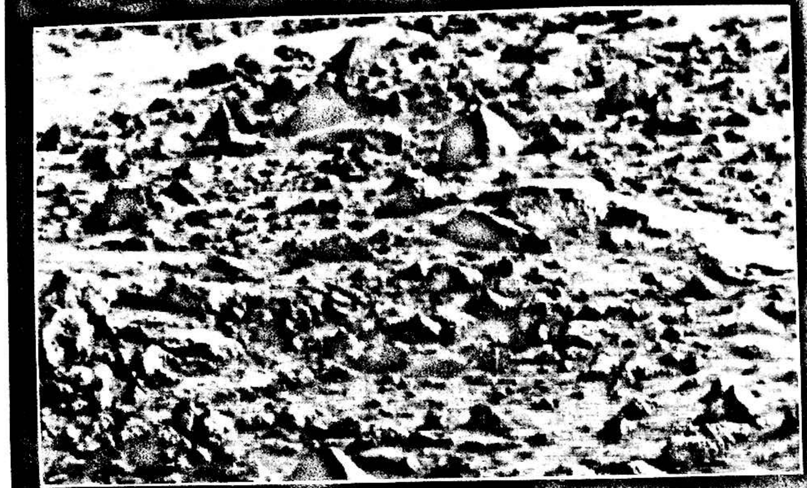
TOPIC I
OBSERVATION AND MEASUREMENT OF THE ENVIRONMENT



The surface of Mars from the Viking I Lander, 1976.

CHAPTER 1
Observation and Measurement

You will know something about observing and measuring if you can:

1. Describe how observations are made.
2. Classify your observations and make meaningful inferences.
3. Make some measurements and state how accurate they are.

1973-1998: Twenty-Five Years of Space History

(Reprinted from *The New York Times*, March 1, 1998)

We on Earth have now become used to the idea of having neighbors on other planets. But what did the Martians think of Earth before we contacted each other? In honor of the twenty-fifth anniversary of the discovery of life on Earth by our Martian friends, we are reproducing the following articles. They are from the largest newspaper on Mars, the *Global Observer*, and trace the history of space travel and interplanetary contact from the Martian viewpoint. (We are indebted to the Martian expert in comparative linguistics, Professor $24C^2x_1$, for his invaluable assistance in making this translation into English.)

March 10, 1973

The latest readings from Earth-1, the first unmanned Martian spacecraft to travel to another part of our solar system, indicate that the planet Earth definitely shows signs of life, but probably not life as we know it on Mars. According to a spokesman for the Space Agency, the seasonal color changes observed by astronomers seem to be associated with the growth of plant life, some of it very large. From collected data it seems that any forms of life on Earth must exist in an atmosphere containing more than 20% oxygen and at temperatures as high as 50°C. The Space Agency is presently working on protective suits for the astronauts who will land on this dangerous planet in a few years.

May 2, 1973

Yesterday's amazing news bulletin announcing the definite existence of life on Earth has left most Martians wondering what is next. Readings taken by sensitive instruments on board Earth-1 prove without any doubt that some form of life exists on Earth. No detailed descriptions of Earth life can be given at this time, since even the best photographs taken from Earth-1 still show the planet at a distance of about 1,200 kilometers—too far away to see small details.

The "blue planet," as every Martian schoolchild calls Earth, is mostly covered by water. Signs of life, such as carbon dioxide in the atmosphere and traces of carbon compounds, probably show the existence of at least water plants. As mentioned in earlier reports, seasonal color changes probably show the existence of land plants. Some scientists think that animal life may also have developed, but this is only an educated guess with the information now available.

One thing that puzzles the scientists at the Space Agency is the apparent high concentration of life in the equatorial and middle regions of Earth and the lack of evidence of life in the more Martian-like polar regions. Evidently, answers to these questions will not be forthcoming until the landing of the first astronauts, now expected in the early 1980's.

* * *

October 15, 1991

Yesterday was a day like no other in the history of any country or planet. At exactly 13:43 Mars Universal Time two Martian astronauts lowered the gangway of Friendship-1 and stepped onto the third planet from the sun, Earth. As had been arranged in the voice contacts that have been going on since the discovery of Earth civilization in 1989, a greeting party of Earth leaders met our astronauts as they touched a foreign planet for the first time. Most observers expressed amazement at the similarity in appearance between Martians and the Earth people, even though there are minor differences, such as skin color and the number of fingers. . . .

OBSERVING YOUR ENVIRONMENT

How many times have you heard someone say, "Try to look at it *my* way!" The "news" articles you have just read were intended to give you a look at the earth from a viewpoint of someone very different from yourself—someone from another planet. How would such a person describe you to his friends? How would you two learn about each other?

Think of the early explorers here on the earth. The first thing they were asked when they returned home from a foreign land was what they had *seen*. What about the first landing on the moon? People on the earth waited impatiently to *see* for themselves, through the miracle of television, what the surface of the moon was like.

If an Earthling met a Martian, the first thing they would probably do would be to *look* at each other. In the story above it was stated that the Martians were amazed at the similarities between Earth people and themselves. This is a simple *observation*—that is, a use of one of the senses to learn something about the environment. Sight, hearing, touch, taste, and smell are senses that give you information about your environment, or surroundings.

Of course, you generally have to do more than just look when you really want to find out about something. Suppose, for example, you wanted to compare your skeleton with that of the Martians. Would your senses give you any information about that? Yes, some direct observations could be made. For example, you could feel the bones in your arm and compare them with those in the Martian's arm. But wouldn't it be better if you could compare X-ray photographs of the bodies of both of you? You can often gain more detailed information about something by using *instruments* than you can with just your unaided senses.

Instruments are used when people need to extend their limited senses. All instruments, from a ruler to the most complicated scientific equipment, answer that need. They were invented when someone wanted to observe something and found that it couldn't be done without using something more sensitive and accurate than the human senses.

SUMMARY

1. Observations involve the interaction of your senses with the environment.
2. Powers of observation can be increased by the use of instruments to extend the human senses.

CLASSIFYING YOUR OBSERVATIONS

You can make all possible measurements and observations about a situation and still not understand what the information you have collected really means. To make some sense out of your observations, you might try to arrange them in groups. This is *classification*. For example, if you were given a tray of buttons and asked to classify them, you might sort them out by color, or by size, or by both color and size. There are often many ways to classify the same material.

After you have organized, or classified, the observations you have made, you may be able to conclude something from the organized information that you could not have stated on the basis of any of the separate observations. This interpretation of your observations is called an *inference*. An inference is a conclusion that follows logically from the information that you have. Detective work provides a good example of the difference between an observation and an inference. In searching for clues a detective may make many observations. But eventually he or she will try to put together the collected information and make an inference about the crime, such as when it occurred, or who committed it.

In the study of earth science you will have many chances to make observations and to draw inferences. It will be important for you to know the difference between these two processes of science.

Let's see how well you understand the meanings of the terms *observation* and *inference*. Below are some statements from the Martian newspaper articles. Which statements would you call observations, and which would you call inferences?

STATEMENT	OBSERVATION OR INFERENCE
1. According to a spokesman for the Space Agency, the seasonal color changes observed by astronomers seem to be associated with the growth of plant life . . .	1. This one should be easy. The "seasonal color changes" are observations; the statement says so directly. But the growth of plant life is an inference from those observations. The words "seem to be . . ." make that rather clear.
2. Any forms of life on Earth must exist . . . at temperatures as high as 50°C.	2. The temperature readings should be called observations, even though no thermometers were actually sent to the earth. It is quite possible to read the temperature of something far away by means of sensitive instruments. (For example, using the Mount Palomar telescope, the temperature of a match could be measured at a distance of about 40 kilometers.)
3. The "blue planet," as every Martian schoolchild calls Earth, is mostly covered by water.	3. That the earth is blue is definitely an observation. What about the statement that the planet is "mostly covered by water"? If you observe a substance that has all the properties of water, are you "observing" water? Or are you *inferring* the presence of water from the observations you made? The line between observation and inference is not always easy to draw.

SUMMARY

1. Classification is an organization of information in a meaningful way.
2. An inference is a conclusion based on available information.

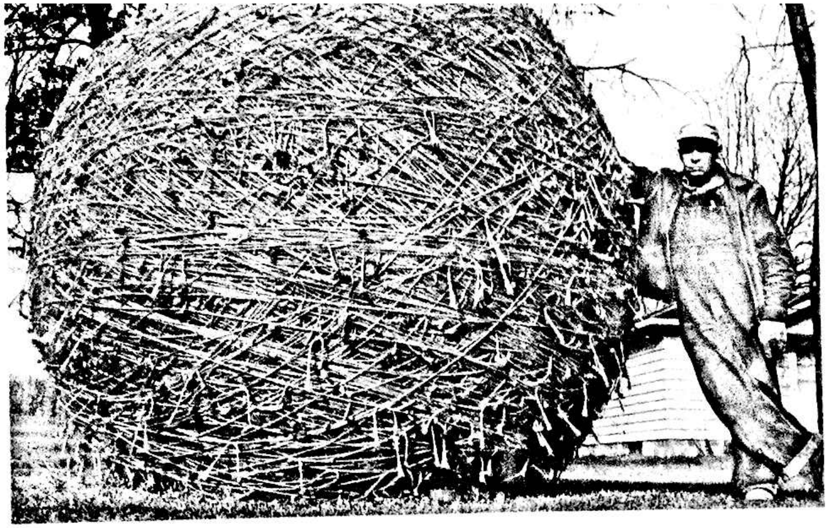


Figure 1-1. The largest ball of string on record is one of 12 ft 9 in in diameter, 40 ft in circumference and weighing 10 tons, amassed by Francis A. Johnson of Darwin, Minn. between 1950 and 1978.

MEASUREMENTS

Most people are fascinated by records—the largest, the fastest, the most, etc. This interest in records is so widespread that the *Guinness Book of World Records**, from which Figure 1-1 is taken, is one of the world's best-selling books. Most of the records in the *Guinness Book* are measurements. Most observations in science are measurements, also. Just what is a measurement?

Units of Measurement. Every measurement consists of a numerical *quantity* and a *unit*. The description of the ball of string in Figure 1-1 includes three measurements—11 feet, 5 tons, 14 years. Feet, tons, and years are all *units* of measurement. The figures 11, 5, and 14 are the quantities of units in the measurements.

Two of the units in this example (feet and tons) are part of the system of measurement called the *English system*. This is the system still in common use in this country, so some of the examples in the next page or two are given in those familiar units. However, almost all the rest of the world uses the *metric system of measurement**, and the United States is now changing over to that system, too. So we will be using metric units for the most part in this text.

Table 1-1. Metric units .

QUANTITY	UNIT	SYMBOL
Length	meter	m
Volume	liter	l
Mass	kilogram	kg
Time	second	s

METRIC PREFIXES

micro	1/1,000,000	one millionth
milli	1/1,000	one thousandth
centi	1/100	one hundredth
deci	1/10	one tenth
kilo	1,000	one thousand

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*The metric system is also called the International System of Measurement, and metric units are called SI units, from the French name *Systeme International*.

Both the quantity of units and the name of the unit are usually needed if the measurement is to make any sense. However, in daily affairs, we often express measurements without stating the units. We can do that because everybody concerned knows which units are meant. For example:

"The weatherman reports that the temperature at 11:00 A.M. was 70. . ."

"Guess what, Sue! My weight was down to 102 this morning!" "Oh, Fran, I wish I had your will power!"

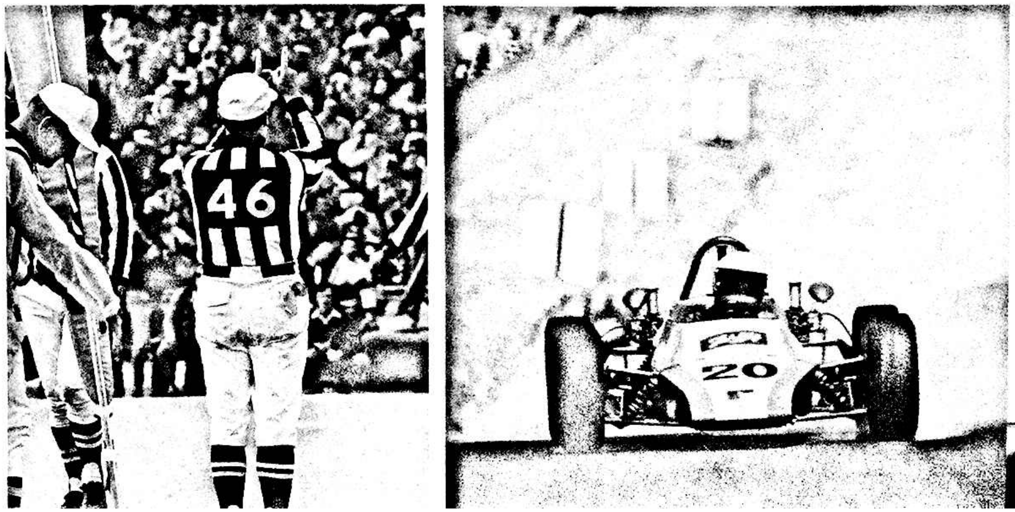
We know the temperature reading was measured in degrees Fahrenheit; we know Fran measured her weight in pounds. The units were understood in each case, and so the measurements had meaning.

Fundamental Units. All measurements, as we have already said, consist of a number and a unit. Certain units of measurement are called *basic*, or *fundamental*. This means that the unit is not a combination of other units.

The fundamental units have been defined by general agreement. For example, the unit of length in the metric system is the *meter*. Until recently, the meter was defined as the distance between two marks on a certain metal bar kept at the International Bureau of Weights and Measures near Paris, France. Today, the meter is defined in a more complex way. But the important point is that there is nothing in nature that tells us how long a meter *must* be. This is something that scientists have to decide among themselves. A meter could have been any length. But once decided, it becomes the fundamental unit of length that all scientists use. All measurements of length (or distance—which is the same thing) are expressed in terms of that unit or its equivalents.

Scientists have discovered that

Figure 1-2. Basic and derived units. With a single measurement of length, the referee can find the distance the ball was moved. Length is a basic unit. Two measurements are needed to find the speed of the car—distance traveled and time of travel. Speed is a derived unit.



there are several different fundamental units that are needed for the measurements they make. In your study of earth science, you will be concerned almost entirely with four of these fundamental units—the units of length, mass, time, and temperature.

Derived Units. Let us refer back to the weather report mentioned earlier. The temperature was 70°F. As we have just stated, the unit of temperature is a fundamental unit. Suppose the weather report continues:

> ". . . The wind is from the northwest at 22 miles per hour, gusting to 35. . . ."

What is the unit of wind speed in this case? You can see that it is a compound unit, made from a unit of length (miles) and a unit of time (hours). The unit of speed is actually a unit of length divided by a unit of time. Units of speed are therefore not fundamental units. Such units are called *derived* units.

Consider another example that is not so obvious.

> "Honey, would you pick up a quart of milk at the store?"

What is being measured by the unit "quart"? This is a unit of *volume*. Volume, however, is not a fundamental quantity. If we think of volume in terms of cubic inches or cubic centimeters, we see that volume is actually a measurement derived by combining units of length. The volume of a rectangular box, for example, is found by multiplying its length by its width by its depth. Every unit of volume can be converted to an equivalent product of three length measurements. For example, the liter is simply a convenient shorthand for 1,000 cubic centimeters (cm^3).

The fundamental units play such an important part in all of science that it is a good idea to take a closer look at them.

Length. Length is the distance between two points. The length of a line on a piece of paper, the length of a football field, the distance to another planet—all are determined by finding out how many times a standard measuring unit fits between two points.

Mass. Mass is usually defined as "the amount of matter" in an object. How do we measure "amount of matter"?

You may be thinking that there is no problem—you can find the mass of an object by weighing it. But isn't there something wrong with that? The weight of an object changes, depending on where it is. For example, you probably know that astronauts weighed much less on the moon than on the earth. Inside an orbiting satellite or in a "space walk" outside a spaceship, astronauts appear to be altogether "weightless" (see Figure 1-3).

Although astronauts may become weightless in a space vehicle, they do not lose their mass. The "amount of matter" in an object remains the same wherever it is. If a weightless astronaut floats across his cabin and collides with the wall, he will be forcibly reminded that he still has his usual mass. A mass resists a change in its motion—a property called *inertia*. The more rapid the change in motion, the greater the force of resistance. That is why collisions cause so much damage. Bringing a moving object to a sudden stop results in very large forces that depend on the mass of the object alone, not its weight.

Figure 1-3. Astronauts in a weightless condition.

Mass and Weight. Weight is not mass, but weight is still a convenient way of measuring mass. The reason for this is that weight is the pull of gravity on a body. This pull near the earth depends on just two things: (1) the distance of the body from the earth's center; and (2) the mass of the body. As long as we stay on the earth's surface, our distance from the earth's center is not going to change very much. Therefore, the weight of the things we measure simply depends on their mass. Unless we need extreme accuracy, we get a perfectly satisfactory measurement of mass on the earth by weighing. In fact, this is such a common and acceptable method of measuring mass that for most purposes mass and weight are expressed in the same units. But it is well to keep in mind the fact that mass and weight are actually two different properties of matter, even though they are numerically related.

Units of Mass. You may be wondering what the unit of mass is. By international agreement, the standard unit of mass is a certain piece of metal kept at the International Bureau of Weights and Measures. Everybody agrees that this body of matter has a mass of 1 kilogram. All other masses are found by comparing them, directly or indirectly, with that standard mass.

Time. Time can be described as our sense of things happening one after another. It is measured by observing a change in something. A clock is nothing more than a machine that regularly registers the swinging of a pendulum, the turning of a small wheel, the vibration of a tuning fork, etc. It does this by indicating numbers that we call hours, minutes, or seconds. You will see in Chapter 6 that time, as we usually think of it, is related to the apparent motions of the sun and stars.

Temperature. Through our sense of touch, we learn quite early in life that some things are hotter than others. Temperature is a measurement that tells us precisely how "hot" something is.

In this country the unit of temperature in ordinary use is the Fahrenheit degree (symbol, °F). On the Fahrenheit scale, the temperature of melting ice is 32°F and the temperature of boiling water at standard atmospheric pressure is 212°F. One Fahrenheit degree is 1/180 of the difference between those two temperatures.

In the metric system and in most scientific work, the Celsius degree is the unit of temperature (symbol, °C). On this scale the melting point of ice is 0°C and the boiling point of water is

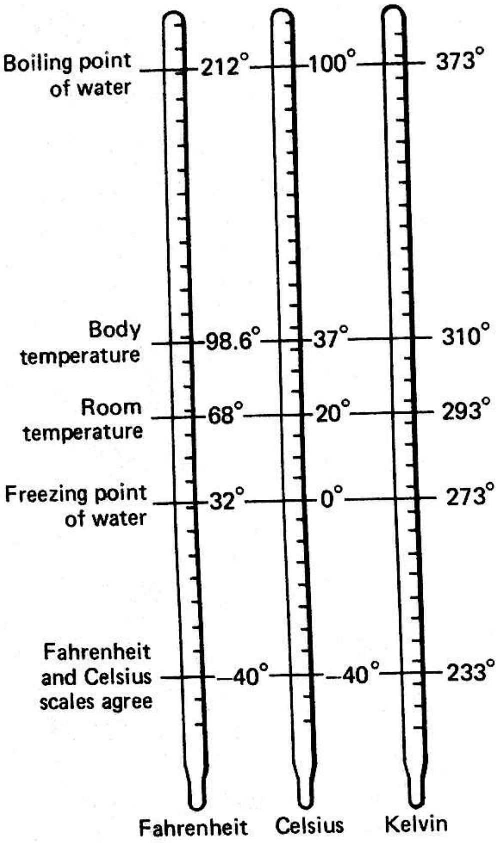


Figure 1-4. Fahrenheit and Celsius temperature scales.

100°C. One Celsius degree is 1/100 of the difference between those two temperatures.

If you live in one of the Northeastern or North Central states, you know from your own experience that temperatures can drop below zero. Temperature measurements below zero are shown as negative numbers (for example, –24°C).

There is no upper limit to temperatures. Temperatures in the interior of stars and in nuclear explosions range into the millions of degrees. There is, however, a *coldest,* or *lowest,* possible temperature. The reason for this is that objects are made colder by taking heat energy out of them. When you have taken all the heat energy they have, you cannot lower their temperatures any further. This lowest possible temperature is the same for all matter, and it is called *absolute zero.* The temperature of absolute zero is —273.16°C (which we usually round off to —273°C).

The Kelvin scale of temperatures is a scale that uses Celsius degrees, but that has its zero point at absolute zero. On the Kelvin scale, 0°K is the lowest possible temperature, the melting point of ice is 273°K, and the boiling point of water is 373°K. Any temperature in °C can be converted to °K by adding 273.

The U.S. Weather Service is still using the Fahrenheit scale in its reports to the public, but most other scientific work is expressed either in Celsius or in Kelvin units of temperature.

Percentage Error. In making any measurement, the chances are that our results will not be absolutely accurate. We can often compare our results with some standard or accepted value to see how closely they agree. But how much error can be allowed before the results become meaningless?

As you may guess, the amount of error that is acceptable varies with the situation. Suppose you measure the distance on a map between your town and the next town and you get a result of 5 miles. If the actual distance is 5½ miles, the chances are this error will have no effect on a trip between the two towns. But if the same degree of

$$\text{Percentage error} = \frac{\text{Difference between measured value and accepted value}}{\text{Accepted value}} \times 100$$

error existed in the calculations used to send astronauts to the moon, those men would be in big trouble!

The amount of error in a measurement is the difference between the values you obtain and the true or accepted values. This is commonly given as *percentage error.* The formula for calculating percentage error is shown at the top of the page.

Suppose you measured the length of a table and obtained a result of 202 cm. A friend measured the same length and obtained a result of 198 cm. To calculate the percentage error in each of these measurements, you need to know the "correct" or "accepted" value of the length of the table. Let's suppose that you have the manufacturer's catalog and you find that the table is described as 200 cm in length. This is the accepted value. The calculations of percentage error of the two measurements are shown below. You and your friend have both made an error of 1%, but yours is an error on the high side, or a positive error, while your friend's error is on the low side, or a negative error.

Rounding Measurements and Calculations. The speed limit on most highways in the United States is 55 miles per hour. One mile is exactly equal to 1.609344 kilometers. If we multiply 55 by 1.609344 to change mi/hr to km/hr, we obtain 88.51392 km/hr as the equivalent of 55 mi/hr. Does this mean that when speed limit signs become

Your % of error =

$$\frac{202 - 200}{200} \times 100 = \frac{2}{200} \times 100 = 1\%$$

Your friend's % of error =

$$\frac{200 - 198}{200} \times 100 = \frac{2}{200} \times 100 = 1\%$$

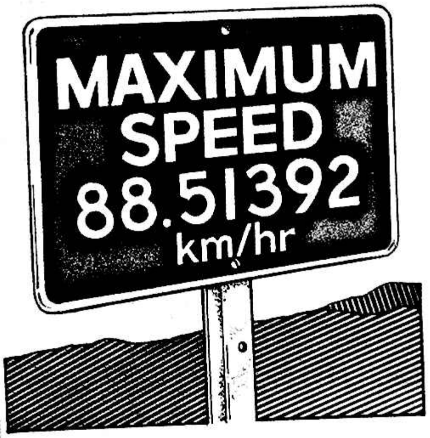


Figure 1-5. U.S. highway sign of the future?

metric they may look like Figure 1-5?

You would probably agree that expressing the speed to so many decimal places is foolish. But how far should a calculation involving measurements be carried? Percentage error can help us decide.

The speedometer in a car is not a very accurate instrument. It probably has a percentage error of about 2%. This means that if you read your speed as 55 mi/hr, your measurement may be off by about 2% either way, or about 1 mi/hr. Your true speed may be anything between 54 and 56 mi/hr. You can't improve your percentage error by changing to km/hr. Your result must still be in doubt by 2%. If you multiply 55 mi/hr by 1.6 to change to km/hr, your result will be 88 km/hr—close enough for all practical purposes. So 88 km/hr is the speed limit we would expect to find on the sign.

In auto racing, a much higher degree of precision is used in determining speeds and records. Distances and times are measured with percentage errors as little as 0.001%. Speeds are calculated to within a thousandth of a mile per hour. For example, the speed of the winner in the 1972 Indianapolis 500-mile race was calculated to be 162.962 mi/hr. To convert this speed to km/hr, we would use the exact conversion factor and carry the result to the same number of decimal places as there are in the measurement. If you do the arithmetic, you should get a result of 262.262 km/hr. It makes sense to say that a speed record of 162.962 mi/hr is equal to 262.262 km/hr. It does not make sense to say that a speed limit of 55 mi/hr is equal to 88.51392 km/hr.

The number of figures or decimal places to keep in a calculation depends on how accurate your measurements are. It is wasted time and effort to carry out calculations to more places than your data has. In your laboratory investigations, keep this idea in mind. Your measurements will usually be made to two or three figures, or with a percentage error of about 1%. When using your measurements in a calculation, you should round off your results to the same two or three figures, or the same 1% margin of error.

For example, suppose you measure a block of wood to the nearest millimeter (0.1 cm), and obtain results like these:

length = 12.4 cm
width = 6.1 cm
height = 2.7 cm

If you use these measurements to calculate the volume of the block by the volume formula

V = length X width X height

you will get a result of 204.228 cm^3. You have not really measured the volume with such high precision. Your result should be rounded to 204 cm^3. You would use the rounded result in any further calculations you need to make.

SUMMARY

1. All measurements consist of a numerical value and a unit of measurement.
2. Some units of measurement are fundamental: they are not combinations of other units. Units of length, mass, time, and temperature are examples of fundamental units. Other units are derived: they are combinations of one or more fundamental units. Units of volume and speed are examples.
3. All measurements are comparisons of the quantity being measured with a standard unit. Scientists use the metric system of standard units.
4. Weight is a measure of the pull of gravity on an object and varies with location. Mass is the amount of matter in an object and does not vary with location. (For most measurements here on earth, we can substitute weight for mass.)
5. Any measurement is an approximation and must be considered to contain some error. The amount of error is usually given as the percentage error.

REVIEW QUESTIONS

Group A

1. What is involved in a direct observation of the environment?
2. How can you increase your powers of observation?
3. Describe three situations in which the use of instruments enables you to gather more information about the environment than would be possible with your unaided senses.
4. What is meant by the term *classification?*
5. If you were given a group of objects, explain, in general terms, how you would classify them.
6. What is an *inference?*
7. What is the difference between an observation and an inference?
8. What are the two parts of all measurements?
9. What is a *fundamental* unit of measurement? Give two examples.
10. What is a *derived* unit of measurement? Give two examples.
11. What system of standard units is used by scientists?
12. What is the difference between *weight* and *mass?*
13. What is *percentage error?*

Group B

1. a. What are some limitations to your direct observations of your environment?
   b. Give an example of an observation that could be made without using an instrument, but that would be improved by using one.
   c. Give an example of an observation that could not be made without the use of an instrument.
2. Give an example, preferably from your own experience, of how a group of observations led to an inference.
3. a. List two factors that can affect the accuracy of a measurement and explain how you would attempt to control each of them.
   b. Explain how a series of measurements could be *precise,* but not *accurate.*