MEASUREMENTS

Measurements are an integral part of our everyday lives, so much so that we often overlook their importance. The clothes that we wear are available in various sizes. The food that we buy and eat is measured by weight or volume, such as grams, kilograms, milliliters, or liters. When we cook, the recipe is measured as well. The size of paper and coins are produced to precise standards. Even the worth of money is a form of measurement. However, measurements like clothing sizes, food quantities, and money value are not universal. For instance, clothing sizes in Europe vary from those in North America. Chefs in Europe prefer to measure liquids and powdered solids by weight instead of volume. Naturally, the value of currencies varies significantly from one country to another.

Accuracy and Precision (Tro, 2023)

Measurements may be accurate, meaning that the measured value is the same as the true value; they may be precise, meaning that multiple measurements give nearly identical values; they may be both accurate and precise; or they may be neither accurate nor precise. The goal of scientists is to obtain measured values that are both accurate and precise.

Accuracy

Accuracy refers to the capability to measure a value that is as close as possible to the actual or true value. In essence, it's the degree of exactness of a measurement. The smaller the reading, the higher the accuracy, as it minimizes the potential for error in the calculation.

Precision

Precision refers to the consistency or repeatability of measurements, that is, how close two or more measurements are to each other.

Example: In target shooting, your goal is to hit the bull's eye to get the maximum score. Suppose four individuals are given 7 shots each to hit their goals, and these are the results:

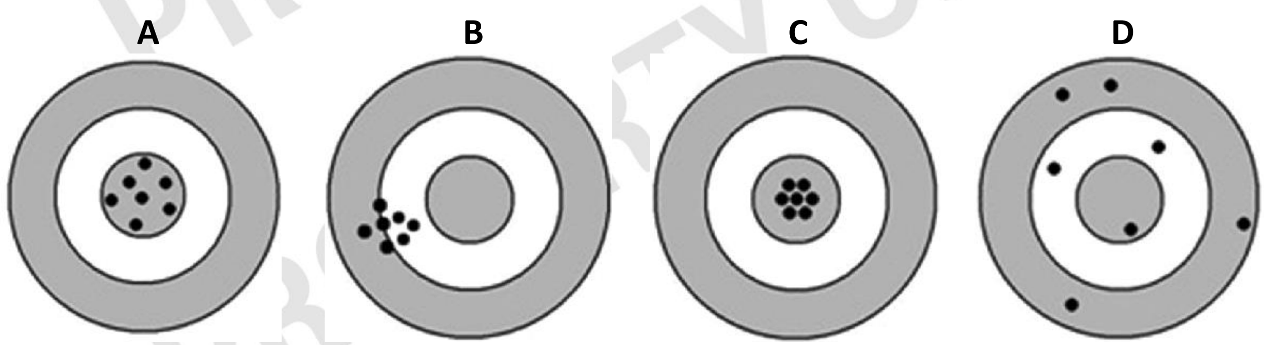


Figure 1: The concept of accuracy versus precision. (n.d.). ResearchGate. https://www.researchgate.net/figure/The-concept-of-accuracy-versus-precision_fig1_312202285

- Results on A show accuracy but limited precision since the target inner circle was hit but the distances from the attempts are far apart.

- Results on B show high precision but low accuracy. The accurate goal is the middle circle, but all attempts are outside the goal. But the attempts are close enough to each other that it looks as if the target is in that place. When a series of measurements is precise but not accurate, the error is usually systematic. Systematic errors can be caused by faulty instrumentation or faulty technique.
- Results on C show both high accuracy and precision, while results on D show low accuracy and precision.

Units and Conversions (Bauer, 2024)

All experimental sciences are based on observation. To be useful to the experimenter and to others, observations often must involve making measurements. Measurement is the determination of the size of quantity—the number of nails, the mass of a brick, the length of a wall. Measurement is defined by both a quantity and a unit, which tells what it is we are measuring.

Most countries use the metric system, while the United States still uses primarily the English system. The English system is based on various units that are not related to one another by a consistent factor. Common units of length, for example, are inches, feet (12 in), yards (3 ft), and miles (1760 yd). The metric system, on the other hand, uses units that are always related by a factor of ten or by a power of ten.

Scientists in all countries use the metric system in their work. The metric system is convenient to use because its units are related by powers of ten. Converting between related units is simply a matter of shifting a decimal point. The metric system adds further convenience. It does not use arbitrary names like the English system, but rather, it defines base units of measure, and any multiple or fraction of these base units are defined by a special prefix.

Prefix	Factor	Symbol	Example
giga	10^9	G	1 Gg = 1,000,000,000 g
mega	10^6	M	1 Mg = 1,000,000 g
kilo	10^3	k, K	1 kg = 1000 g
deci	10^{-1}	d	1 dg = 0.1 g
centi	10^{-2}	c	1 cg = 0.01 g
milli	10^{-3}	m	1 mg = 0.001 g
micro	10^{-6}	µ	1 µg = 0.000001 g
nano	10^{-9}	n	1 ng = 0.000000001 g
pico	10^{-12}	p	1 pg = 0.000000000001 g

Table 1 Metric System Prefixes

For factors that have a negative exponent, alternative relationships can be derived.

Example: <u>1 mg = 1 x 10^{-3} g</u> can be redefined as <u>1000 mg = 1 g</u>

<u>1 kb = 1 x 10^{-6} Gb</u> is also synonymous to <u>1,000,000 kb = 1 Gb</u>

Because our imports and goods are primarily coming from the US, our system of measure is a mix of English and Metric. In the science and health-related disciplines, conversion of units is required between different systems. Listed in the table below are commonly used conversion factors between English and Metric units.

English Unit	Metric Unit
1 lb. = 16 oz	453.6 g
1 in	2.54 cm
1 yd	0.9144 m
1 mi	1.609 km
1 fluid oz	29.57 mL
1 qt	0.9464 L
1 gal	3.785 L
1 ft^3	28.32 L

Table 2.English/Metric Conversion

Le Système international d'unités (SI)

In 1960, an organization of scientists met in France to determine standards for scientific measurements. This group established the SI units (from the French, Système International) listed here.

Unit	Symbol	Quantity
Meter	m	length
kilogram	kg	mass
second	s	time
ampere	A	electric current
kelvin	K	temperature
mole	mol	amount of substance
candela	cd	luminous intensity

Table 3. SI units

All other units, called derived units, are based on these by multiplication or division and then applying the appropriate prefix or combination of units. For example, if the mass of an object is measured in grams, it could be converted to the SI unit of mass, the kilogram, by dividing the measured mass in grams by 1000 and adding the prefix kilo to the quantity. An example of a derived unit that involves a combination of units is volume. The SI-derived unit for volume is cubic meters (m^3), which for a box would mean measuring length, width, and height in meters, and then multiplying them together.

It's also important to note that some derived units are combinations of base units. For example, velocity is a derived unit represented as meters per second (m/s), which is a combination of the base unit meter (m) for length and second (s) for time. Another derived unit is density. Density is the ratio of mass to volume for a given substance ($\rho = M/V$). An example of the derived unit for density is grams per cubic meter (g/m^3) for solids or kilogram per liter (kg/L) for liquid measure.

Conversion of Units (Bauer, 2024)

Measurements must be interpreted, often by mathematical manipulation of the data. This manipulation often involves converting one set of units into another using relationships between them. Two approaches to such conversions are ratios and dimensional analysis. In both cases, an analysis of the units provides clues to the correct solution of the problem.

Example: Convert 30 min into hours

Ratio Approach
This technique uses a known relationship to compare unknown relationships. We know the equivalence of two quantities as 1 hour = 60 min. Using this to solve: $\frac{1\ hour}{60\ min} = \frac{?\ hours}{30\ min} \rightarrow \frac{30 \times 1}{60} = 0.5\ hours$

Notice that the units of minutes cancel out, leaving the units of hours, which is the unit called for in the problem.

Dimensional Analysis
In the dimension analysis approach, we get to the form of the manipulated ratio more quickly. We multiply the known quantity by the ratio, so that units cancel, and we get the unknown quantity with the desired units:

$$\text{Time in hours} = 30\ \text{min} \times \frac{1\ \text{hour}}{60\ \text{min}} = \frac{30\ \times 1\ (\cancel{\text{min}} \times\ \text{hours})}{60\ \cancel{\text{min}}} = 0.50\ \text{hours}$$

In the dimensional-analysis approach, units in the numerator and denominator of a fraction are treated the same as numbers—canceled out, multiplied, divided, squared, or whatever the mathematical operations demand. We set up the conversions so that desired units are introduced and beginning units cancel out.

Conversion of Derived Units

When converting, it is best to use dimensional analysis. Work from the given units and multiply ratios until the required units are achieved.

Example: The density of a material is 100 mg per cubic centimeter.
Convert to g per cubic meter (g/m^3)

$$\mathbf{100\frac{mg}{cm^3}} \times \frac{1\ g}{1000\ mg} \times \frac{100\ cm}{1\ m} \times \frac{100\ cm}{1\ m} \times \frac{100\ cm}{1\ m} = \mathbf{1000\frac{g}{m^3}}$$

Remember, when dealing with derived units that involve squares or cubes (like area or volume), the conversion factors themselves must also be squared or cubed. As illustrated in the example, when converting cubic centimeters to cubic meters, the conversion factor would be

$$\frac{100\ cm}{1\ m} \times \frac{100\ cm}{1\ m} \times \frac{100\ cm}{1\ m}\ OR\ \left(\frac{100\ cm}{1\ m}\right)^3 = \frac{100\ cm^3}{1\ m^3}$$

Significant Figures (Bauer, 2024)

Numbers used in chemistry can be placed into two categories.

Some numbers are exact.
They are established by definition or by counting. Defined numbers are exact because they are assigned specific values:

Example:	12 in = 1 ft	2.54 cm = 1 in
	10 mm = 1 cm	1 foot = 3 yard

Numbers established by counting are known exactly because they can be counted with no errors. Since defined and counted numbers are known precisely, there is no uncertainty in their values.
Examples are distance from point to point, capacity, and no. of passengers.

Other numbers are not exact.
They are numbers obtained by measurement or from observation. They may also include numbers resulting from a count if the number is very large. There is always some uncertainty in the value of such numbers because they depend on how closely the measuring instrument and the experimenter can measure the values.

Examples: temperature, humidity, and time for sunset.

Determining the Number of Significant Figures
Every number represents a specific quantity with a particular degree of precision that depends on the way it was determined. When we work with numbers, we must be able to recognize how many significant figures they contain. We do this by first remembering that nonzero digits are always significant, no matter where they occur. The only problem in counting significant figures, then, is deciding whether a zero is significant. To do so, use the following rules:

Rule	Example	
A zero alone in **front of a decimal point** is not significant; it is used simply to make sure we do not overlook the decimal point	**0**.2806 **0**.002806	Not significant
A zero to the **right of the decimal point but before the first nonzero** digit is simply a place marker and is not significant	0.**00**2806	Not significant
A zero **between nonzero** numbers is significant	28**0**6 0.0028**0**6	Significant
A zero at **the end of a number and to the right of the decimal point** is significant	0.002806**0** 2806.**0**	Significant
A zero at the end of a number and to the left of the decimal point may or may not be significant. We cannot tell by looking at the number. It may be precisely known, and thus significant, or it may simply be a placeholder. If we encounter such a number, the best we can assume is that any trailing zeros are not significant.	2806**0**.00	Maybe or May not be significant

The following table summarizes the significant figures in the numbers we just considered. The digits that are significant are highlighted.

Number	Count of Significant Figures
0.**2806**	4
0.00**2806**	4

2806	4
0.00**28060**	5
2806.0	5
28060	Assume 4

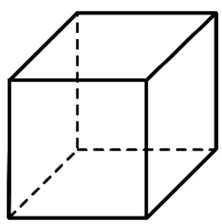
Table 4. Zeros: Significant or not?

NOTE: Why are end zeros not significant if they affect the value of the number greatly?

Zeros at the end of a number, particularly those after a decimal point, are often not considered significant because they do not contribute additional information about the precision of the measurement. To avoid creating an ambiguous number with zeros at its end, like 28060, we write the number in scientific notation so that the troublesome zero occurs to the right of the decimal point. In this case, it is simple to show whether the zero is significant (2.8060×10^4) or not (2.806×10^4). The power of ten, 10^4, is not included in the count of significant figures since it simply tells us the position of the decimal point.

Density Measurements (Hodgkins, n.d)

Objects float or sink in water, not due to their Density is the amount of mass per unit volume. It is a derived unit wherein the unit volume varies between solids and liquids. It can be expressed as mass per cubic length, mass per capacity, or liquid measure.



Volume = LWH
*Units in m^3, km^3, ft^3…

Volume = capacity
*Units in ml, L, fl. oz…

Water, a dense substance with a standard density of 1 g/cm^3, is often used as a benchmark in density demonstrations. Objects will float on water if their density is less than 1 g/cm^3, and they will sink if their density exceeds 1 g/cm^3. Cork, for instance, floats on water due to its extremely low density of approximately 0.2 g/cm^3, which is significantly lower than the density of water. Other liquids have different densities too and could be used as carrier liquid for other solids and liquids as well.

Solids Density (kg/m^3)		Liquid Density (kg/m^3)		Gas Density (kg/m^3)	
Gold	19300	Water	1000	Chlorine	3.2
Uranium	19050	Mercury	13546	Carbon dioxide	1.98
Copper	8930	Methanol	792	Air	1.3
Iron	7870			Helium	0.18
Oakwood	650				

Table 5. Densities of materials

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