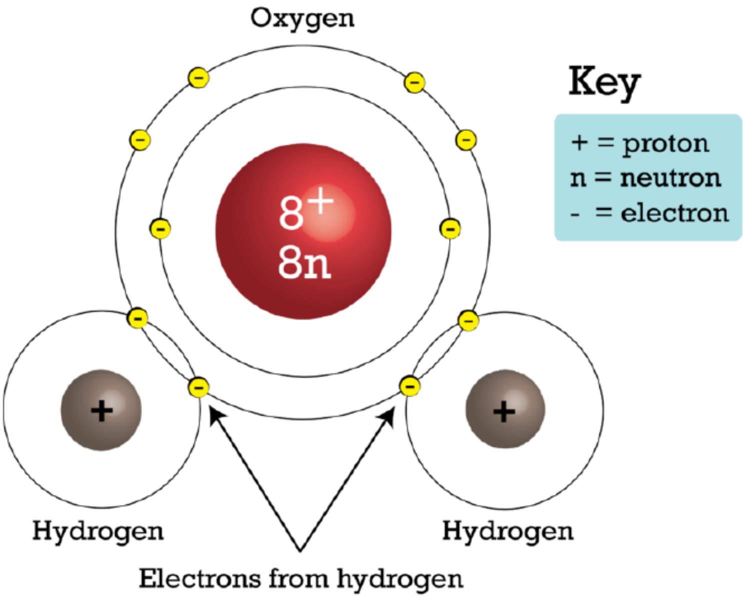


FIGURE 2.11

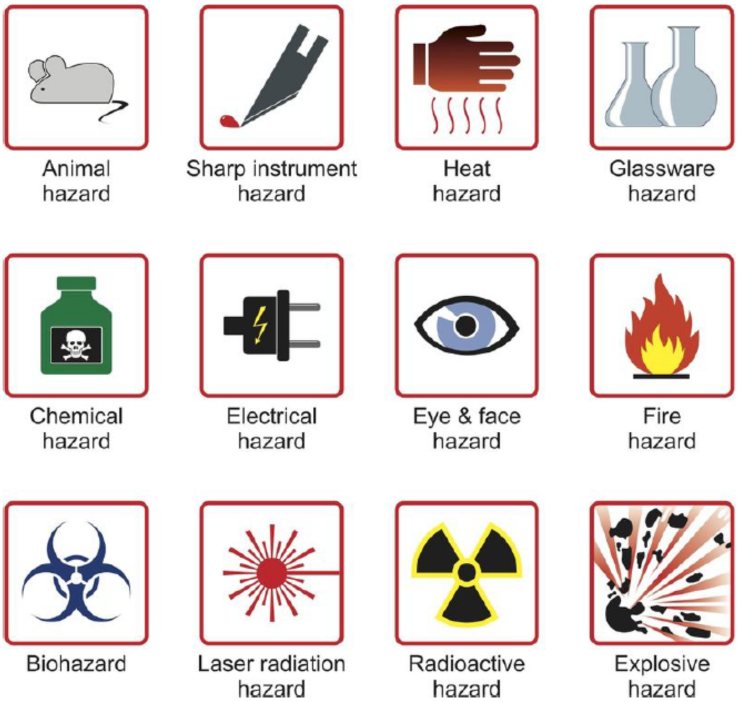
This model represents a water molecule. It shows that a water molecule consists of an atom of oxygen and two atoms of hydrogen. What else does the model show?

## Staying Safe in Science

Research in physical science can be exciting, but it also has potential dangers. Whether in the lab or in the field, knowing how to stay safe is important.

### Safety Symbols

Lab procedures and equipment may be labeled with safety symbols. These symbols warn of specific hazards, such as flames or broken glass. Learn the symbols so you will recognize the dangers. A list of common safety symbols is shown in **Figure** 2.12. Do you know how to avoid each hazard? You can learn more at this URL: http://www.angelfire.com/va3/chemclass/safety.html.



### Lab Safety Rules

- Wear safety gear, including goggles, an apron, and gloves.
- Wear a long-sleeved shirt and shoes that completely cover your feet.
- Tie back your hair if it is long.
- Do not eat or drink in the lab.
- Never work alone.
- Never perform unauthorized experiments.
- Never point the open end of a test tube at yourself or another person.
- Always add acid to water — never water to acid — and add the acid slowly.
- To smell a substance, use your hand to fan vapors toward your nose rather than smell it directly. This is demonstrated in **Figure** 2.13.
- When disposing of liquids in the sink, flush them down the drain with lots of water.
- Wash glassware and counters when you finish your lab work.
- Thoroughly wash your hands with soap and water before leaving the lab.