Chemistry is the study of **matter**.

Matter is made up of **atoms**.

The **periodic table** currently lists 116 different **atoms**. New atoms are being discovered.

Atoms consist of **protons** and **neutrons** held tightly in the nucleus. The nucleus is surrounded by a diffuse cloud of **electrons**.

Chemistry is known as the central science. Other branches of chemistry include biochemistry (the chemistry of life), geology (the chemistry of soil and rocks), organic chemistry (the chemistry of carbon containing compounds), inorganic chemistry (the chemistry of compounds that do not contain carbon), analytical chemistry (quantitative chemistry), and physical chemistry (the study of natural laws).

Science uses the **scientific method** to systematically investigate nature. The steps of the scientific method include:

- **Planning** an experiment to evaluate nature
- **Observing** the experiment by recording data
- **Explaining** the data by forming a **hypothesis**.

A **hypothesis** is a tentative proposal that explains the results of one or more experiments.

A hypothesis can be tested by new experiments. After much experimental testing, a hypothesis may be confirmed, revised, or rejected depending on whether the hypothesis correctly predicted the findings of the new experiments.

A **natural law** is a confirmed hypothesis that has a mathematical relationship to describe the results. A natural law can never be proven to be correct by the scientific method. Instead, useful natural laws explain many observations and do not have scientific data that demonstrates incorrectness. An example of a natural law that meets this definition would be the ideal gas law. Most scientists know that the ideal gas law is not strictly correct because no gases have ideal behavior under all conditions. Scientists have already revised the ideal gas law, but the new laws are much more complicated to use. As a result, the ideal gas law will likely be taught in introductory science courses for many years to come because of its usefulness.

A **scientific theory** is a confirmed hypothesis, but unlike a natural law, it does not have a mathematical relationship that describes the results. A scientific theory can never be proven to be correct by the scientific method. Instead, useful theories explain many observations, and they do not have scientific data that overwhelms the usefulness of the theory. Examples of theories that meet this definition would be molecular orbital theory and the theory of evolution.

Scientific Measurements

A **measurement** is a **number** with a **unit** and an **uncertainty**. Measurements are made all the time while cooking (a cup of sugar), driving (ten gallons of gasoline, 65 miles per hour), working (filling 70 orders per hour), and waking (at 6:05 a.m.).

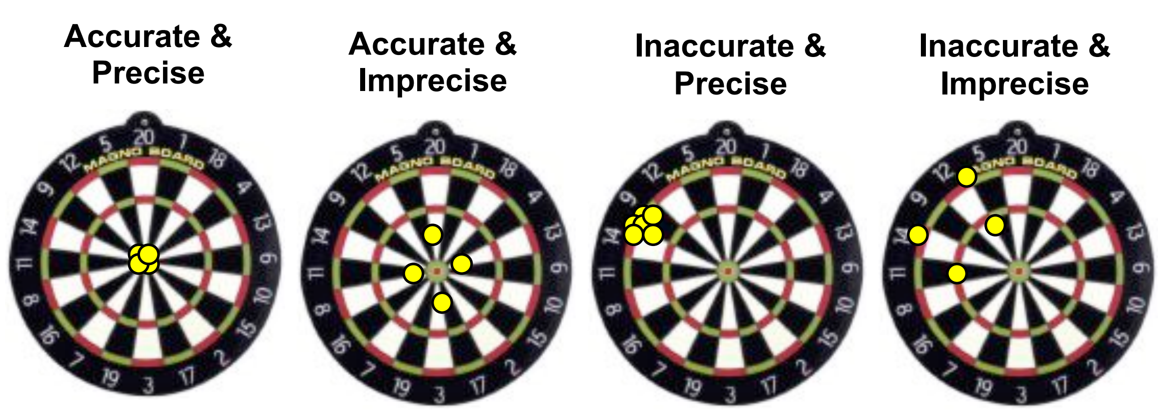
Using the example from cooking, the **number** is 1. The **unit** is cups. Without additional information about the measurement, the **uncertainty** is presumed to be ±1 cup, which is ±1 in the last significant digit. The actual measurement is expected to be between 0 cups (1 cup minus 1 cup) and 2 cups (1 cup plus one cup).

Taking a second example from waking up, the **number** is 6:05. The **units** in this measurement are hours (6), minutes (5), and a.m. (morning). Without additional information about the measurement, the **uncertainty** is presumed to be ±1 minute, which is ±1 in the last significant digit. The actual time of waking is expected to be between 6:04 a.m. (6:05 a.m. minus 1 minute) and 6:06 a.m (6:05 plus one minute).

Significant Digits
The digits in a correctly recorded measurement are called **significant digits**. There are rules for determining the number of significant digits in improperly recorded measurements. Rules for counting significant digits in improperly recorded measurements will be discussed later.

Accuracy and Precision
Accuracy is the agreement of measurements with the true value. To determine the accuracy of one or more measurement, we need to know the true or accepted value. **Precision** is the agreement of measurements with each other. Measurements that are closer together are more precise.

A dartboard can be a helpful example to describe accuracy and precision. Darts that are accurate and always hit the true value (the bull's eye) are both accurate and precise. If the average of the measurements hits the bull's eye, the measurements are accurate on the average, yet imprecise because the individual darts are far from each other. Darts that consistently hit the wrong target are inaccurate and precise. Darts that inconsistently hit the wrong target are inaccurate and imprecise.



Common Units and Measurements

Below are some common units that are used for scientific measurements.

Table 1. Common units, symbols, meaning, and an example measurement

Unit	Symbol	Meaning	Example Measurement
mass	g	grams	60.080 g chocolate (measure with a balance)
length	m	meters	2.05 m tall (measure with a ruler)
volume	L	liters	2.0 L of soda (measure with a bottle)
time	s	seconds	15.0125 s to race (measure with a watch)

Mass is a measure of the amount of matter (atoms) in a substance. Mass refers to a different measurement than weight. Weight is affected by the amount of gravity, while mass is not.

Mass Measurements, Uncertainty and Counting Significant Digits

We can learn additional information about the uncertainty from the equipment used to make a measurement. Using Table 1 above, the mass measurement, 60.080 g of chocolate is known to 5 **significant digits**. Count each of the digits (6, 0, 0, 8, and 0) in the number as one significant digit each for a total of 5 significant digits. The balance measures to the nearest thousandth of a gram ±0.001 g, so that would be the expected uncertainty of the balance without being able to see the readout of the balance.

The next three figures are balances from a lab. With the exception of a zero to the left of the decimal point for numbers between zero up and one, all digits from a digital readout are significant. The balance on the left has five significant digits (6, 0, 0, 8, and 0), and the balance on the right has three significant digits in the measurement (8, 0, and 0). The zero to the left of the decimal is not significant for numbers between zero and one. To count **significant digits** in a properly recorded number, start the counting with the first **nonzero** digit from the left of the number.

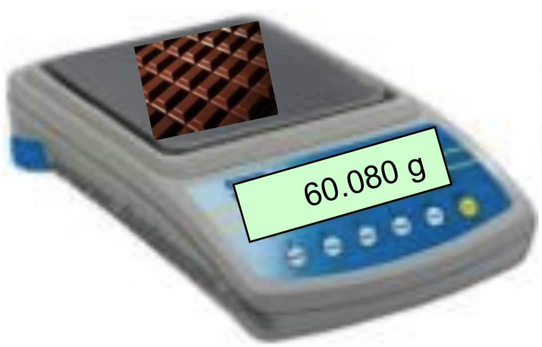


Figure 1. Electronic balance shows five significant digits in a measurement

Figure 2. Electronic balance shows three significant digits in a measurement

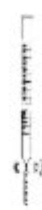
The balance in Figure 3 has been used to make a mass measurement of a small sliver of chocolate. The mass, 0.009 g, has one significant digit (9). Start counting from the left with the first nonzero number (0 – not significant, 0 – not significant, 0 – not significant, 9 significant).

Figure 3. Electronic balance shows one significant digit in a measurement

Volume Measurements, Equipment, Precision, Uncertainty, Measurement, Significant Digits, and Accuracy

Table 2 lists some laboratory glassware along with the precision, uncertainty, a typical measurement, the significant digits in the measurement and the accuracy. In order to determine accuracy, the true or correct value would be needed. The correct value can often be determined by measuring a standard. If a suitable standard is not available, then the accuracy of equipment cannot be determined.

Table 2. Equipment along with precision, uncertainty, measurement, significant digits, accuracy.

					
Equipment	Graduated cylinder	Volumetric Flask	Buret	Pipet	Syringe
Precision	±0.5 mL	±0.1 mL	±0.05 mL	±0.02 mL	±0.005 mL
Precision	Least precise				Most precise
Uncertainty	Most uncertain				Least uncertain
Measurement	35.5 mL	100.0 mL	10.05 mL	25.00 mL	1.115 mL
Significant digits	3	4	4	4	4
Accuracy	Can't tell	Can't tell	Can't tell	Can't tell	Can't tell

Rules for Counting Significant Digits

A placeholder is a zero that holds the power of 10. Placeholder zeros are usually not significant digits as described below. There are three rules for placeholder zeros.

1) To count significant digits in a **properly recorded** number, start the counting with the first **nonzero** digit from the left of the number.

2) For numbers between zero and one, placeholder zeros are never significant.

3) For numbers greater than or equal to 10, placeholder zeros are presumed not to be significant unless there is a decimal point in the number. To avoid ambiguity with placeholder zeros, write numbers in **scientific notation**.

Placholder Rule 1
There are six significant digits in 60.0001
There are five significant digits in 60.000
There is one significant digit in 5

Placeholder Rule 2
For this example, the underlined digits are significant. The remaining zeros are placeholder zeros that are not significant digits.
There is one significant digit in 0.0005
There are two significant digits in 0.0055
There are three significant digits in 0.00505
There are three significant digits in 0.00500

Placeholder Rule 3
For this example, the underlined digits are significant. The remaining zeros are placeholder zeros that are presumed not to be significant digits.

Significant Digits	Number
two	55
three	505
one	500
two	710,000
three	500.
Six	710,000.

Exact Numbers
Exact numbers are considered to have as many significant digits as are needed, so the rules of significant digits do not apply. Items that can be counted exactly, such as coins, eggs, and cars, are examples of exact numbers. Some conversion factors are exact.

Rounding
All digits in a correctly recorded measurement are significant digits. During calculations, especially division, digits that are not significant can occur. After calculations, the final answer must be rounded to the correct number of significant digits. There are three rules for rounding

1) Keep all digits until the final calculation and round the final answer.
2) If the first nonsignificant digit is less than 5, drop all nonsignificant digits.
3) If the first nonsignificant digit is 5 or more, increase the last significant digit by one then drop all nonsignificant digits.

Instructions will be provided later for how to keep track of significant digits during calculations. Examples of rounding numbers using rules 2 and 3 appear below.

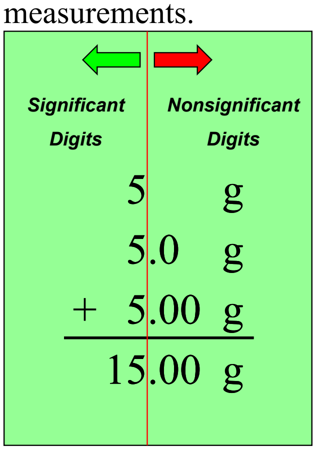
Examples of rounding
Rule 2
Round 91.2349 given that this number has 4 significant digits. The first nonsignificant digit, 4, is underlined, 91.23<u>4</u>9. Because 4 is less than 5, drop all nonsignificant digits. The rounded answer to four significant digits is 91.23.

Rule 3
Round 91.2350 given that this number has 4 significant digits. The first nonsignificant digit, 5, is underlined, 91.23<u>5</u>0. Because the digit is 5 or more, increase the last significant digit by one and drop all nonsignificant digits. The rounded answer to four significant digits is 91.24.

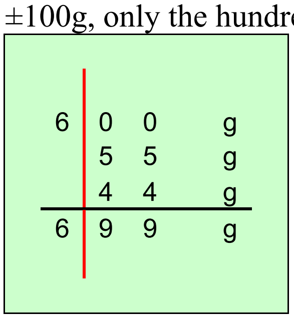
Instructions for Keeping Track of Significant digits During Calculations

Addition and Subtraction

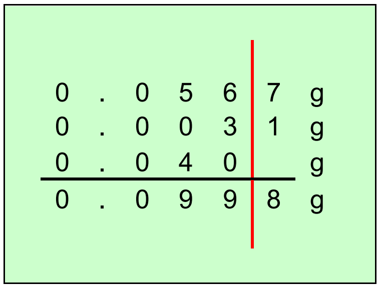
In addition and subtraction, the number with the most uncertainty (least precision) determines the number of significant digits in the answer. In the example below, 5g has the most uncertainty because the number is known to ±1g. The number 5.0g is known to ±0.1g, and the number 5.00g is known to ±0.01g. The vertical red line in the figure below indicates the position of the last significant digit. The correct, rounded answer is 15. Note that the answer can have a different number of significant digits than the measurements.



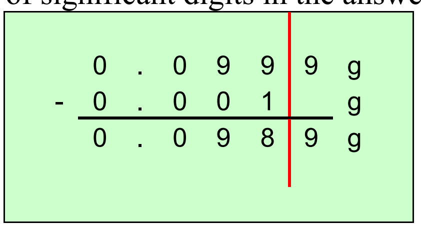
When adding the numbers 600g, 55g, and 44g, the intermediate answer is <u>6</u>99g. The correct, rounded answer is 700g. Because the number 600g is presumed to be known to ±100g, only the hundreds place is significant in the answer.



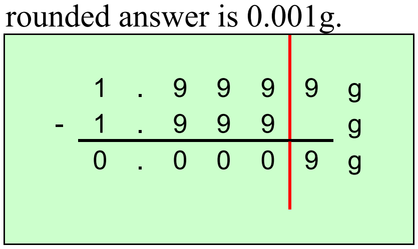
When adding the numbers 0.0567g, 0.0031g, and 0.040g, the number 0.040g has the most uncertainty (±0.001g) and limits the significant digits in the answer. The vertical red line in the figure below indicates the position of the last significant digit. In the figure below, the intermediate answer is 0.0998. The correct, rounded answer is 0.100g. Note that the answer can have a different number of significant digits than the measurements.



When subtracting, follow the same rules as for addition. In the example below, 0.001g is to be subtracted from 0.0999g giving 0.0989g as the intermediate answer. Because 0.001g has a greater uncertainty, as indicated by the vertical red line, it limits the number of significant digits in the answer. The correct, rounded answer is 0.099g.



In the example below, 1.999g is to be subtracted from 1.9999g giving 0.00009g as the intermediate answer. Because 1.999g has a greater uncertainty, as indicated by the vertical red line, it limits the number of significant digits in the answer. The correct, rounded answer is 0.001g.



Multiplication and Division

The rule for multiplication and division is to keep as many significant digits in the final answer as in the measurement with the fewest significant digits.

Take, for example: $18\text{cm} \times 0.03\text{cm} = 0.54\text{cm}^2$

Because 0.03cm has only one significant digit, the correct, rounded answer is 0.5cm^2.

As a second example, take: $989.84\text{cm} \times 181.28\text{cm} \times 0.25\text{cm} = 44859.55\text{cm}^3$

Because 0.25cm has only 2 significant digits, the final answer is 45000cm^3.

For a third example, take: $98.4856g / 18cm^3 = 5.471422g/cm^3$
Because $18cm^3$ has only 2 significant digits, the final, rounded answer is $5.5g/cm^3$.

Scientific Notation
Writing numbers in scientific notation helps to specify the correct number of significant digits. The format for a number in scientific notation is:

$D.D \times 10^n$

where the first D must be a nonzero digit and n is an integer that indicates the power of 10. Positive values of n indicate big numbers (bigger than 1), while negative values of n indicate fractions (smaller than 1 and bigger than 0).

Example: $1.0 \times 10^2 g = 100g$

Solution: To convert the scientific notation to a number, move the decimal two places to the right because of the positive value for n. Scientific notation makes it clear that the measurement has 2 significant digits. The number 100g is presumed to have only one significant digit.

Example: $1.0 \times 10^{-3} g = 0.0010g$

Solution: To convert the scientific notation to a number, move the decimal three places to the left because of the negative value for n.

Example: $3{,}500{,}000g = 3.5 \times 10^6 g$

Solution: To convert a number to scientific notation, put a decimal point after the first nonzero digit and indicate the positive power of 10 for a large number. The decimal had to be moved 6 places to the left to get 3.5, so n=6.

Example: $0.0000700m = 7.00 \times 10^{-5} m$

Solution: To convert a number to scientific notation, put a decimal point after the first nonzero digit and indicate the negative power of 10 for a fractional number. The decimal had to be moved 5 places to the right to get 7.00, so n=-5.

Be sure that you know how to use your calculator for scientific notation. The EE or EXP button is usually used to enter numbers in scientific notation.

Unit Equations
Unit equations describe a mathematical equality between two different units, for example, 1 hour = 60 minutes. Many such equations exist including $1mm=1x10^{-3}m$, 1lb=454g, and 1 inch = 2.54cm. Any unit equation can be written as a unit factor in order to convert one set of units into another. Unit equations and unit factors (conversion

factors) are usually known to enough significant digits so that they do not reduce the number of significant digits in a calculation.

Unit Factors
Any unit equation can be written as two unit factors. For example, 1 hour = 60 minutes can be written as two possible unit factors:

$$\frac{1 \text{ hour}}{60 \text{ minutes}} \quad \text{or} \quad \frac{60 \text{ minutes}}{1 \text{ hour}}$$

The correct unit factor (conversion) to use depends on the problem.

Example: Convert 3.00 hours to minutes.

Solution: We have hours. We need minutes. Select the conversion factor with hours in the denominator and minutes in the numerator so that the answer will be given in minutes.

$$3.00 \text{ hours} \times \frac{60 \text{ minutes}}{1 \text{ hour}} = 180 \text{ minutes} = 1.80 \times 10^2 \text{ minutes}$$

Example: Convert the speed 65 miles/hour into yards/second (1 mile=1760 yards).

Solution: In the numerator, we have miles that needs to be converted into yards. In the denominator, we have hour that needs to be converted to seconds.

$$\frac{65 \text{ miles}}{\text{hour}} \times \frac{1760 \text{ yards}}{1 \text{ mile}} \times \frac{1 \text{ hour}}{3600 \text{ seconds}} = \frac{31.77778 \text{ yards}}{\text{second}}$$

= 32 yards/second (2 significant digits because 65 miles/hour has 2 significant digits).

Percents
A percent gives the number of parts out of 100 total parts. For example, an exam score of 95% means 95 points awarded out of 100 total points.

Example: If the exam consisted of 35 points, how many points were awarded?

Solution: Start with the 35 total points and calculate points awarded using percent as a unit factor.

$$35 \text{ total points} \times \frac{95 \text{ points awarded}}{100 \text{ total points}} = 33.25 \text{ points awarded}$$

Because points is an exact measurement that can be counted, the answer is 33.25 points awarded (to as many significant digits that are needed).

Similarly, percents can be used to solve many types of scientific problems.

Example: An ore is known to contain 35.15% silver by mass. How many pounds of silver can be found in 712 pounds of ore?

Solution: Start with the 712 pounds of ore (the lab measurable) and calculate the pounds of silver using the percent as a unit factor.

$$712 \text{ pounds ore} \quad \times \quad \frac{35.15 \text{ pounds silver}}{100 \text{ pounds ore}} \quad = \quad 250.268 \text{ pounds silver}$$

The measurement, 712 pounds, has three significant digits, so the answer must be expressed to 3 significant digits, 250 pounds silver or 2.50×10^2 pounds silver.

Example: How would the answer be different in the above example if the ore contained the same percentage of silver, the mass of ore was 712 grams, and the answer is to be expressed in grams of silver?

Solution: The answer is numerically identical. Just the units change.

$$712 \text{ grams ore} \quad \times \quad \frac{35.15 \text{ grams silver}}{100 \text{ grams ore}} \quad = \quad 250.268 \text{ grams silver}$$

The measurement, 712 grams, has three significant digits, so the answer must be expressed to 3 significant digits, 250 grams silver or 2.50×10^2 grams silver.

Percents can be calculated using experimental data. See the examples below.

Example: If a test contains 40 points of multiple-choice questions and 10 points of worked problems, what percent of the test is worked problems?

Solution: The definition of percent is the quantity of interest over the total quantity available times 100%.

$$\frac{10 \text{ points worked problems}}{10 \text{ points worked problems} + 40 \text{ points multiple choice}} \quad \times \quad 100\% \quad = \quad 20\%$$

Because points are an exact number, the answer has as many significant digits as are needed.

Example: If a sample ore that contains both copper and oxygen contains 39.10 g of copper and 13.03 g of oxygen, what is the percent of copper in the ore?

Solution: Use the definition of percent to express the grams of copper ore over the total grams of ore (sample).

$$\frac{39.10 \text{ g copper}}{39.10 \text{ g copper} + 13.03 \text{ g oxygen}} \times 100\% = 75.0047957\ \%\text{ copper}$$

The answer has four significant digits because the measurements have four significant digits and the mathematics instructs to keep four significant digits. The addition in the denominator instructs to keep four, and the division also instructs to keep four significant digits. The correct answer to the correct number of significant digits is 75.00% copper or 7.500×10^1% copper.