

## Chapter 2

# ***Experiments and Variables***



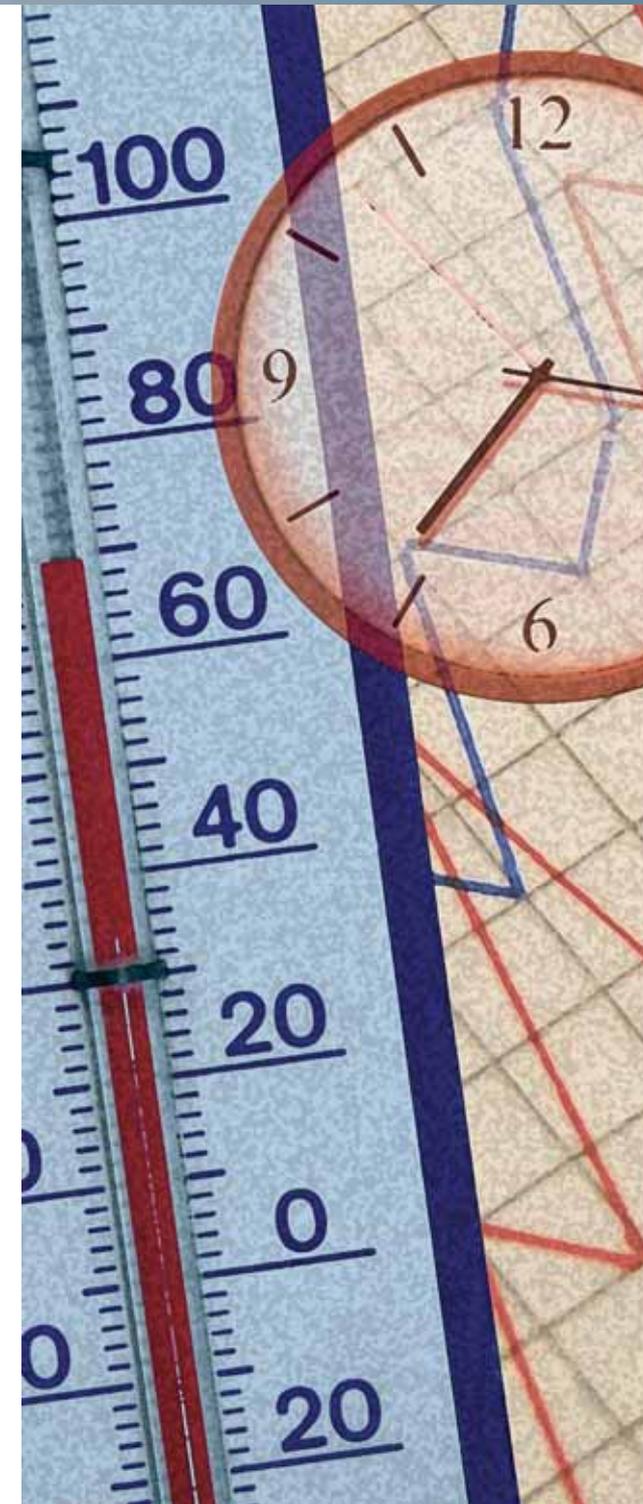
On Aug. 21, 2003, on a specially built hill in Irvine, California, six adults climbed into cars with no motors and rolled downhill. Called the Extreme Gravity Race, the cars reached speeds of up to 60 miles per hour as they raced down the hill using nothing but gravity for energy. Fiercely competitive, each of the six cars represented a different design and engineering team. The race featured teams from five different automakers. Each team had created the slipperiest, low-friction car they could, using carbon fiber, titanium and many high-tech materials.

How did the cars reach such high speeds using nothing but gravity? How did each design team evaluate its car so that it would be as fast as possible? Answers to these questions involve experiments and variables. Read on, and you will find out how people learn to make things better, faster, or more efficient!



### **Key Questions**

1. *How do scientists know when they are right?*
2. *How is an experiment designed?*
3. *What is the purpose for taking the average of many measurements?*



## 2.1 Variables and Relationships

Imagine you are in a submarine exploring the deepest part of the ocean. There is no light. You cannot see anything around you. How do you know where you are? How do you tell the rest of your exploration team where you are? What you need is a way to precisely describe where you are at every moment and communicate this information to your fellow explorers. When scientists need to communicate precise information they use *variables*. A variable is a quantity that can be precisely described, such as the depth of a submarine.

### What is a variable?

#### Variables and values

A **variable** is a quantity that has a **value** which describes something. For example, *color* is a variable. If you are choosing a car to buy, color is often an important variable. For a particular car, the values of color could be red, blue, brown, black, or yellow. The variable *color* represents all possible choices and a value, red, is a specific choice.



When talking about the car, it is clearest to use the variable (color) to describe all possible values. For example, you would say, “What colors do you have?” It is much more difficult to list all possible colors one at a time: “Do you have silver?” “Do you have blue?” “Do you have brown?” “Do you have black?” “Do you ...?”

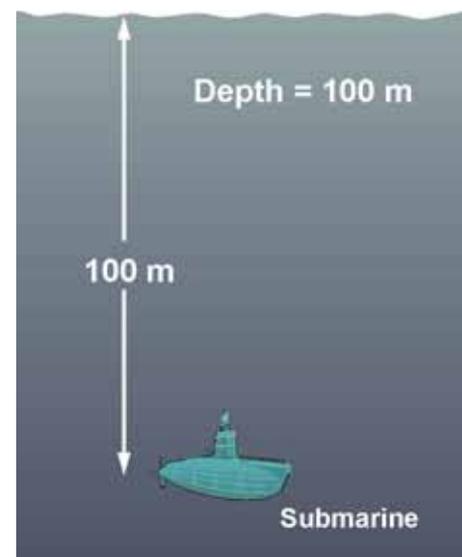
#### Variables often have values of numbers with units

In science, many variables represent numbers with units. In the example in Figure 2.1, the depth below the surface is a variable. The name of the variable is depth. The value can be any number between zero (at the surface) and the distance between the surface and the bottom. For example, you could specify your depth as 100 meters. Mathematically, you would write this as  $depth = 100\text{ m}$ . If your team calls on the radio and asks, “What is your depth?”, they are asking for the value of the variable *depth* at that exact moment. You would respond, “My depth is 100 meters.”

### VOCABULARY

**variable** - a quantity that can be precisely specified, often with a numerical value. For example, position and speed are variables.

**value** - the particular number (with units) or choice that a variable may have.



**Figure 2.1:** The variable *depth* represents all possible values for the distance between the surface and the submarine. At any moment, the submarine has a specific value of *depth*. At the moment in the picture, the *depth* is 100 meters.



## Using variables in physical science

### Variables in the car and track experiments

Consider doing an experiment with a small car that rolls along a straight track (Figure 2.2). What variables affect the motion of the car in this system? What kinds of values can each variable take? What kinds of instruments are used to measure the variables?

#### Mass

Mass is an important variable in many experiments. Mass is measured with a balance and has units of grams or kilograms.

#### Time

Time is an important variable in many experiments. In your investigations, time is measured in seconds using a stopwatch or photogate timer.

#### Position

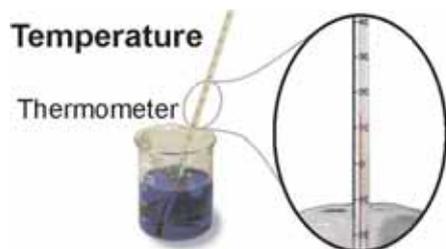
Position is another important variable. Position is measured in meters or centimeters (Figure 2.3).

#### Angle

Angle is another important variable. The track may be set at different angles. The car will travel at different speeds depending on the angle at which you set the track.

#### Temperature

In your investigations in chemistry, you also will measure different variables. For example, temperature is a variable that is important in many experiments. Temperature is measured with a thermometer and has units of degrees Celsius ( $^{\circ}\text{C}$ ) or degrees Fahrenheit ( $^{\circ}\text{F}$ ).



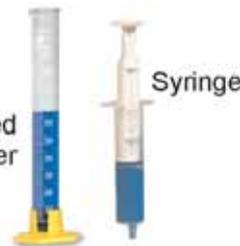
Temperature

Thermometer

Volume

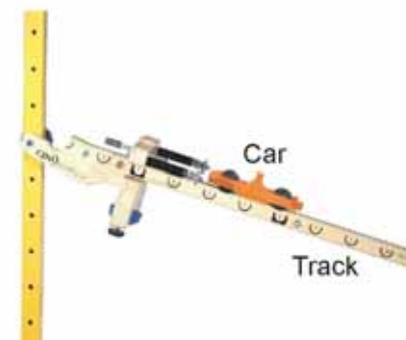
Graduated cylinder

Syringe

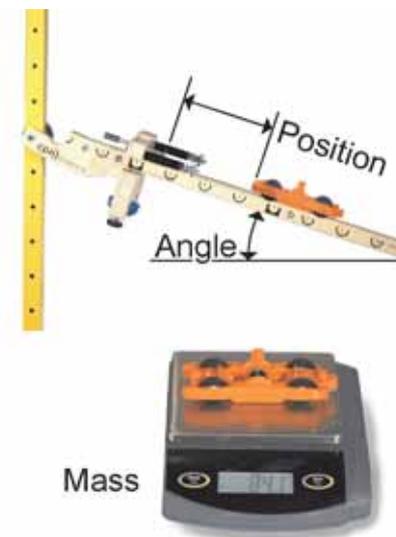


#### Volume

Volume is a variable that you will use to measure liquids like water. Volume is measured in cubic centimeters (cc) or milliliters (mL). One cubic centimeter is the same as one milliliter. Graduated cylinders and syringes are used to measure volume in different experiments.



**Figure 2.2:** The car and track used in many of the investigations.



**Figure 2.3:** Mass, position, and angle are important variables when doing experiments with the car and track.

## Graphs show relationships between variables

### Relationships between variables

*Physical science is all about relationships between variables.* For example, you are rolling a car down the track. You suspect that increasing the angle would make the car go between points A and B in less time. How do you find out if your suspicion is correct? You need to know the relationship between the variables *angle* and *time*.

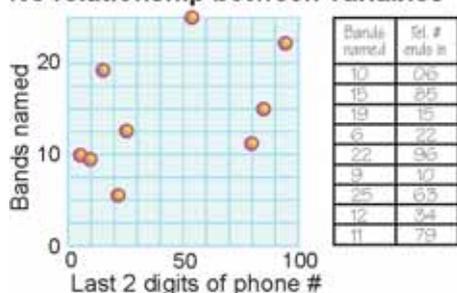
### Patterns on a graph show relationships

A good way to show a relationship between two variables is to use a **graph**. A graph is a mathematical diagram that shows one variable on the vertical (or *y*) axis and a second variable on the horizontal (or *x*) axis. Each axis is labeled with the range of values the variable has. In Figure 2.4, the *x*-axis (angle) has data values between zero and 50 degrees. The *y*-axis (time) has data values between zero and 0.3286 seconds. You can tell there is a relationship because the graph is a curve that slopes down and to the right.

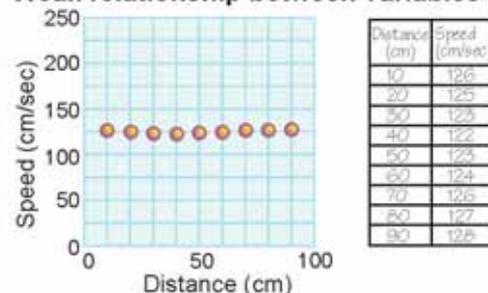
### Recognizing a relationship from a graph

Two variables may have a strong relationship, a weak relationship, or no relationship at all. In a strong relationship, large changes in one variable make proportionately large changes in the other variable, like in Figure 2.4. When there is no relationship, the graph looks like scattered dots (below left). A weak relationship is in between strong and none, meaning large changes in one variable cause only small changes in the other.

No relationship between variables

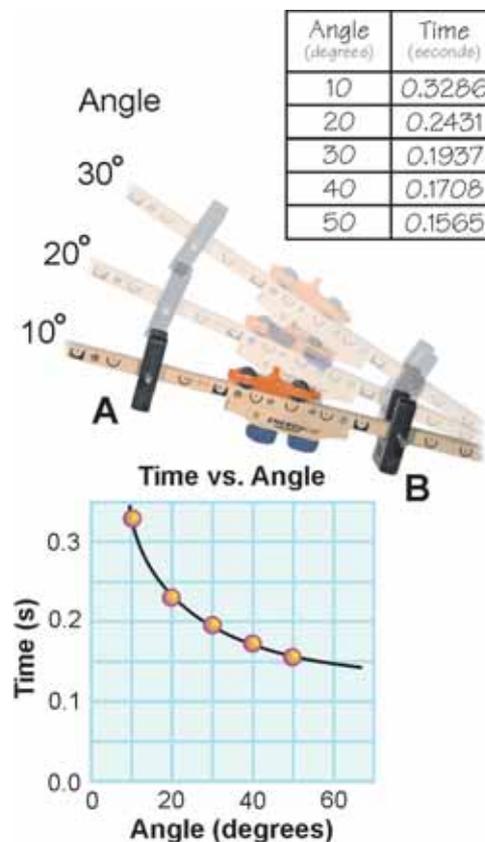


Weak relationship between variables



## VOCABULARY

**graph** - a mathematical diagram showing one variable on the vertical (*y*) axis and the second variable on the horizontal (*x*) axis.



**Figure 2.4:** Investigating how quickly the car gets from A to B as the angle of the track is changed. What kind of relationship does the graph show?



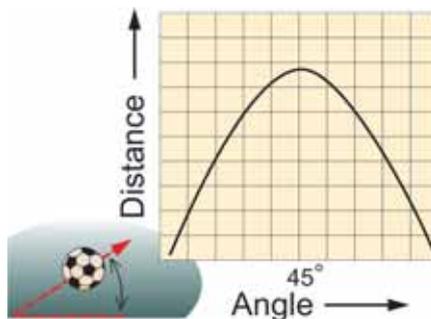
## Direct and inverse relationships

**Direct relationships** In a direct relationship, when one variable increases, the other also increases. For example, if you add a volume of water to water already in a beaker, the mass of water increases. The relationship between mass and volume is a direct relationship. Graphs showing direct relationships usually slope up and to the right, like the graph in Figure 2.5. This is also called a *linear relationship*.

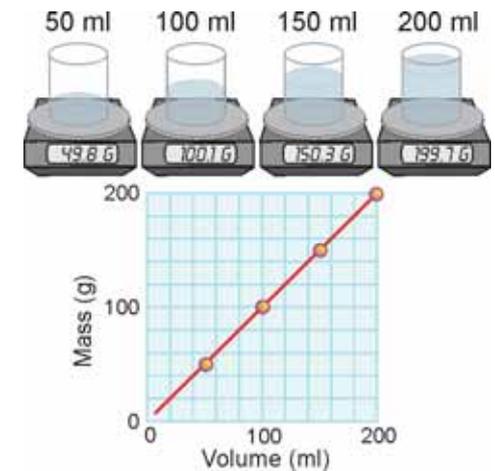
**Inverse relationships** In an inverse relationship, when one variable increases, the other decreases. For example, suppose you put one kilogram of water on the stove for 10 minutes. The temperature of the water increases. If you put two kilograms of water on the same stove for the same time, the temperature would increase only half as much because the heat is spread out over twice the amount of water. The relationship between temperature and mass for this experiment is an inverse relationship. The graph of an inverse relationship often slopes down to the left, like the graph in Figure 2.6.

**Relationships involving more than two variables** Many natural laws relate three or more variables. In fact, the example of the stove involves three variables: mass, time, and temperature. When more than two variables are involved you must do careful planning to figure out the relationships. For example, to figure out the relationship between mass and temperature, you should keep the time the same. It is easiest to figure out the relationships between individual variables by changing them only one at a time.

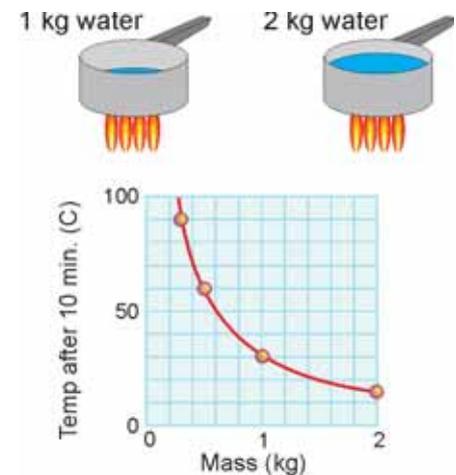
**Complex relationships**



Some relationships are neither direct nor inverse. The graph on the left shows the distance a soccer ball flies when kicked at different angles. The maximum distance is near 45 degrees. Increasing the angle past 45 degrees decreases the distance. Decreasing the angle below 45 degrees also decreases the distance. This is a *nonlinear relationship*.



**Figure 2.5:** The relationship between mass and volume of water is an example of a direct relationship.



**Figure 2.6:** If heating time is kept constant, the relationship between temperature change and mass is an inverse relationship.

## Designing a graph: dependent and independent variables

### What to put on the x- and y-axes

To a scientist, a graph is a language that shows the relationship between two variables. Graphs are drawn a certain way just like words are spelled a certain way. The first rule in making a correct graph is to choose which variables to put on which axis.

### The independent variable

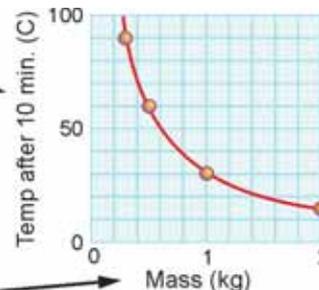
Graphs are usually created to show a cause and effect relationship between two variables. A graph makes it easy to see if changes in one variable *cause* changes in the other variable (the *effect*). The variable that causes the change is called the **independent variable**. In an experiment, this is the variable that the experimenter is free to change. *By agreement among scientists, the independent variable goes on the x-axis.* In the example, mass is the independent variable so mass goes on the x-axis (horizontal).

### The dependent variable

The **dependent variable** shows the effect of changes in the independent variable. *The dependent variable goes on the y-axis.* In the example, temperature is the dependent variable and therefore goes on the y-axis (vertical).

**Dependent variable**  
This is the variable that responds to changes in the independent variable.

**Independent variable**  
This is the variable that causes the changes in the dependent variable.



### If time is a variable

Time is often an exception to the rule about which variable goes on which axis. Time usually goes on the x-axis even though you may not think of time as an independent variable.

## VOCABULARY

**independent variable** - in an experiment, a variable that is changed by the experimenter and/or causes changes in the dependent variable.

**dependent variable** - in an experiment, a variable that responds to changes in the independent variable.



## SOLVE IT!

### 4 steps to making a graph

**Step 1:** Choose which will be the dependent and independent variables. The dependent variable goes on the y-axis and the independent variable goes on the x-axis.

**Step 2:** Make a scale for each axis by counting boxes to fit your largest value. Count by multiples of 1, 2, 5, or 10.

**Step 3:** Plot each point by finding the x-value and drawing a line upward until you get to the right y-value.

**Step 4:** Draw a smooth curve that shows the pattern of the points. Do not just connect the dots.

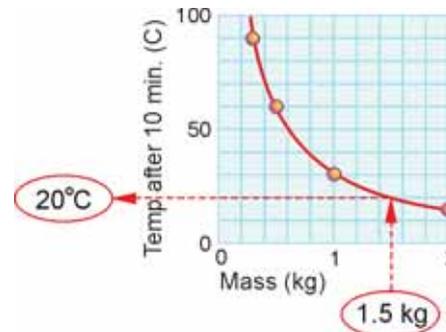


## Reading a graph

### Using a graph to make a prediction

Suppose you want to find out what the temperature of 1.5 kilograms of water would be after 10 minutes on the stove. But you only measured the temperature with 1 and 2 kilograms, not with 1.5 kilograms. The graph can give you an accurate answer even without your doing the experiment.

- 1) Start by finding 1.5 kg on the  $x$ -axis.
- 2) Draw a line vertically upward from 1.5 kg until it hits the curve representing what you actually measured.
- 3) Draw a line across horizontally to the  $y$ -axis.
- 4) Use the scale on the  $y$ -axis to read the predicted temperature.



### Large graphs are more precise to read

For this example, the graph predicts the temperature to be  $20^{\circ}\text{C}$ . Predictions are more accurate when the graph is large enough to read precisely. That is why it is a good idea to make your graphs fill as much of the page as you can.

### A graph is a form of model

A graph is a simple form of model. Remember, a model is a relationship that connects two or more variables. Scientists use models to make and test predictions.



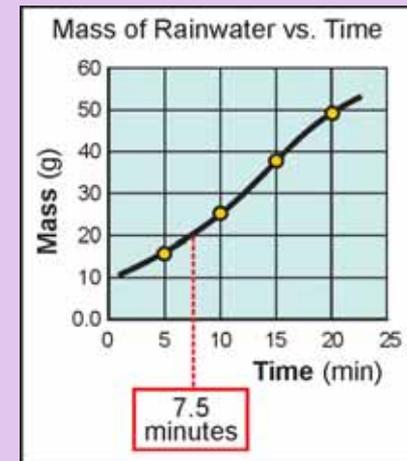
## SOLVE IT!

A student measures the mass of water collected every five minutes on a rainy day.

Time (min)	Mass (g)
0	0
5	17
10	26
15	38
20	49

Design a graph to show the student's data. Once you have the graph, estimate when 20 grams of water was collected.

Time is the independent variable, therefore mass is the dependent variable. The mass axis should go from 0 to at least 50 grams. The time axis should go from 0 to at least 20 minutes. The graph shows that 20 grams of rainwater fell in the first 7.5 minutes.



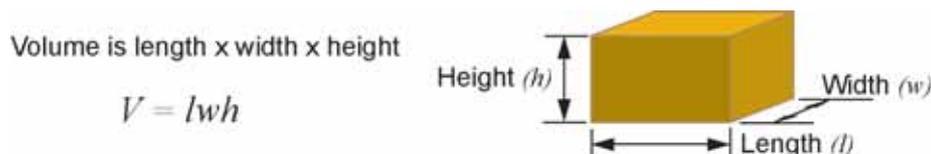
## Using math to describe relationships between variables

### Math is the language of variables

Math is the best language to describe relationships between variables. A graph is good for getting a quick picture of a relationship. However, math is more accurate and more useful. Like any foreign language, you have to learn to read and write math before it can be useful to you. Math allows us to solve problems as routine as balancing a checkbook or as complicated as landing a robot on Mars.

### Using letters to represent variables

When you write out a relationship in math, you use a single letter or symbol to represent each variable. For example, what is the relationship between volume and size for a box? The diagram below shows the relationship written out two ways.



### Operations

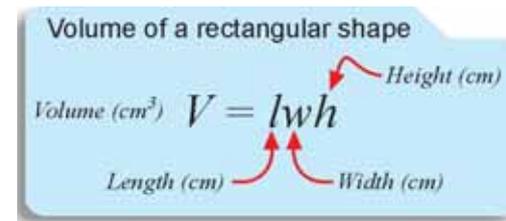
The relationships between variables are represented in math by *operations*. Four operations you know are: add, subtract, multiply, and divide. To show addition or subtraction you put the symbol between the variables. However, there are two ways to represent multiplication and division. In fact, you will rarely see the multiply or divide symbol. Instead, two variables written right next to each other mean they should be multiplied together. Two variables on top of each other mean the top one is divided by the bottom one. All four operations are shown in Figure 2.7.

### Formulas

A formula is a relationship that gives one variable in terms of other variables. Think of each variable as a box to hold the value of that variable. To use the formula, you substitute actual values for the corresponding variables. Then add, subtract, multiply, or divide the numbers as directed by the formula. In this book, important formulas will be shown as “cards” with the variables and their units identified (Figure 2.8).

Add $a$ and $b$	$a + b$
Subtract $a$ from $b$	$b - a$
Multiply $a$ and $b$	$a \times b$ or $ab$
Divide $a$ by $b$	$a \div b$ or $\frac{a}{b}$

**Figure 2.7:** The basic math operations and how they are written and read.



**Figure 2.8:** An example of a formula for the volume of a rectangular box.



## Solving for one variable in terms of the others

**Using a formula** A formula is an exact description of the relationship between variables. Formulas allow you to calculate any one variable if you know the values of the others. This is easiest when the variable you want is by itself on one side of the equal sign ( $=$ ). For example, the volume ( $V$ ) of a box is length ( $l$ )  $\times$  width ( $w$ )  $\times$  height ( $h$ ). If you know the length, width, and height, you plug values in for the variables and do the multiplication as directed by the formula (Figure 2.9).

**Solving an equation** In many problems the variable you want is not by itself. Getting the variable you want by itself is known as *solving* the equation (equation being another word for formula). Suppose the box must have a volume of 1,500 cubic centimeters — about the right size to hold a coffee cup. You want the box to be 10 centimeters wide and 15 centimeters long. How high should the box be?

**Solving an equation with values** Let's do the problem with numbers first. To calculate the required height, write down the formula substituting the values you know.

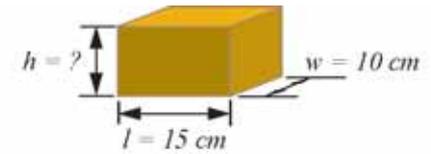
$$1500 = 15 \times 10 \times h$$

Next, do the operations you can. For example, multiply 15 times 10. Last, divide both sides by 150. Dividing by 150 cancels out the 150 on the right-hand side of the formula, leaving only the variable  $h$  (height), which gives you the solution:  $h = 10$  cm.

$$1500 = 150h \rightarrow 10 = h$$

**Solving an equation with algebra** We can also solve the problem using algebra to rearrange the formula. Once you have the formula in the form “ $h = \dots$ ” then you can plug in the numbers and find the required height. Many problems must be solved this way because the relationships are too complex to calculate using just numbers.

$$V = lwh \rightarrow h = \frac{V}{lw} \rightarrow h = \frac{1500}{15 \times 10} = 10 \text{ cm}$$



Formula:	$V = lwh$
Known values:	$1,500 = (15)(10)h$

**Figure 2.9:** Using a formula to calculate the volume of a rectangular box.



Solving math problems is a lot like playing a game. As in all games, there are rules you have to follow. You win the game when you get the variable you want all by itself on one side of the equals sign.

Here are a few of the rules:

**Rule 1:** Anything you do on the left of the equals sign ( $=$ ) you must also do on the right. If you subtract 10 from the left, you must also subtract 10 from the right. If you divide the left by  $w$ , you must also divide the right by  $w$ .

**Rule 2:** Anything divided by itself equals one

**Rule 3:** Given three variables  $a$ ,  $b$ , and  $c$ , the following are true:

$$ab + ac = a(b + c)$$

$$\frac{a}{c} + \frac{b}{c} = \frac{a+b}{c}$$

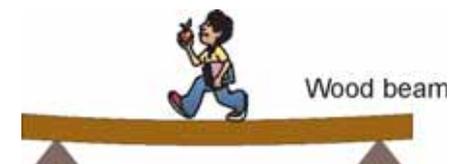
## 2.1 Section Review

- An engineer designing a house needs to know how much force it takes to break different size beams of wood (Figure 2.10). List at least five variables important for figuring out this information.
- Let the variable  $m$  be the mass of a student. Which of the following is NOT a possible value that  $m$  can have?
  - 51 kilograms.
  - 51,000 grams.
  - 51 meters.
- Figure 2.11 shows four different graphs. Which one shows a direct relationship? Which one shows an inverse relationship? Which one shows a complex relationship? Which one shows no relationship?
- A student does an experiment that measures the temperature at which water freezes when different amounts of salt are mixed in. What is the independent variable in the experiment? What is the dependent variable?
- A student collects data on the distance between people's outstretched fingertips and their height. The data are shown in the graph in Figure 2.12. If a person's height is 1.7 meters, what is the most probable distance between his outstretched fingertips?
- On a car trip, the distance you travel is equal to the speed you go multiplied by the time that you are driving. Write this relationship as a formula, using  $d$  to represent distance,  $v$  to represent speed, and  $t$  to represent time.
- Which TWO of the following formulas are mathematically correct? Being correct means what is on the left of the equals sign *always* has the same value as what is on the right.

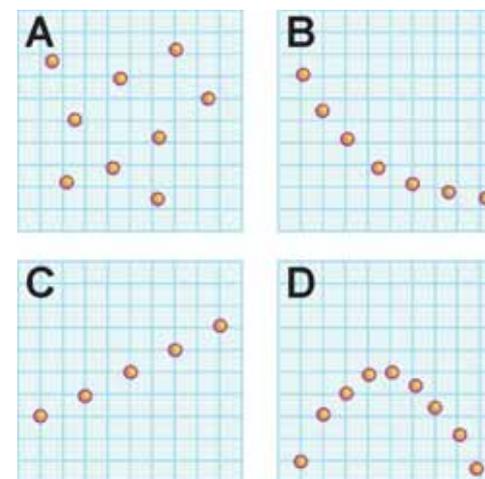
a)  $ab = a + b$       c)  $a + a + b = 2a + b$

b)  $\frac{a-b}{b} = \frac{a}{b} - 1$       d)  $a + b - b = a - 2b$

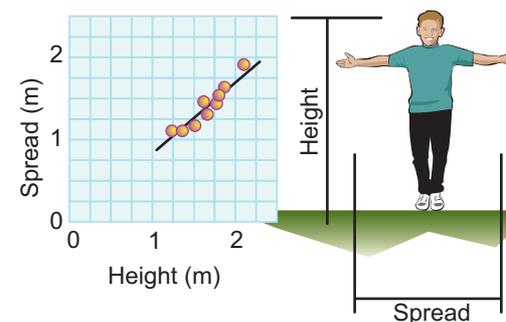
- Solve the equation  $f = ab - c$  for the variable  $c$ .



**Figure 2.10:** The wood beam in question 1.



**Figure 2.11:** Four different graphs.



**Figure 2.12:** A graph showing the spread of people's arms compared with their height.



## 2.2 Experiments and Data

If you wish to know someone's name, it's easy enough to ask, "What is your name?", and get a simple answer: "Sandra." If you want to know how something works in science, the questions are not so easy because the answers are not so easy. Earlier we talked about the importance of inquiry. Inquiry is how science is learned. Inquiry is built around questions, and doing *experiments* is how scientists learn the answers to questions about nature and technology.

### Experiments provide the test of truth

**Experiments** An **experiment** is a situation specially set up to investigate the relationships between specific variables. Scientists do experiments to gather evidence so they can evaluate their ideas. An example of an idea (or hypothesis) could be: "The temperature of water increases proportional to the amount of time you apply heat." One way a scientist could test this idea is with an experiment that measured the temperature of water at different times while heat was applied.

**The importance of experiments** Experiments are important in science because *experiments are the test of whether a hypothesis is correct or not.*

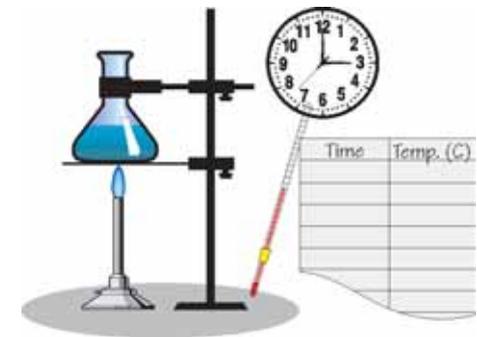
***In science, a hypothesis is correct ONLY if it agrees with the results of actual experiments.***

Something is true in science ONLY if it agrees with what actually happens. People's opinions of what *did or should or could* happen are NOT scientific tests of what is true and what is not true. The best way to test a theory or hypothesis is to do experiments that provide scientific evidence.

**Observations may substitute for experiments** There are times when experiments cannot be done, such as in astronomy. Then a theory may be tested by comparing predictions of the theory with observations of what occurs in nature (Figure 2.14).

### VOCABULARY

**experiment** - a situation specially set up to investigate relationships between variables.



**Figure 2.13:** An experiment to test the hypothesis that the temperature of water increases proportional to the amount of time you apply the heat.



**Figure 2.14:** There are several competing theories for how the solar system formed. Solar systems cannot be re-created in experiments so the theories are tested by comparing them with observations of the actual solar system.

## Designing a good experiment

**The importance of experiment design** A good experiment is carefully planned and carried out. If the experiment is well designed, the results will help you learn what you want to know. If the experiment is poorly designed, the results may fool you into believing the wrong things. Many people have been mistaken and confused by results of poorly designed experiments.

**The hypothesis** The first step in designing a good experiment is to clearly state what you want to test (the *hypothesis*). Remember, a hypothesis is a tentative statement about how or why something happens. For example, “Cars rolling down steep ramps go faster than those rolling down shallow ramps” is a good hypothesis. It is good because it may be tested by doing an experiment (Figure 2.15).

**The procedure** The second step is to plan how you will test your hypothesis. This part of experiment design is called the **procedure**. A good procedure describes the equipment you use, the techniques you use, and the data you collect from the experiment. For example, you could measure the time it takes a car to roll between two photogates as you vary the angle of the ramp. The procedure should contain enough information for someone else to repeat your experiment the exact same way you did.

**Data** The purpose of experiments is to collect scientific evidence. In many experiments the scientific evidence will be **data**. Data are usually the values of variables that you measure during an experiment. For example, the ramp angle and time between photogates are data.

**Analysis and conclusion** Once you collect your data, you need to **analyze** it. Analyzing includes thinking about, graphing, or doing calculations with the data. If your experiment was successful, your analysis will lead you to a **conclusion**. A conclusion is a statement of what you learned from the experiment. A conclusion must always be supported by data and analysis. For example, that cars roll faster down steeper ramps is a conclusion supported by data that shows what the cars did on ramps of various heights in the experiment.

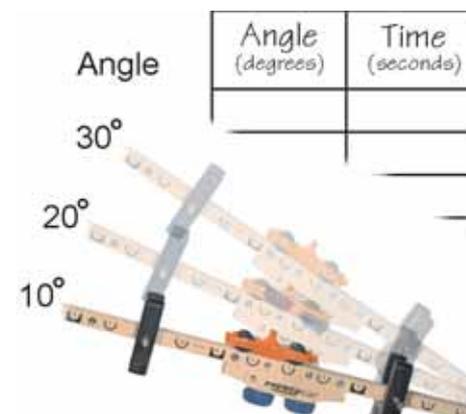
### VOCABULARY

**procedure** - a description of an experiment that details the equipment used, the techniques used, and the data collected.

**data** - information collected during an experiment or other scientific inquiry. Data are often values of variables measured in an experiment.

**analysis** - the process of evaluating data. Analysis may include thinking, creating graphs, doing calculations, and discussing ideas with others.

**conclusion** - a statement of what was learned in an experiment or observation.



**Figure 2.15:** An experiment to test whether cars rolling down steeper ramps go faster.



## Experimental and control variables

**Only one variable is changed in an ideal experiment** In an ideal experiment only a single variable is changed at a time. If anything happens in the experiment, you can then assume what happened was caused by the variable you changed. On the other hand, if you make many changes at once, you will never be able to sort out which one caused what happened. The experiment will still *work*, you just won't be able to understand its results.

**The experimental variable** The variable you allow to change in an experiment is called the **experimental variable**. This is usually the variable that you have direct control over. Going back to the experiment with a car on a ramp, the angle of the ramp is the experimental variable.

**Control variables** In real experiments there are often many variables that matter. If only one variable is allowed to change, then the others must be kept constant. Constant means NOT allowed to change. Variables that are kept constant are called **control variables**. Many variables affect the car on the ramp. For example, changing the mass of the car, pushing it, or releasing it from a different position all change how quickly the car moves between the photogates. If you want to test the effect of steeper ramps you need to ensure that the ramp angle is *the only variable that changes*. The mass and release position should stay the same for every angle you test. Mass and release position are control variables in this experiment.

**Identifying the experimental variable** In some tests you may be asked to identify the experimental variable by looking at data collected in an experiment. The most reliable way to do this has two steps:

- Step 1) Eliminate all the variables that remain constant since these are controlled variables.
- Step 2) Of the remaining variables, the experimental variable is the one the experimenter has changed — and often in equal steps, such as every 2 minutes or every 5 centimeters.

### VOCABULARY

**experimental variable** - a variable that changes in an experiment.

**control variable** - a variable that is kept constant in an experiment.

#### Control variables

Mass, Position, Starting point,  
Distance between photogates,  
Force applied at start

#### Experimental variable

Angle

**Figure 2.16:** Control and experimental variables for the effect of angle on the time between photogates.

Controlled variables				
Mass	Position	Angle	Start	Push
58 g	40 cm	10 deg.	10 cm	no
58 g	40 cm	20 deg.	10 cm	no
58 g	40 cm	30 deg.	10 cm	no
58 g	40 cm	40 deg.	10 cm	no

**Figure 2.17:** The angle is the experimental variable because it changes and is set by the experimenter.

## Accuracy, errors, and averages

**Accuracy** In science, the word **accuracy** means how close a measurement is to the true value of what is being measured. For example, suppose it takes a car exactly 0.125 seconds to pass between two photogates. *You have no way to know the exact true time.* The best you can do is make a measurement and *assume* that your measurement is the true time. The table in Figure 2.18 shows several measurements of the time made by different students using different techniques. Which is the most accurate? Which is the least accurate?

**Error** In your experiments with motion you will use a photogate timer to make measurements to the nearest 0.0001 seconds. You will notice that you rarely get the exact same time three times in a row *even if you do the exact same thing.* This is because any measurement always contains some **error**. Error is the difference between a measurement and the true value of what you are trying to measure. The errors are small if the experiment is accurate.

**The average** When you make many measurements of the same thing you will notice that they cluster around an **average** value. Some measurements are more than the average and some are less. To calculate the average you add up all the measurements and divide by the number of measurements you have. For example, the average of the times in Figure 2.18 is 0.1253 seconds.

**Why taking the average is useful** The average of several measurements is usually more accurate than a single measurement. The average is more accurate because errors in the negative direction partially cancel errors in the positive direction.

$$\text{Avg} = \frac{.1255 + .1248 + .1252 + .1256 + .1252}{5} = 0.1253 \text{ s}$$

Measurement	Error	-	+
0.1255 s	+0.0002 s		█
0.1248 s	-0.0005 s	█	
0.1252 s	-0.0001 s	█	
0.1256 s	+0.0003 s		█
0.1252 s	-0.0001 s	█	

### VOCABULARY

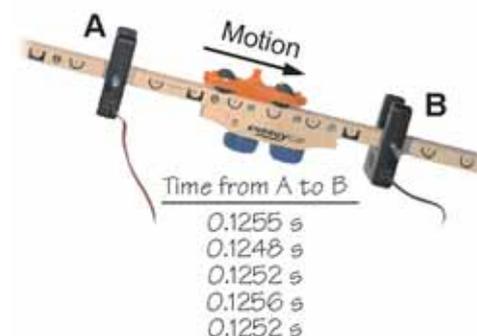
**accuracy** - describes how close a measurement is to the true value.

**error** - the difference between a measurement and the true value.

**average** - a mathematical process in which you add up all the values, then divide the result by the number of values.

Average

$$\text{Avg} = \frac{\text{sum of values}}{\text{number of values}}$$



**Figure 2.18:** Some data collected by different students using different techniques. Each measurement is the time for a car to roll between two photogates.



## Reproducibility: When are two results the same?

### A new condition for reproducibility

In Chapter 1 we said one of the criteria for scientific evidence was that it be *reproducible*. Reproducibility means *two* things that we can now discuss more carefully.

1. Others who repeat the same experiment get the same result (which is what we said in Chapter 1).
2. If you repeat the experiment the same way, you always get the same result.

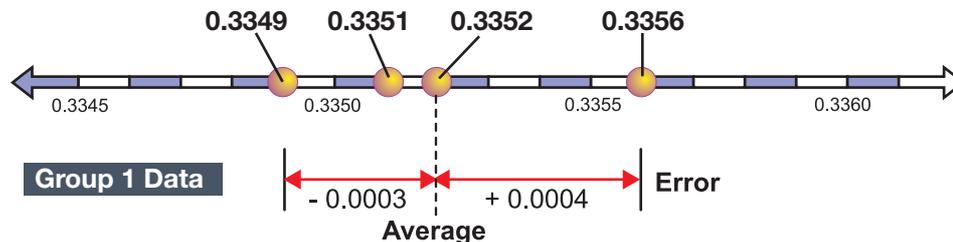
### When different numbers are “the same”

According to rule number 2, an experiment is most reproducible when errors are small. However, even small errors *are still errors*. This brings up an important question: How can you tell if two results are the same when both results have errors in them? The word “same” when applied to experimental measurements does not mean what it does in ordinary conversation. Two measurements are considered the same if their difference is less than or equal to the amount of error. *This is important to remember.*

*Two measurements are considered the same if their difference is less than or equal to the amount of error.*

### How to estimate the error

How can we know the error if we do not know the true value of a measurement? The way scientists estimate the error is to *assume the average is the true value*. The error is roughly the largest difference between the average and a measured value. The number line below shows Group 1’s (sidebar) data with the estimated error.



### SOLVE IT!

Two groups of students do an experiment in which they measure the time it takes a car to roll between two photogates. Each group makes four measurements and takes the average. One group claims its results are the same. The other group claims its results are different. Who is right?

Group 1	Group 2
Time (s)	Time (s)
0.3356	0.3346
0.3351	0.3353
0.3349	0.3350
0.3352	0.3347
<b>Average</b>	<b>Average</b>
0.3352	0.3349
<b>Error</b>	<b>Error</b>
$\pm 0.0004$	$\pm 0.0004$

You need to know the size of the error. For both groups, the largest difference between the average and a measured value is 0.0004. Therefore, the error is approximately  $\pm 0.0004$  seconds.

The difference between the two groups’ results is only 0.0003 seconds. This difference is NOT greater than the error, therefore, scientifically, **the results are the same**.

## Drawing conclusions from data

### We do experiments to reach conclusions

The point of experiments is to produce data that allows a scientist (like you) to come to a conclusion. The conclusion tells whether your idea, the hypothesis, is right or not. *You need to know about errors before you can make a conclusion.* For example, suppose you think that pointy cars roll faster down a hill. An experiment tests cars with different shapes by measuring the time between two photogates. Your hypothesis (pointy cars roll faster) predicts that the time between photogates should be less for the pointy car.

### A sloppy experiment

One group rolls each car once and records the time in a data table (Figure 2.19). Their results show a shorter time for the pointy car. This seems to confirm the hypothesis. Are they right? Have they proved that pointy cars go faster?

### A better experiment

Scientifically there is no way to tell if the time difference for Group 1 is **significant** or not. A difference is only significant if the difference is greater than the amount of error. The same experiment is also done by a second group. The second group did five identical trials for each shape. Doing identical trials allowed the second group to estimate its errors. The largest difference between the average and a measured value is 0.0007 for the blunt car and 0.0006 for the pointy car.

### When differences are significant

The second group can say that, scientifically, the data do NOT show that pointy cars are faster. At the speeds in their experiment, the shape of the car made no *significant* difference. In fact, shape only starts to become an important factor at speeds at least five times higher than those you will observe in your investigations.

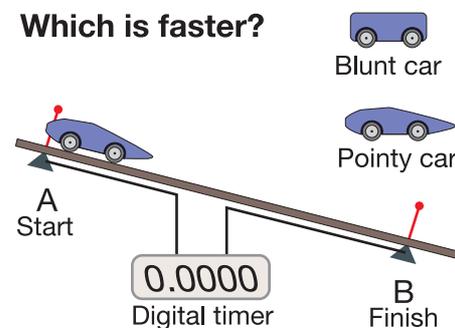
### How numbers can be different but still the same

Two results are significantly different only when the difference between them is greater than the error. This is an important consideration because experiments rarely produce exactly the same numbers twice in a row. Numbers that are “different” in a mathematical sense may not be *significantly* different in a scientific sense.

## VOCABULARY

**significant** - a difference between two measured results is significant if the difference is greater than the error in measurement.

### Which is faster?



### Group 1

Blunt	Pointy
0.3545 seconds	0.3542 seconds

### Group 2

Blunt	Pointy
0.3540 seconds	0.3542 seconds
0.3550 seconds	0.3548 seconds
0.3541 seconds	0.3538 seconds
0.3539 seconds	0.3540 seconds
0.3546 seconds	0.3541 seconds

### Averages

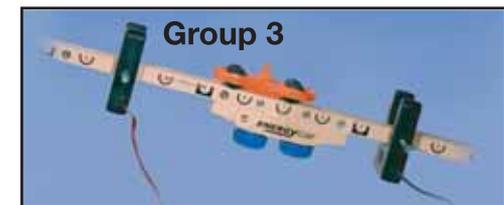
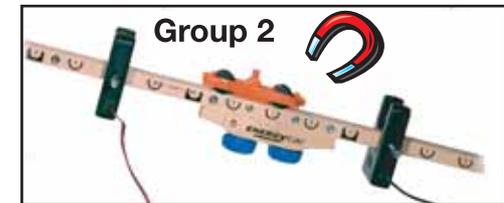
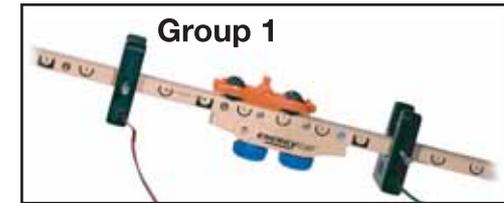
$0.3543 \pm .0007$	$0.3542 \pm .0006$
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**Figure 2.19:** An experiment to test whether the shape of a car has an effect on its speed going downhill.



## 2.2 Section Review

- Georgiana has the idea that salt water heats up faster than fresh water. Which of the following would be acceptable scientific proof of her hypothesis?
  - Three of her friends believe it.
  - She read on an Internet website that it was so.
  - She did an experiment that showed it.
- A careful description of how an experiment is conducted is called
  - a data table.
  - a procedure.
  - an analysis.
  - a conclusion.
- Explain why all variables but one should be controlled in a well designed experiment.
- Is it possible to measure the true value of a physical property, such as mass? Explain why or why not.
- Three groups do the same experiment rolling a car through two photogates. The track is set at the same angle and all other variables are kept the same for each group. The data is shown in Figure 2.20. The first group does the experiment in the daylight. The second group does it under a magnet. The third group does the experiment in the dark. Group 2 claims that its experiment shows that magnets make the car go faster. Is their claim supported by the evidence? Explain why or why not.
- Which of these sets of data has an average of 10.5?
  - 8.5, 9.5, 10.5, 11.5.
  - 9.0, 10.0, 11.0, 12.0.
  - 10.0, 10.5, 11.0, 11.5.
  - 10.5, 10.6, 10.7, 10.8.
- What does it mean when two values are different but not *significantly* different?



Group 1	Group 2	Group 3
Time A to B	Time A to B	Time A to B
0.343	0.339	0.341
0.346	0.338	0.337
0.341	0.345	0.344
0.340	0.341	0.340
0.349	0.339	0.339

**Figure 2.20:** The three experiments of question 5.



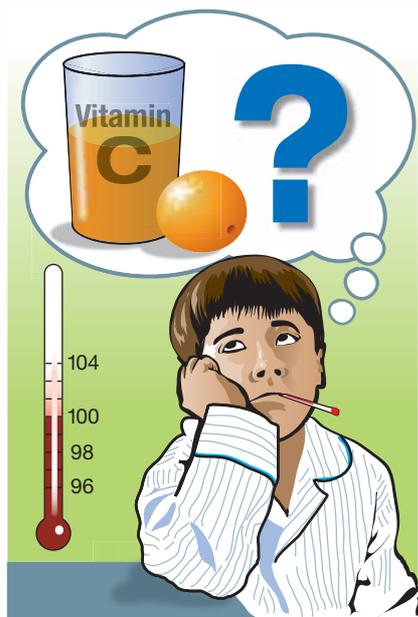
## Testing the Power of Suggestion

Have you ever bought one brand of a common item instead of another, just because you heard a name in an ad? We all do that. Ads sometimes influence us through the power of suggestion. We recognize the name of the product. We may not be sure why. And then we buy the product.

When the power of suggestion occurs in medicine, it is called the “placebo effect.” A placebo is a substance that has no healing properties. Yet this same substance causes a patient’s condition to improve. Why? Because he or she believes it has the power to do so. This is the placebo effect.

Is it real? One way to try to find out is through a scientific experiment. This will test the hypothesis. A hypothesis is an idea that is based on evidence and that, most importantly, can be tested. In this case, the hypothesis is that the placebo effect is real. People who take a placebo for an illness will get well.

Let’s imagine an experiment that will test the placebo effect. The hypothesis will be tested on a group of people that, or “subjects.” All of the people in the experiment need to believe that they are receiving the same treatment for the same problem. They need to believe that they are all being treated in exactly the same way. This is called a “blind” test. The subjects do not know if they are receiving a medicine or other treatment or a placebo.



For our experiment, let’s assume our subjects are concerned about catching a cold. They all believe that taking high doses of vitamin C helps prevent colds. Some of the subjects will be given a placebo, but they will believe it is vitamin C. If the placebo effect is real, everyone in the experiment should catch fewer colds. It should not matter if a subject is taking vitamin C or not.

### Test the hypothesis

Half of the subjects will receive vitamin C pills. The other half will take pills that look the same but are placebos. For example, they might be made of powdered sugar.

To test the effect, all of the subjects take the “vitamin” pills for a month. We record how all of them respond to the pills. This becomes our experimental data. At the end of the experiment, which group caught fewer colds? If there is no difference, the placebo effect may be real.

To test the hypothesis further, we would also follow up. When the experiment ends and the powdered sugar is no longer being given to half of the test subjects, do the number of colds caught by the subjects go up?

If so, then we have more evidence to support our hypothesis. What were the results when the subjects believed they were taking vitamin C? How do those results compare with what happened when they stopped taking the pills? This is the point of comparison.

### Keep conditions the same

For a good scientific experiment, other factors must also be considered. As experimenters, we need to be sure that conditions are the same at every point in the experiment. For example, how did the weather change? Did any subject's overall well-being change (with, for instance, a death in the family, a broken arm, a job loss, for instance)? Were the subjects getting the same amount of rest before and after you gave them the pills? Were the subjects eating the same types of food before and after? These factors are called "variables." For the experiment to be a success, the variables need to be controlled.

Let's assume everything was controlled in our experiment. The placebo effect is real. A person believes that a treatment will work. Then it is suggested that this type of treatment will work. The hypothesis is tested using controlled, observable, scientific methods and the results are measured.

Before a new drug can be sold, it must prove to be more effective against a disease than a placebo.



### Real or imagined?

Some scientists believe the placebo effect is a myth. Simple experiments like one discussed cannot prove that the effect is real. This is because all of the variables cannot be controlled. Does taking the placebo reduce a subject's anxiety? Does it bring down stress levels? Does the extra attention and care the subject receives affect the results? Do encouraging messages trigger the subject's response to the placebo?

Variables play an important role in the outcome of any experiment. Most often, even the doctor conducting the test does not know which subjects are receiving a placebo. This type of test is known as a double-blind study. It means both the subject and the experimenter are "blind" about who is receiving a placebo. This is how new drugs are tested before they are sold.

Whether or not you believe in the placebo effect, it is important for all experiments to be objective. Using a placebo helps keep experiments with human subjects objective because it separates the actual effects of a medicine from effects caused by how a patient *feels* about a medicine. A doctor's attitude about a medication can also effect how it works in a patient. Using the double-blind technique is a second way of maintaining objectivity because it separates the doctor's own opinions from the results of the experiment.



#### Questions:

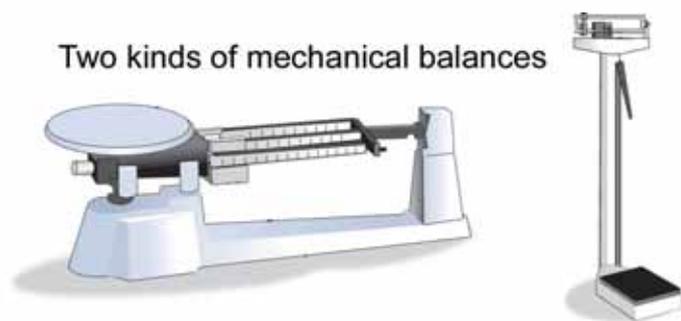
1. Why are drugs tested in double-blind studies?
2. What is the placebo effect?
3. What is a hypothesis?
4. How is a "double-blind" study set up?

## CHAPTER ACTIVITY **Guess the Gram**

Mass is the measure of the amount of matter an object contains. An object's mass is related to its size (volume) and the density of the material from which it is made. Common units for measuring mass include the gram and kilogram. One kilogram is equal to 1000 grams. In this activity you will be using a triple beam balance to measure mass and estimate the masses of everyday objects.

### Materials:

Balance capable of measuring 300 grams  $\pm$  0.1 grams  
Assorted items such as coins, paperclips, rubber bands, washers, marbles, popcorn kernels, etc.



### What you will do

1. Make sure your balance is calibrated properly and shows a reading of zero when it is empty. Make adjustments to the thumb screw if necessary.
2. Copy the table shown to the right.
3. Choose an object from your assortment that you believe has a mass close to one gram. Record the name of the object in the first row of the table.
4. Use the balance to measure the mass of the object to the nearest tenth of a gram. Record the mass in the table in the first try column.
5. Unless your mass was exactly one gram, make a second attempt to find one or more objects with a mass of one gram. Record the object(s) you selected, measure the mass, and record the mass.
6. Repeat with all the other masses in the table.

Mass (g)	Object(s)	Mass (g) first try	Object(s)	Mass (g) second try
1				
5				
10				
25				
50				
100				
250				

### Applying your knowledge

- a. Did the accuracy of your estimations increase as the activity went on?
- b. Calculate your error in estimating the mass of the 10 gram object on your first try. Calculate your error in estimating on your second try.
- c. Estimate the mass of the following objects in grams:
  - your textbook
  - an unsharpened pencil
  - a sheet of notebook paper
  - a compact disc
- d. Estimate your mass in grams and in kilograms.
- e. If you wanted to estimate the mass of a car, would you use grams or kilograms?

# Chapter 2 Assessment

## Vocabulary

Select the correct term to complete the sentences.

variable	dependent variable	graph
independent variable	experiment	control variable
procedure	conclusion	experimental variable
average		

### Section 2.1

1. A mathematical picture that may show a pattern between two variables is a \_\_\_\_.
2. On a graph of two variables, the variable that causes changes in the other is the \_\_\_\_.
3. A quantity which can have many values is a \_\_\_\_.
4. The variable on a graph which is most often represented on the y-axis is the \_\_\_\_.

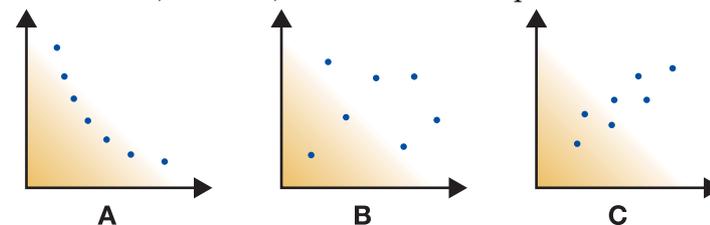
### Section 2.2

5. A situation set up to investigate the relationship between certain variables is called a(n) \_\_\_\_.
6. A statement of what was learned in an experiment is called a(n) \_\_\_\_.
7. The description of how an experiment is done, including equipment, techniques used and the type of data collected is the \_\_\_\_.
8. The variable that you change in an experiment is called the \_\_\_\_.
9. In an experiment, variables that are NOT allowed to change are \_\_\_\_ variables.
10. The sum of all measured values divided by the number of measurements is called the \_\_\_\_\_ value.

## Concepts

### Section 2.1

1. Name four types of variables you might commonly use in doing an experiment. For each variable, name a unit and an instrument or tool that could be used to make that measurement. An example is *force-newton-spring scale*; where *force* is the variable, *newton* is the unit, and *spring scale* is the measuring instrument.
2. Identify the relationship for each graph pictured below as either direct, inverse, or no relationship.



3. You have designed an experiment to test whether stretching a spring farther will cause it to shoot a marble a greater distance. You record the distances the spring is stretched, and the distances the marble travels with each release. Answer the following questions about your experiment.
  - a. Name the independent variable.
  - b. Name the dependent variable.
  - c. Name the variable you would graph on the x-axis.
  - d. Name the variable you would graph on the y-axis.

### Section 2.2

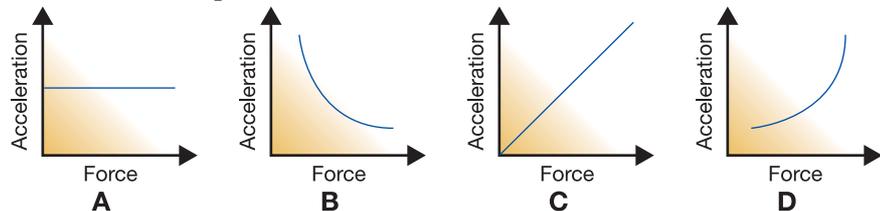
4. Write an **X** next to each hypothesis that could be tested by experiment.
  - a. \_\_\_\_ Steeper ramps result in higher speeds.
  - b. \_\_\_\_ Red apples taste better than green apples.
  - c. \_\_\_\_ Alien life forms are hiding on Earth.
  - d. \_\_\_\_ A parallel universe exists that cannot be detected.

5. Celia designs an experiment to test if the speed of a wagon changes as masses are added when a constant force is applied for 2 meters. As masses are added to the wagon, she measures decreasing values of speed. She draws a graph that shows that the mass and speed are inversely related. Based on the description of Celia's experiment:
- Identify a control variable mentioned in the procedure.
  - Identify the experimental variable in the procedure.
  - Write a hypothesis for this experiment.
  - Identify the data in this experiment.
  - State a conclusion for this experiment.

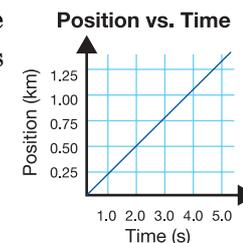
## Problems

### Section 2.1

- A graph is 20 boxes by 20 boxes. Time is plotted on the  $x$ -axis and its range is 0 to 40 minutes. Position is plotted on the  $y$ -axis and the range is 0 to 20 meters. What should the scale be for each axis of this graph?
- The density of a material is calculated by dividing the mass of the material by its volume. If  $d$  represents density,  $m$  represents mass, and  $V$  represents volume, write a formula to represent this relationship. Is the relationship between density and volume direct or inverse?
- Which of the following graphs shows an inverse relationship?



4. The graph to the right represents the position of a rocket above the ground as time passes.
- What is the position of the rocket after 3.0 seconds?
  - Does this graph show a direct or inverse relationship?



### Section 2.2

- If the width of a machine part should be 4.00 cm with an acceptable error of  $\pm 0.03$  cm, which of the following lengths is significantly different?
  - 4.04
  - 3.98
  - 4.29
- Jaden measured the mass of a 2002 penny on a mass balance 4 different times. Kylie repeated the same measurement 4 times using the same penny and the same mass balance. Their results are shown below:

Trial	Jaden	Kylie
1	2.45 g	2.51 g
2	2.49 g	2.50 g
3	2.55 g	2.49 g
4	2.51 g	1.70 g

- What is the average of Jaden's measurements? Of Kylie's measurements?
- Who had the most accurate measurements? Explain your reasoning.
- What is the "true" mass of the penny?