Chapter 1

About Science

THE MAIN IDEA

Science is the study of nature's rules

1.8 Significant Figures

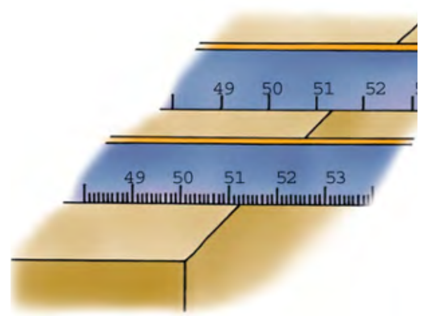
Three kinds of numbers are used in science—those that are counted, those that are defined, and those that are measured. The exact value of a counted or defined number can be stated with absolute certainty. For example, you can count the number of chairs in your classroom or the number of fingers on your hand. Your final count is 100% on the mark. (Of course, this assumes you counted correctly, which is easy when the numbers are small but not so easy when the numbers run into the millions, as occurs during an election.)

Defined numbers are about exact relationships and are defined as being true. The defined number of centimeters in a meter, the defined number of seconds in an hour, and the defined number of sides on a square are examples. Thus, defined numbers are not subject to error (unless you forget a definition).

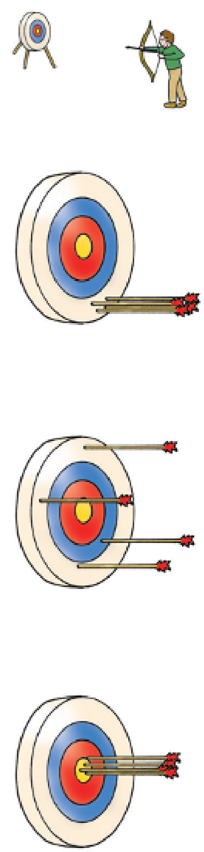
Every measured number, however, no matter how carefully measured, has some degree of uncertainty. This uncertainty (or margin of error) in a measurement can be illustrated by the two meter sticks shown in **Figure 1.15**. Both sticks are being used to measure the length of a table. Assuming that the zero end of each meter stick has been carefully and accurately positioned at the left end of the table, how long is the table?

The upper meter stick has a scale marked off in centimeter intervals. Using this scale, you can say with certainty that the length is between 51 and 52 centimeters. You can say further that it is closer to 51 centimeters than to 52 centimeters; you can even estimate it to be 51.2 centimeters.

The scale on the lower meter stick has more subdivisions—and therefore greater precision—because it is marked off in millimeters. With this scale, you can say that the length is definitely between 51.2 and 51.3 centimeters, and you can estimate it to be 51.25 centimeters. With greater precision you are able to reasonably read off more numbers.



Λ Figure 1.15
Which meter stick offers more precision?



Λ Figure 1.16

Consider archery as a model for the difference between precision and accuracy. Which shows good precision but poor accuracy? Which shows both? Which shows neither?

With both rulers there are digits that are certain and one digit (the last one) that is estimated. Note also that the uncertainty in the reading from the lower meter stick is less than the uncertainty in the reading from the upper meter stick. The lower meterstick can give a reading to the hundredths place, but the upper one can give a reading only to the tenths place. The lower one is more precise than the top one. So, in any measured number, the digits tell us the magnitude of the measurement and the location of the decimal point tells us the precision of the measurement.

Precision means close agreement in a group of measured numbers; accuracy means a measured value that is very close to the true value of what is being measured. If you measure the same thing several times and get numbers that are close to one another but are far from the true value (perhaps because your measuring device is not working properly), then your measurements are precise but not accurate. An example would be measuring your weight repeatedly on a broken scale.

Significant figures are the digits in any measured value that are known with certainty plus one final digit that is estimated and hence uncertain. These are the digits that reflect the precision of the instrument used to generate the number. They are the digits that have experimental meaning. The measurement 51.2 centimeters made with the upper meter stick in Figure 1.15, for example, has three significant figures, and the measurement 51.25 centimeters made with the lower meter stick has four significant figures. The rightmost digit is always an estimated digit, and only one estimated digit is ever recorded for a measurement. It would be incorrect to report 51.253 centimeters as the length measured with the lower meter stick. This five-significant-figure value has two estimated digits (the final 5 and 3) and is inappropriate because it indicates a precision greater than the meter stick can obtain.

CONCEPT **CHECK**

How many significant figures in a. 43,384 b. 43,084 c. 0.004308 d. 43,084.0 e. 43,000 f. 4.30×10^4

CHECK YOUR ANSWER

a. 5 b. 5 c. 4 d. 6 e. 2 f. 3

In addition to the rules cited on the next page, there is another full set of rules to be followed for significant figures when two or more measured numbers are subtracted, added, divided, or multiplied. Briefly, you can never gain significant figures. You can only lose them. Thus, your final answer should contain no more precision (significant figures) than with what you started. This is explored further within the *Conceptual Chemistry* video on significant figures.

Here are some standard rules for writing and using significant figures.

RULE 1
In numbers that do not contain zeros, all the digits are significant:

4.1327	five significant figures
5.14	three significant figures
369	three significant figures

RULE 2
All zeros between significant digits are significant:

8.052	four significant figures
7059	four significant figures
306	three significant figures

RULE 3
Zeros to the left of the first nonzero digit serve only to fix the position of the decimal point and are not significant:

0.0068	two significant figures
0.0427	three significant figures
0.0003506	four significant figures

RULE 4
In a number that contains digits to the right of the decimal point, zeros to the right of the last nonzero digit are significant:

53.0	three significant figures
53.00	four significant figures
0.00200	three significant figures
0.70050	five significant figures

RULE 5
In a number that has no decimal point and that ends in one or more zeros, the zeros that end the number are not significant. (To scientists, the decimal point is very important. Its presence or absence has great implications in regard to the precision of a measurement.)

3600	two significant figures
290	two significant figures
5,000,000	one significant figure
10	one significant figure
6050	three significant figures

RULE 6
When a number is expressed in scientific notation, all digits in the coefficient are taken to be significant:

4.6×10^{-5}	two significant figures
4.60×10^{-5}	three significant figures
4.600×10^{-5}	four significant figures
2×10^{-5}	one significant figure
3.0×10^{-5}	two significant figures
4.00×10^{-5}	three significant figures

Calculation Corner: Unit Conversion

Often in chemistry, and especially in a laboratory setting, it is necessary to convert from one unit to another. This process is called "unit conversion" or sometimes as "unit analysis" or "dimensional analysis".

To convert from one unit to another, you need only multiply the given quantity by a conversion factor. A conversion factor is a ratio where the numerator and denominator represent the equivalent quantity expressed in different units. Because any amount divided by the same amount is equal to one, all conversion factors are effectively equal to one. For example, the following two conversion factors are both derived from the relationship 100 centimeters = 1 meter. Note that the numerator and denominator represent the same distance, but expressed in different units.

$$\frac{100 \text{ centimeters}}{1 \text{ meter}} = 1 \qquad \frac{1 \text{ meter}}{100 \text{ centimeters}} = 1$$

Because all conversion factors are effectively equal to 1, multiplying a quantity by a conversion factor does not change the value of the quantity. What does change are the units. Suppose you measured an item to be 60 centimeters in length. You can convert this measurement to meters by multiplying it by the conversion factor that allows you to cancel centimeters.

$$\underset{\substack{\uparrow \\ \text{quantity} \\ \text{in centimeters}}}{(60 \text{ centimeters})} \; \underset{\substack{\uparrow \\ \text{conversion} \\ \text{factor}}}{\frac{(1 \text{ meter})}{(100 \text{ centimeters})}} = \underset{\substack{\uparrow \\ \text{quantity} \\ \text{in meters}}}{0.6 \text{ meter}}$$

You can create two conversion factors for every equality. For example, from **Table 1.2** we see that 1 kilometer equals 0.621 miles. To create these two conversion factors, show a unit as the numerator in one conversion factor but as a denominator in the other:

1 km / 0.621 mi 0.621 mi / 1 km

Multiply the quantity provided to you by the conversion factor of choice, which is the one that shows the original unit in the denominator. This way, the original unit will be canceled, leaving you with the desired new unit. The following example starts with 26.2 miles. To convert this to kilometers, we multiply by appropriate conversion factor, which has miles in the denominator. This allows for the units of miles to cancel. The result is the same quantity expressed in units of kilometers. This calculation tells us that a distance of 26.2 miles is the same as 42.2 kilometers.

(26.2 miles) (1 km/0.621 miles). =. 42.2 km

Always be careful to write down your units. They are your ultimate guide, telling you what numbers go where and whether you are setting up the equation properly. Remember, you should set up a conversion factor so that the desired unit is always in the numerator and the unit to be cancelled is always in the denominator.

Conversion factors can be combined to allow multiple conversions in a single equation.

EXAMPLE

How many pounds are there in 48 ounces? Set up a string of conversion factors using data from Tables 1.2 and 1.3.

ANSWER

Start by writing down the given quantity, which in this case is 48 ounces. Multiply by a series of conversion factors to transform this quantity into the desired unit—from ounces to grams, from grams to kilograms, and then from kilograms to pounds:

$$(48\ \text{oz})\left(\frac{28.345\ \text{g}}{1\ \text{oz}}\right)\left(\frac{1\ \text{kg}}{1000\ \text{g}}\right)\left(\frac{2.205\ \text{lbs}}{1\ \text{kg}}\right) = 3\ \text{lbs}$$

Of course, the above conversion could be done in a single step knowing that 16 ounces equals 1 pound. A string of conversion factors in a single equation, however, becomes quite useful when the direct conversion factor is unknown.

YOUR TURN

Multiply each physical quantity by the appropriate conversion factor to find its numerical value in the new unit indicated. You will need paper, a pencil, a calculator, and Tables 1.2 and 1.3.

a. Show that 7320 grams is 7.32 kilograms
b. Show that 235 kilograms is 518 pounds
c. Show that 4585 milliliters is 4.846 quarts
d. Show that 100 calories is 0.1 kilocalories
e. Show that 100 calories is 400 joules

Perhaps you are wondering about how many digits to include after you calculate a conversion. Were you perplexed, for example, that the answer to (e) is 400 J and not 418.4 J? Key is that after multiplying or dividing you should never end up with more significant figures than you started with. For example, the number 100 has only one significant figure. Multiplying any number by 100 will give a product that will also have but one significant figure.