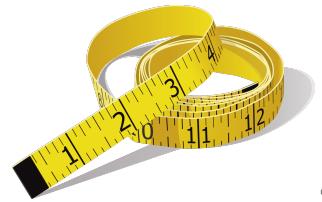


# 1

## Measurements

**M**EASURING is an important part of our everyday lives, and very probably you took several measurements today. You might now be sipping a cup of coffee, or perhaps you checked the outside temperature on a street thermometer. You might be planning to bake a cake and need to use a scale and a cup to measure the flour and sugar. A cup, a thermometer, or a scale are measuring devices. It is critical to know how to accurately measure properties and, more importantly, how to transform measurements using prefixes and unit conversions. By learning how to measure and perform operations with units, you will gain experience performing basic chemistry calculations.



### 1.1 Units of Measurements and systems of units

You probably heard the term liter, kilogram or meter. These are units of measurement. Units can be classified into different *systems of units*. For example, the unit *meter* belongs to a different system than the unit *mile*. In particular, here we will address three main systems: the English System, the Metric System, and the International system. The *Metric System* (MS) is used by scientists throughout the world and is the most common measuring system based on the meter. The English system is mostly used in the US. The *International System of Units* (SI) adopted the metric system in 1960 to provide additional uniformity for units used in the sciences. Table 1.1 summarizes some of the fundamental units for the three systems. This chapter will be mostly based on the SI units. In the following, we will introduce some common units.

*Length* What is your height? Length refers to distance and both the metric and SI unit of length is the meter (m). A smaller unit of length would be the centimeter (cm) that is commonly used in chemistry. The most important units of length are: meter, inch and mile.

*Mass* What is your weight? The mass of an object is a measure of the quantity of material it contains. You may be more familiar with the term weight than with mass. However, mass and weight are not exactly the same, as weight is a measure of the gravitational pull on an object. It differs depending on your location in the earth—in particular the height of your location. In the metric system, the unit for mass is the gram (g). The SI unit of mass, the kilogram (kg), is used for larger masses such as body weight. Pound, lb, is another unit of mass. The most important units of mass are: g, kg and lb.

*Temperature* How is the weather today? Is it cold or hot? You use a thermometer to measure temperature and for example assess how hot an object is, or how cold it is

▼Scales measure mass



© www.wallpaperflare.com

▼Watches are used to measure time



© www.wallpaperflare.com

▼Beakers can carry a liquid volume



© wikipedia

▼Thermometers measure temperature



© Pixabay

▼pipets are used in chemistry practice to add an exact volume of liquid



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outside, or perhaps to determine if you have a fever. Temperature tells us how hot or cold an object is. Temperature can be measured in numerous units such as Celsius ( $^{\circ}\text{C}$ ), Fahrenheit ( $^{\circ}\text{F}$ ), or kelvins (K).

**Time** How long is your commute to from home work? It might take you hours to go to work, or maybe minutes. You probably think of time as years, days, minutes, or seconds. Of all these units, the International System of units (SI, abbreviated from the French Système international) uses seconds (s) to measure time. Still, time can be measured in s, min, or h and during this chapter we will learn how to convert units of time.

**Volume** How much milk do you usually buy? Maybe a gallon. Volume is the amount of space that a substance occupies. A liter (L), not a fundamental but a derived SI unit, is commonly used to measure volume. The milliliter (mL) is more convenient for measuring smaller volumes of fluids in hospitals and laboratories. Gallon is still used in every-day life. L, mL and gallon are units of volume. Units of volume are in general cubic units, so for example one liter is the same as one  $\text{dm}^3$ . We will cover cubit units further in this chapter. Chemical laboratory work commonly require the measurement of volume. There are two main type of glassware used to measure volume in a chemistry lab: graduated tools and volumetric tools. Volumetric pipets, flasks and burets are the most accurate; the glassware makers calibrate these to a high level of accuracy, usually measured in terms of the tolerance, which is the uncertainty in a measurement made with the glassware. Class A volumetric glassware has a lower tolerance than Class B; for class A, the tolerance can be as low as 0.08 ml for a 100 ml flask or pipet. Generally, measurements with class A volumetric glassware can be considered reliable to two places after the decimal point. Graduated cylinders, beakers and Erlenmeyer flasks have less accuracy than volumetric glassware. Graduated cylinders can generally be considered reliable to within 1 percent. Beakers and Erlenmeyer flasks should not be used to measure volume unless you need only a very crude estimate because their accuracy for volume measurements is so poor. They can hold a much larger volume than any of the other types of glassware, however, which makes them useful for mixing solutions.

**Concentration** Even though we will devote a whole chapter to solutions and concentration, it felt important to introduce here the unit molarity. In chemistry, the unit molarity (M) refers to the concentration of a solution. That is the larger this number, the larger molarity, the more concentrated a solution will be. In other words, there will be more substance in the solution.

### Sample Problem 1

State the type of measurement indicated in each of the following:

- (a) 1ft (foot)      (b) 20Kg      (c) 3L      (d) 300K

#### SOLUTION

- (a) length; (b) mass; (c) volume; (d) temperature;

#### ❖ STUDY CHECK

State the type of measurement indicated in each of the following: (a)  $800^{\circ}\text{F}$   
(b)  $1\text{m}^3$  (c) 3m (d) 67s

**Table 1.1 Different unit systems**

Measurements	Metric System	International System (SI)	English System
Length	Meter (m)	Meter (m)	Foot (ft)
Mass	Gram (g)	Kilogram (kg)	Pound (lb)
Time	Second (s)	Second (s)	Second (s)
Temperature	Celsius ( $^{\circ}$ C)	Kelvin (K)	Fahrenheit ( $^{\circ}$ F)
Volume*	Liter (L)	Cubic meter ( $m^3$ )	Gallon (gal)
Amount of substance	Mole (mol)	Mole (mol)	Mole (mol)
Electric current	Ampere (A)	Ampere (A)	Ampere (A)

\*Not a fundamental unit

## 1.2 Scientific notation

Numbers in science can often be very large or tinny numbers. For example, the mass of the earth is 59000000000000000000000000000000 grams, whereas the size of an atom is of the order 0.0000000001cm. Scientific notation is a standard notation extensively used among the scientific community to simplify numbers. Numbers not expressed in scientific notation are referred to as numbers in full notation (e.g. 0.234g). Numbers expressed in scientific notation place the decimal after the first significant digit while being accompanied by a power of ten (e.g.  $2.34 \times 10^{-1}$ g). In order to express a number (e.g. 345000g) in scientific notation, we just need to leave the first digit followed by the decimal point which was moves in this case to the left 5 places, giving  $3.45 \times 10^5$ g. The power of ten can contain a positive or a negative exponent. Positive exponents represent large numbers, whereas negative exponents represent numbers smaller than 1. Below are two examples of full and scientific notation. On one hand a number smaller than one:

$$0.000134\text{g} \quad (\text{full notation}) \quad 1.34 \times 10^{-4}\text{g} \quad (\text{scientific notation})$$

On one hand a number smaller than one:

$$4500000\text{g} \quad (\text{full notation}) \quad 4.5 \times 10^6\text{g} \quad (\text{scientific notation})$$

## 1.3 Prefixes & Conversion Factors

Let's consider the following measurements: 1 km, 2 cm, and 3 m that can be read as one kilometer, two centimeters, and three meters. The word kilo (**k**) and centi (**c**) are called prefixed whereas meter (m) is a simple unit. Kilometer is larger than meter, whereas centimeter is smaller than a meter. Prefixes such as kilo or centi are attached to units in order to make numbers more manageable. For example, the radius of the earth is 6356 km, and this number is easier to handle than 6356000m. At the same time, we can attach any prefix to different units. Hence, we can talk about a centimeter (**cm**) but also about a centisecond (**cs**) or centiliter (**cL**). All these units have the same prefix. Table 1.1 lists some of the metric prefixes, their symbols, and their decimal values.

*How to identify prefixes?* Look for example at the measurement 2 cm. Centi (**c**) is the prefix and means  $1 \times 10^{-2}$  and meter (m) is the unit which refers to length.

Another example, 7 kg means kilogram. Kilo (k) is the prefix and means  $1 \times 10^3$ , whereas gram (g) is the unit that refers to mass. The prefix refers to the first letter whereas the unit refers to the last letter.

Would you prefer to be paid a kilodollar, a dollar or a centidollar? A unit with a prefix can be bigger or smaller than the plain unit—this is the unit without prefix—, depending on the prefix. The following prefixes make the unit smaller: deci, centi, milli, micro, nano, pico and femto. For example a fs (femtosecond) is smaller than a s (second). Differently, the following prefixes make the unit larger: Tera, Giga, Mega. For example a Tb (terabyte) is larger than a b (byte). byte is a unit used in computer science.

**Table 1.2 Different prefixes**

Prefix	Symbol	Meaning	Value
exa	E	$10000000000000000000$	$1 \times 10^{18}$
peta	P	$1000000000000000000$	$1 \times 10^{15}$
tera	T	$10000000000000$	$1 \times 10^{12}$
giga	G	$1000000000$	$1 \times 10^9$
mega	M	$1000000$	$1 \times 10^6$
kilo	k	$1000$	$1 \times 10^3$
hecto	h	$100$	$1 \times 10^2$
deca	da	$10$	$1 \times 10^1$
—	—	$1$	$1 \times 10^0$
deci	d	$0.1$	$1 \times 10^{-1}$
centi	c	$0.01$	$1 \times 10^{-2}$
milli	m	$0.001$	$1 \times 10^{-3}$
micro	$\mu$	$0.00001$	$1 \times 10^{-6}$
nano	n	$0.000000001$	$1 \times 10^{-9}$
pico	p	$0.000000000001$	$1 \times 10^{-12}$
femto	f	$0.000000000000001$	$1 \times 10^{-15}$
atto	a	$0.000000000000000001$	$1 \times 10^{-18}$

*How to write unit equalities and conversion factors* Unit equalities are simple expressions that relate a unit with a unit with prefix. For example: one centimeter (cm) is  $1 \times 10^{-2}$ m. Hence we can write this as a unit equality:

$$1\text{cm} = 1 \times 10^{-2}\text{m} \quad \text{unit equality}$$

Let's compare cm and m. The first, cm, is a unit with a prefix, whereas m is simple a unit of length without a prefix. In order know how many m are there in a cm we need to write down a conversion factor. Think about prefixes as synonymous of a number. In this way, centi stands for  $1 \times 10^{-2}$ , so

$$\frac{1\text{cm}}{1 \times 10^{-2}\text{m}} \quad \text{or} \quad \frac{1 \times 10^{-2}\text{m}}{1\text{cm}} \quad \text{conversion factor}$$

The relationship above is also called a *unit factor* as both ratios equal to one.

### Sample Problem 2

Complete each of the following equalities and conversion factors:

$$(a) 1\text{dm} = \underline{\hspace{2cm}} \text{m} \qquad (c) \underline{\hspace{2cm}} \text{nm} = \underline{\hspace{2cm}} \text{m}$$

$$(b) 1\text{km} = \underline{\hspace{2cm}} \text{m} \qquad (d) \underline{\hspace{2cm}} \text{m} = \underline{\hspace{2cm}} \text{cm}$$

**SOLUTION**

(a)  $1\text{dm} = 1 \times 10^{-1}\text{m}$ ; (b)  $1\text{km} = 1 \times 10^3\text{m}$ ; (c)  $\frac{1\text{nm}}{1 \times 10^{-9}\text{m}}$ ; (d)  $\frac{1 \times 10^{-2}\text{m}}{1\text{cm}}$ ;

**❖ STUDY CHECK**

Second is a unit of time. Complete each of the following equalities and conversion factors involving seconds:

(a)  $1\text{cs} = \underline{\hspace{2cm}}\text{s}$  (b)  $\underline{\hspace{2cm}}\text{s} = 1\text{Ts}$  (c)  $\underline{\hspace{2cm}}\text{s} = 1\text{Ms}$

## 1.4 Using Conversion Factors

Unit equalities in the form of conversion factors are used to convert a unit into another. Sometimes one wants to get rid of a prefix, such as when we transform centimeter (cm) into meter (m). Sometimes, one wants to convert a prefix into another prefix. An example would be converting centimeters (cm) to millimeters (mm). Let's work on some example.

*Removing or adding prefixes* Imagine that you need to remove a prefix from a unit, and convert 3 km (we will call this one the original unit) in meters (this is the final unit). First, you would need the conversion factor corresponding to the prefix (centi) from Table 1.2. Then you need to arrange the conversion factor placing the prefix at the bottom of the fraction. This will cancel out the prefix in the original unit and in the bottom part of the conversion factor, hence leaving the final unit on top of the conversion factor. The arrangement would be:

$$3\cancel{\text{km}} \times \frac{1 \times 10^3\text{m}}{1\cancel{\text{km}}} = 3000\text{m}$$

Imagine now that you need to add a prefix into a unit, and convert 4000 m in km. The same would apply for this case, but now you will have to arrange the conversion factor so that the prefix is on the top:

$$4000\cancel{\text{m}} \times \frac{1\text{ km}}{1 \times 10^3\cancel{\text{m}}} = 4\text{km}$$

### Sample Problem 3

The length of a textbook page is 20cm. Convert 20cm to meters, expressing the result in scientific notation.

**SOLUTION**

In order to convert 20cm into meters, we need to remove the prefix (centi) leaving the unit (meter) without any prefix. We will use the conversion factor that relates m to cm:  $\frac{1 \times 10^{-2}\text{m}}{1\text{cm}}$  or  $\frac{1\text{cm}}{1 \times 10^{-2}\text{m}}$ . We will arrange the conversion factor so that cm cancels giving m and hence we will use  $\frac{1 \times 10^{-2}\text{m}}{1\text{cm}}$ :

$$20\cancel{\text{cm}} \times \frac{1 \times 10^{-2}\text{m}}{1\cancel{\text{cm}}} = 2 \times 10^{-1}\text{m}$$

The original units and on the bottom of the conversion factor cancel and we get meters, the final unit.

 **STUDY CHECK**

Convert 100m to km, expressing the result in scientific notation.

*Switching prefixes* In order to switch a prefix into another prefix, such as transforming 30 millimeters (30 mm) into centimeters (cm), you will need two different conversion factors: the first conversion factor will remove the original unit (mm) introducing an intermediate unit, meters (m), whereas the second conversion factor will remove the intermediate meter and introduce the final unit (cm). You will get the conversion factors from Table 1.2. You will arrange the first conversion factor so that the original unit cancels out with the bottom of the first conversion factor, giving you an intermediate unit. You will arrange the second conversion factor so that the intermediate unit cancels out with the bottom of the second conversion factor giving the final unit. For this example:

$$30\text{mm} \times \frac{1 \times 10^{-3}\text{m}}{1\text{mm}} \times \frac{1\text{cm}}{1 \times 10^{-2}\text{m}} = 3\text{cm}$$

**Sample Problem 4**

The length of a textbook page is 20cm. How many mm correspond this length, expressing the result in scientific notation.

**SOLUTION**

We want to convert 20 cm into mm, that is, we are switching prefixed. In order to do this, you need two conversion factors:  $\frac{1 \times 10^{-2}\text{m}}{1\text{cm}}$  and  $\frac{1 \times 10^{-3}\text{m}}{1\text{mm}}$ . You will have to arrange the number (20cm) and the two conversion factors in the following form:

$$20\text{cm} \times \frac{1 \times 10^{-2}\text{m}}{1\text{cm}} \times \frac{1\text{mm}}{1 \times 10^{-3}\text{m}} = 2 \times 10^3\text{mm}$$

 **STUDY CHECK**

Convert 100mm to km, expressing the result in scientific notation.

*Square or cubic units* How big is your apartment? You might be living in a  $750\text{ft}^2$  loft in Brooklyn or in a larger house Upstate. Often times we encounter cubic or square units such as cubic centimeter ( $\text{cm}^3$ ) or square feet ( $\text{ft}^2$ ). The equivalencies for cubic or square units should take into account the unit power (power of two or power of three). If  $1\text{cm} = 1 \times 10^{-2}\text{m}$ , for square units the relation should be squared and  $1\text{cm}^2 = 1 \times (10^{-2})^2\text{m}^2 = 1 \times 10^{-4}\text{m}^2$ . Another example, for the case of mm and  $\text{mm}^3$ :

$\frac{1\text{mm}}{1 \times 10^{-3}\text{m}}$	and	$\frac{1\text{mm}^3}{1 \times 10^{-9}\text{m}^3}$
---	-----	---

Let us work on an example in which we want to convert  $30\text{m}^2$  into  $\text{m}^2$ :

$$30\text{m}^2 \times \frac{1\text{cm}^2}{1 \times 10^{-4}\text{m}^2} = 3 \times 10^5\text{cm}^2$$

**Sample Problem 5**

How many  $m^2$  is  $20cm^2$ , expressing the result in scientific notation.

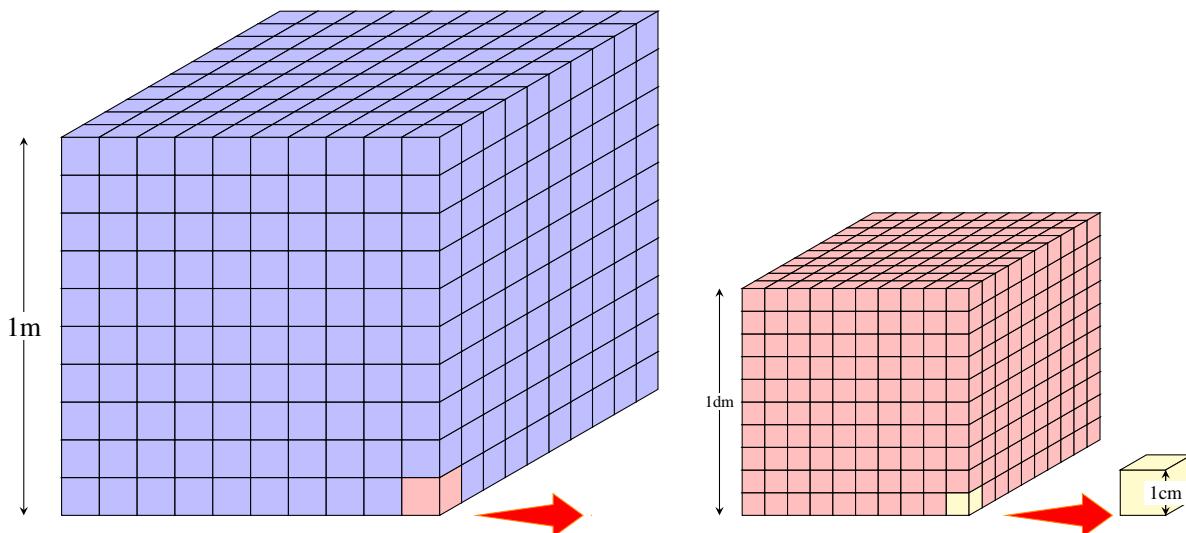
**SOLUTION**

In order to convert  $20cm^2$  to square meters, we need to remove the centi prefix and that will give us the unit square meter without any prefix. We will use the conversion factor that relates  $m^2$  to  $cm^2$ :  $\frac{1 \times 10^{-4}m^2}{1cm^2}$  or  $\frac{1cm^2}{1 \times 10^{-4}m^2}$ .

$$20cm^2 \times \frac{1 \times 10^{-4}m^2}{1cm^2} = 2 \times 10^{-3}m^2$$

**◆ STUDY CHECK**

Convert  $100m^3$  to  $dm^3$ , expressing the result in scientific notation.



**Figure 1.1** The left cube with a side of 1m has a volume of  $1m^3$ . The central cube with a side of 1dm has a volume of  $1dm^3$ , that is 1L. The right cube with a side of 1cm has a volume of  $1cm^3$ , that is 1mL.

**Units of volume** Units such as L or mL are units of volume. As volume is a three-dimensional property, those units somehow have to be related to the units of length. In fact one liter is the same as one  $dm^3$  and one mL is the same as one  $cm^3$  (See Figure 1.1). In the allied health field, the units mL is also written as cc as in cubic centiliters.

$$1L = 1dm^3 \text{ and } 1mL = 1cm^3$$

Let us work on an example in which we want to convert  $30cm^3$  into L:

$$30cm^3 \times \frac{1mL}{1cm^3} \times \frac{1 \times 10^{-3}L}{1mL} = 3 \times 10^{-2}L$$

**Sample Problem 6**

Convert  $30 m^3$  into L, expressing the result in scientific notation.

**SOLUTION**

In order to convert  $m^3$  into L we just need to remember that the L actually refers to  $dm^3$ , therefore is connected to meter. We will first convert  $m^3$  into  $dm^3$  and

then  $dm^3$  into L.

$$30m^3 \times \frac{1dm^3}{1 \times 10^{-3}m^3} \times \frac{1L}{1dm^3} = 3 \times 10^4 L$$

#### ◆ STUDY CHECK

Convert 40L to  $cm^3$ , expressing the result in scientific notation.

**Table 1.3 Table containing some common unit equalities**

Unit	Equality
Inches (in)-centimeters (cm)	2.54 cm = 1 in
miles (mi)-meters (m)	1 mi = 1609.34m
minutes (min)-hours (h)	60 min = 1 h
minutes (min)-seconds (s)	60 s = 1 min
pound (lb)-grams (g)	454 g = 1 lb
cubic centimeter ( $cm^3$ )-mililiters (mL)	1 mL = 1 $cm^3$
Liter (L)-cubic decimeters ( $dm^3$ )	1 L = 1 $dm^3$
drops-mililiters* (mL)	1 mL = 15 drops

\* There are several definitions of a drop

*Using other equalities* How many hours is 300 minutes, or how many centimeters is 2 inches? Some of the units conversion are not based on a power of ten relationship and do not contain prefixes such as kilo or centi. Table 1.3 lists some of the common equalities that can be easily converted into conversion factor. As an example, the unit equivalency between hours and minutes is  $60\text{min} = 1\text{h}$  and the conversion factor would be  $\frac{60\text{min}}{1\text{h}}$  or  $\frac{1\text{h}}{60\text{min}}$ .

#### Sample Problem 7

Convert 20 in to cm, expressing the result in scientific notation.

#### SOLUTION

We want to convert 20 inches into centimeters. The relationship between Inch and centimeter is given in Table 1.3. In order to do this, you need the conversion factor:  $\frac{1\text{in}}{2.54\text{cm}}$  or  $\frac{2.54\text{cm}}{1\text{in}}$ . You will have to arrange the number (20 in) and the conversion factor in the following form:

$$20\cancel{\text{in}} \times \frac{2.54\text{cm}}{1\cancel{\text{in}}} = 5.080 \times 10^1 \text{cm}$$

#### ◆ STUDY CHECK

Convert 200mL to drops, expressing the result in scientific notation.

## 1.5 Measurements and uncertainty

Most chemistry experiments require the measurement of a property (mass, volume, temperature, color...), and the validity of those experiments will depend on the reliability of each measurement. The reliability of a measurement is usually considered in terms of its

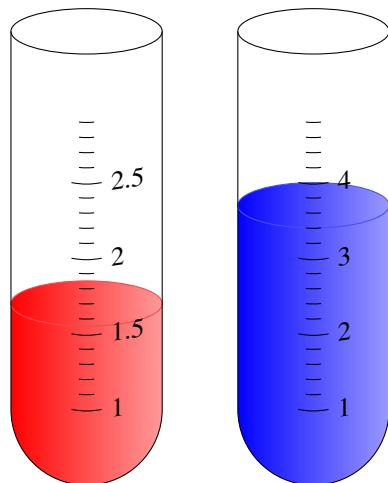
*accuracy* and its *precision*. At the same time, when performing an experiment often times, one needs to repeat measurements. The results need to take into account the average measurement as well as the standard derivation of the series of results.

*Uncertain and certain digits: how to report measured numbers*

Consider the volume as measured in the glassware on the left side of Figure 1.2. Some would say the liquid meniscus occurs at 1.52mL. Mind we need to estimate the last number by interpolating between the 0.1mL marks. As the last digit of the number associated with the volume measurement is estimated, another person could measure the volume as 1.53mL. The table below indicates the measurements of five different people.

Person	Volume(mL)
1	1.52
2	1.53
3	1.51
4	1.57

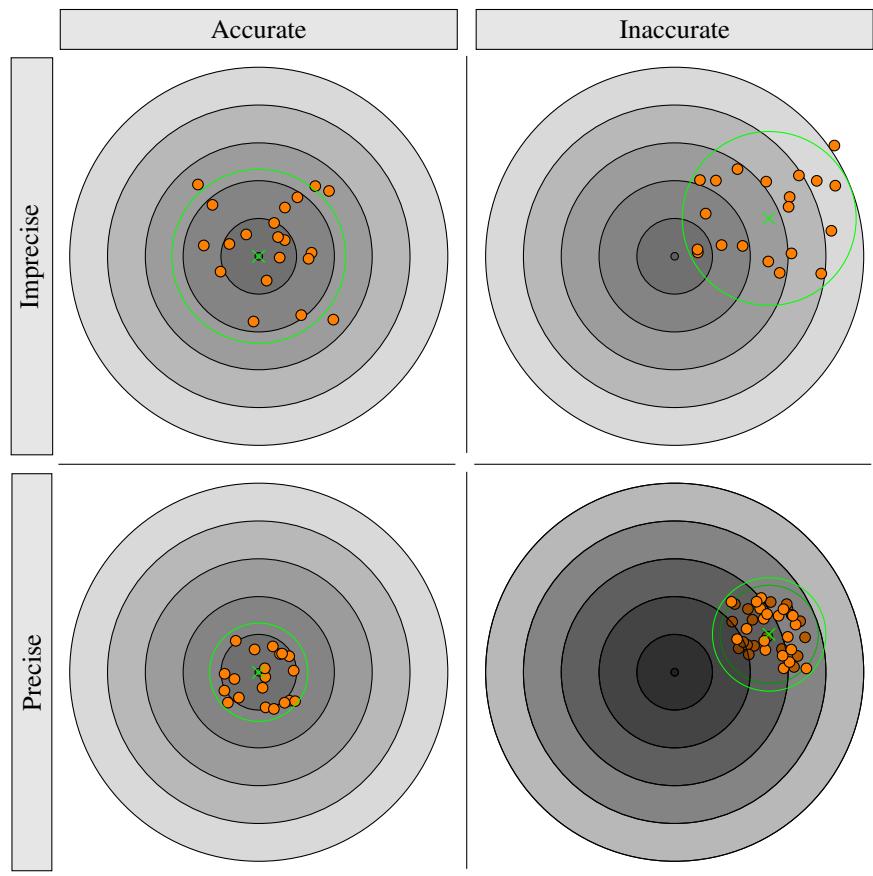
All measurements have in common the 1.5 part. The digit 5 is called a certain digit. The digit to the right of 5 is called the uncertain digit, as in a measurement it needs to be estimated. When reporting a measurement, we need to report up to the uncertain digit. These numbers on measurement are called *significant figures*. It is important to understand that all measured properties are subject to uncertainty. Uncertainty depends on one hand on the measuring device. The uncertainty on the left meniscus in Figure 1.2 is on the hundreds of the mL, whereas on the right meniscus occurs on the tenths of mL. Uncertainty also depends on the measurement process. As the uncertain digit needs to be reported in every measurement, the uncertainty on the last number on measurement is normally assumed to be  $\pm 1$ . For example, the right meniscus should be reported as  $1.52 \pm 1\text{mL}$



**Figure 1.2** Two measuring devices. (Left side) The measuring device gives volumes to the hundredth place. (Right side) The measuring device gives volumes to the tenth place.

*Precision and accuracy* The terms precision and accuracy are two different terms often used to describe the reliability of measurement. Accuracy refers to the degree of agreement between the measured value and the true value, the real value of the property measured. Measurements that closely agree with the true value are accurate. Precision refers to the agreement between several measurements. Two measurements are accurate when they are close, independently of the true value of the property measured. Two different types of errors occur during a measurement. On one hand, random error refers to the fact that measured values can be above or below the

true value. On the other hand, systematic error is an error that occurs each time in the same direction. Figure 1.3 displays accurate and inaccurate measurements as well as precise and imprecise measurements.



**Figure 1.3** (Top Left) An accurate but imprecise measurement (Top Right) An inaccurate and imprecise measurement (Top Left) An accurate and precise measurement (Bottom Right) An inaccurate but precise measurement

## 1.6 Significant Figures

Exact numbers result from counting. For example, think about how many eggs are there in your refrigerator, there might be three and this number is an exact number. Differently, numbers that result from a measurement are called measured values and they are subject to uncertainty—in another words error. For example, if you weight a single egg in a scale depending of the type of scale you used you will measure 70g or 71g or maybe 70.8g. The mass of an egg is a measured property and hence some of the digits of the measurement are uncertain. The goal of this section is, given a value, calculate the number of significant figures of a number (we will refer to significant figures as SF, or SFs). Another goal is to estimate significant figures in calculation in order to express the result with the right number of digits and significant figures.

*Significant figures of numbers* In general all numbers different than zero are significant and for example the number 123 has three significant figures. Similarly,

the number 45 has two significant figures. Zeros are also significant except when:

**P Exception 1** A zero is not significant when placed at the beginning of a decimal number.

For example, the number 0.123 has three significant figures, as the first zero is not significant. Similarly, the number 0.002340 has four significant figures as the first three zeros are not significant but the last zero it is. Mind the rule affects only the zeros at the beginning. A final example:

$$0.032 \text{ (2SF)}$$

**P Exception 2** A zero is not significant when used as a placeholder in a number without a decimal point.

For example, the number 1000 has only one significant figure, and the number 3400 has two. Let us consider more examples. The number 120 has two significant figures, as according to the second rule the last zero is not significant. Differently, the number 1203 has four significant figures, as the zero in between two numbers is not affected by neither the first nor the second rule. A final example,

$$3200 \text{ (2SF)}$$

**P Exception 3** A zero in a number expressed on scientific notation is significant

For example the zero in  $3.0 \times 10^{-2}$  is significant, and the number has 2SFs. A final example:

$$3.2020 \times 10^2 \text{ (5SF)}$$

### Sample Problem 8

Indicate the number of significant figures in the following numbers: 123, 4567, 1200, 340, 0.001, 0.023 and 0.0405.

#### SOLUTION

123 has three significant figures, whereas 4567 has four SF. 1200 has only 2SF as the last two zeros are not significant, and 340 has only 2SF as the last zero is not significant. 0.001 has only one significant figure as the first 3 zeros are not significant and 0.023 has only two SFs. Finally, 0.0405 has three SFs as the first two zeros are not significant but the zero between 4 and 5 is indeed significant.

#### ❖ STUDY CHECK

Indicate the number of significant figures (SFs) in the following numbers: 4560, 0.123, 1000 and 0.0030.

*Significant figures in calculations* There are two different rules that allow you to express the result of a calculation with the correct number of figures.

**P Rule 1 (+ –)** For additions or subtractions, the results has the same number of decimal places as the number with the least decimal places in the calculation. For example:

$$34.3451 + 34.5 = 68.8 \text{ (+ – less decimals)}$$

If you add  $34.3451 + 34.5$  you will obtain 68.8451, however, as 34.3451 has four decimal places (4DP) and 34.5 has one decimal place (1DP), the result of adding both numbers will have to have only one decimal place, therefore 68.8451 needs to be rounded to 68.8 (1DP). Overall, we have:

$$34.3451 \text{ (4DP)} + 34.5 \text{ (1DP)} = 68.8 \text{ (1DP)}$$

**¶ Rule 2 ( $\times \div$ )** For multiplications and divisions, the number of significant figures of the result should be the same as the least number of significant figures involved. For example, if you carry the following multiplication:

$$4500 \times 342 = 1500000 (\times \div \text{less SFs})$$

the number 4500 (2SF) has two significant figures, whereas the number 342 (3SF) has three significant figures. If we multiply both numbers the results should contain just two significant figures. The result of multiplying  $4500 \times 342$  is 1539000 (4SF), however, this number needs to be rounded into two significant figures into 1500000 (2SF). Overall we have:

$$4500 \text{ (2SF)} \times 342 \text{ (3SF)} = 1500000 \text{ (2SF)}$$

### Sample Problem 9

Do the following calculation with the correct number of figures.

$$\begin{array}{r} 88.5 - 87.57 \\ \hline 345.13 \times 100 \end{array}$$

#### SOLUTION

We will analyze each number indicating the number of SF and Digits (DP): 88.5(3SF, 1DP), 87.57(4SF, 2DP), 345.13(6SF, 2DP) and 100(1SF, 0DP). The result of doing the addition needs to be rounded to one single decimal place:  $88.5 - 87.57 = 0.93 \simeq 0.9$ . After that we have only multiplications and divisions and hence we will now focus on the number of SFs:

$$\begin{array}{r} 0.9 \text{ (1SF)} \\ \hline 345.13 \text{ (5SF)} \times 100 \text{ (1SF)} \end{array}$$

The result of this operation needs to be rounded to one SF:

$$\frac{0.9}{345.13 \times 100} = 2.6077 \times 10^{-5} \simeq 3 \times 10^{-5} \text{ (1SF)}$$

#### ❖ STUDY CHECK

Do the following calculation with the correct number of figures:  $(24.56 + 2.433) \times 0.013$

*Rounding* The following rules indicate how to round numbers:

**¶ Rule 1** If the digit to be removed is less than 5 then the preceding digit stays the same. For example, 1.123 rounds to 1.12.

**¶ Rule 2** If the digit to be removed is more or equal than 5 then the preceding digit is increased by one. For example, 1.126 rounds to 1.13

**¶ Rule 3** When rounding to a specific number of significant figures we need to look only to the first number to the right of the last significant figure. For example, 1.126 rounds to two SF as 1.1

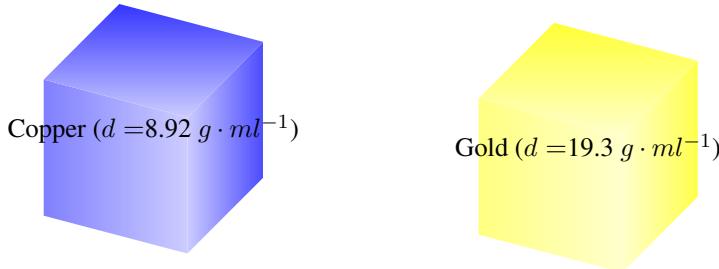
Now, let us analyze a few useful cases. Imagine we need to round the number 1234cm to two SF. The results would be 1200cm. Similarly, imagine we need to round the number 0.01264cm to two SF. The results would be 0.013cm.

## 1.7 Density

Density refers to the mass of a substance with respect to its volume. This is a unique property for each substance. Indeed, density is often used as an identification tag. The formula for density is

$$\text{Density} = \frac{\text{Mass of substance}}{\text{Volume of substance}} \quad (1.1)$$

For example, the density for copper is  $8.92 \text{ g} \cdot \text{ml}^{-1}$  and for gold is  $19.3 \text{ g} \cdot \text{ml}^{-1}$ . By measuring density only, you would be able to differentiate copper from gold. The larger density the more compact is an object and that means the more mass per volume it has. At the same time, for the same volume, the larger density the larger the mass of the metal.



*Density and mixing* A small piece of ice will float on water. The reason for that is density: density of ice ( $0.9 \text{ g/mL}$ ) is smaller than density of water ( $1.0 \text{ g/mL}$ ) and hence ice will stay on top of water. Objects with density larger than  $1 \text{ g/mL}$  will sink whereas objects with density smaller than this value will float. If you add a drop of vegetable oil to a glass of water, the drop will float. This is because the density of oil is smaller than  $1 \text{ g/mL}$ .

**Table 1.4 Density of some common substances at 273.15 K and 100 kPa**

Substance	Density ( $\text{g}/\text{mL}$ )	Physical State
Helium	0.2	gas
Hydrogen	0.1	gas
Water	1.0	Liquid
Cooking oil	0.9	Liquid
Mercury	13.5	Liquid
Tetrachloroethene	1.6	Liquid
Gold	19.3	solid
Plastics	1.2	solid
Ice	0.916*	solid

\*Ice is given at  $T < 273.15 \text{ K}$

#### Sample Problem 10

In the figure, we mixed three liquids of density: A ( $0.5 \text{ g/mL}$ ), B ( $2 \text{ g/mL}$ ) and C ( $1 \text{ g/mL}$ ). Identify each liquid.



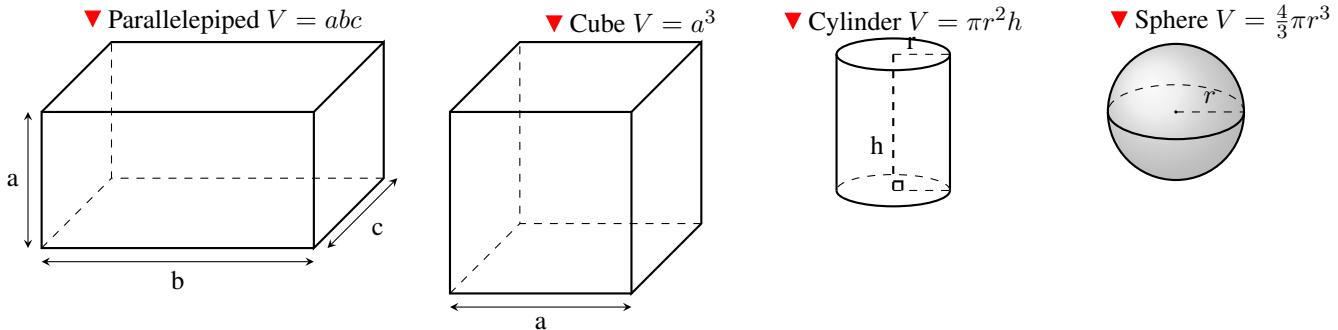
#### SOLUTION

The heavier the liquid, that is the larger density, the lower the liquid will arrange in the mixture. From top to bottom we have A, C and B.

#### ❖ STUDY CHECK

Indicate the order that the following invisible liquids will appear in a cylinder when mixed: (a) benzene(0.87 g/mL) and (b) water(1 g/mL)

*Density and the volume of objects* Density depends on volume and in particular the larger volume the smaller density. Figure 1.4 displays the formulas to calculate the volume for some common objects, like a sphere or a cube. For example, the radius of a sphere with density  $d$  and mass  $m$  corresponds to  $\sqrt[3]{m/4d \cdot \pi}$ , and the side of a cube with density  $d$  and mass  $m$  corresponds to  $\sqrt[3]{m/d}$ .



**Figure 1.4** Volume of some objects

The density of liquids results from measuring the mass of a given volume of the liquid. Differently, density is harder to obtain for solids. For metals, we can calculate density by the immersion method: when a metal is immersed in water, the water rises. This increase in volume corresponds to the volume of the solid. This way, density results from the direct measurement of mass and by the measurement of volume by displacement. The following example demonstrates density calculation with the immersion method.

#### Sample Problem 11

After adding a 30g object into a cylinder filled of water, the level of water rises from 60mL to 90mL. Calculate the density of the object.

#### SOLUTION

Density is mass over volume. The mass of the object is 30g and its volume is  $(90-60)\text{mL}$  that is 30mL. Hence:  $d = 30\text{g}/30\text{mL} = 1\text{g/mL}$ .

#### ❖ STUDY CHECK

A lead weight used in the belt of a scuba diver has a mass of 226 g. When the weight is placed in a graduated cylinder containing 200.0 mL of water, the water level rises to 220.0 mL. What is the density of the lead weight (g/mL)?



# CHAPTER 1

## UNITS AND MEASUREMENTS

**1.1** Solve for  $x$  in the following algebraic equations:

(a)  $3x + 1 = 5$

(d)  $\frac{3x+1}{2} = 2$

(b)  $2x - 1 = 5$

(e)  $\frac{2x-1}{3} = 2$

(c)  $\frac{3}{2} = \frac{1}{2x}$

(f)  $\frac{2}{3} = \frac{1}{3x}$

**1.2** Compute the following calculations involving scientific notation:

(a)  $\frac{6.5 \times 10^3}{3 \times 10^2}$

(c)  $\frac{1.3 \times 10^{-3}}{2.5 \times 10^{-2}}$

(e)  $\frac{1}{3.4 \times 10^{-1}}$

(b)  $\frac{6.1 \times 10^{-3}}{3 \times 10^4}$

(d)  $\frac{2.4 \times 10^{-3}}{5.4 \times 10^{-6}}$

(f)  $\frac{1}{4.1 \times 10^{-4}}$

**1.3** Indicate the magnitude measured in the following measurements: (a) 2 L (b) 5 cm

**1.4** Indicate the magnitude measured in the following measurements: (a) 100 Kg (b) 10h

**1.5** Answer the following questions: (a) Indicate the metric base unit for mass (b) Indicate the metric base unit for mass (c) Indicate metric base unit for volume

**1.6** Answer the following questions: (a) Indicate basic unit of mass in the SI (b) What magnitude measures the amount of space occupied by a substance

## PREFIXES & CONVERSION FACTORS

**1.7** Fill the gap in the following unit equalities or conversion factors:  $1dm = \underline{\hspace{2cm}} m$

**1.8** Fill the gap in the following unit equalities or conversion factors:  $1cm = \underline{\hspace{2cm}} m$

**1.9** Fill the gap in the following unit equalities or conversion factors:  $\frac{1nm}{\underline{\hspace{2cm}}} m$

**1.10** Fill the gap in the following unit equalities or conversion factors:  $\frac{1fs}{\underline{\hspace{2cm}}} s$

**1.11** Fill the gap in the following unit equalities or conversion factors:

$1Tm = \underline{\hspace{2cm}} m$

$1qt = \underline{\hspace{2cm}} mL$

$1dm = \underline{\hspace{2cm}} m$

$1L = \underline{\hspace{2cm}} dm^3$

$1cg = \underline{\hspace{2cm}} g$

$1lb = \underline{\hspace{2cm}} g$

$1ms = \underline{\hspace{2cm}} s$

$1in = \underline{\hspace{2cm}} cm$

**1.12** Fill the gap in the following unit equalities or conversion factors:

(a)  $\frac{1km}{\underline{\hspace{2cm}}} m$

(d)  $\frac{\underline{\hspace{2cm}} L}{10^{-3}L}$

(b)  $\frac{1cm}{\underline{\hspace{2cm}}} m$

(e)  $\frac{\underline{\hspace{2cm}} L}{10^{-2}L}$

(c)  $\frac{1ms}{\underline{\hspace{2cm}}} s$

(f)  $\frac{\underline{\hspace{2cm}} g}{10^{-1}g}$

## USING CONVERSION FACTORS

**1.13** Fill the gap in the following unit conversion:

$$20 \cancel{cm} \times \frac{\underline{\hspace{2cm}} m}{1 \cancel{cm}} = 0.2m$$

**1.14** The following conversion factor is used to convert  $100\mu m$  into m. Fill in the gaps:

$$100 \cancel{\mu m} \times \frac{\underline{\hspace{2cm}} m}{1 \cancel{\mu m}} = 1 \times 10^{-4}m$$

**1.15** The following conversion factor is used to convert  $40m$  into nm. Fill in the gaps:

$$40 \cancel{m} \times \frac{1nm}{\underline{\hspace{2cm}}} = 4 \times 10^{10}nm$$

**1.16** Complete the following unit conversion:

$$100 \cancel{Gm} \times \frac{\underline{\hspace{2cm}} m}{\cancel{Gm}} = \underline{\hspace{2cm}} m$$

**1.17** Complete the following unit conversion:

$$50 \cancel{km} \times \frac{\underline{\hspace{2cm}} m}{\cancel{km}} = \underline{\hspace{2cm}} m$$

**1.18** Complete the following unit conversion:

$$2\cancel{\text{m}} \times \frac{\text{cm}}{\cancel{\text{m}}} = \underline{\hspace{2cm}} \text{cm}$$

**1.19** Complete the following unit conversion:

$$0.3\cancel{\text{m}} \times \frac{\text{mm}}{\cancel{\text{m}}} = \underline{\hspace{2cm}} \text{mm}$$

**1.20** Complete the following unit conversion:

$$(a) 0.5\cancel{\mu\text{g}} \times \frac{\text{g}}{\cancel{\mu\text{g}}} = \underline{\hspace{2cm}} \text{g}$$

$$(b) 125\cancel{\text{L}} \times \frac{\text{mL}}{\cancel{\text{L}}} = \underline{\hspace{2cm}} \text{mL}$$

$$(c) 100\cancel{\text{nm}} \times \frac{\text{m}}{\cancel{\text{nm}}} = \underline{\hspace{2cm}} \text{m}$$

**1.21** The following conversion factor is used to convert 30 cm into km. Fill in the gaps:

$$30\cancel{\text{cm}} \times \frac{\cancel{\text{m}}}{1\cancel{\text{cm}}} \times \frac{1\text{km}}{\cancel{\text{m}}} = 3 \times 10^{-4}\text{km}$$

**1.22** The following conversion factor is used to convert 50 dm into cm. Fill in the gaps:

$$50\cancel{\text{dm}} \times \frac{\cancel{\text{m}}}{1\cancel{\text{dm}}} \times \frac{1\text{cm}}{\cancel{\text{m}}} = 500\text{cm}$$

**1.23** Fill the gap in the following conversion factors:

$$20\cancel{\text{cm}} \times \frac{1 \times 10^{-2}\text{m}}{1\cancel{\text{cm}}} \times \frac{1\text{mm}}{1 \times 10^{-3}\cancel{\text{m}}} = \underline{\hspace{2cm}} \text{mm}$$

**1.24** Set up the conversion factor to convert 500 cm into inches:

$$50\cancel{\text{cm}} \times \underline{\hspace{2cm}} = \underline{\hspace{2cm}} \text{in}$$

**1.25** Fill the gap in the following conversion factors:

$$20\cancel{\text{cm}} \times \underline{\hspace{2cm}} = 7.87\text{in}$$

**1.26** Compute the following power of ten calculations:

$$(a) (10^2)^2$$

$$(c) (10^{-6})^2$$

$$(b) (10^2)^3$$

$$(d) (10^{-2})^2$$

**1.27** Set up the conversion factor to convert  $400\text{cm}^2$  into  $\text{m}^2$ :

$$400\cancel{\text{cm}^2} \times \frac{\underline{\hspace{2cm}}}{\cancel{\text{m}}} = \underline{\hspace{2cm}} \text{m}^2$$

**1.28** Fill the gap in the following unit equalities or conversion factors:

$$1\text{cm}^2 = \underline{\hspace{2cm}} \text{m}^2$$

$$1\text{cm}^3 = \underline{\hspace{2cm}} \text{m}^3$$

$$1\text{dm}^3 = \underline{\hspace{2cm}} \text{m}^3$$

$$1\text{dm}^2 = \underline{\hspace{2cm}} \text{m}^2$$

### SIGNIFICANT FIGURES

**1.29** Carry the following calculations with the correct number of digits or significant figures:

$$(a) 0.2301 + 0.123$$

$$(c) 88.1 - 87.57$$

$$(b) 0.2301 - 1.12$$

$$(d) 24.56 + 2.4$$

**1.30** Carry the following calculations with the correct number of digits or significant figures:

$$(a) 523 \times 5000$$

$$(c) 27.0 \times 0.01$$

$$(b) 5 / 0.123$$

$$(d) 345.13 / 100$$

**1.31** Indicate the number of SFs. (a) 0.0032 m (b) 5100 m (c) 0.510 m (d) 0.0051 m (e) 500 m (f) 45.030

**1.32** Which of the following measurements contains the designated CORRECT number of significant figures?

- (a) 0.05600 cm (5 SF) (b) 0.0304 cm (3 SF) (c) 456 000 cm (3 SF) (d) 1.304 cm (2 SF) (e) 3.12050 cm (4 SF)

### DENSITY

**1.33** Determine the density (g/mL) of a 0.01 L sample of a salt solution that has a mass of 50 g.

**1.34** Which one of the following substances will float in gasoline, which has a density of 0.66 g/mL? Assume no mixing: (a) table salt (2.16 g/mL) (b) balsa wood (0.16 g/mL) (c) sugar (1.59 g/mL) (d) aluminum (2.70 g/mL) (e) mercury (13.6 g/mL)

**1.35** You have a large water tank used as a cooler in a party and you have a bunch of cans: a coke can, a diet coke can, a water can and a schweppes can. You add all unopened cans on the tank. Describe the final vertical distribution of cans in the tank. Which can will stay on top and which will sink in more?

**1.36** A nugget of gold with a mass of 521 g is added to 50.0 mL of water. The water level rises to a volume of 77.0 mL. What is the measured density of the gold?

**1.37** A graduated cylinder contains 28.0 mL of water. What is the new water level after 35.6 g of silver metal is submerged in the water if the density of silver is 10g/mL?

**Answers** **1.1** (a) 0.33 (b) 3 (c) 0.33 (d) 1 (e) 3.5 (f) 0.5 **1.3** (a) 2 L (volume) (b) 5 cm (length) **1.5** (a) g (b) volume (c) L **1.7**  $1 \times 10^{-1}$  **1.9**  $1 \times 10^{-9}$  **1.11**  $1\text{Tm} = 10^{12}\text{m}$   $1\text{dm} = 10^{-1}\text{m}$   $1\text{cg} = 10^{-2}\text{g}$   $1\text{ms} = 10^{-3}\text{s}$   $1\text{qt} = 1\text{mL}$   $1\text{L} = 1\text{dm}^3$   $1\text{lb} = 454\text{g}$   $1\text{in} = 2.54\text{cm}$  **1.13**  $1 \times 10^{-2}$  **1.15**  $1 \cdot 10^{-9}$  **1.17**  $5 \cdot 10^4\text{m}$  **1.19**  $3 \cdot 10^2\text{mm}$  **1.21**  $1 \cdot 10^{-2}; 10 \cdot 10^3$  **1.24**  $19.68\text{in}$  **1.25**  $\frac{1\text{in}}{2.54\text{cm}}$  **1.27**  $0.04\text{m}^2$  **1.29** (a)  $0.2301 + 0.123 = 0.353$  (b)  $0.2301 - 1.12 = -0.89$  (c)  $88.1 - 87.57 = 0.5$  (d)  $24.56 + 2.4 = 27.0$  **1.31** (a) 0.0032 m (2SF) (b) 5100 m (2SF) (c) 0.510 m (3SF) (d) 0.0051 m (2SF) (e) 500 m (1SF) (f) 45.030 m (6SF) **1.33**  $5\text{g} \cdot \text{ml}^{-1}$  **1.35** from top to bottom: coke, diet, schwepes, water **1.37**  $31.56\text{mL}$